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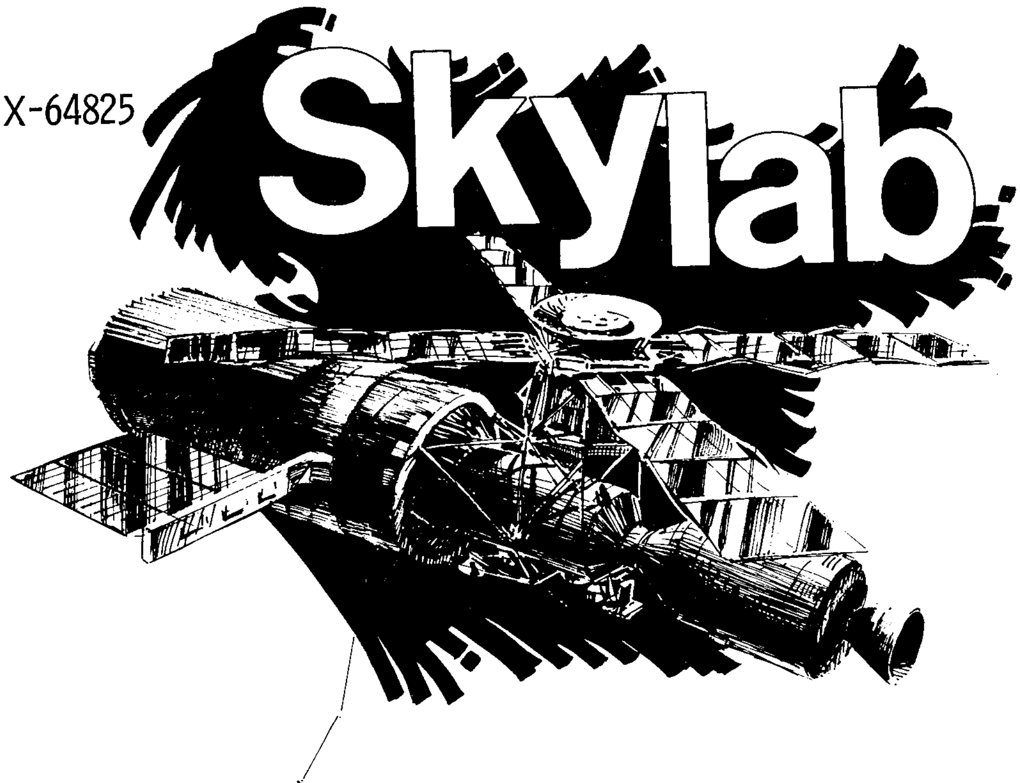

MSFC SKYLAB CREW SYSTEMS MISSION EVALUATION

Skylab Program Office

NASA

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- Page 192, fifth paragraph, first sentence should read as follows:
  "Experiments S019, S073/T027, S149, T025, T027, S183, S201 and a TV . . ."

- Page 196, paragraph 3. Substitute the term "detector package" for "... door on the experiment housing . . ." in the first sentence, and for "... experiment door ..." in the third sentence.

- Page 200 delete the last sentence of the sixth paragraph and substitute with: The experiment hardware and procedures were adequate and the experiment operations were acomplished with only minor anomalies; one triple exposure, and one of the filters became contaminated causing loss of data.

- Page 203 delete paragraph two and substitute with:
  Due to solar SAL obstructions by the thermal shield, the S019 AMS was utilized to obtain some of the S063 data, resulting in a much smaller FOV. This required that an adapter be flown up on the SL-3 to accomodate S063 on the SMS.

- Page 205 delete heading numbered 5. and substitute with:
  5. S073/T027 - Gerenschein/Zodiacal Light and Contamination Measurement-Photometer System

- Page 205 delete the first sentence in Paragraph one of sub heading 5a. Operations and substitute with:
  The experiment S073/T027 Photometer System was scheduled for operation during SL-2, SL-3 and SL-4.

- Page 206 delete partial paragraph at top of page and substitute with: ... was moved out of the camera's view. The T025 Canister was mounted to the S019 AMS using the S063 adapter. No anomalies were reported. However, all SL-4 photographs were out of focus, apparently due to a missing pressure plate in the Nikon 02 camera.

- Page 209 delete line one of the second complete paragraph and substitute with:
  The crew also experienced a jamming problem with the DAC film magazine which caused the entire spectrograph to cease functioning.

- Page 210 add this sentence as written to the end of the last paragraph: One of the harness dector modules was left in the MDA for retrieval should a revisit to the Skylab ever be made.

- Page 212 add this sentence as written to the end of the last paragraph. However, all the photographs were taken at the wrong focus setting, resulting in out-of-focus pictures.

- Page 214, first paragraph, second sentence, should read:
  "The equipment for the D024, consisting of two thermal control coated samples, two polymeric film sample panels, and two return containers..."

- Page 214 delete heading marked "2." written in correct form as:
  2. M512 (M551, M552, M553, M555) - Material Processing in Space M479 - Zero Gravity Flammobality - M518 (M556-M566) - Multipurpose Electric Furnance

- Page 216 delete the words (and surface tension) from the end of sentence one, paragraph one, and add the following phrase to the end of the sentence: "... and material science investigation in the areas of crystal growth, immiscibles, composites, diffusion, and eutectics."

  Delete the last sentence of the first paragraph and substitute with: Experiments M551-M553, M555, M556-M566 and M479 utilized the M512 facilities.

- Page 217 add a paragraph between paragraph six and seven, correctly written:
  Angles between various celestial targets were to be observed, and the mean error and standard deviation between successive readings in a group were to be used as a measure of any change in the crewman's ability, to make decisions and measurements as caused by the space environment.

- Page 217 delete from paragraph seven, line two "... all three ...", replace with, "... the last two ..."

- Page 217 add a sentence to the last paragraph, correctly written:
  During SL-4, the transparent wardroom window cover was left in place for all but the last two groups of sightings. The mean error and the standard deviation were large when the cover was in place.

- Page 219, second paragraph, after the last sentence add the following:
  "Also, the upper atmosphere of the earth was to be photographed."

- Page 220, first paragraph, first sentence, delete: "... and Zodiacal light..."

- Page 220, first paragraph, lines 5, 6, 7 substitute the work "Nikon" for the word, "DAC".

- Page 220, second paragraph, first sentence should read as follows:
  As an alternate method .... truss, and a new occulting disc were designed and launched on SL-3.

- Page 221, first paragraph, first sentence should read as follows:
  The T025 experiment was performed from the anti-solar SAL on SL-3 and SL-4, and with the S019 AMS on SL-4 with only minor problems.

- Page 221, second paragraph should read as follows:
  T025 was not originally designed for EVA use but, with the addition of the specially designed EVA bracket, occulting disc assembly and filters (illustrated in section VI, E), ultraviolet photographs were taken of the earth's upper atmosphere.

- Page 221, add a paragraph following the last paragraph as follows:
  Upon return to earth, it was learned that the carrousels had not apparently rotated wither due to the failure of the crewman to initiate the power to the experiment or due to the extreme low temperature at the anti-solar SAL for which the experiment was not designed.

- Page 224, fifth paragraph, third sentence should read as follows:
  To reduce/eliminate .... the LSU of its wiring and insulation, leaving only the O_2 line.

- Page 227, second paragraph, prior to first sentence add:
  "The Skylab crews suggested that ..."

- Page 228 delete last sentence of seventh paragraph i.e. "The FMU's were placed..."

- Page 228, eighth paragraph, first sentence, delete, "... adjacent to the film vault..."

- Page 228, last paragraph, third line, third word change from "five" to "two"

- Page 228 delete last sentence of the last paragraph and rewrite as follows:
  Of the two performaces conducted, one shirt sleeve and one suited run was planned for each of the SL-3 and SL-4 missions.

- Page 229 delete second paragraph and rewrite as follows:
  b. Post Mission Assessment-Experiment T020 was performed as planned on SL-3 with the test pilot operating the FCMU three times. The first two runs were performed in shirtsleeve while the last was flown suited. The suited run was conducted utilizing both the Life Support Umbilical (LSU) and Secondary Oxygen Pack (SOP) configurations. On SL-4, T020 was performed twice; both in shirtsleeves.

- Page 231, third paragraph, first sentence should read as follows:
  "The first SL-4, T020 run was performed in shirtsleeves..."

- Page 231, first paragraph, second sentence shoudl read as follows:
  Using a scalpel...stripped of wiring and insulation, leaving only the O_2 line.

- Page 232 add a sentence to the end of the first paragraph as follows:
  An additional data pass was made on SL-3.

- Page 232, second paragraph, second sentence, add to the end of the sentence the following: "...during the dark cycle of the moon."

- Page 232, paragraph four, line two, delete second work "SL-3" and replace with "SL-4".

- Page 232, paragraph 2b., rewrite as follows:
  b. Post Mission Assessment - Student experiment ED25 was not performed due to the failure of one CMG.

- Page 233 delete first word, line two of first paragraph, "SL-3" and substitute with, "SL-2".

- Page 233, paragraph 4b, first sentence, rewrite to read as follows:
  "b. Post Mission Assessment - Due to ... was rescheduled for a second performance on SL-4". Delete the fourth and fifth sentences.

- Page 233, paragraph 5b, second sentence, replace "Ten days..." with "Twenty-three hours..."

- Page 234 change the third sentence of third paragraph to read as follows: The experiment was performed early-, mid-, and late-mission by all three crewmen.

- Page 236, paragraph 8a, first sentence, change "SL-2"to "SL-4".

- Page 236 delete paragraph 8b amd substitute with the following paragraph:
  b. Post Mission Assement - Due to the high OWS temperatures after launch, and subsequent on-ground testing, it was determined that the seed germination probability had been significantly reduced. Resupply of seeds was carried out on SL-3 and performance of ED 61/62 was accomplished during SL-4. The seeds were implanted and photographed as scheduled with no anomalies reported.

- Page 239 delete the last two sentences on page.

- Page 240 delete the third paragraph.

- Page 240, paragraph 11a, second sentence, substitute "behind" for "in".

- Page 240 delete the last sentence of the fifth paragraph, i.e. "Next, the mass...".

- Page 241, third line, add the following sentence:
  An additional dector was launched on SL-4.

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16. ABSTRACT

THIS REPORT PRESENTS A CONCISE PERFORMANCE EVALUATION OF MSFC RESPONSABLE SKYLAB CREW SYSTEM HARDWARE. THE GEORGE C. MARSHALL SPACE FLIGHT CENTER HAD PRIMARY HARDWARE DEVELOPMENT AND SYSTEM INTEGRATION RESPONSABILITIES FOR THE SKYLAB ORBITAL CLUSTER MODULES EXCLUSIVE OF THE COMMAND AND SERVICE MODULE AND INCLUDING MANY OF THE DESIGNATED EXPERIMENTS. THIS REPORT ALSO INCLUDES HARDWARE DESIGN DESCEIPTIONS, POST-MISSION ASSESSMENTS, AND HARDWARE DESIGN RECOMMENDATIONS WITH POTENTIAL APPLICATION TO FUTURE PROGRAMS.

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INTRODUCTION

The voice tapes, films, and extensive crew debriefing comments, resulting from over 500 man-days in earth orbit during the Skylab Mission, were extremely rich in crew systems design information and demonstrated examples of man's productivity in a space environment. Since Skylab was NASA's first, large earth-orbital experimental laboratory, crew systems data obtained from the Skylab Program development experience, as well as mission findings, will no doubt be used as a prime data bank for defining design criteria for the Shuttle Payload laboratories. Although a complete compilation of pertinent film, voice transcripts, and supporting data from the mission, dealing with crew systems design, is available at Marshall Space Flight Center, this report was structured to summarize and document the more significant results in this area for future reference. In varying degrees, these findings will have significant impact on crew accommodation provisions now planned for the Shuttle Orbiter and its associated payloads.

The habitability provisions of the Skylab vehicle, with over 10,000 cubic-feet of living and experimental workspace, was rated quite high by all the crew members. A significant part of the success, in providing a productive environment for the scientific and experimental research, can be attributed to the combined man-machine integration effort, accomplished pre-mission, by experiment suppliers, module and support contractors, and NASA personnel. One of the biggest challenges in the design of Skylab man-machine interfaces was properly accounting for the lack of gravity in a manner so as not to degrade or impair the crew's performance in conducting their research, maintenance activities, and the normal day-to-day functions associated with personal hygiene, eating, recreation, etc. The reporting of this aspect of the mission, the highly publicized and successful contingency repair work, and other activities falling under the man-machine engineering discipline, is summarized for each system. These summaries include a short introduction on the system design and intended use, a performance assessment including hardware anomalies, crew subjective evaluations, an accounting of expendables where applicable, and conclusions which potentially could affect future programs.

SECTION I. SKYLAB CONFIGURATION EVOLUTION-A PERSPECTIVE VIEW

The arrangement and configuration of each major Skylab module can best be understood by reference to initial program goals and directions, which continued to exert profound influence even after significant program changes had been made.

As initially planned, the primary purpose of Skylab, then termed Apollo Applications Program (AAP), was the conduct of a low altitude, low inclination earth-orbital mission, using a spent S-lVB stage as an orbital workshop, with a crew of three men, open ended to 28-days duration. This workshop was to have been revisited, up to one year later, by a second crew, which was to bring the Apollo Telescope Mount (ATM) mated to a modified Lunar Excursion Module (LM) Ascent Stage. The LM/ATM was to have docked to the cluster with this revisit lasting 56-days.

Plans to occupy the spent S-lVB stage, coupled with the projected use of the Saturn I launch vehicle, exerted significant influence over the Skylab configuration. Even after these limitations were removed, with the decision to launch Skylab dry and completely outfitted atop the first and second stages of a Saturn V, program considerations, i.e., cost and projected schedule impacts, prevented wholesale configuration changes which might have then been possible. Each of the major elements will be discussed and include a brief explanation of "how they got the way they were."

A. Multiple Docking Adapter (MDA)

As its name implies, the MDA was initially intended to accommodate the simultaneous docking of a number of other modules. Originally, the MDA was equipped with five docking ports, one axial and four radial, which might have been used for LM/ATM docking, resupply, or data return modules, had the program need later arisen. However, the MDA also served another function which, along with vehicle envelope restrictions, determined its size (10-ft. diameter by 17-ft. length). This module was to have been the launch stowage container of all experiment equipment and most provisions necessary to render the cluster habitable. This equipment was later to have been deployed at various locations throughout the cluster. Certain experiments were to remain in the MDA for their operations thus requiring permanent crew stations. Although the requirement was later relaxed, the MDA was to have served as the primary contingency crew quarters in the event the Orbital Workshop (S-lVB stage) was to prove uninhabitable.

With the decision to launch the cluster dry, the "storehouse" function of the MDA largely disappeared because operational equipment could be launched at its use location. Also, the added payload capability of the Saturn V allowed the ATM, without the modified LM, to be launched at the same time. Controls and displays, associated with the ATM, had been located in an integrated panel designed for the LM. With only minor modifications, this panel was placed in the MDA just forward of the MDA/Airlock Structural Transition Section (STS) interface. The added payload capacity also permitted the addition of a series of earth resources experiments which were located in the MDA. The functions for which the MDA was initially configured were not the functions the MDA finally served.

B. Airlock Module (AM) and Structural Transition Section (STS)

Situated between the MDA and the Orbital Workshop. The AM/STS configuration and functions were perhaps least affected by the "wet to dry" decision. From the outset, this element was intended to provide extra-vehicular activity (EVA) capability and serve as the "systems control center" for the cluster. This module provided the cluster with its two-gas control systems, power distribution and control system, and data/communications systems. Most of these systems controls were located in the STS adjacent to the MDA. The crew station associated with these controls envisioned the crewman positioned with his feet secured in the MDA. When the ATM control and display panel was later repositioned to the MDA, the STS control crew station was slightly compromised.

C. Orbital Workshop (OWS)

Originally, activities associated with the OWS consisted of little more than demonstrating that a spent propulsive stage could be rendered safe enough for entry and habitation. Plans for use of the OWS gradually became more ambitious, but the "wet to dry" decision exerted the most significant influence over the internal design features of the S-1VB stage. The open grid, widely used in the OWS for floors, ceilings, and partitions and originally developed primarily to permit the unobstructed flow of liquid hydrogen during powered flight, was now to serve two important functions; to allow the free flow of ventilation air and provide widely available crew mobility and stability aids. The floor plan, which evolved during the "wet" period, was heavily influenced by the need for access to various tank penetrations and the requirement for simplicity in as much as few OWS systems could be preinstalled, since few could withstand exposure to liquid hydrogen. The first crew would have been faced with the large task of converting a rocket fuel tank into a habitat. The number of separate compartments was held to a minimum and included a large forward compartment, an aft experiment area primarily devoted to biomedical experimentation, a combined waste management and hygiene compartment, a food management compartment, and two sleep compartments--one standard and one experimental. Later, the requirement for the experimental sleep compartment was deleted thus allowing the food management compartment to be enlarged. Otherwise, the crew quarters floor plan was unchanged from its initial "wet" launch configuration. Thus, the OWS general arrangement was largely determined by early program constraints, most of which were later eliminated.

Although the OWS general arrangement was virtually unaffected by the "wet to dry" decision, it then became possible to preinstall most of the habitability provisions. Increased payload capability permitted more liberal weight allowances for systems and expendables thereby permitting more ambitious mission planning and allowing for habitability improvements. For example, it became possible to add an active food freezer/chiller system thereby enhancing the quality of food. Additionally, since the OWS would never be exposed to liquid hydrogen, it was possible to add a viewing window, relocate the scientific airlocks from the STS to the OWS forward compartment, and install an airlock, across the LOX/LH_2 common bulkhead, to create a trash container in the unused oxidizer tank. All of the items previously launch-stowed in the MDA for later deployment in the OWS could be "launched in place." This reduced activation time and permitted a far more ambitious subsystem design.

During the early evolution of the OWS, designers consciously attempted to retain a "visual gravity vector", i.e., one surface was designated as the "floor" with all nomenclature and operations planned around this reference surface. While it was recognized that "up" and "down" designators are arbitrary in a weightless environment, it was felt that it should be observed unless there was a strong reason to deviate from the chosen convention. As designed evolved, certain deviations were made in the OWS. The sleep restraints were suspended between the "floor" and "ceiling" and use of the fecal collector demanded that the crewman "sit on the wall." In other parts of the vehicle, layout considerations appeared to legislate against maintaining consistent conventions. In the MDA, operation of the ATM console required a crew position approximately 90-degrees to the vehicle center line, while monitoring of the nearby STS controls and displays required that crewmen orient themselves parallel with the vehicle axis.

The original AAP vehicle configuration is illustrated in Figure 1. The "as-flown" Skylab vehicle configuration, i.e., depicting the thermal curtain and the missing Solar Array System wing assembly, is provided in Figure 2.

This report does not attempt to trace the design evolution of each system through development of the Skylab Program, but only describes and assesses system performance as finally designed.

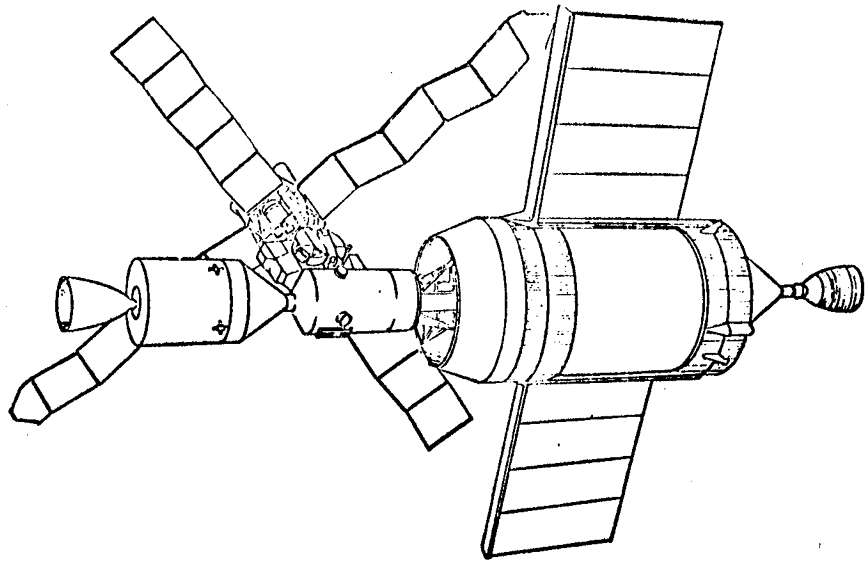


Figure 1. AAP Vehicle Configuration - 1967

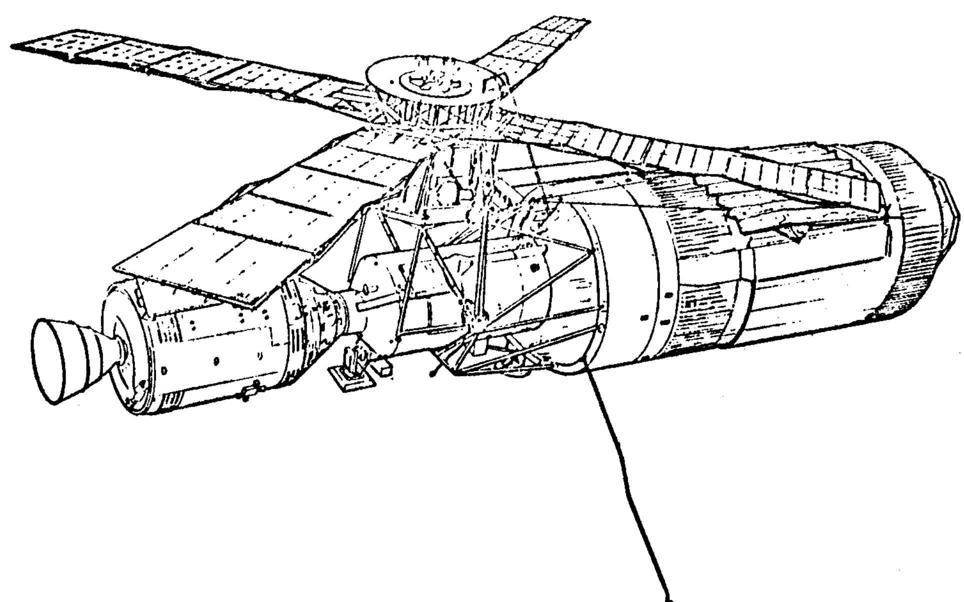


Figure 2. Skylab "As-Flown" Configuration

SECTION II. HABITABILITY, ARCHITECTURAL, AND CREW PROVISIONS

A. Water System

The OWS water system consisted of equipment for the storage, microbiological control, distribution, and dispensing of potable water. Potable water was provided for drinking, food and beverage reconstitution, crew personal hygiene, housekeeping, and water flush of the urine separators. Water was also provided for servicing the Life Support Umbilicals (LSU), the Pressure Control Units (PCU), and the fire hose. Water tank number 6 was reserved for contingency use which included servicing the AM EVA/Intra-Vehicular Activity (IVA) cooling loop, the ATM control and display panel/Earth Resources Experiments Package (EREP) cooling loop, and the M512 experiment facility. Servicing of this equipment was accomplished by using the 60-foot AM Sodium Chromate Deservicing Umbilical. An illustration of the OWS water system is provided by Figure 3.

1. Water Storage, Treatment, and Distribution

a. Design Description

(1) Water Tank - Water storage equipment consisted of ten stainless steel water tanks evenly spaced around the circumference of the forward compartment. Each water tank was constructed of stainless steel and had a minimum storage capacity of 600-pounds usable water. Contained inside each water tank was a sealed metal bellows, which allowed nitrogen gas to provide the pressurant to maintain the water supply pressure required for water distribution. An illustration of a typical water storage tank is included in Figure 4.

Each water tank was an individual unit, supplied with nitrogen gas from the AM by way of a manifold system.

Water management included the actual amount of water (loaded and expellable), the allocation of water tanks for specific functions, and the manner in which it was utilized by the crew. The following is a detailed accounting of the amount of water loaded onboard the OWS for utilization during the three missions.

Tank No.	Loaded Water Tank (Lbs)	Expellable Water Tank (Lbs)
1	661.2	595.2
2	661.1	595.1
3	661.2	595.2
4	655.6	589.6
5	655.6	589.6
6	660.2	594.2
7	662.0	596.0
8	658.8	592.8
9	638.4	572.4
10	661.6	595.6
TOTAL	6575.7	5915.7

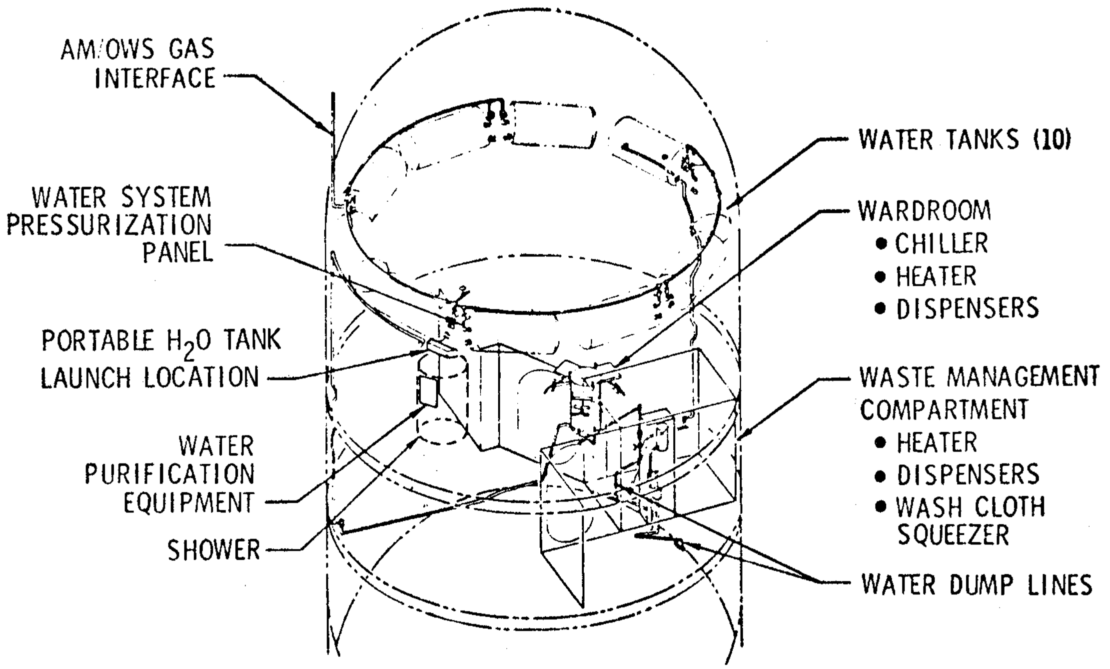


Figure 3. OWS Water System

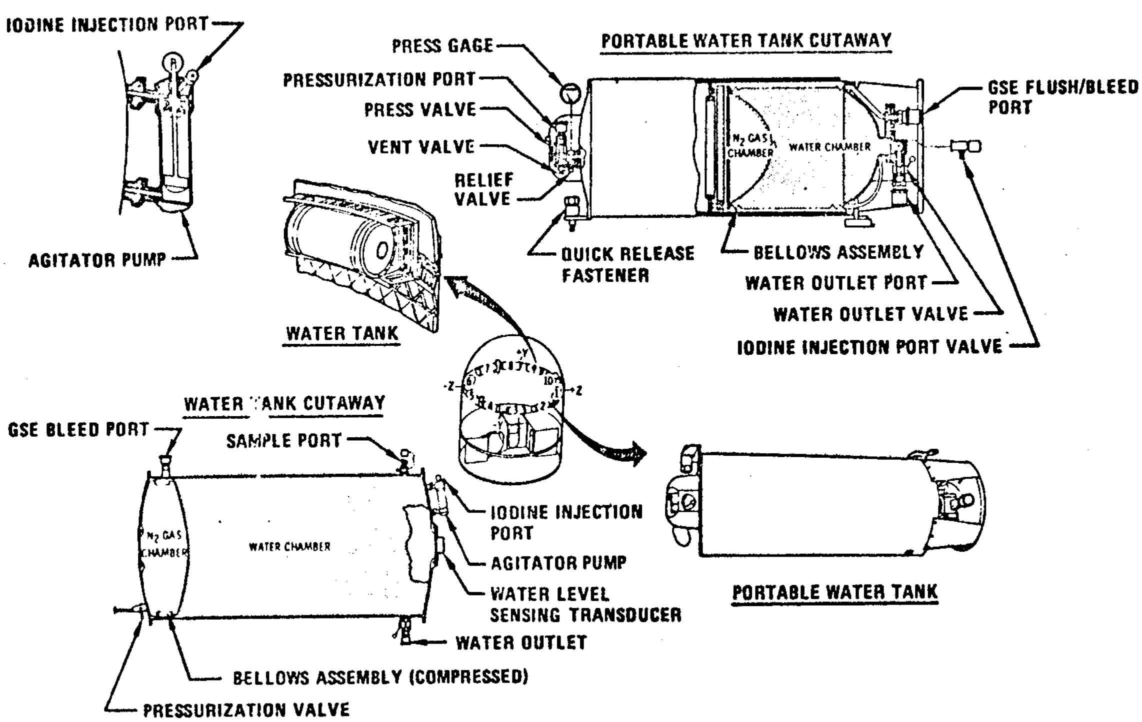


Figure 4. Water Storage Provisions

The water tanks carried onboard the OWS were allocated for use as follows:

Tank No.	Sequential Usage
1	First Wardroom Tank - First Mission
2	Third Wardroom Tank - Second Mission
3	Fourth Wardroom Tank - Third Mission
4	Fifth Wardroom Tank - Third Mission
5	Sixth Wardroom Tank
6	Urine Flush/Contingency Tank/Fire Hose
7	First Waste Management Compartment Tank-First/ Second Mission
8	Second Waste Management Compartment Tank-Second/ Third Mission
9	Contingency (Wardroom or Waste Management/EVA Suit Loop
10	Second Wardroom Tank - Second Mission

(2) Water Tank Heater Blankets - Each water tank was provided protection against freezing by an electrical heater blanket wrapped around the circumference of the tank. The heater blanket was controlled by an electronic module, including a backup thermostat, and was designed to maintain the water temperature between 56-60^{o}F during uninhabited periods. Due to the elevated temperatures during the missions, the water tank heaters were not operated.

(3) Water Purification - Water purification was provided to sample, analyze, and treat the water. The water was purified with iodine used as a biocide. The water purification equipment was launched and stowed inside a metal container (F505) mounted on the Forward Compartment wall under water tank 2. The water purification equipment consisted of two water samplers, two reagent containers, two iodine injectors, two iodine containers, one color comparator, and one waste sample container. The duplicated pieces of equipment were divided into two groups: primary and backup. Figure 5 illustrates the water purification equipment.

Each of the ten water tanks was initially charged with iodine until the concentration was 12-ppm. With normal depletion of iodine with time, the concentration, at the time of consumption, was expected to be a maximum of 6-ppm. The depletion would be a result of iodine reacting to form iodides while in contact with various metal surfaces, and while passing through the cation cartridge.

The crew was to periodically sample the iodine levels and, if necessary, recharge the water tank with the 30,000-ppm iodine solution from the water purification equipment iodine container. The amount of iodine to be injected was to be determined by using the

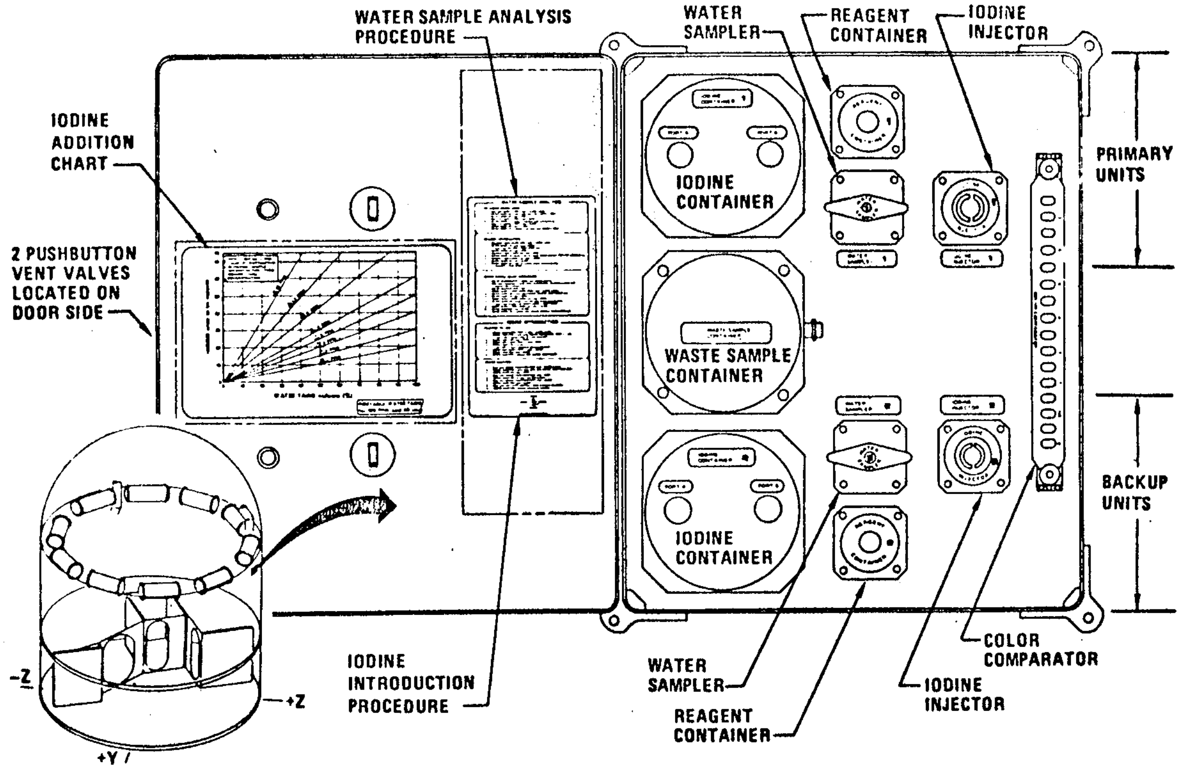


Figure 5. Water Purification Equipment

"iodine addition chart", which scheduled water tank volume (%) and iodine concentration. In order to provide safe drinking water, the iodine concentration was to have been 0.5 ppm or greater. Sampling equipment and a color comparator provided the crew a means of periodically determining the iodine concentration to ensure that the level was always above 2-ppm. If the level was low, the crew was to use an iodine injector to increase the iodine concentration.

(4) Nitrogen (N_2) Distribution Network - The water system N_2 distribution network provided a regulated gas supply to each of the water tanks. This gas supply was used to operate the water storage tank bellows to allow for water expulsion. The source of the N_2 distribution network gas supply was the 4000-psig N_2 tanks in the AM, which were regulated to 150-psig in the AM and then to 35-psig in the OWS.

(5) Tank N_2 Chamber - The water tank N_2 chamber consisted of a dome and metallic bellows in each of the water tanks. At launch, each of the tank N_2 gas chambers was pressurized to 30-psig with the gas pressurization valve on each tank closed.

(6) Portable Water Tank - The portable water tank was provided for sterilization of the water distribution system during second and third mission activation. It was also provided to serve

as a contingency water supply in the event of failure of the normal water distribution system. The portable water tank was launched with the iodine solution containing 30,000-ppm and when filled with approximately 26-pounds of water, the iodine concentration would be 100-ppm. The solution was then to be injected into the water distribution system for a biocide soak. An illustration of the portable water tank is included in Figure 6.

(7) Cation System - The water cation system (deionization cartridge) consisted of a stainless steel container holding approximately 66-cubic inches of ion exchange resin. The function of this system was to remove metal ions from the water as it passed through the resin bed. The resin bed was pretreated prior to flight and at the end of each mission to compensate for the absorption of iodine, which would have adversely affected the water system.

(8) Wardroom Water Distribution - The Wardroom distribution system consisted of a flex line from the designated water storage tank to a hard line on the upper wall of the habitation area. The hard line extended down the wall to the crew quarters floor, underneath the floor to the Wardroom table. In the table, it branched to both the water heater and chiller. The heater was connected to a food and beverage reconstitution dispenser extending through the top of the table. The chiller was connected to a food and beverage reconstitution dispenser and three individual drinking guns. A schematic of the Wardroom water system is provided by Figure 7. An illustration of the Wardroom water dispensing equipment is included as Figure 8.

(9) Waste Management System Water Distribution - The waste management water system provided water for personal hygiene and urine flush. The personal hygiene water was supplied by a flex line from a water storage tank via a hard-line network extending to the personal hygiene locker (H825) in the Waste Management Compartment (WMC), where it connected to the water heater. Figure 9 illustrates this system.

The urine flush system consisted of a supply network from water tank 6 to a dispenser in the WMC which could meter 50-ml increments of water/iodine solution to flush the urine separators daily, if needed.

A schematic of the WMC water system is provided by Figure 10.

b. Post Mission Assessment - The water tanks survived the launch environment with no apparent problems. There was initial concern for the integrity of the water tanks during the time period between launch and habitation. Because of the elevated temperatures in the OWS, it was feared that the water would expand and damage the bellows. Upon arrival of the first crew, the integrity of the water

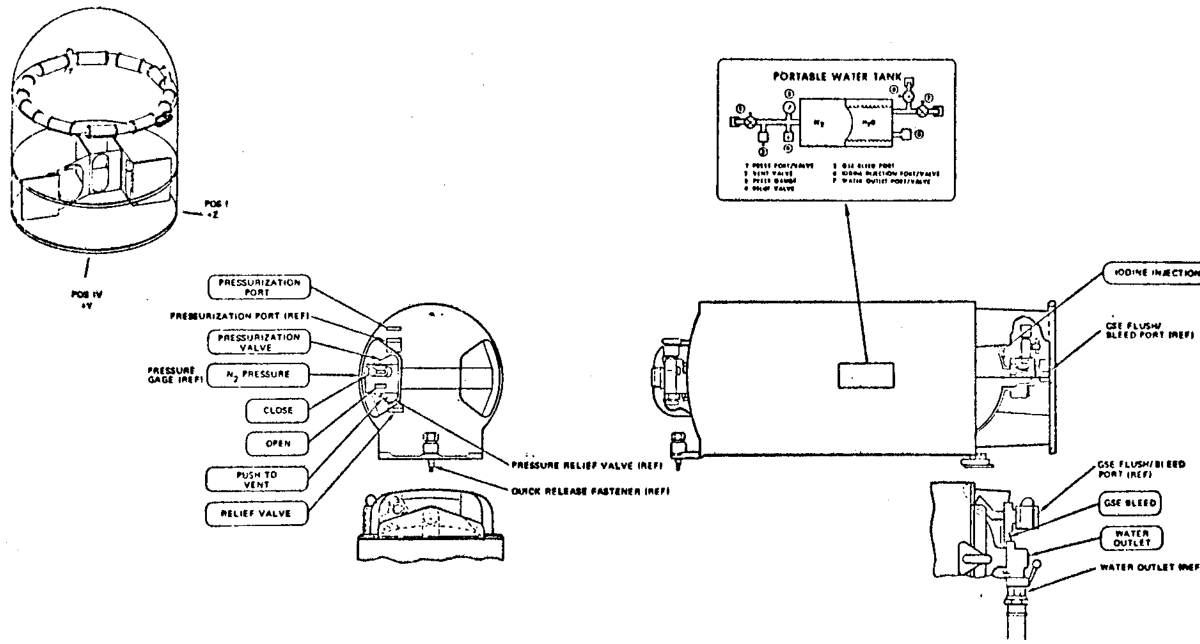


Figure 6. Portable Water Tank

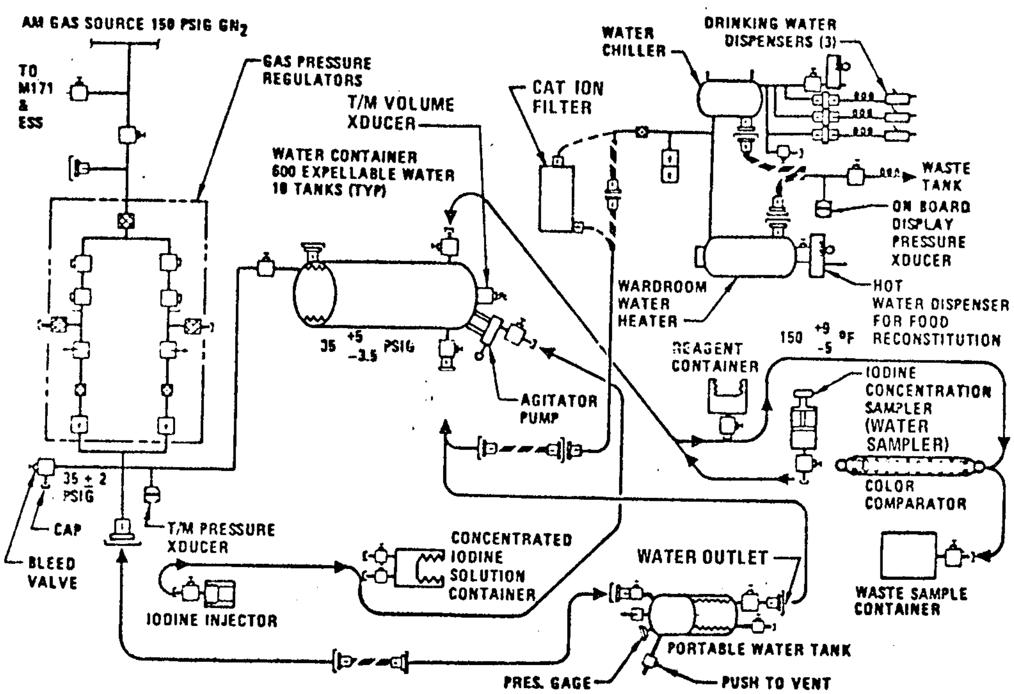


Figure 7. Water System Schematic (Wardroom)

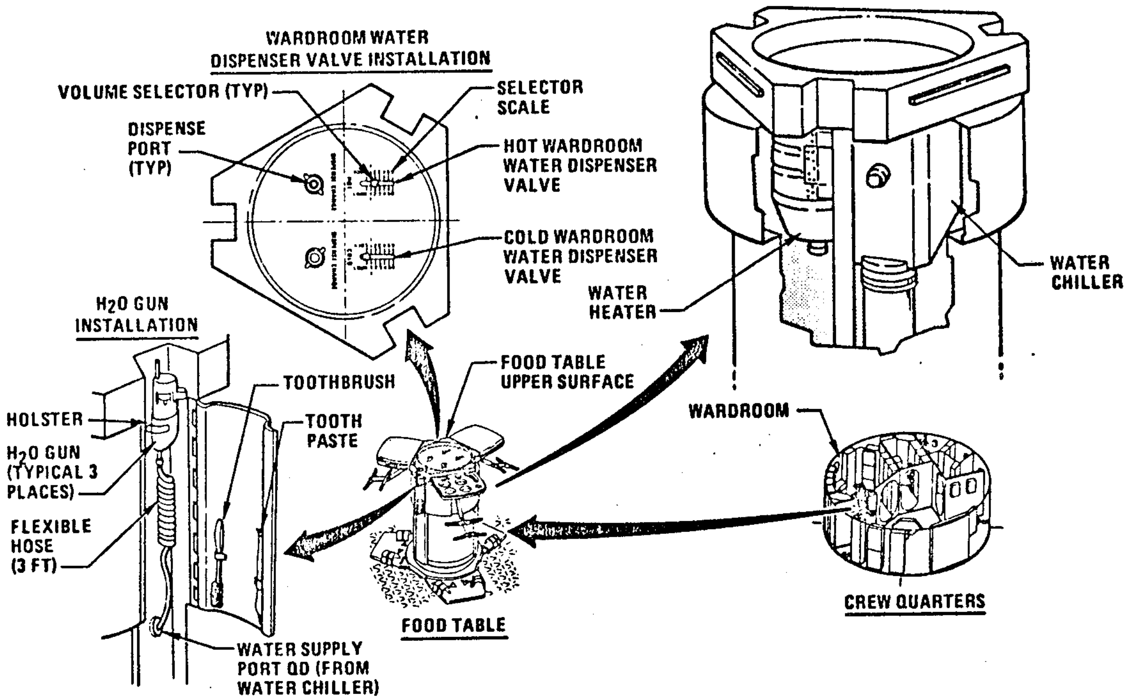


Figure 8. Water Management Dispensers (Wardroom)

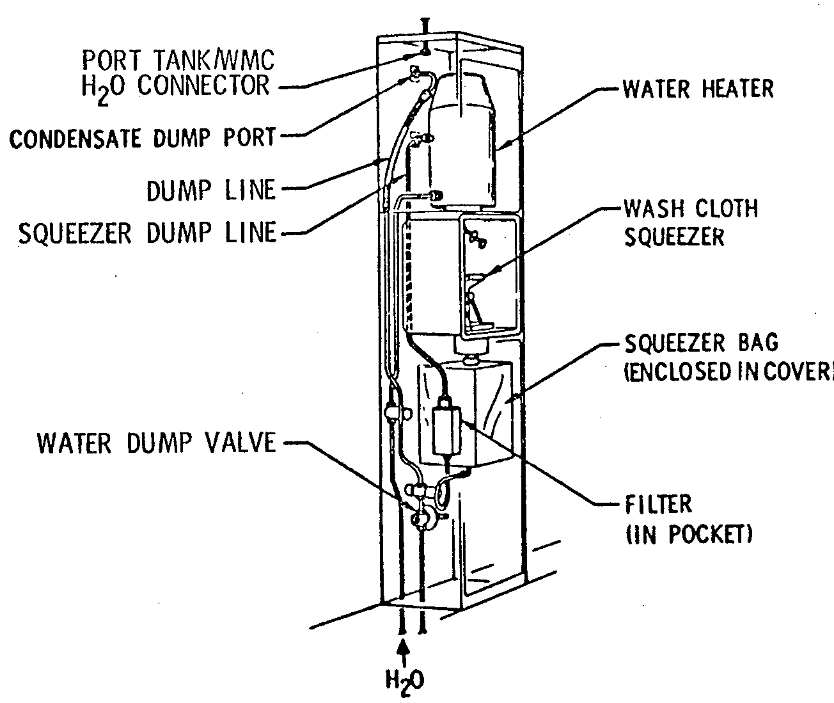


Figure 9. Water Management System (WMC)

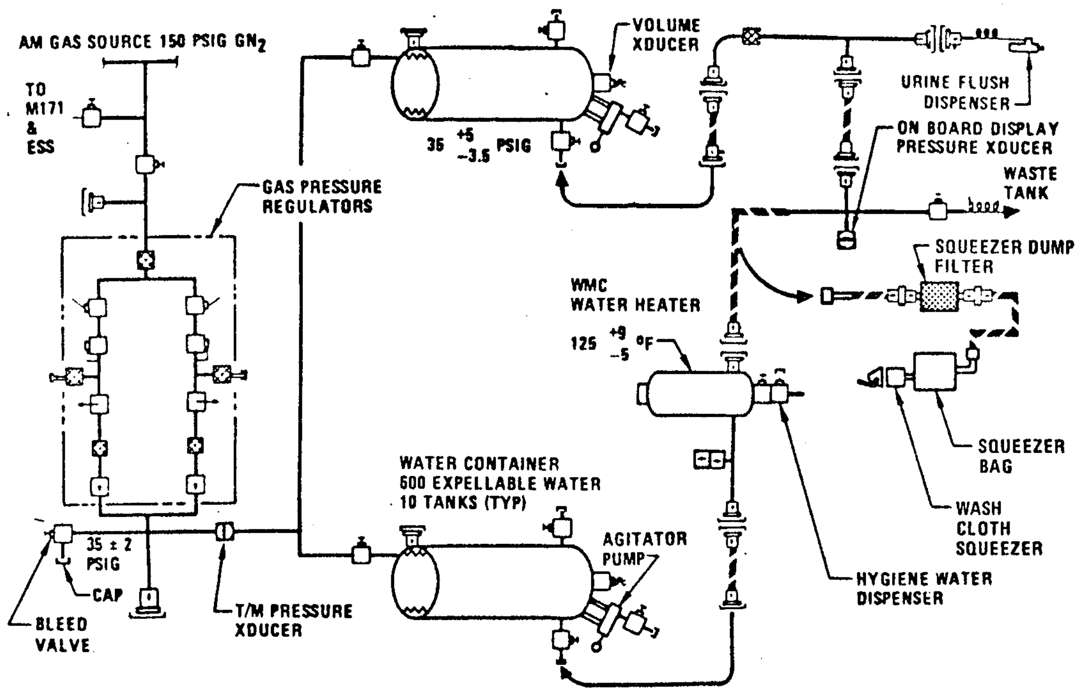


Figure 10. Water System Schematic (WMC)

tanks was verified. The temperature of the water tanks was approximately 130°F. With the deployment of the parasol heat shield, the vehicle temperatures began to drop. The water tank temperatures also dropped, at a slower rate, reaching equilibrium temperatures within several days. During initial water system activation, water tanks 1 and 7 were connected to the Wardroom and WMC distribution systems respectively; the gas pressurization valves on water tanks 1 (Wardroom), 6 (fire hose), 7 (WMC), and 9 (AM equipment) were opened; and the N_2 distribution network was activated with no reported anomalies. Initially, there was some concern that the N_2 supply line from the AM may have been damaged when the meteoriod shield was lost during launch. The regulated system pressure of 35-psig was verified inflight, during the first mission, by attaching the portable water bottle (gas side) to the system and monitoring the pressure gauge. This was the only time the portable water tank was used during the first mission. It was used during the other missions to check the N_2 system pressure and for initial Wardroom network sterilization.

The urine flush system was not activated during the three missions.

For the second and third missions, the Wardroom and WMC water systems were activated and deactivated without incident, the regulated gas supply to the water tanks performed in a normal manner, and water purification equipment was successfully utilized by the crew.

Figure 11 summarizes the total water usage during all three missions. Water usage, from each mission, was as follows:

(1) First Mission - At the termination of the first mission, water consumption from tank 1 (Wardroom) was 494-pounds (versus a 575-pound allocation) as determined by telemetry data measurement L7008. Water consumption from tank 7 (WMC) was 143-pounds (versus a 256-pound allocation) per telemetry data measurement L7014. The crew consumed only 67% of the water allocated. Water consumption curves for tanks 1 and 7 are included as Figures 12 and 13. Drinking water consumption charts, for the three crewmen, are included as Figure 14.

(2) Second Mission - At the end of the second mission, the water consumption from tanks 10 and 2 (Wardroom) was 496.3-pounds, and 330.4-pounds, respectively. The water used from tank 7 (WMC) was 344.5-pounds. Total water usage on the second mission was 1297.5-pounds, which compares to an allocated usage of 1787.7-pounds. Included in Table 1 is the planned complementary water budget for the Wardroom and WMC. The second mission crew used only 69% of the water allocated.

Consumption charts for the second mission for tanks 10 and 2 are provided by Figure 15. Water usage from tank 7 (WMC) is included as Figure 16.

During the second mission, a daily log was kept on the water consumed by the crew. This data was obtained by monitoring the Evening Status Reports which gave the individual water gun cycles and the changes to the planned crew menus. Individual drinking water consumption charts for the second crew are included as Figure 17.

Personal hygiene and contingency water usage (tanks 7 and 9) could not be determined daily, except by monitoring the water tank volume transducers (L7014 and L7016) which were monitored only periodically. An average of 4.5-pounds of water was used daily except for when showers were taken. Also, approximately 60-pounds of hot water was dumped from tank 7 into the waste tank in an attempt to thaw the WMC dump probe. The only use from contingency tank 9 was servicing the Life Support Umbilicals and Pressure Control Units prior to EVA.

(3) Third Mission - At the end of third mission, the water consumption from tanks 2, 3, 4, and 5 (Wardroom) was 330.4, 544.2, 333.6, and 416.6-pounds, respectively. The water used in the WMC from tank 8 was 430.8-pounds. During this mission, a daily log was kept on crew water consumption in the wardroom. Daily water consumption charts for each individual crewman are included as Figure 18.

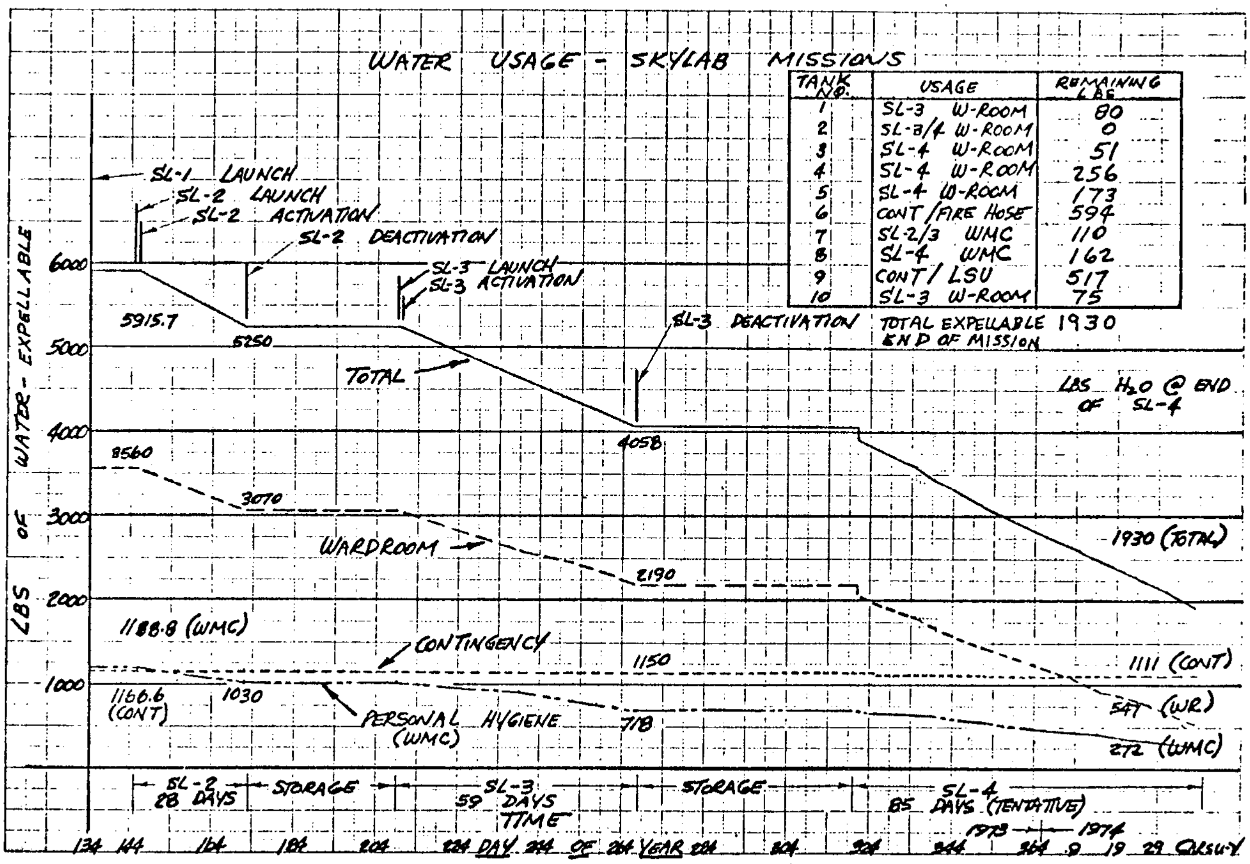


Figure 11. Water Usage - All Three Missions

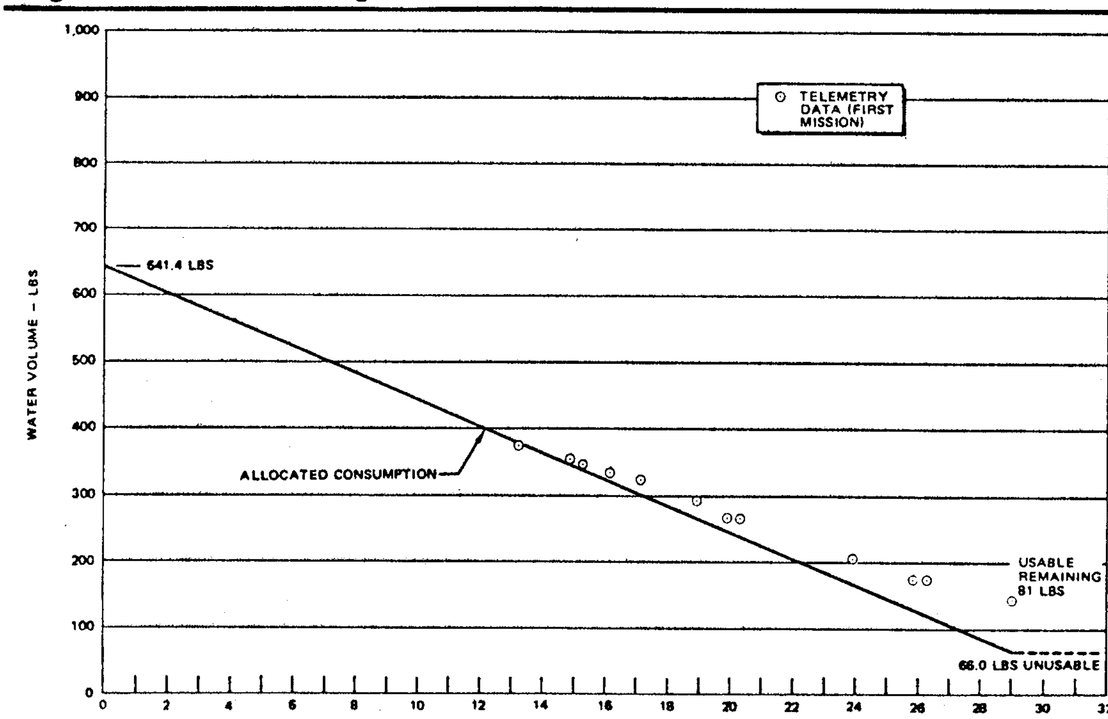


Figure 12. Water Consumption - Tank No. 1 (Wardroom) - First Mission

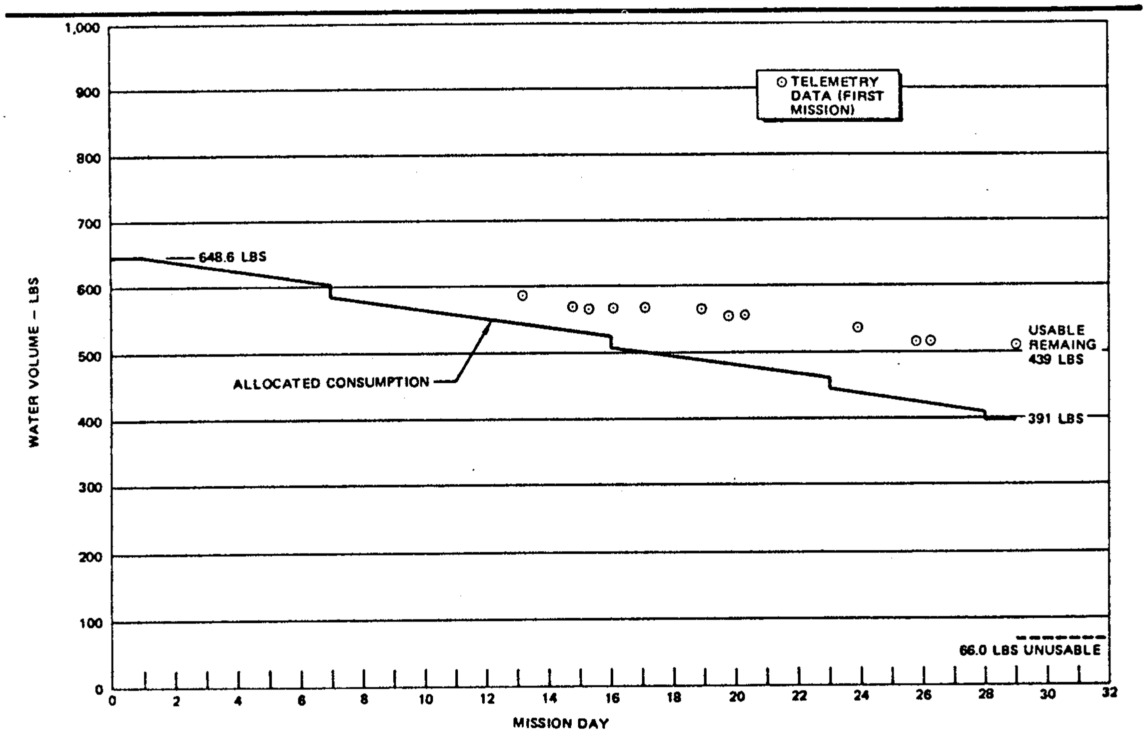


Figure 13. Water Usage - Tank No. 7 (WMC) - First Mission

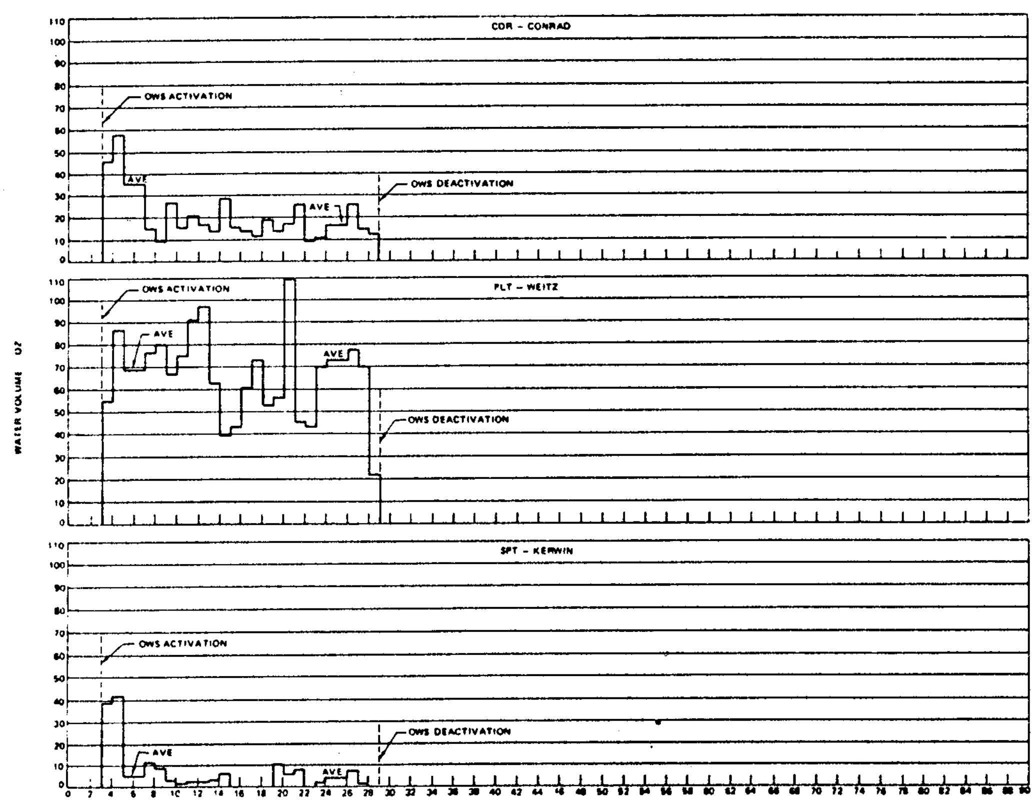


Figure 14. Drinking Water Consumption - First Mission

FUNCTION	MAXIMUM 3 CREWMEN USE RATE	TOTAL REQUIREMENT, LB		CONTAINERS REQUIRED	USABLE AVAILABLE [a], LB	REMAINING USABLE, LB
METABOLIC TANKS:						
CM RETURN	24 LB/MISSION	72.0				
METABOLIC	22.5 LB/DAY	3028.4				
WR SYSTEM BLEED (END OF MISSION)	15 LB/MISSION	45.0	3282.9	[1, 10, 2, 3, 4, 5]		
WR SYSTEM MICROBIOLOGICAL FLUSH	21 LB START 1ST MISSION 58 LB START 2 & 3 MISSIONS	137.0			3549.6	266.7
IODINE SAMPLING		0.5				
WMC TANKS:						
WM SYSTEM BLEED (END OF MISSION)	7.5 LB/MISSION	22.5				
HOUSEKEEPING	4 LB/DAY	544.2		[7, 8, 9]		
PERSONAL HYGIENE	3 LB/DAY	409.8	1336.8		1774.8	438.0
OWS SHOWER	6 LB/SHOWER (1 SHOWER/MAN/WEEK)	360.0				
IODINE SAMPLING		0.3				
URINE SEPARATOR TANK:						
URINE FLUSH	600 ML/DAY	180.3				
URINE SEPARATOR BLEED	3.5 LB/MISSION	10.5				
LSU RESERVICING		34.8				
ATM C&D PANEL RECHARGE		24.0	254.9	6	591.6	336.7
CONDENSING HEAT EXCHANGERS RESERVICING		3.9				
M479 EXTINGUISHING		1.3				
IODINE SAMPLING		0.1				
				TOTAL REMAINING		1041.4

[a] BASED ON ACTUAL USABLE QUANTITY OF 591.6 POUNDS PER CONTAINER

Table 1. Water Budget

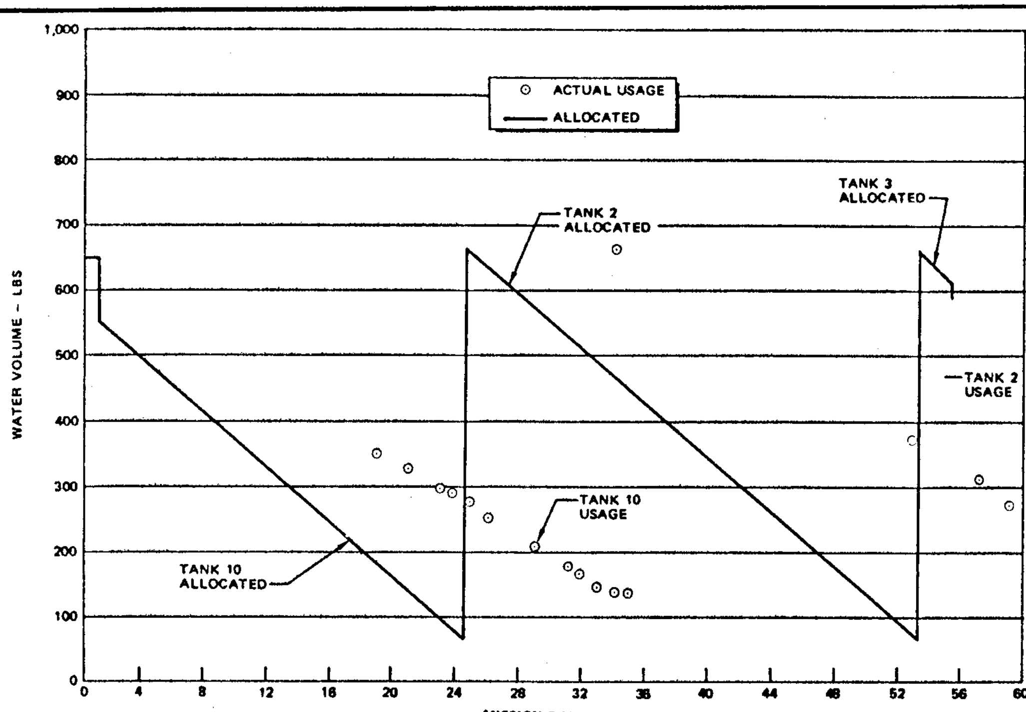


Figure 15. Water Consumption - Tanks No. 10 and 2 (Wardroom) - Second Mission

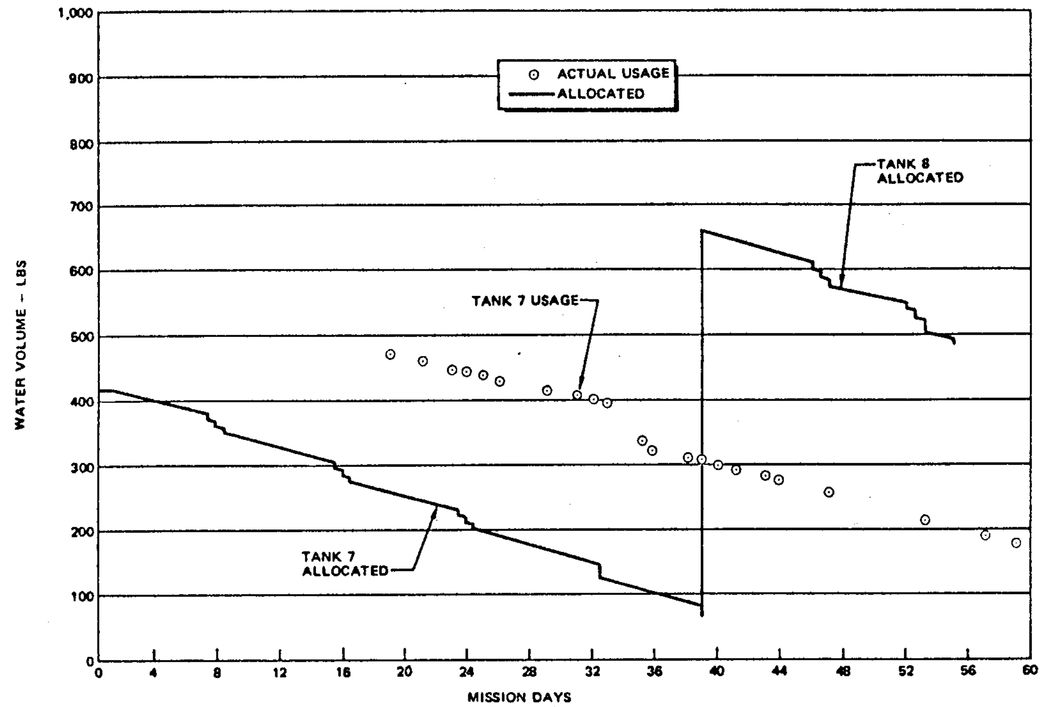


Figure 16. Water Usage - Tank No. 7 (WMC) - Second Mission

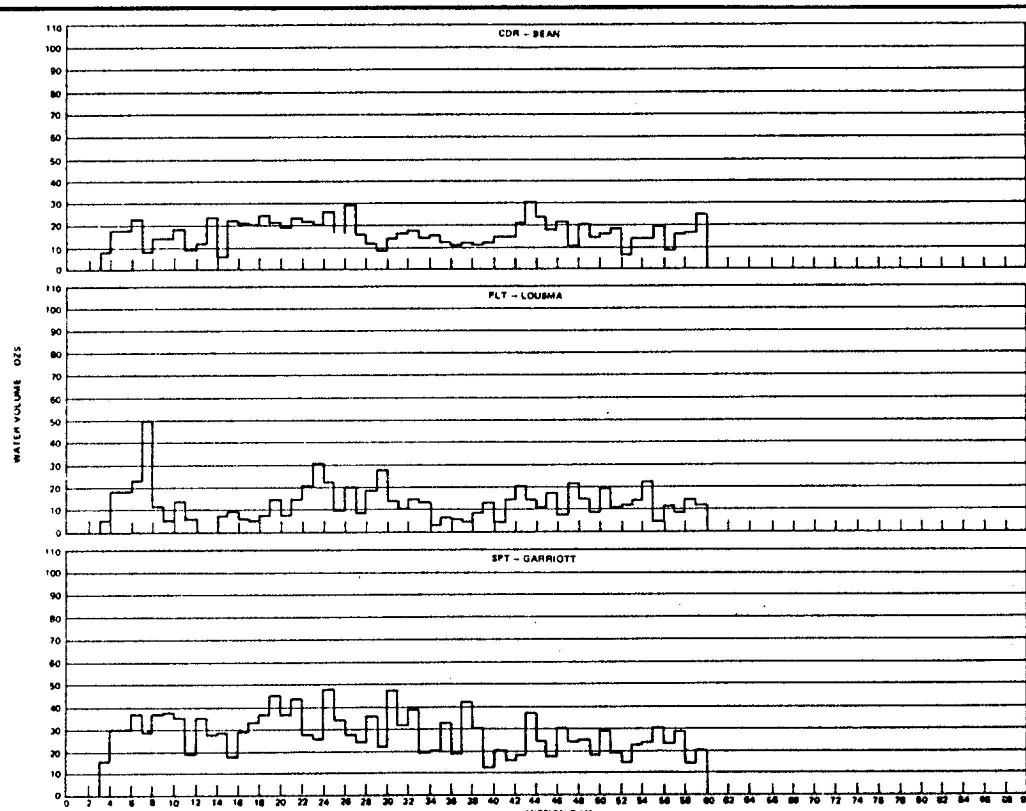


Figure 17. Drinking Water Consumption - Second Mission

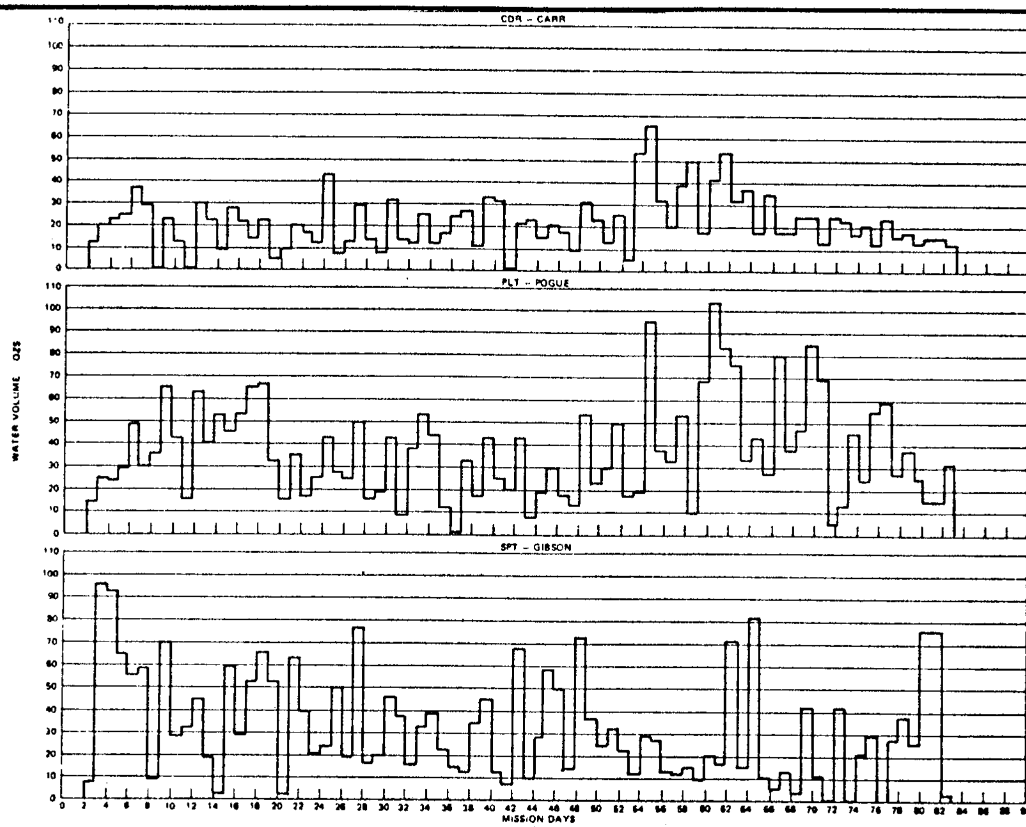


Figure 18. Drinking Water Consumption - Third Mission

The following water samplings and iodine injections were performed, during the three missions, to maintain water purity:

<u>Water Sampling</u>

DOY 147	Water Tank No. 1	2.0 ppm
DOY 147	Water Tank No. 7	2.0 ppm
DOY 148	Wardroom Chiller	3.8 ppm
DOY 153	Water Tank No.1	9.0 ppm
DOY 153	Water Tank No. 3	8.0 ppm
DOY 153	Water Tank No. 6	10.0 ppm
DOY 153	Water Tank No. 10	10.0 ppm
DOY 158	Wardroom Chiller	1.0 ppm
DOY 211	Water Tank No. 10	6.0 ppm
DOY 211	Water Tank No. 7	Data Not Available
DOY 211	Wardroom Chiller	7.0 ppm
DOY 226	Water Tank No. 3	4.0 ppm
DOY 226	Water Tank No. 4	7.0 ppm
DOY 233	Water Tank No. 2	5.0 ppm
DOY 233	Water Tank No. 8	3.0 ppm
DOY 233	Water Tank No. 9	0.0 ppm
DOY 238	Wardroom Chiller	3.5 ppm
DOY 265	Water Tank No. 2	2.0 ppm
DOY 265	Water Tank No. 5	6.0 ppm

DOY 265	Wardroom Chiller	Data Not Available
DOY 324	Water Tank No. 3	8.0 - 9.0 ppm
DOY 337	Water Tank No. 4	5.0 ppm
DOY 338	Water Chiller	9.0 ppm
DOY 339	Water Tank No. 5	6.0 ppm
DOY 340	Water Tank No. 5	9.0 ppm
DOY 340	Water Tank No. 6	6.0 ppm
DOY 341	Water Tank No. 8	4.0 ppm
DOY 342	Water Tank No. 9	1.0 ppm

Iodine Injections

DOY 147	Water Tank No. 1	40 Units
DOY 172	Cation Filter	17 Units
DOY 211	Wardroom Network Soak	40 Units
DOY 238	Water Tank No. 3	25 Units
DOY 238	Water Tank No. 5	40 Units
DOY 238	Water Tank No. 7	30 Units
DOY 238	Water Tank No. 8	30 Units
DOY 238	Water Tank No. 9	90 Units
DOY 267	Water Tank No. 2	15 Units
DOY 267	Cation Filter	17 Units
DOY 324	Water Tank No. 3	30 Units
DOY 337	Water Tank No. 4	20 Units
DOY 339	Water Tank No. 5	20 Units
DOY 340	Water Tank No. 6	20 Units
DOY 341	Water Tank No. 8	20 Units
DOY 342	Water Tank No. 9	75 Units

A total of 529 cc of iodine solution was injected into the water system. The amount of iodine solution available onboard was 2760cc (30,000 ppm), leaving a remainder of 2231cc at the end of the third mission. Water system samples were returned from each mission. Comprehensive analyses were conducted on each sample, with the results shown in Tables 2, 3 and 4.

The WMC water dump system operated normally during the first mission. However, during the second mission, the WMC water dump heater probe failed due to icing. The probe was removed and replaced with a spare unit. The system then operated in a normal manner. An electrical check was performed on the probe with no indication of heater malfunction. Prior to the dump heater probe replacement, hot water was dumped into the system in an attempt to clear the obstruction. The WMC system onboard pressure gauge read off-scale high (2-psia) regardless of the time the system was evacuated into the waste tank. Additional troubleshooting revealed a pressure transducer failure. The crew was instructed to vent overnight and then activate the system, since gas in the WMC presented no problems

Properties	Limits	Results
Electrical Conductivity (Micromno/cm @ 25°C)	Reference Only	3.6 X 10
PH (6 25°C)	4-8	4.6
Total Residue (mg/l)	91.	--
Taste and Odor (at 45°C)	Reference Only	--
Turbidity (Units)	11	9 Nephelos Units
Color True (Units)	Reference Only	1
Dissolved Gases (% by Volume)	0.5	--
Biocide (ppm)	Reference Only	--
Particulate/500 ml		
0-10 Microns	Reference Only	--
10-25 Microns	Reference Only	--
25-50 Microns	Reference Only	--
50-100 Microns	Reference Only	--
100-250 Microns	Reference Only	--
Sterility		
Total Bacteria	Negative	--
Total Coliform	Negative	--
Anaerobic Analysis	Negative	--
Yeast and Molds	Negative	--
Ionic Species in mg/ml		
Cadmium	0.01	0.01
Calcium	5.6	--
Chromium (hex)	0.05	0.01
Copper	1.0	0.05
Iron	0.3	0.1 Filtered 0.02
Lead	0.05	0.05
Manganese	0.05	0.01
Mercury	0.005	0.005
Nickel	0.05	0.05
Silver	0.05	--
Zinc	5.0	0.11
Iodide	Reference	25
Selenium	Reference	0.01
I_2		0.5
Silicon		0.5
Potassium		7.0
Magnesium		0.5
Sodium		0.1
Arsenic		0.1
Aluminum		0.5

Table 2. Potable Water - Tank No. 1 - First Mission

Properties	Limits	Results
Electrical Conductivity (Micromho/cm @ 25°C)	Reference Only	32
PH (@ 25°C)	4-8	4.8
Total Residue (mg/l)	91.	--
Taste and Odor (at 45°C)	Reference Only	
Turbidity (Units)	11	5
Color True (Units)	Reference Only	5 to 10
Dissolved Gases (% by Volume)	0.5	--
Biocide (ppm)	Reference Only	--
Particulate/500 ml		
0-10 Microns	Reference Only	--
10-25 Microns	Reference Only	--
25-50 Microns	Reference Only	--
50-100 Microns	Reference Only	--
100-250 Microns	Reference Only	--
Sterility (Colonies/150 ml)		
Total Bacteria	Negative	--
Total Coliform	Negative	--
Anaerobic Analysis	Negative	--
Yeast and Molds	Negative	--
Ionic Species in mg/ml		
Cadmium	0.01	.01
Calcium	5.6	.1
Chromium (hex)	0.05	.02
Copper	1.0	.01
Iron	0.3	.29
Lead	0.05	.02
Manganese	0.05	.01
Mercury	0.005	.005
Nickel	0.05	.03
Silver	0.05	.02
Zinc	5.0	.02
Iodide and Iodine	Reference	33.4
Selenium	Reference	
I_2		.05
Silicon		.5
Potassium		8.8
Magnesium		.5
Socium		1.74
Arsenic		--
Aluminum		.5
Additional Data		
Nitrogen (ppm)		.1
Nitrate (ppm)		7.0
Nitrite (ppm)		.01

Table 3. Potable Water - Tank No. 2 - Second Mission

Properties	Limits	ANALYSIS AT LOADING TANK #1	TANK #5	ANALYSIS AT RETURN TANK #1	TANK #5	CHILLER
Elec Conductivity (Micromho/cm at 25°C)	Ref. Only	20	21	233	310	45
PH (at 25°C)	4-8	5.1	4.9	1.8	7.8	4.9
Total Residue (mg/l)	91	20.4	19.4			
Taste and Odor (at 45°C)	Ref. Only					
Turbidity Units	11	<0.2	<0.2	24	17	16
Dissolved Gases (% by Volume)	.5	.5	.3			
Biocide (ppm)	Ref. Only	11.0	11.8	1.0	1.0	.7
Particulate/500 ml						
0-10 Microns	Ref. Only	40	360			
10-25 Microns	Ref. Only	69	290			
25-50 Microns	Ref. Only	95	140			
50-100 Microns	Ref. Only	8	4			
100-250 Microns	Ref. Only	3	2			
Sterility (Colonies/150 ml)						
Total Bacteria	Negative	Neg.	Neg.			
Total Coliform	Negative	Neg.	Neg.			
Anaerobic Analysis	Negative	Neg.	Neg.			
Yeast and Molds	Negative	Neg.	Neg.			
Ionic Species in mg/ml						
Cadmium	.01	<.005	<.005	.013	.026	<.001
Calcium	5.6	<.02	<.02	25	40	.2
Chromium (hex)	.05	<.02	<.02	.024	.035	.015
Copper	1.0	<.01	<.01	>.005	<.005	<.005
Iron	.3	.02	<.02	.15	.26	.15
Lead	.05	<.05	<.05	>.05	<.05	<.05
Manganese	.05	<.01	<.01	.04	.03	<.005
Mercury	.005	<.005	<.005	.00125	.0005	.0001
Nickel	.05	<.02	<.02	.19	.07	<.01
Silver	.05	<.01	<.01	>.005	<.005	.005
Zinc	5.0	<.005	<.005	.01	.01	<.01
Iodide and Iodine	Ref. Only	11.0	15.3	16.4	18.5	11.9
Selenium	Ref. Only	<.01	<.01	<.01	<.01	<.01
I_2				1.0	1.0	.7
Silicone				.24	.24	.10
Potassium				5.2	5.9	9.6
Magnesium				.40	2.5	<.01
Sodium				.52	.62	.12
Arsenic				.05	<.05	<.05
Aluminum				.05	<.05	<.05
Additional Data						
Nitrogen (Total)				10.12	11.29	.424
Nitrate				.11	.08	.02
Nitrite				.01	.01	.004
Organic Carbon				27	30	1
Color				25	20	5
Amonia Nitrogen				10	11.2	.4
Chloride				13.5	13.0	13

Table 4. Potable Water - Tank No. 1, 5, and Chiller - Third Mission

if the pressure indication was true. Activation, without the transducer, was no problem. The network was used throughout the second and third missions with no further difficulty.

During the first mission, a flow decrease from the WMC hot water dispenser was reported. The dispenser valve was replaced with the spare unit and the flow returned to normal. The crew reported evidence of contamination in the removed unit.

A summary of crew observations, relative to the water system, are as follows:

- The iodine levels in the water tanks remained above the predicted depletion rates. Iodine taste in the water wasn't noticeable. Chilled water tended to remove the iodine taste.
- The water temperature, both hot and cold, was excellent. There was no condensation associated with the Wardroom water chiller.
- The food reconstitution dispensers were adequate. The location of the leak reported on the food reconstitution dispenser was merely a little blow-by on the dispenser and tended to collect on small radii, giving the appearance of being a leak.
- Recommendations were made to have the food reconstitution water selector dispensing volume increased to 8-ounces, compared to 6-ounces, because many of the beverage packets required 8-ounces of water.
- There were no problems encountered distinguishing color on the low end of the color comparator.
- The tank bellows locator (water measuring device) worked satisfactorily on all the water tanks because of the magnet location stripe provided on the side of each tank.
- The tank bellows locator on the condensate tank provided less than desirable results because there was no location stripe on the tank.

The as-flown concept of water storage, transfer, expulsion, and general management was proven to be completely satisfactory, workable, and feasible as an approach where weight allowance is not a critical consideration. However, it is generally acknowledged that future space programs will have to explore and develop other potential concepts, such as water reclamation, which is less weight-costly.

B. Waste Management System

The Waste Management System collected, sampled, processed, and stored all crew metabolic wastes. This included provisions for collection, preservation and management of feces, urine, and vomitus.

The major functions of the Waste Management System were to provide a comfortable means for the crew to perform daily fecal and urine eliminations and also provide a means of sampling and preserving this material for return to the ground for biomedical analysis.

The Waste Management System consisted of a fecal/urine collector, collection and sample bags, sampling equipment, odor control filters, blower, waste processor, urine freezer, and other necessary supplies.

The fecal/urine collector provided means for collecting both feces and urine using airflow, as a gravity substitute, to separate the waste material from the body. Urination could be performed either in the standing position or in the seated position, at the discretion of the crewman. Urination and defecation could be performed simultaneously, if desired. An illustration of the Waste Management System is provided in Figures 19 and 20. The fecal/urine collector functional interfaces are shown in Figure 21. The basic components of the fecal and urine collector are illustrated by Figures 22 and 23.

1. Fecal Collection

a. Design Description - Fecal collection equipment was designed to collect and control all consistencies of fecal matter. It provided airflow through a fecal collection bag for containment and a filter for odor control. A separate fecal collection bag was provided for each defecation. Airflow also helped separate the fecal matter from the body. The crewman used the fecal collection system by positioning themselves on the fecal collector contoured seat and achieving a sufficiently tight seal interface using the lap restraint belt, hand holds, and foot well restraints. The system equipment was designed to interface with the waste processing system. Backup or contingency mode equipment was also provided. Illustrations of a fecal bag and contingency fecal bag are provided in Figures 24 and 25 respectively.

b. Post Mission Assessment - During all three missions, the crew used the fecal collector as the primary mode of collection. The fecal collection equipment worked successfully and the crews expressed general satisfaction. There were no significant anomalies reported relative to the collector module, air flow, odor control, or fecal bag management. As expected, there were both favorable and unfavorable comments relative to specific aspects of the fecal collector. These are summarized in the following paragraphs.

It was recommended that, on longer missions, the seat be fabricated from a softer material and that the outside diameter flange on the

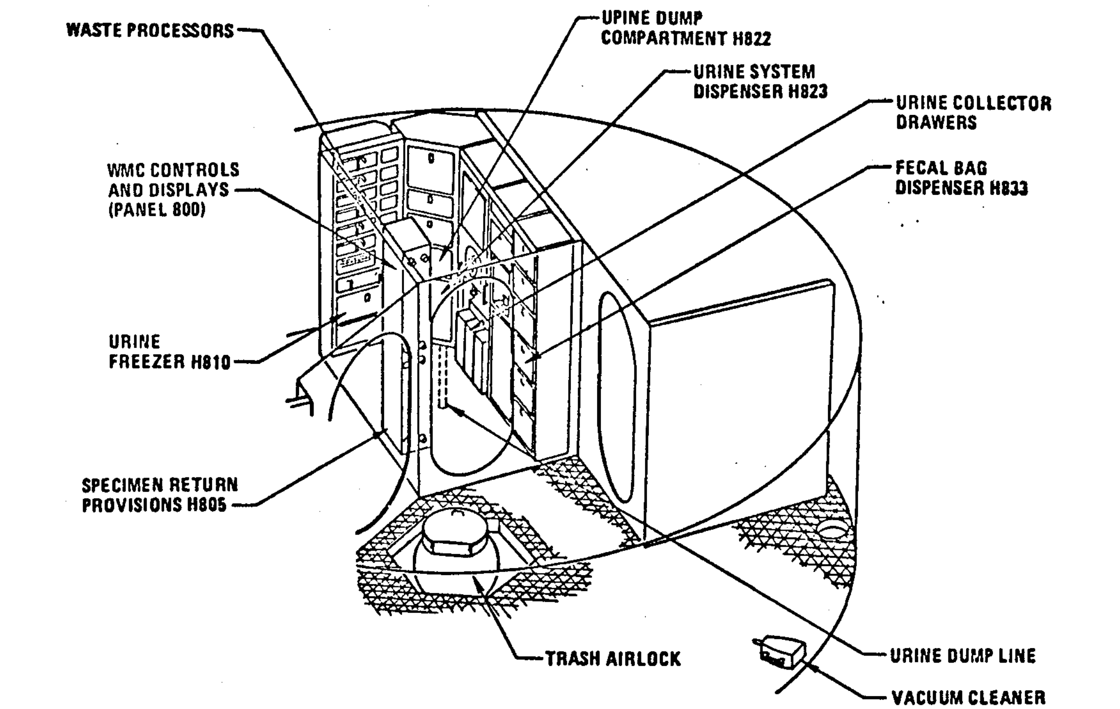


Figure 19. OWS Waste Management Compartment

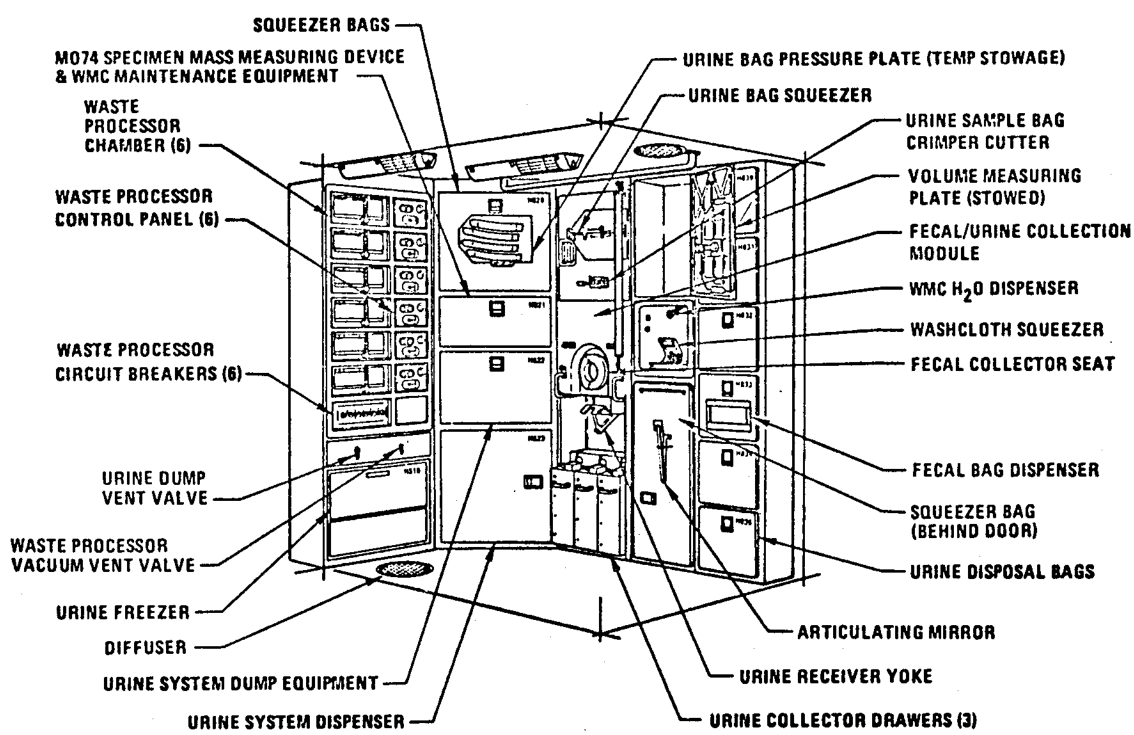


Figure 20. OWS Waste Management Compartment

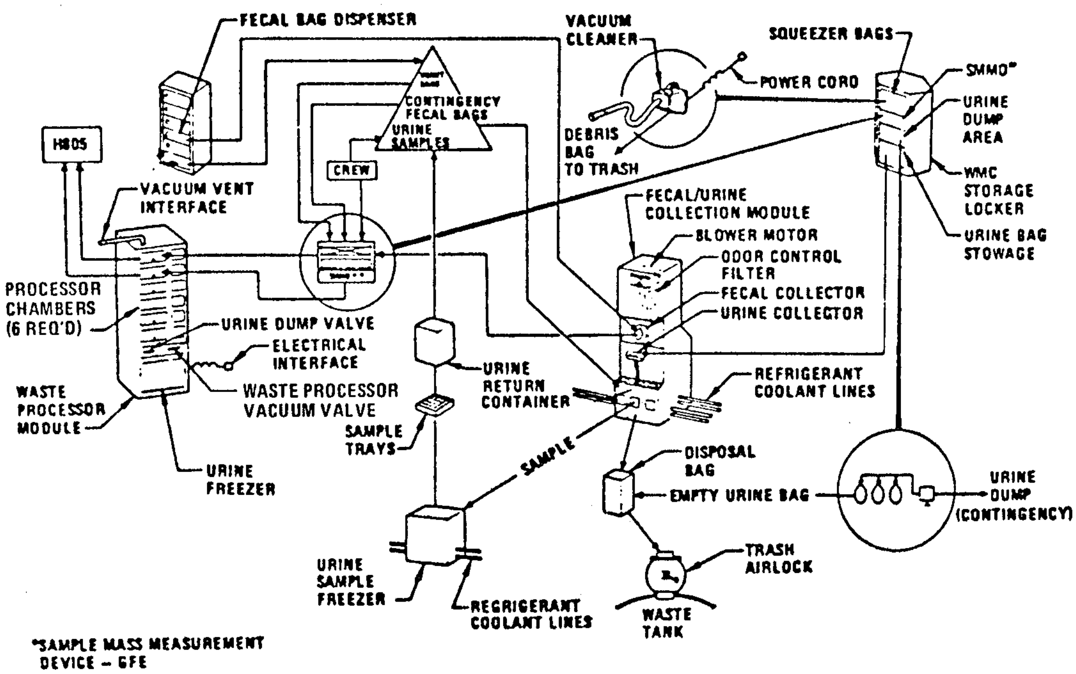


Figure 21. Fecal/Urine Collector Functional Interfaces

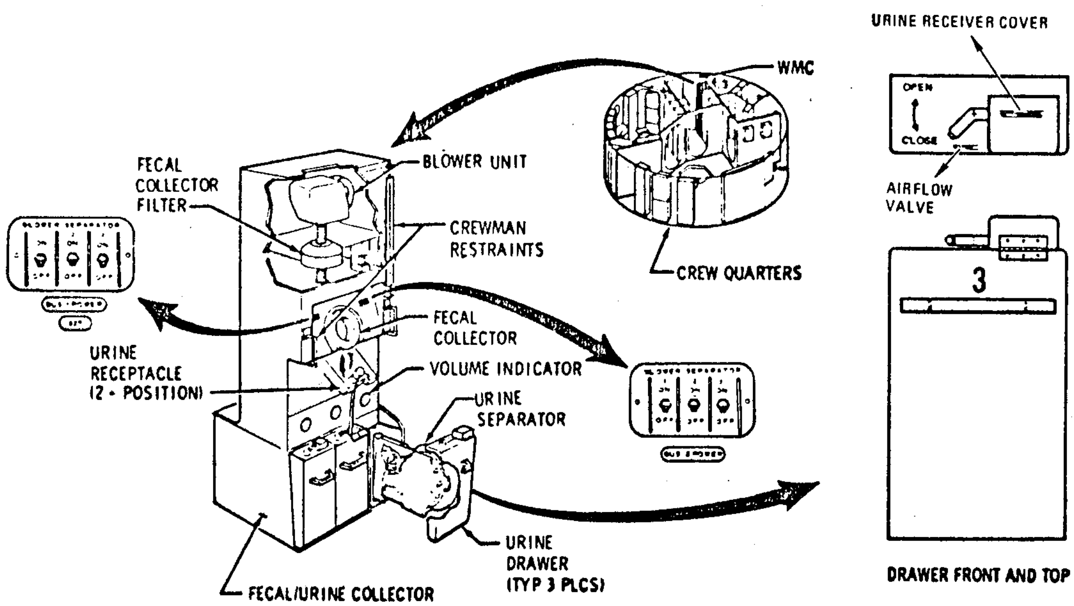


Figure 22. Fecal/Urine Collector

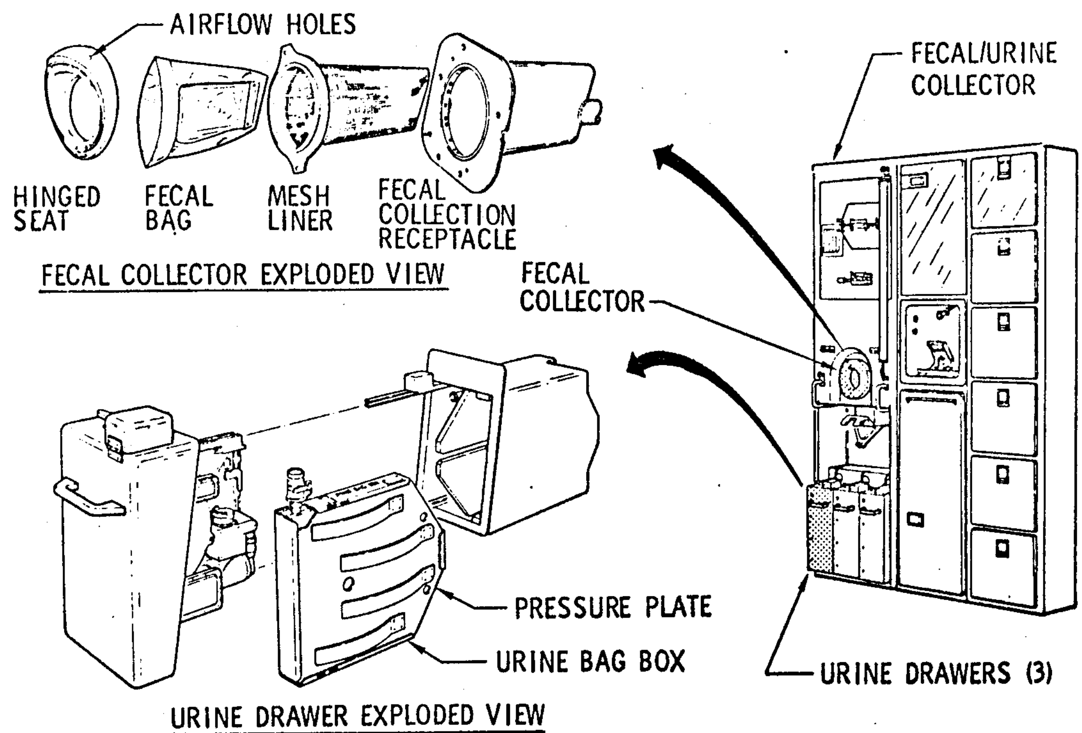


Figure 23. Fecal/Urine Collection Hardware

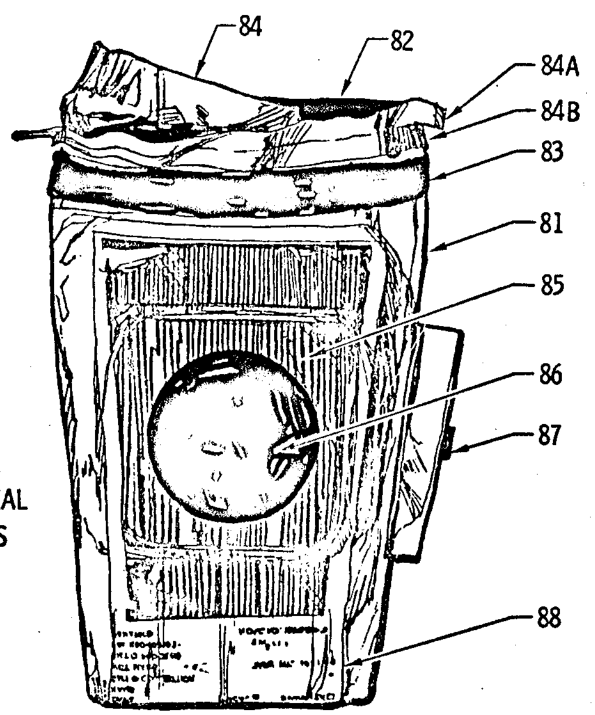


Figure 24. Fecal Collection Bag

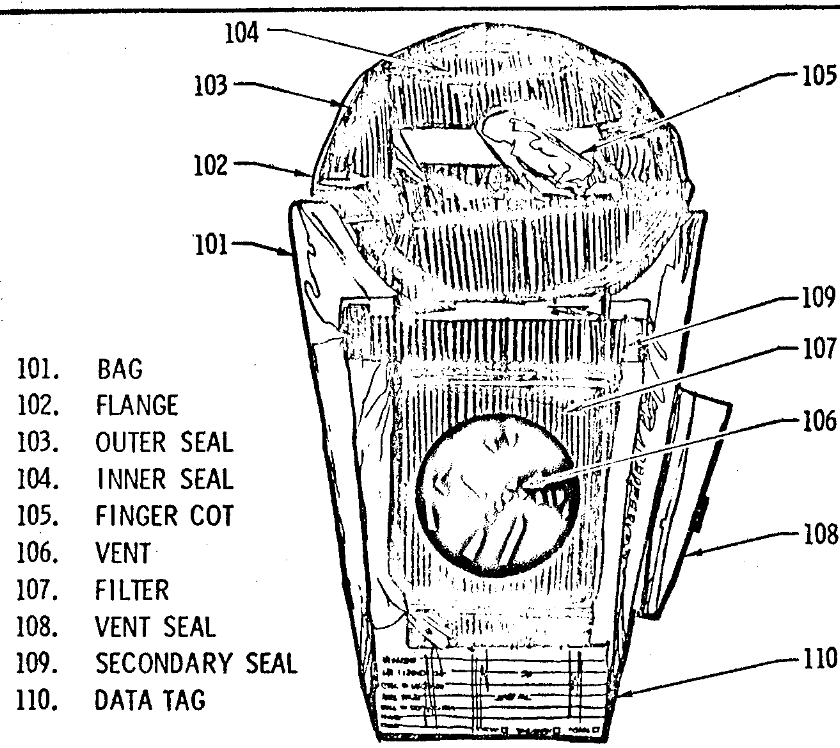


Figure 25. Fecal Contingency Collection Bag

seat be widened. This would make it easier to obtain a good airflow seal and eliminate the undesirable severe "crouch" position required for proper sealing. It was felt that a normal one-g orientation of the fecal collector would have eliminated the troublesome aspect of the crewman's head being too close to the opposite wall (Ceiling). The vertical as-flown orientation of the fecal collector was also undesirable from the aspect that, when seated, the crewman's body blocked out all the light, thus making it most difficult to read. Most crewmen expressed a desire for a horizontal and corner location.

The airflow system of collecting feces was considered to be an acceptable concept and worked well. However, it was felt that higher airflow would have provided more satisfactory results. A 50-percent airflow increase was the suggestion of one crewman with the other crewmen only recommending an increase. The amount of seal obtained using the restraints/handholds related directly to the efficiency of the collector. Triangle shoes could not be used during fecal collection in the foot wells and had to be removed each time.

Minor difficulties were encountered while installing the fecal bag in the fecal receptacle. The second cuff occasionally proved difficult to install. Fecal bag sealing was accomplished by making a one-inch fold instead of one half-inch folds. Bag sealing was accomplished with the blower on, and although there were no seals which leaked, the crews commented on the "unforgiving" sticky adhesive on the bag. Several of the fecal bag black rubber outer cuffs came loose during the first mission and were discarded and replaced with new bags. It was recommended by one crewman that the fecal bag should be deeper. When expelling a normal bolus, it touched the bottom of the fecal bag and, therefore, pushed back on the anus. When it broke free, it started rubbing around on the cheeks creating a messy situation. If the bag would be three to five-inches longer, this would have decreased the mess and cleanup time. There were no fecal bags damaged during use and no filter or seal leaks. A consumable summary for fecal bags for all missions is included in the Stowage-Consumable Summary portion of this report.

There was no difficulty in wiping; however, the articulating mirror was always used. All crewmen used approximately two wipes each, which they placed in the bag, and then used a wet washcloth for final cleaning which was then deposited in the urine disposal bag. Controls and wipes were readily accessible, which was most benefical in terms of system operation and effectiveness.

The WMC odor control system was rated outstanding as odors did not persist.

There were two contingency fecal collections which occurred prior to WMC activation. The use of the paste-on contingency fecal bag was reported to be a messy and undesirable operation requiring excessive cleanup. It was also a time consuming task requiring approximately one hour. No bag damage, leakage or waste management interface difficulties during subsequent processing were reported. The excessive time required to perform the "management tasks" associated with the fecal collection process, such as bag change-out, mass measurement, logging of data, processing, etc., were recognized by the crewmen as not inherent in the design of the system, but the result of the M071/M073 experiment requirements.

2. Urine Collection

a. Design Description - The urine collection equipment was designed to collect and control the urine from the crewmen. It had two modes of operation; (a) airflow, and (b) using a cuff without airflow. The first mode used airflow through a receiver and hose into a centrifuge for air urine separation and then into a urine collection bag. The second mode used a "roll-on" cuff into a bag directly without airflow. A sample was taken from the urine collection bag every twenty-four hours and then the collection bags were replaced. The sample was subsequently placed in the urine freezer and frozen for return. Additional equipment was also provided to accomplish urine chilling, volume determination, sampling, freezing, and disposal. Figures 26 and 27 illustrate the basic components. Equipment used for collecting and sampling are illustrated by Figures 28 through 30. Figure 31 provides a schematic of the centrifugal collection system.

Urine collected during pressure suited operations (launch, M509, EVA) was collected by the Urine Collection and Transfer Assembly (UCTA) which also interfaced with the urine sampling equipment, so that frozen samples could be brought back while using UCTA's.

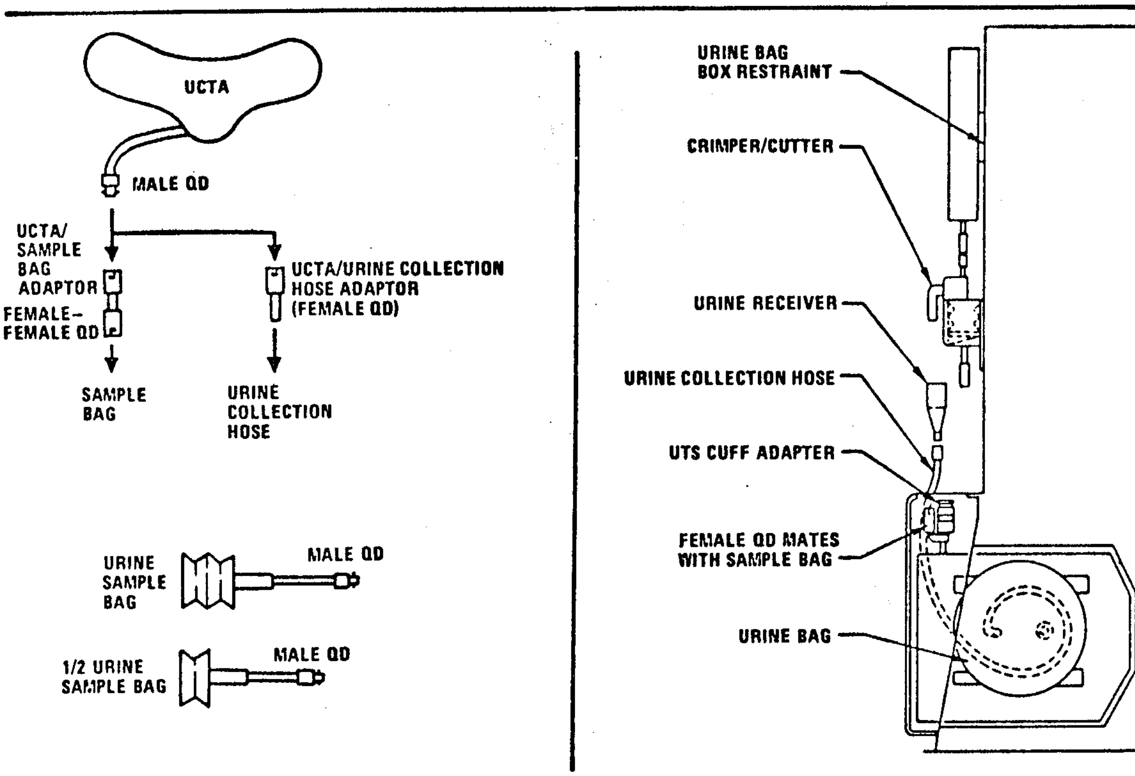


Figure 26. Urine System (4000 ml)

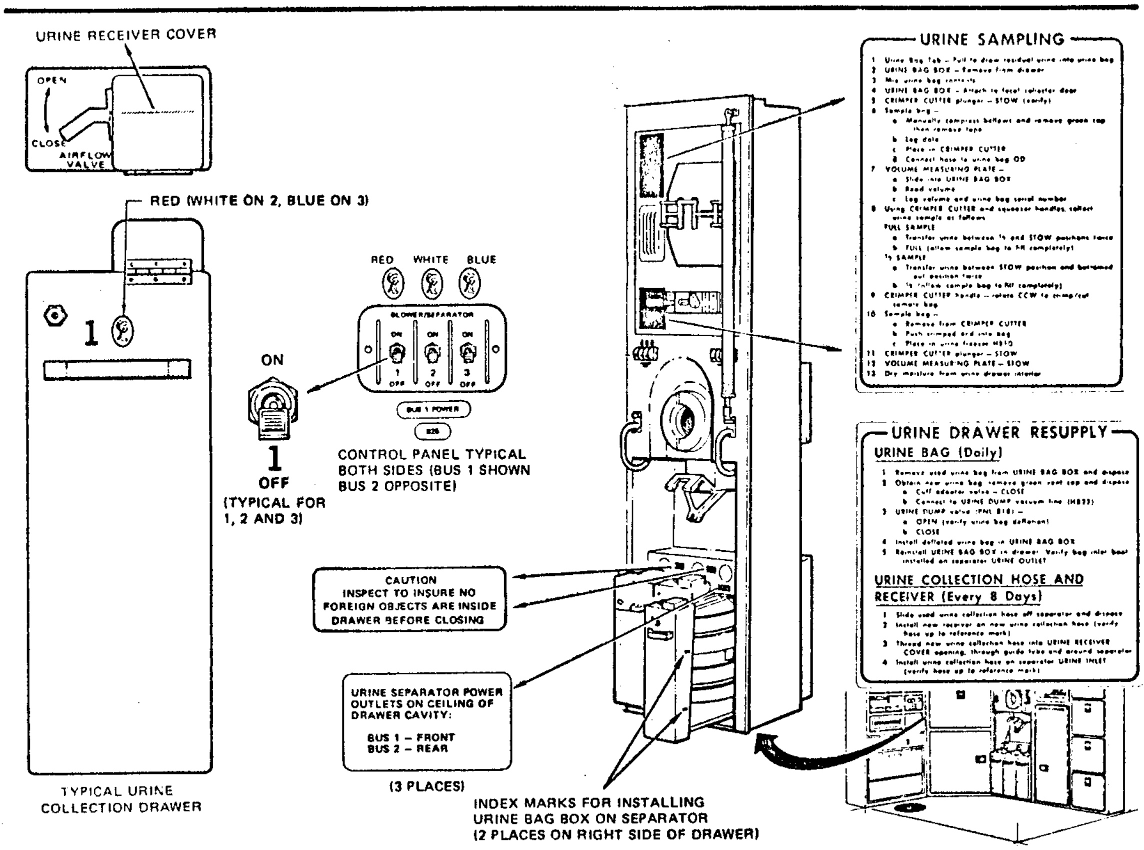


Figure 27. Fecal/Urine Collector

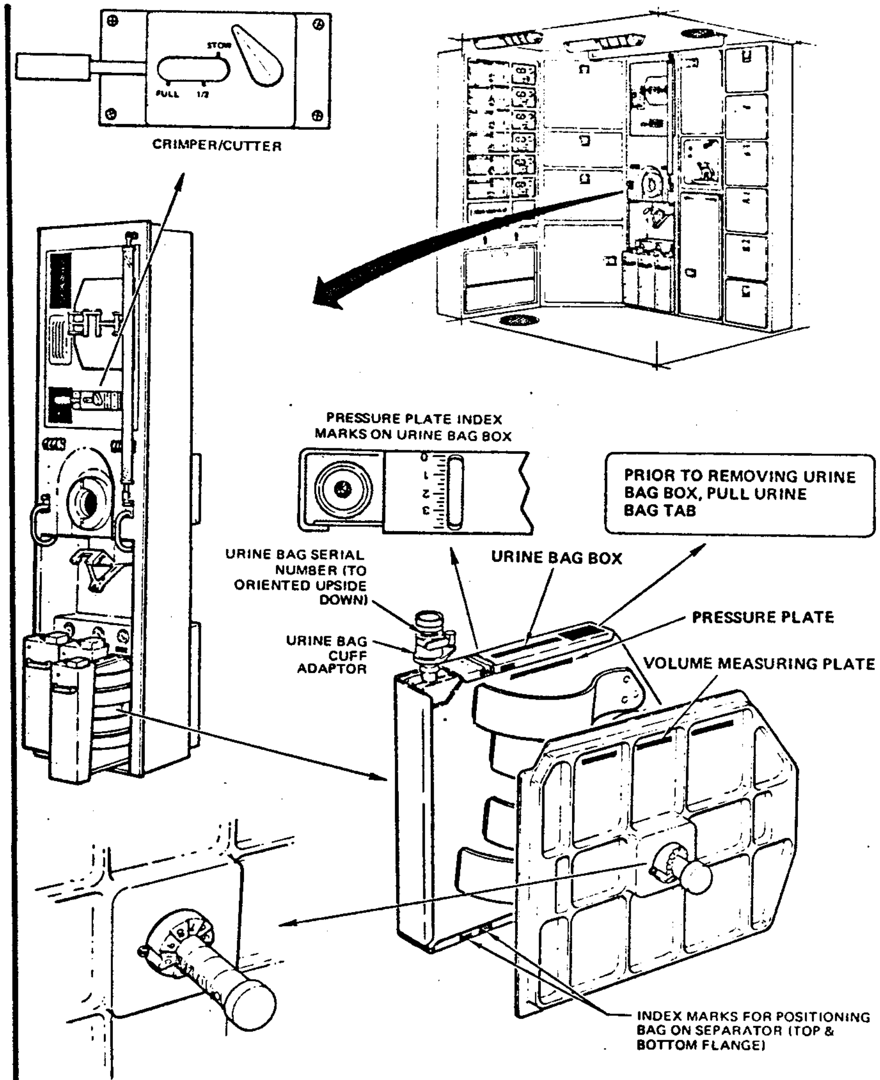


Figure 28. Urine Collection and Sampling Equipment

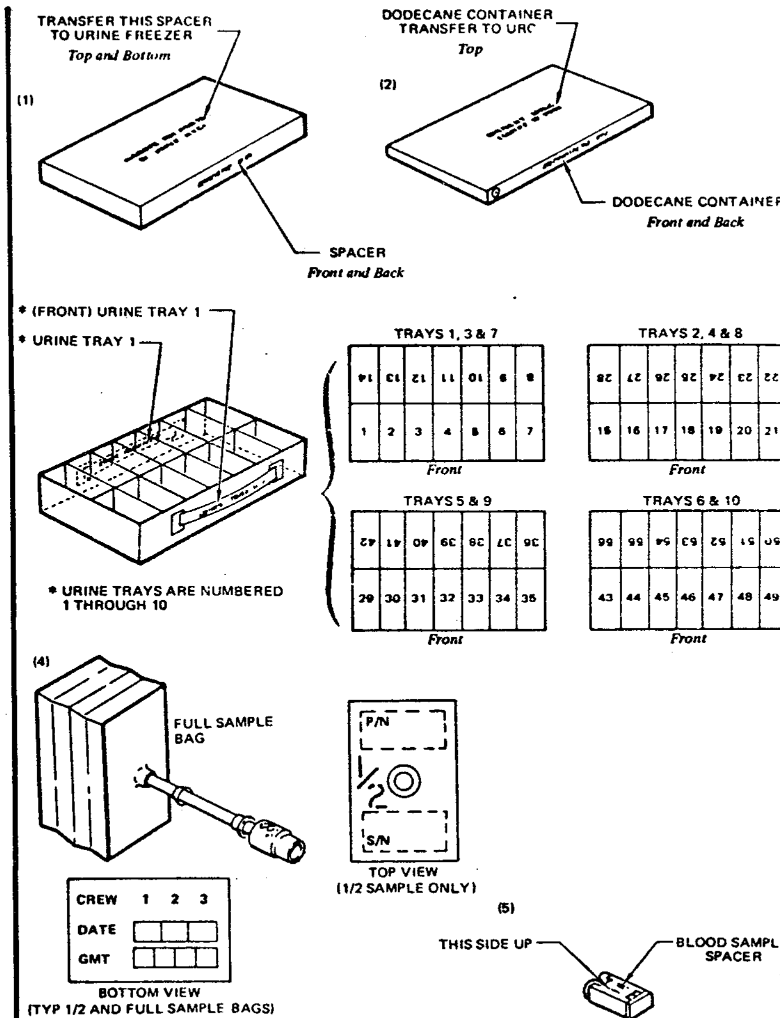


Figure 29. Urine Sample Bags, Blood Sample Spacer, and Urine Freezer Equipment

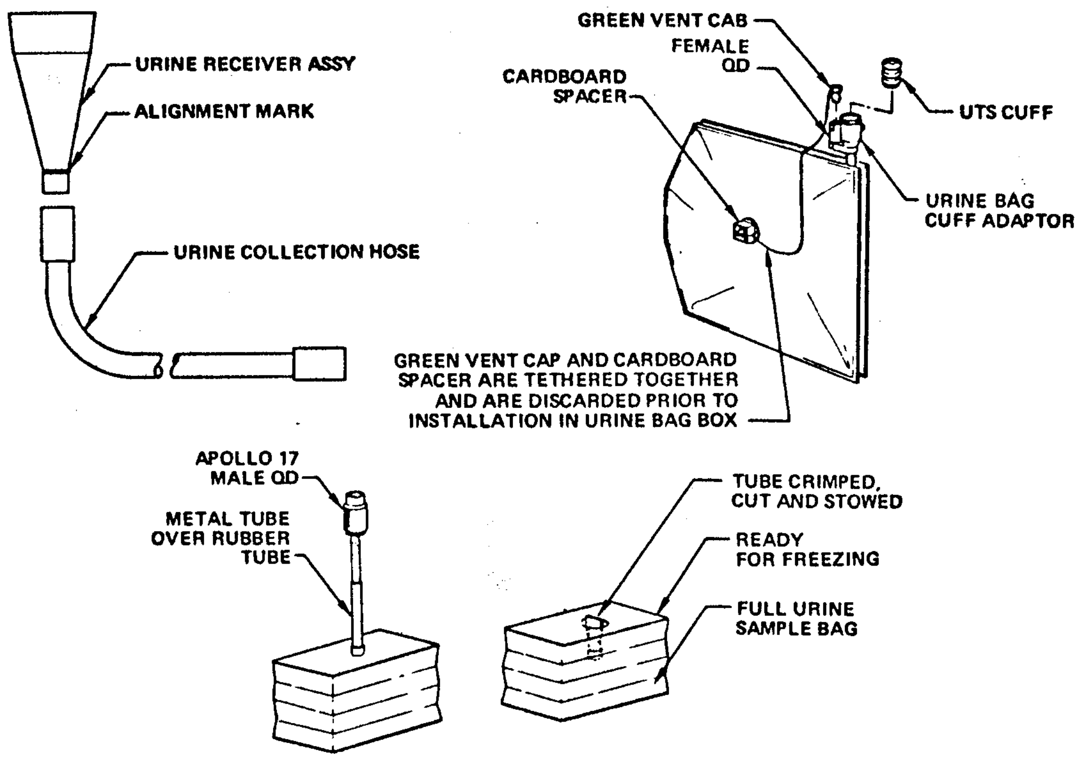


Figure 30. Urine Collection and Sampling Equipment

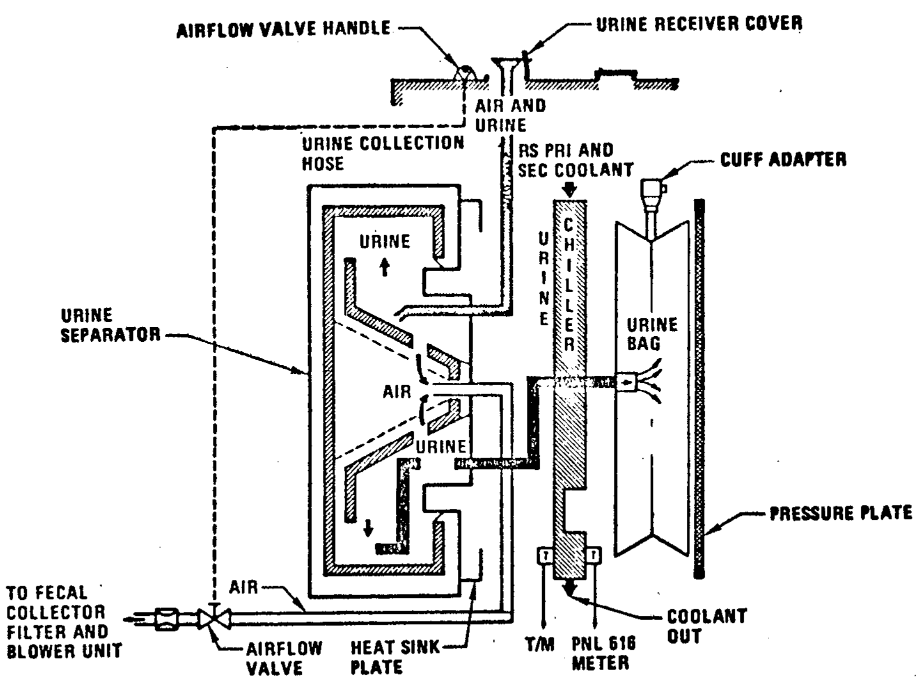


Figure 31. Urine Drawer Schematic

Each crewman had a separate urine collection system contained in one of three drawers mounted in the fecal/urine collector. A 120 ml - 130 ml sample was drawn from each crewman's daily "pooled" urine collection using the following procedure. The urine bag was attached to the front of the upper fecal/urine collector door and a sample bag connected to the urine bag with an interconnecting hose attached to the sample bag. The sample bag was then placed in a crimper/cutter mechanism and filled by applying pressure to the urine bag with squeezer handles. The interconnecting hose was then cut and crimped with the crimper/cutter. The urine sample was then frozen in the urine freezer and maintained below a maximum specified temperature until returned to earth for bio-medical analysis.

Expendable equipment, used to collect and sample urine, included: urine collection bags, sample bags, receivers, urine collection UCTA/ sample bag adaptors, UCTA/urine collection hose adaptors, hoses and roll-on cuffs. Table 5 lists the total equipment launched, excluding additional resupply items, which are included in the Stowage-Consumable Summary section.

b. Post Mission Assessment - The centrifugal system was the primary method of urine collection used by all crews, with occasional use of the roll-on cuff and UCTA's, and all equipment operated satisfactorily. Using a blower/separator system, which eliminated the need for cuffs, makes the act of urination a natural act. The bag system was considered good assuming the procedure called for pooling the urine all day, then dumping. Several of the crewmen even urinated while "floating free" and "upside down", using no restraints, and reported satisfactory results. The crewmen considered one foot restraint adequate for stand-up urination. As with the fecal collection, there were both favorable and unfavorable comments in the assessment of the urine collection system. These are summarized in the following paragraphs.

The system remained surprisingly clean and relatively free from unpleasant odors throughout all the missions. The third crew did not perform the final microbiological cleaning and changeout of contaminated areas and equipment, but did swab some areas to obtain bacteria samples to determine which type lives with crewmen in the zero-g environment. Near the end of the third mission, there was a report of an ammonia odor emminating from the collection module. The odor was apparent when the blower was operating, indicating a failure of the odor control filter. The odor control filter, designed for 28 days of operation, had been operating for 51 days at the time the crew reported the odor. It was recommended that the filter and blower, if necessary, be replaced with spares available on board. The odor was reported to have increased in intensity during the last week of the mission with the blower itself, not the filter, appearing to be the source. No further conversations with the crew regarding this problem were found, consequently, it is not known if these units were replaced.

BAGS

3 MEN X 140 DAYS = 420 - 9 (ACTIVATION) + 21 SPARES = 432

SAMPLE BAGS

FULL BAGS: 3 MEN X 140 DAYS = 420 - 9 (ACTIVATION) - 90 (BLOOD SAMPLES) + 54 SPARES = 375

HALF BAGS: 3 MEN X 2 ACTIVATION HALF SAMPLES X 3 MISSIONS = 18

18 (ACTIVATION) + 90 (BLOOD SAMPLES) - 108 + 17 SPARES = 125 HALF SAMPLE BAGS

TOTAL SAMPLE BAGS: 375 (FULL) + 122 (HALF) - 500 TOTAL

RECEIVERS

3 MEN X 18 (8 DAY CHANGE) = 54 + 6 SPARES = 60

HOSES

3 MEN X 18 (8 DAY CHANGE) = 54 + 6 SPARES = 60

FQD/FQD

3 MEN X 3 MISSIONS + 1 SPARE = 10 ADAPTERS

FQD/HOSE

3 MEN X 6 EVA + 1 SPARE = 19 ADAPTERS

Table 5. Urine Collection Equipment Selection Criteria

The crewmen had occasions to accomplish satisfactory urine collection using the UCTA. The crewmen experienced problems with the proper fit of the UCTA cups and excessive air in the UCTAs. The samples were taken per procedure, but air remained in the samples also. The crew estimated that UCTA samples contained approximately 70-percent air. This was later confirmed by the sample volumes measured post-flight. Different techniques were employed to reduce this problem, but a recommended method of reducing air in the sample bag was not provided. There were no difficulties encountered regarding the method used to squeeze urine samples from the UCTA.

During the first mission, low airflow in the urine receivers was reported during inital urine collection. This was corrected by installing a fecal bag in the fecal receptacle, thereby providing the necessary pressure drop required to balance the airflow between the fecal and urine collection subsystems for normal operation. Later in the first mission, with low airflow in Urine Drawer No. 3, the separator was changed and satisfactory airflow returned. There was no visible blockage of the urine filter and the centrifuge had no urine in it when it was changed. This same separator was reported to have been "cruddy" with a grey substance in the motor to separator gear areas during deactivation motor and separator replacement. The gear area was subsequently wiped off before the motor was installed on the new separator. Only one urine drawer had a tendency to stick while closing, being difficult to close the last inch of travel. The crewman was reluctant to slam the drawer and thereafter applied a force slowly which adequately closed the door. It was reported once, that two separators were "on" simultaneously and the resulting current did not open the circuit breaker. Operation of the urine collector during the second mission was normal through mission day 59, when, on deactivation of Urine Drawer No. 3 it was found that the suction line had debonded and floated away from the suction line. The seal was captured, taped to the collector face, and photographed. Examination of the returned photograph pin-pointed the failure and a repair kit was fabricated for the third mission crew to remedy the problem. Figure 32 illustrates the problem and the repair technique used by the third crew successfully. During the latter part of the third mission, the crew reported that urine crystals began forming over all separators at the juncture between the two halves of the separator. The crystals were removed but reformed. It appeared to be the result of a very gradual time-constant process that was progressive over the entire mission. This phenomenon was observed occurring on all separators but did not seriously impair urine collection activities.

There was no major spillage or breakage of urine or sample bags, although an occasional minor leaked was noted and a few bags broke during the third mission. The loose urine was readily cleaned up and created no serious problem. Additional urine droplets were cleaned up as required at the boot interface to the urine separator. Occasionally, the urine hoses were pinched when caught behind the separator motor. This was corrected by insuring that the urine hose was not in a position to become pinched prior to closing the drawer. The crews changed hoses and receivers on a regular basis, varying from one week to two weeks. No difficulty was experienced installing a new urine bag in the urine bag box and on the separator. During the third mission, in order to conserve the limited supply, the crew started using urine bags for more than one day due to the extended mission duration. The urine drawers were considered to be in an inaccessible area and difficult to properly inspect because the lighting was inadequate. The connectors were all hidden well back inside the drawers; however, one crewman stated that he learned to mate and unmate the connectors by feel during training. One grounding strap on the urine drawer kept separating frequently, even during normal removal and reinstallation.

The noise level of the separators was not disturbing during use; however, when used during sleep periods, the sleeping crewmen were on occasions, awakened by the separator noise. This was mainly attributed to the relatively low noise levels in the spacecraft which made any other noises seem loud and disturbing and should be a consideration in future designs.

The condensation in the urine drawer chillers was minimal and confined to the chiller plates. This condensation was wiped daily as a part of bag change-out. The average temperature for the three chillers for the duration of the mission was 45^{o}F. Early in the mission,

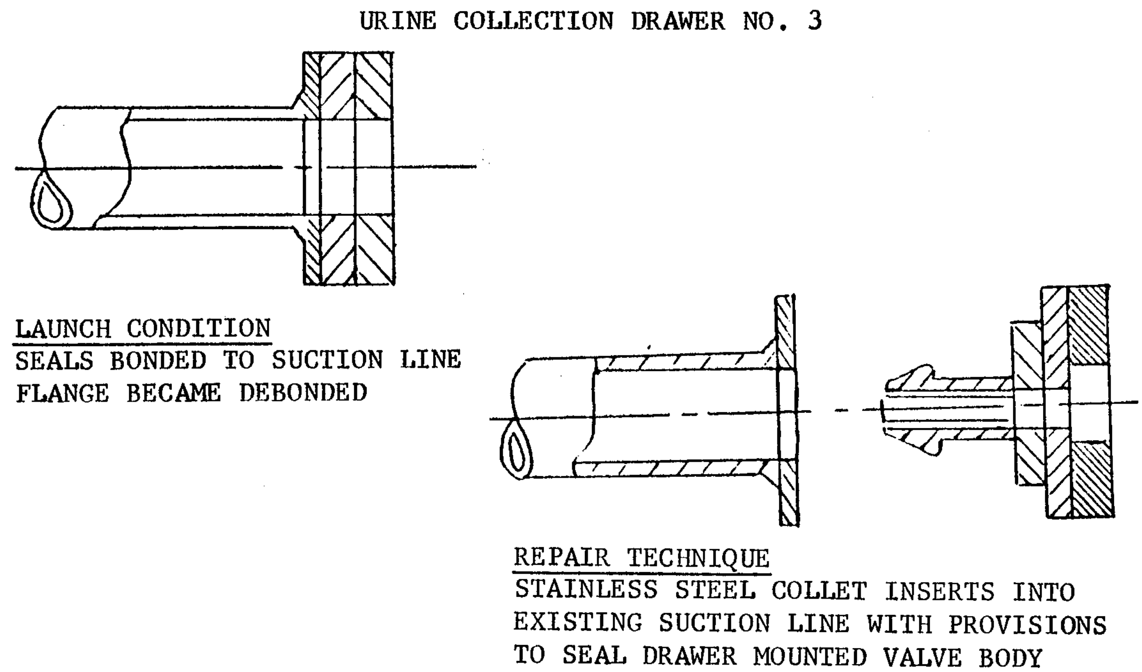


Figure 32. Urine Collection Drawer Seal Debonding - Second Mission

a temperature of 56°F was noted for Urine Chiller No. 1, for an extended period. The crew reported that this was caused by inadvertently leaving the collector blower/separator switch on. Correcting the switch position, returned the urine chiller to its normal operating temperature.

The urine collection and sampling system was operated and maintained in a similar manner by all crewmen. Task times were about the same with each crewman normally performing his own tasks. There was some minor urine spills but they were cleaned up with wipes, towels and soiled clothing. The most significant problem in the urine system was the low sample bag volumes and air entrapment in the samples. The system was designed to collect samples from 120 to 130 ml, but the samples were approximately 80 to 100 ml. During sample extraction, all crewmen noticed small air bubbles entrapped in the urine in the sample bag. It was never ascertained where the air bubbles originated and no recommended procedure was devised to elimate them. The other tasks required for sampling, i.e., crimp cutting of the sample bag tube, pushing the crimped tube into the sample bag, installing the bag into the freezer tray, and handling the freezer trays with frozen bags, had no difficulties. During a third mission trial run of stowing the urine trays in the return container, the crewman reported difficulty inserting the trays. Of the four positions, the outer two trays could not be fully inserted without encountering resistance. The cause of the problem was determined to be sample bags frozen above the top of the tray. Removal of all the cardboard spacers from the return container still did not provide sufficient space for the trays. In further conversations, the crewman indicated he felt he could force the trays into the container adequately. Several of the samples were decapitated, but it was felt that since they would remain frozen they would not loose their integrity.

The daily urine volume (mechanical versus LiCl analysis) for each crewman during the first and second mission is plotted in Figures 33 and 34 respectively. The daily urine sample size for each crewman during the first and second mission is plotted in Figures 35 and 36 respectively. Daily urine volume and sample size data was not available for the third mission crewmen. The urine volumes for each of the crewmen as determined by the analysis for lithium concentration in the returned samples are provided by Tables 6, 7 and 8. Post mission analyses revealed that the sample volumes were lower than the planned 120 ml and urine sampling data had a minor learning curve at the start of each mission for each crewman.

The urine bags were evacuated through the urine dump system, prior to the daily installation in the urine drawers to void the bags of air. During urine bag evacuation, one inlet check valve "squealed", indicating air passing through the check valve. The bag was disposed and subsequently the general practice by the crew was to use the inlet boot plug. During the third mission, urine bag "swelling" was encountered while cycling the trash airlock and the three full urine bags were dumped into the waste tank through the urine dump system. On several occasions during urine dump, the crew had difficulties with undissolved boric acid tablets in the urine bags. On another occasion the urine dump system became clogged, but was later unplugged. There was no report of leakage, spillage, or contamination in the dump compartment resulting from use of the urine dump system.

There was a lack of provisions for securing items, during the sampling and urine bag changing process, which contributed to inefficient urine system management and loose items frequently floating within and out of the WMC.

A way to wipe off the penis after urination is need for future design iterations. It was felt there could be a slight airflow at a certain point on the lid of the collection cup that would blow the urine into the cup, thus eliminating all the hassle. Also, because of the low airflow, when a crewman urinated an additional volume, the centrifuge stopped up, thus causing backflow.

As in fecal collection, the amount of time required for the various management tasks associated with urine collection, i.e., sampling, measuring, bag replacement, etc., must be reduced in the future.

3. Waste Processor

a. Design Description - The waste processor was designed to process crew feces and vomit bags, PGA suit desiccants, and film vault desiccants. The processor was capable of using heat or space vacuum to sublimate water and "dry" the material.

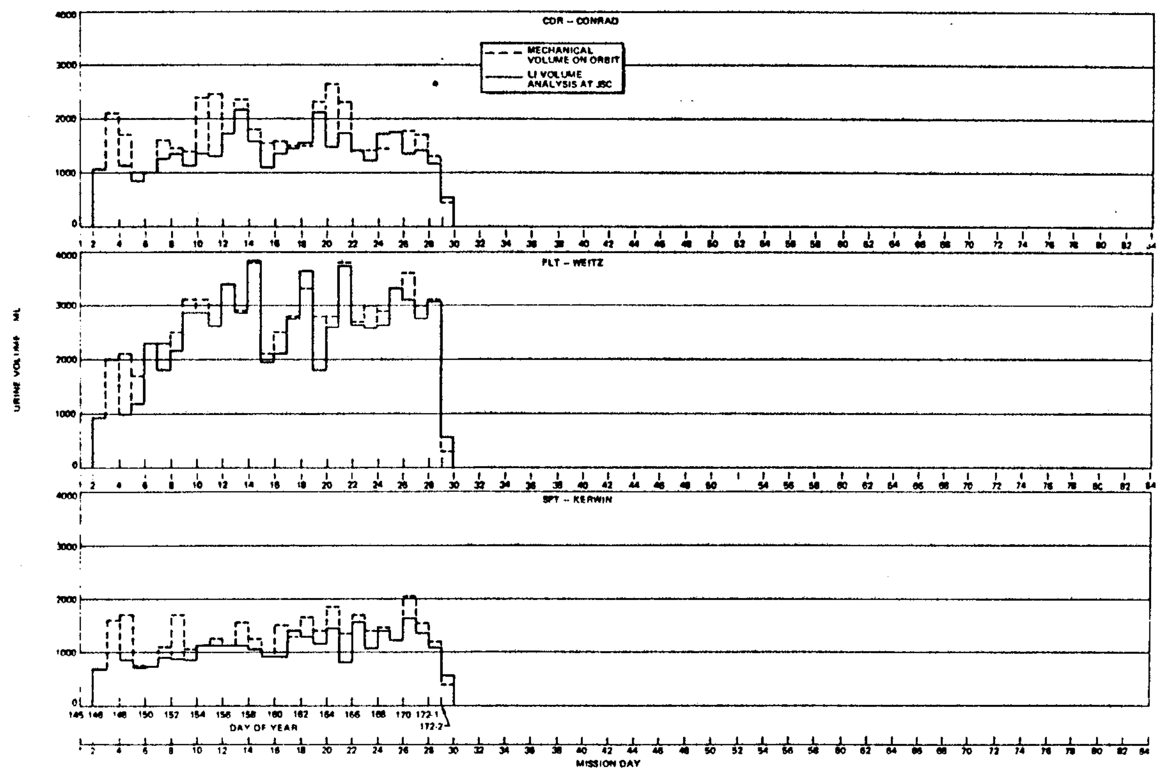


Figure 33. Daily Urine Volume (Mechanical vs. Li Analysis) - First Mission

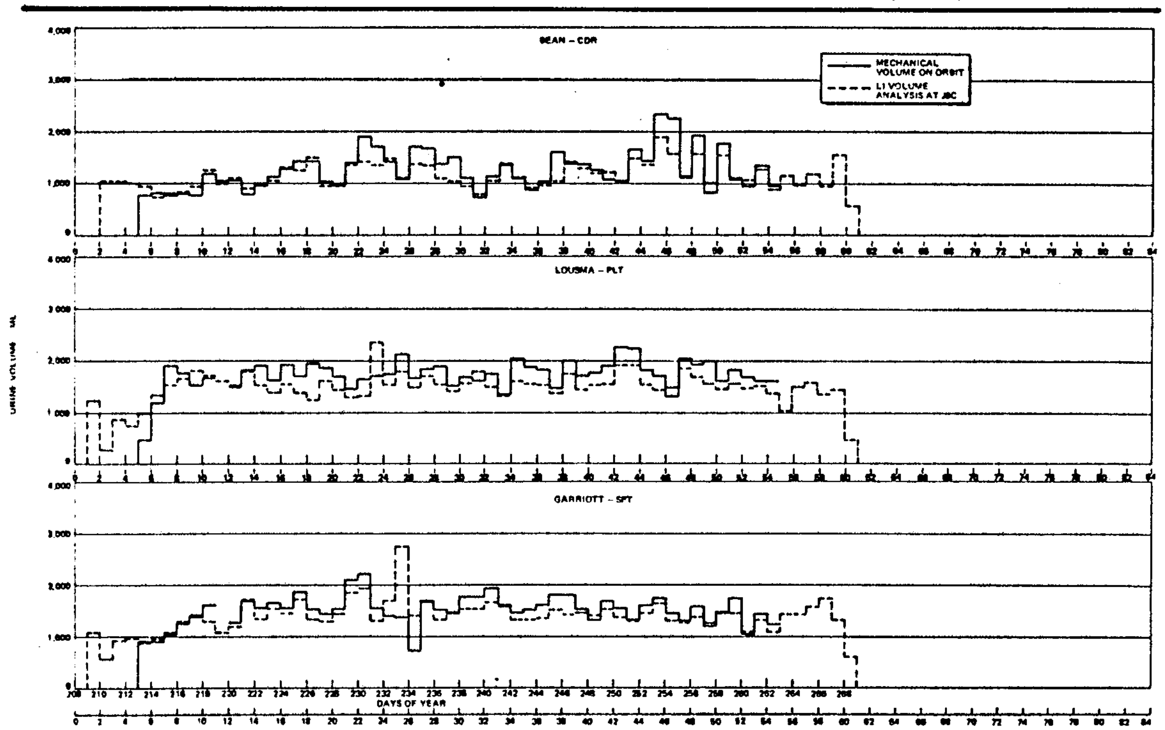


Figure 34. Daily Urine Volume (Mechanical vs. Li Analysis) - Second Mission

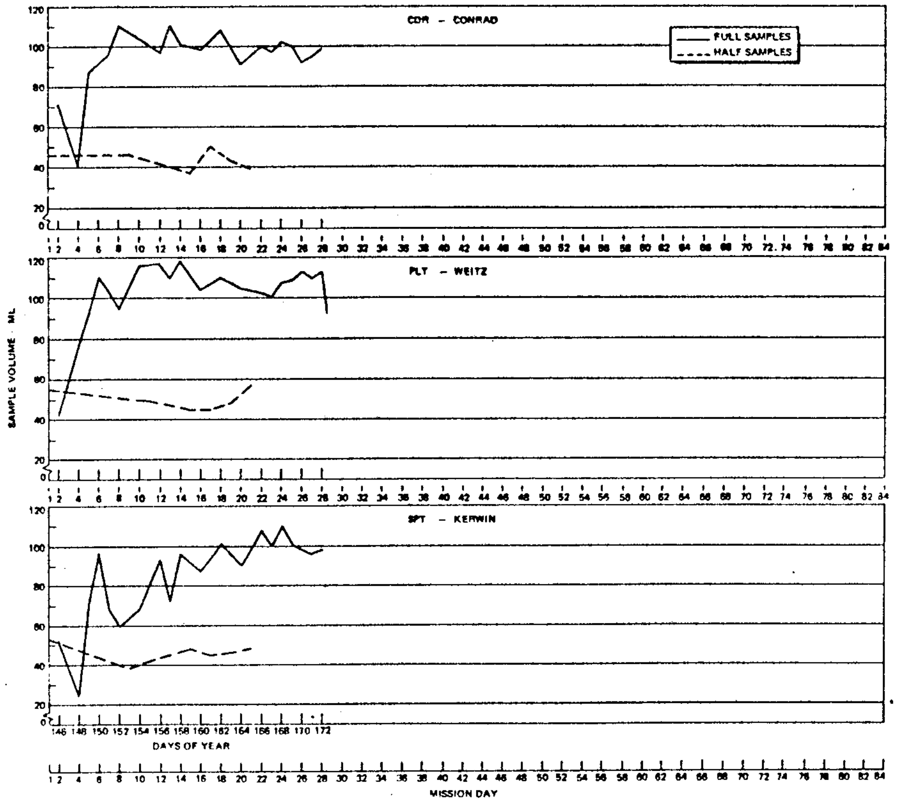


Figure 35. Daily Urine Sample Size - First Mission

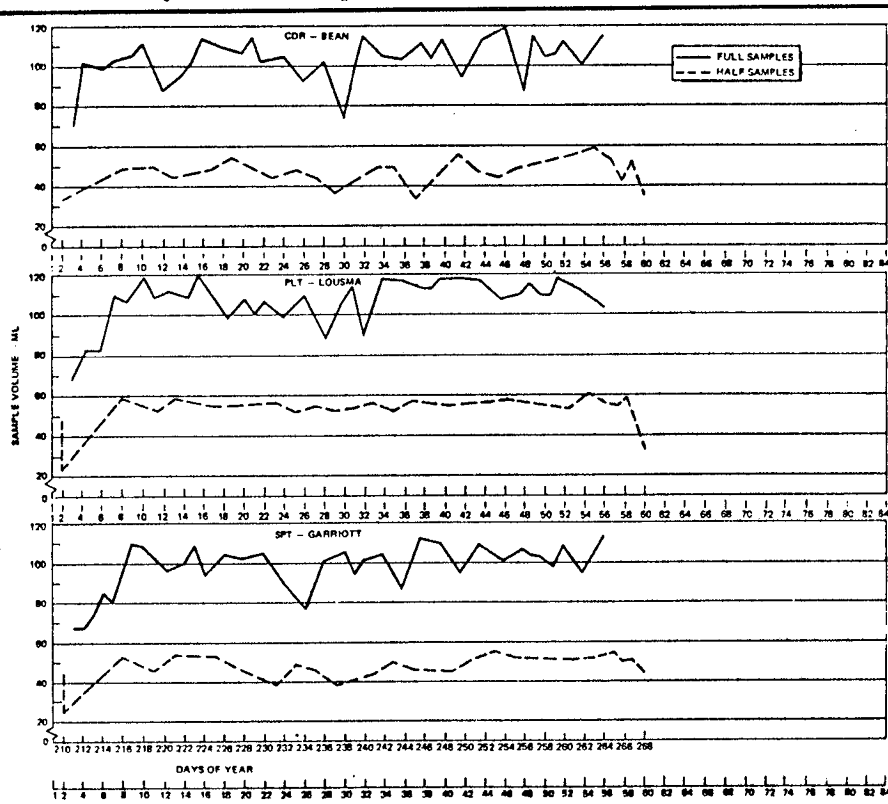


Figure 36. Daily Urine Sample Size - Second Mission

DOY	MD	CDR	SPT	PLT
145	1	Li Trace Only	Li Trace Only	Li Trace Only
146	2	1057 ml	687 ml	913 ml
147	3	Not Received	Not Received	Not Received
148	4	1125 ml	849 ml	981 ml
149	5	831 ml	702 ml	1185 ml
150	6	1000 ml	725 ml	2309 ml
151	7	1256 ml	894 ml	1800 ml
152	8	1336 ml	884 ml	2166 ml
153	9	1146 ml	858 ml	2869 ml
154	10	1358 ml	1129 ml	2869 ml
155	11	1120 ml	1301 ml	2624 ml
156	12	1734 ml	1120 ml	3374 ml
157	13	2162 ml	1116 ml	2869 ml
158	14	1558 ml	1034 ml	3838 ml
159	15	1104 ml	919 ml	1943 ml
160	16	1358 ml	918 ml	2114 ml
161	17	1452 ml	1400 ml	2739 ml
162	18	1564 ml	1282 ml	3631 ml
163	19	2103 ml	1164 ml	1794 ml
164	20	1480 ml	1439 ml	2607 ml
165	21	1723 ml	809 ml	3720 ml
166	22	1406 ml	1564 ml	2629 ml
167	23	1235 ml	1085 ml	2585 ml
168	24	1733 ml	1406 ml	2629 ml
169	25	1743 ml	1230 ml	3315 ml
170	26	1350 ml	1631 ml	3112 ml
171	27	1412 ml	1356 ml	2773 ml
172-1	28	1168 ml	1101 ml	3081 ml
172-2	28	533 ml	560 ml	565 ml

Table 6. Daily Urine Volume (Li Analysis) - First Mission

DOY	MD	CDR POOL VOL (LiCL)	SPT POOL VOL (LiCL)	PLT POOL VOL (LiCL)
210	1	1041 ml	1082 ml	1237 ml
211	2	1024 ml	924 ml	858 ml
212	3	993 ml	950 ml	748 ml
213	4	924 ml	878 ml	965 ml
214	5	718 ml	950 ml	1341 ml
215	6	789 ml	1094 ml	1515 ml
216	7	840 ml	1267 ml	1652 ml
217	8	908 ml	1421 ml	1778 ml
218	9	1241 ml	1288 ml	1689 ml
219	10	974 ml	1070 ml	1345 ml
220	11	1086 ml	1188 ml	1476 ml
221	12	894 ml	1727 ml	1778 ml
222	13	974 ml	1345 ml	1520 ml
223	14	1034 ml	1543 ml	1388 ml
224	15	1286 ml	1450 ml	1530 ml
225	16	1239 ml	1729 ml	1366 ml
226	17	1493 ml	1330 ml	1239 ml
227	18	936 ml	1278 ml	1594 ml
228	19	944 ml	1437 ml	1437 ml
229	20	1330 ml	1832 ml	1286 ml
230	21	1404 ml	1937 ml	1308 ml
231	22	1330 ml	1308 ml	2318 ml
232	23	1462 ml	1696 ml	1520 ml
233	24	1066 ml	2741 ml	1775 ml
234	25	1352 ml	1408 ml	1476 ml
235	26	1323 ml	1660 ml	1696 ml
236	27	1077 ml	1301 ml	1535 ml
237	28	1010ml	1146 ml	1408 ml
238	29	903 ml	1530 ml	1546 ml
239	30	757 ml	1530 ml	1769 ml

Table 7. Daily Urine Volume (Li Analysis) - Second Mission - 1 of 2

DOY	MD	CDR POOL VOL (LiCL)	SPT POOL VOL (LiCL)	PLT POOL VOL (LiCL)
240	31	1117 ml	1654 ml	1471 ml
241	32	1356 ml	1551 ml	1290 ml
242	33	1076 ml	1313 ml	1577 ml
243	34	882 ml	1291 ml	1546 ml
244	35	930 ml	1313 ml	1515 ml
245	36	1023 ml	1493 ml	1342 ml
246	37	1391 ml	1423 ml	1729 ml
247	38	1270 ml	1437 ml	1417 ml
248	39	1164 ml	1417 ml	1507 ml
249	40	1191 ml	1515 ml	1530 ml
250	41	984 ml	1360 ml	1889 ml
251	42	1471 ml	1291 ml	1889 ml
252	43	1335 ml	1455 ml	1520 ml
253	44	1872 ml	1642 ml	1441 ml
254	45	1535 ml	1306 ml	1476 ml
255	46	1096 ml	1253 ml	1838 ml
256	47	1566 ml	1389 ml	1678 ml
257	48	984 ml	1248 ml	1551 ml
258	49	1520 ml	1450 ml	1441 ml
259	50	1081 ml	1476 ml	1551 ml
260	51	1041 ml	1082 ml	1459 ml
261	52	1240 ml	1315 ml	1517 ml
262	53	859 ml	1082 ml	1362 ml
263	54	1117 ml	1439 ml	1045 ml
264	55	947 ml	1439 ml	1488 ml
265	56	1155 ml	1597 ml	1572 ml
266	57	916 ml	1805 ml	1338 ml
267	58	1525 ml	1338 ml	1425 ml
268	59	545 ml	619 ml	465 ml

Table 7. Daily Urine Volume (Li Analysis) - Second Mission - 2 of 2

MISSION DAY SL-4	URINE VOLUME MECHANICAL - ml		
	CDR	SPT	PLT
1			
2			
3			
4	1200	3500	2400
5	1200	2750	1500
6	1400	1500	1600
7	0800	1200	3000
8	1800	1700	0900
9	1800	1600	2400
10	1200	1100	2400
11	1500	1700	2100
12	2100	1500	3000
13	1200	1300	1500
14	1800	1600	2800
15	1300	1700	1600
16	1900	2100	1850
17	2200	1200	2200
18	2500	2200	3000
19	1100	2300	2000
20	1400	2950	2600
21	2200	1400	2000
22	1200	1450	1700
23	1650	1450	1800
24	1900	2400	2100
25	2000	1400	1250
26	1300	1200	2200
27	2250	1500	1850
28	1200	1250	1500
29	1600	1500	1900
30	2100	1600	2300
31	1000	1250	1800
32	1350	1700	2000
33	1550	1100	1500
34	0900	1150	1300
35	1850	2000	1850
36	2000	1100	2300
37	1200	1750	2000
38	1600	1550	2250
39	2000	2250	1800
40	1750	2200	1100
41	0800	1650	2200
42	2000	0950	1850
43	0850	1850	1100
44	1900	2050	1950
45	1700	1200	1800
46	1750	1350	1500
47	1800	2100	1750
48	2100	2250	2250
49	0900	0750	1450
50	2100	2200	2500
51	2100	3050	1900
52	1750	1750	2100
53	3600	1750	2650
54	--	--	--
55	2400	3850	2700
56	2600	1800	3350
57			
58	2750	1700	2500
59	1600	1750	2000
60	1800	2100	2400
61	1000	2300	1300
62			
63			
64	1750	1400	1700
65			
66			
67	1300	1300	1800
68	2650	4000	2650
69			
70	1850	1900	1900
71	2600	1950	4200
72			
73	2800	1600	4200
74	1700	0950	1900
75	2100	1450	1800
76	1150	1900	1250
77	1200	0850	2250
78	2100	2000	2600
79	1700	3000	2600
80			
81			
82	2150	1800	2000
83	2300	2700	2100
84			

Table 8. Daily Urine Volume (Li Analysis) - Third Mission

Each sealed fecal bag was placed in one of the top four chambers (1 thru 4) in the processor after determining the mass on a Specimen Mass Measuring Device (SMMD). The system was designed for heat application to the bag at a nominal temperature of 105°F to decrease the drying time, although processing could be conducted without heat by exposing the chamber to the waste tank vacuum and extending the drying time. Gases escaped from the fecal bag through a vent port.

Using heat, the drying time was determined from a chart which correlated the mass and drying time. In the event mass could not be determined, a processing time of 20 hours for normal specimens provided adequate drying. "Over drying" was not detrimental to biomedical analysis. The dried fecal bags were stored unrefrigerated in bundles for return. The same operational procedures applied to vomitus bags.

The lower two chambers (5 and 6) in the processor were reserved for drying PGA and film vault desiccants.

An illustration of the waste processor is provided in Figure 37.

b. Post Mission Assessment - With the exception of the first mission, the waste processor was used as planned using heat for the feces, vomitus, PGA, and film vault desiccants. During the first mission, due to the requirement to reduce electrical power consumption, all drying was accomplished using space vacuum rather than the processor heaters with the exception of two fecal bags "heat dried" on the last day of the mission. Both methods worked satisfactorily as did all hardware components.

Each crew used four chambers for fecal drying and two chambers for desiccant drying. During the first mission, most feces was processed for 26-48 hours; however, a few bags were left in the chamber for as long as four days with no damaging effects. Average processing time for the other two missions was not specifically reported.

During the second mission, a probe replacement was performed to correct an off-scale high pressure measurement (waste processor exhaust line pressure).

4. Urine Freezer

a. Design Description - The urine freezer was provided to freeze and store individual crew urine and blood samples. It consisted of a freezing chamber, urine trays, spacers, and dodecane (heat sinks) containers. The urine freezer reduced the temperature of the sample to below +27°F within 3 hours, to 0°F within 6 hours, and to below -2.5°F within 8 hours after simultaneous insertion of the samples into the freezer. An illustration of the urine freezer is provided in Figure 38.

b. Post Mission Assessment - The crews used the urine freezer, as planned, during the three missions with the equipment operating as designed. Urine freezer temperatures remained within specification for the duration of the mission.

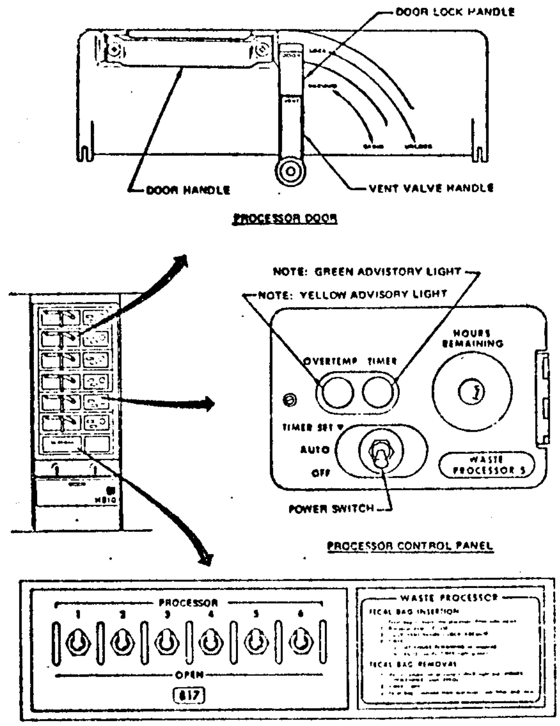


Figure 37. Fecal Processor

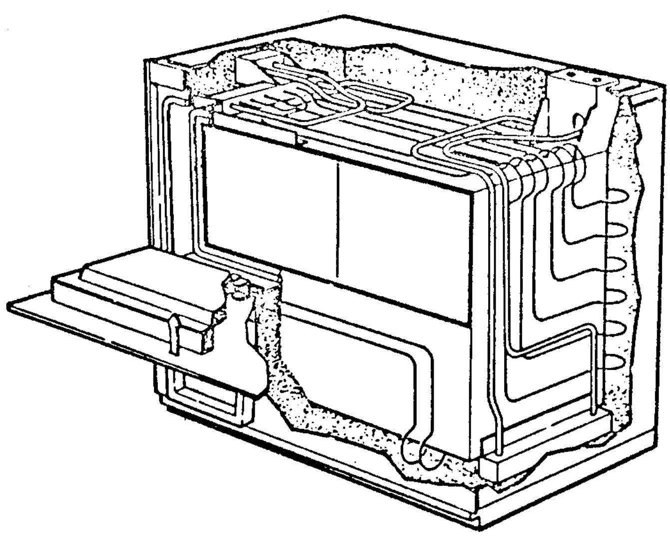


Figure 38. Urine Freezer

Some ice formed around the doors during the second mission which necessitated removal by scraping; however, it was not reported to have reoccurred during the third mission.

5. <u>Suit Drying</u>

a. Design Description - The suit drying equipment consisted of a blower, hoses, and desiccant bags and was provided to remove moisture from inside the pressure suits after each suited operation. Pressure suits were dried at three suit drying stations located in the OWS Forward Compartment. Drying was accomplished by installing a suit in the drying station, which consisted of the portable PGA foot restraints attached to the Forward Compartment floor, and a hanger strap, which suspended the suit between the floor and the water ring foot restraints. The blower unit, contained in ring container D424, forced drying air through a hose into the suit. Moisture was dried by the air and collected by the desiccants, which were subsequently dried in the two lower (5 and 6) waste processor chambers. Figure 39 illustrates this suit drying concept.

b. Post Mission Assessment - The suit drying station equipment was used as planned throughout the mission, with the exception of the initial drying after the first crew's activation. There is conflicting information relative as to when and where the suits were actually dried the first time.

The suit drying equipment operated satisfactorily. However, there was a tendency for the blower (power module) in the ring container to become too hot to touch if operated with the ring container door closed per the procedure. There was no explanation for the occurrence, therefore the blower was operated with the container door open during suit drying operations. The noise level of the blower during long time operation was unobjectionable. Hose assembly lengths, hangers, straps, etc. were acceptable and functioned properly.

According to the first crew, the suit drying time was approximately 10 hours. Drying time data was not received from the other two crews. Desiccants were dried from 10 to 24 hours. The third crew had difficulties installing several of the desiccants in the processor chambers because they were too long and interferred with the door closure. This resulted in prolonged drying time because of some minor atmosphere leakage overboard which impeded the drying process.

The first two crews reported no evidence of bacterial growth or odor in the suits after drying. However, the third crew reported finding some fungus growth in the LCGs.

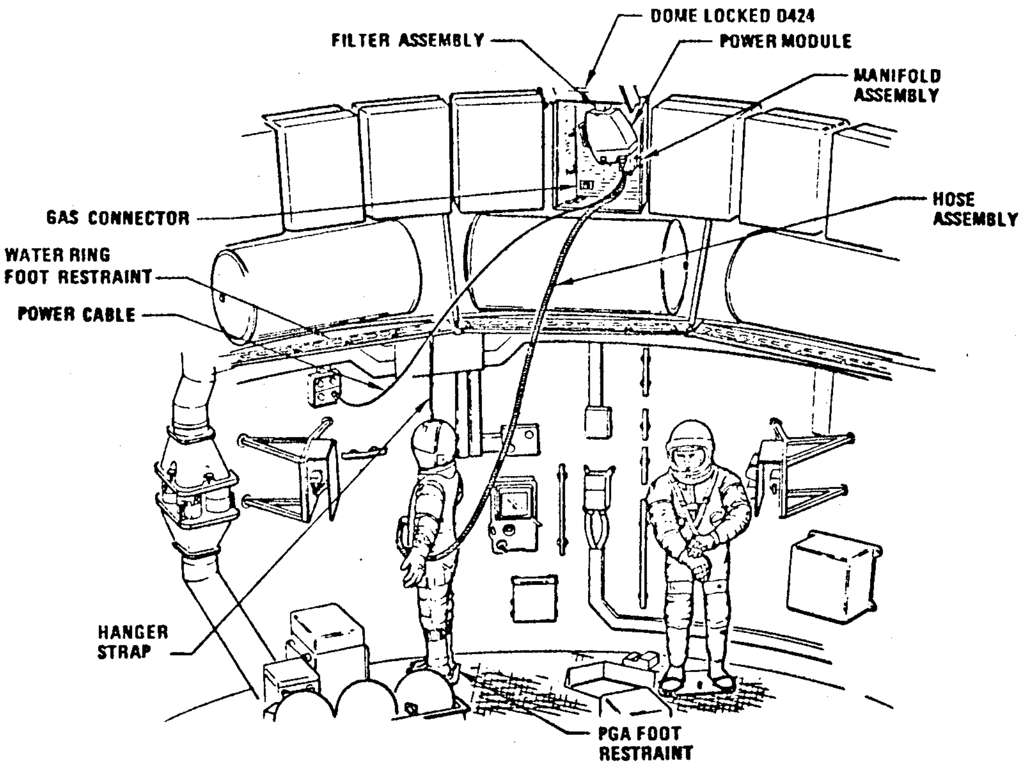


Figure 39. Suit Drying Station

C. Personal Hygiene Provisions

The personal hygiene subsystem was designed to provide all supplies and equipment necessary for skin and dental health, good grooming, and the hygiene needs for all three missions.

Major hardware and equipment supplied for personal hygiene were as follows:

- Water Module (Washcloth Squeezer and Water Dispenser)
- Wipes and Tissues
- Mirrors
- Washcloth and Towel Drying Equipment
- Hygiene Kits (GFE)
- Shower (GFE)
- Towels and Washcloths
- Soap

Personal hygiene equipment location is illustrated by Figure 40.

1. Handwasher

a. Design Description - A partial body cleansing facility was provided in the WMC water module locker and consisted of a water dispenser (handwasher) and washcloth squeezer, with squeezer bag and filters.

Hot water was emitted from the water dispenser for use with a washcloth and soap for cleansing. The washcloth was to be placed in the washcloth squeezer and the squeezer handle pulled down to remove the excess water from the washcloth into a squeezer bag. Water collected in the squeezer bag was drained through a squeezer filter into the waste tank by the normal drain (vacuum dump) system. Figure 41 illustrates the WMC water dispenser, squeezer location, and operating characteristics.

b. Post Mission Assessment - All crewmen felt that the personal hygiene equipment was an absolute necessity and that all equipment operated satisfactorily.

The WMC water dispenser flow/distribution was acceptable. The only comment made by the crews was that it should be enclosed to contain and control the water better while washing. A ball of water had a tendency to build up on the dispenser indicating flow rate need not be higher. The washcloth did not have to be held against the dispenser because the water could be "shot" into it. The water never bounced or splashed, but would ball up and then saturate the washcloth.

During the first mission, the water dispenser valve clogged and was replaced with a spare. The second mission crew carried two spare valves for replacement in the event of additional failures; however, this did not occur.

In general, the washcloth squeezer worked well. Some of the crewmen complained about it leaking around the teflon seal and

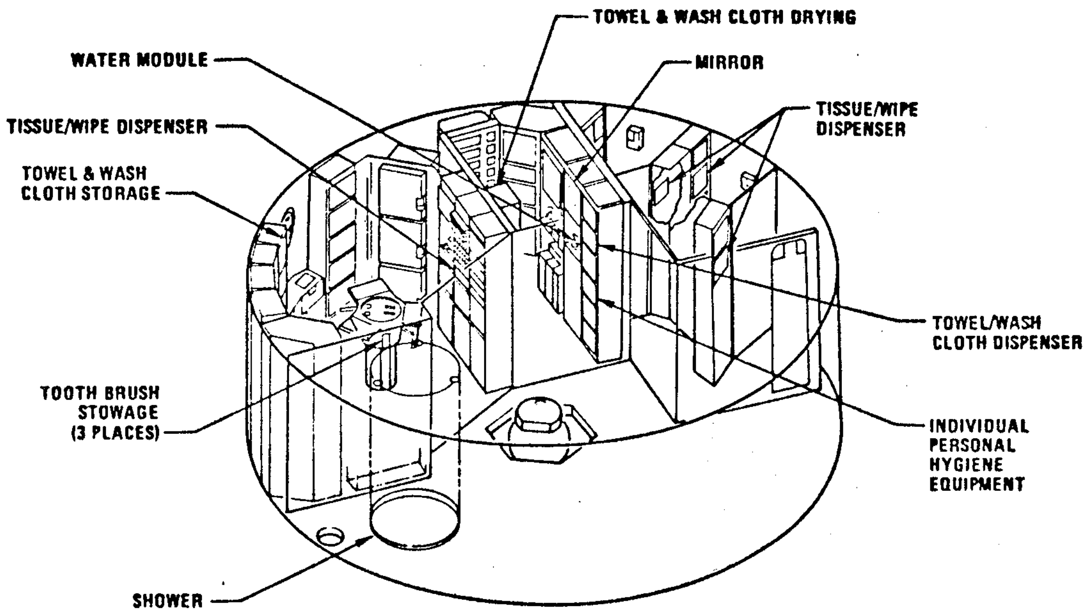


Figure 40. Personal Hygiene Equipment

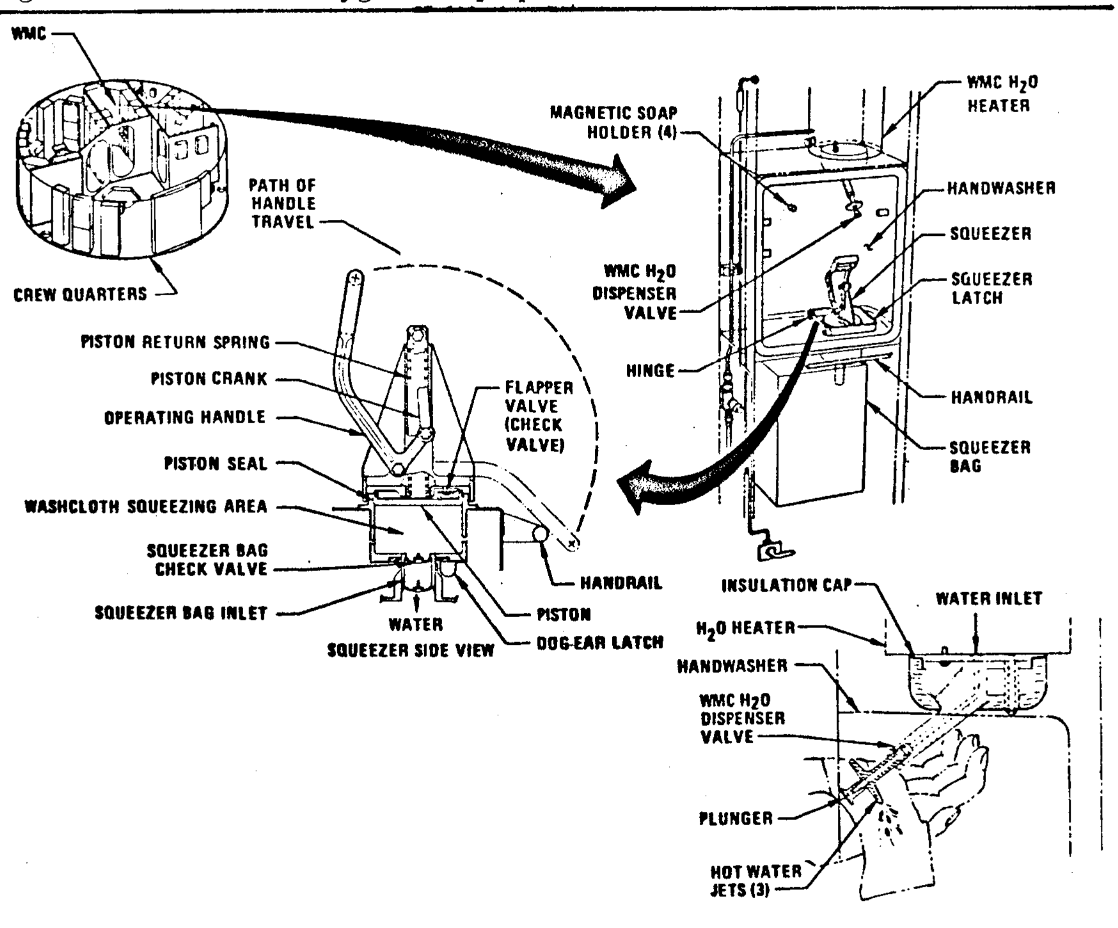


Figure 41. WMC Water Module

recommended that a double seal be installed on the piston to prevent leakage and improve the water transfer interface between the cylinder and the squeezer bag. They also recommended that the system be enlarged to accept towels. The crews stated that the technique of placing the washcloth in the squeezer was important to a successful operation cycle, and that a good vacuum in the squeezer bag was also a requirement.

During the second mission, the squeezer malfunctioned because of a bad Bal seal, causing water leakage. The seal was replaced, thus correcting the problem. To eliminate this problem in future designs, the crew recommended the use of a double seal.

There were five each squeezer water collection bags and filters launched in the OWS. This provided a usage rate of one squeezer bag and filter per mission, plus two spare squeezer bags and filters. Installation of the squeezer bag was no problem. The crew would dump the squeezer bag approximately every three days when it was about 2/3 full, and recommended that the dump cycle be automatic.

Fifty-five soap bars were provided for the three missions, giving a usage rate of 1 bar/man/2 weeks and 5 bars/month for housekeeping and cleaning tasks. This, for example, provided eleven bars for the first mission; however, the crew reported that they used only one bar for the entire mission.

2. Shower

a. Design Description - The shower was an enclosed compartment, requiring crew deployment, with continuous airflow which circulated water over the crewman in a somewhat conventional manner. A water bottle, filled from the WMC water system and pressurized with GN_2 to expel the water, was attached to the ceiling at the shower location. A spray nozzle connected to the water bottle by a transfer hose, expelled water onto the crewmen when operated. A suction head, connected by hoses to a centrifugal separator with a collection bag for water retention, was provided to "vacuum" the water from the crewman and shower interior. A power module pulled the air from the separator and was protected from the separator by a hydrophopic filter, which trapped contaminents, thus preventing them from migrating through the power module into the OWS atmosphere.

Foot restraints were provided for use while showering these will be discussed in the Mobility/Stability Aids section. Shower schematic and configuration are illustrated by Figures 42 and 43.

b. Post Mission Assessment - All crewmen agreed that taking a shower periodically was very desirable. However, they also complained, in varying degrees, about the shower system. The primary complaint was the inadequacy of the power module. Because of its low air-flow rates, the time involved in the cleanup of shower water too lengthy. In fact, all crewmen considered the whole showering

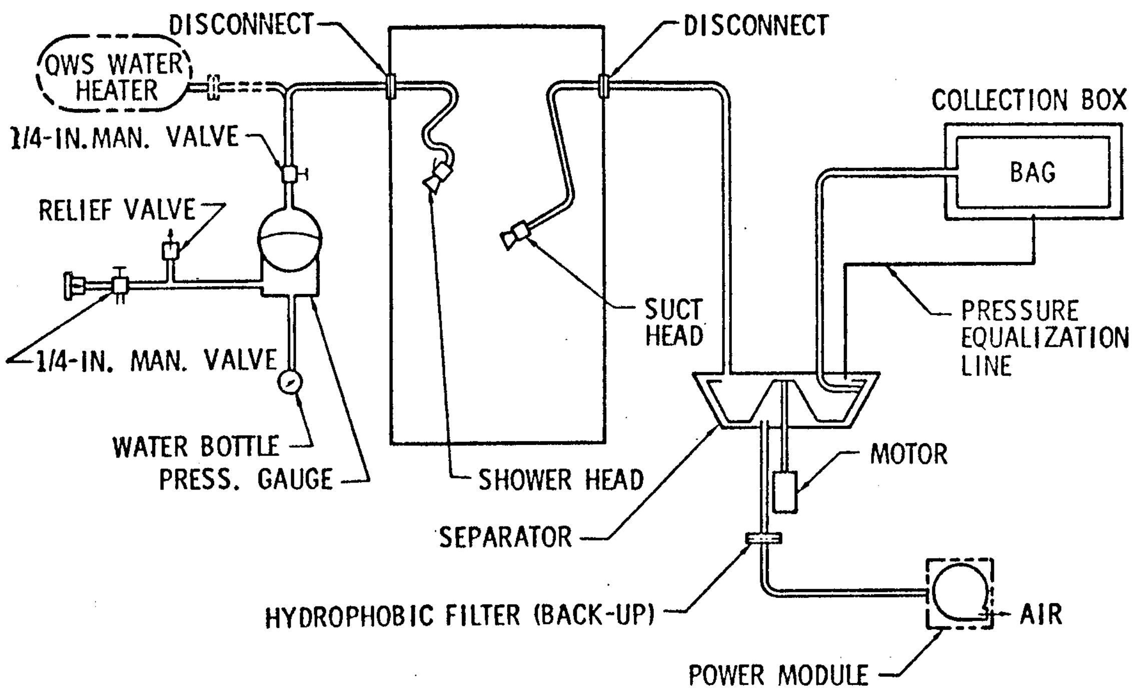


Figure 42. Shower Centrifugal Schematic

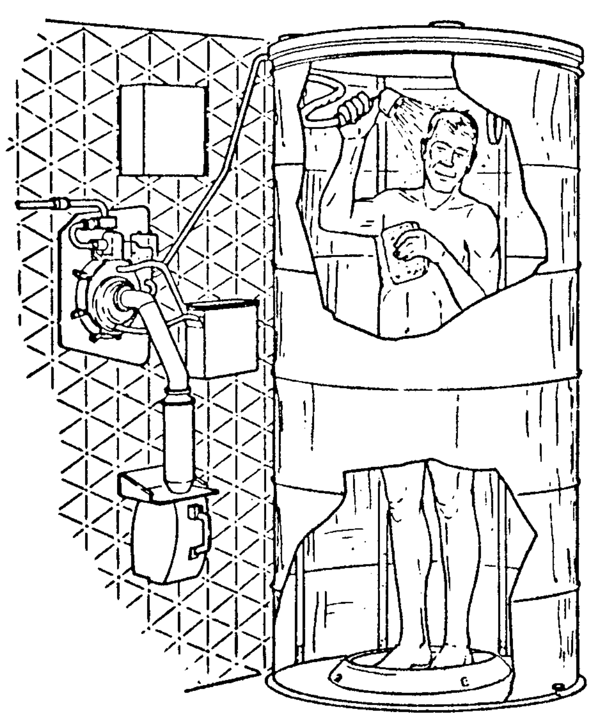


Figure 43. Shower Equipment

procedure too time consuming. In the future, the shower system should be hard-lined to minimize crew imvolvement. This includes both water dispensing and collecting procedures.

There were some minor complaints concerning the Miranol soap; specifically, the soap odor and feel, after showering, were considered undesirable.

All crews agreed that six-pounds of water, per shower, was adequate.

3. Hygiene Equipment

a. Design Description

(1) Wipes - There were four types of wipes provided; wet wipes, dry wipes, biocide wipes, and general purpose tissues.

Wet wipes were provided primarily for food cleanup and housekeeping. There were seven wet wipe dispenser packages launched with the single dispenser located in the Wardroom.

Dry wipes were primarily provided for personal hygiene (fecal collection) in the WMC. There were 23 dry wipe dispenser packages provided with a minimum of 196 wipes per package. This allowed a usage rate of 10 wipes/man/day, with a 10-percent contingency. There were 11 dry wipe dispensing locations; seven in the Wardroom, three in the Sleep Compartment and one in the WMC. A typical wipe dispenser is illustrated by Figure 44.

Biocide wipes were provided for housekeeping activities which required disinfecting. This included such tasks as cleaning food spills and fecal/urine system decontamination. Five biocide wipe packages were provided with 70 wipes per package. This allowed a usage rate of 2 wipes per day with a 10-percent contingency. There was a single biocide wipe dispenser located in the WMC.

General purpose tissues were provided for general housekeeping and personal hygiene tasks. There were 11 tissue dispenser packages with a minimum of 392 tissues per package. This allowed a usage rate of 12 tissues/man/day, with a 10-percent contingency. There were 11 general purpose tissue dispenser locations; six in the Sleep Compartment, four in the Wardroom and one in the WMC.

(2) Towels and Washcloths - Reuseable 12-inch square washcloths were provided for personal hygiene and vehicle cleaning. There were a total of 840 washcloths stowed in dispensers containing 28 washcloths each. Each dispenser was spring-loaded such that, as a washcloth was removed, the next one moved into position for dispensing. The single dispensing location, H831 in the WMC, contained three dispensers, one for each crewman, providing a 14-day supply at a usage rate of 2 washcloths/man/day. There were nine lockers in the Wardroom containing washcloth dispensers for resupplying the dispensing location.

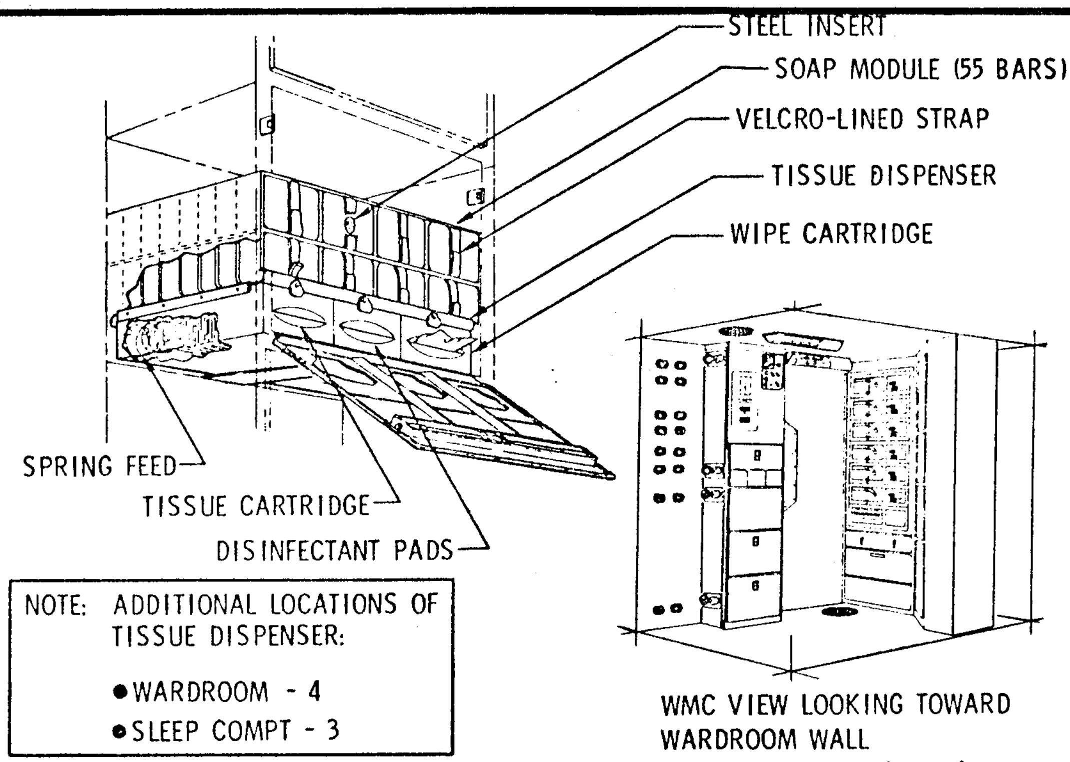


Figure 44. Tissue/Wipe/Biocide Wipe Dispenser and Soap (H803)

Reuseable 14 by 32-inch towels were provided for skin drying. There were a total of 420 towels, each towel individually rolled and banded with three paper bands which were easily removed and disposed of when towel was used.

There were five dispenser modules containing 18 towels each. The primary dispenser module location, compartment H831, provided a six-day supply, at a usage rate of one towel/man/day. There were four dispenser modules stowed in the Wardroom, 126 individual towels in locker S900 of the Sleep Compartment, and 204 individual towels in ring container D418 for resupply of the WMC dispensing location.

Both the washcloths and towels were made of rayon polygnostic terrycloth, with colored stitching (red, light blue and blue) on the edges for individual crewman identification. There was a colored "Snoopy" decal on each washcloth dispenser which corresponded to the washcloth color.

An illustration of the washcloth/towel dispenser is provided by Figure 45.

(3) Washcloth and Towel Drying Equipment - Fluorcarbon rubber towel and washcloth drying cups were provided in high usage and accessible areas in various compartments of the OWS. Six portable towel cups, which interfaced with snaps provided throughout the vehicle, were located in compartment E625. The corner of a washcloth or towel was inserted into a cup allowing the washcloth or towel to be dried by the OWS atmosphere. The towel and washcloth drying concept is illustrated by Figure 46.

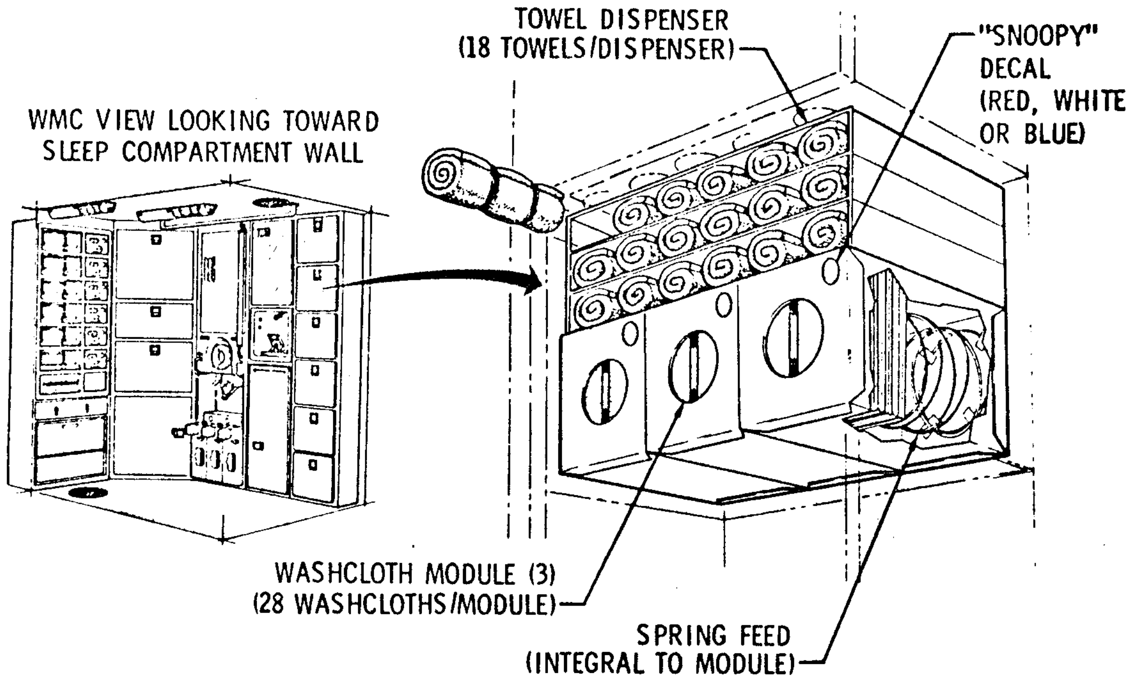


Figure 45. Washcloth/Towel Dispensers

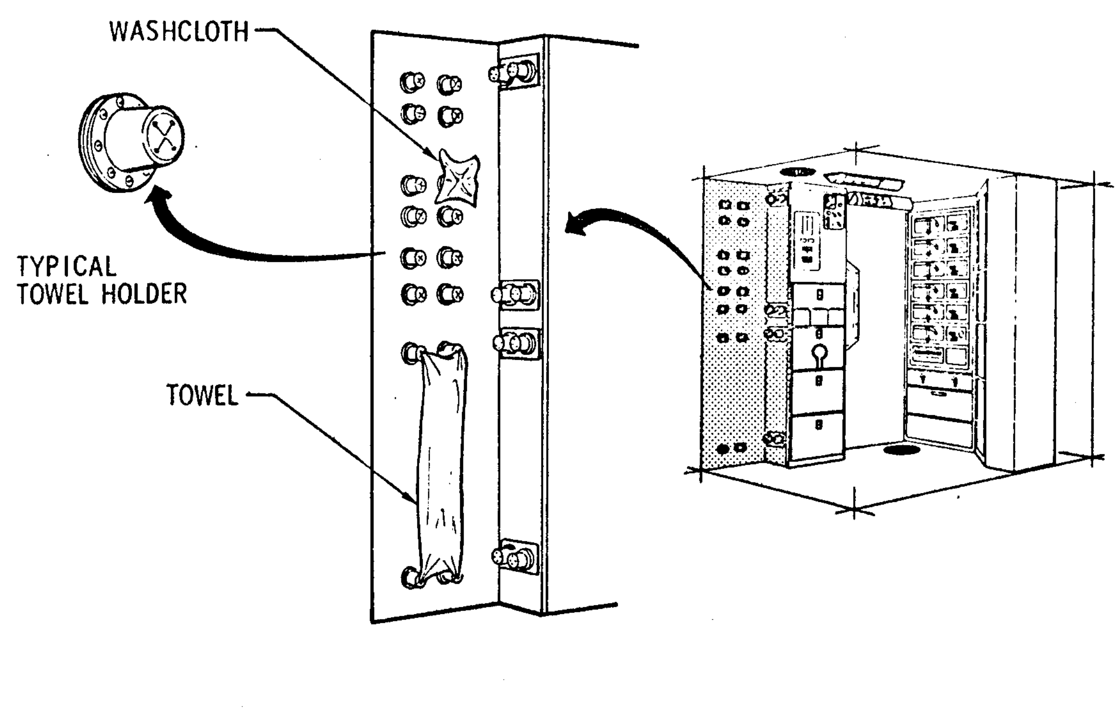


Figure 46. Washcloth/Towel Drying Area

(4) Hygiene Kits - One personal hygiene kit was provided in each of three lockers (H830, H832, H834) in the WMC for the first mission. Locker S935, in the Sleep Compartment, contained 6 personal hygiene kits for the second and third mission crewmen plus a hygiene resupply kit for all missions. The personal hygiene kits contained equipment for shaving, skin care, dental care, hair grooming, nail care, and body deodorizing.

The hygiene kit had velcro attached to interface with mating velcro provided in various locations. The hygiene kit configuration is illustrated by Figure 47.

(5) Mirrors - Unbreakable polished stainless steel mirrors were located in the WMC and the Sleep Compartments. Two mirrors, mounted in the WMC, were used for performing partial body cleansing, hair brushing, hair trimming, and nail clipping. An articulating mirror was provided for use during fecal collection. One mirror was bonded inside the top stowage compartment in each of the three sleep areas for the crewman's personal use. Mirror locations are illustrated by Figure 48.

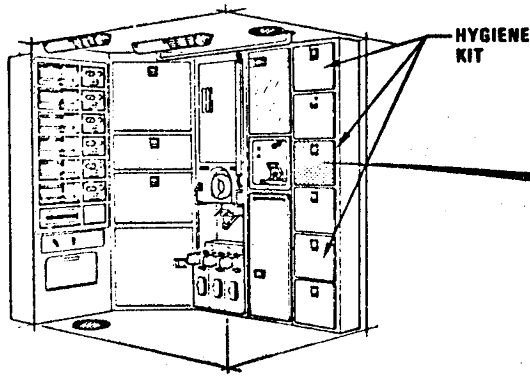
b. Post Mission Assessment - The wipes were assessed as satisfactory. The biocide wipes left an iodine coloration on the wiped area but came off with little or no problem. The second crew reported that, after deactivation, their hands became yellow as a result of biocide cleaning, but faded away several days after splashdown. Biocide wipes were used in anticipated quantities. The third crew stated they would have preferred a sponge with a handle for biocide wiping.

The general purpose tissues and utility wipes were adequate. The second crew used rags (old shirts and shorts) for cleaning instead of general purpose tissues, since cloth was faster and more esthetically pleasing. On future flights, a cloth should be considered for wiping and cleaning spills. The third crew felt a handkerchief, made from the same material as the cleaning cloth, should have been provided.

Due to zero-g nasal congestion, the entire mission used more tissues than anticipated. The third crew ran out of tissues in some dispenser locations and had to use utility wipes, for tissue applications. This should be considered during planning on future missions.

All crews used the towels and washcloths in a normal manner for personal hygiene and also used them for washing the windows and wiping spills. The first crew used all 84 towels allotted for their mission and divided equally the 89 towels brought up in the CM. The second crew did not report their towel usage; therefore, it was assumed they used their allotted quantity.

The third crew took an additional 30 towels in the CM to supplement their on-board supply. The crews suggested that the towels be made larger and from a more absorbent material. Towel allocation should be evaluated for future flights using the information in the consumable summary.



TYPICAL HYGIENE KIT CONTENTS	
SHAVING CREAM	6 OZ
RAZOR	1
STYPIC PENCIL	1
TOOTHPASTE	3 OZ
TOOTHBRUSH	1
DENTAL FLOSS	80 IN.
SOAP	4 OZ
EMOLIENT	6 OZ
SAFETY SWABS	30
HAIR BRUSH	1
HAIR CREAM	3 OZ
NAIL CLIPPERS	1
DEODORANT	1 1/2 OZ
EXPECTORANT COLLECTOR	15

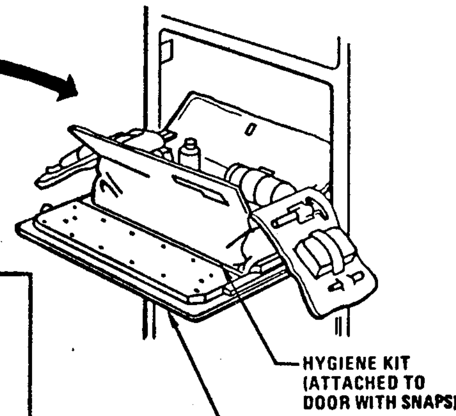
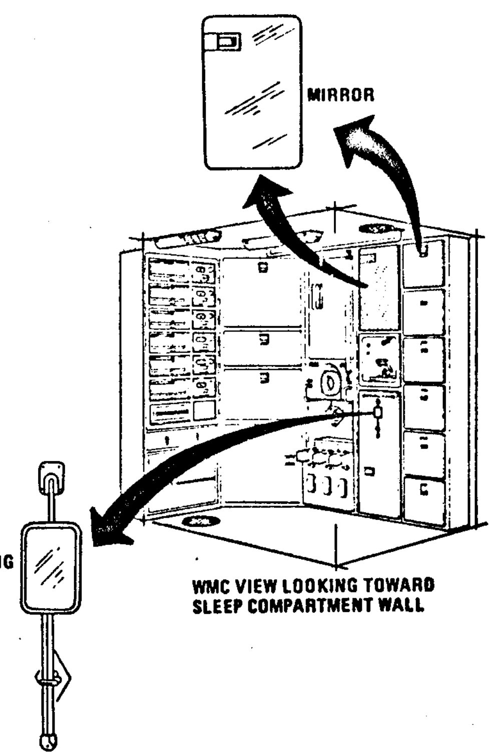


Figure 47. Personal Hygiene Kit



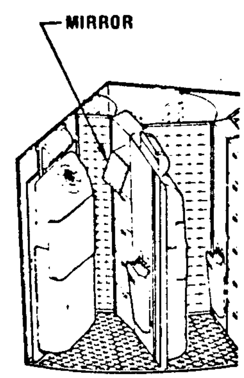


Figure 48. Mirror Locations (WMC/Sleep Compartment)

The drying station provided a convenient and effective means of drying the towels and washcloths. The only problem reported was that the towels had a tendency to float away from the wall into the work areas if they were restrained at a single point (one corner). The third crew felt the restraints were too crowded. There was no report of having used the portable towel holders. The restraint approach should be standard equipment on future missions for towel and washcloth drying as well as a general fabric restraint.

The crews stated that a more "personalized" hygiene kit would have been more useful. There were too many items included that they hadn't previously used and other items that would have been desirable but were not included. Because of the double flap design, the hygiene kits were hard to get into. The crews suggested that the individual kit items should be restrained in an open area for easier accessibility.

Because of the elevated temperatures in the OWS prior to initial crew occupation, the first crew's inspection of stowage locker S935 revealed that certain items in the resupply kit and the personal hygiene kits for the second and third missions were damaged. The Alpha Keri hand cream containers and toothpaste tubes had ruptured. The shaving cream containers were intact, but the cream was unuseable because it had hardened. The damaged items were discarded and resupplied on SL-3.

The only crew comment pertaining to the mirrors was that they were too dull. The articulating mirror, used for hygienic cleansing after fecal collection, was considered necessary and extremely useful.

D. Sleep Provisions

Three individual sleep areas were provided in the OWS Sleep Compartment. Each sleep area had a sleep restraint, privacy curtain, light baffle and other equipment such as air diffusers, lights, Speaker Intercom Assembly (SIA), stowage compartments, temporary stowage restraints, etc. An illustration depicting the OWS sleep compartment layout and arrangement is provided by Figure 49.

The sleep restraints, provided for each of the three astronauts, were identical in design. They were adjustable, thus permitting the astronauts to assume a sleep position of their choice. They also provided a means for reasonably rapid egress under emergency conditions. The restraints were secured at several attach points in a manner that minimized drifting and gyration.

A privacy curtain was provided for each sleep area to partition it off from the other sleep areas, as well as provide a light barrier from other sections of the Sleep Compartment.

A light baffle was provided for each sleep area. Each baffle attached to the ceiling and provided a barrier against lighting from the Forward Compartment area, yet permitted air flow from the floor air diffusers.

1. Sleep Restraints

a. Design Description - Each crewman was provided with an individual sleep restraint which attached between floor and ceiling, providing body restraint while sleeping. A sleep restraint, shown in Figure 50, was made up of the following items:

(1) Sleep Restraint Frame - The sleep restraint frame was a welded tubular frame. The frame was designed to be supported between the floor and ceiling grids utilizing polybenzimidole (PBI) straps and attachment hardware.

The frame and restraint had the capability of being used and supported in a number of different locations, such as the OWS Forward Compartment, Experiment Compartment, MDA, etc.

(2) Thermal Back Assembly - The thermal back combined teflon coated glass fabric, durette batting, PBI fabric, and fluorel coated webbing material in providing thermal protection.

The back assembly was attached to the sleep restraint frame by means of one of the two rows of snaps on the periphery. The other row of snaps were provided for individual adjustment.

(3) Comfort Restraint and Top Blanket - The comfort restraint was basically a sleeping bag made from a PBI loose knit fabric. This material provided the crewman with limited ventilation.

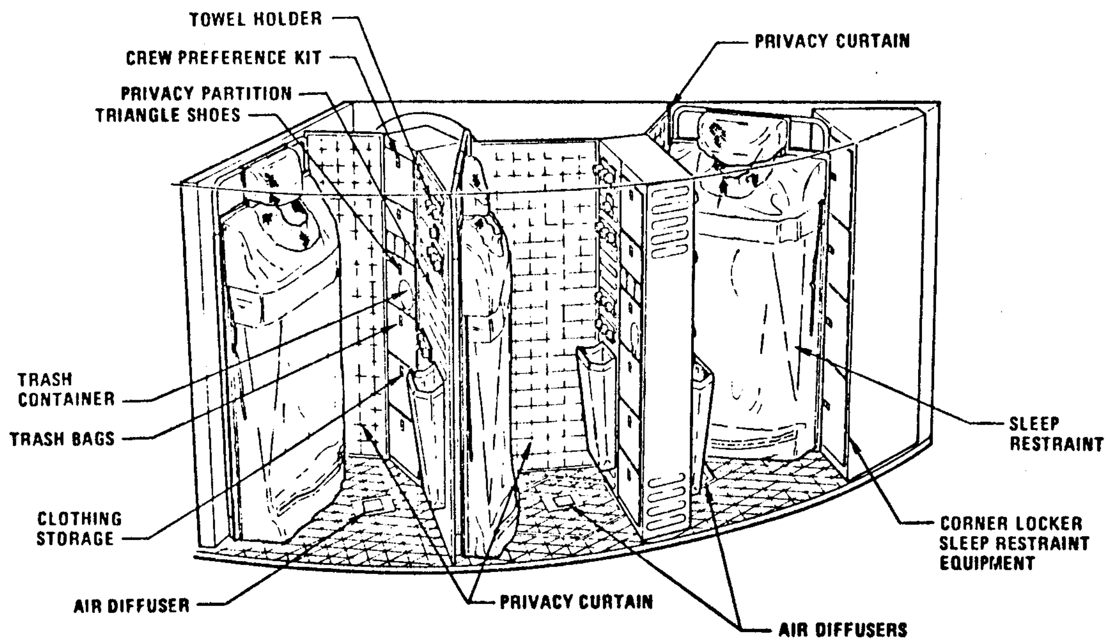


Figure 49. Sleep Compartment Equipment

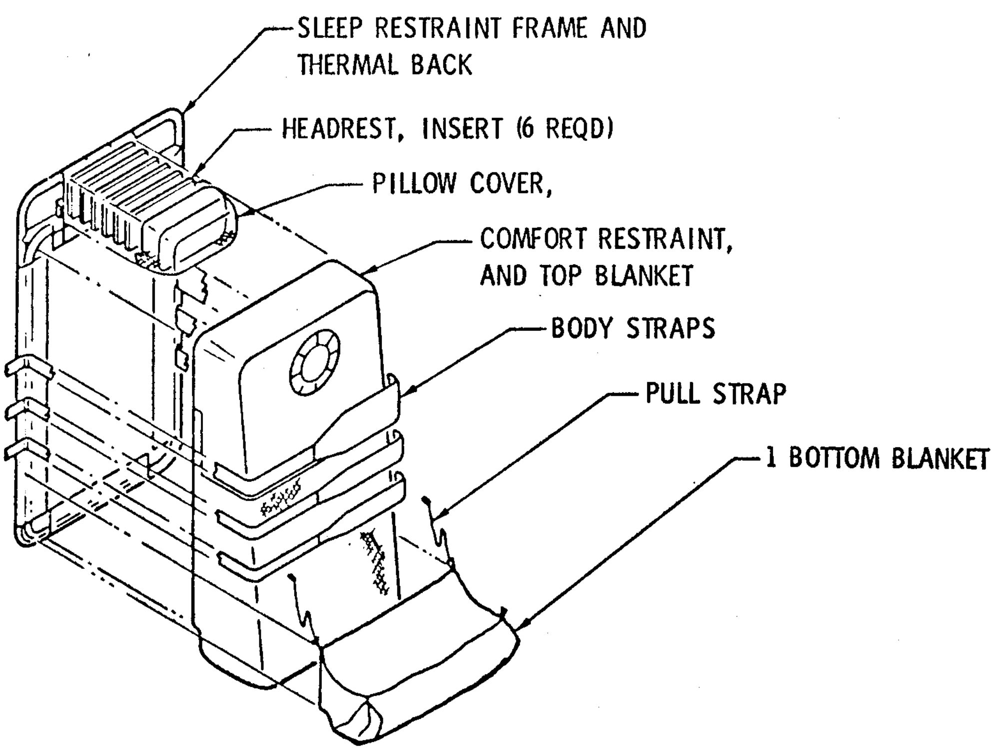


Figure 50. Sleep Restraint Equipment

A stretchable knit fabric was used to make the upper or top blanket. The crewman's head was placed through the expandable opening allowing the blanket to be spread over the shoulders and chest area.

The restraint and top blanket were attached to the thermal back by two zippers, one on each side.

(4) Bottom Blanket - The bottom blanket was made of heavy PBI fabric containing two spandex "vee" panels. This blanket attached to the bottom half of the thermal back by two zippers. The blanket had a zippered stowage pouch near the bottom side of the frame for restraining the blanket during launch and when not in use.

(5) Headrest Inserts - The headrest inserts consisted of a PBI covered heat resistant foam panel. The sleep restraint contained six headrest inserts on launch. These inserts were held in place by an attached headrest cover. The crewman selected the quantity of inserts providing the best head support.

(6) Headrest Cover - The headrest cover stretched over the quantity of headrest inserts used. This cover was made of PBI fabric and was attached by a zipper to the thermal back.

The headrest provided a means to restrain the head from drifting during sleep. A head restraint was fabricated from loose knit PBI allowing for ventilation and was placed over the forehead or entire head, at the crewman's option. One side of the head restraint was sewn to the headrest cover. The other side was attached to the thermal back with velcro.

(7) Body Straps - Three body straps were provided for each sleep restraint and were constructed from stretch knit PBI fabric, spandex, PBI webbing and fluorel coated webbing. The design of these straps allowed them to stretch as the crewman changed his sleep position. Adjustment in length was possible by releasing the buckles.

The straps were used to restrain the crewman's body while inside or outside the comfort restraints.

Soiled straps were changed periodically by releasing the buckles at one end and disengaging snaps at the other end.

The sleep restraint assembly was installed in each sleep area prior to launch. The frame, thermal back assembly, and headrest inserts were used for all three missions with the other items being changed periodically.

There were 27 comfort restraint/top blankets stowed in the Sleep Compartment, providing for a change every 14-days for each sleep restraint.

There were 12 bottom blankets stowed, providing for a change every 28 days for each sleep restraint. Twenty-seven headrest covers were stowed, providing for a change every 14-days for each sleep restraint. Twelve large body straps and 24 small body straps were stowed to provide a change of body straps every 28 days. One large and two small body straps were required for each sleep restraint.

b. Post Mission Assessment - There were no significant anomalies reported relative to the sleep restraint equipment.

In general, the crewmen felt the sleep restraint equipment was quite satisfactory. Specific comments relative to potential improvement and equipment use is summarized as follows:

(1) Due to the meteoroid shield problem, high temperatures in some areas of the Sleep Compartment motivated several crewmen to relocate the restraint equipment to cooler areas of the vehicle. At least one crewman preferred the restraint equipment attached to the OWS floor, similar to one-g orientation, rather than attached to the Sleep Compartment wall, perpendicular to the floor.

(2) Use of the pillow and blankets varied among the crewmen, depending on personal preference and spacecraft temperature conditions.

(3) On occasion, the Sleep Compartment was used for a temporary storage area during the day. The sleep restraint proved useful for handling bulky items, such as urine bags, supply modules and similar bulky items.

(4) Additional elastic body straps, with adjustment capabilities were requested by several of the crewmen during debriefings.

(5) Additional thought relative to easier ingress and egress was specifically requested by one crewman. For future designs, ingress and egress, other than through the restraint neck, may alleviate this problem.

(6) In general, changeout of the restraint equipment was probably more frequent than needed. For future missions, a reduction in required changeout bedding would reduce stowage requirements and crew time involved in the housekeeping tasks. It was specifically requested that nomenclature be provided on such items as upper and lower blankets, pillow inserts, and body straps. Nomenclature labels should give item name and/or usage, orientation of attachment, and frequency of changeout.

2. <u>Privacy Curtains</u>

a. Design Description - A teflon coated glass fabric privacy curtain was provided for each crewman's sleep area. Each curtain was stowed against a locker or wall to allow the crewman's egress and ingress into his sleep area. When placed in the use position, the curtain separated each crewman's sleep area from the

Sleep Compartment passageway, as shown in Figure 49.

The curtain also served as a barrier to block light from sources in the crew quarters. These privacy curtains were not designed to block or reduce sound from entering the sleep areas.

Each curtain was held in position with velcro, which mated to velcro on the lockers and walls. This feature was simple to operate and provided for breakaway emergency egress from the sleeping area.

b. Post Mission Assessment - Privacy curtains were not used as often as intended because the normal sleep configuration was with most of the lights off in the OWS, the wardroom window shades closed, and all three crewmen scheduled to sleep simultaneously. This varied from all lights off for the first two missions to "several" on for the third mission. Use of the curtain was a crew preference item. The curtain provided no sound proofing, which should receive attention in future designs. This feature was requested by several crewmen during the mission. No anomalies were reported relative to the privacy curtains.

3. Light Baffles

a. Design Description - A fabric light baffle was provided for each sleep area. The light baffle was designed to be supported by snaps and velcro that mate to snaps on the ceiling and velcro on the walls and lockers. When the baffle was installed, it provided a light barrier from the Forward Compartment area. It was designed to allow flow-thru ventilation, while providing a non-reflective surface for the crewman. The light baffle in the center sleep area had a section the size of the emergency escape exit fastened with velcro for break-away emergency egress. An illustration of the Sleep Compartment light baffles is included in Figure 51.

The light baffles were constructed of two layers of fabric. The inter-layer (side facing the Sleep Compartment) was white teflon coated glass fabric. The layer facing the Forward Compartment was black teflon coated glass fabric. To provide stiffness, the louvres contained 4 layers of the above fabrics.

b. Post Mission Assessment - The crew reported the airflow tended to close or collapse the fabric louvres, reducing air circulation. This problem was solved on orbit by cutting some triangular shaped pieces of cardboard and inserting them into the louvre stiffeners, and taping them in place. This fix kept the louvres open and allowed proper ventilation in the sleep areas. The light baffles were not used as often as planned since all OWS lights were usually off and the window shade closed.

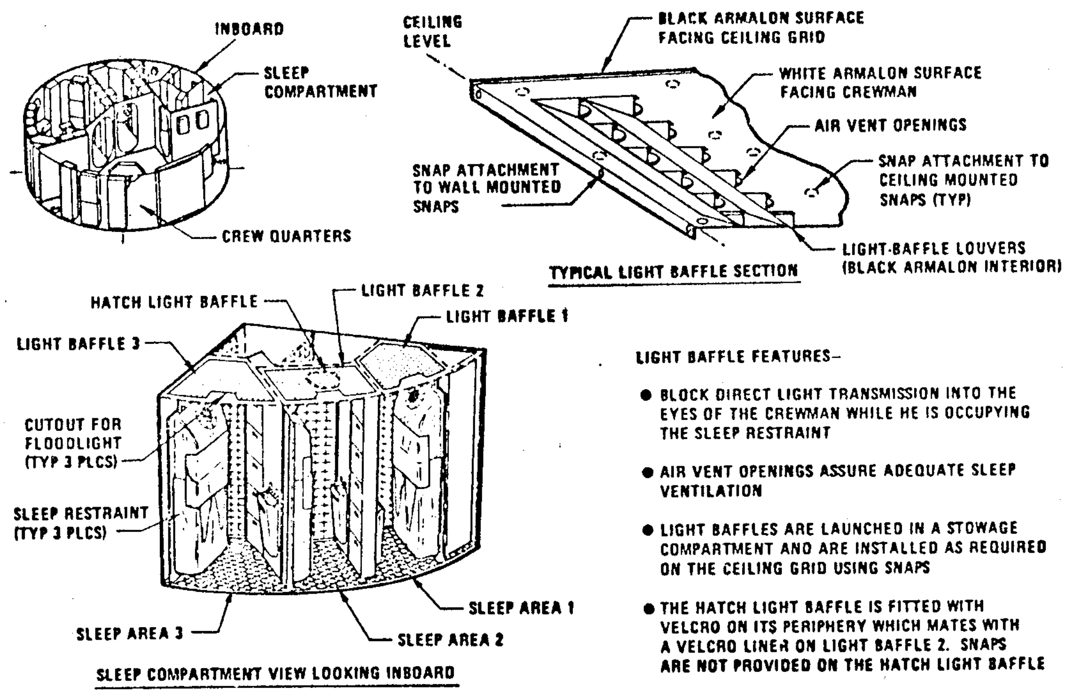


Figure 51. Sleep Compartment Light Baffles

E. Food Management System

The food management system provided the equipment and supplies required for storage, preparation, service, and consumption of the food supply for all three mission crews.

Included in this system were the following items:

- Food Galley/Pantry
- Food Table
- Food Stowage Containers
- Food Freezers and Chillers
- Transfer and Resupply
- Food Management Performance

An illustration of the food management equipment location is included in Figures 52 and 53.

1. Food Galley/Pantry

a. Design Description - The food galley/pantry provided for stowage of approximately seven days of canned food and beverages for three crewmen. These food items were stowed in pull-out drawers, which were color coded with red, white, or blue crewman designated decals. Three Wardroom lockers were used to provide canister transfer/resupply stowage. Other Wardroom lockers restrained miscellaneous items such as utensils, wipes, wet wipes, food tray lid stowage, and the Specimen Mass Measurement Device (SMMD). The galley/pantry also contained a temporary stowage area for food overcans used for collecting used food cans, food can lids, and beverage packets. An illustration of the galley/pantry and food items stowed within the galley are shown in Figures 54 and 55.

Note: The following items were associated with the food galley/pantry equipment but are not assessed in this report. Any statements regarding these items are for reference only.

- Food
- Food Containers (can and bag liner)
- Beverage Containers
- Seasoning Dispensers
- Food Heater Tray

b. Post Mission Assessment - The food galley/pantry system operated satisfactorily. However, several criticisms and potential improvements were noted by the crews. The major criticisms with the system were: (1) the crew had to handle the food too many times between launch stowage container and meal preparation; (2) all crewmen did not have equal access to the pantry from their respective eating stations; and (3) due to the daily menu tray layout of the pantry, there was generally poor accessibility to any specific item in the pantry. The crews suggested using interchangeable stowage racks or dispensers for common food items that could be transferred from stowage locker to pantry without having to remove food packets

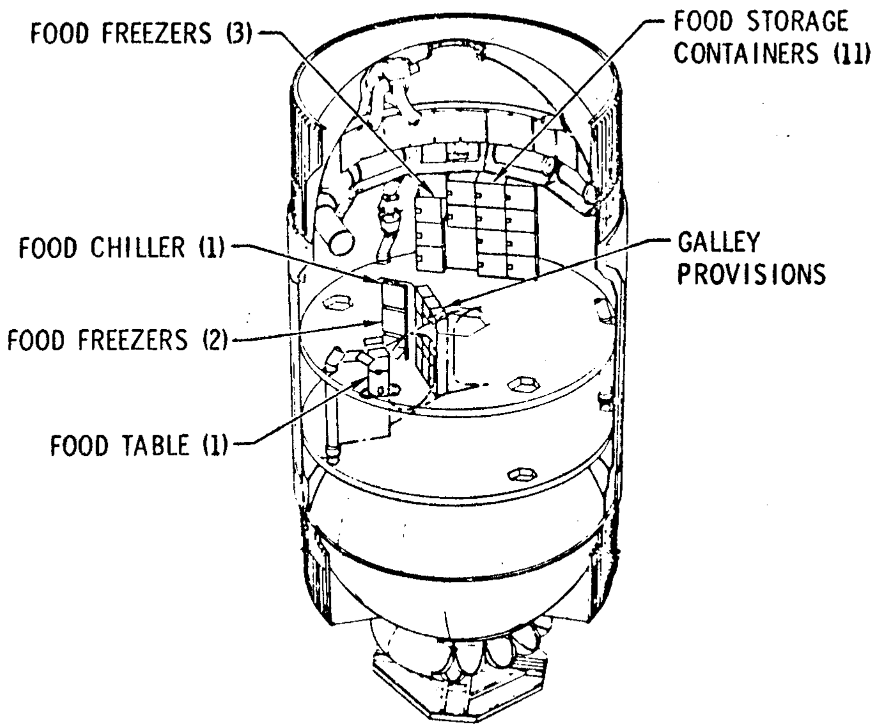


Figure 52. Food Management System

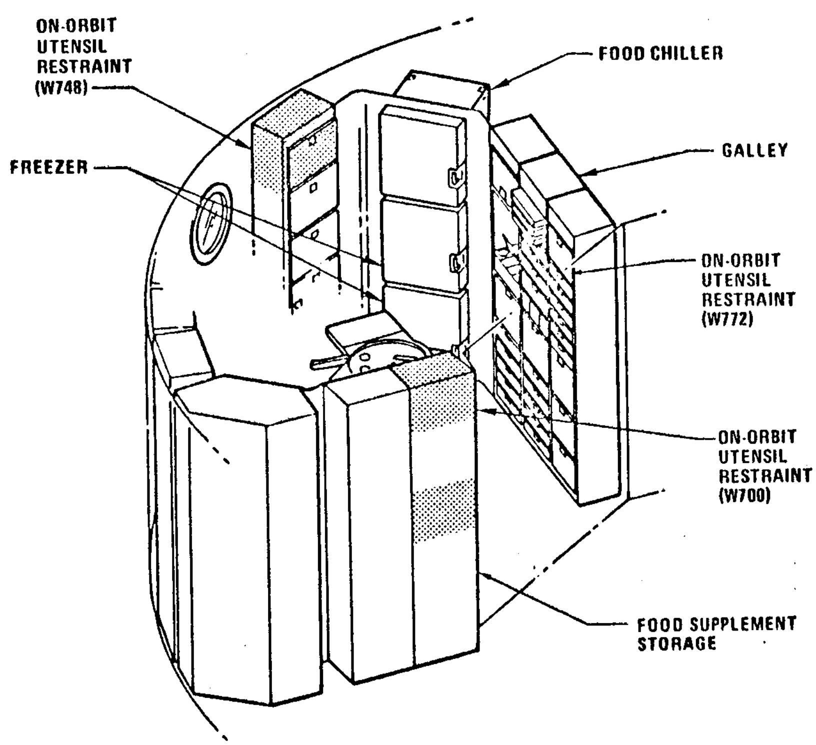


Figure 53. Food Management Equipment (Wardroom)

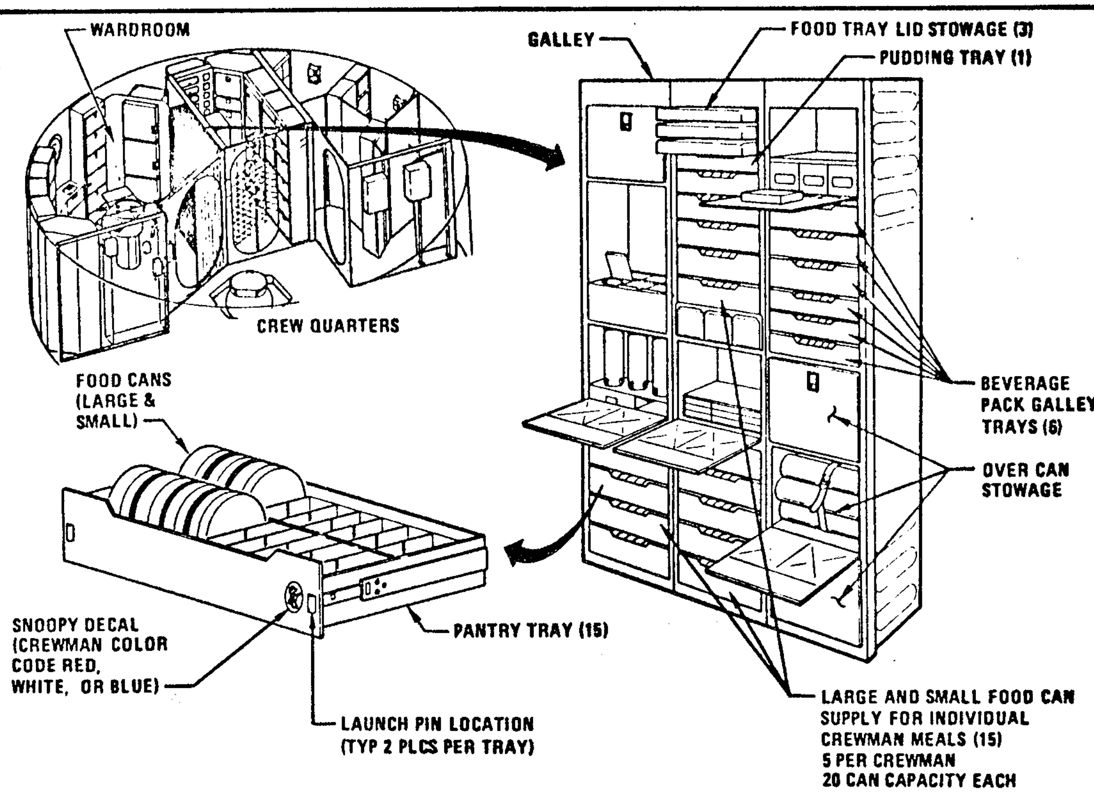


Figure 54. Daily Ambient Food Supply

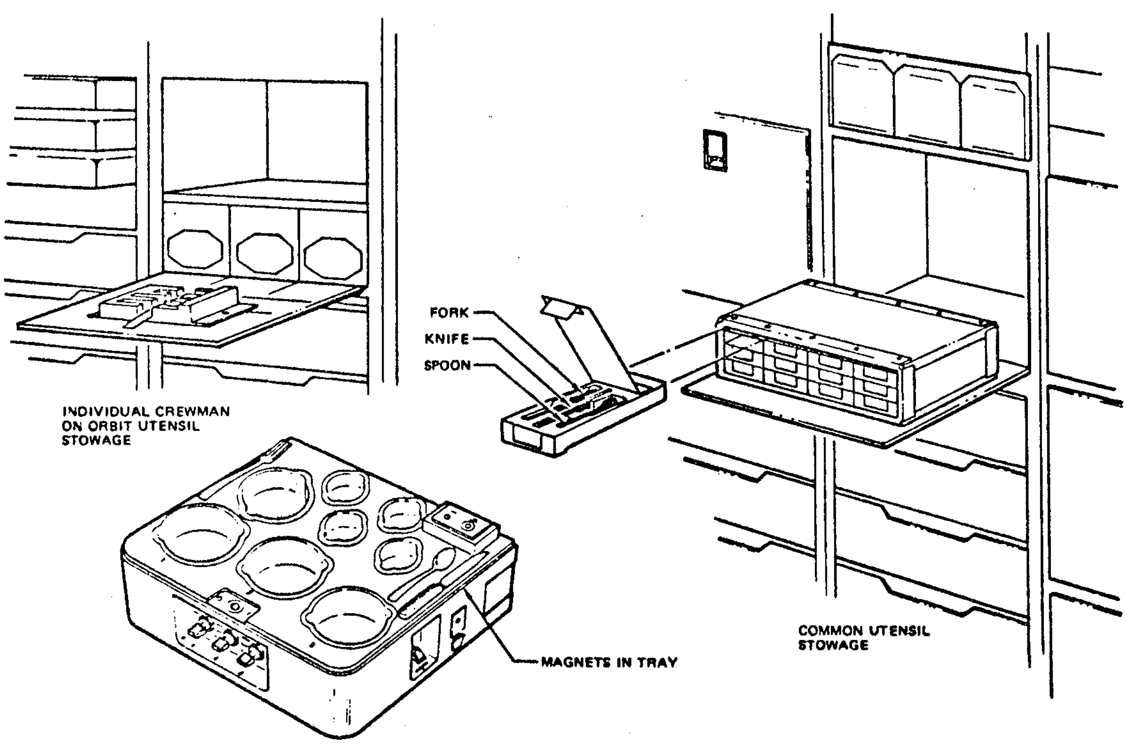


Figure 55. Utensil Stowage

from the containers. This, along with a non-daily menu tray pantry layout, would minimize food handling requirements, while affording better accessibility to individual pantry items. Associated with the food galley/pantry system was the food can disposal system. The crews criticized this system as being too small to operate effectively and, due to its design intricacies, too difficult to keep clean. All surfaces of the system, including the six lid openings and lids themselves, became soiled easily and remained that way constantly because of the continuous contact with used food cans.

The crews also had the following minor criticisms of the stowage provisions for their individual eating utensils: (1) the utensils were hard to reach from the eating stations; (2) the utensil compartments did not restrain the utensils adequately; and (3) the compartments were difficult to clean.

2. Food Table Equipment

a. Design Description - Final food preparation and consumption was accomplished at the food table. The food table, illustrated in Figures 56 and 57, allowed three crewmen to prepare and consume their food simultaneously.

A removable table cover was stowed on the ceiling grid above the food table when not in use.

The food table pedestal housed the water chiller and heater. The water chiller provided cold water through a dispenser valve on the table's upper surface for chilled reconstitution of rehydrated foods and beverages. In addition, the water chiller provided cold water to three crewmen designated water guns for drinking. The water heater provided hot water for reconstitution of rehydrated foods and beverages. Figures 58 thru 61 illustrate the basic configuration and arrangement of these items.

Each of the three food table eating stations was provided a set of permanent foot restraints and an adjustable thigh restraint as illustrated in Figure 62. The foot restraints were composed of two adjustable straps for bare-foot restraint and two cleat receptacles to accept and retain the cleats of the triangle shoes.

The adjustable thigh restraint, used in conjunction with the foot restraints, provided a means of stabilizing the crewman while occupying the food management station.

There were three crew designated food trays with removable lids, illustrated by Figures 63 and 64. Each tray and lid was identified by color coded decals. The tray lids were used to cover the trays during periods of unattended food heating/preparation, or when the trays were stowed. While the crewman was making final food preparations or eating, the tray lid was stowed in the galley.

Each tray contained four large and four small food can receptacles, with restraints, for restraining the cans during food preparation and consumption. Three of the four large receptacles were provided

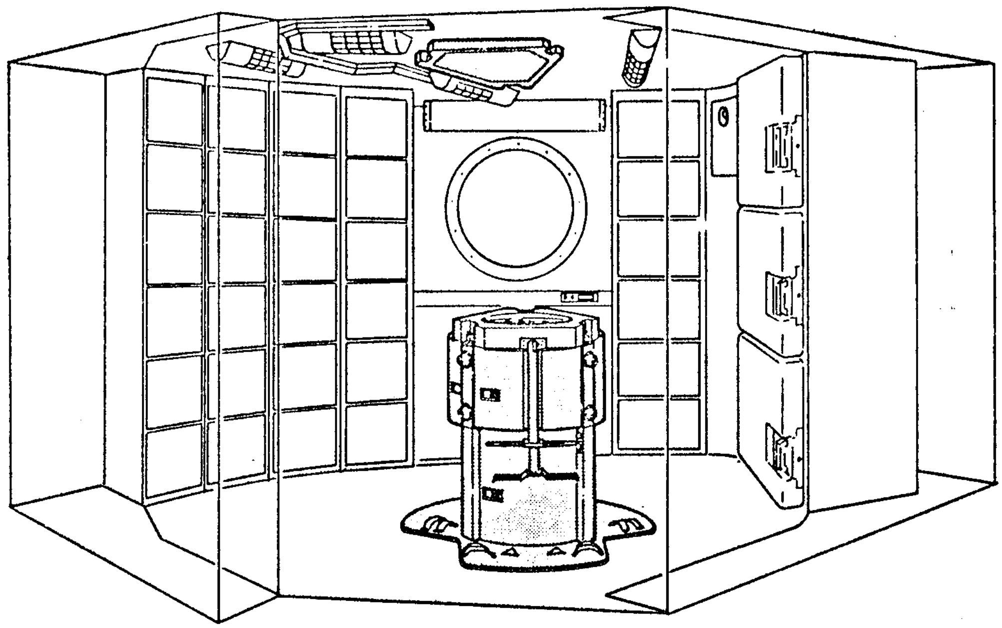


Figure 56. Food Table and Restraints

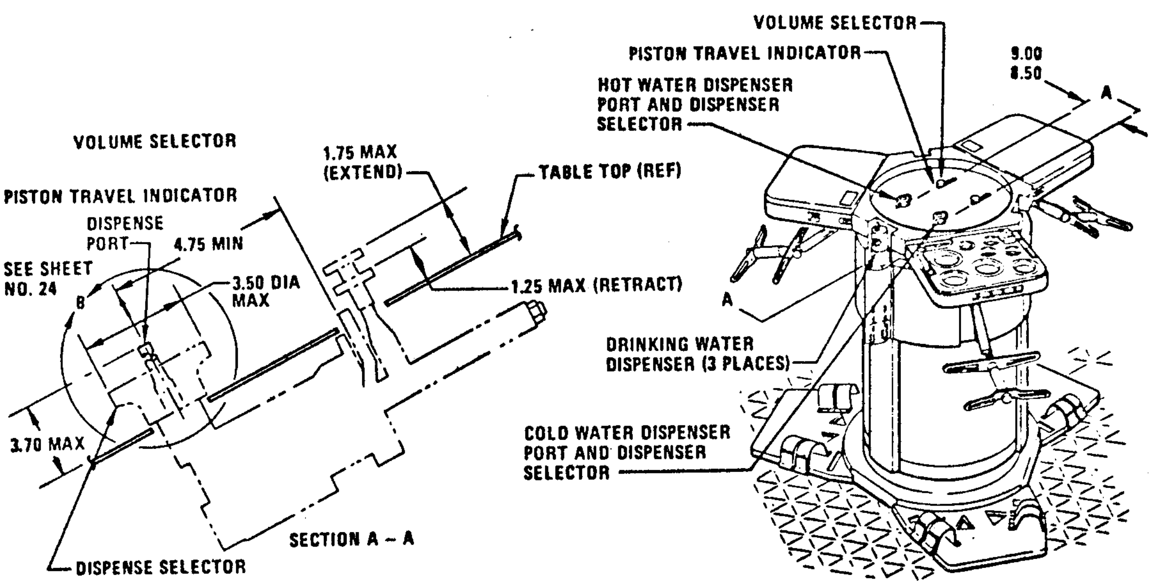


Figure 57. Food Reconstitution Water Dispensers (Wardroom)

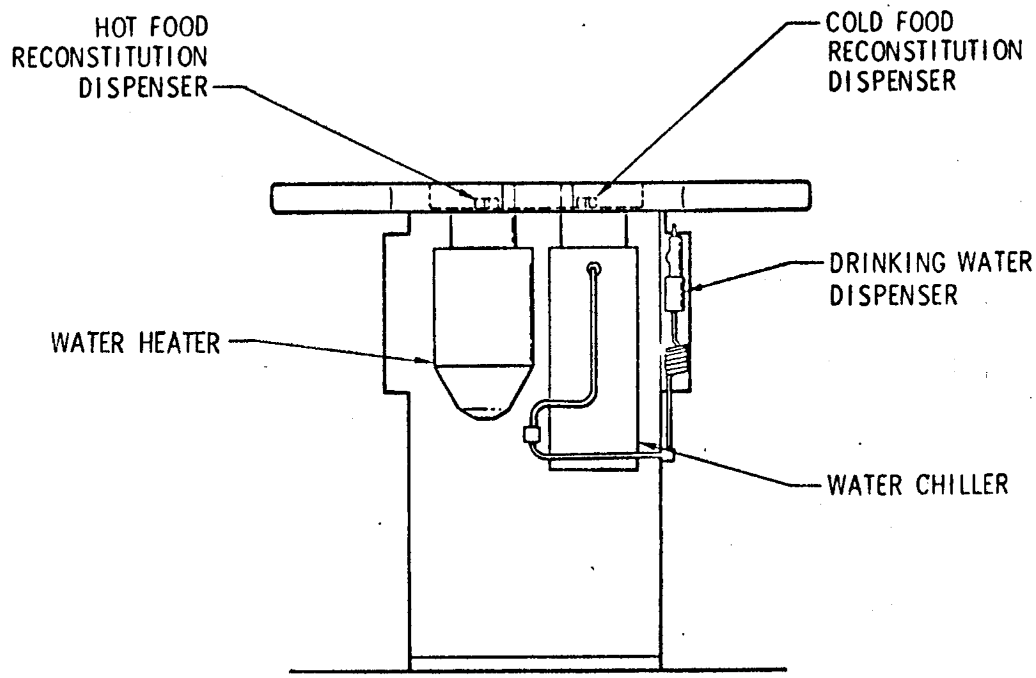


Figure 58. Water Equipment (Wardroom)

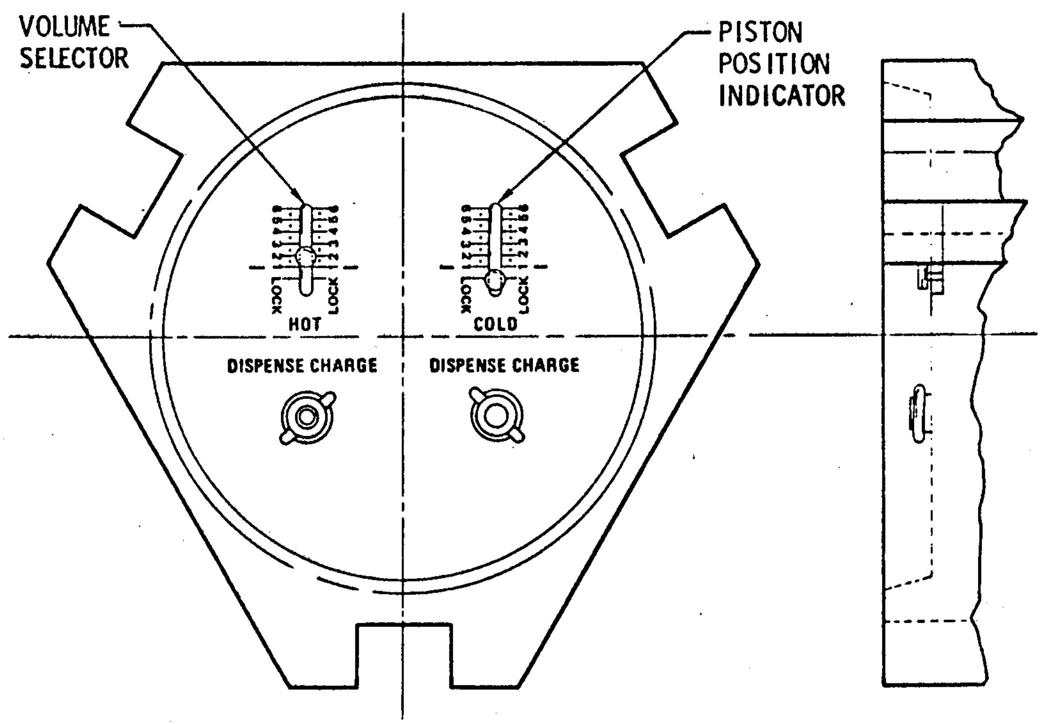


Figure 59. Table Top Water Slectors (Hot and Cold)

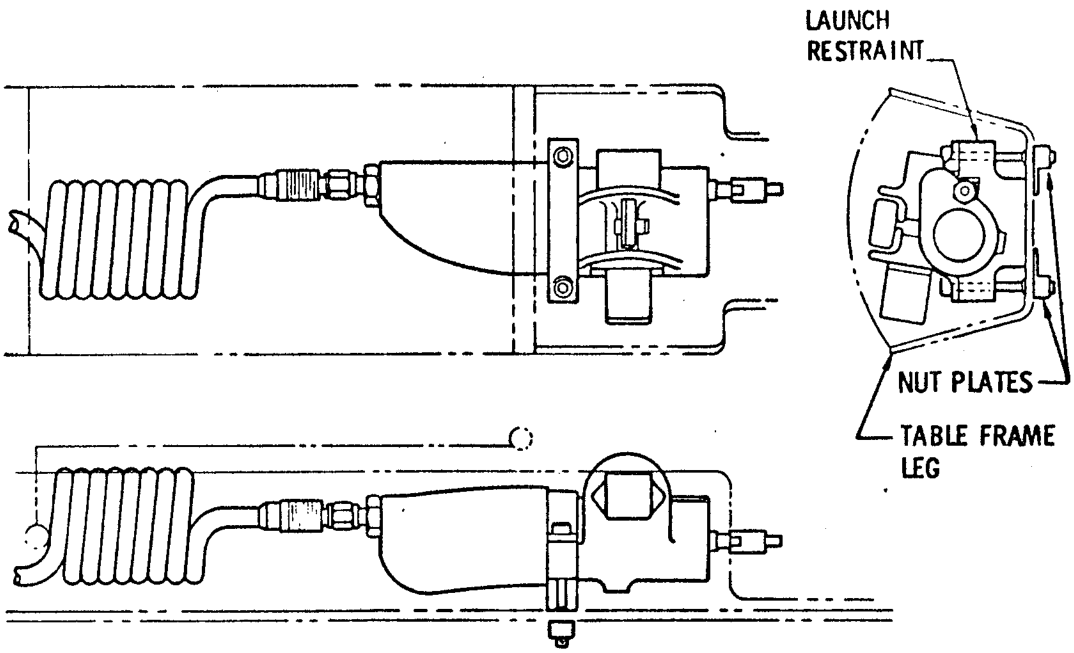


Figure 60. Drinking Water Gun

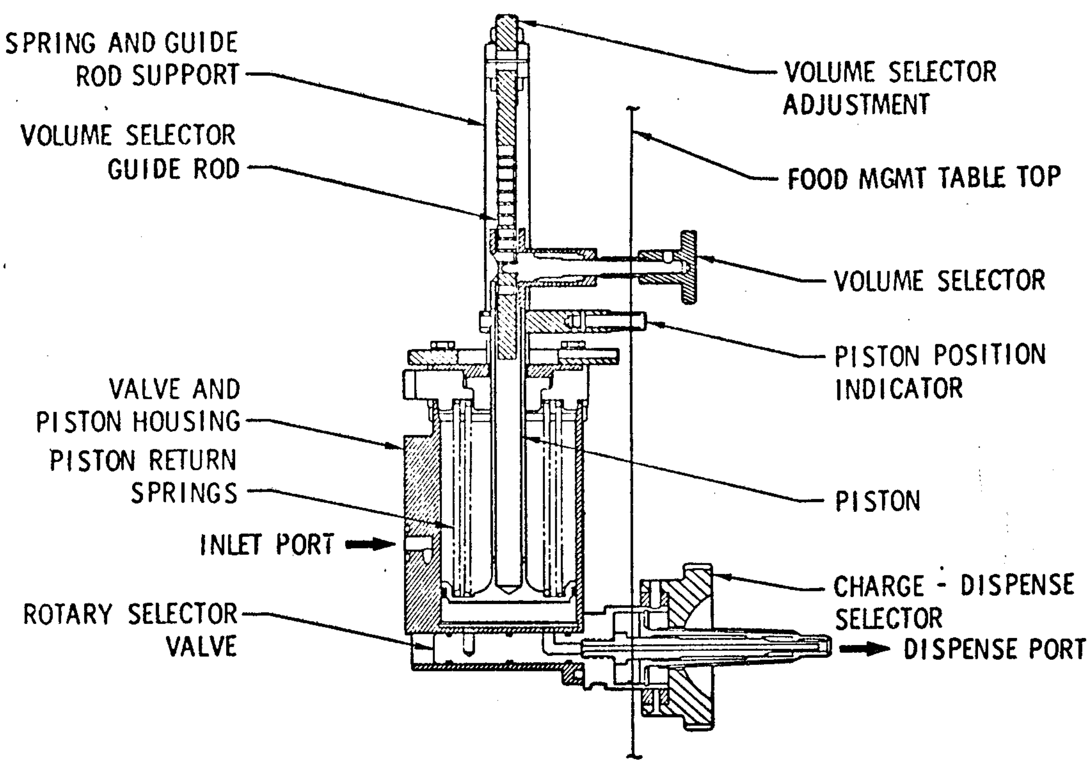


Figure 61. Food Reconstitution Water Dispenser (Cutaway)

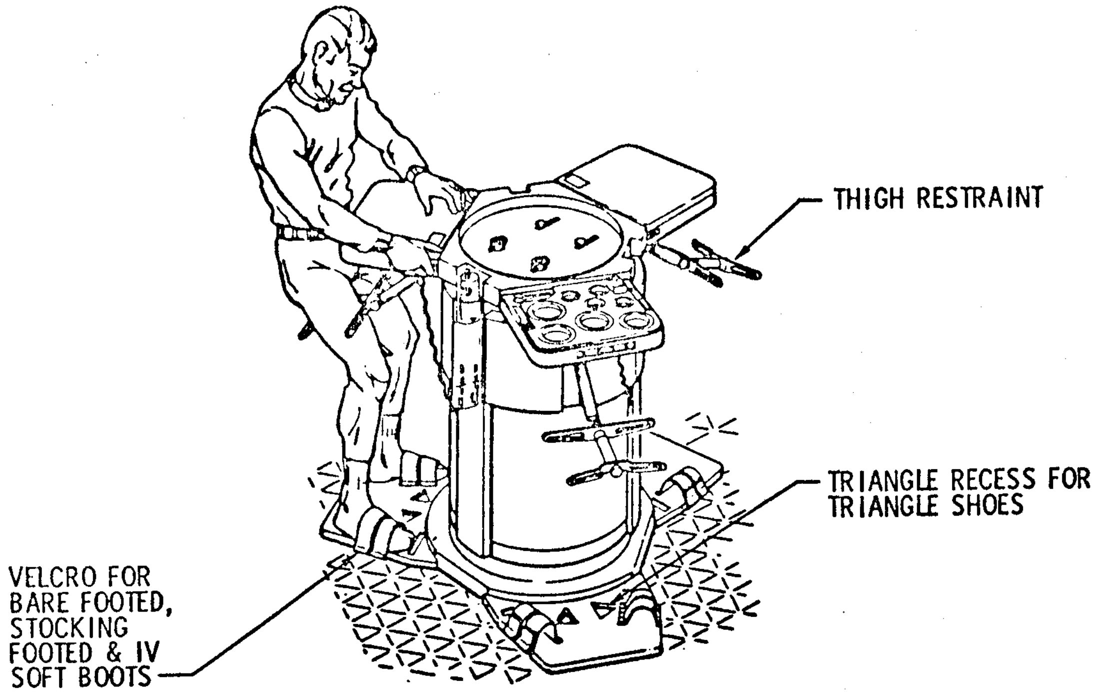


Figure 62. Food Table Restraints

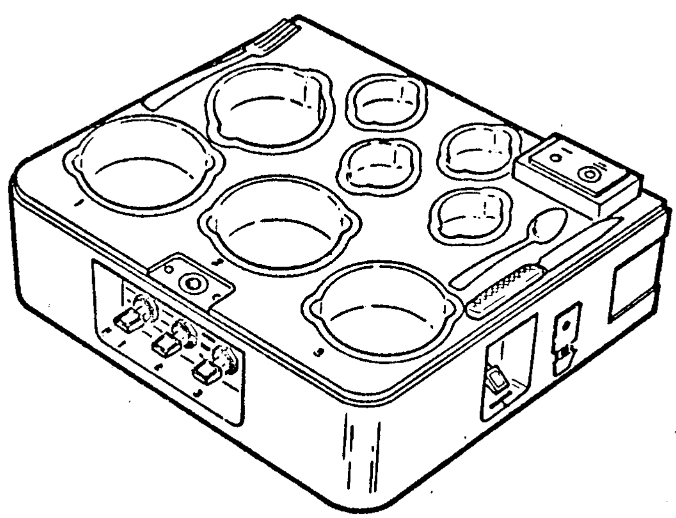


Figure 63. Food Tray (GFE)

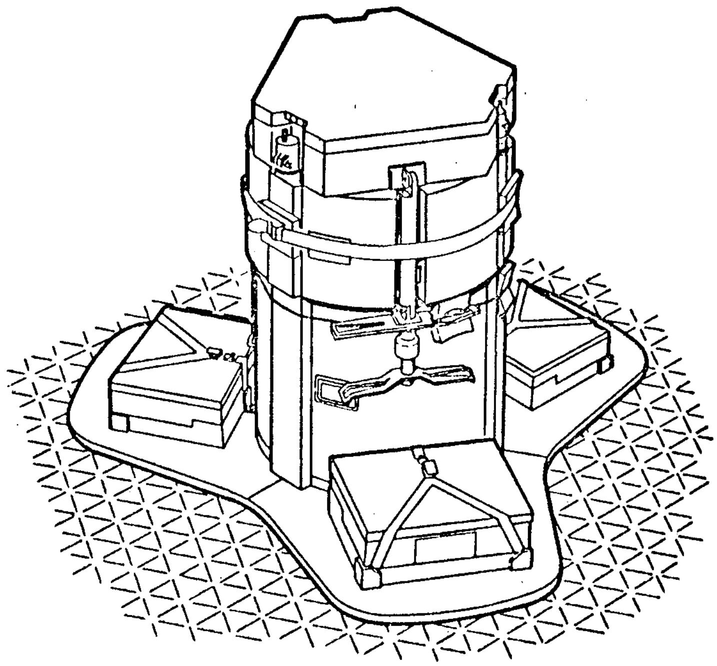


Figure 64. Table and Food Tray Launch Configuration

independent heating controls for heating various frozen foods. The small receptacles restrained the small food cans and beverage containers.

b. Post Mission Assessment - Crew comments related to the food table were favorable. The food preparation system worked satisfactorily. All food table area restraints worked well, with the exception of the foot restraints. The SL-4 crew removed the table foot restraints and used the grid floor. During all three missions, the table was used as a work bench and reading/writing area. This prompted comments that brighter, individual lighting was required for each food table crew station, along with restraints on the table top to hold books, checklists, etc. A minor criticism of the food tray itself was the food can restraints did not securely hold the food cans in place all the time.

3. Food Storage Containers

a. Design Description - The food storage containers were designed to restrain the ambient canister restraint assemblies during launch and on-orbit use. All eleven containers were common in design and construction. The container sides and backs were corrugated aluminum panels. The doors were similar to the standard locker compartment doors, using the common locker door latch illustrated by Figures 65 and 66.

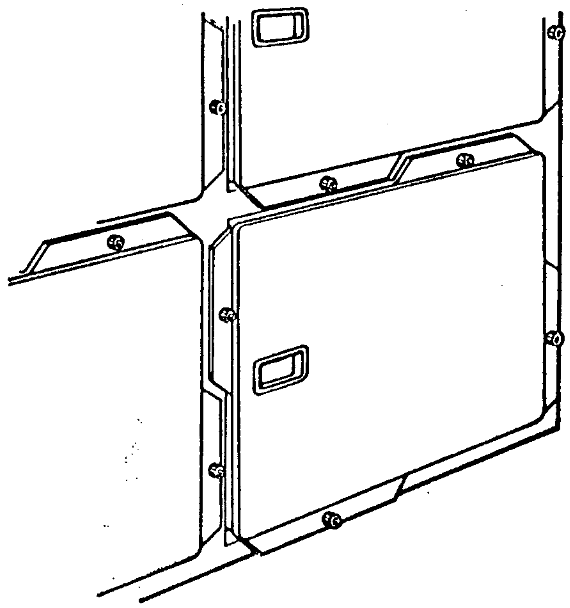


Figure 65. Ambient Food Container (Foward Compartment)

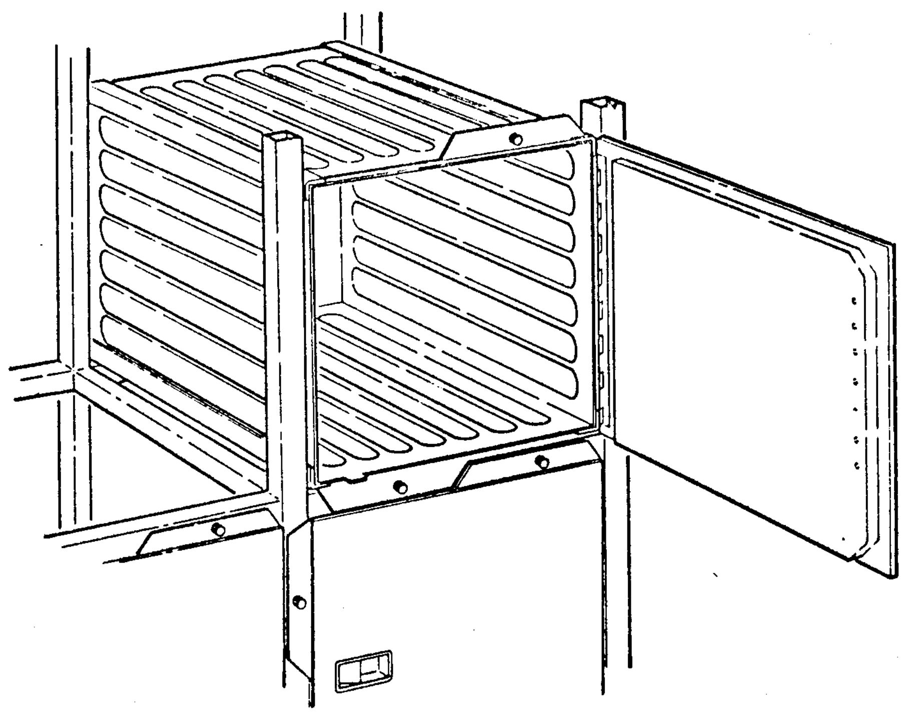


Figure 66. Ambient Food Container (Foward Compartment)

Six food containers were attached to the Forward Compartment floor during launch, shown in Figure 67. The first crew then unbolted and transferred all six food containers to their on-orbit or use location as illustrated by Figure 68. The five remaining containers were launched in the container support structure. The container support structure was designed for easy crew accessibility, located just in-board of the electrical cabinet adjacent to the refrigeration pumping unit, illustrated by Figure 69.

As the food supplies within the food containers, Figures 70 thru 73, were depleted and the canister restraints discarded, the empty food containers assumed their second design function. Trash and transfer items (such as PCU container, CO_2 absorbent shims, etc.) were removed from the CM and placed in these empty food containers. As additional food containers became available during all missions, they were used for this same purpose.

b. Post Mission Assessment - It is assumed that the food containers performed as designed during launch, transfer, and installation into the support structure. The crew reported the flanges on the edge of the containers were used as holding devices during transfer and installation in the food container stowage rack. The food containers were among the largest items the crews were required to transfer and relocate on-orbit. Reports from the crews indicated this was accomplished easily.

4. Food Freezers and Chillers

a. Design Description - There were five food freezers in the OWS, three located in the Forward Compartment and two in the Wardroom. These freezers were used to launch and maintain frozen food packages. The single food chiller, located in the Wardroom, was used during launch as stowage for an ambient food module, and on-orbit for stowage of left-over food items and experiment hardware. Each of the food freezers contained enough food for three crewmen for 28 days, approximately 50.4-pounds of frozen food, such as steaks, prime rib, ice cream, etc. All frozen food was contained in cans and overcans as illustrated by Figure 74.

The freezer and chiller compartment designs accommodated the standard food canister restraints during launch and orbital use. The freezers were foam filled shells with a trigger latch operated foam filled door. Each door/freezer interface was a vented gasket, which helped the refrigeration system to maintain the frozen food at approximately $-10^{\circ}F$.

b. Post Mission Assessment - The freezers and chillers were satisfactory from a crew standpoint. Although the crews felt the frozen food was the best, they had the following freezer/chiller system comments and criticisms: (1) the freezer space utilization

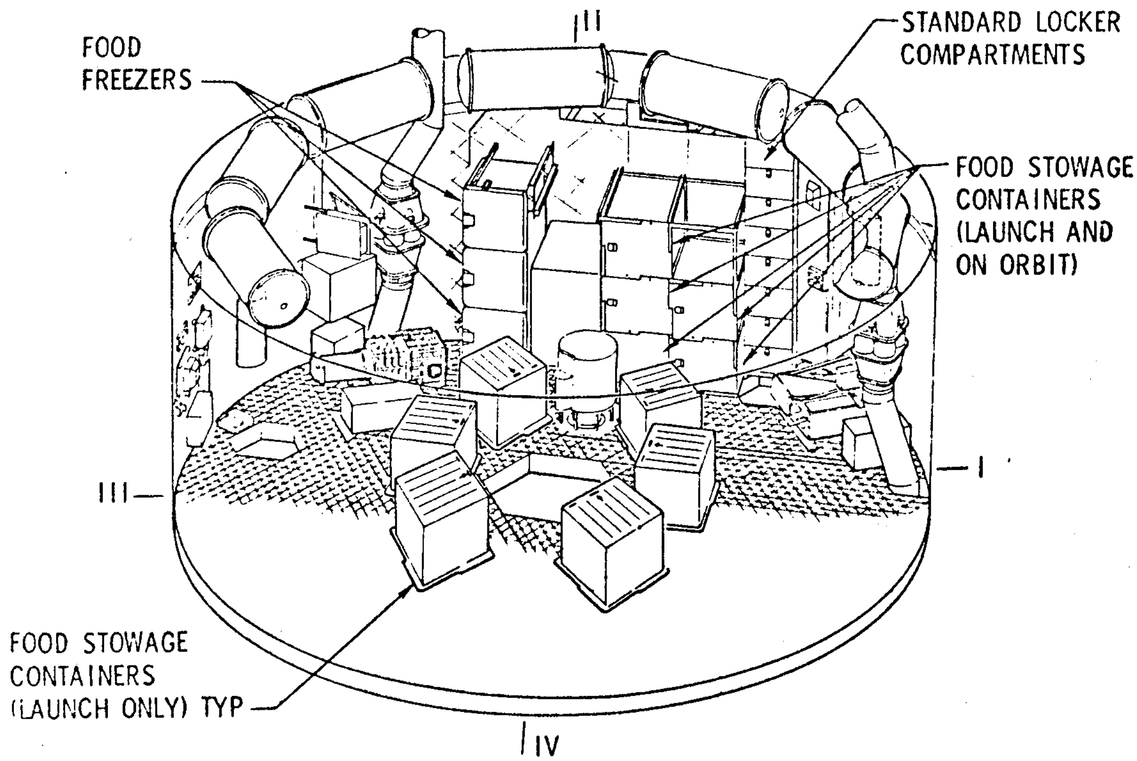


Figure 67. Food Stowage Containers - Launch Configuration

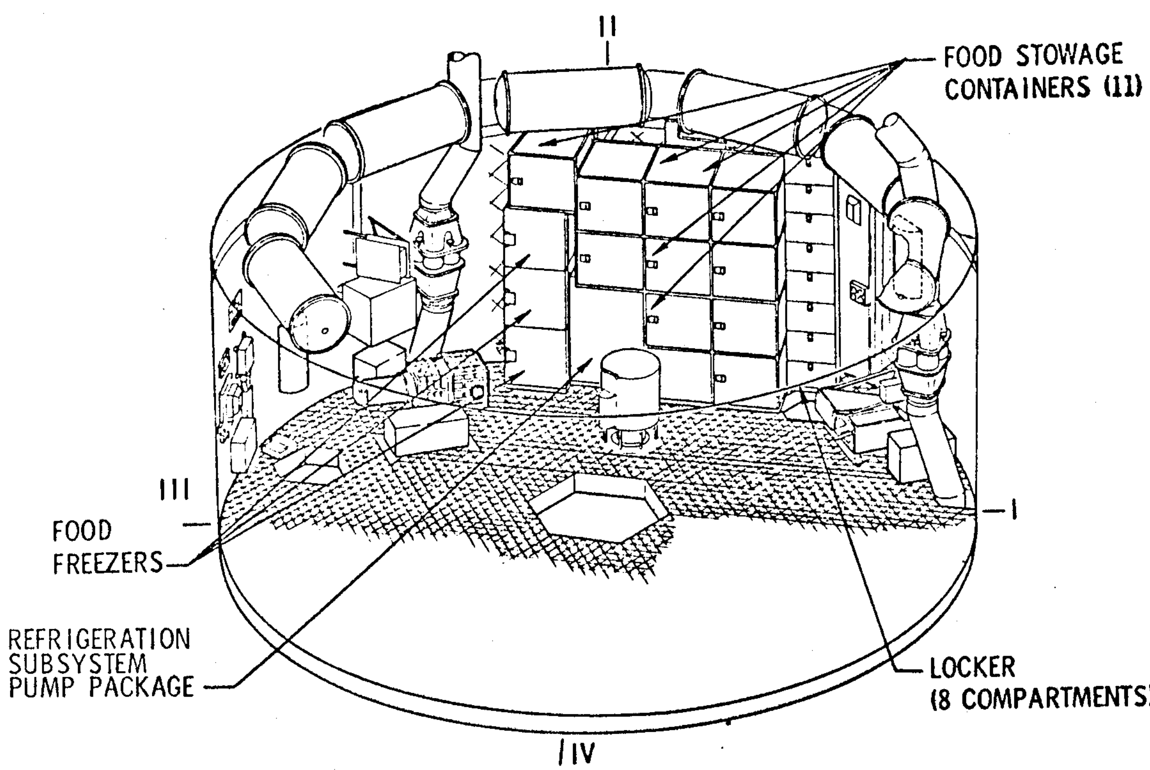


Figure 68. Food Stowage Containers - On-Orbit Configuration

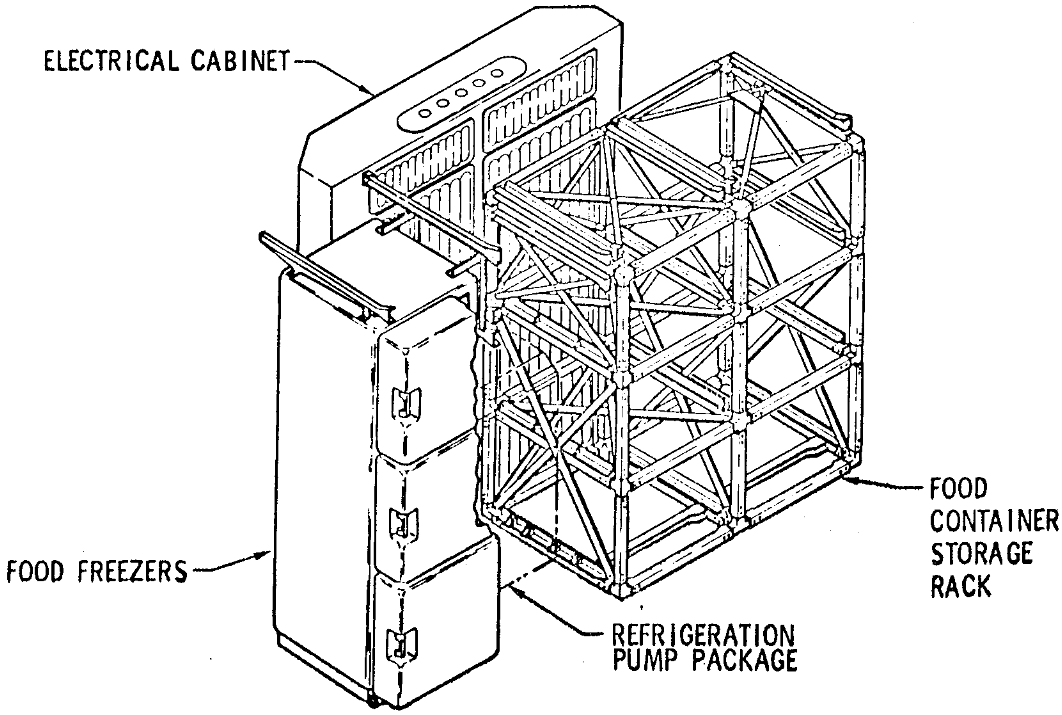


Figure 69. Food Freezer/Food Container Support Structure

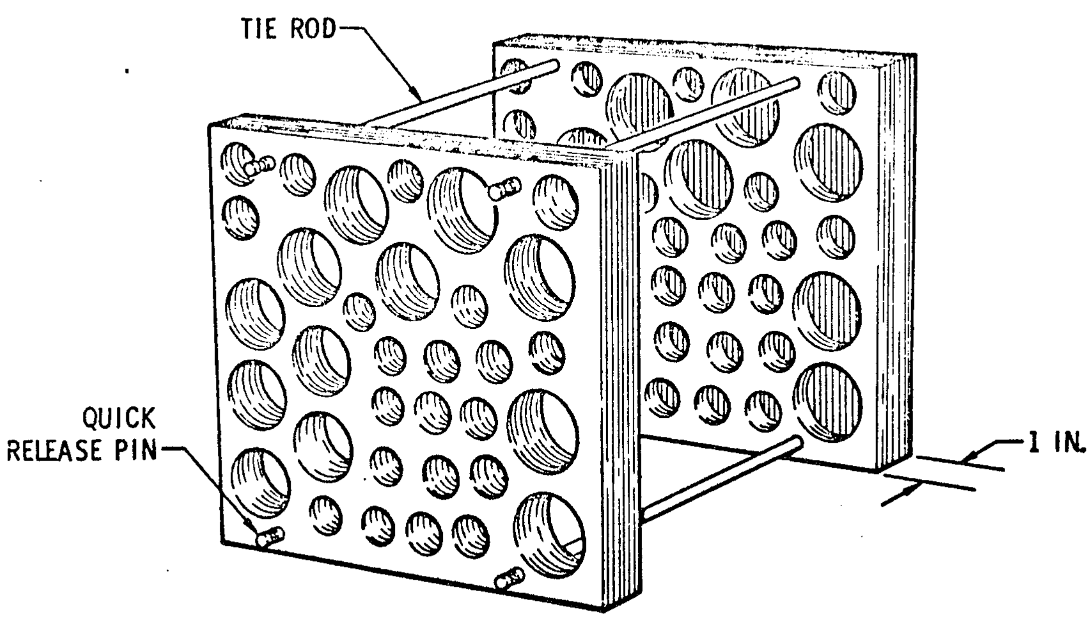


Figure 70. Ambient Food Canister Restraint

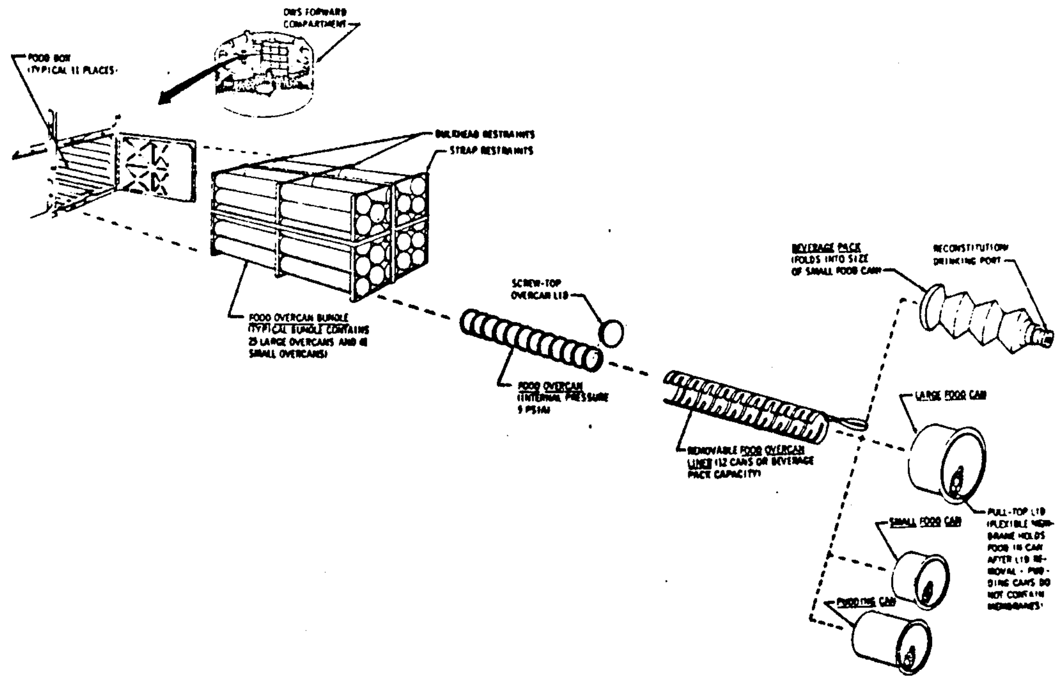


Figure 71. Ambient Food Storage Concept

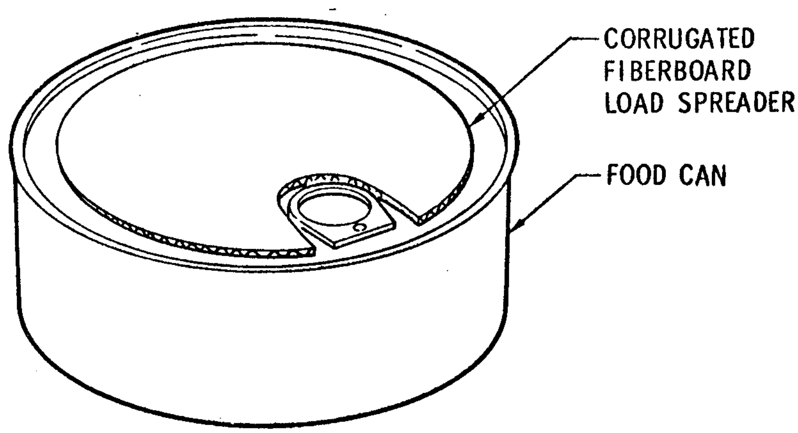


Figure 72. Ambient Food Can

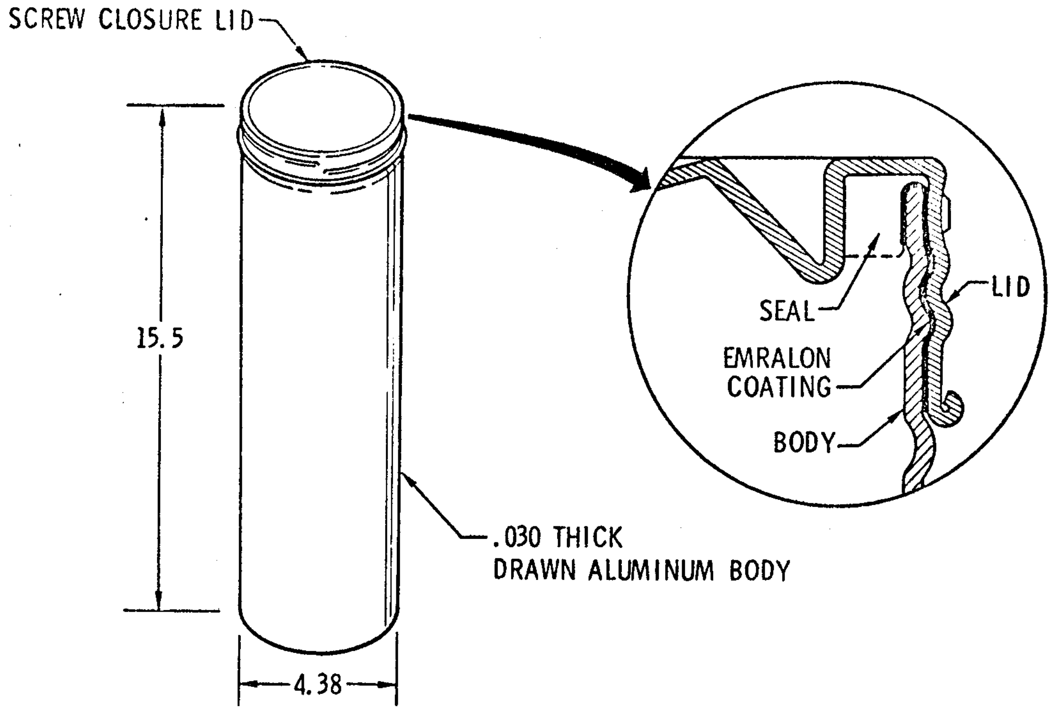
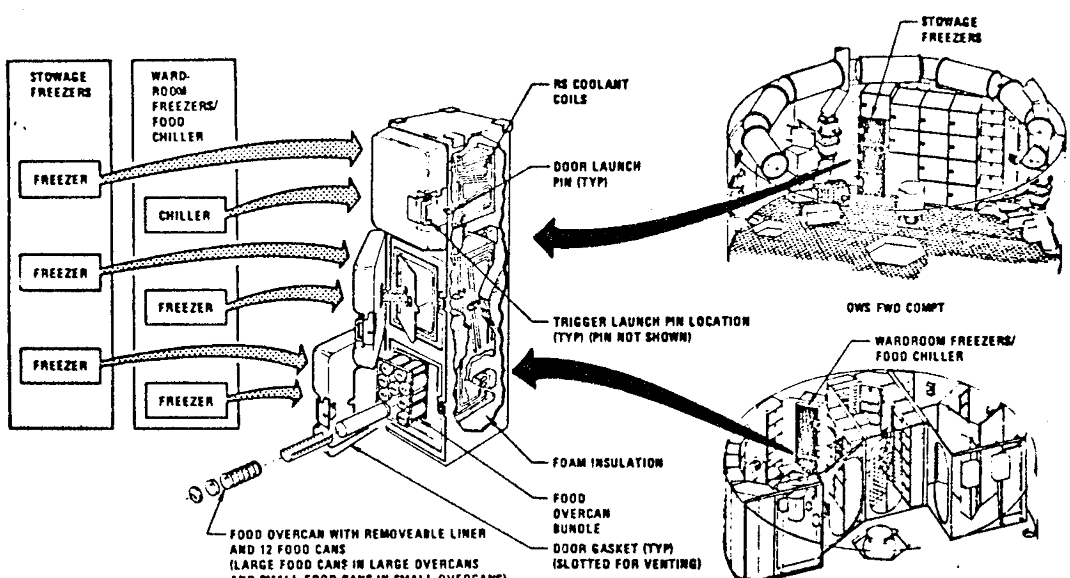


Figure 73. Ambient Food Overcan



FREEZERS	FOOD CHILLER
• 28 DAY SUPPLY FROZEN FOOD EACH • −10 ± 10°F • ALL FOOD LAUNCHED ABOARD SWS	• CHILLS FOOD AND BEVERAGES PRIOR TO CONSUMPTION AND PRESERVES INCOMPLETELY CONSUMED FOOD AND BEVERAGES FOR A 24 HOUR PERIOD • 45 +0 −12°F

Figure 74. Frozen Food Storage and Supply

was poor (approximately 60% to 70%), even though the freezers were relatively small; (2) loose food items in the freezers should have been restrained in some manner; and (3) ice built up in between the freezer and canister doors, reducing freezer accessibility and requiring the crews to develop and perform an unscheduled maintenance procedure. The door ice buildup was a progressive event, requiring the crew to use such implements as a pinch bar or screwdriver to remove the ice when it impaired freezer access. The crews felt that significantly more food could have been stored in the freezers had a different packaging system been used.

5. <u>Transfer and Resupply</u>

a. Design Description - Food transfer and resupply was an integral part of the food management system operation. Original planning was to employ a pantry concept, i.e., food trays and storage areas in the Wardroom. The pantry was designed to accommodate approximately seven days of food, with the crew transferring bundles of food from the Forward Compartment food stowage containers to the Wardroom pantry for resupply, as required.

At the beginning of each mission, CM food was also transferred to the Wardroom and stowed in the pantry for crew consumption.

b. Post Mission Assessment - Equipment used for food transfer and resupply was considered satisfactory. Food containers were easily released and transferred to on-orbit stowage locations, food bundles were easily transferred from the Forward Compartment stowage containers to the Wardroom, and individual food and beverage packets were easily installed in their assigned locations in the pantry drawers. The frozen food was also easy to transfer, by bundle, from a freezer in the Forward Compartment to one in the Wardroom.

However, the overall food transfer system was far more time consuming than desirable, with the actual ambient/frozen food handling approximately three times as great as it should have been. The crews recommended hardware design and food management procedures that minimize the time and frequency of food handling. At a minimum, it was suggested the incorporation of food handling bags to aid in food transfer, while reducing the number of transfer trips from stowage lockers to the Wardroom.

F. Housekeeping

Equipment used for housekeeping included trash collection equipment, a vacuum cleaner, and microbial control equipment.

1. Trash Collection - Trash was considered to be those items of loose equipment no longer having a defined use. Trash was collected by segregating it into two categories: biologically active trash, such as urine bags and food cans; and nonbiologically active (inert) trash, such as launch restraint hardware and non-flammable fiberboard packing.

Biologically active trash was placed in bags and cycled through the Trash Airlock (TAL) into the waste tank.

Inert trash was placed in plenum (duffel) bags and stowed in the plenum area aft of the crew quarters floor or in available lockers.

a. Design Description - Trash and disposal bags were fabricated from vented armalon and were cylindrical in shape. The bags were equipped with self enclosures which sealed the bag when full.

Trash bags were designed to be installed in a standard size locker and attached to the inside of a special trash locker door. A circular opening on the locker door allowed access to the bag diaphragm for insertion of trash without opening the locker door. A hinged access cover was located over the circular opening in the locker door. Both dry and moist solids were disposed of in trash bags. When full, trash bags were closed, taped, and disposed of through the TAL. Trash bag location and configuration are depicted in Figure 75.

Disposal bags and urine disposal bags were designed to interface with snap patterns provided throughout the vehicle. Disposal bags were capable of containing urine separators, charcoal canisters, or other large disposable items considered as contamination sources. Urine disposal bags were designed to contain urine collection bags. When full, they were closed, taped, and disposed of through the TAL. An illustration of the disposal bag is shown in Figure 75.

Plenum bags were designed to contain stowage trash which was not considered a contamination source. The plenum bags were stowed in the plenum area, beneath the crew quarters floor, by attaching them to cables provided in that location. Hooks for this attachment were an integral part of the individual plenum bags. A plenum bag and its orbital stowage is illustrated by Figures 75 and 76.

b. Post Mission Assessment - In general, the various trash and disposal bags were used as planned on all missions. The trash bag usage was less than anticipated, while the disposal bag usage was greater than planned.

Only minor anomalies were encountered with trash collection equipment during the entire mission. However, anomalies were reported relative to problems which developed while cycling disposal bags through the TAL. These problems are discussed in the Trash Disposal section.

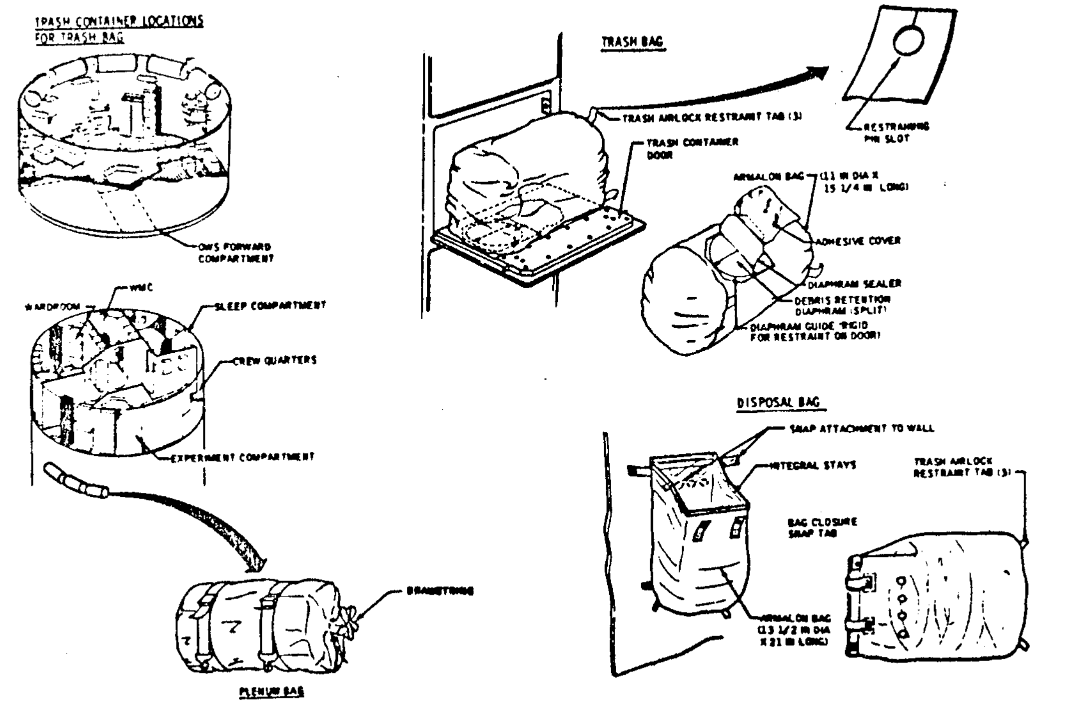


Figure 75. Trash Collection Bags

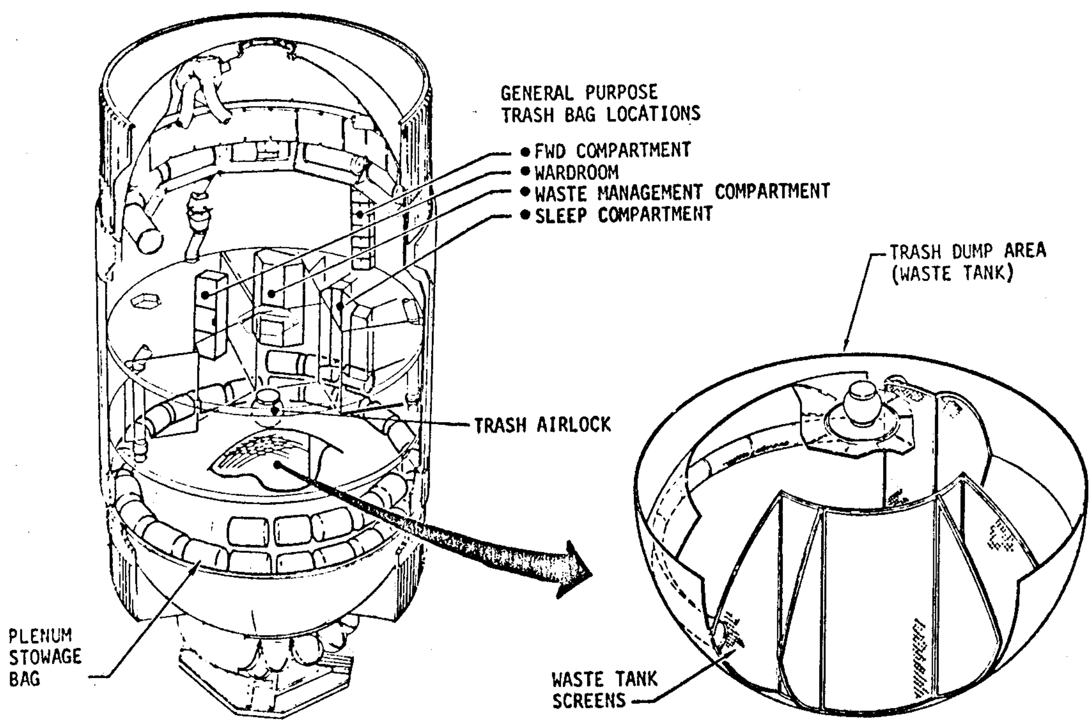


Figure 76. Trash Disposal Subsystem

The following paragraphs discuss problems and improvements associated with the trash collection provisions:

(1) The location of the trash bags in the Wardroom was such that the crewmen interfered with each other while trying to obtain access to the trash lockers. The crew rearranged the trash lockers, thereby providing a more convenient trash disposal location for each crewman. This was accomplished by removing the hinge pin from a trash door and "swapping" it with a regular door at a different location.

Until the rearrangement was accomplished, trash bags were not being used as frequently as planned. As an example, during the first mission, the crew "swapped" locker door W775 for locker door W750 to give the CDR a convenient place to put trash. They then swapped locker door E621 with locker door W702 to give the SPT a convenient location to put trash. This "swapping" kept the functions of each locker the same. Lockers W750 and E621 were relocated trash lockers. The crew also stowed a disposal bag on the snaps between the CDR's seat and the doorway.

(2) The collection of wet wipes, used to clean food and urine spills, wet washcloths, and towels, etc., should be disposed of in an internal locker and not in a disposal bag that stows on the wall.

(3) The location of bags in the Sleep Compartment was satisfactory, but there was not much trash generated in this area.

(4) The trash bags were considered excellent and worked very well. The plenum bags were effective for the dry trash, such as empty washcloth containers, wipe containers, and towel containers when the crew ran short of disposal and urine disposal bags. The plenum bag was rated excellent because of this additional stowage capability.

(5) The spring top on the urine disposal bags was very convenient and worked well. It was pointed out that there should be an easier way of sealing the urine disposal bags to prevent low bleed leaks. The method used was acceptable, but it was considered cumbersome. The flaps were wrapped around and snapped to prevent the urine disposal bags from venting in the waste tank.

(6) It was decided that there should be alternate methods of trash disposal for future space stations. A trash compactor, or something similar, was mentioned as a possible candidate.

A total of three hundred and sixty-six (366) trash bags were launched. Of this quantity, 73 bags were allocated for the first crew, but only 22 were used. The second crew was allocated 146 bags of which 62 were used. The third crew used 162 trash bags. The quantity of trash bags used (246) was less than that allocated (366). The provisioning for future programs should consider these actual usage rates.

One hundred and sixty-eight (168) disposal bags were launched. Thirty-three (33) disposal bags were allocated for the first mission, but 48 were used. The second crew used 54 of 68 allocated disposal bags. The third crew ran out of disposal bags on MD 25, having used the remaining 66 disposal bags.

One hundred and forty-nine (149) urine disposal bags were launched. The first crew used 40 urine disposal bags. Thirty-seven (37) additional bags were launched in the second CM and a total of 98 urine disposal bags were used during the second mission. Eighteen (18) additional urine disposal bags were launched in the third CM. The third crew used 85 urine disposal bags.

Of the 28 plenum bags on board, 5-3/4 were filled by the first crew. By the end of the second mission, a total of 9 plenum bags were filled and stowed in the plenum area. The third crew used 13 plenum bags.

2. Vacuum Cleaner

a. Design Description - The crews were provided with a vacuum cleaner and a selection of vacuum cleaner tools (accessories) for a variety of housecleaning applications. The vacuum cleaner contained a replaceable debris bag with a filter that prevented liquid penetration into the power unit. The full debris bag was removed, sealed, and discarded as required. The vacuum cleaner, fecal/urine collector, suit drying station, and shower all used an identical power module. This provided an interchanged capability in the event of a power module malfunction.

A brush attachment was provided for cleaning ventilation system debris collection screens. A surface tool was available for flat surface cleaning. A crevice tool was used to clean nooks and crannies in the Skylab cluster. Figure 77 provides an illustration of both the vacuum cleaner and the cleaner accessories.

b. Post Mission Assessment - The crew reported that the vacuum cleaner worked satisfactorily in cleaning the debris screens. The crew decided that housekeeping involving cleaning of ventilation debris screens should be accomplished about every 3 days, instead of once per week.

In general, all vacuum cleaning tools worked well. Twenty-five (25) vacuum cleaner debris bags were used throughout the mission. The vacuum cleaner was not used to collect wet debris nor for any use other than dry debris collection. There were no recommended changes to the vacuum cleaner procedures.

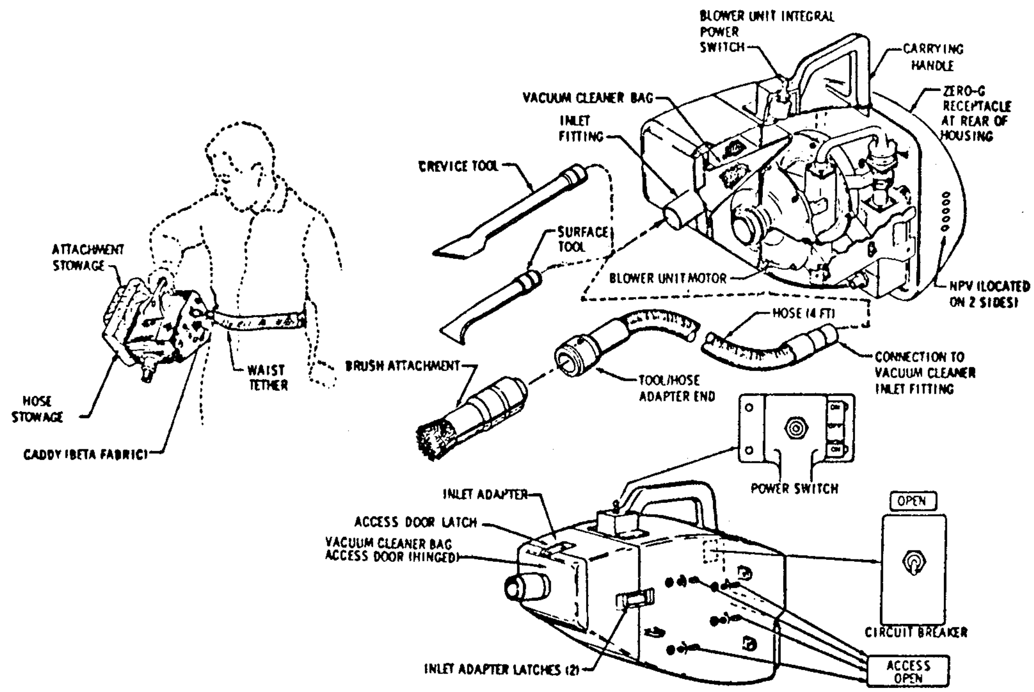


Figure 77. Vacuum Cleaner and Accessories

The crew stated that a vacuum cleaner was a very necessary device for many cleaning tasks, but recommended that the system have more capability, more attachments, and additional vacuum power.

The vacuum cleaner was used about 15-minutes on each occasion. The bag was changed after every use. The bag replacement time was 5 to 10-minutes.

A usage rate of one vacuum cleaner debris bag per day was planned for all missions with a total supply of 140 debris bags. The first crew used 5 bags and the second crew used 10 bags. The third crew did not report vacuum cleaner debris bag usage because of the large quantity remaining after the first two missions. On future missions, the vacuum cleaner debris bag allocation should be planned using the consumable summary included in the Stowage section.

3. Microbial Control

a. Hardware Design Description - The hardware designed for microbial control included biocide wipes (using iodine as the bactericidal agent) and wet wipes (using zepherin chloride as the bactericidal agent). The biocide wipes were used for general surface disinfecting as well as major organic spills. The wet wipes were used for food utensils and food tray cleanup. A collapsible cleaning rod was provided for disinfecting the metabolic analyzer (M171) exhaltion hose. Additional microbial control relied on the use of general purpose tissues and utility wipes.

b. Post Mission Assessment - The crews generally used the microbial control equipment as planned. However, they developed some interesting variations. A rag bag was established in the Crew Quarters near the M131 experiment for stowage of not too dirty used clothing and towels. These articles were used for major clean-up jobs, such as wiping urine spills. They also found that there was considerable cleaning capability left in the wet wipes after the first use. After cleaning up their eating utensils and tray, the wet wipe was used to clean the wardroom area.

In general, the wipes worked as planned. Crew comments relative to potential microbiological contamination sources were quite consistant among the three crews and can be summarized as follows:

(1) The area around the food table in the Wardroom, both above the table and grid below, proved to be the most difficult to keep clean. A suggestion for improving this situation was to provide solid surfaces both above and below the immediate food table area. A removable or hinged grid would also permit cleaning of free-floating food debris.

(2) The biocide wipes did a satisfactory job, but were tedious to use. The crews would have preferred a single-step biocide that did not have to be washed off. A handle or holder for the biocide wipes would have kept the iodine off the hands and would have been preferred. The crew suggested an aerosol biocide and the ability to clean up with rags. A request for an aromatic disinfectant, rather than the aseptic odor of the current biocide, was voiced several times.

(3) Soft rags were superior to wipes for cleaning up large areas. The allocation of wipes and tissues was insufficient. Requests were made to have many more utility wipes and general purpose tissues for future missions.

(4) Housekeeping schedules should not be rigid; that is, most areas can be cleaned on an "as required" basis. The crew thought there was too much housekeeping on a scheduled basis, i.e., the fecal seat was cleaned when it was dirty and not once a week, as per schedule. Also, debris screens should be cleaned when they are obviously dirty. Comments of this nature were voiced by all Skylab crews. Housekeeping schedules may be relaxed to some degree in future flights. However, it must be kept in mind that microbial growth is not always visible. The problem of growth of molds in the Liquid Cooled Garments (LCGs) illustrate that once microbial growth gets started, it may be difficult to remove.

(5) The third crew experienced several minor urine spills. The biocide wipes performed satisfactorily in handling these

spills. The rupture of a urine bag in the trash airlock proved to be a major source of odor. Repeated treatment with the biocide failed to remove the odor from this area. It was believed that the biocide did work on the accessible portion of the trash airlock. However, urine may have passed under the lower lip of the TAL and became entrapped, causing a foul aroma. The solution to this problem would appear to be a redesign of the TAL. Similar design problems were noted when cleaning the spills in the urine separator compartments. The crews complained of poor accessibility while cleaning spills. Poor lighting in the WMC made inspection and cleaning of the urine drawers inadequate. Smooth surfaces within the drawer would have made cleaning easier. There was no way to completely clean the urine drawer.

(6) Some areas were omitted from the housekeeping procedures. The food overcan disposal area was not on the housekeeping procedure, but became dirty with all the leftover food, and required frequent cleaning.

(7) A minor discoloration (iodine) to objects being disinfected with the biocide wipes was reported. This was not considered significant and the crew did not report any serious objection. The quantity of biocide wipes (350) provided for the Skylab mission appeared to be adequate. The usage rate may be found in the Stowage section consummable summary tables. No mention was made as to the adequacy or inadequacy of the collapsible rod provided for cleaning of the M171 metabolic analyzer exhalation hose. It was assumed that the cleaning rod performed satisfactorily.

(8) The third crew commented that they found almost everything "polished clean" and were really impressed with the overall cleanliness of the vehicle. They complimented the second crew on the effective and extensive cleaning job. The biocide cleaning seemed to handle all reported contamination.

There were "definite odors" in the Wardroom, which eminated from the food disposal wells. These were cleaned with biocide wipes every 3 days.

G. Trash Disposal

Trash disposal was accommodated in the Skylab vehicle as follows:

a. Non-flammable, noncontaminating trash was collected in plenum bags and stowed in the plenum area or in designated empty lockers.

b. Possible contamination producing (microbiological) and flammable trash was collected in trash bags, disposal bags, and urine disposal bags and deposited in the waste tank.

1. Trash Airlock (TAL)

a. Design Description - A TAL was provided in the crew quarters to eject filled trash bags, disposal bags and urine disposal bags into the waste tank (initially the liquid oxygen tank of the SIVB Stage). Bags are illustrated by Figures 78, 79, and 80.

The TAL was designed to provide a means of placing possible contamination producing trash into a chamber that was isolated from the habitation area. The inner chamber could be continuously vented when not in use to prevent possible bacteria growth. Figure 81 illustrates the basic operating components of the TAL and Figure 82 depicts the operating sequence. For operation, the crew pressurized the TAL to cabin pressure and opened the lid. Bagged trash was placed in the lock and the lid closed and locked. The lock was then vented, the outer door opened and the trash ejected through the lock into the waste tank. After ejection the outer door was placed in the closed position. The TAL had a projected use design goal of 750 cycles. Ground testing of the qualification TAL certified the unit for 3000 cycles.

b. Post Mission Assessment - The TAL was used by all three crews, as designed, to dispose of biologically active trash. The first crew used the TAL 110 times or approximately 15% of the design life; the second crew used it 214 times, or an additional 29% of the design life; and the third crew used the TAL 332 times, adding an additional 44% to the design life. The total TAL usage for all three missions was approximately 656 cycles or 85% of the total design life.

Based on the use of the total bags (trash, disposal, urine disposal, and vacuum cleaner) of 116, 224, and 323 for the first, second, and third missions respectively, the TAL was used an average of less than four times a day, never exceeding the operational design life of five cycles per day.

The TAL, in general, was operated as designed and planned. On occasion, excessive crew effort was required to compress the lid O-Ring and disengage the interlock before the door handle could be moved.

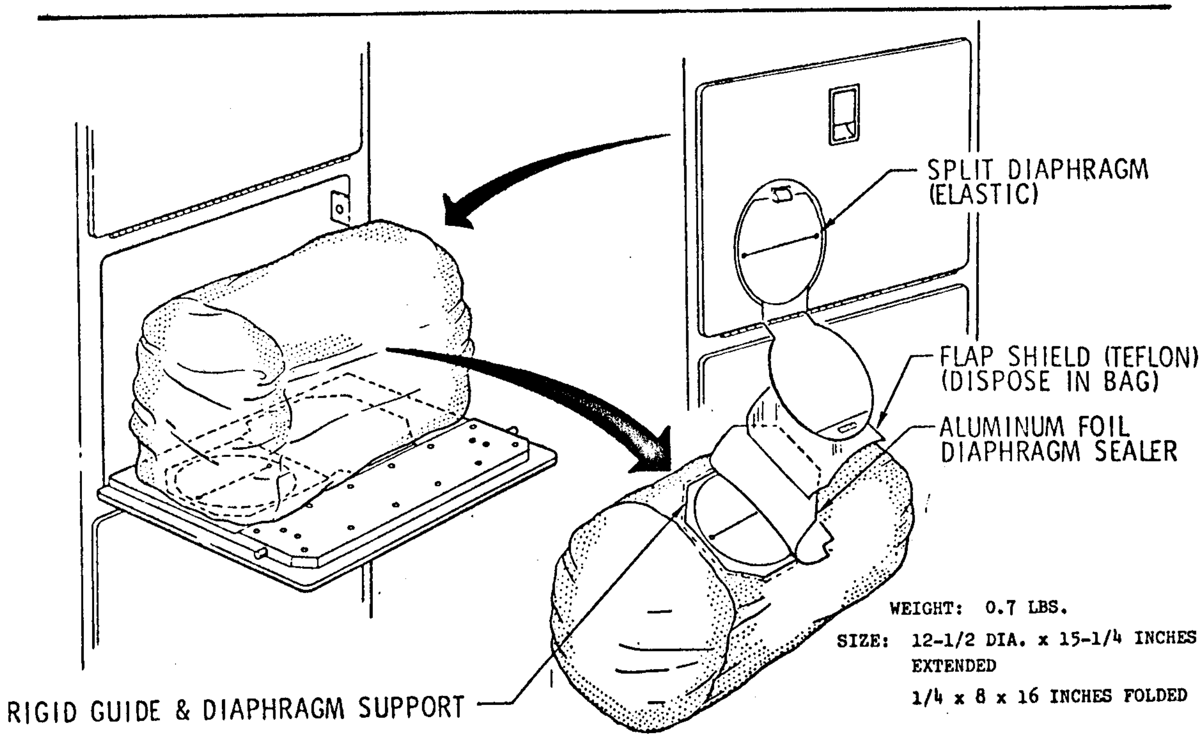


Figure 78. Trash Bag

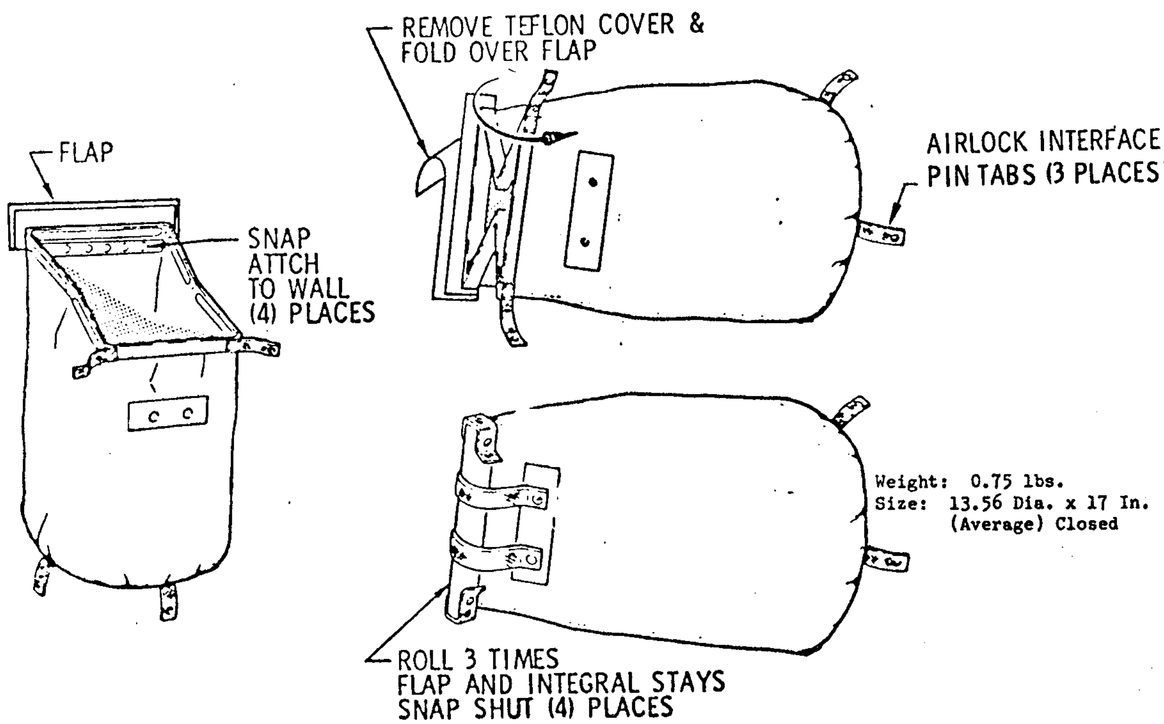


Figure 79. Disposal Bag

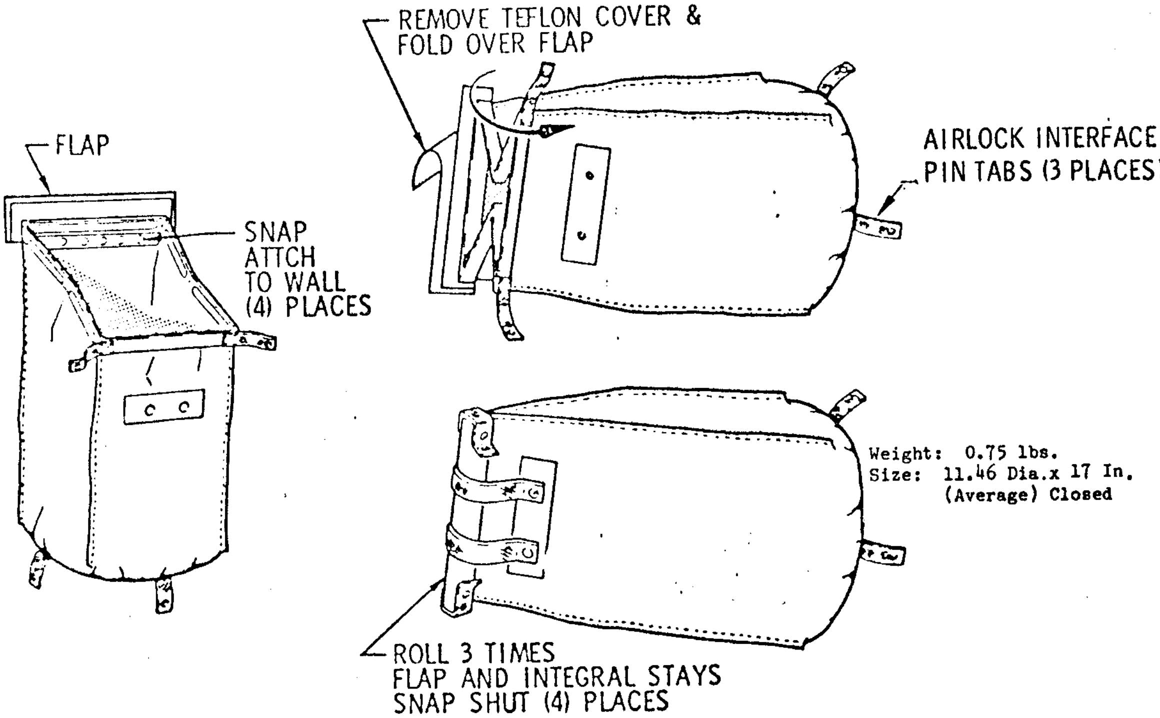


Figure 80. Urine Disposal Bag

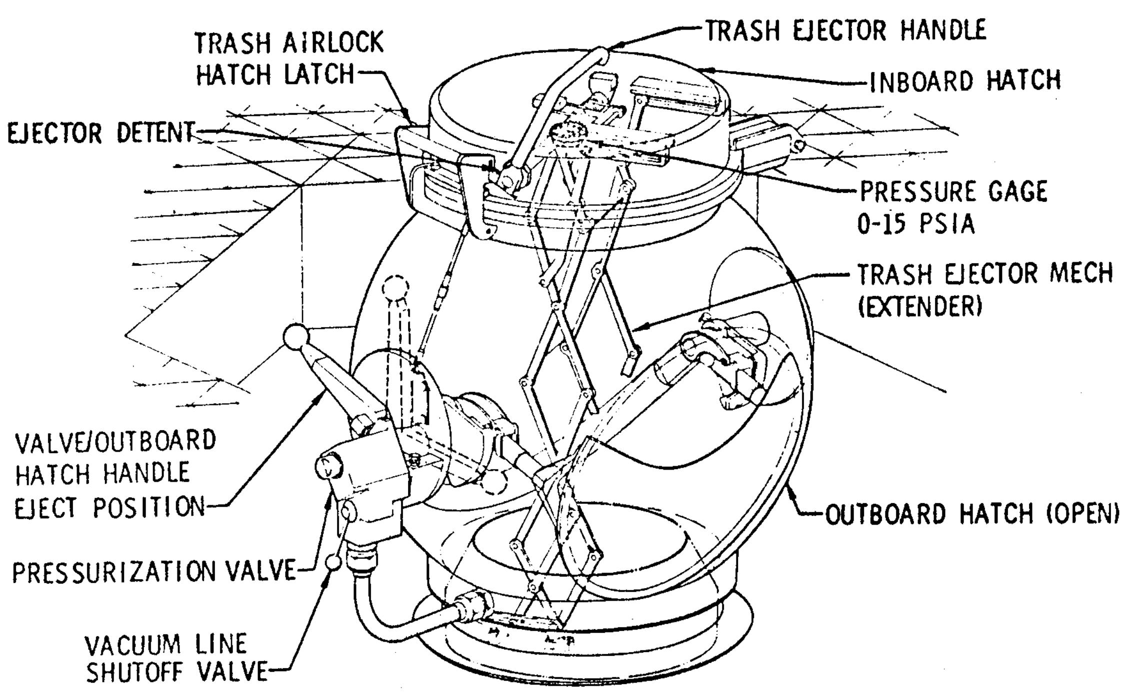


Figure 81. Trash Airlock (TAL)

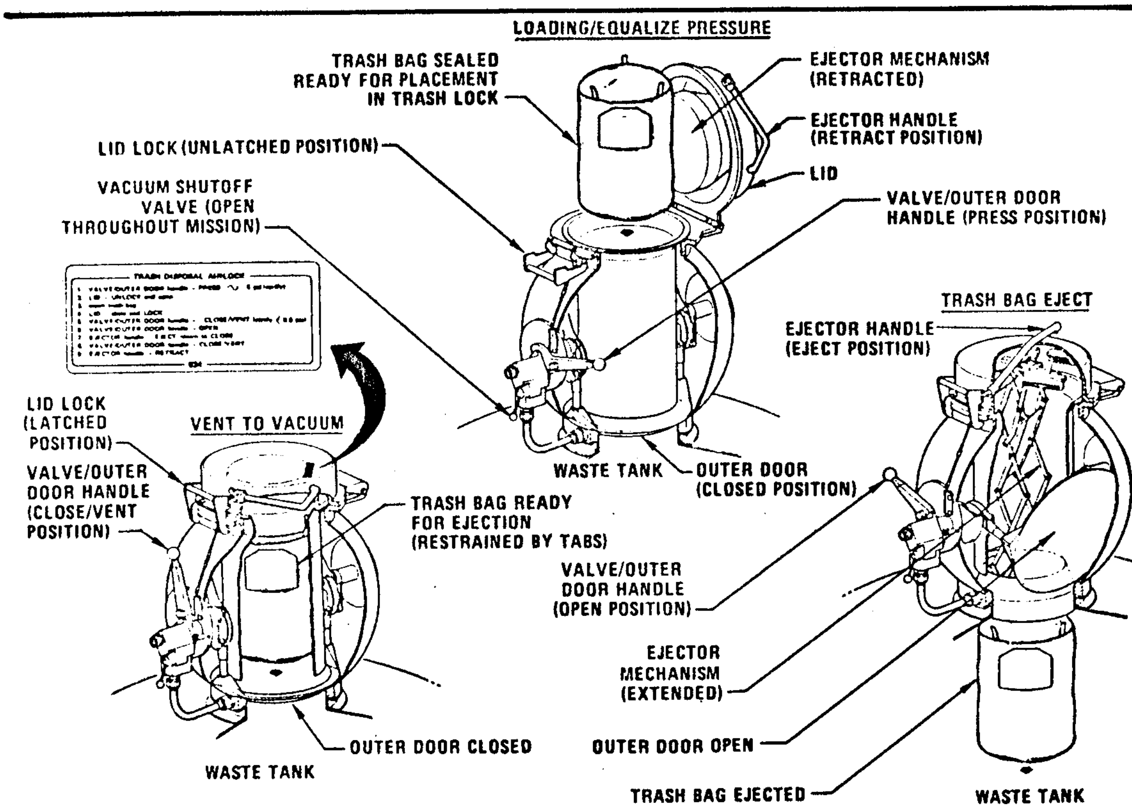


Figure 82. Trash Airlock Operation

During the mission, the following anomalies were associated with the use of the TAL:

a. First Mission

(1) During disposal of a trash bag filled with UCTA's (which apparently had high air content), the force required to eject the bag was extremely high due to inflation of the urine bags in the airlock. The crew commented that closer control of the amount of material placed in each trash bag plus wrapping grey tape around bags to reduce and control air content, would prevent this type of problem from re-occurring.

(2) The TAL outer door jammed when a waste disposal bag, containing a molecular sieve charcoal canister and four extra-vehicular activity gloves, lodged in the ejector cylinder while being dumped. The crew corrected the problem by cycling the ejector mechanism.

(3) As a result of the above anomaly, the trainer at JSC and the mockup at MSFC were used to investigate the remaining items scheduled for TAL disposal. During these investigations, it was found that it was possible to jam a urine separator (with the motor installed) in the TAL. Therefore, it was recommended that the

crew should not attempt to dispose of the urine separators through the TAL, but should stow them in the empty T027 Sample Array stowage container. This container was then evacuated to inhibit possible bacteria growth.

b. Second Mission

(1) Early in the second mission, a slow decrease in habitation area pressure was noted. The magnitude of this leakage was 6 lb/hr. The crew was awakened 6 hours later by the sound of makeup gas being added to the cluster. They were instructed to check the position of the TAL handle and found it midway between the positions "PRESS" and "CLOSE/VENT." This position allowed leakage from the habitation area through the TAL spool valve into the waste tank. The handle had been bumped into this "midway" position several times during the first mission; consequently, the second mission crew had been cautioned about the potential problem. Following this incident, the crew began restraining the TAL handle in the "PRESS" position, between uses, with a general purpose restraint. No further instances of leakage were traced to the TAL.

(2) The interlock linkage between the lid lock and the outer door handle was reported bent during TAL operation. In the opinion of the crew, the damage did not appear to impair the operation of the TAL or compromise the safety of the procedure. This opinion was confirmed by ground tests. It was not clear, even after the Second Mission Crew Technical Debriefing, whether the lid closing and locking force had increased. The force required to compress the O-ring sufficiently to disengage the lid-to-latch interlock, so that the lid lock may be latched, had always been marginal for one man in zero gravity. The recommendation was made for the third crew to deactivate the lid-to-latch interlock by taping. This reduced the seal compression, and therefore the closing force required, prior to latching.

Very little additional risk resulted from this interlock deactivation. An assessment was made, using the mission support TAL, to determine the cause of the interlock rod damage. It is believed that the bent rod was a result of operating the lid latch while the outer door handle was in the wrong position. This situation would have caused the interlock rod to experience high compression loads and possibly cause a slight bow (permanent set). Video tapes confirmed that the bend was minor and no loss of interlock function was involved. Additionally, the interlock rod had no effect on the amount of force required to operate the lid latch.

A review of checkout data indicated that the on-board spare seals did not exhibit associated closing forces significantly different from the onboard installed seal:

S/N (Installed):	21-25 lb
S/N 1 (Spare):	21-25 lb
S/N 6 (Spare):	33-35 lb
S/N 1001D (Spare:	21-25 lb

Although improvement did not seem likely with a seal changeout, the crew was advised that if they wanted to "shop around" through the spare seals and choose the one they considered best, this was acceptable. The crew elected to leave the TAL "as-is".

c. Third Mission

(1) When the crew arrived there were 66 available disposal bags onboard. The other bags available for use as trash bags were the trash bags and the urine disposal bags. The urine disposal bags were in short supply, so the crew used the trash bags almost exclusively and saved the urine disposal bags for the disposal of urine. The crew reported that the urine disposal bags worked well and they initially got three to five full urine bags into the disposal bag and through the TAL. About halfway through the mission, problems developed with urine disposal bags jamming in the TAL. From that time period through the end of the mission, the crew dumped urine through the urine dump system and then rolled and taped the empty urine bags and cycled them through then placed them in the TAL.

(2) The CDR performed as operator of the TAL for the entire mission. He reported that he could operate the TAL by himself at the beginning of the mission, but the system changed or became warped, because later in the mission, he could no longer operate it by himself. It became necessary for one man to stand on it, brace his hands in the hatch on the floor above, and force the lid to the TAL downward, while the CDR threw the latching handle up over the edge of the lip of the cover and locked it down. On the average, TAL dumps were necessary only about once every 3 days. The crew report that, as trash accumulated, they would put it down in the well between the TAL and the floor of the experiment compartment until there were five or six bags. Trash dumps were usually done in the evening before retiring.

(3) There was a major urine spill (leaking urine bag) reported in the TAL about midway through the mission. This was cleaned with biocide wipes. The crew reported that in spite of cleaning, a urine odor in the TAL persisted throughout the remainder of mission.

(4) Another problem reported in the TAL operation was the lack of mobility restraints for the operator. If the well was full of trash bags, there was no room for the operator to anchor himself by putting a leg down into it.

Other than the anomalies discussed above, the operation of the TAL was acceptable and accomplished its intended purpose during the course of the three missions. Continuous care was exercised in avoiding TAL operation with over-filled trash bags, i.e., more than two urine bags per disposal bag or large items with protrusions. These precautions reduced the possibility of jamming. The later mission crews continued to use some form of restraint to maintain the valve/outer door control handle in the "CLOSE/VENT" or "PRESS" position when the TAL was not in use. No items were reported to have been cycled through the TAL without being placed in some type of bag. The crews expressed on several occasions their dependence on the TAL and their concern about the situation that would result from a permanent malfunction. They also, occasionally, criticized the amount of time needed for trash disposal and termed the operation a "nuisance."

There was 2233-cubic feet of accessible volume in the waste tank for the ejected trash items. This volume was consumed by biologically active trash and can be expressed as a packing factor (volume available/volume used). Table 9 summarizes the full extended volume of the various trash collection bags in determining the volumes and packing factors for the waste tank. The trash bags were maintained at approximately their extended volume by the sublimation of the ice resulting from a moisture in their contents.

The first packing factor listed would be achieved at the end of the last mission if all available trash bags were put through the TAL. The second packing factor is for the waste tank at the end of the first mission; and the third packing factor is at the end of the second mission. The fourth packing factor denotes the completion of the third mission.

Additional biological passive trash was collected in the plenum bags (4.5 cubic feet each). A total of 28 plenum bags (Figure 83) were launched; 13 (a total of 58.5 cubic feet) were used during the entire mission; however, only nine of these (40.5 cubic feet) are known to have been stowed in the Plenum Area.

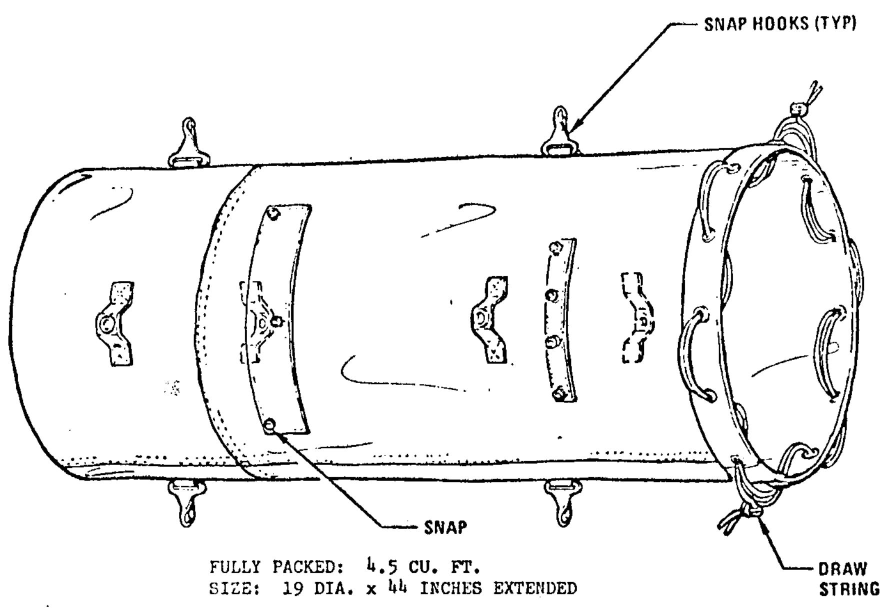


Figure 83. Plenum Bag

ITEM	VOLUME OF ITEM $FT.^3$	TOTAL TRASH BAGS AVAILABLE		TRASH BAGS USED FIRST MISSION		TRASH BAGS USED SECOND MISSION		TRASH BAGS USED THIRD MISSION	
		NUMBER	VOLUME	NUMBER	VOLUME	NUMBER	VOLUME	NUMBER	VOLUME
Trash Bag	1.0840	366	397	22	23.85	62	67.21	162	175.61
Disposal Bag	1.41076	168	237	48	67.73	54	76.18	66	93.11
Urine Disposal Bag	1.02909	204	190	40	40.84	98	100.85	66	87.47
Vacuum Cleaner Bag	0.01236	140	2	5	0.06	10	0.12	10	0.12
Misc.	-	-	-	1	0.59	-	-	-	-
Total Per Mission		878	826	116	123.06	224	244.36	304	356.31
Running Total for Missions		878	826	116	123.06	340	367.42	644	723.73
Packing Factor = Volume Available / Volume Used			2.70		18.15		6.08		3.09

NOTE: The waste tank original (launch) usable volume was 2233 cubic feet.

TABLE 9. WASTE TANK VOLUME USED

H. Debris Control

1. Design Description - Airflow, used as a gravity substitute, was the prime active method of debris control in the Skylab cluster. The airflow screen collectors were augmented by various types of passive closeouts which were designed to keep debris out of inaccessible areas. Inaccessible areas were defined as any place where debris was not visible or within reaching distance of a crewman. Special tools were provided to assist in retrieving debris that eluded the closeouts. The prime example of airflow debris collection was the OWS. Air was circulated from a plenum chamber, under the crew quarters area, through diffusers, to a mixing chamber located in the dome area and was returned to the plenum area by fans clustered in three return air ducts. This configuration provided open area air velocity ranging from 0.10 to 0.23 meters/sec (20 to 45 feet per minute) and a screen velocity of 1.48 meters/sec (283 ft./min.). The open grid construction of the OWS floor allowed adequate air and debris passage. This velocity was sufficient to move all debris and loose parts to the four 60-mesh screens in the dome area mixing chamber. Circulated airflow, similar to the OWS, was used in the other modules for debris collection. Passive debris control was accomplished by use of various types of closeouts. The flexible mesh, secured by velcro, in the MDA was one type. See Figures 84 and 85 for other examples.

The vacuum cleaner was designed to pick up the accumulated debris from the screens and was scheduled periodically for that use. The vacuum cleaner was also used to collect spilled liquids even though the liquid systems (water, urine collection, personal hygiene and food) were designed to minimize such occurrences.

2. Post Mission Assessment - Loose debris migrated to the areas where the airflow was the greatest, i.e., MDA ventilation fans screen, OWS heat exchanger fans screen and OWS mixing chamber. The migration of debris by the air circulation system made debris control with the vacuum cleaner very convenient. The screen's effectiveness in debris control was unexpected, but this principle should be capitalized in future spacecraft designs. Passive debris closeouts are still required to keep large objects from lodging behind equipment, lockers, or panels and are a necessary requirement for future design.

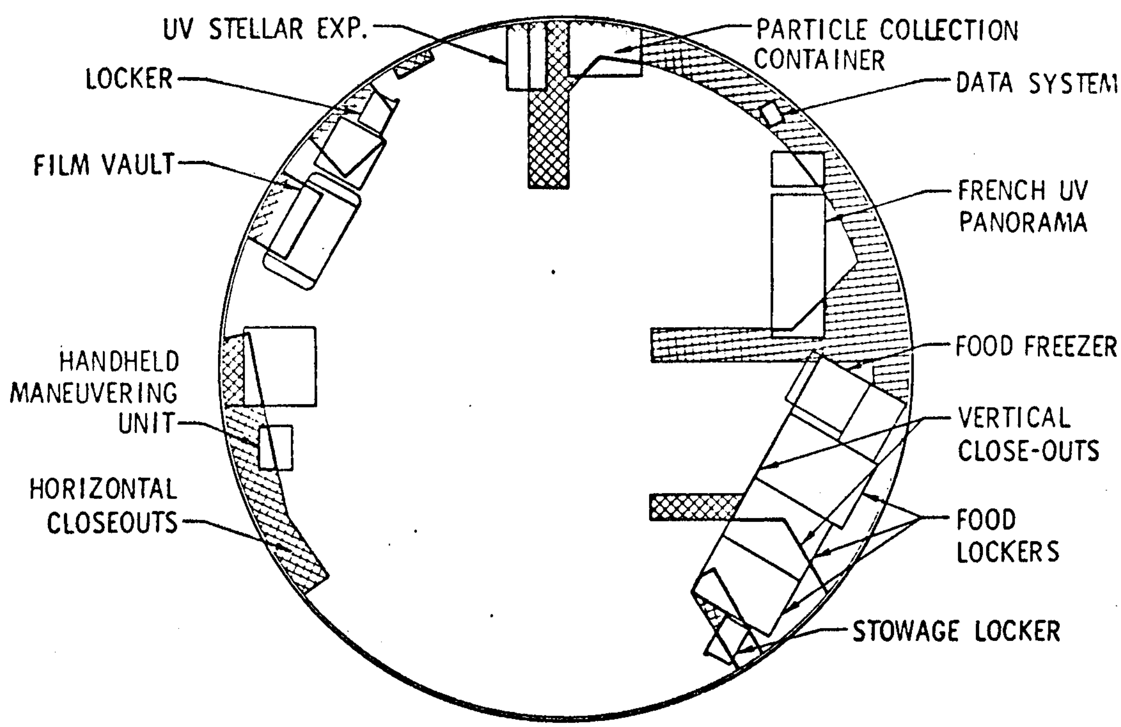


Figure 84. Closeouts - OWS Aft Ceiling

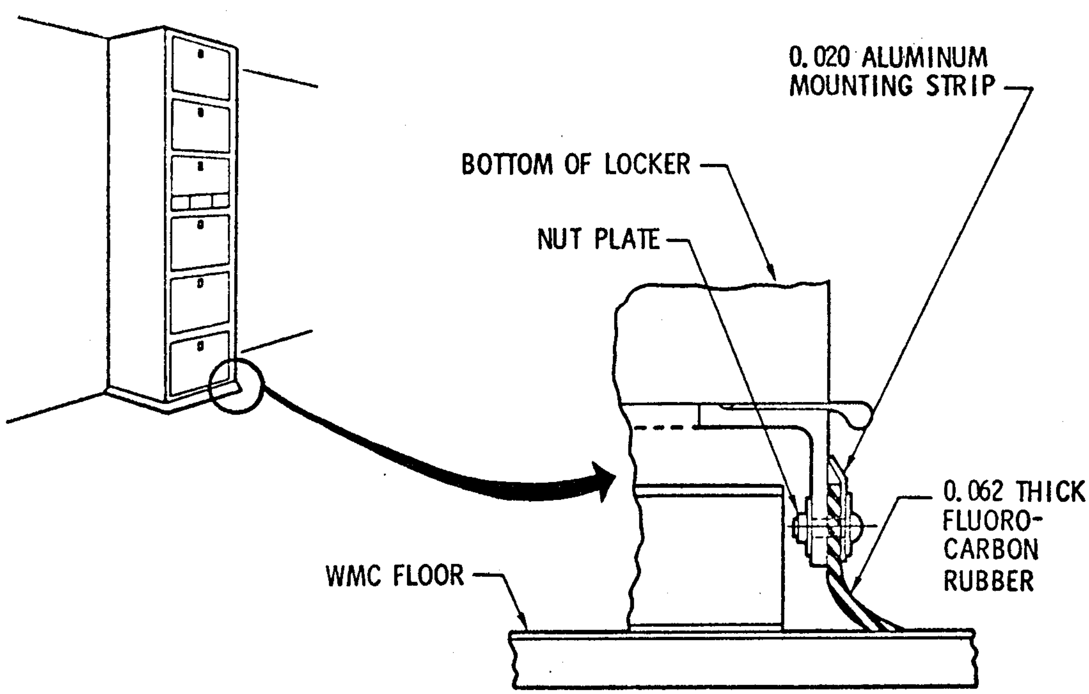


Figure 85. Closeouts - WMC Floor

I. Hatches

1. OWS Access Hatch

a. Design Description - Initial entry into the OWS from the AM was made through a 40" diameter OWS hatch located at the apex of the dome, as illustrated in Figure 86. This hatch operated on two in-line hinges, opened into the OWS area, and automatically latched in place in a stowed position.

The handle, located in the center or hub of the hatch, operated at loads of approximately 25-lbs. This handle operated a cam/roller action to the equalization position to separate the pivot fittings from base fittings, opening nine .025-inch diameter holes for pressure equalization. This handle locked automatically in either the open or closed position. The hatch assembly consisted of two major structural parts which were the SIVB access-cover adapter and the sealing hatch. This hatch contained redundant check valves and operating handles which could be used from either side.

b. Post Mission Assessment - The OWS hatch was used as the aft airlock hatch for all EVAs. The second crew experienced some difficulty securing the OWS hatch prior to EVA. The difficulty was caused by performing hatch closing procedure steps out of sequence. This caused no significant time delay in either the EVA prep or EVA. Performance of the OWS hatch hardware was nominal for all Skylab missions.

2. MDA Hatches

a. Design Description - There were two MDA 30-inch diameter pressure hatches, one located in each of the MDA docking port tunnels. These hatches are illustrated in Figure 87. The hinges were designed so that the hatch opened into the MDA to engage a detent latch for stowage in the open position. The locking mechanism was a spider arrangement of six latch assemblies operated by a center mounted hatch handle. A delta pressure gage was provided in the hatch for reading pressure from either side. Equalization across the hatch (CSM tunnel to the MDA) was accomplished by using the hatch mounted equalization valve that was capable of being manually operated from either side of the hatch. The valve had a screw-on cap on the CM side over the valve orifice that had to be removed for valve operation.

A hatch locking device was provided on the CSM side of the hatch. This locking latch restrained the hatch handle in the closed position until released by a crewman. A contingency method for release of the hatch locking device from the MDA side consisted of a T-handle bolt that was screwed through the door. As the bolt was unscrewed, it allowed the launch lock to be released, which permitted activation of the interior hatch handle, releasing the door.

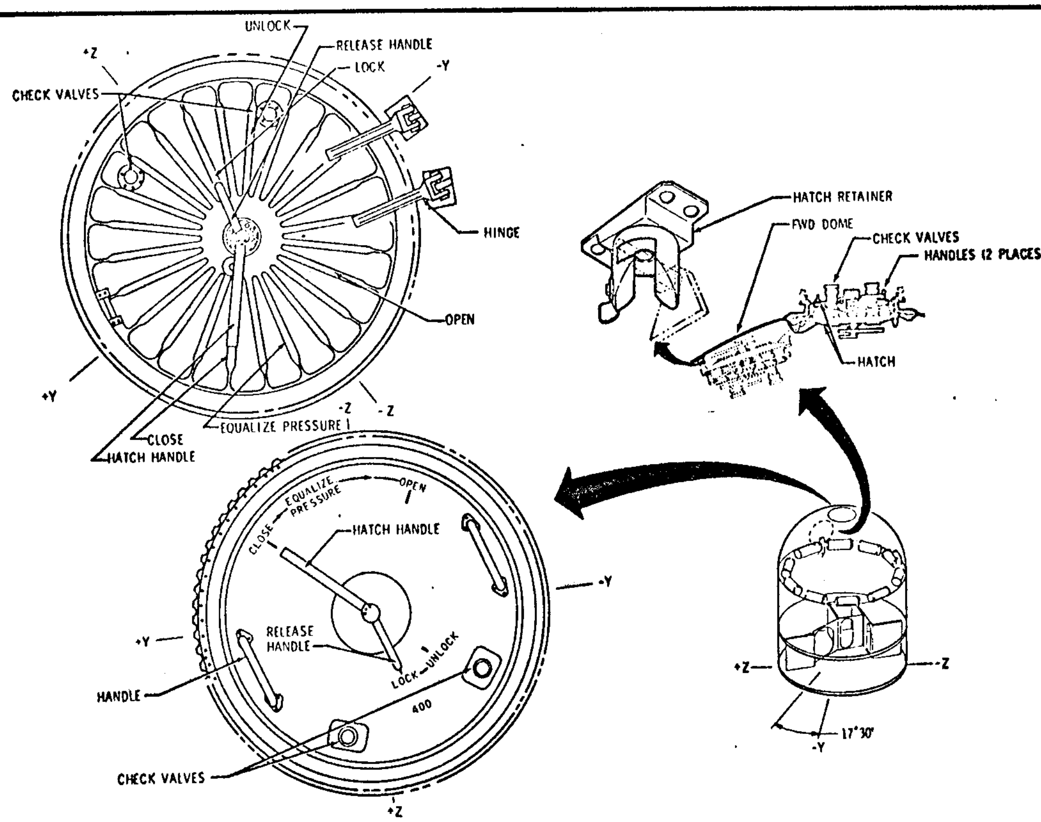


Figure 86. OWS Hatch

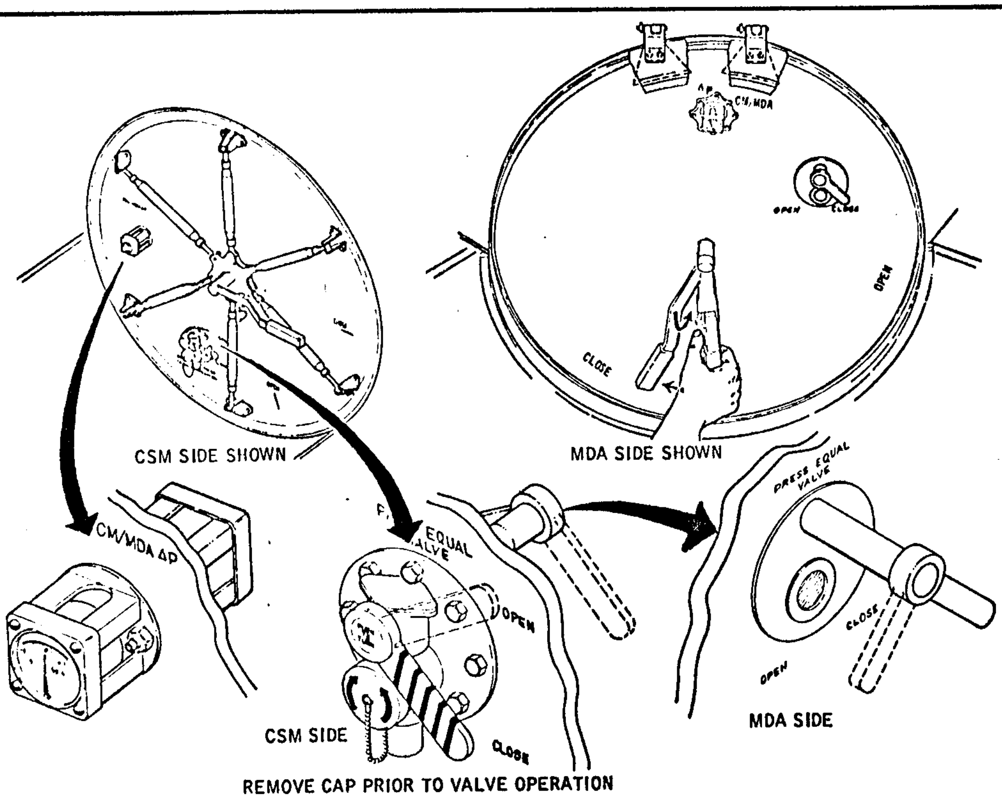


Figure 87. MDA Hatch

An additional contingency mode was provided on the axial hatch by a tool box (M104) that contained tools for forcing or dismantling the hatch in case of opening mechanism failure.

b. Post Mission Assessment - For Skylab, the axial hatch and its associated entry hardware performed as intended and all crew operations were as specified in the checklist. There were no adverse crew comments on MDA hatch operations. However, as a note of interest, the pressure equalization valve on the MDA hatches were designed with handles on each side of the hatch. The pressure could not be equalized until the screw-on cap on the external side of the equalization valve was removed. This design presented no problems for the Skylab mission, but a recent analyses of docking an unmanned module to either MDA docking port brought to light that the use of the pressure equalization valve, to equalize pressure between the two modules, was inhibited because the screw-on cap would prevent pressure equalization. In that case, pressure equalization would have to be accomplished by removing a bolt that penetrated the pressure hatch. The requirement to equalize pressure from the MDA side would have been a contingency mode of operation and somewhat unlikely. However, the screw on cap as a redundancy provision on hatch equalization valves should be reconsidered when designing hatches for future spacecraft. The redundant system should be in the valve itself rather than an add-on device, that renders the valve inoperable when it is installed.

3. <u>AM Hatches</u>

a. Design Description

(1) Lock Compartment Hatches - There were two AM lock compartment hatches, each 49.5-inches in diameter with stiffeners attached radially, as illustrated by Figure 88. An 8.5-inch diameter dual pane window in each hatch enabled viewing of the lock from both ends (aft and forward compartments). A pressure equalization valve was installed in each hatch which could be operated from either side of both hatches and was used during pressurization and depressurization of the lock compartment. Only the forward AM hatch was closed during EVA. The OWS hatch was closed in lieu of the aft AM hatch to give additional space in the AM.

Each hatch was hinged to fold along the tunnel wall and was restrained by a velcro strap. Each latching system used a cable that ran along the periphey of each bulkhead and drove nine hatch latch assemblies. An over-center feel device and a positive lock were included in the handle mechanism. The aft hatch could be detached from its hinge yoke by removing two quick release pins and could be re-installed at the flexible tunnel extension to isolate the AM from the OWS for "contingency mode" operations.

(2) EVA Hatch - The EVA hatch, Figure 89, was a converted Gemini design which had a single motion latching mechanism rather than the original rachet design. Two of the features which

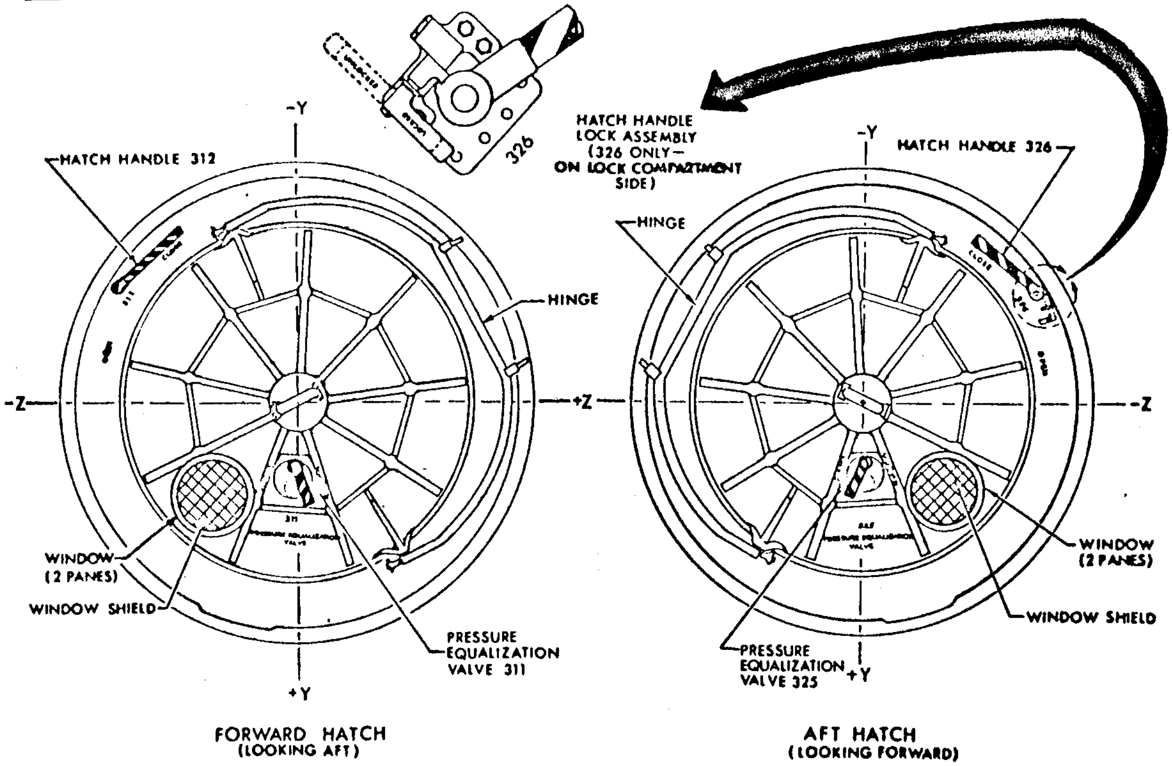


Figure 88. Lock Compartment Hatch

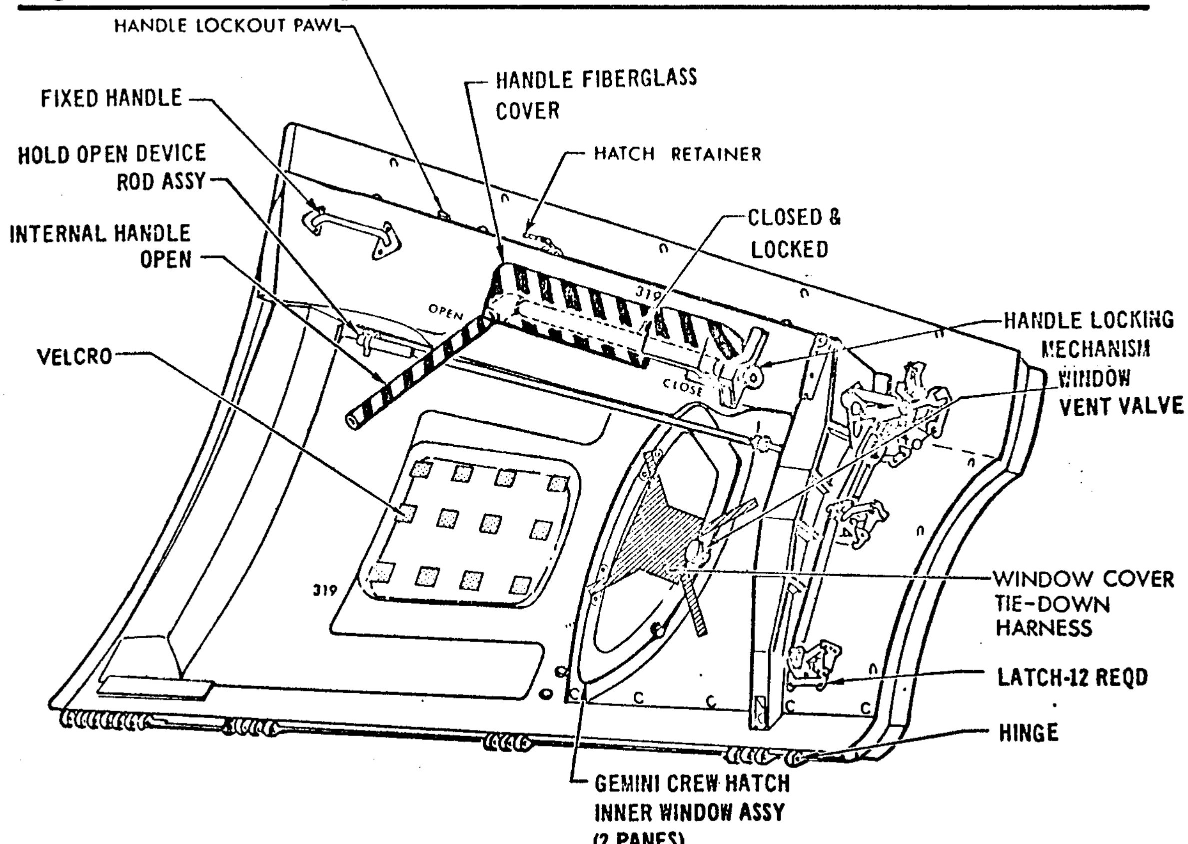


Figure 89. EVA Hatch

this hatch provided were: (a) the handle lockout, and (b) the hatch retainer. The handle lockout prevented the latching dogs from being closed when the hatch is in an open position, thereby precluding sill damage which might occur due to closing the hatch in that configuration. The hatch retainer caught the hatch in a partially open position as it was being opened, thus preventing differential pressure loads from popping the hatch open if the lock compartment was not completely vented.

A double pane window in the hatch enabled viewing of the aft portion of the EVA bay. The space between the panes could be vented with the window vent control.

b. Post Mission Assessment - The lock and aft compartment entry was normal and no problems were experienced with forward and aft hatches. Egress/ingress operation during the EVA's thru the EVA hatch was reported satisfactory.

During the SL-2 Crew Debriefing, a suggestion was made to add a second removable screen to the hatch equalization valve, to compensate for icing during depressurization. The crew stated that both internal and EVA hatch sizes were satisfactory and they had no problems in handling the hatches during opening and closing.

J. Crew Stations

The term crew station is generally associated with areas where a crewman was scheduled to spend considerable time in the performance of assigned tasks. This section will discuss work space, layout, reach envelopes, habitability, and compatibility between crew stations. Crew provisions within each crew station, such as lighting, restraints, communications, etc., are discussed in detail in other sections of this report.

1. MDA Crew Station

a. Design Description - Crew stations in the MDA were designed to provide for: (1) passage between the Command Service Module (CSM) and the AM; (2) stowage of hardware and experiment support equipment; (3) CSM probe and drogue stowage; and (4) performance of experiments. The primary MDA crew stations were the Apollo Telescope Mount Control and Display Console (ATM C&D), Earth Resources Experiment Package (EREP) C&D panel, EREP Viewfinder Tracking System (VTS), and the M512/479 Material Processing Facility. Figures 90 and 91 illustrate these crew stations.

With the expansion of the MDA-installed experiments, it became obvious that task and volume sharing would be required as part of crew station definition. Crew convenience and optimum work station classification of equipment were compromised by continual additions of stowage items to the MDA, even after stowage closeout of the OWS at Kennedy Space Center (KSC). This form of configuration development resulted in a partially unorganized arrangement of the MDA hardware and equipment, which was installed circumferentially around the module.

(1) ATM C&D Crew Station - The ATM C&D crew station consisted of the ATM C&D panel, foot restraint platform, chair, and Speaker Intercom Assembly (SIA). The ATM C&D console was originally designed for seated operation and installation in the Lunar Module for AAP. Although changes were made in the panel for Skylab, its basic size and shape remained unchanged. Early in the program, the crewmen elected to operate the ATM C&D panel from a standing position on the premise that: (a) two crewmen may be required at the ATM C&D, and (b) the STS control and display panel would require monitoring while the crewmen were physically oriented at the ATM C&D panel. At the time Skylab was being readied at KSC, the Skylab Restraint Assembly (Chair) was installed, at the request of the crew, to provide additional restraint while operating the ATM C&D panel.

(2) EREP C&D Crew Station - The EREP C&D crew station consisted of the C&D panel, the S190 camera array, the S190 stowage container, a SIA, and the M512/479/EREP foot restraint. The major

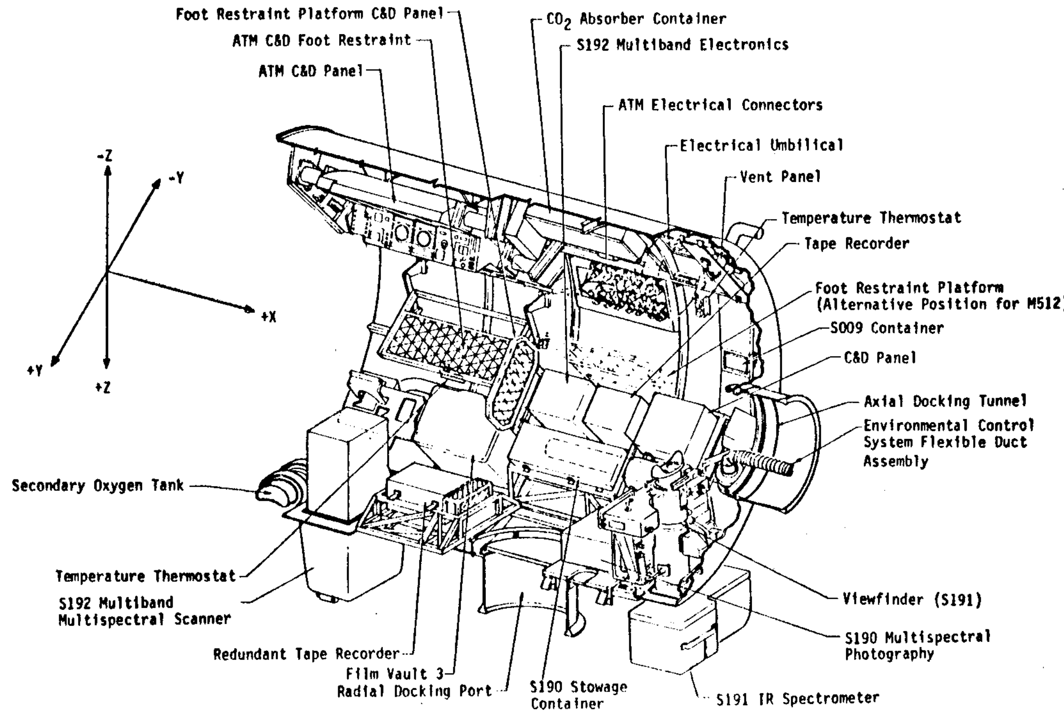


Figure 90. MDA Crew Stations

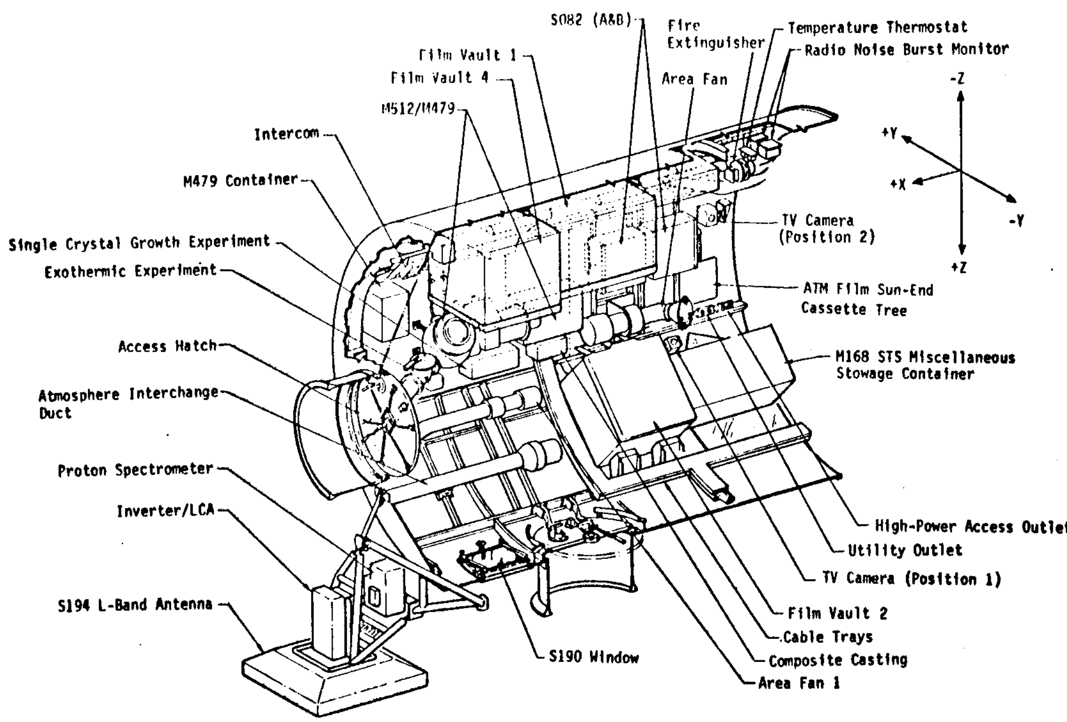


Figure 91. MDA Crew Stations

crew interface, with MDA hardware, was the foot restraint. The original foot restraint concept for the EREP C&D console was a grid platform, serving both the EREP C&D panel and the VTS. Functions on the C&D panel were not fully developed and quite limited; therefore, it was decided to remove the EREP C&D panel foot restraint, but leave the VTS foot restraint. This concept was later reversed thereby removing it from the VTS and placing the foot restraint back at the EREP C&D panel. The rationale was that handholds mounted on the VTS panel would adequately position the crewman and give him the freedom to quickly move away from the station and back again. The crew believed this would be easier to do if they did not have to disengage their feet from the foot restraint grid. The EREP C&D foot restraint was combined with the M512/479 crew station foot restraint by providing the capability to mount the grid in either position.

(3) EREP VTS Crew Station - The VTS crew station consisted of the Viewfinder Tracking System, its associated C&D panel and a clipboard restrained on the S191 closeout cable cover. A crewman at this station utilized the SIA located adjacent to the M512/479 Material Processing Facility. No foot restraint was provided at the VTS crew station. Handholds on the VTS panel were provided for crew positioning and operation at this station. The crewman also interfaced with the EREP SIA and the EREP C&D panel. Neither of these units were positioned to provide this capability from a foot restraint.

(4) M512/479 Material Processing Facility Crew Station- The M512/479 crew stations consisted of the M512/479 experiment facility, M512/479/EREP foot restraint, SIA, and controls for furnace venting. The M512/479 crew station foot restraint utilized the same restraint platform provided at the EREP C&D console, but repositioned for the M512/479 experiment. The placement of the restraint the MDA provided the crewman with access to all pallet-mounted M512/479 equipment, the SIA and the two 4-inch vent valve handles controlling the experiment furnace venting. Wall mounting of M512/479 and the orientation of the mounting pallet made it possible for the crewmen to operate the experiment from a near standing position.

b. Post Mission Assessment - The MDA and the primary work stations were used as intended by all crews, with the performance of experiments being the major activity. Additionally, three other activities occurred in the MDA which were not planned: at least two PGA's were stowed in the MDA at various times between EVA's after suit drying was completed; at least one crewman during each mission slept in the MDA at one time or another due to the elevated temperature of the sleep compartment, and; the Rate Gyro Six-Pack was installed during the second mission at location M170.

The crews performance proved that man can function effectively, in a cylindrical spacecraft module, in a zero-g environment and hardware orientation. However, there existed a longer period of adaptation to working the cylindrical layout of the MDA than in the floor to ceiling orientation of the OWS. All Skylab crews expressed a feeling of disorientation when arriving in the MDA, until they found a familiar piece of experiment hardward to key on. Most crewmen found that they used the ATM C&D panel or the EREP experiment hardware to orient themselves in the MDA. It also took the crewmen longer to locate a particular stowage container in the MDA than in the OWS, where the stowage containers were installed in a floor to ceiling arrangement. This suggested that, in future spacecraft, it would be more efficient to lay out experiment and stowage hardware in a one-g orientation, even in small cylindrical vehicles like the MDA'. At the very least, the early design concept for small cylindrical vehicles should provide for functional grouping of hardware. Stowage containers should be grouped in a common direction and area like the OWS experiment compartment stowage containers, or circumferentially in a particular location like the OWS ring lockers.

Each crew considered the volume of the MDA sufficient for working and hanging onto things, but expressed problems with traffic, when two crewmen were working in the MDA and a third crewman tried to get past. The MDA volume was suitable for its designated functions as a multiple docking adapter for a larger space station and experiments/stowage module. The volume ideally should be increased for a similar type module used as a single space station experiments module for a crew of three.

Comments relative to the ATM C&D crew station were generally favorable except for the incompatibility of a crewman working at the ATM C&D panel while another crewman was working at the STS control and display panels. The layout of the ATM controls and displays is discussed in the Controls and Displays section. Foot restraint platform and chair assessment data is contained in the Mobility/ Stability Aids section. Generally, however, reach envelopes were considered to be less restricted using the foot restraint platform. The ATM C&D integral panel lighting emitted a pleasant effect when the MDA floodlights were off; however, this was not necessary. When the floodlights were turned on, the ATM C&D edge lighting effect disappeared and when the ATM C&D lights were used along, the checklists could not be read. There was a general degradation in the brightness of the ATM C&D counter lights with usage.

Comments concerning the EREP C&D crew station were favorable. The crews saved setup time at the EREP C&D by leaving the communication cables and communication carrier (soft caps) connected to the SIA'.

A significant deficiency of the EREP VTS crew station was the lack of a crewmen foot restraint. It is necessary to have a foot restraint at all crew stations requiring the crewman to operate controls and manipulate charts/checklists for long durations. The only annoying problem associated with this crew station was with the clipboard mounted on the EREP experiment S191 closeout cable cover. The clipboard, attached to the cable cover by two snaps, was used to hold checklists, maps, photographs or target sites, etc. and unsnapped several times when used by the crewman.

The crew operated at the M512/479 Material Processing Facility crew station as planned and reported no major problems. Temporary stowage of a PGA near the crewman's head caused minor infringement of work envelope.

2. AM Crew Station

a. Design Description - The crew stations in the AM were designed to provide: (1) passage between the MDA and OWS; (2) stowage of system and experiment support hardware; (3) primary system controls; (4) an EVA airlock and (5) EVA support hardware. The primary AM crew stations were the STS, Lock Compartment, Aft Compartment and EVA FAS Workstation which is discussed in the EVA section. The internal arrangement of the AM is illustrated in Figures 92 and 93.

The equipment in the AM was arranged circumferentially around the interior with all control panels and individual controls positioned in similar orientations. The crewman's design orientation throughout the AM was for the body to be parallel to the vehicle's X-axis with the head aft, the natural position for a crewman as he translated from the CSM into the AM during activation. AM equipment modules were designed to offer minimum protuberances into the vehicle's interior and to provide large radii corners wherever projections could not be entirely avoided.

(1) STS Crew Station - The STS Crew Station consisted of the STS C&D panels, system hardware stowage containers, four viewing windows, handrails and handrail lights. Because they had the same diametrical dimensions and were joined directly together, the STS and MDA were essentially an integral module and often considered one and the same. This close relationship can be noted from crew comments which often referred to them interchangeably. To provide a functionally operable crew station in the STS, agreements had to be reached across this physical interface. The teleprinter access door and cabin heat exchanger fire sensors cover which open into the MDA, and adequate space in the MDA for changing the H_2O separator plates on the condensing heat exchangers are examples of the type of coordination which was required. In other areas, specifically around the ATM console as was expected, interferences existed between these compartments. The STS was divided into four equipment groups and arranged to allow space between the containers for access to the STS windows and equipment inflight maintenance (IFM). An STS window which provided external viewing was located between each of these equipment quadrants. The space was sized to be large enough to provide

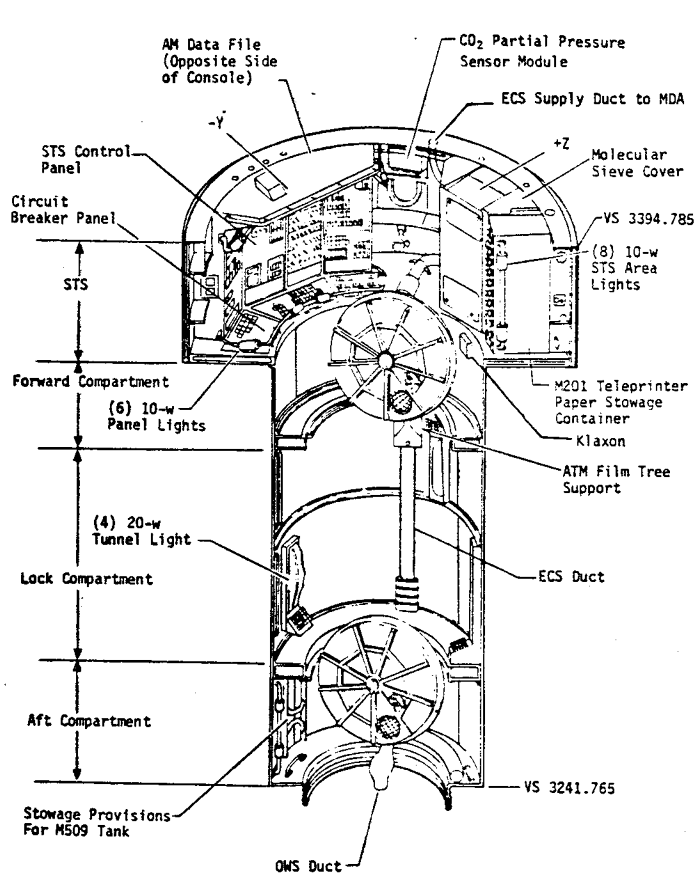


Figure 92. AM Internal Arrangement

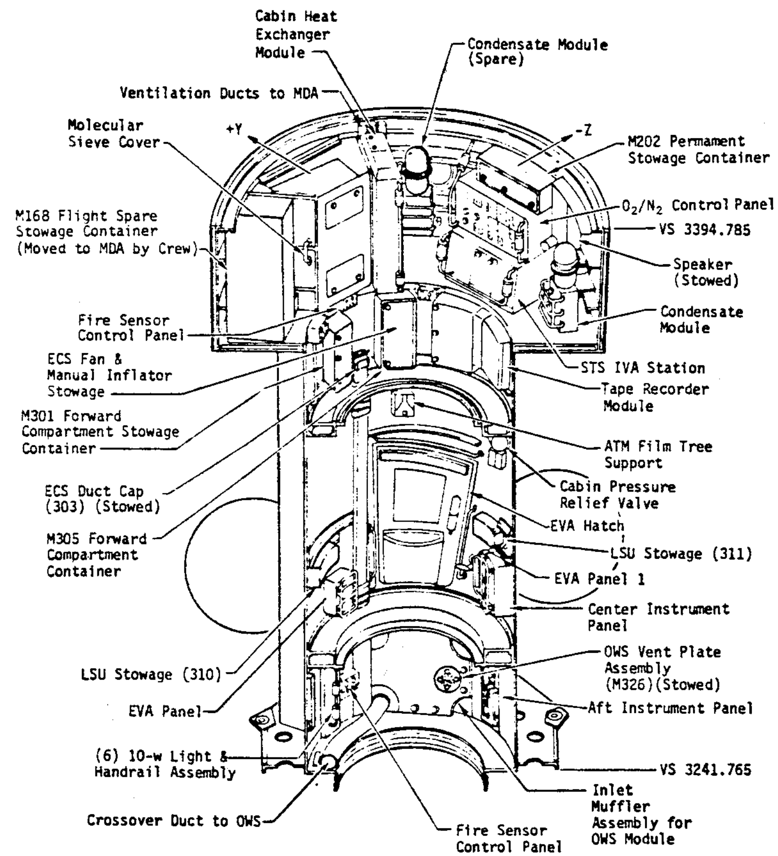


Figure 93. AM Internal Arrangement

adequate access for a crewman with ancillary equipment such as cameras, sextants or other optical viewing devices, yet small enough that sufficient body restraint could be obtained by bracing between the adjacent equipment surfaces, thus allowing two-handed tasks to be performed. The groupings were also planned such that each module had at least one side exposed to an access space for entrance into the interior of a module through a removable cover. Additional access was provided through hinged doors on the front of the equipment, such as the doors on the mol sieve covers through which the replacement of solids traps and/or mol sieve fans was accomplished. Handrails and handrail lights were installed at strategic locations as a protection and aid for the crew during translations. A handrail type lamp which provided a 360^{o}, non-glare light source was used. A sufficient but minimal number of units were utilized to provide an adequate illumination level for the required inflight operations to be performed. Placement and arrangement of the lamps provided an even and consistent lighting level throughout the compartment, including the recessed areas between the equipment quadrants. As a safety precaution, it was not considered desirable to bring the unprotected, raw power lines into the vehicles interior where they would be exposed to an oxygen-rich atmosphere. To preclude this, the circuit breaker panels were designed to penetrate the AM pressure wall. Using this method, the cables from the primary power source were left on the outside of the spacecraft and the lines on the inside were protected by circuit breakers. The Forward Compartment served as an extension of the STS and contained equipment ancillary to that crew station purposes. The operational units in the Forward Compartment were the AM tape recorder module and the klaxon for the Caution and Warning System; the other two units were stowage containers with IFM spares. No control panels or lights were present in this compartment. The klaxon was located behind the opened AM forward internal hatch. This location was selected so that the hatch would act as an audio baffle for this siren and provide aural protection for a crewman should he be nearby when it was energized.

(2) Lock Compartment Crew Station - The Lock Compartment Crew Station consisted of the EVA hatch, two internal hatches, two redundant EVA control panels, two film tree receptacles, and lock compartment control panel and valves. It was originally intended to use the Lock Compartment solely for EVA support, but later decided to use the Aft Compartment as an extension. The equipment required for EVA's was located in the Lock Compartment near the EVA Hatch for convenience. The control panels had the same orientation as those in the STS. AM lighting is discussed in detail in the Illumination section.

Spherical stowage containers for the Life Support Umbilical (LSUs) were on the exterior of the vehicle and presented only a round opening to the interior. The LSU sphere covers were used for launch restraint of the LSU connectors and were temporarily stored in the aft compartment for EVA. No internal volume was consumed for this function and no physical obstructions were created by it.

(3) Aft Compartment Work Station - Besides acting as an extension for the Lock Compartment, the Aft Compartment contained the facility for recharing the M509 Experiment propulsion supply bottle and access to the OWS Heat Exchanger module. To avoid a physical obstruction in this area, the M509 recharge assembly, which held the bottle during recharge, was designed to be folded-up when not in use.

b. Post Mission Assessment - The AM and the primary work stations were used as intended by all crews. Additionally, two other activities occurred in the AM which were not planned: (1) servicing the coolant loop in the STS and; (2) stowage of additional support equipment in the Lock Compartment for several contingency EVA activities.

The Skylab crews indicated that the arrangement of AM crew station equipment was very satisfactory. The radial arrangement, orientation, and grouping of the control panels in the STS was convenient and worked well. Information concerning the inadvertent tripping of circuit breaker switches by the crewmen, while translating through the STS, is contained in the Controls and Displays section.

The STS windows proved to be of greater value than had been expected. They worked well for the planned events such EVA coordination, attitude correlation, external structure inspection, space viewing and Earth viewing. In addition, they were invaluable for the unscheduled events such as deployment of the sun shades, SAS deployment and later to periodically monitor the condition and orientation of the thermal shields. The inside surface of the STS windows on the shade side sometimes fogged up with the cover open. The fog dispersed shortly after the cover was closed. The STS window covers became difficult to operate. One cover would not close completely; nevertheless, the window was still being totally covered.

The access provided inside the mol sieve covers for servicing the H_2O separator plates was more than adequate. This was an area which had been difficult to simulate in one-g but worked satisfactorily during flight.

The crewman operating the ATM console interferred with other crewmen translating through the vehicle or working in the STS compartment. Since the ATM C&D position was occupied for extensive periods of time, this interference was an annoyance.

The design and arrangement of the handrails in the AM were good, although there were insufficient crewman restraints available to perform the unscheduled servicing of the coolant loop.

The volume of the lock compartment for EVA preparations and operations was acceptable. The compartment was large enough to accommodate the equipment and crew, yet small enough to provide adequate body restraint. The functional usage arrangement of the equipment in the lock compartment was well designed. The ease with which the LSUs were removed from and returned to stowage was particularly noticed.

The operations of the hatch mechanisms and repressurization valves were very smooth. During crew translations, the internal hatch sills were "knee bumpers" if the trajectory was not perfect. The sill visible from the airlock, the opening from the STS, and the forward side of the forward hatch had not been protected.

3. OWS Crew Station

a. Design Description - The crew stations in the OWS were designed to provide: (1) primary crew quarters and habitation equipment; (2) stowage of hardware and experiment support equipment; (3) stowage of crew equipment and consumables; (4) OWS systems control and displays; and (5) volume for the performance of experiments. The OWS crew stations were the Forward Compartment, Wardroom, Waste Management Compartment, Sleep Compartment, Experiment Compartment, and Plenum Area and are illustrated in Figure 94. The equipment in the OWS was installed on compartment walls, floors, and ceilings and was primarily arranged in a vertical or circumferential one-g orientation. This arrangement was possible because of the open grid floors dividing the lower crew quarters from the plenum area and the forward compartment.

(1) Forward Compartment Crew Station - The forward compartment was the largest of all crew occupied areas in the entire cluster. Equipment located in the forward compartment were the WMC ventilation fan, food freezers, refrigeration pump unit, ventilation ducts, fans and mixing chamber, biocide monitoring equipment, scientific airlocks, miscellaneous lockers and stowage provisions, film vault and photographic equipment, ring containers (for large volume stowage items) and the large food containers. Also stowed and operated in the forward compartment were the hardware items associated with the various scientific, technical and medical experiments.

(2) Wardroom Crew Station - The Wardroom was a "pie-shaped" compartment on the crew quarters level. Facilities in this crew station included a galley, food freezer and chiller, food table, viewing window, experiment equipment, crew entertainment center, plus stowage compartments for flight data, clothing and other supplies. Figure 95 illustrates the general arrangement and layout of the Wardroom.

(3) Waste Management Crew Station - The WMC was a compact rectangular room located at the crew quarters level. This

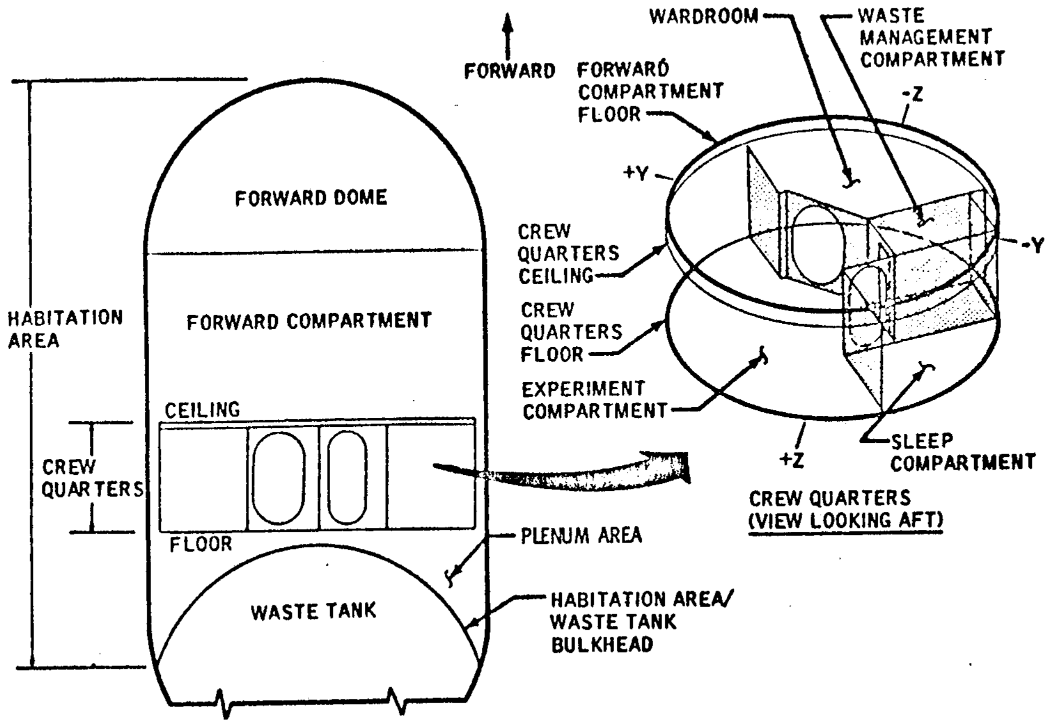


Figure 94. OWS Basic Layout and Arrangement

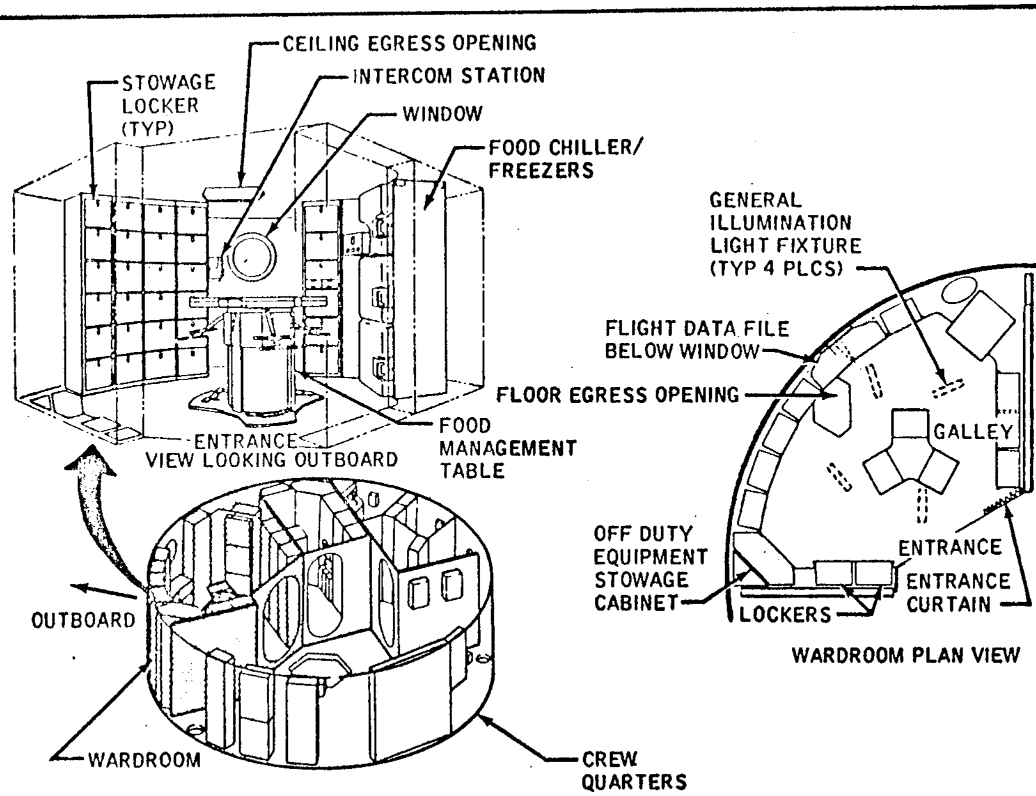


Figure 95. Wardroom Layout and Arrangement

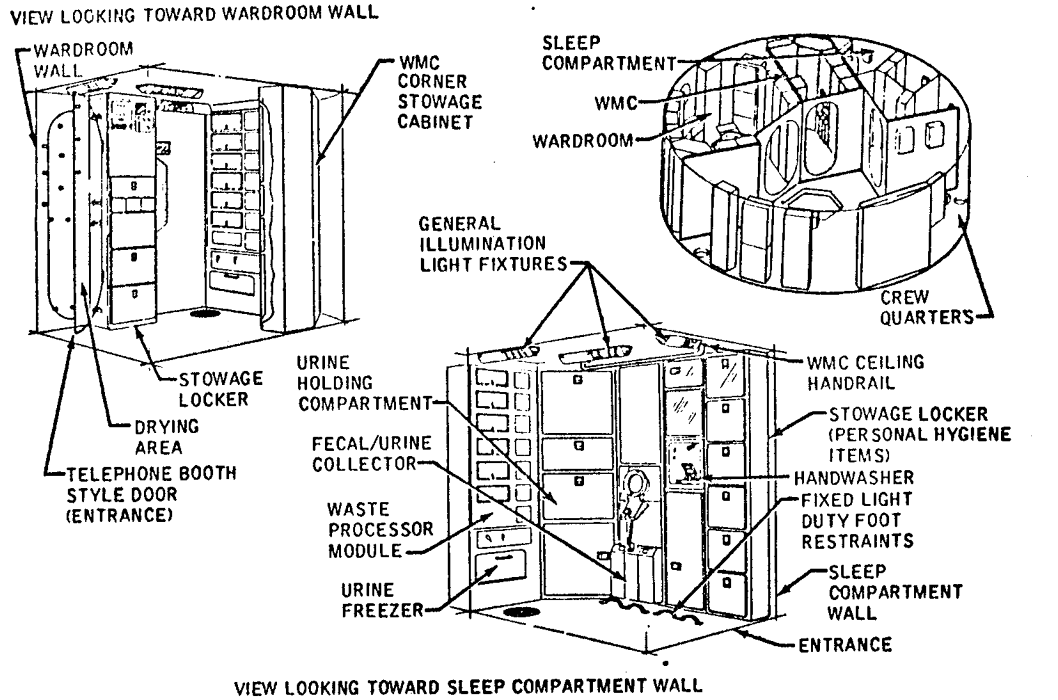


Figure 96. WMC Layout and Arrangement

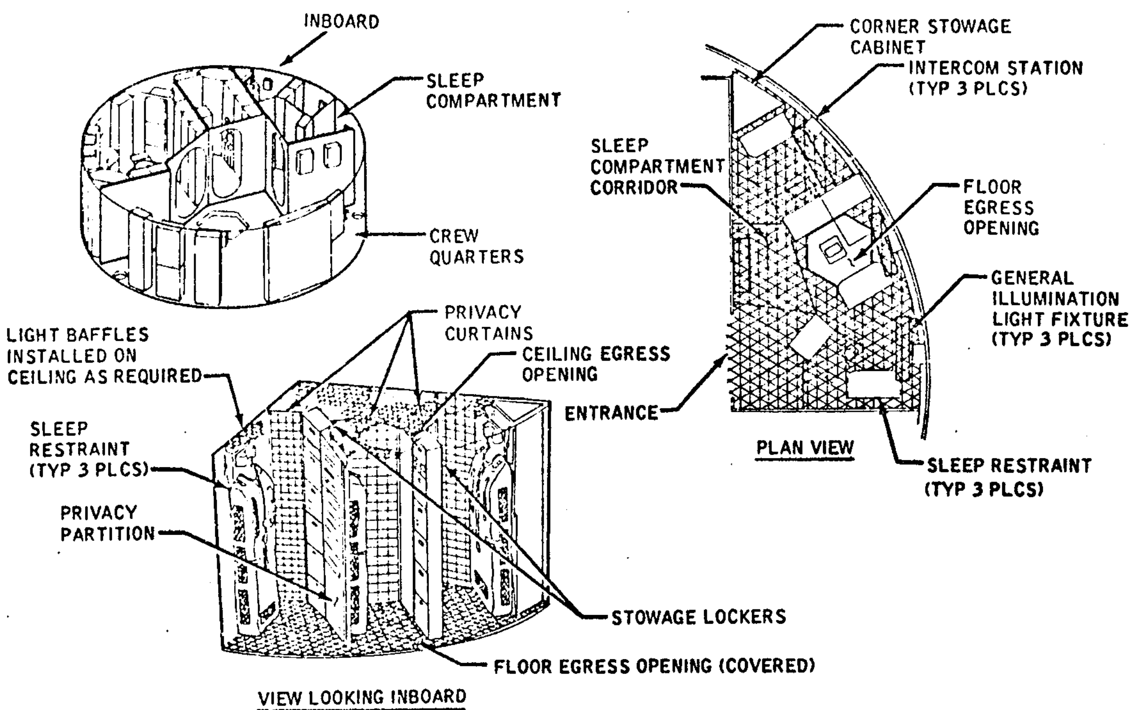


Figure 97. Sleep Compartment Layout and Arrangement

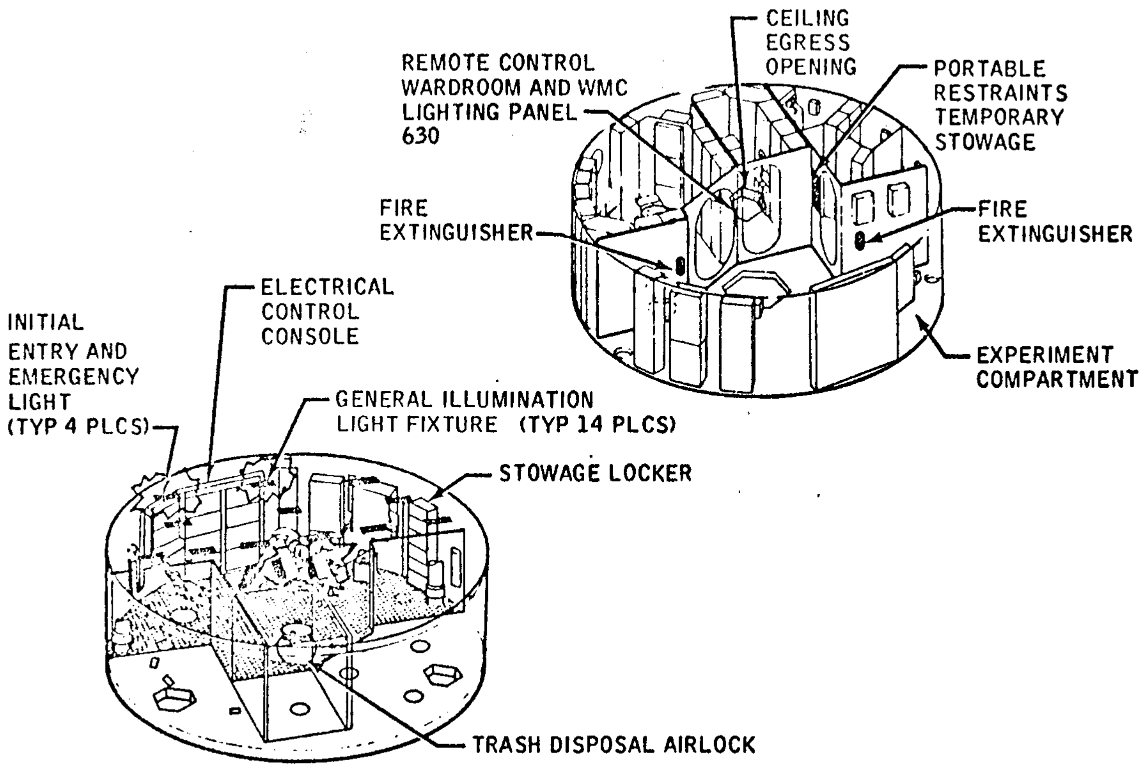


Figure 98. Experiment Compartment Layout and Arrangement

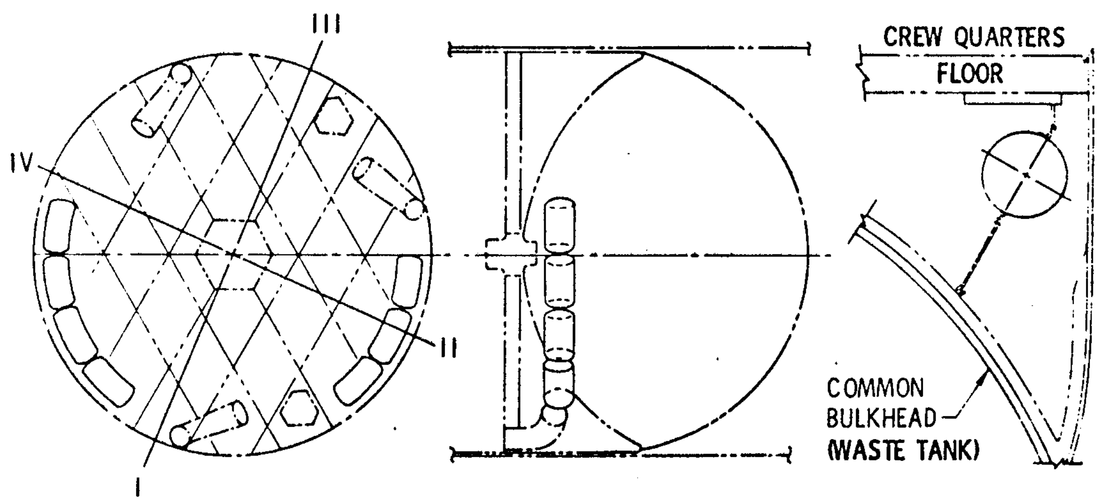


Figure 99. Plenum Bag Installation

crew station contained the urine/fecal collection equipment, a H_2O dispenser for washing, a washcloth squeezer, stowage lockers for washcloths, towels, wipes and tissues, waste processors, a urine freezer, towel and washcloth drying provisions, and supplies necessary for waste management including urine bags, hoses, receivers, sample bags, fecal bags, etc. The latter items were located in lockers and dispensers within the WMC with resupplies located throughout the OWS. Figure 96 illustrates the general arrangement and layout of the WMC.

(4) Sleep Crew Station - The three sleep areas were located in the sleep compartment on the crew quarters level, provided each crewman with individual sleeping quarters, which contained a sleep restraint, light, stowage lockers, SIA, and towel holders, The SPT's sleep area was provided with sleep monitoring devices, equipment associated with Experiment M133. These three areas comprised the smallest crew-occupied compartment. An illustration of the general arrangement and layout of the Sleep Compartment is shown in Figure 97.

(5) Experiment Compartment Crew Station - The experiment compartment had an approximate semicircular floor plan and was the largest volume crew station on the crew quarters level. It contained the trash airlock, numerous medical experiment devices, shower, and the OWS electrical control panels. A hexagonal opening to the Forward Compartment was directly forward of the trash airlock. Entry to the Wardroom, WMC and Sleep Compartment were available from the Experiment Compartment. A folding metal door was installed at the entrance to the WMC and fabric closures were installed at the Wardroom and Sleep Compartment entrances. An illustration of the general arrangement and layout of the experiment compartment is provided by Figure 98.

(6) Plenum Crew Stations - The plenum area was an irregular shaped area between the crew quarters floor and common bulkhead (waste tank) and provided volume for permanent stowage of biologically inactive (inert) trash. The stowage concept utilized armalon "plenum" bags stowed as illustrated in Figure 99.

b. Post Mission Assessment - The Forward Compartment was used for performance of experiments, stowage of equipment, pre and post EVA, as well as unscheduled exercise, recreational aerobatics, and gymnastics. Experiments that required the use of a SAL were restricted to the -Z SAL because the +Z SAL was used to deploy the parasol and the modified T027 canister was left in place throughout the mission. The most significant fact about the large volume is that it did not present any difficulty to the crews in terms of translation or mobility, and more than adequately served the performance and evaluation needs of the M509 and T020 flying experiments. The mass of the film vault doors and drawers proved troublesome and required the crewmen to use the triangle shoe for restraint. The 250-pound food boxes were relocated from their floor launch position to their on-orbit rack location by one crewman. Relocating the condensate tank, using the lower leg restraints located on ring lockers D424 and D430, made the relocation "like a piece of cake". The mixing chamber screen in the forward compartment provided a type of working table for handling small items. It could be said that the mixing chamber screen proved the airflow concept of the cancelled M507 Gravity Substitute Work Bench Experiment.

The Wardroom, primarily the food preparation and eating area, also proved to be a natural place to congregate and relax. The general size and arrangement of the Wardroom, with the central table pedestal, proved satisfactory with the exception of two problems concerning stowage arrangements and restraints. The first crew was able to rearrange the stowage locker door fronts to provide each crewman with a trash disposal locker, readily available from his position at the table. However, all crews were not able to correct the problem of the SPT not having easy access to his food stowage. Consequently, this resulted in the SPT translating over the food table, interfering with the other crewmen, or imposing upon the other crewmen to "serve" him. The pantry provisions in the Wardroom proved somewhat inadequate for the third crew because their menus were augmented by supplemental food which did not fit into the pantry concept. For the first two crews, overage foods were restowed in the forward compartment food boxes in order to provide room for the next week's menu. The third crew used the empty clothing lockers as additional food stowage in the Wardroom.

The food table, with restraints and bungees, was used with some success as a location for doing "paper work". A desk, or similar facility, where various management tasks such as report writing, check-list updating, etc., could have been performed, was needed. The food table was not suitable for these tasks. An assortment of office supplies, as well as special purpose lighting, should be made available.

The Wardroom window, with its changing kaleidoscope of the Earth, was a significant factor in maintaining crew morale and provided the facility for photographing numerous Earth features. Looking out the window, with or without binoculars, was the most relaxing and enjoyable crew off-duty activity. Even though the view from the window was adequate, the crews expressed a desire for additional, and even larger, windows. Increased clearance around the window would have permitted access by more than one crewman at a time. It would have also enhanced the interface capability for crew hardware used with the window. The placement and orientation of the window proved desirable most of the time. It was suggested that a hood be provided for light protection while using the window. In some instances, internal spacecraft glare and illumination made it difficult to perform night-time observations out the window.

The wardroom window developed an ice problem between the two layers of glass. A special procedure was developed which evacuated this inner chamber of the window. The procedure had to be repeated periodically (every 7 to 10 days) by all crews in order to remove the ice that formed from the water vapor in the cabin air that slowly backfilled the cavity.

The WMC was used for normal relief of body waste matter, drying feces and desiccants in the waste processors, measuring urine, taking urine samples, storing urine samples in the freezer, personal hygiene tasks, and body washing needs. The WMC was acceptable in size, layout, and function for use by one crewman at a time. However, the lack of usable foot restraints (grid for triangle shoes) was a problem and the absence of separation between the waste management and personal hygiene facilities was somewhat objectionable. The spills and housekeeping problems anticipated in the WMC did not materialize; therefore, the floor could have been grid, compatible with foot restraints.

The sleep areas were used for sleep periods or off-duty resting, as desired. There was a need for more personal stowage and temporary restraints in the sleep areas. Noise, ventilation, and personal comfort preferences (lights, music, etc.) were disturbing to the other sleeping crewmen. Noise sources, in varying degrees, such as the power module on the WMC fecal/urine collector and the ATM C&D cooling pumps in the STS, occasionally disturbed sleep periods when in operation. One crewman reversed his sleep restraint in order to increase the ventilation about his head. In doing so, the SIA was out of reach when he was in the sleep restraint, and also required him to install a portable light on the floor for reading. One crew hung moist towels in the Sleep Compartment to achieve their desired comfort preference.

The Experiment Compartment was used extensively to perform medical experiments, physical training on the ergometer, trash disposal, taking showers, and systems monitoring activities. The compartment was somewhat crowded, but the layout and arrangement was satisfactory. The "vertical" or 1-g orientation made the many experiment operations seem more like the 1-g trainer. The congestion around the shower was due to the fact that the shower was an experiment added late in the program. The noise of the ergometer hindered communication and could be heard on the SIA's and recorded channels.

Access to the plenum for stowage of the "plenum bags" was very satisfactory.

The open floor grid on both floors (Forward compartment and crew quarters) provided for crewman foot restraint, attach points for temporary tethering, handholds, and unaided communication between compartments. The main floor beams and intercostals were so close to the grid that the triangle shoes were not usable in some areas. The grid could have been slightly larger for easier hand accessibility for debris removal.

K. Mobility-Stability Aids

Mobility-stability aids were provided throughout the Skylab cluster to assist the crews in translating to and from work stations and for restraint, while performing various mission tasks. Mobility-stability aids included fixed devices, which were preinstalled for specific operations, and portable restraints, which could be installed by the crew at a variety of work stations. In addition to these aids, there were numerous items of equipment located throughout the cluster which could serve as mobility-stability aids, although that was not their primary function.

1. Design Description

a. Fixed Aids

(1) Fixed Handrails and Handholds - Fixed handrails and handholds were preinstalled throughout the cluster to assist the crewmen in translation and to assist them in maintaining temporary body stability in activity areas. Figure 100 illustrates the fixed mobility-stability aids within the entire Skylab vehicle. The handrails, around the MDA hatches, were the only mobility aid provisions in the MDA.

(2) WMC Foot Restraints - WMC foot restraints were provided to enable the crewmen (while barefooted, stocking-footed, or wearing soft boots) to use the urine collector and handwasher, and to perform various hygiene and maintenance tasks with both hands free. These restraints were mounted on the WMC floor and were adjustable to accommodate various foot sizes. This concept is shown by Figure 101.

(3) Fireman's Pole - A fireman's pole was provided in the OWS forward area to assist the crewmen in translating from the OWS access hatch to the Forward Compartment floor and is illustrated in Figure 100. The fireman's pole was launched in it's stowage location, then assembled and installed in it's use location on-orbit. A fireman's pole was not provided in the MDA because of the proximity of the hardware.

(4) Food Table Restraints - Each of the three food table eating stations were provided with foot and thigh restraints as illustrated in Figure 102. The foot restraints, comprised of two adjustable foot restraint straps, were designed to be used barefoot, in stocking feet, or while wearing soft boots. Triangle shaped openings were also provided to accommodate the triangle shoes.

The thigh restraints were attached to the upper portion part of the food table pedestal and provided the crewmen a means of stabilization in a semi-seated position while eating. These restraints were friction hinged at the table to permit elevation selection and out-of-the way stowage for access to the food table pedestal doors, and at the midpoint, to provide selection of the desired seating position.

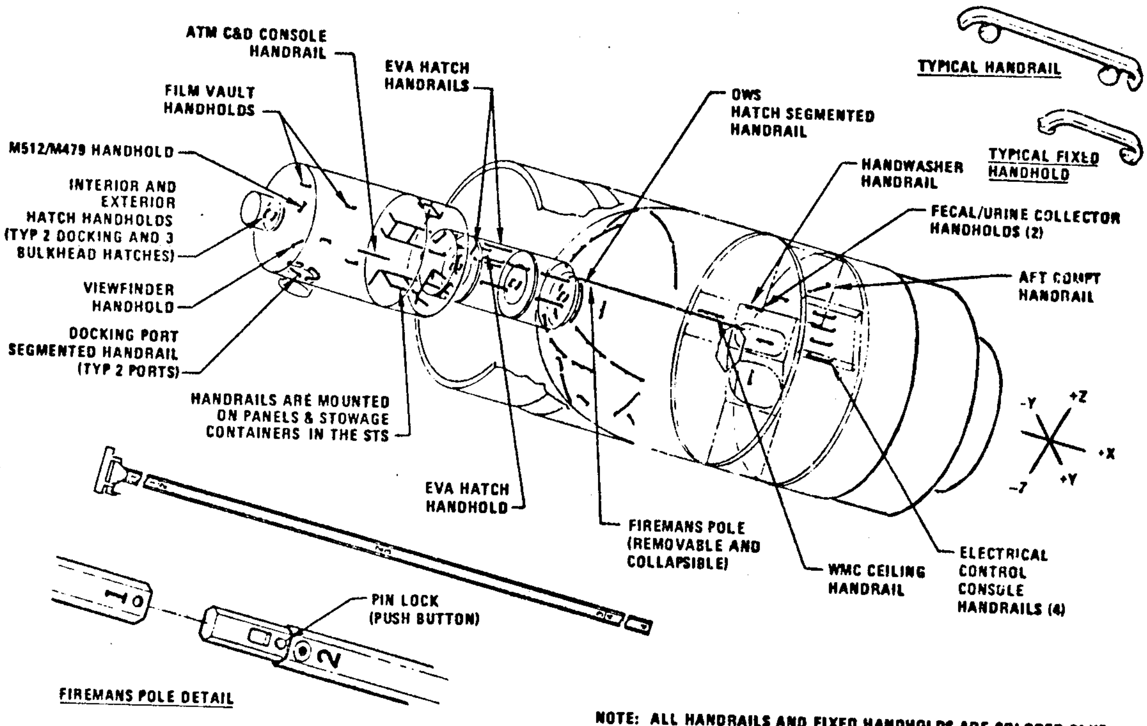


Figure 100. Handrail Restraints

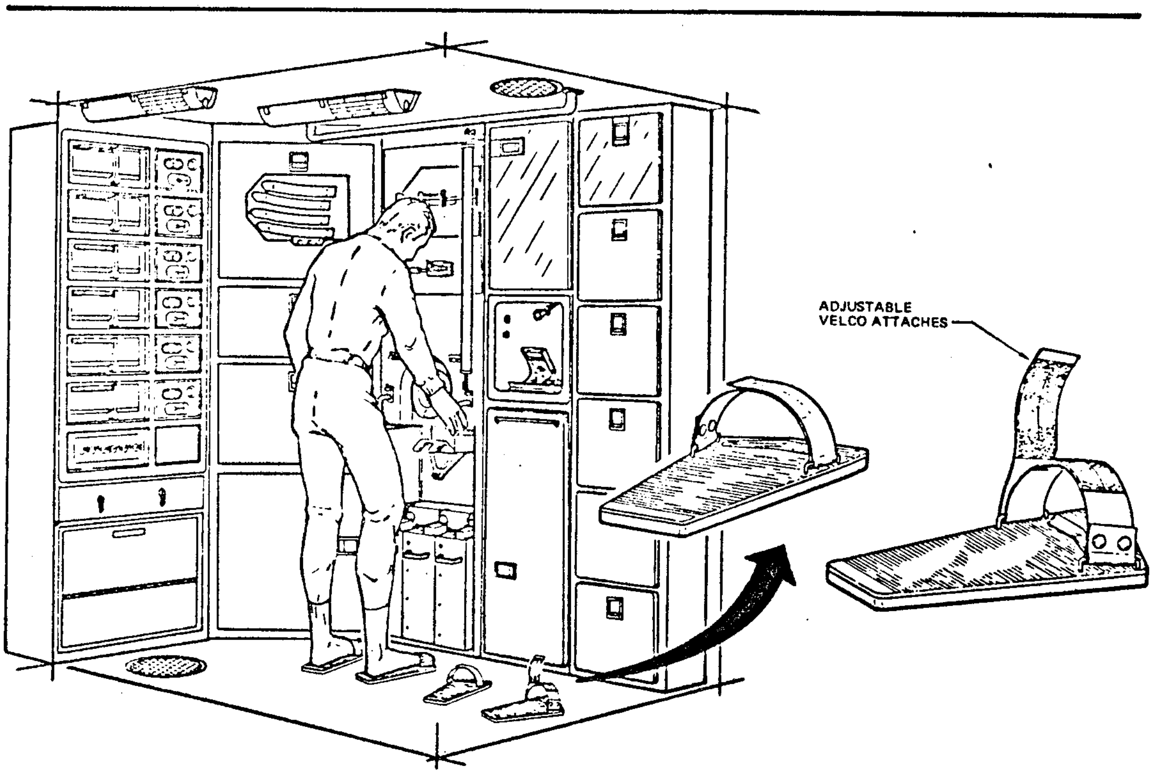


Figure 101. Foot Restraint-Fixed

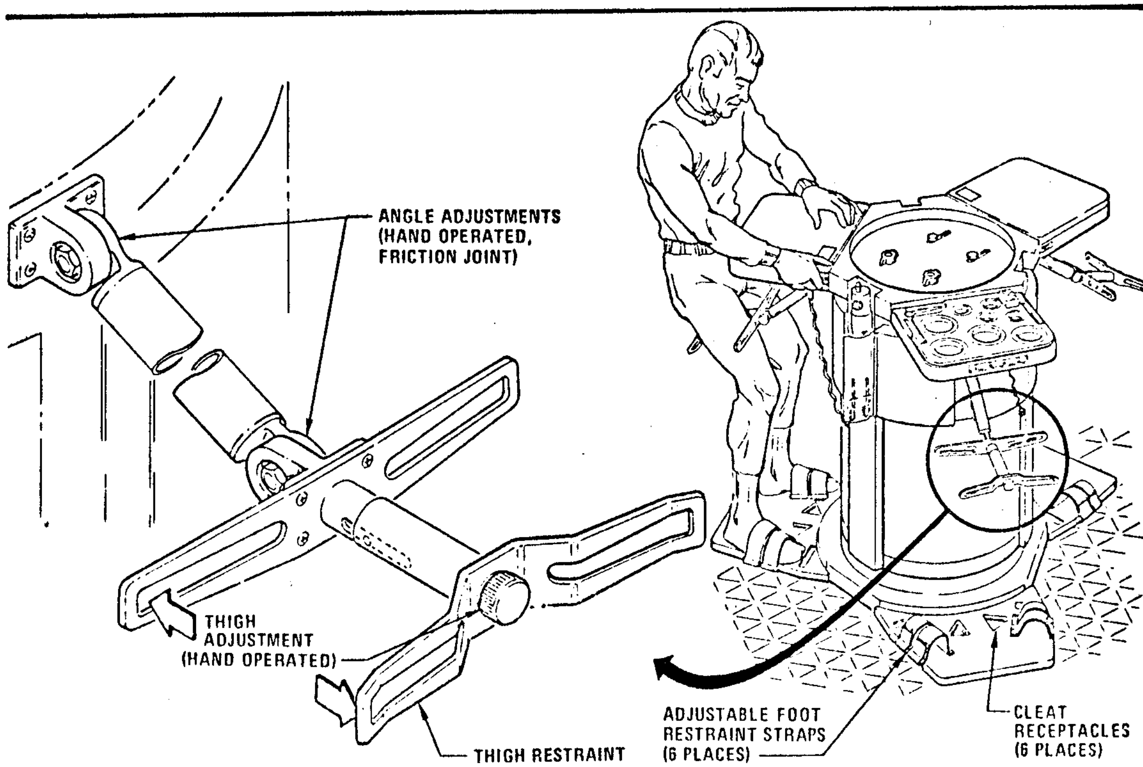


Figure 102. Food Table Restraints

Each thigh restraint was fitted with a slide adjustment permitting confirmation to each individual crewmen's thighs.

(5) Water Tank Foot Restraint Platforms - Water tank foot restraint platforms, illustrated by Figure 103, were provided for use with the triangle shoes. They were designed to assist the crewmen in restraining and maintaining body orientation for applying any necessary forces, with both hands free, while accessing equipment in the dome ring lockers. These restraints were located in the forward compartment immediately below the water stowage tanks.

(6) OWS Lower Leg Restraints - OWS lower leg restraints were located on dome ring lockers D424 and D430 and were provided to assist two crewmen in translating, positioning and installing the condensate holding tank to its on-orbit location in the forward dome. The lower leg restraints are illustrated by Figure 104.

(7) Floor and Ceiling Grid - Floor and ceiling grid was used by the crew as both a handhold and as a locking device for the triangle shoe. These grids were equalateral triangle cutouts machined from aluminum plate and are illustrated by Figure 105. The grid concept originated with the original "wet" workshop requirement to allow liquid hydrogen drainage during the launch and boost phases through preinstalled floors and walls.

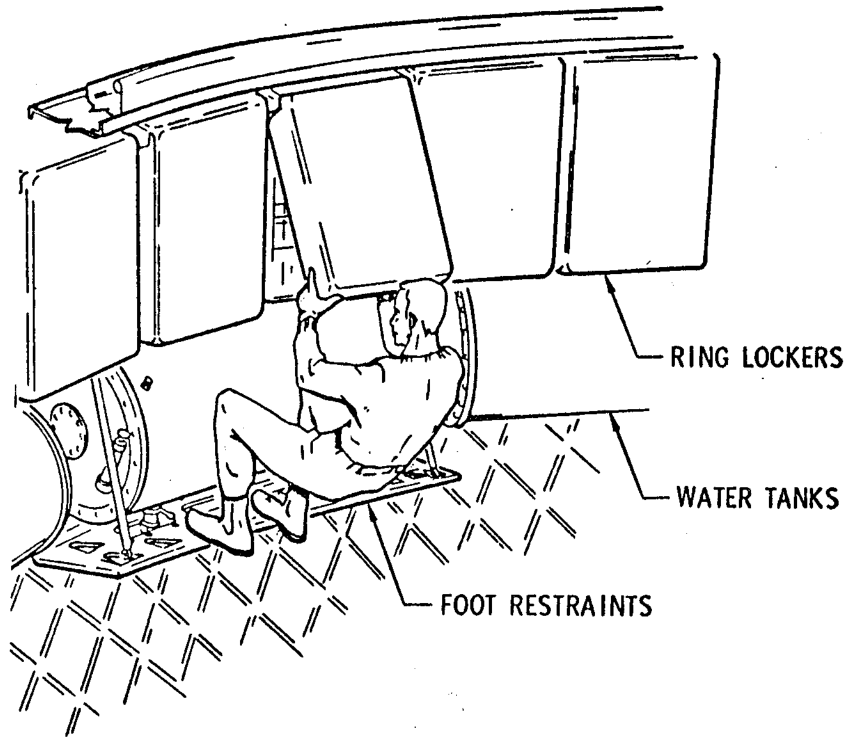


Figure 103. Dome Locker Restraints

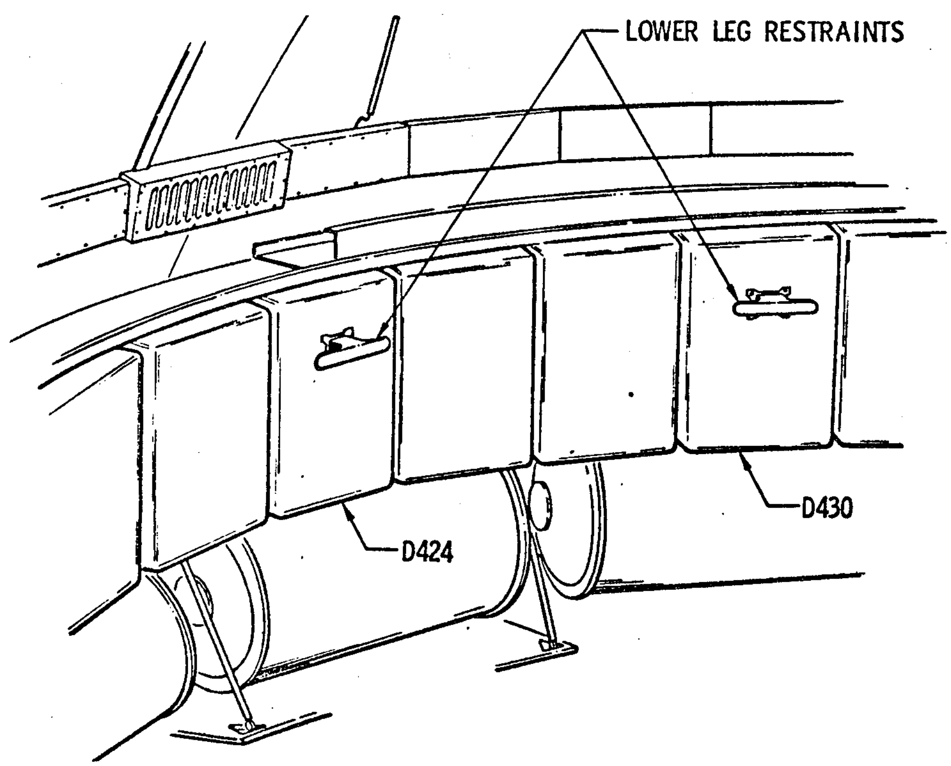


Figure 104. Lower Leg Restraints

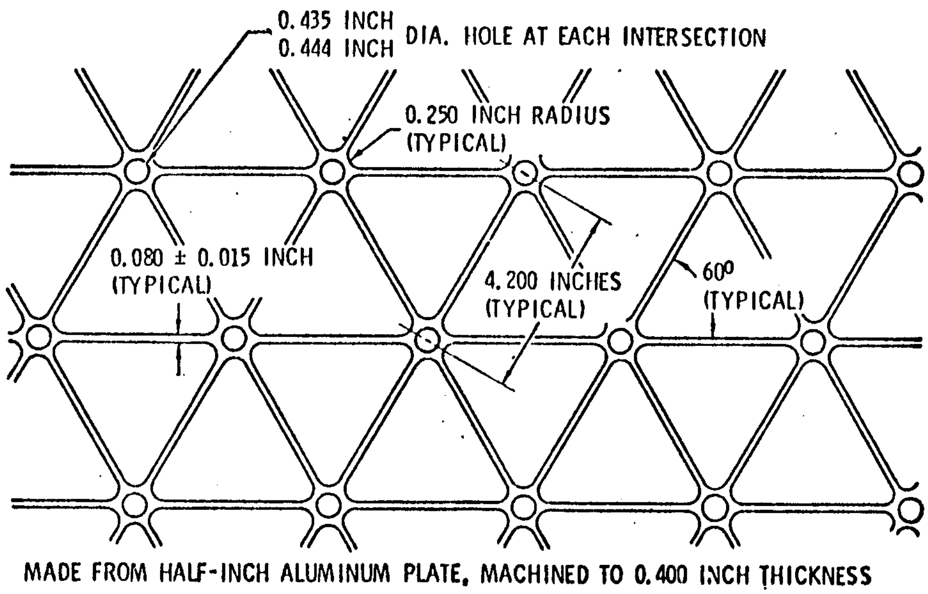


Figure 105. Floor Grid Pattern

(8) Fecal Collector Restraints - Fecal collector restraints were provided in the WMC at the fecal/urine collection module. The restraints consisted of (1) a lap belt to secure the crewman against the contour seat, (2) handholds located on both sides of the seat, and (3) a bar restraint located in the lower portion of the fecal collector unit which allowed the seated astronaut to firmly restrain his lower extremities. The fecal collector restraints are illustrated by Figure 106. A toe well was located in the door below the handwasher near the floor. It was to be used as a foot restraint while performing various hygiene activities such as cutting hair so the crewman could be close to the WMC ceiling air flow debris filters.

(9) Shower Foot Restraint - The shower foot restraint, permanently installed on the shower floor, was doughnut shaped and enabled the crewman to have both hands free while showering. This restraint is illustrated in Figure 107.

(10) ATM Foot Restraint Platform - The ATM foot restraint platform was designed to provide a crew restraint for operations at the ATM Control & Display Console. It was composed of Skylab triangular grid and was the same length as the ATM C&D console with and approximately 20-inches wide. The foot restraint was vertically adjustable in 3 positions, at 6-inch increments, relative to the console. The ATM Foot Restraint Platform, depicted in Figure 108, was designed for use with the triangle shoes and the Skylab Restraint Assembly.

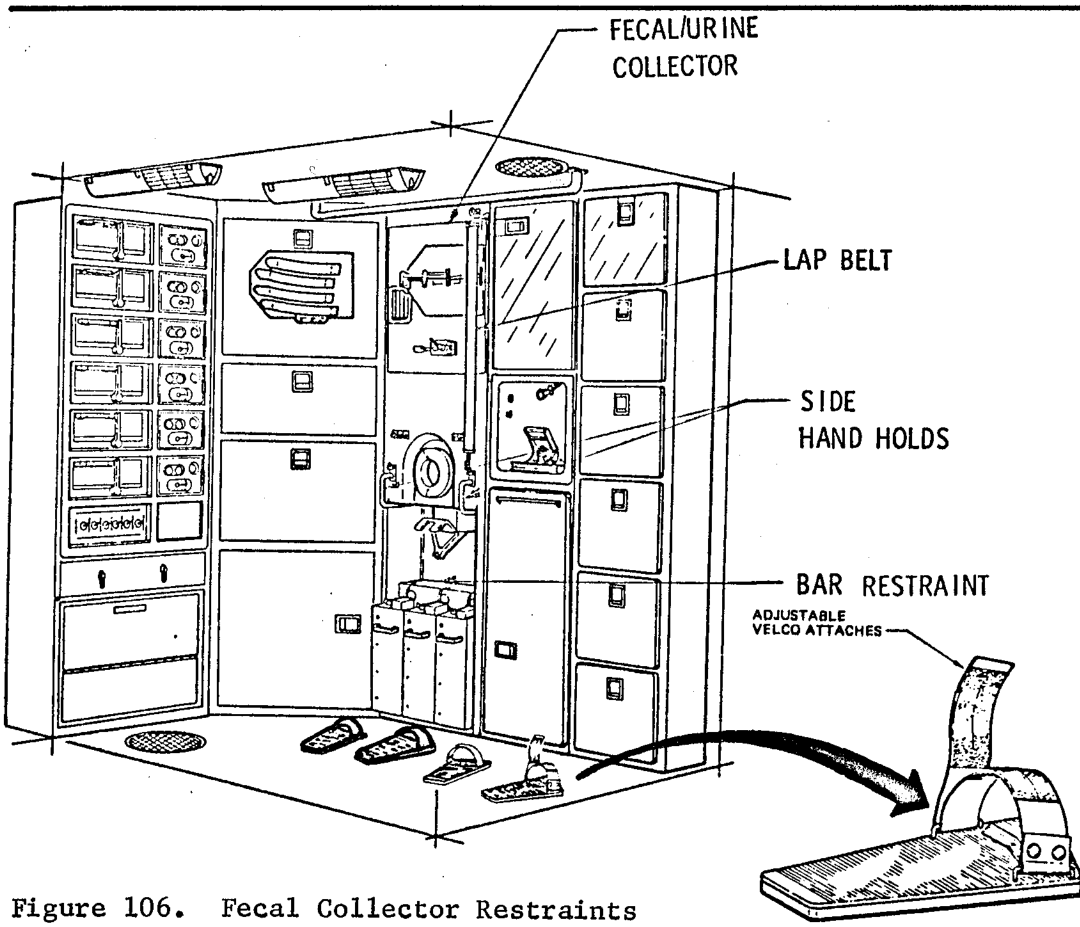


Figure 106. Fecal Collector Restraints

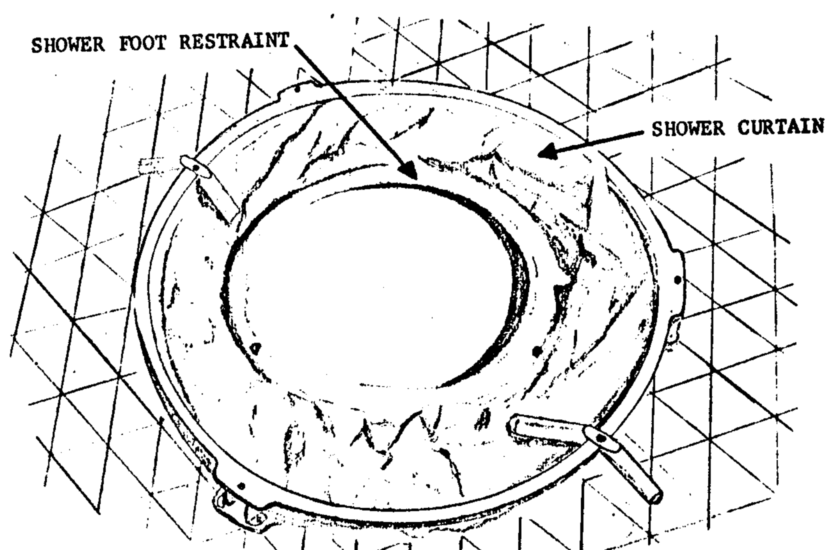


Figure 107. Shower Foot Restraint

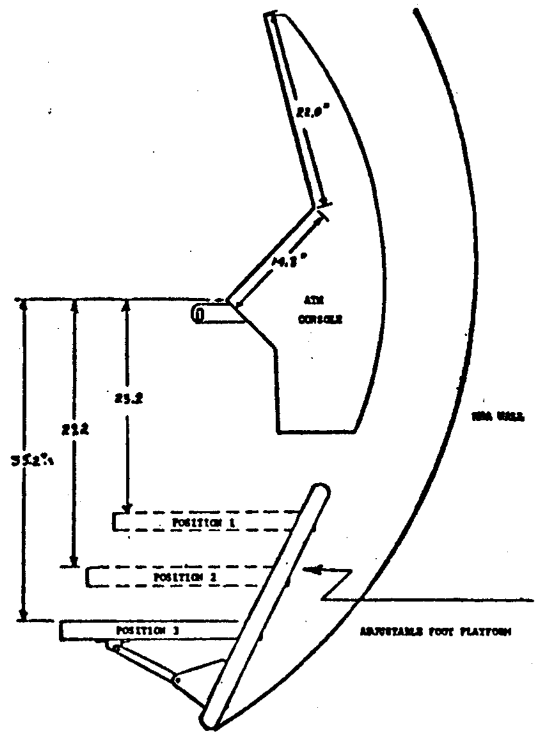


Figure 108. ATM Foot Restraint

(11) Skylab Restraint Assembly (ATM Seat/Backrest, ATM Chair, Captain's Chair) - The Skylab restraint assembly was designed to provide the crew with a chair-type body restraint while working at the ATM Control & Display Console. The chair was designed to attach anywhere along the ATM Foot Restraint Platform. The chair had eleven height adjustment positions above the ATM Foot Restraint, while the back of the chair was adjustable to nine positions of tilt. The seat had five tilt adjustment positions with respect to the ATM Foot Restraint Platform. A tubular foot restraint rail, which the crewman could employ as a foot reaction point, was also provided. Figure 109 illustrates this restraint.

(12) M512/EREP Foot Restraint - The M512/EREP foot restraint was a portable triangular grid platform similar to the ATM Foot Restraint Platform. It was used to restrain a crewman working at either the M512/M479 workstation or the Earth Resources Experiment Package (EREP) workstation in the MDA. The M512/EREP Foot Restraint was installed parallel to the X-axis in the EREP position.

b. Portable Aids

(1) Portable Pressure Garment Assembly (PGA) Foot Restraints - Three PGA foot restraints were provided on the forward compartment floor for use with the pressure suits to: (a) restrain the PGA boots for suit drying, (b) restrain a PGA suited crewman near M509, and (c) generally restrain the PGA suited crewman on the forward compartment floor. Figure 110 illustrates these restraints.

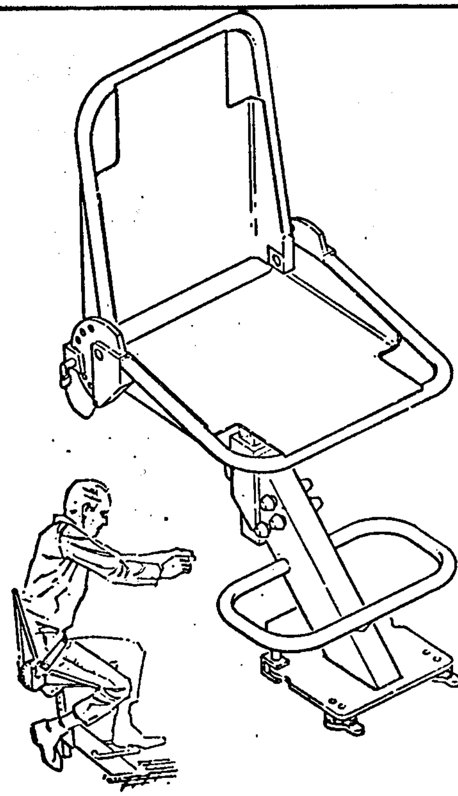


Figure 109. Skylab Restraint Assembly

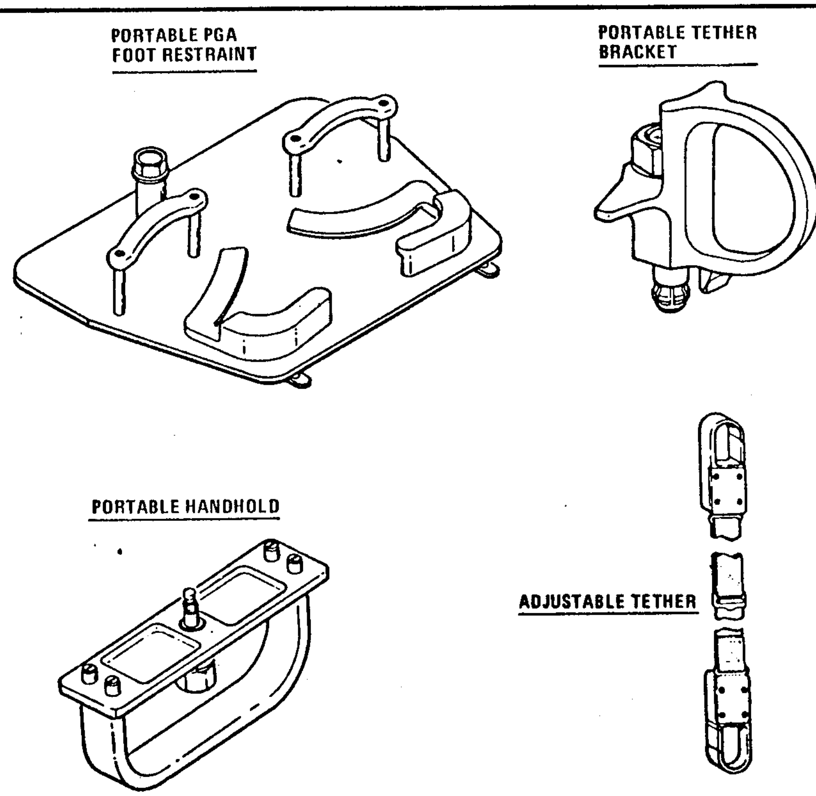


Figure 110. Portable Restraints

(2) Portable Handholds - Six portable handholds were provided to enable the crewmen to install handhold restraints, as required, in areas where open grid was available. These items are shown in Figure 110.

(3) Portable Tether Brackets - Nine portable tether brackets were provided to enable the crewmen to install restraint points for long and short straps and equipment restraints wherever open grid was available. The brackets provided smooth, rounded attach points for straps and restraints. Portable tether brackets are illustrated in Figure 110.

(4) Adjustable Tethers (Forward Compartment) - Two adjustable tethers were provided. One was launched in place, with one end attached to the dome hatch bracket and the other end to the forward compartment floor near the central access opening. It was provided as a translation aid from the AM to the OWS crew quarters compartment. The other adjustable tether was launched in place with one end attached to the forward compartment wall handholds (near +Z SAL), then strung through the condensate tank handholds and attached to one of the dome handholds. It was provided as a means for guiding and stabilizing the condensate tank while translating the tank from its launch location on the forward compartment floor to its on-orbit location. The adjustable tether is illustrated by Figure 110.

c. Shoe Restraints (Triangle Shoes) - Triangle shoes were provided for each of the crewmen to enable them to lock their feet into open floor and ceiling grid, the water tank foot restraint platforms, the bicycle ergometer foot pedals, and the food table foot restraints. The triangle shoes provided a means of stabilizing, maintaining body orientation, and applying forces with both hands free. In addition to the triangular indexing cleats, three sizes of conical (mushroom) cleats were also provided. Shoe and cleat configurations are shown by Figure 111.

2. Post Mission Assessment - Translation within the vehicle proved to be easily accomplished by pushing off and floating to any particular destination. Locomotion modes varied according to the volume and architecture of the areas being traversed. Movement in open spaces, typical of the dome area in the OWS, was accomplished mostly head first along the principal body axis. This was also the case in the smaller compartments, where vehicle structure and interior layout dictated restricted movement. In most cases, in the living and experiment areas of the vehicle, where equipment was one-gravity oriented, the crews moved about erect with respect to the architectural arrangement, as one would do in any earth-based laboratory. The OWS one-g orientation provided the crewman with a visual reference system thereby permitting easy orientation, location recognition, and

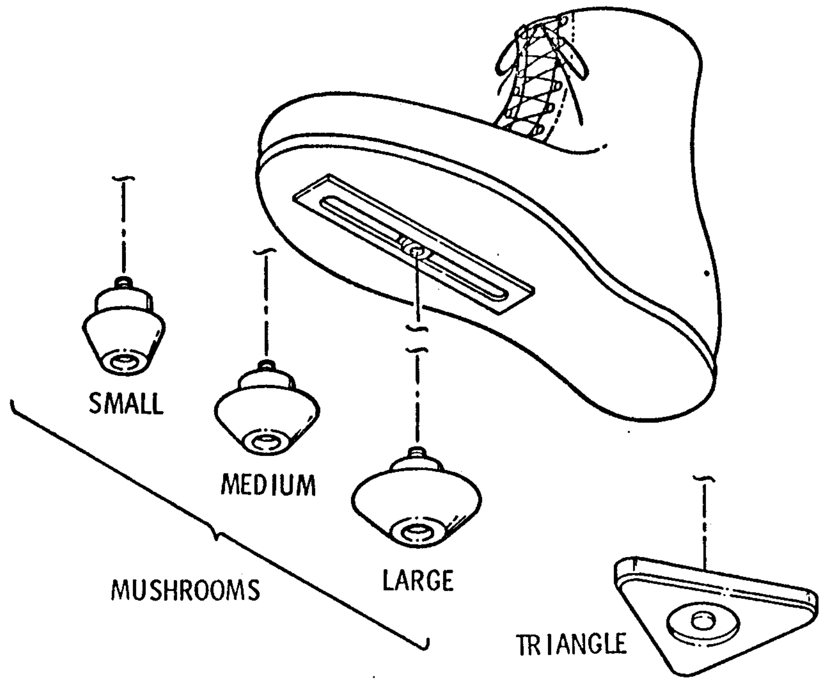


Figure 111. Shoe Restraints

equipment identification. Pre-mission crew training was certainly enhanced by this layout.

The crew experienced no problems with mobility, nor did they experience any significant motion sickness and very little disorientation as a result of translation activity. Cluster activation activities proved to be easy. Apparently, the crew did not injure themselves by impacting stationary objects when translating by free floating.

Locomotion in and through the various compartments was no problem; the shape of the doors was considered acceptable. In moving around the vehicle and stabilizing themselves, the crew often used their toes. They dragged their feet over the grid, stuck their toes into the grid and under hardware for restraint.

Handling and translating large objects presented no problems. On the other hand, small items, in quantities, were difficult to manage; future manned missions will require better methods.

A variety of restraint devices, including foot restraints, lower leg restraints, pelvic restraints, and a somewhat conventional crew seat, were provided. In general, all the restraints performed as designed. While there were some individual preferences for specific tasks, the crew consensus was that a good foot restraint was superior for most tasks, and in some opinions, for all tasks.

The most popular body restraint used on Skylab was similar to ordinary tennis shoes fitted with interlocking triangles on the sole, which could be attached into the triangular grid floors and ceilings of the OWS and the MDA restraint platforms.

In future spacecraft design, particular attention should be given to specific locations along a translation paths where directional changes or tunnel entry will be required. A buffer of soft material should be provided to protect the lower body extremities.

Some problems and design considerations for handling and translating large cargo or experiment items defined by the crew are as follows:

- The food box was a reasonable size container (approximately 20" X 22" X 30"/200 pounds) to translate and not considered too large for one man to maneuver in zero-g.
- Large items should be easily grasped to allow guidance during translation.
- Long and thin items are easy to handle if one can see the end of the item being maneuvered.
- Very large or heavy items can be maneuvered if the crewman is adequately restrained.

A detailed description of crew usage and assessment of specific mobility/stability items follows.

a. Fixed Aids

(1) Fixed Handrails and Handholds - Crew members assessed the handrails as adequate. There appeared to be an adequate quantity of fixed handrails, but many of them were in low use areas, such as the OWS forward dome. It is now obvious that hand-over-hand translation inside a large space station, such as the OWS, is not required as a means of locomotion. Fixed handrails were used primarily as a "spring board" for body movement or as a "brake" or "clutch" for re-orientation. The crew felt that many of the handrails located at work stations should have been foot restraints.

The arms were the major means for the crewmen to propel themselves in zero-g. This afforded great significance to the placement of handholds and handrails throughout the vehicle. The SL-3 and SL-4 crews made numerous comments regarding the need for a greater number of fixed aids to be deployed throughout the vehicle. Comments also indicated that high traffic areas are prime candidates for additional aids. The aids should protrude above equipment for easier accessibility. Another suggestion made was to locate handrails at hatch openings and if possible, place them just inside the tunnel of the hatch opening. The concensus of all crewmen was a need for more handholds and handrails. These aids should be located as close as possible to equipment thereby keeping "torque forces" and "opposite forces" as close together as possible.

(2) WMC Foot Restraints - The two locations of the foot restraints in the WMC were judged to be unsatisfactory. They were assessed as not satisfactory when used in the non-nominal mode (with the triangle shoes). The velcro did not hold well, and it was too stiff and too short. A new concept for WMC foot restraint straps was developed by JSC and was flown on the second mission.

This newly supplied strap did not perform as expected and was also assessed as inadequate. Both the second and third crew assessed these devices similarly. The strap was too short to be used with triangle shoes; the strap was too long for use without triangle shoes; and it kept getting caught in the urine drawers.

(3) Fireman's Pole - The crews found this item to be useful and, at times, preferred it over the flexible strap. Due to the pole rigidity, they could grab it and change direction easily and more accurately than with the flexible strap. The only objections were that: a) it was possible to cut one's hands on the attachment roll pins, and b) the pole tended to rattle loudly when impacted, disturbing crewmen attempting to sleep.

(4) Food Table Restraints - The table thigh restraints were considered satisfactory and were usually used either as intended, by design, with the thighs between the cross bars, or with the knees over the innermost of the two cross bars, which was an improvised method for using the restraint. All three crews were able to adjust the thigh restraint tightly enough and at angles pleasing to each individual crewman.

Some crewmen used the foot restraint with the triangle shoes, some used the restraint straps, and some did not use the foot restraint at all. The light-duty foot restraints were seldom used because they were not compatible with the triangle shoes, and were assessed as inadequate because they came out of their slots and were difficult to reinstall. This also applied to the revised straps launched on the second mission.

The use of the triangle shoes at the food table was the most preferred method, with the cutouts for the triangle shoes used most of the time. The third crew removed the foot restraints and used the floor grid for the triangle shoes with the thigh restraints. This provided more attach points for the triangle shoes and was used for the remainder of the mission.

(5) Water Tank Foot Restraint Platform - The crewman used this restraint in various ways. One crewman engaged one foot in the triangular cutouts; others engaged both feet or stabilized with the hands only. While installing water hoses and the condensate tank hoses, one crewman laid parallel to the platform and grasped it between his knees to allow freedom of both hands. All three crews assessed the water tank foot restraint as very good and necessary for most tasks performed in that area, particularly while working in the ring lockers.

(6) Lower Leg Restraints - These restraints were used, as intended, while attaching the condensate holding tank to its on-orbit location. No other usage of this device was reported during the second or third mission. Crew assessment indicated that they worked well.

(7) Grid - The floor and ceiling grid was used by all three crews, as anticipated, for mobility and restraint. All crews commented favorably on the usefulness of the grid. The two most common complaints were: (1) the lack of more grid and, (2) the blockage of the grid by either the installed equipment or the supporting structure. Besides its use in conjunction with the portable restraints, the grid itself was continually used as a handhold or foothold. The WMC restraint evaluation always referred to the lack of grid. The second crew suggested, during the debriefing, that grid should have been provided in the WMC.

One minor deficiency associated with the grid was the problem of particle migration, such as food crumbs and spills. The grid was difficult to clean because of the small holes, sharp corners, etc.

(8) Fecal Collector Restraints - Fecal collector restraints were assessed by the three crews in somewhat different methods.

In general, they felt the restraints allowed them to satisfactorily accomplish fecal collection. They all agreed that both the handholds and foot restraints must be used. Some felt that the belt was an absolute necessity, while others stated that it was not required. They all commented, however, that in one way or another the equipment served its intended purpose.

The major complaint about the WMC was the lack of adequate restraints for the performance of the various management tasks associated with waste management and M071/M073 experiments, such as urine and fecal bag changeout, sampling, cutting, crimping, etc.

(9) Shower Foot Restraint - The shower foot restraint was assessed as effective for its intended use; however, it should have been padded for barefoot use. Because of its simplicity, this restraint concept could be considered for application in other areas.

(10) ATM Foot Restraint Platform - The use of the triangle foot restraint, contrasted to the Skylab Restraint Assembly (ATM Seat/Backrest), seemed to be the better operation stability aid. The SL-3 and SL-4 crews did not report or express any fatigue due to remaining upright at the ATM C&D. The crewmen considered this foot restraint very adequate in performing all tasks at the ATM C&D panel. The SL-2 crew did prefer the Skylab Restraint Assembly; however the foot restraint was also deemed acceptable for ATM operations. The ATM foot restraint, used throughout the mission in the lowest position, permitted the crewman an operational envelope completely adequate to perform all ATM operational tasks. It was suggested that the lowest position (position 3, Figure 108) could have been even lower.

(11) Skylab Restraint Assembly - The SL-2 crew used the ATM Seat/Backrest Restraint continuously, thought it was very useful and prevented them from becoming very tired while operating the ATM C&D Panel. The SL-3 and SL-4 crews thought that this restraint merely

restricted their reach envelope, therefore, used it very little. The SL-3 and SL-4 crews did not recommend a seat/backrest to be part of future consoles. For those crewmen who used the ATM seat/backrest assembly for additional restraint, the freedom of motion and reach envelope was restricted. The reach envelope at the ATM C&D crew station, while using the chair, included the entire ATM C&D panel, SIA, TV selector switch on the left, and the very nearest checklists and the checklist compartment. By loosening the chair lap belt, the Video Tape Recorder (VTR), all the checklists, and the radio noise burst monitor were within easy reach.

(12) M512/EREP Foot Restraint - The EREP Foot Restraint worked exceptionally well. The crewmen also agree on the need for a similar restraint at the VTS station. The triangular foot restraints were constantly acclaimed as a good restraint. It is evident that the crews desired this type of restraint at all work stations. The concept of supplying one portable foot restraint for use at numerous locations should be discouraged, especially when it must be relocated many times during the mission.

b. Portable Aids

(1) Portable PGA Foot Restraints - These restraints: were successfully used by all the crews in a normal manner for suit donning/doffing, suit drying, and during EVA; were assessed as functioning satisfactorily; and were considered to be a firm requirement. One of the PGA foot restraints was modified for the Twin-Pole Sail Deployment EVA by removing the two pip pins. These pip pins, installed to keep the feet in and keep the PGA's located by themselves during suit donning and drying, worked satisfactorily. It should be noted that the third crew rated the suit donning task as being 3-4 times more difficult in zero-g than in one-g.

(2) Portable Handholds - The portable handholds were used in the vicinity of the bicycle ergometer when the first crew rode the ergometer. The second crew used the portable handholds for stability when performing the soaring mode of T013. During the first mission, two portable handhold attachment devices (astropins) were broken. Neither the second nor third crew reported any anomalies; however, both crews felt that the portable handholds were not required.

(3) Portable Tether Brackets - The first crew used the brackets to rig ropes with handles to restrain themselves on the seat while operating the bicycle ergometer. No other usage was mentioned. The second and third crews did not use the portable tether brackets.

(4) Adjustable Tether - The first crew used this tether during initial activation of the OWS, but removed it later in the mission. The second and third crews used the adjustable tether for evaluation purposes, but removed it and used no translation aid

during most of their missions. The tether was broken (date unknown) during the first mission, but was repaired with tape from the repair kit. The adjustable tether was assessed to be minimally adequate during all missions. It was judged to be unnecessary and not required, except possibly during the early portions of the mission.

(5) Shoe Restraints (Triangle Shoes) - The shoes were used with both the triangle and conical cleat restraints. Most of the preinstalled hardware, requiring foot restraint capability, was designed to accept the triangle cleat. The conical cleat was added later in the program, consequently, did not have the total flexibility of the triangle cleat.

The crews thought that the triangle cleated shoes were the most essential, useful, and versatile restraint device they had available; and was preferred over the conical cleat because it provided more restraint. The conical cleats were used infrequently because they required constant inward and outward force applied, with both feet, into the corner of the grid, for restraint.

Because the conical cleat was not designed for use with the food table foot restraint and bicycle ergometer, it became a matter of convenience to use the triangle cleats, rather than switch back and forth.

One triangle cleat was broken during the third mission when the film vault door accidently hit the side of a crewman's shoe. However, it was suspected that the triangle had already fatigued, and no additional details were provided.

The crews had a tendency to drag their toes over surfaces, in order to slow down, causing the shoe toes to abrade. In recognition of this problem, protective wear caps were launched on the second and third missions. This corrected the toe wear problem but did not halt the overall shoe wear problem. The third crew expressed displeasure with the design, as well as the detailed and lengthy installation procedure, of the toe guards.

c. Ancillary Equipment - All equipment, located within the OWS, was assessed as ancillary restraints during the engineering and manufacturing phase. All equipment was "rounded", "smoothed", etc., wherever possible, so that it could be used by the crew for translation and restraint. Favorable comments were received from the crew relative to the adequacy of this equipment.

The corner posts on stowage lockers were designed such that they could be used as vertical handholds. In the Wardroom, the edges of the locker stanchion were recessed enabling the crew to grab them with their fingers. The crews thought both of these capabilities were a good idea.

A summary matrix depicting crew assessment of Skylab restraints appears in Table 10.

	PERFORMANCE				
	EXTREMELY WELL	SATISFACTORY	IMPROVEMENTS REQUIRED	UNACCEPTABLE	NOT REQUIRED
FIXED RESTRAINTS					
Fixed Handrails & Handholds		X			
WMC Foot Restraints				X	
Fireman's Pole		X			
Food Table Thigh Restraints			X		
H_2O Tank Foot Restraint Platform	X				
OWS Lower Leg Restraints		X			
Floor and Ceiling Grid	X				
Fecal Collector Restraints		X			
ATM Foot Restraint Platform		X			
Skylab Restraint Assembly			X		
M512/EREP Foot Restraint		X			
Shower Foot Restraint		X			
PORTABLE AIDS					
PGA Foot Restraints		X			
Portable Handholds					X
Portable Tether Brackets					X
Adjustable Thethers			X		
Triangle Shoes		X			

Table 10. Crew Assessment of Skylab Restraints

L. Stowage

Stowage in the OWS dome area, forward compartment and crew quarters consisted of various sized stowage compartments, dispensers, refrigerated and ambient temperature food storage containers, refrigerated urine storage, urine return containers, a film vault and miscellaneous stowage provisions (e.g., tie-down straps, brackets, fiberboard packing and boxes) as illustrated in Figures 112 and 113. All Stowage in the OWS was vented to cabin atmosphere by the stowage equipment door or lid joint. The Skylab cluster stowage containers were systematically coded by location. Stowage in the dome was assigned (D) 400 series numbers, in the Forward Compartment (F)500 series numbers, in the Experiment Compartment (E)500 numbers, in the Wardroom (W)700 numbers, in the WMC (H)800 numbers, and in the Sleep Compartment (S)900 numbers.

OWS stowage compartments were of six basic sizes as illustrated in Figure 114. These stowage compartment interiors, with the exception of the D400 series, had holes on the top and bottom of the compartments into which adjustable straps and other restraint hardware were attached for launch and/or orbit restraint of the stowed items. The D400 series stowage compartments stowed items were restrained with permanent straps or bolts, since each stowed item was custom-mounted.

The MDA stowage containers consisted of various designs including ATM film vaults, flight data file, CO_2 absorber and miscellaneous stowage. The MDA stowage was assigned (M)100 series numbers.

The AM stowage also consisted of various size and shape containers including containers for solids traps, teleprinter paper, flight data file, light bulbs and CO_2 filter cartridges. The AM stowage was assigned series numbers (M)200 for the structural transition section and (M)300 for the tunnel section.

MDA and AM stowage facilities are illustrated in Figure 112.

1. Containers

a. Design Description - The stowage containers were designed to house various items of loose equipment. All OWS containers defined as standard compartments, which were the most numerous, had the same internal dimensions and door configuration. In addition to being used for launch stowage, some of the containers doubled as dispensers, trash containers and on-orbit containers for transfer items. The film vaults in the MDA and OWS were designed with varying wall-thicknesses to provide radiation protection based on film sensitivity and length of storage.

b. Post Mission Assessment - The third crew reported that the OWS film vault door latches did not function properly. Instances were cited where the right-hand door would come ajar when the left-hand door was closed.

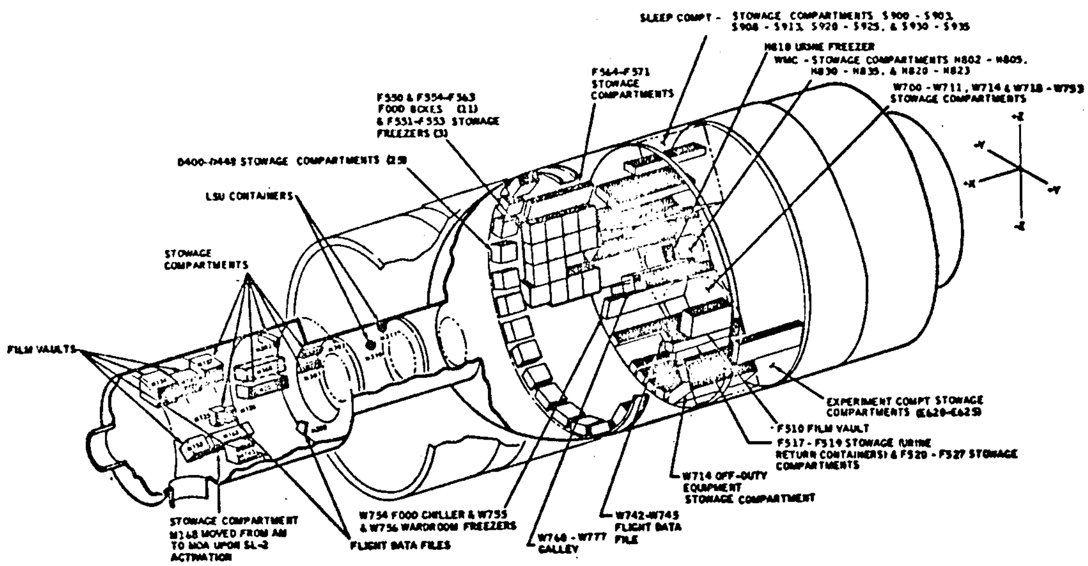


Figure 112. Skylab Stowage System

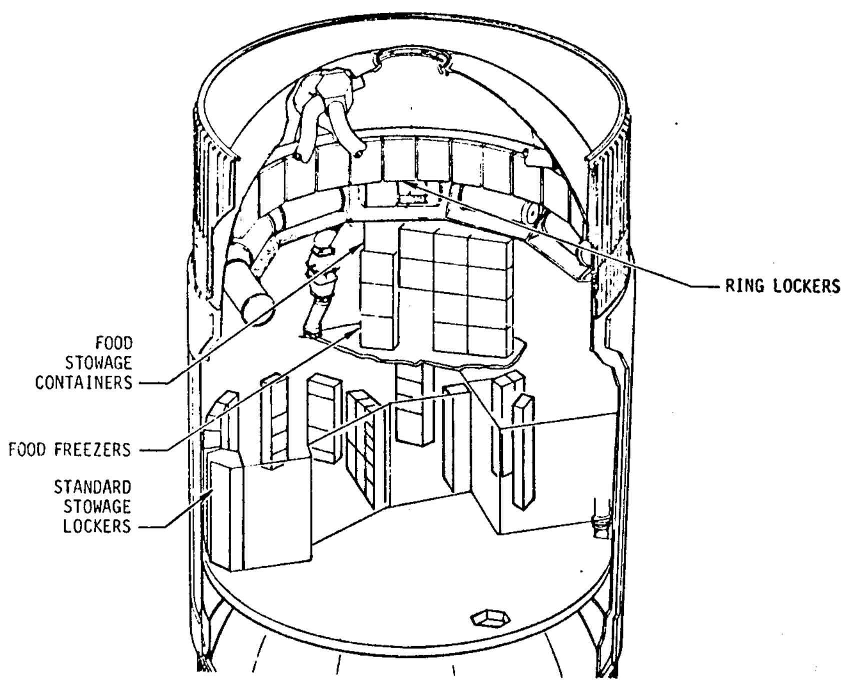


Figure 113. OWS Stowage System

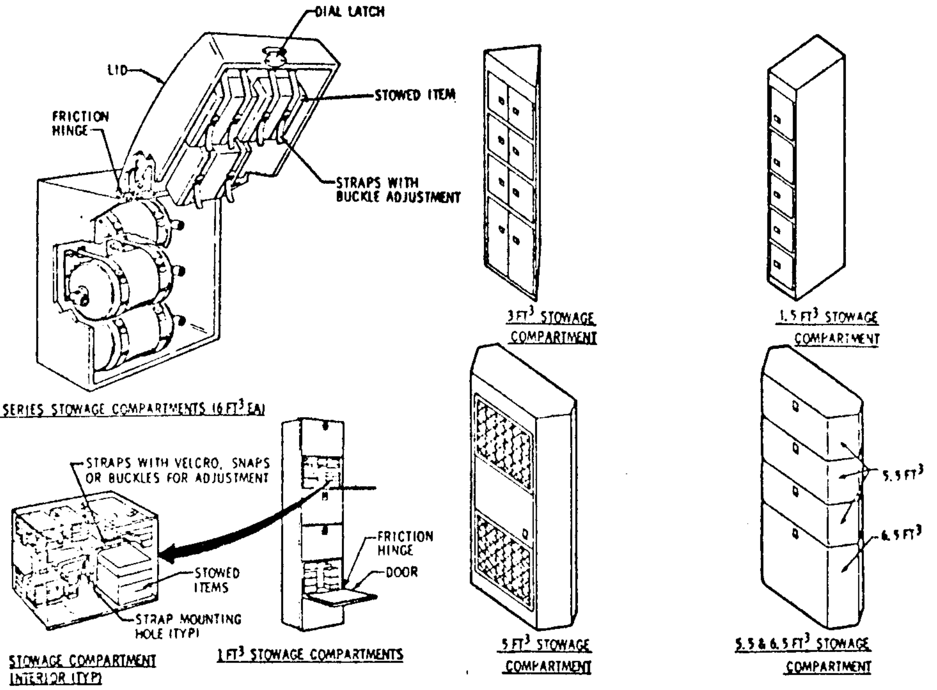


Figure 114. OWS Stowage Compartment Configuration

Several of the OWS standard compartment door latches failed or did not provide a positive latch. The third crew considered them under designed.

Because of the springs on both the OWS tissue access doors and trash doors not holding the doors closed, the crewmen occasionally snagged their clothes.

The containers functioned as planned except for the anomalies listed above. The door openings provided adequate access to contained items. The doors remained closed during the launch phase and were easy to operate with none of the latches jamming. The standard doors and standard hole patterns proved very versatile.

Some of the crewmen felt that the stowage compartment doors should have been built with a restraint (similar to the bungee) on the exterior surface. These were improvised on-orbit utilizing the bungee.

The OWS film vault design made it difficult to use. The doors being hinged in the middle prevented both doors being open at one time and consequently, transferring items from one side to the other was difficult. Also, the drawers should have had a lid to prevent items from floating up, thereby restricting the drawer above from closing. The crewmen recommended that sleep area stowage for each crewman should contain only his individual equipment not the other crewman's equipment, towels, etc. There should also be one door in the sleep compartment that opens like a "Ben Franklin" desk for tasks such as writing.

2. Internal Arrangement

a. Design Description - The internal arrangement was designed to provide equipment stowage in use areas and in some instances to group like items together; that is, spares, dispenser resupply items, photographic equipment, etc.

b. Post Mission Assessment - In most instances, the hardware arrangement proved satisfactory, was utilized as designed, with no anomalies reported.

Trash generation areas should be closely evaluated during training to identify optimum placement of containers in the flight vehicle. This point was well illustrated when the first crew exchanged some container doors to provide each crewman a trash compartment in the wardroom. This demonstrated the versatility of the standard compartment doors. These changes were accomplished by pulling the hinge pins, exchanging the doors, and reinstalling the hinge pins.

Comments from the crews indicated that some changes to the stowage system are recommended. For example, tools should be stowed together and identified by tool type rather than by tool use. They recommended that the trash bags should be stowed in one, central location. Also, items stowed in drawers should be identified by labels placed on the exterior of the drawer to indicate the drawer's contents. Finally, they recommended that increased stowage volume should have been provided in the Experiment and Waste Management Compartments.

3. Equipment Restraints

a. Design Description - Equipment restraints fall into two general categories: launch restraints and on-orbit restraints. Launch restraints were designed to protect equipment during powered flight and allow removal of equipment for usage on-orbit. On-orbit restraints were designed to restrain equipment at various temporary locations during the mission. This included short straps, long straps, equipment restraints, universal mount, and bungees, etc. The short strap was 12-inches long with snaps 4-inches on center. The long strap was 26-inches long and could be adjusted from approximately 22-inches to 8-inches. Velcro was provided on the long strap for adjustment. Bungees were fabricated from coiled springs with attach snaps and hooks on each end. They were approximately 11-inches long and stretched to approximately 16-inches. There was also a supply of "stick-on" snaps and Velcro in the repair kit for use at the crew's option.

b. Post Mission Assessment - The launch restraints were used as planned. On-orbit restraints were used extensively. The short straps should have been a couple of inches longer to make them more useful.

The First Mission crew reported the 400-foot film cassette restraints in OWS film vault drawer B kept moving to the rear of drawer. The restraining tab was apparently not locking the film cassette in place in the drawer. These restraints existed in other film vault drawers and worked satisfactorily.

The second crew found camera equipment loose in one of the OWS film vault drawers. The stowage requirements had not been anticipated prior to SL-1 launch and therefore restraints had not been provided.

In some instances, mosite restraints allowed small items to float free. The pudding can restraints in the food galley allowed the cans to float out. This restraint was categorized as inadequate.

There were no anomalies reported for MDA or AM stowage hardware.

No malfunction of stowed equipment was reported as a direct result of the launch environment. All stowage containers, stowage positions, and restraints were used as anticipated.

The crew recommended more temporary stowage facilities throughout the vehicle. The straps, used extensively in the OWS, were somewhat difficult to use because they were stiff and rough, and in some cases, inside stowage containers, the buckles wound up in hard-to-reach places when the locker was partially empty.

The crewmen commented that there should have been more on-orbit stowage facilities near use locations. An example is a more permanent stowage capability for photographic equipment near the Wardroom window.

One concept of stowage that the crews disliked was bags in bags and a little cubical for numerous individual items (e.g., the flashlight stowage). One point to be made is that launch padding is not needed for on-orbit stowage.

4. Fasteners

a. Design Description - A variety of different crew operated fasteners were used on the Skylab vehicle. Reasons for these differences include:

(1) The participation of several contractors, and attendant high costs which would have been incurred by strict requirement for design commonality.

(2) An effort by all participating designers to select the appropriate fastener for each application.

The lack of design commonality was a positive, though unanticipated, bonus in that it permitted a comparative evaluation of several types of fasteners which may be candidates for future spacecraft application. The results of the ranking of nineteen fasteners by the Skylab 2 and 3 crewmen was obtained. Table 11 briefing describes each fastener and provides the average rating (based on a 1-10 scale), the rank order, and a synopsis of comments for each.

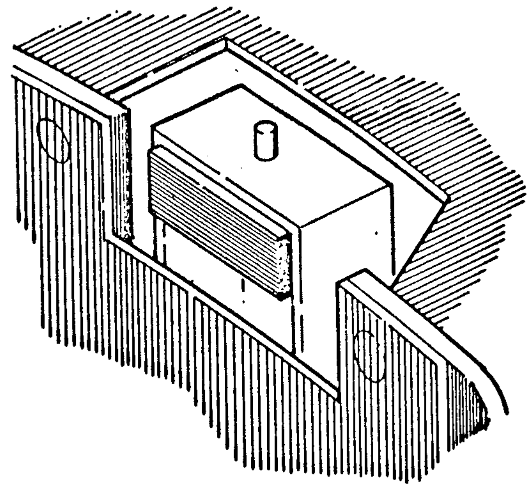
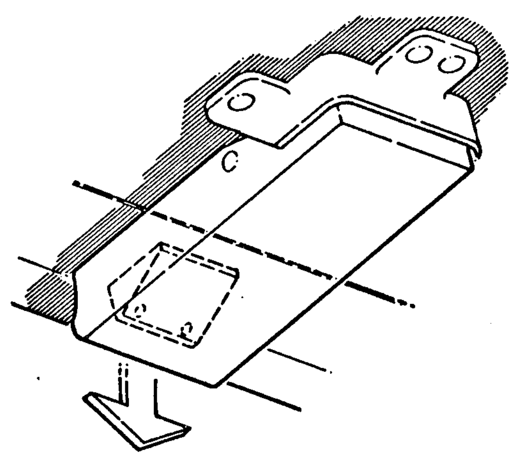
CREW CONSENSUS	DESCRIPTION
1 RANK — **8.83** MEAN RATE COMMENT: Appears to be easiest of all to use. It is recommended for wider application, including interior usage, particularly where strongly positive latching is not required.	Magnetic Latch FASTENER  SKYLAB USE: ATM VC Film Access Doors in-orbit.
2 RANK — **8.75** MEAN RATE COMMENT: Due to ease of its operation, this is an excellent latch.	Springed Ramp Latch FASTENER  SKYLAB USE: OWS Ring Locker Doors.

Table 11. Skylab Fastener Evaluation-1 of 10

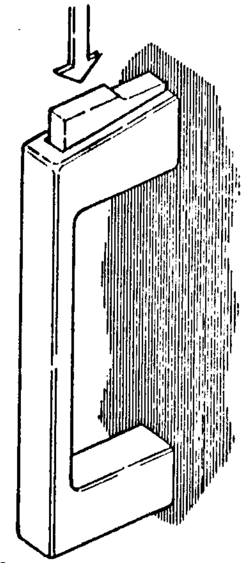
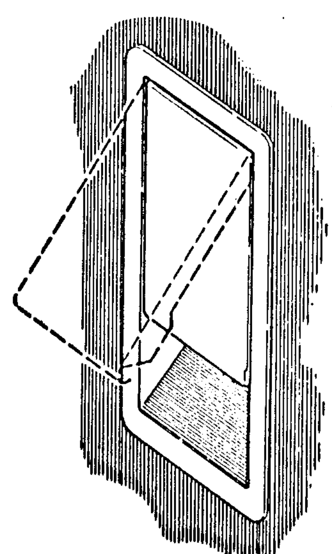
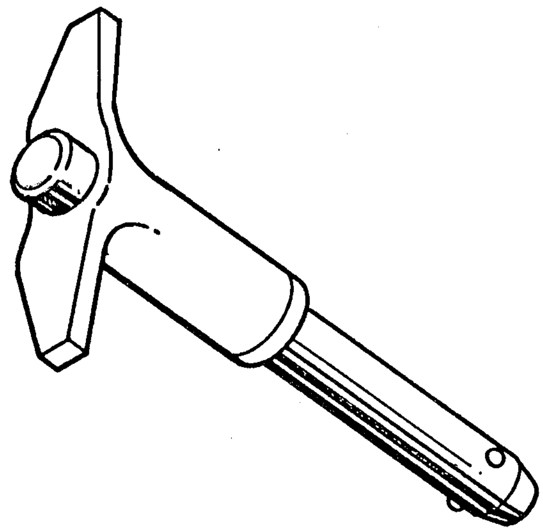
CREW CONSENSUS	DESCRIPTION
RANK: 3 — MEAN RATE: 8.50 COMMENT: Slamming the door to achieve closure is undesirable. Slamming was found to be required because of ice build-up in the freezer. Low ratings attributed to this feature were therefore given less weight resulting in an overall high rating for the latch.	Handle and Trigger Latch FASTENER  SKYLAB USE: Food freezer and refrigerator doors.
RANK: 4 — MEAN RATE: 8.50 COMMENT: Easy to use, however requirement to slam the door or lift the latch handle to achieve proper latch engagement on closure is an undesirable feature.	Lift Handle Latch (Adamsrite) FASTENER  SKYLAB USE: OWS Crew Compartment Locker doors.

Table 11. Skylab Fastener Evaluation-2 of 10

CREW CONSENSUS	DESCRIPTION
RANK: 5 MEAN RATE: 7.00 COMMENT: Wide divergence of opinion given. Criticality of alignment is undesirable. However, it is appropriate for use as a launch lock.	FASTENER: Pip Pin  SKYLAB USE: Multiple usage, but mainly as a launch lock.

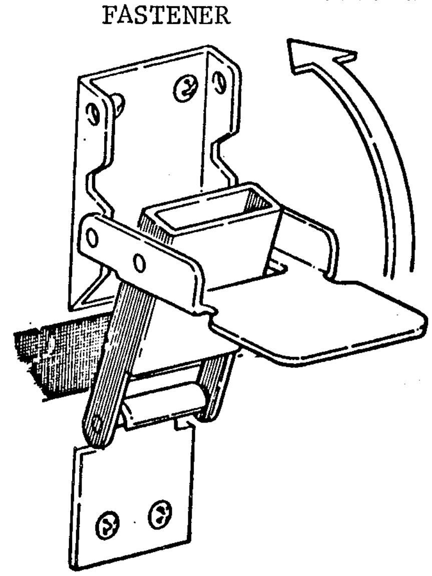
CREW CONSENSUS	DESCRIPTION
RANK: 6 MEAN RATE: 6.6 COMMENT: Could be a "superior" latch if provided with friction hinges to prevent "flopping" when disengaged.	FASTENER: Suitcase Latch  SKYLAB USE: Various equipment storage box lids.

Table 11. Skylab Fastener Evaluation-3 of 10

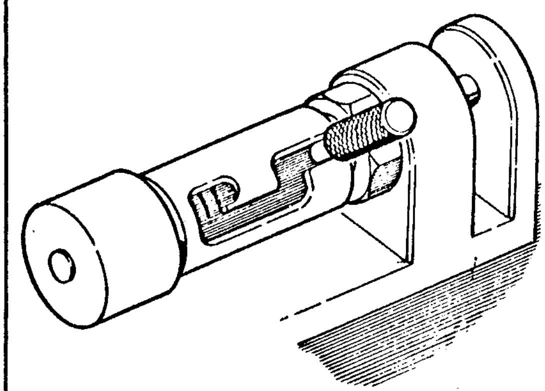
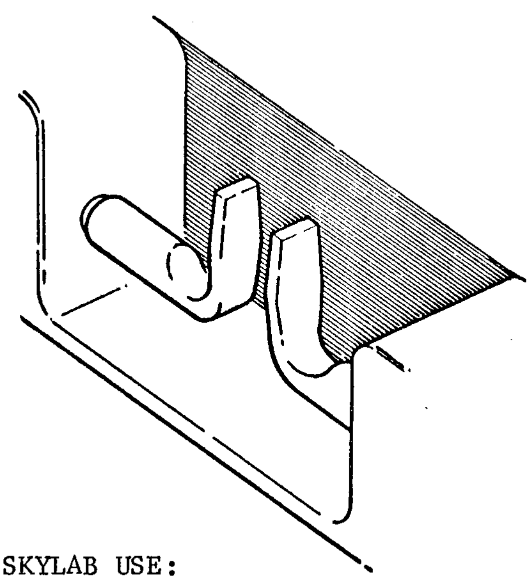
CREW CONSENSUS	DESCRIPTION
7 RANK — 6.00 MEAN RATE COMMENT: Opinion varied. Alignment problems exist but is adequate for infrequent use.	Rifle Bolt Latch FASTENER  SKYLAB USE: S082A & B Film Tree and S190A Covers.
CREW CONSENSUS	**DESCRIPTION**
8 RANK — 6.00 MEAN RATE COMMENT: Not frequently used, however some problems of alignment exist.	Squeeze Spring (Dog Ear) Latch FASTENER  SKYLAB USE: MDA Flight Data File, CO_2 Absorber box, and Miscellaneous Stowage Container.

Table 11. Skylab Fastener Evaluation-4 of 10

CREW CONSENSUS

9 — RANK

5.40 — MEAN RATE

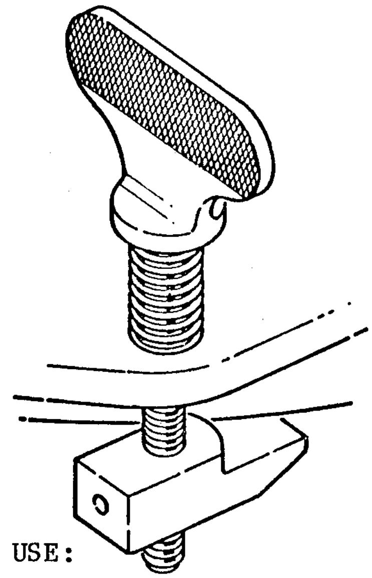
COMMENT:

Infrequently used; however "too much pushing and turning" is required to engage screw. Having "three or four leads per turn" would be better.

DESCRIPTION

Thumb Screw and Dog Latch

FASTENER



SKYLAB USE:

M512 Experiment cover.

CREW CONSENSUS

10 — RANK

5.34 — MEAN RATE

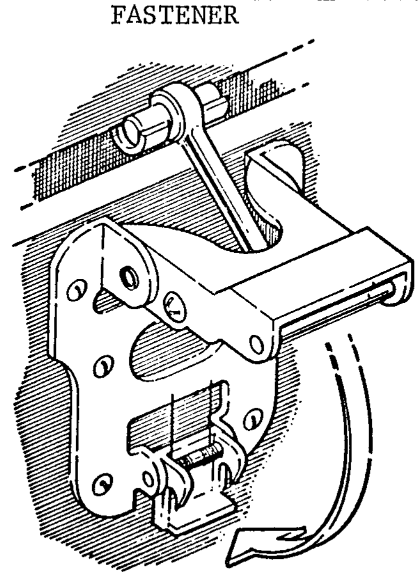
COMMENT:

Similar to suitcase type, would be better with friction hinges to prevent "floating to the locked position". This is particularly bothersome when multiple operation is required

DESCRIPTION

T-Bar Latch

FASTENER



SKYLAB USE:

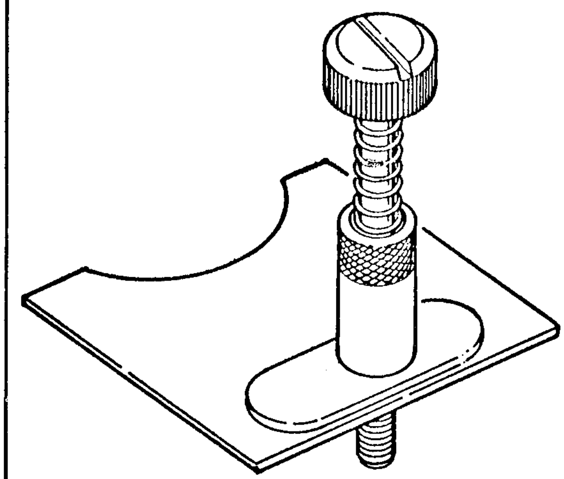
Portable fan cover and T027 storage box lid.

Table 11. Skylab Fastener Evaluation-5 of 10

CREW CONSENSUS		DESCRIPTION
11 RANK	5.20 MEAN RATE	Springed Slot Screw FASTENER

COMMENT:

Same as Thumb Screw and Dog Latch, required "too much pushing and turning". Would be better with "three or four leads per turn."

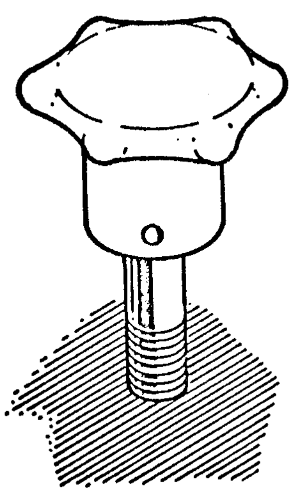


SKYLAB USE:
OWS Forward Compartment
PLV fan and fan connector access covers.

CREW CONSENSUS		DESCRIPTION
12 RANK	5.00 MEAN RATE	Knob Handle Screw FASTENER

COMMENT:

Used only as launch lock; required too many turns for disengagement.



SKYLAB USE:
OWS Forward Compartment,
PLV Fan Cluster launch lock.

Table 11. Skylab Fastener Evaluation-6 of 10

CREW CONSENSUS

13 — RANK

4.75 — MEAN RATE

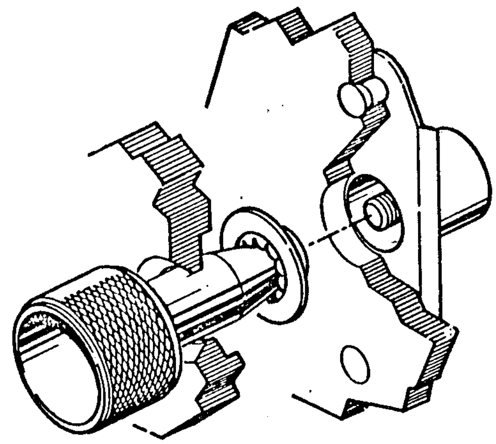
COMMENT:

Wide variance of opinion. Good for small items but not on large bulky, covers; difficult to align; retainer ring may be broken if used frequently; may be adequate for infrequent use.

DESCRIPTION

Locking Screw Latch (Calfax)

FASTENER



SKYLAB USE:

OWS intercom box installations and extensively throughout the airlock as panel and cover fasteners.

CREW CONSENSUS

14 — RANK

4.33 — MEAN RATE

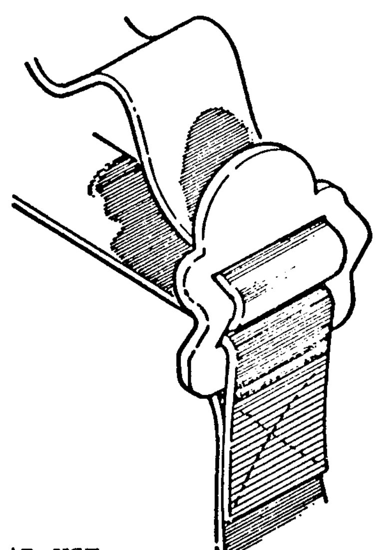
COMMENT:

Good restraint but difficult to work with. Rough strap difficult to work through buckle for tightening. A smoother material may help.

DESCRIPTION

Restraint Straps

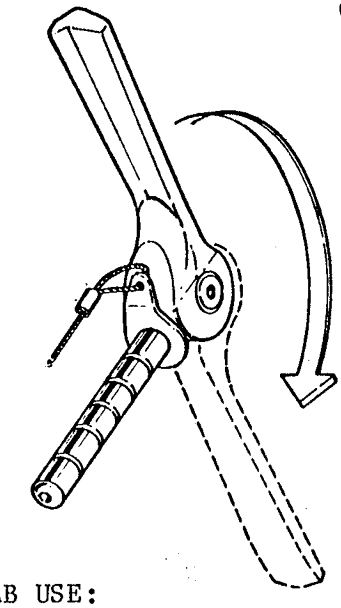
FASTENER



SKYLAB USE:

Restrain equipment in storage lockers.

Table 11. Skylab Fastener Evaluation-7 of 10

CREW CONSENSUS	DESCRIPTION
15 RANK — 4.00 MEAN RATE COMMENT: Difficult to align; where existing, the handle lock button too small. Satisfactory for infrequent use.	Expandable Sleeved Pin FASTENER (Expando Grip)  SKYLAB USE: OWS tripod leg lock and MDA film vault door lock.

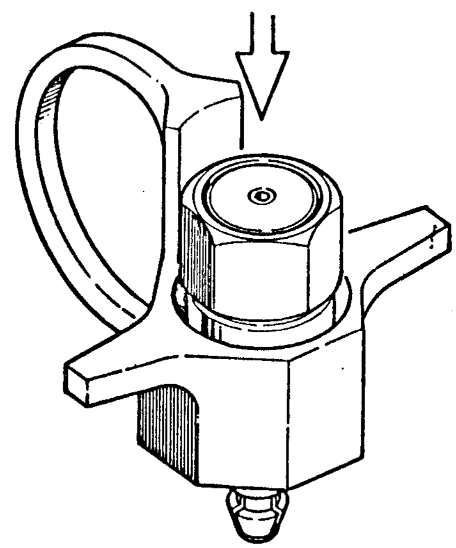
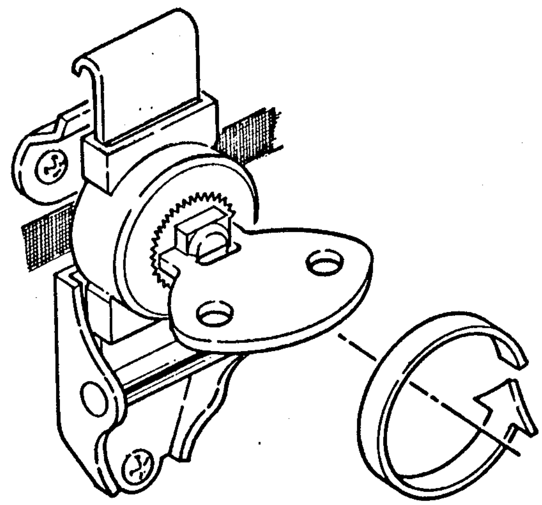
CREW CONSENSUS	DESCRIPTION
16 RANK — 3.67 MEAN RATE COMMENT: Infrequently used, too "cumbersome" to use, too hard to adjust, even requiring a tool at times.	Astro Pin FASTENER  SKYLAB USE: Portable tether attachment. Made to engage in triangle grid, also used to attach portable foot restraints to triangle grid.

Table 11. Skylab Fastener Evaluation-8 of 10

CREW CONSENSUS		DESCRIPTION
17 RANK	3.50 MEAN RATE	Twist Strap & Hook Latch FASTENER (Dialatch)

COMMENT:

Like the other "strap type latches" (T-Bar and Suitcase) this latch "floats" to hooked position; two hands often needed to complete fastening; particularly difficult when used in multiples.

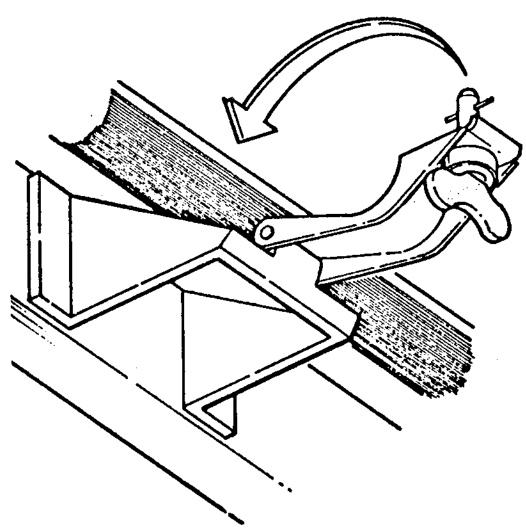


SKYLAB USE:
OWS Portable Lights

CREW CONSENSUS		DESCRIPTION
18 RANK	3.00 MEAN RATE	Twist Lock FASTENER (Camlock)

COMMENT:

Difficult to engage, required twisting to engage, then twisting to tighten; too small for effective grip; and especially hard to operate in small, confined areas.



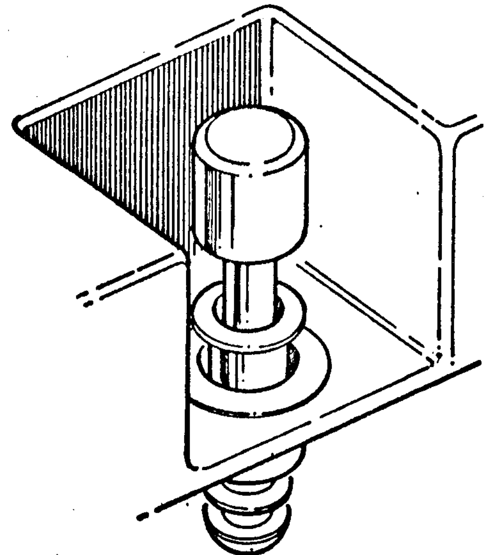
SKYLAB USE:
OWS Water Hose Retention

Table 11. Skylab Fastener Evaluation-9 of 10

CREW CONSENSUS		DESCRIPTION
19 RANK	2.00 MEAN RATE	Push Button Latch FASTENER

COMMENT:

Not positive locking - comes loose when bumped; sometimes jams requiring tool to release; tends to deteriorate with use.



SKYLAB USE:
Food Tray lid to tray fastener.

Table 11. Skylab Fastener Evaluation-10 of 10

b. Post Mission Assessment - Most of the different types of fasteners onboard were used extensively by one or more crewmen from each manned mission.

Some of the lift handle latches (used on OWS standard lockers) were broken as previously mentioned.

Several of the locking screw latch (Calfax) captive retainers were broken.

The push button latch (used on food tray lid) slipped all the way through the latching hole in the mating surface several times and required prying with pointed tools from underneath. Also, when latched, it did not give a positive latch and was accidently released when bumped.

In addition to the fasteners in Table 11, two latches were provided outside the vehicle on the film access doors of Apollo Telescope Mount (ATM) for use during Extravehicular Activity (EVA). The center work station (VC) access door latch, Figure 115, functioned adequately but was criticized by the crewmen because its operation (push-to-open, pull-to-close) was opposite of that normally expected. It is noted, also, that a separate lock was required for launch.

The Sun End Workstation door latching mechanism, Figure 116, combined launch restraint and orbital operation in the same mechanism. Its orbital operation as a door lock was excellent. It also served as a handhold when in the locked position.

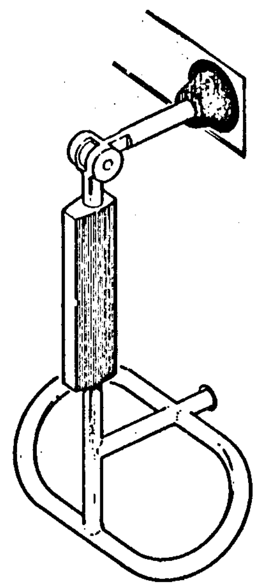


Figure 115. ATM VC Film Access Door

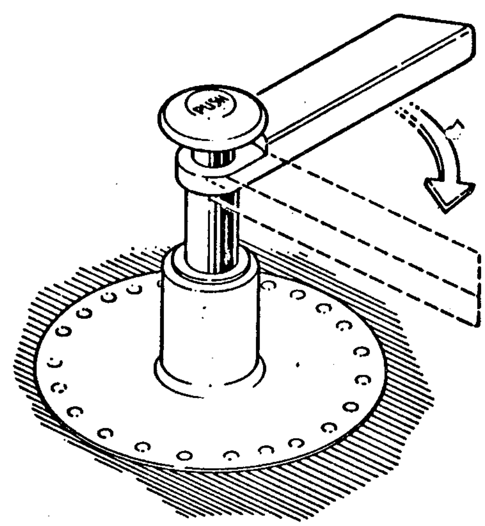


Figure 116. ATM VS Film Access Door Lock

The crew's subjective evaluation of the Skylab fasteners is shown in Table 12. Fasteners are ranked according to mean ratings. Comments accompanying the completed rating forms indicated that some crewmen used a given fastener more than other crewmen. Ratings turned in by crewmen who used the fastener frequently were weighted more heavily than the ratings by crewmen who seldom used the device. Weighted ratings are indicated by an asterisk. In cases where mean ratings for two fasteners were identical, the higher rank was assigned to the fastener with the lower standard deviation, since that would indicate a greater agreement among the crewmen.

Table 13 reflects the ranking of all nineteen fasteners as a single group. However, the rating process also involved evaluation of each of these for its specifically assigned function(s). For example, magnetic latches were not directly comparable with threaded fasteners because each served a different function; certain fasteners required reinforcement to withstand launch loads, and some did not; some fasteners were frequently used, some were not. Accordingly, the fasteners were divided into three categories within which they were ranked. The results are shown in Table 13.

All nineteen fasteners were rated by each of the six Skylab crewmen on a subjective 1-10 scale. It is recognized that unique design requirements will often dictate special fastening techniques, some of which perhaps received low scores on this evaluation. However, it is useful to note that the two factors which appear to account for most of the differences in ratings are:

(1) Design and operational simplicity.

(2) Sensitivity to minor misalignment between mating parts.

The most positively rated fasteners are those of simple, straightforward design and those which can tolerate minor changes in alignment. Conversely the most consistent criticism of poorly - rated fasteners is their alignment criticality. Stringent alignment is difficult to maintain through launch or with repeated use, and manual alignment is an additional demand on crew effort.

The magnetic latch, which received the most favorable rating, is not suitable for launch and return restraint. A useful combination might be a magnetic latch coupled with a separate launch/return positive restraint which could be maintained open during orbit.

In several cases, minor design modifications might have resulted in significantly higher fastener ratings. For example, the chief criticism of "suitcase" type latches was that, after release, it tended to "flop" and sometimes re-engage. Built-in friction at the hinge point might eliminate this objection.

Several other criticisms concerned fastener application rather than faults with fasteners per-se. For example, alignment-critical fasteners might be acceptable for use on substantially rigid mating pieces but not on relatively flexible sheet metal covers.

5. Placards and Labels

a. Design Description - Placards and labels are designed to provide location information for stowed items and procedure information for equipment operation.

FASTENER	MEAN RATE	STD DEV
1. Magnetic Latch	8.83	1.07
2. Springed Ramp Latch	8.75	1.07
3. Handle & Trigger Latch	8.50	0.87
4. Lift Handle Latch	8.50	1.12
5. Pip Pin	7.00	1.83
6. Suitcase Latch	6.16	1.46
7. Rifle Bolt Latch	6.00	1.63
8. Squeeze Spring Latch	6.00	2.19
9. Thumb Screw & Dog Latch	5.40	1.62
10. T-Bar Latch	5.34	1.53
11. Springed Slot Screw	5.20	1.33
12. Knob Handle Screw	5.00	1.67
13. Locking Screw Latch (Calfax) *	4.75	2.27
14. Restraint Straps	4.33	1.79
15. Expandable Sleeved Pin Expando Grip	4.00	1.63
16. Astro Pin	3.67	1.97
17. Twist Strap and Hook Latch (Dialatch)	3.50	1.38
18. Twist Lock (Camlock)	3.00	1.15
19. Push Button Latch*	2.00	0.82

***Rating weighted in accordance with frequency of use (see "Discussion" above).**

Table 12. Rank Order, Crew Subjective Evaluation of Skylab Fasteners

On Orbit Only*	Launch and On-Orbit Use: Frequently Engaged/ Disengaged in Flight	Launch and On-Orbit Use: Infrequently Engaged/ Disengaged in Flight
1. Magnetic Latch	1. Springed Ramp Latch	1. Rifle Bolt Latch
2. Handle & Trigger Latch	2. Lift Handle Latch	2. Thumb Screw & Dog Latch
3. Squeeze Spring Latch	3. Pip Pin	3. T-bar Latch
4. Push Button Latch	4. Suitcase Latch	4. Springed Slot Screw
	5. Locking Screw Latch (Calfax)	5. Knob Handle Screw
	6. Restraint Straps	6. Expandable Sleeved Pin (Expando Grip)
	7. Twist Strap and Hook (Dialatch)	7. Astro Pin
		8. Twist Lock (Camlock)

***Required Additional Provisions to Withstand Launch Evironment**

Table 13. Use Category Ranking of Fasteners

b. Post Mission Assessment - The placards and labels were used as planned with no anomalies reported.

The second mission crew dated the plenum bags to provide identification for retrieval of an item, if requested.

Confusion was experienced by the first crew with the TAL. The stowage location number for the TAL was E699 and the procedure referred to it by this number. However, that number did not appear on the TAL. The operational procedure decal for the TAL was designated 634. There was a distinction between "Panel" numbers and "Stowage Location" numbers. In most instances, these numbers defined different physical locations within the vehicle. In this case, the two numbers identified the same location, but had two different applications.

Location of labels on the tool kits prevented easy reading and was a complaint of the crew. A more logical numbering system in the OWS forward compartment would have been helpful (i.e., separate series of numbers for OWS forward compartment wall and OWS forward compartment floor). Time was wasted while searching for stowage locations which were not identified as being on floor or wall.

In areas where many small components with similar names or shapes are utilized, there should be a picture or sketch for each item at their use location. An example of this is the OWS Water System.

6. Transfer Stowage

a. Design Description - Transfer stowage hardware was designed to contain equipment off-loaded from the Command Module and other parts of the cluster. Other than restraints designed primarily for launch of equipment, the transfer stowage provisions consisted of additional straps in existing containers, disposal bags, and plenum bags.

b. Post Mission Assessment - The hardware was used as planned and worked as designed. No anomalies were reported. Planned transfer items were secured in the programmed locations.

There should have been a provision to restrain the IMSS in the rear of the chiller.

7. Consumable Summary - A summary of OWS consumables following the first mission is included as Table 14.

A summary of OWS consumables following the second mission is included as Table 15.

A summary of OWS consumables following the third mission is included as Table 16.

	On-Board at SL-1 Launch	On-Board at End of First Mission	Quantity Used - First Mission	Quantity Expected Usage First Mission	Remarks
Trash Bags	366	344	22	73	
Disposal Bags	168	120	48	33	
Urine Disposal Bags	149	109	40	28	
Utility Wipes	23 Boxes @ 196 = 4508	21.5 Boxes	1.5 Boxes	4.6 Boxes	
GP Tissues	11 Boxes @ 392 = 4312	9 Boxes	2 Boxes	2.2 Boxes	
Biocide Wipes	5 Boxes @ 70 = 350	4.6 Boxes	0.4 Boxes	1 Box	
Wet Wipes	7 Boxes	6.4 Boxes	0.6 Boxes	1.4 Boxes	
*Plenum Bags	28	22	6		
Urine Collection Bags	432	360	75	3/Day 84	3 Urine Bags carried on SL-2 CM
Fecal Bags	465	417	48	84	
Vacuum Cleaner Bags	140	135	5	24	

* 6 Plenum Bags are in the Plenum Ares (5 full and 1-3/4 full).

Table 14. Consumable Summary - First Mission - 1 of 2

	On-Board at SL-1 Launch	On-Board at End of First Mission	Quantity Used First Mission	Quantity Expected Usage First Mission	Remarks
Urine Sample Bags	375	312	63	66	
1/2 Urine Sample Bags	125	104	21	18	
Contingency Fecal Bags	185	184	1	A/R	
Washcloths	840	747	93	168	
Towels	420	385	35	84	

Table 14. Consumable Summary - First Mission - 2 of 2

Item	On-Board at SL-1 Launch	On-Board at End of Second Mission	Quantity Used Second Mission	Quantity Expected Usage Second Mission	Quantity Used First and Second Missions	Quantity Expected Usage First and Second Mission	Remarks
Trash Bags	366	282	62	146	84	219	
Disposal Bags	168	66	54	68	102	101	
Urine Disposal Bags	149	48	98	59	138	87	37 Urine Disposal Bags were resupplied on SL-3.
Utility Wipes	23 Boxes @ 196 = 4508	14.8 Boxes	6.7 Boxes	9.2 Boxes	8.2 Boxes	13.8 Boxes	
GP Tissues	11 Boxes @ 392 = 4312	3.6 Boxes	5.4 Boxes	4.4 Boxes	7.4 Boxes	6.6 Boxes	
Biocide Wipes	5 Boxes @ 70 = 350	2.1 Boxes	2.5 Boxes	2 Boxes	2.9 Boxes	3 Boxes	
Wet Wipes	7 Boxes	4.6 Boxes	1.8 Boxes	2.8 Boxes	2.4 Boxes	4.2 Boxes	
*Plenum Bags	28	19	3	A/R	9	A/R	
Urine Collection Bags	432	185	178	3/Day 168	253	252	3 Urine Bags Carried on SL-3 CM
Fecal Bags	465	282	135	168	183	252	
Vacuum Cleaner Bags	140	125	10 **	48	15	72	

* 9 Plenum Bags are in the Plenum Area ** Estimated

Table 15. Consumable Summary - Second Mission - 1 of 2

Item	On-Board at SL-1 Launch	On-Board at End of Second Mission	Quantity Used Second Mission	Quantity Expected Usage Second Mission	Quantity Used First and Second Missions	Quantity Expected Usage First and Second Missions	Remarks
Urine Sample Bags	375	204	108	132	171	198	
1/2 Urine Sample Bags	125	33	71	36	92	54	
Contingency Fecal Bags	185	177	7	A/R	8	A/R	
Washaloths	840	517	230	336	323	504	
Towels	420	300	85	168	120	252	

Table 15. Consumable Summary - Second Mission - 2 of 2

Item	On-Board at SL-1 Launch	On-Board at End of Third Mission	Quantity Used Third Mission	Quantity Expected Usage Third Mission	Quantity Used First, Second, and Third Missions	Quantity Expected Usage First, Second, and Third Missions	Remarks
Trash Bags	366	120	162	146	246	366	37 Urine Disposal Bags were resupplied on SL-3.
Disposal Bags	168	0	66	68	168	168	
Urine Disposal Bags	149	0	66	59	204	146	18 Urine Disposal Bags were resupplied on SL-4.
Utility Wipes	23 Boxes @ 196 = 4508	.3 Boxes	14.5 Boxes	9.2 Boxes	22.7 Boxes	23.0 Boxes	
GP Tissues	11 Boxes @ 392 = 4312	3 Boxes	.5 Boxes	4.4 Boxes	8.0 Boxes	11.0 Boxes	
Biocide Wipes	5 Boxes @ 70 = 350	2.0 Boxes	.1 Boxes	2 Boxes	3.0 Boxes	5 Boxes	
Wet Wipes	7 Boxes	4.0 Boxes	.6 Boxes	2.8 Boxes	3.0 Boxes	7.0 Boxes	
Plenum Bags	28	15	4	A/R	13	A/R	
Urine Collection Bags	432	0	185	3/Day 168	438	420	
Fecal Bags	465	90	192	168	375	420	
Vacuum Cleaner Bags	140	115	10 **	48	25	120	

**Estimated

Table 16. Consumable Summary - Third Mission - 1 of 2

Item	On-Board at SL-1 Launch	On-Board at End of Third Mission	Quantity Used Third Mission	Quantity Expected Usage - Third Mission	Quantity Used First, Second, and Third Missions	Quantity Expected Usage First, Second, and Third Missions	Remarks
Urine Sample Bags	375	0	204	132	375	330	
1/2 Urine Sample Bags	125	0	53	36	145	90	20-1/2 Urine Sample Bags were resupplied on SL-4
Contingency Fecal Bags	185	177	0	A/R	8	A/R	
Washcloths	840	193	324	336	647	840	
Towels	420	142	188	168	308	420	30 Towels were resupplied on SL-4.

Table 16. Consumable Summary - Third Mission - 2 of 2

M. Illumination

1. Fixed Illumination - The fixed illumination system was designed to provide interior lighting for initial entry, normal and emergency crew activities, and experiment operations. This system included fluorescent lights located in the MDA and in the OWS forward and crew quarter compartments, and incandescent lights in the AM and EVA work/translation areas. The fluorescent floodlight design concept was selected to obtain maximum illumination levels at minimum power consumption.

a. Design Description

(1) OWS Illumination - The OWS contained 42-floodlights for internal illumination as illustrated in Figure 117. Eighteen were located in the Forward Compartment, with eight lights on the forward dome and ten lights around the upper walls. Four were installed in the Wardroom, three in the WMC, three in the Sleep Compartment, and fourteen in the Experiment Compartment. To identify the location for the dome and upper wall lights in the Forward Compartment, the floodlight number was marked on the housing hinged cover. For the Crew Quarters light installation, the housing had marking numbers on both the integral light switch plate and on the opposite end plate. These floodlight numbers corresponded to the nomenclature on the remote light switch panels 616 and 630 and on the circuit breaker panel 613. In addition, a red stripe marking was placed on the hinged cover of floodlights used for initial entry and emergency purposes. Emergency lights were powered from two emergency busses from the AM and would have illuminated automatically if the cluster lost power. There were four emergency lights in the Forward Compartment and four in the Crew Quarters. These lights are illustrated by Figure 117.

Each floodlight circuit was protected by an individual circuit breaker and was routed through a panel mounted control switch. Most panel mounted control switches controlled groups of individual lights. Each floodlight assembly design included a local integral light switch with "OFF-LOW-HI" modes of control. The floodlight bulb was installed in a protective housing and was replaceable.

General illumination requirements were as follows: (Ref: OWS CEI Specification, Paragraph 3.3.1.8).

	Area	Footcandle (ft-c) - Minimum
(a)	Sleep Compartment	4.5
(b)	Wardroom	5.0-Average 3-ft from ceiling
(c)	Waste Mangement	9.0
(d)	Work Experiment Compartment	5.5
(e)	Forward Compartment	1.0-Average 3-ft from light source

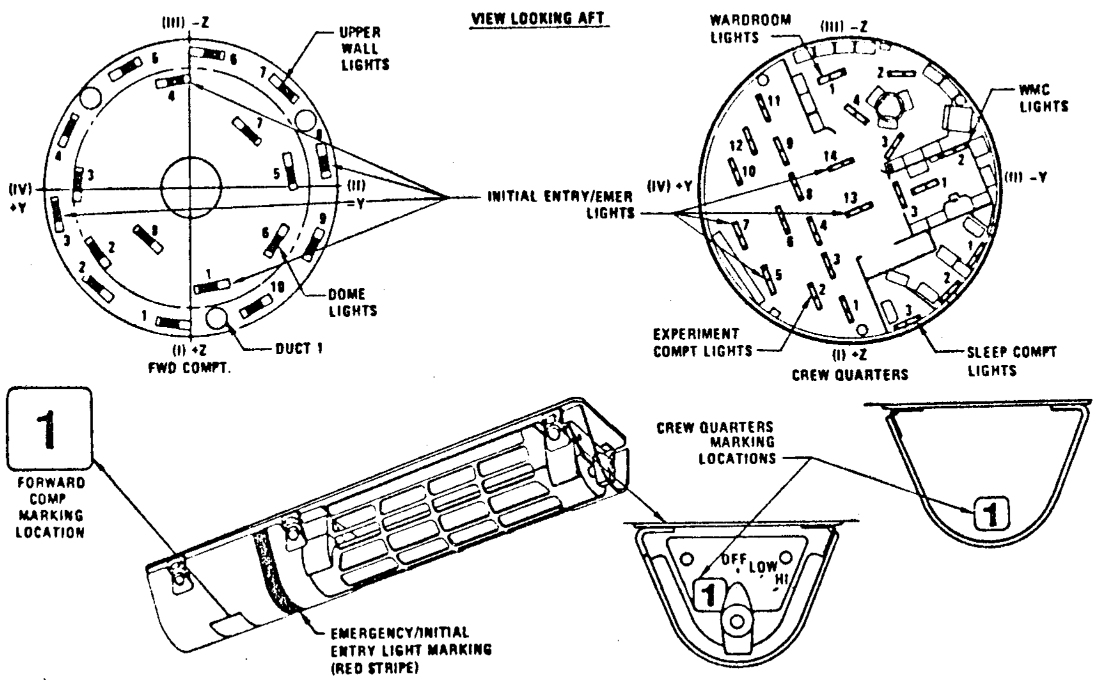


Figure 117. Light Locations and Markings

(2) MDA Illumination - The MDA contained eight floodlights. Four were located on the forward cone and four in the remaining area. The lights on the forward cone were marked FWD 1 through FWD 4 on the housing hinged cover. The lights in the remaining area were marked AFT 1 through AFT 4. One switch, near the MDA hatch, controlled all eight lights when the individual light switches were on and the two MDA light circuit breakers on panel 202 were closed. There were two floodlights used for emergency purposes (FWD 2 and AFT 3). In case of power loss on both AM busses, these lights would be powered by emergency power busses.

The odd numbered lights were supplied power by bus AM 1 through MDA lights 1 circuit breaker. The even numbered lights were supplied power by bus AM 2 through MDA lights 2 circuit breaker. The floodlight assemblies were the same as those in the OWS.

General illumination requirements were to provide an illumination level of 5 ft-c minimum at the ATM C&D console and the Experiment M512/M479 work station, and a general illumination level of 3.5 ft-c minimum when measured along the X-axis of the MDA.

(3) AM Illumination - The AM contained twenty ten-watt lights (fourteen in the STS and six in the AFT Compartment) and four twenty-watt lights in the Lock Compartment. EVA lights included four twenty-watt lights in the FAS area, eight twenty-five watt floodlights in the Film Transfer area, five twenty-watt lights at the ATM

Center Work Station and seven twenty-watt lights at the Sun End Work Station. All of the above were incandescent lights. Two of the STS lights and one lock compartment light were utilized as emergency lighting and would have been activated upon failure of both AM busses. The two STS emergency lights were Instrument Panel Flood Lights Number 8 and Number 10. The lock compartment emergency light was Number 4.

General illumination requirements were to equal or exceed 5 ft-c at 3-feet from the source of illumination in all habitable areas. EVA lighting was to provide a minimum of 2 ft-c at 3-ft from the source of illumination along EVA routes and 5 ft-c at 3-ft from the source of illumination on EVA work surfaces.

b. Post Mission Assessment - The crew used the illumination system during all missions, as anticipated, and all equipment operated in a normal manner. The crew reported that, during the work day, they usually had all of the lights turned on "HIGH" all of the time. All of the lights were usually turned off at night. On several occasions, lights were left on as night lights in the forward part of the cluster (AM, MDA, etc).

It was also noted that the crew used the head mounted lamp from the medical kit to perform certain maintenance tasks. This light provided sufficient illumination and was used particularly in the unlighted plenum area.

There were no reported anomalies associated with the OWS and AM illumination systems during the missions, other than some lamp replacements in the AM. An anomaly occurred in the MDA when Aft lights 2 and 4 went out. While performing the malfunction procedure, it was found that the switch on Panel 207 was intermittent. This was corrected by taping the switch closed. The power shortage, caused by the SAS problem on the first mission, required that power be conserved whenever possible. Use of the lighting system was therefore kept to an absolute minimum until EVA SAS deployment. During the second mission, light use was restricted in order to reduce OWS temperature during the high beta angles.

The illumination system operated as designed during the missions. Comments indicated that the crew considered the overall system to be adequate for its intended purpose with the following exceptions: (1) for closeup work like repair of items, (2) for shaving, and (3) for reading in the sleep quarters. The opinion of the crewmen was that the overall light levels should have been higher. The crews thought that the AM had the best lighting in the cluster and the EVA lighting was rated excellent. The crews thought it would have been highly desirable to have had fixed illumination in the plenum area.

The only expendables used were the bulb replacements in the AM. Less than 10% of the 120 AM spare bulbs were used.

Spotmeter readings of luminance levels in foot-Lamberts were obtained during the second mission and are listed in Table 17. CEI

Panel Number Location	Spotmeter Reading in Ft. Lamberts
Wardroom Table	3.5
Compartment E624	2.0
Panel 617	2.5
Compartment H831	3.5
Compartment H820	4.0
Location F544	1.0
T013 FMU #2	0.9
Compartment F555	1.2
Film Vault	0.9
Ring Container D408	1.2
Ring Container D446	1.2
Compartment S908	0.3
Compartment S912	1.8
M512 C&D 105	2.5
VTS Control Panel 109	2.5
EREP Control Panel 110	2.0
VTR Electronics 122	1.0
ATM C&D Console 130	1.3
EREP Primary Tape Rcdr 131	2.5
Miscellaneous Stowage Container 157	1.25

Table 17. Spotmeter Readings - Second Mission

specification illumination requirements, for the various cluster modules, were expressed in ft-c, as listed on the preceding pages, or divided Luminance in ft-L is equal to the illumination in ft-c, multiplied by the percentage reflectance of the surface. The measurements taken throughout the cluster were made by placing a sheet of paper on the surface of a panel and taking a spotmeter reading normal to the surface of the paper. The reflectance of the paper was about 85-90%. Converting the measured values from ft-L to ft-c does not give a direct comparison with the specification levels because they required a particular illumination value at a given distance from the light source. The panels were at varying distances from the light sources. Therefore, no quantative comparative analysis can be made between the in-flight spotmeter readings and the CEI specification requirements.

The first and second crew's subjective evaluation of ambient illumination throughout the cluster was that it was adequate, but somewhat marginal. The third crew felt that illumination was adequate. However, all three crews used flashlights, at various times, to provide supplemental lighting for IVA tasks.

2. Portable Illumination - Portable lights for special applications, were used to supplement the lighting system, by attaching the portable lights to the universal mount, which in turn attached to various structural members.

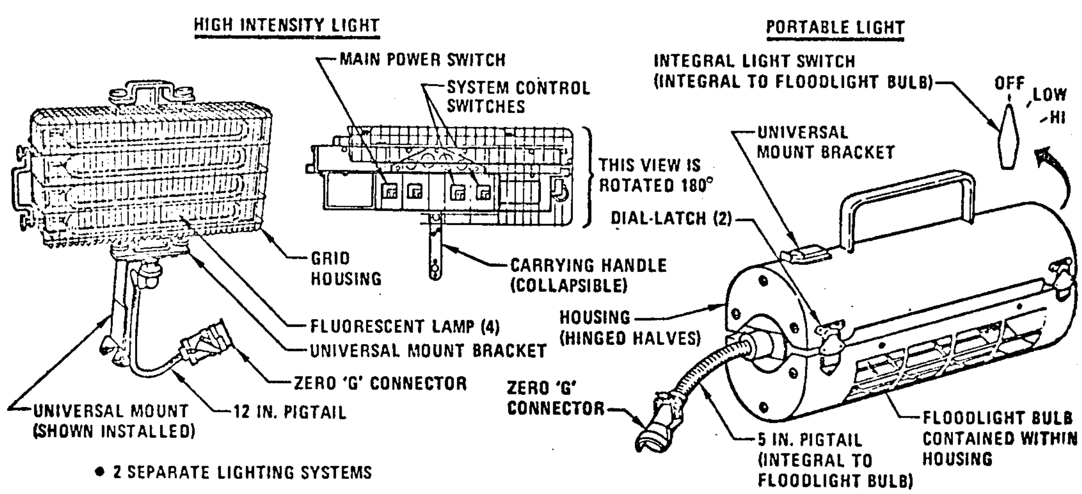
a. Design Description - The portable lights provided supplemental levels of illumination for crew operations requiring reading, writing, and other special operational and experimental tasks.

There were two types of portable lights - the low-power portable (3 each) and the high-intensity (2 each). The low-power portable light, identical to the general illumination system, used a replaceable flood light mounted in a protective case. The high intensity light used four high watt fluorescent lamps. Power, for the low-power portable lights, was provided by utility outlets used with utility cables. Power, for the high-intensity lights, was provided by the high power accessory cables. The high-intensity light and portable light are illustrated by Figure 118.

b. Post Mission Assessment - The crew reported that they made considerable use of portable light by attaching it to the universal mount and then attaching the mount to various structural members. The portable light performed as designed; however, the crews remarked that cable management was the biggest single problem when using this light. They felt cable reels were needed as were more and better cable tiedowns.

The high-intensity lights were used as planned and met all requirements. Prolonged use of the high-intensity light in certain areas resulted in locally elevated temperatures

There were no reported bulb replacements associated with these lights.



- 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

- 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

Figure 118. Portable Lights

N. Crew Communications

The Skylab Communication System was designed as a functional part of the Orbital Assembly (OA) Audio System to provide; 1) direct voice link between Skylab and the Space-Flight Tracking and Data Network (STDN) via the Command Module (CM) S-Band, 2) bio-medical data to the STDN through the AM PCM Telemetry System, 3) audio and visual displays of warning tones generated by the Caution and Warning System, 4) control for the operation of the Voice and Data Recording System in the AM, and 5) intercommunications between the astronauts within the OA.

This section will be concerned with the intercommunications link (audio system) and vocal (unaided) communications within Skylab.

1. Audio System

a. Design Description - The Audio System consisted of thirteen communications stations. These stations were located within the OA as follows:

Location	Quantity
Experiment Compartment (600, 627)	2
Waste Management Compartment (801)	1
Wardroom (702)	1
Sleep Compartment (901, 902, 903)	3
Forward Compartment (520, 540)	2
Dome Area (401)	1
ATM Panel (131)	1
M512 Facility (116)	1
MDA Dome Area (102)	1

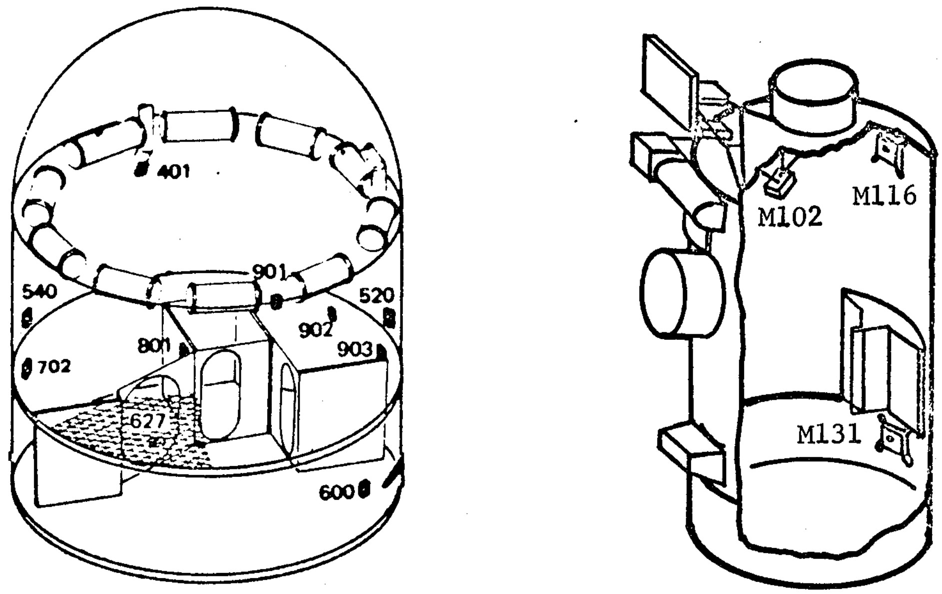
An illustration of these communication station locations is provided by Figure 119.

The audio system was a two-channel operating service, channels A and B, to each communication station.

Each communication station in the OA provided for simplex operation (talk or listen) with a speaker and a microphone. The station also provided the capability of headset voice functions for duplex (simultaneous talk and listen) voice communications between crew members within the vehicles, or between crew members in the OA and the STDN, on both channels. A typical Speaker Intercom Assembly (SIA) is shown in Figure 120.

Additional equipment provided for use with the SIA's included:

(1) Crew Communications Umbilical (CCU) - These 15-feet umbilicals transmitted communications, biomedical data, and caution and warning information between the SIA's and the communications carrier for IVA pressure suited operations, or the constant wear garment used with the biomedical vest.



ORBITAL WORKSHOP

MULTIPLE DOCKING ADAPTER

Figure 119. Speaker Intercom Assembly Locations

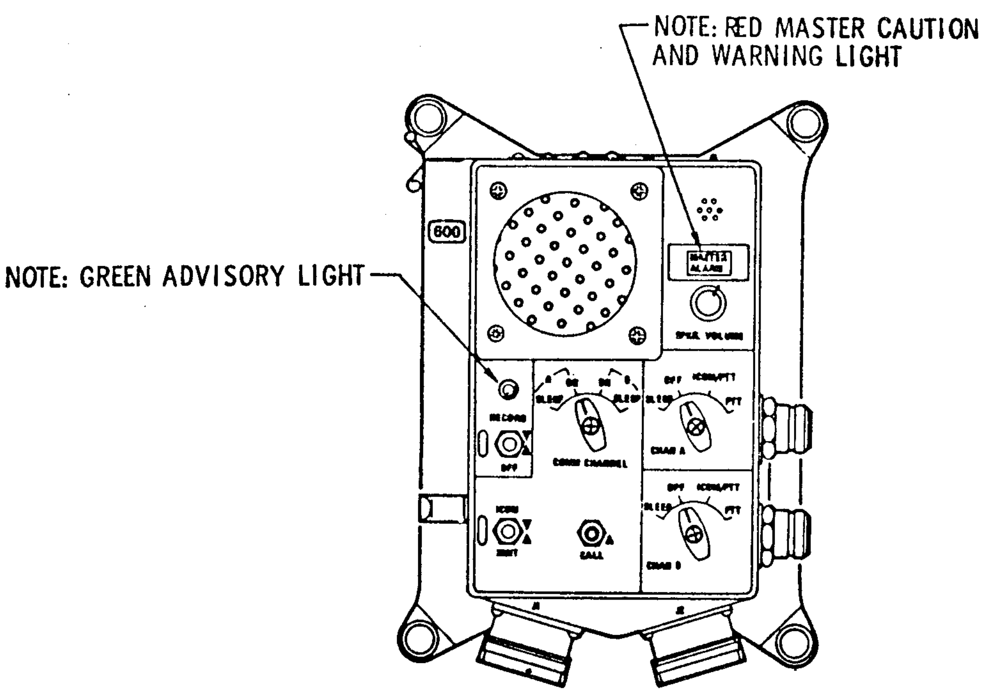


Figure 120. Speaker Intercom Assembly (SIA)

(2) Lightweight Crewmans Communications Umbilical (LCCU) and Communications Control Head - The LCCU was 15-feet long and carried communications and caution and warning tones. It mated to the SIA's and was used with the communications control head and lightweight headset. The communications control head provided volume control and transmit switch capability for the LCCU.

(3) Communications Carrier and Lightweight Headset - Both units provided talk and listen capability with the communications umbilicals. The communications carrier was intended primarily for suited operations with the CCU, and the lightweight headset for use with the LCCU.

b. Post Mission Assessment - The crews used the audio system hardware as anticipated. There were some operational modifications required as a result of an acoustic feedback problem encountered on all missions, which was a source of annoyance to all the crews.

Reduction of this feedback condition required volume setting adjustments on the intercom boxes or utilization of SIA's in other areas. Use of the SIAs tended to be limited to one SIA at a time, at usable volume, although the Sleep Compartment SIAs could be left on without interfering with other SIAs. SIAs in the Experiment Compartment and at the -Z SAL had the most frequent feedback problem.

Tests, prior to the second mission, indicated that the feedback problem could be alleviated if the volume selectors on all SIAs were set at approximately "9 o'clock". However, this procedure proved to be ineffective during the mission,because the setting provided insufficient volume for effective communications, unless the crewman was in the immediate proximity of the SIA. This condition was further aggravated by equipment noise in the vicinity of the listener. The problem continued with no noticeable reduction during the second mission. To prevent acoustic feedback, it was necessary to reduce the volume of all OWS SIAs to a low level, except the one in the Wardroom, which was maintained at an acceptable volume. The volume of the Waste Management Compartment SIA could be moderately increased without producing serious acoustic feedback. If the volume of the boxes, located either by the ergometer or over the -Z SAL, were increased, annoying acoustic feedback occurred.

Channel A was selected over channel B for voice recording as a result of an audio system problem. This selection was made after tests, between the crew and the ground control, demonstrated the deficiency of channel B. The crew also noted that equivalent audio levels were "9 o'clock" for channel A, and "11 o'clock" for channel B. It was estimated that channel B was about three decibels lower than channel A, on the same volume setting.

Occasional loss of information occurred when the crew failed to realize that AM recorder dumping had been initiated by ground command. Although recorder dumping was normally announced to the crew and its initiation caused loss of the green recording light on the SIA, poor coordination occasionally occurred. To avert the loss of AM tape recorder data/information, system design should prevent simultaneous tape recorder dump and crew operation.

A malfunction of a hand-held microphone occurred. The mike was subsequently marked with red tape and stowed. The crew considered the microphone a desirable item and recommended that replacements be brought up with the third crew. It was also reported, at the Crew System Debriefing, that the second mission crew replaced the SIA at the -Z SAL because the transmit switch had failed in the ON position.

With the exception of the acoustic feedback problems, the audio system (crew interface portion) operated in a satisfactory manner. Locations of SIA's within the OWS was reported satisfactory, although the SIA in the forward dome (401) was not used. Volume level was also described as satisfactory.

Use of the headset did not disable the speaker in the SIA and caused interference and annoyance with other crew activities.

Communications performance with the umbilicals was satisfactory; however, cable stiffness tended to dislodge the lightweight headset from the crewman's head. The major portion of communications directly utilized the speaker intercom boxes.

2. Vocal (Unaided) Communication - There is no hardware associated with this assessment other than the acoustical characteristics created by the entire configuration of the OA. It is, therefore, an evaluation of the oral and vocal communication results and peculiarities that currently exist in the zero-g and reduced pressure equivalent.

Unaided voice communication was somewhat difficult within the OWS. One could be heard in the OWS from the MDA if one shouted very loudly, but normal voice communication from the OWS to the MDA was impossible. The crew concluded that this condition was due to poor sound transmission (a function of 5-psi pressure levels) rather than to noise interference. Noise levels were considered low within the spacecraft.

The voice communication, in confined areas such as the Wardroom, was considered by the crew to be like "right here", although there was a tendency to get "close to the guy you were talking to." Unaided voice communication from the Wardroom or Experiment Compartment to the dome area was possible, but required "yelling".

SECTION III. CONTROLS AND DISPLAYS

Controls and displays included a variety of equipment throughout the OA which required crew operation and monitoring. The controls and displays provided a direct interface between the crew members and hardware systems.

Controls included hardware items which the crew operated to bring about equipment and/or performance changes, i.e., toggle switches, push buttons, circuit breakers and hand operated valves. Some controls required operation in conjunction with displays.

Displays included equipment which provided information to the crew concerning the function and status of its system or subsystems, i.e., meters, indicator lights, and gauges.

A. Orbital Workshop

1. Design Description - Controls and displays were located throughout the OWS'. All equipment which could feasibly be located in a single location was included at the Power Distribution and Control Console in the Experiment Compartment. All other controls and displays were installed remotely at their use location.

Controls and displays were designed in accordance with accepted human engineering practices. Nomenclature and labeling was selected to identify controls and displays and to ensure rapid and positive recognition. Control and display configurations are defined and illustrated in the OWS Configuration Nomenclature document, MDC G0837C.

2. Post Mission Assessment - The crews used the OWS controls and displays as planned during the entire course of the Skylab mission.

Crew comments indicate that these hardware items were used in a normal manner, as anticipated prior to flight.

During the Skylab mission, there were several anomalies which occurred relative to false fire alarm indications. The first false indication occurred early during the first mission in the Sleep Compartment, and was attributed to an increase in sensitivity of the fire sensor, as a result of the high temperature environment at the time. The crew turned the fire sensor "OFF" until the temperature returned to normal. No further alarms were generated.

The second false fire indication occurred in the Wardroom during the second mission and was attributed as an effect of the South Atlantic Anomaly. The alarm went off again within ten seconds after reset. After the second reset, no further alarms were generated.

During the third mission, the crew also reported some false fire alarm indications. No specific cause has been reported relative to these anomalies.

During the first mission, the crew reported that the experiment mode select switch on Panel 617 was loose. Procedures were developed and a tool kit check performed in the High Fidelity Mockup at MSFC and recommendations transmitted to JSC. No report of crew action relative to this problem was reported. The second crew also reported that this same switch was loose. The crew reported that they would fix it, but no verification was received. This same problem also recurred during the third mission, but no fix was attempted. The crew decided that, during future usage, they would verify that the rotary switch was all the way to the "A" (Stop) position, and then count to the desired position to make certain that the switch was properly positioned.

There were no specific adverse or critical crew comments relative to the assessment of the OWS controls and displays. The first crew indicated that the concept of wickets and partial recess, which was used, was a good compromise toward switch and circuit breaker protection. The second crew commented that finger clearances between wickets and switches/circuit breakers were adequate. The third crew made no specific comment relative to OWS controls and displays. Therefore, it is concluded that the overall layout, arrangement, groupings, etc. of the OWS controls and displays proved to be adequate and acceptable for all missions.

B. Airlock Module

1. Design Description - Control and display mechanization for the AM was unique. All other U. S. spacecraft had been designed exclusively for either manned or unmanned operation. The AM was designed for both. The AM C&D panels provided the crew option of ground control (via DCS) or onboard control of Skylab systems and equipment. The primary control capability was thus vested onboard during the manned phases. The crew had the option of relegating control of various components within a given system to DCS. Equipment and controls, unique to manned mission phases (fans, lighting, molecular sieves), had conventional mechanization with only onboard controls capability. Conversely, some functions that did not effect manned phases, such as 2-watt transmitter selection, had only ground control capability. Controls for remotely mounted systems and equipment were located on the main STS C&D panel along with displays which provided operating information or feedback to the crew.

Panels and controls were numbered to facilitate communication and documentation reference. The numbering system started with 100 series numbers for the forward end of the vehicle (MDA) and ran to 1000 series numbers in the OWS aft areas. The AM used 200 series numbers in the STS and 300 series numbers through the tunnel section for panel identification.

All circuit breakers for AM power were located on panels 200, 201 and 202 on AMS 157 bulkhead. The circuit breakers, as were all other panels, were protected by bar guards which provided operating reaction points, minimized inadvertent operations, and allowed visual assessment of circuit breaker position. Circuit breaker arrangements on each panel were grouped by function and system. Color coded bands beneath the breakers denoted the bus from which each breaker derived its power. The color code was also depicted in the Bus Distribution schematic on panel 211.

Schematic diagrams were superimposed directly on control panels, where panel space allowed. Where a panel was insufficient or controls seldom used, functional flow diagrams were located on adjacent areas.

Control positions were shown by indicator lights for momentary switches or detents and pointers for valves and rotary switches. Special tools needed for control operation were tethered adjacent to the required location. Controls requiring unusual manipulation were marked with operating instructions.

Controls and displays were located throughout the AM to provide crew operational capability near the equipment being operated or controlled. Thus, perceptible cues to equipment operating status, such as fan start up or compartment venting, could be easily detected at the control operating position.

The combination of main AM C&D panel and ECS equipment in the STS provided a crew station arrangement where all system interactions (cluster attitude, EPS, ECS, C&W, etc) and control responses could be ascertained at a single control station.

Caution and Warning (C&W) contained visual annunciators and inhibit/enable switches for redundant sensors. C&W generated audible alarm tones were transmitted by the AM audio system to the SIA speakers and the low level audio systems. Emergency tones for fire or rapid Delta-P were sounded by klaxons independent from the AM audio system. Audio levels were adjustable by controls on panel 207.

Individual C&W sensors could be inhibited by the inhibit/enable switches to prevent repeated false alarms by malfunctioned sensors. These switches also allowed parameter isolation for trouble shooting where one visual annunciator was used for multiple parameters. The fire alarm system was mechanized to allow replacement and adjustment of individual sensors without triggering the emergency alarms in C&W.

Lever lock type toggle switches were used on control panels in the EVA lock compartment and on critical functions in the STS. The EVA panels used lever lock switches to prevent unintentional controls operation due to the limited mobility and field-of-view of a suited crewman.

AM meters were universal indicators that would interface with different transducers with change only to scale and internal resistance required. The meter scale was stepped to put the needle and scale in one plane and eliminate parallax. The scale was translucent white with black graduations which provided easy viewing by meter internal illumination or by ambient cabin lights. All AM meters were located adjacent to their related controls.

Color coding of selected AM controls was used to emphasize the specific nature of those controls to the crew. Emergency controls or crew interface was indicated by aviation red (i.e., fire extinguisher ports).

A black and yellow cautionary striped band denoted a crew interface that should be used with caution and adequate preparation (i.e., lock compartment depressurization valve). Items to be discarded on activation were painted green. In addition, a variety of anodized aluminum decals and markers were used to emphasize critical crew interface and provide easy visual identification of similar connectors whose functions were not interchangeable. While not actually a color code, black or white stripes were used on all crew operated electrical connectors to show major keyway locations.

2. Post Mission Assessment - AM C&D arrangement in Skylab was based on a combination of judgments by experienced spacecraft engineers and empirical data drawn from previously successful Mercury and Gemini programs. The unique and unprecedented long term habitability requirements of Skylab, coupled with revisits by different crews with somewhat different mission goals, provided an unequalled opportunity to evaluate the performance of C&D design in a single vehicle by crews of varied technical backgrounds, interest, personalities and capability levels. Thus, any criticism, common to separate crews, should indicate the need for serious evaluation and design investigation.

Skylab manned mission successes have indicated that the AM panels are adequate to insure satisfactory completion of mission goals. Circuit breakers were inadvertently operated on panels 200, 201, and 202, apparently due, in part, to the panel design. The 90-degree bend in the panels made it difficult to see and resulted in procedural errors. The panels were also located in the high traffic forward tunnel area and inadvertent operation was caused by translating crewmen's feet and hands. The circuit breaker bar guards could not absolutely prevent stray feet and hands from moving the circuit breakers.

ECS/TCS C&D mechanization provided superior capability to accommodate all required operational modes. The crews were able to take positive action to select various modes of system operation that insured completion of mission goals. In addition to providing solution to ECS/TCS malfunctions, the ECS mechanization allowed crew manipulation of fans to reduce power consumption during the early SL-2 mission.

Capability to control OWS Heat Exchanger fans from panel 390 allowed OWS heat exchangers cleaning to restore OWS duct flow. Capability to select ATM coolant pumps allowed uninterrupted operation when ATM coolant loop indicated malfunctions. Mol sieve controls allowed selection of alternate fans/inverters when one inverter failed. Redundant systems and control capability in the Condensate Control Panel permitted normal operation after the apparent failure of a dump probe heater during SL-3 activation. Individual control capability of N_2 regulators on panel 225 O_2/N_2 Controls Panel allowed manipulation of those regulators to correct N_2 pressure regulation problems.

Mechanization of the EPS system C&D allowed safe preservation of the AM electrical systems until the SL-2 crew could deploy the remaining OWS array. Controls capability to isolate AM batteries from the electrical system, while permitting ATM supplied power to run necessary AM systems, insured the survival of AM batteries until OWS solar array power became available. Bus load sharing adjustments in the AM EPS allowed full use of AM PCGs and batteries with only one OWS solar array functioning.

No failures occurred in the indicator lights on the EPS C&D panel. Light intensity and color selection was proven adequate for mission requirements.

All AM meters and their internal lighting performed without failure or malfunction. The AM meters showed no tendency to drift out of calibration. The meter scale graduations and nomenclatures proved adequate for display of legible, non-ambiguous data. Geometric relationship between AM meters and their related controls and systems was also proven adequate to accomplish mission goals. EPS voltage adjustment, using Regulator Bus Adjust pots and Bus voltage meters for exclusive on board control, was not attempted. Instead, a combination of TM data feedback from ground readouts with manual pot adjustment by the crew was used. This type of system allows greater versatility and reduces crew monitoring requirements.

Audible alarms generated by C&W were suitable for anticipated orbit conditions. Alarm loudness adjustments on panel 207 were available had the interior operating noise levels in Skylab required adjustment of alarm audio levels. The preset sound levels, coupled with SIA and Klaxon locations, provided complete coverage of the orbital cluster without causing physical hearing damage to the crews. Visual alarms and annunciators in the C&W system were adequate to initiate proper crew reaction and provide system trouble-shooting capability. The sensor isolation capability, made possible by the inhibit/enable switches, eliminated false alarms from a drifting duct flow sensor and eased EVA prep time requirements by quick isolation of tunnel fire sensors.

For future manned spacecraft, circuit breakers, or any controls, should be separated from paths of high crew traffic. Also, physical operation of AM breakers is similar to toggle lever switches. Operation of these breakers requires access from two opposite sides of the breaker. Consideration should be given to push-pull type breakers for selected applications.

However, if a circuit breaker is to be used regularly for switching functions, the toggle type lever is superior to the push-pull actuation.

Organization of Skylab electrical power system controls physically separate the AM EPS from ATM CBRM controls. The C&D design of the two electrical power systems is very different. Since both control sets perform quite similar functions, some crew training time and on-orbit operational time could have been saved if the systems used a common control panel and similar or identical C&D design and mechanization.

The lack of controls malfunction in the AM EPS indicates possible advantages in its C&D design. Displays in the AM EPS could be improved to enhance on-board fine adjustment of AM bus voltages by the addition of a meter "scaling switch" that would expand meter sensitivity and scale.

A manual backup (bypass, or control) for critical automatic control functions should be mandatory for all C&D mechanizations. This is normal aircraft and spacecraft design practice which would have been useful for coolant loop temperature control. A central servicing location for both coolant loops internal to the vehicle would have greatly reduced the effort required to generate an on-orbit reservice technique.

For spacecraft with long orbital lifetime, design parameters for on-orbit repairs and servicing requirements must be included in the mechanization and arrangement of vehicle controls and displays. An on-orbit maintenance plan for all critical systems should be designed into the vehicle, even with redundant systems.

Caution and Warning parameters provided in Skylab were large in number and included some items that recent orbital operations have shown to be unnecessary: "Duct-Flow" for the gas interchange duct could be replaced with fluttering strips of paper or eliminated entirely, since stagnant gas pockets have proven to be no problem as long as some air mass flow is available. The emergency fire warning system differs from the rest of the C&W system. This difference (remote sensors & control panels) required added crew training, in locating and silencing the alarms. The audible alarms must be silenced for good crew communication and the difference between silencing a fire alarm and other audible alarms could cause confusion. The memory system for "emergency" parameters should be similar to that of other C&W parameters.

Internal lighting for AM meters, based on Skylab experience, was proved unnecessary. In applications such as Skylab, where the operating crewman did not have to change visual field from outside the vehicle to inside the vehicle (i.e., docking and station keeping in CSM), internally lighted meters are not required.

C. Apollo Telescope Mount

1. <u>Design Description</u> - The Apollo Telescope Mount Control and Display Panel, Figure 121, was designed to perform sophisticated astronomy observations using seven telescope assemblies. It represents the most complex scientific control and display console flown in an orbital mission.

During operation of the astronomy observation experiments, specific operational problems occurred in connection with the panel's controls and displays, as is evidenced by mission data from SL-2, SL-3, and SL-4. These problems are described in ensuing paragraphs, in order to pinpoint those problem areas where man/system interfaces show operational inadequacy. Subjective crew comments and an in-depth analysis of SL-2 telemetry data were used to study the panel design features which contributed to operational problems. In some instances, these design problems are specifically identified with the objective that similar mistakes be avoided on future missions (i.e., on Shuttle payload control panels).

2. <u>Experiment Interface Evaluation</u> - The experiment interface area represents the highest area of operational activity, in that the performance of the operational procedures (building blocks) is centered around this functional area. This accounts for the fact that the same area is the location of the highest number of man/machine interface problems. The information below presents the subjective comments obtained from real-time crew comments, crew voice transcripts and debriefings. These comments are not intended to be a judgment of design adequacy or inadequacy but, rather, to identify obvious problem areas and prevent their recurrence in future designs.

a. Hydrogen Alpha Telescopes 1 and 2 - The man/system interface problems incurred during the Hα experiment, Figure 122, were relatively minor. The most significant problem dealt with operation of the Hα1 mode (frames/minute) switch. The crew cited numerous instances when they had left the MODE SELECT switch (3 position toggle switch) in the wrong position.

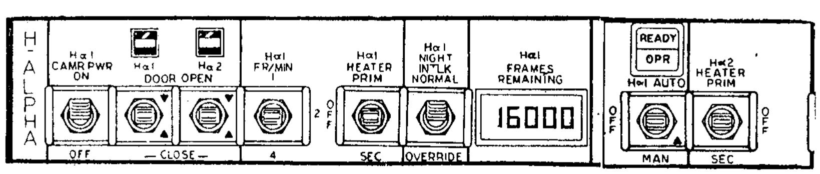


Figure 122. Hydrogen Alpha Telescopes 1 and 2 C&D

Two causal factors for this occurrence have been postulated. First, the frames/minute mode is controlled by a three position toggle switch, but other experiment mode switches are rotary types. The specific problem associated with a toggle switch is that determination

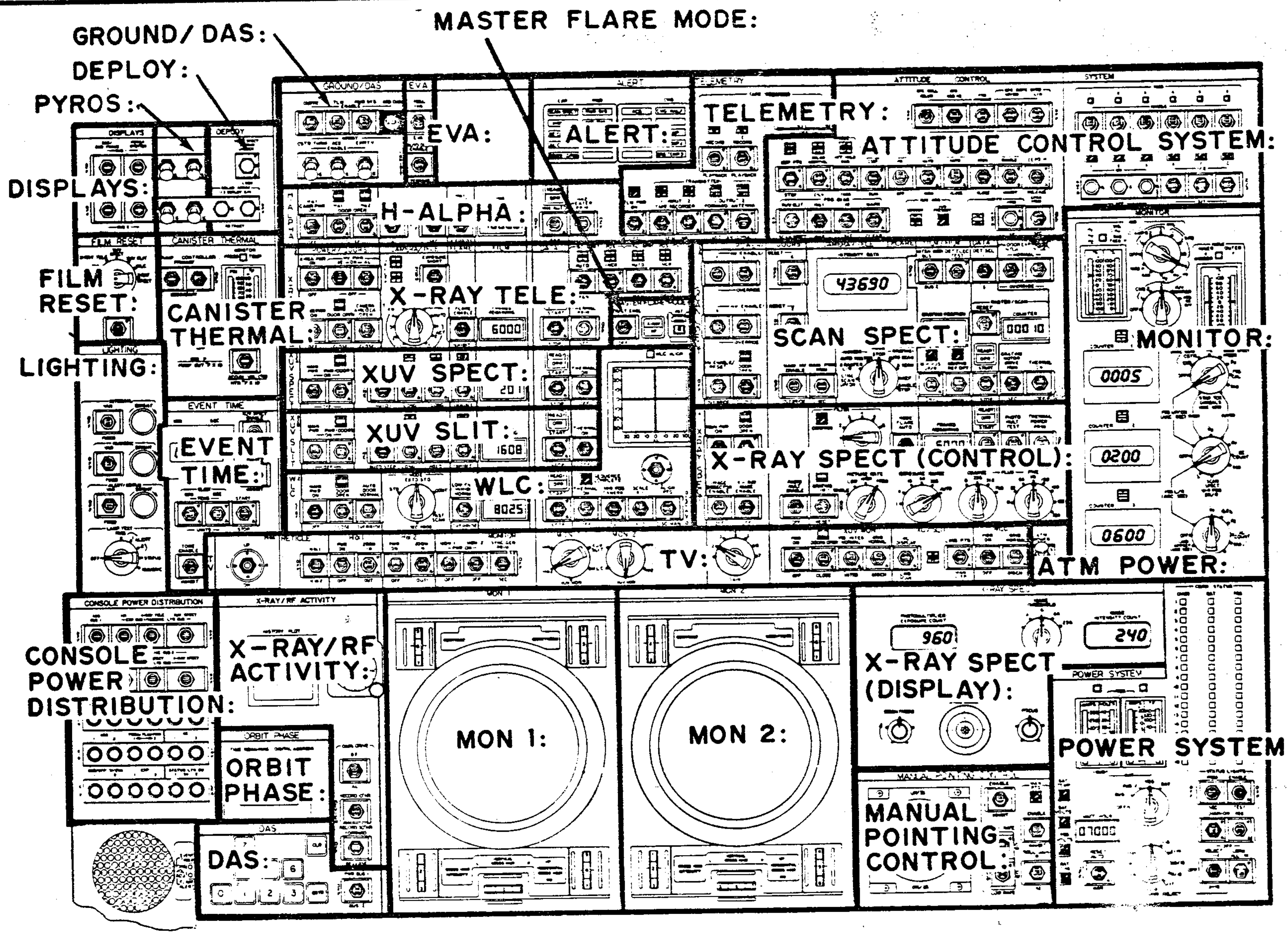


Figure 121. ATM Control and Display Panel

of the actual position of the switch commanded is solely dependent on the operator's visual reference. This means that a crewman looking straight onto the panel at some angle below eye level may be unable to distinguish the actual position of the switch. This problem is inherent in the use of latching toggles without position talkbacks.

A second factor that might explain the inaccurate switch positioning is the location and symbology used for displaying the operational procedures for Hα . These instructions are located on the bottom line of the building block, and they are not highlighted by a block as are instructions for the other experiments.

b. S056 X-Ray Telescope - The S056 experiment, Figure 123, had certain internal hardware design problems; the "active modes" took an additional frame, or timed out longer than specified. This

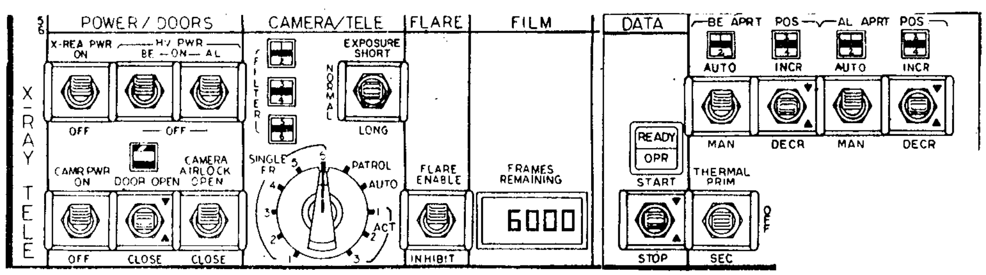


Figure 123. S056 X-Ray Telescope C&D

created certain interface problems with other experiments in relation to the total time required for a particular operating set of experiments. The controls and displays allocated to the S056 experiment appeared functionally adequate, and no sequential operation problems occurred. The only area which might have been improved was the separation of functions allocated to the X-Ray Event Analyzer portion of the panel and the experiment area.

c. S082A XUV Spectrograph (Extreme Ultraviolet) and S082B Extreme Ultraviolet (XUV) Slit - The reason for combining discussion of these experiments is that most of the problems associated with them resulted from the similar appearance of the two (Figure 124), thereby creating many points of confusion. Indeed, in some areas on the control panel, there is a one-to-one switch correspondence -- a reasonable causal factor for error. For example, the crew would often set up an operational sequence correctly on one of the experiments but would then activate the START switch on the other experiment.

The failure of the S082B experiment timer function during the Skylab Mission required the addition of an auxiliary timer. The timer consisted of a MODE SELECT switch, a START/STOP switch, and a READY/ OPERATE light. The timer was very similar in purpose to the S054 experiment but differed functionally because of the interconnection

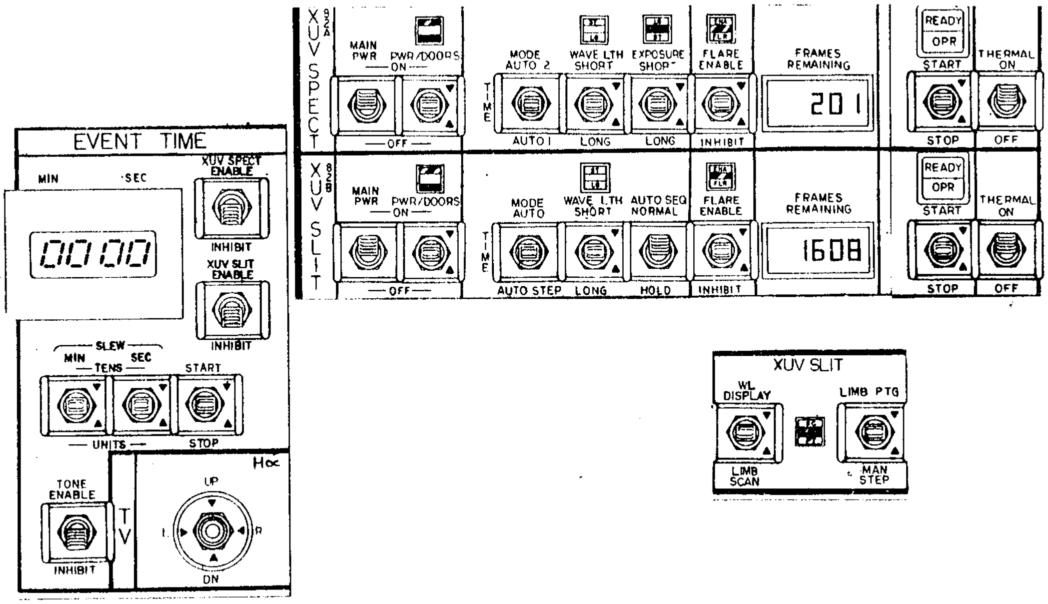


Figure 124. S082A and S082B XUV Instruments C&D

with the ATM electronics power distributor located in the ATM console. The interconnection between the ATM and the auxiliary timer involved the making of two electrical connections. The crew was able to perform this using connector pliers contained in the on-board tool kit. The auxiliary timer was affixed to the top of the ATM console and operated satisfactorily during the entire Skylab Mission. The crew incurred no significant interface problems with the exception of the reach distance between the two modules.

d. S052 White Light Coronagraph (WLC) - From its original design, the S052 experiment, Figure 125, had one inherent man/system interface problem associated with the READY/OPERATE light. The indication for an operate condition was only given after the completion of the first frame (≈10-15 sec). The null state before this illuminated condition served to indicate that the experiment was in an off condition, which, if the crewman were not paying close attention, could be very confusing.

The second problem area on S052 involved the procedural step of turning off the S052 WLC TV power before closing the aperture door. The crewman often forgot to perform this function (which was not required during nominal experiment operations). Althought this error was made on several occasions by the crew, no irreparable damage was done to the WLC vidicon from exposure to direct sunlight. For future designs, however, when this type of oversight must be prevented, a mechanical or electrical interlock is desirable. Reliance on crewman memory of procedures is not a dependable preventive measure.

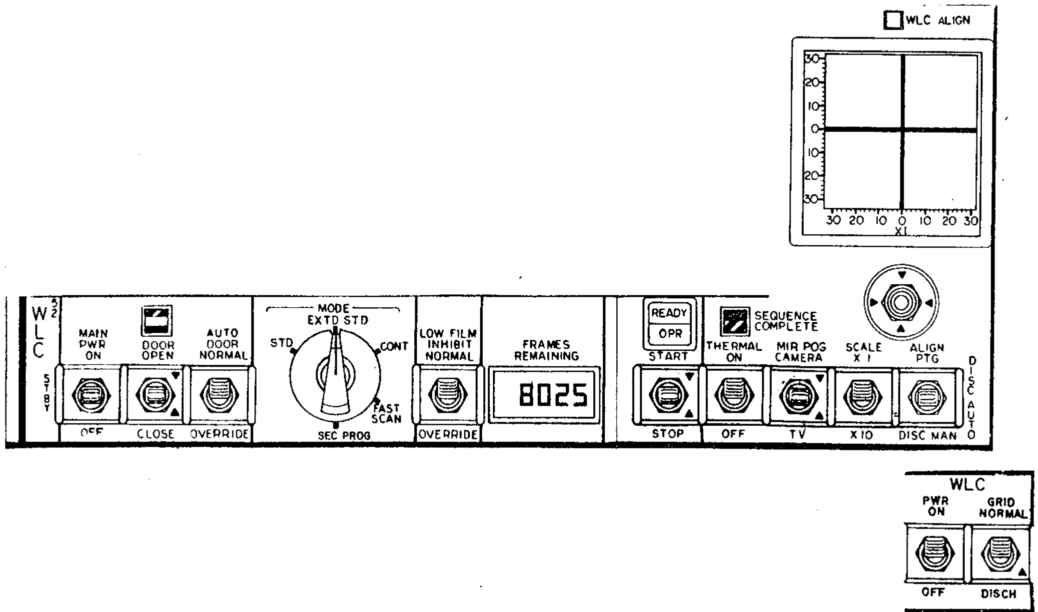


Figure 125. S052 White Light Coronagraph C&D

e. S055 Scanning Polychromator Spectroheliograph - There were no major problems in performance of the S055 experiment, Figure 126, with the unimportant exception that the crew frequently allowed the experiment to collect data past the appointed building block end times. As this instrument had no limit on film, however, this overrun factor was not significant, as long as it did not impact the overall timeline.

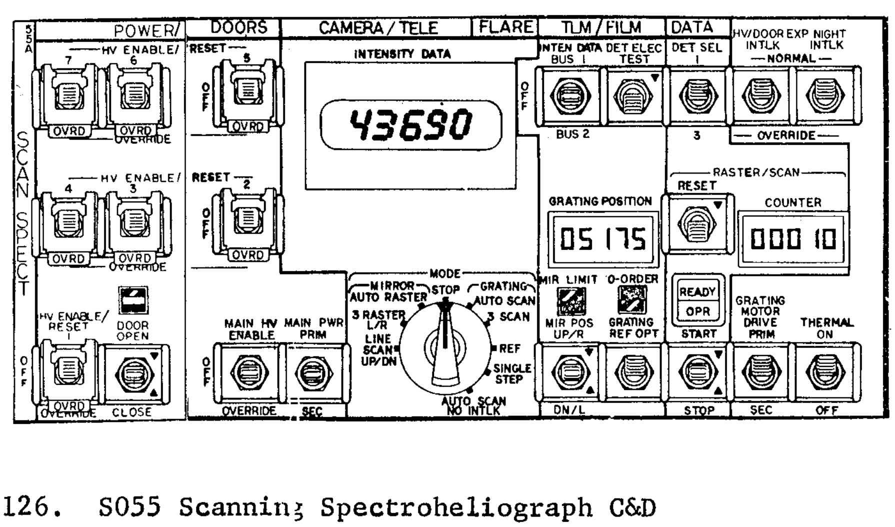


Figure 126. S055 Scanning Spectroheliograph C&D

The installation of the lockout switch guards on the high voltage detectors prevented any occurrence of inadvertent selection of the override position. This design addition facilitated efficient man/machine interface.

f. S054 X-Ray Spectrographic Telescope - The S054 experiment, Figure 127, was considered the most operationally complex of all ATM experiments. The crew exercised only a limited number of the experiment's operational modes, due to the limited variety of solar activity occurring during mission flight. The mode most frequently used was the manual preprogrammed mode which used only a limited amount of film and had a simplified operational sequence.

There were several equipment malfunctions which caused operational interface problems during the mission. These problems were significant, but did not severely impact operational data collection. The primary problem which occurred during the SL-2 Mission was the failure of the experiment's READY/OPERATE light. This failure created an inability to determine when the experiment was actually in an operating mode. To rectify this problem during SL-3, an auxiliary timer was flown. This timer consisted of an ON/OFF switch, a mode TIME SELECT switch, and a READY/OPERATE light, and it was located on top of the control/display console. Because the timer module was equipped with a long electrical extension, the SL-4 crew was able to affix it adjacent to the START/STOP switch. The cord was strung along the rows of toggle

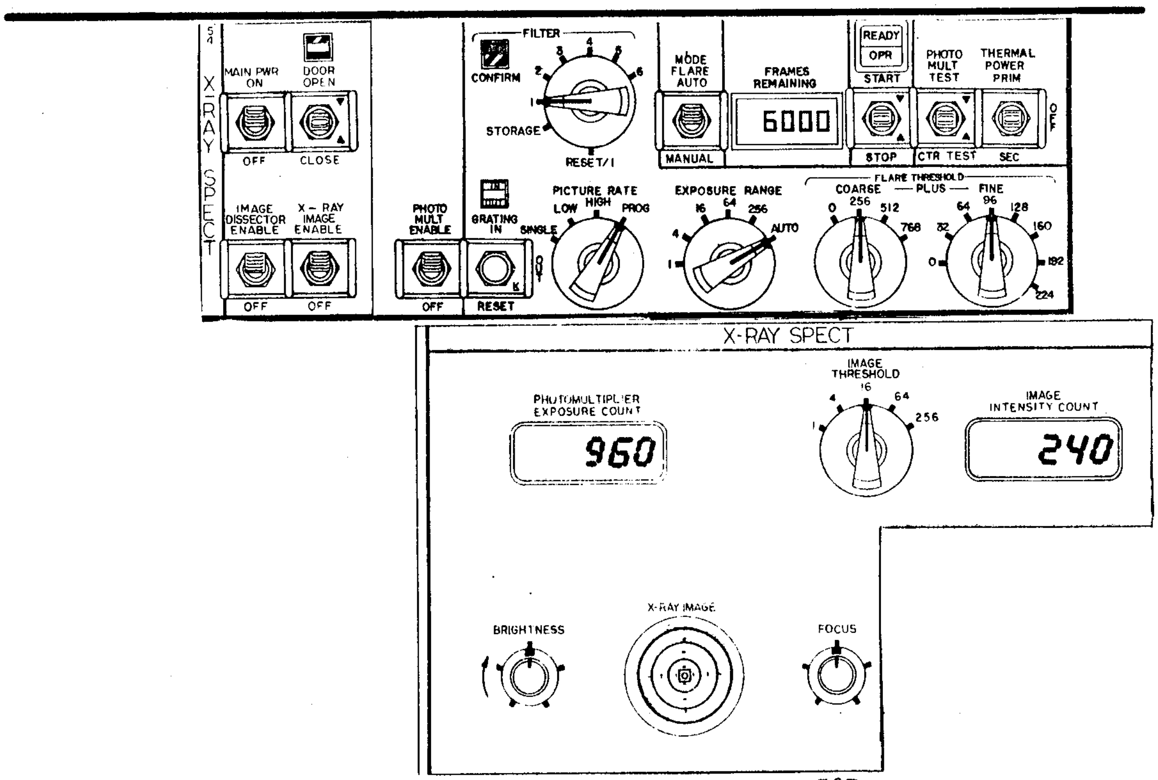


Figure 127. S054 X-Ray Spectrographic Telescope C&D

switches, near the inner edge of the experiment borderline, and taped to the toggle switch wicket guards. There was no interconnect between the timer and the ATM switching circuitry or the experiment. A 28V auxiliary outlet next the the C/D panel in the MDA was used as a power supply.

The problems associated with the timer included the feature of starting the timer simultaneously with the experiment. This created the problem of the crew's being distracted by performing two operations. Another unsatisfactory feature was the color selection of the READY/OPERATE light, which was a very bright yellow for READY and white for OPERATE. The crews found these colors and illumination levels quite annoying.

The X-ray scope which displays PMEC X-ray activity was also too high in intensity, and the crewmen found it uncomfortable to look at. They compensated for this inadequacy by placing a paper cone, Figure 128, over the scope, allowing it to be visible only from directly above and thereby eliminating its interference with other C&D activities. This significantly improved the operator interface by extending the total time an operator could remain at the panel without becoming fatigued.

3. <u>System Interface Evaluation</u>

a. ATM Alert Lights - The alert status lights on the ATM panel, Figure 129, were intended to provide an instantaneous indication of some abnormal and potentially critical system condition. These system alert indicators covered system parameters such as CMG-bearing temperature, aperture door position, etc. The philosophy of this concept was basically acceptable in that it supplied status of noncritical system functions, but it was not anticipated that certain of these functions would persist during the entire mission with contingency procedures failing to remedy the alert condition. As a result, these persistent indications caused extensive confusion. When a new alert would be illuminated, the crewman could not detect its presence because of the surrounding color noise. This problem existed throughout the mission and rendered the system ineffective. It was recommended that the crew place masking tape over the illuminated status lights to temporarily eliminate their interference.

b. X-ray Activity History Records - The activity history plotter, Figure 130, had one extremely undesirable feature involving the review capability built into the unit. A crewman could easily run all the recording paper off the roll and jam it, if close attention were not paid. As a result, this malfunction occurred on the first mission and was irreversible, because the unit was sealed and the stuck mechanism could not be reached.

Figure 128. ATM Restraint Device

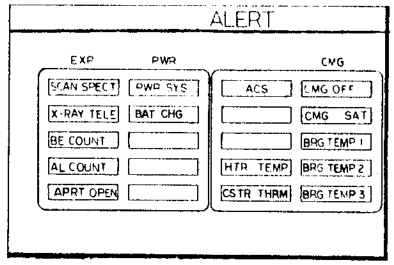


Figure 129. ATM Alert Status Lights C&D

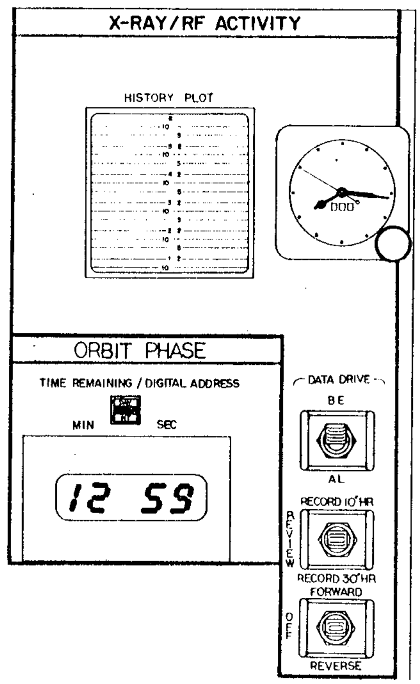


Figure 130. ATM X-Ray History Plotter C&D

c. Extreme Ultraviolet (XUV) Integration System - The purpose of this system, Figure 131, was to provide a data source which would indicate the presence of some significant solar activity and could display this information to the crew. The operating procedure required the crewman to point at the active region and manipulate a

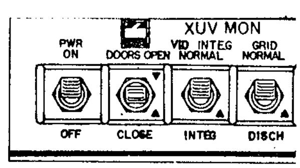


Figure 131. ATM Extreme Ultraviolet Monitor Integrated C&D

control (toggle switch), held in the DOWN position for a predetermined time, which stored the image on a memoscope, and, when released, presented the image on the CRT at 1/30-sec intervals for 10-sec. This procedure was repeated until the crewman operator had identified the active source of solar activity. The comments of the crewmen have validated the importance of this system in aiding data collection; they felt strongly, however, that due to the repeated use required, a simplified operational sequence would have helped the operation.

d. The ATM Control and Display Console Restraint (Chair) - The ATM C&D console restraint, Figure 128, was designed and built because it was known that prolonged hours of operating the ATM console would be tiring. The restraint, designed for all nine Skylab crewmen, was based on current anthropometric data, Figure 132. The primary users of the system were the SL-2 crew, who originated the concept. Further information on the ATM C/D seat restraint is given in Section II. K of this document.

4. Design Solutions and Recommendations - The following recommendations are the result of a cursory evaluation of crew systems data primarily extracted from crew debriefings and comments.

- The building blocks were hardly recognizable after all the modifications that were made to them. Future modification procedures should allow for some easier method of showing changes (e.g., a transparent surface and grease pencil).
- The problem with the activity history plotter should have been corrected before flight, or else the hardware should have been eliminated. The problem could easily have been solved had an access capability been provided.
- The alert status light noise problem could have been prevented if a method of individually turning each light off had been present (i.e., DAS, toggle switch).
- The status flags should have been a darker grey to contrast with the opposing white.
- The confusion caused by the similarity in the S082A and S082B experiments could have been dispelled simply by color coding the ATM console.
- The XUV monitor fatigue problem could have been eliminated if a preprogrammed automatic timer had been used to integrate the activity, rather than requiring the crewman to depress the control.

5. Results of SL-2 Telemetry Data Analysis - During SL-2, telemetry data which described the status of the ATM experiments and supporting subsystems were transmitted to ground tracking stations for use by Mission Support personnel for troubleshooting and status monitoring. A portion of these telemetry measures were used after the mission to recreate the panel's operation in terms of control actuations and display readings. The paragraphs below briefly describe

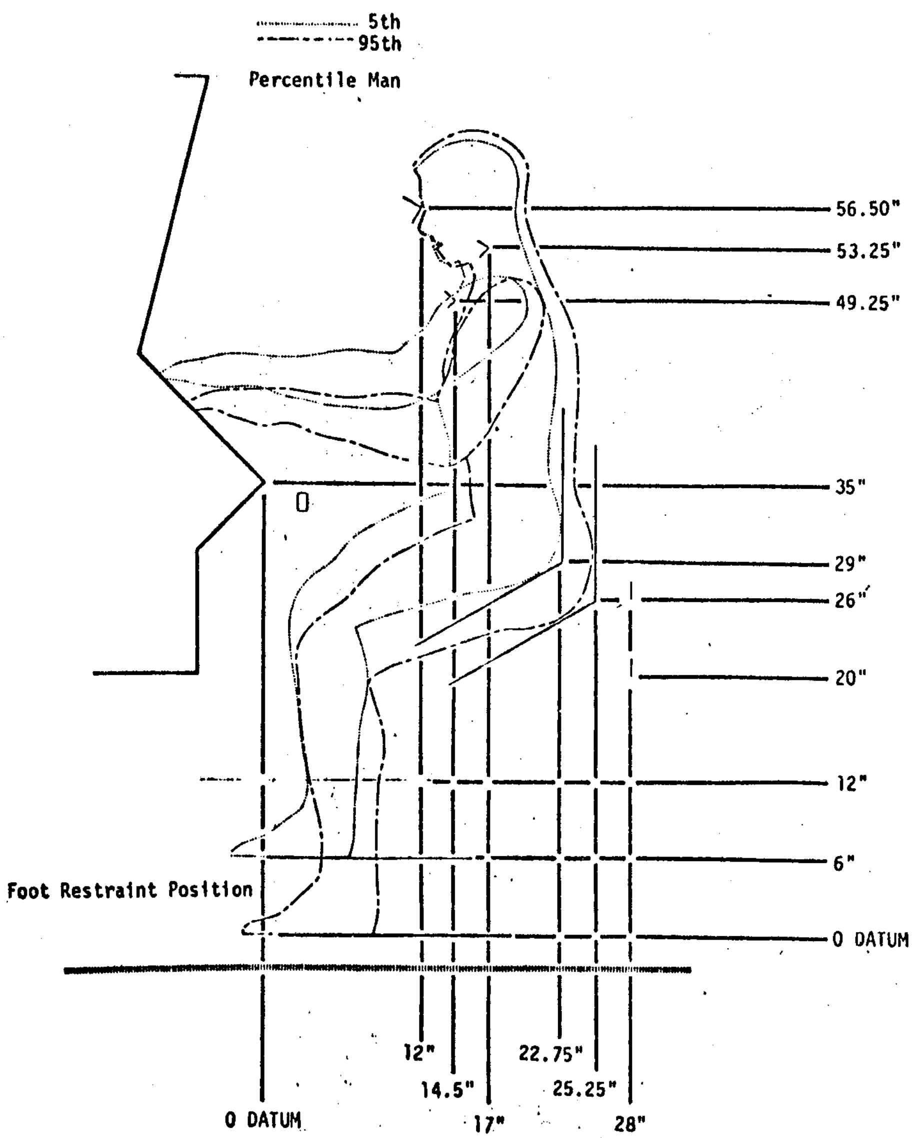


Figure 132. Astronaut Anthropometric Data

the data collection and reduction operations and the conclusions that were drawn from analysis of the data. These data support many of the conclusions drawn from the subjective evaluations discussed earlier in this report section.

a. Data Collection - The ATM control panel was evaluated to determine the information that would be required to reconstruct the panel's operation after the mission. The specific controls and displays that were used in the operation of the ATM building blocks were identified, as was the information required to describe their operation (e.g., switch position). The ATM telemetry measures were then examined, and the measures that describe the pertinent ATM controls and displays were identified and requested from the Huntsville Operations Support Center (HOSC).

During SL-2, these telemetry data were received on approximately 80 magnetic data tapes.

b. Data Reduction - These tapes were processed using a data reduction computer program. This program sorted the data into files for the seven ATM experiments. It also determined control actuations and display readings along with the Day of Year and Greenwich Mean Time (GMT) when they occurred. This resulted in seven sets of print-outs, one for each ATM experiment. The print-outs identified the controls and displays for the experiment, and listed the control's position and the display reading as a function of time.

c. Data Analysis/Conclusions - These panel operations were compared with the operations identified in the building block panel operating procedures. This comparison resulted in the identification of operational problem areas and panel design features that contributed to panel operation deviations. The major findings are:

- The three position toggle switch with three fixed positions had a deviation rate of 9%*. This indicates that a visual display such as a mechanical flag or status light should have been used with this type of switch to prevent incorrect settings.
- Experiment modes that had to be manually timed were often timed incorrectly. Although several multipurpose timers were available, they were apparently not used all of the time. A variable timer dedicated to each experiment with continuous modes of operation ($H\alpha$, S052, S055) would have prevented this problem.
- 25% of the control actuation deviations which occurred with S082B involved confusion with S082A. In these cases the S082B experiment was set up and operated

*"Deviation Rate" is defined as the number of deviations which occurred with a type of control divided by the number of times that type of control was used. Therefore, this 9% deviation rate means that 9% of the time the three position toggle switch was used, it was used incorrectly (e.g., commanded to the wrong position).

according to the S082A building block procedures. This probably occurred because the S082A and B controls and displays were almost identical and had approximately the same control labeling nomenclature and building block instructions. These problems could have been prevented if the experiments had been separated on the panel, labeled differently (S082 and S084, for instance) and had different control labeling nomenclature. For the SL-3 and SL-4 missions, large red and blue decal letters "A" and "B" were placed on the respective instruments. Also, strips of red and blue tape were added to the outside experiment boundary to aid in distinguishing one from the other. The effectiveness of this color coding in alleviating the confusion caused by the similar appearance of the two experiments will be determined during SL-3 and SL-4 data reduction.

- Isolated control actuations had a higher deviation rate (21%) than control actuations that were part of a sequence (2%). Approximately half of these could have been prevented if an integral timer had been provided for each experiment that had operating modes requiring manual timing.
- The panel's left side had a higher deviation rate (6%) than the right side (2%). This was caused primarily by several three position toggle switches on the left side which were used improperly 9% of the time.
- Building blocks with multiple parts (up to five) separated by a time allocated for pointing commands had distinctly different control deviation rates for each part. The first and last parts had low deviation rates (3% and 7%), and the central part had a significantly higher deviation rate (18%) as illustrated in Figure 133. An improvement could probably have been realized by limiting the number of building block parts, while increasing the number of building blocks.

6. Summary and Conclusions - The design of the ATM C&D Console progressed through numerous design stages. Most significant of these was the wet to dry workshop change. There were numerous improvements as a result of program redirection, but there were a considerable number of problems left uncorrected. One might conclude that these discrepant design areas have had their impact on accomplishing the optimum man/machine interface. However, a closer evaluation of the design job done on this complex scientific system leads one to conclude that the job was well done. In retrospect, most design engineers who worked on Skylab would like to modify their past design based on the knowledge gained from three manned missions. The most common item

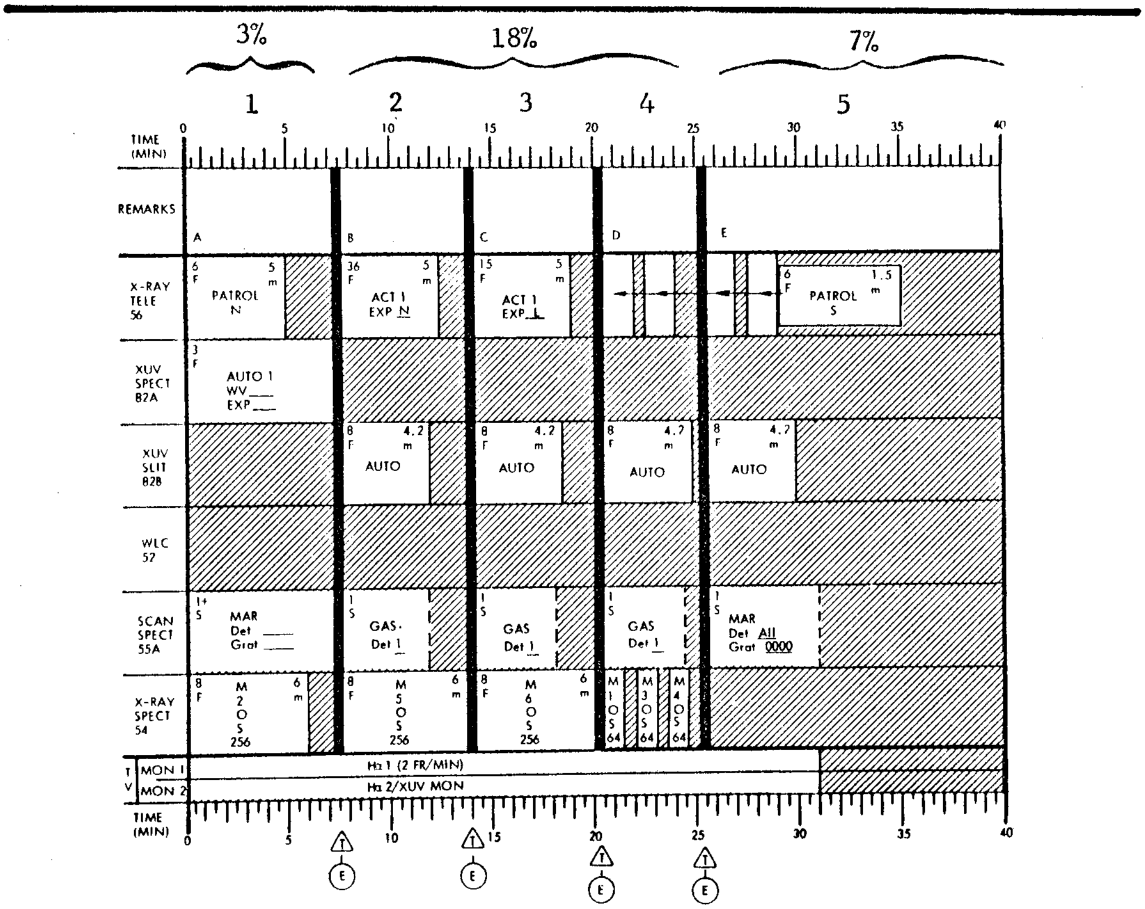


Figure 133. Sample Building Blocks With Five Parts

cited by most ATM C&D engineers and crewmen when asked, "What would you change?",is the console structure. More specifically a wrap-around configuration that would improve crewman reach and visibility and enhance component allocation. In conclusion, it is imaginable that a significant number of modifications could be made to improve the overall ATM design, but effectiveness of design preparation and implementation is reflected in performance. Based on this criterion, one might safely say that the design was good, since the data actually collected for ATM more than doubled the anticipated results.

APPENDIX A

CREW DEBRIEFING

(Comments on C&D Systems Operation--Summary)

1. The S054 READY/OPERATE light failure required installation of an auxiliary timer.
2. Displays were extremely stable during vehicle disturbances.
3. Significant oscillation occurred on the roll rate display when the high rate X 2 switches were used. The crew made attempts not to use the X 2 switches to avoid the problem.
4. Subthreshold flares were not detected on-board.
5. The History Plotter (Be channel) might have given a good curve indication of postflare activity data if it had not jammed.
6. The S052 READY/OPERATE timing light was 56-sec. (null state delay) instead of 9-sec. per design spec.
7. The SL-2 crew commented that the brightness of the numeric display on bus 2 (fixed) was not uncomfortable. The integral lighting was very rarely used, because of the power limitations during SL-2. Due to this, the crew used only ambient lighting, to which they easily adapted.
8. There was considerable ambiguity between gray and white indicators on the status flags.
9. The similarity between the S082A and S082B instruments did create some problems in operating differentiation.
10. Procedure for the XUV Monitor operating INTEGRATE switch was very tiring and complicated.
11. Several of the systems alert lights remained on during the entire mission, making detection of a new malfunction/alert visually impossible.
12. The white light coronagraph (S052) instrument required the TV switch to be cut off prior to closing the doors. The purpose of this procedure was to avoid exposing the vidicon to direct sunlight.
13. Performance on-orbit proved to be very similar to performance on the ATM simulator, and the habits formed during training never changed.
14. The ATM cue cards were modified so much that they were hardly recognizable.
15. The TV presentation did not provide sufficient detail. The resolution of the on-board TV was not as good as the instruments themselves.
16. A useful tool would have been a lexicon or log to record significant ATM comments to update each panel operation on the occurrences of activities on the sun's disc.
17. The X-ray scope PMC appeared to saturate at a flare utensity of 500 counts rather than the 1000 counts for which it was designed.

18. The GRATING SELECT switch was inadvertently left in the MECHANICAL position when it should have been in the OPTICAL position.
19. The crews commented that experiment setup times improved with repetition.
20. One crewman stated that the X-ray Be/Al History Plotter design was ineffective for continued use because of the tendency of the paper drive unit to hang up.
21. The RNBM was not useful in data analysis because of characteristic design in band and range sensitivity.
22. The XUV Monitor was a good correlative display for a flare.
23. The Hα display was a good tool for viewing through the building blocks and pointing and surveying the active regions on the sun.
24. The Hα reticules worked normally.

SECTION IV. COROLLARY EXPERIMENTS

A. Corollary Experiments Summary

Corollary experiments involved three major categories of experimentation consisting of: scientific, with objectives to acquire photographic data of solar and stellar phenomena; technological, with objectives to measure contamination levels surrounding the OA; and operational, with objectives to assess technological innovations which assisted the crew in performing space related tasks.

Performance of the corollary experiments during Skylab achieved most of the designed and planned functional objectives. The knowledge obtained from their operation and the acquired data have provided insight that will be implemented into the design and operational requirements of future manned spacecraft.

The following are some conclusions derived from the on-orbit corollary experimentation that is applicable to future spacecraft hardware designs and operations.

- An adequate maintenance workstation with appropriate tools and restraints should be included in future spacecraft design.
- Crew manipulation of large experiment equipment presents no problems. Multiple, small items were found to be difficult to constrain and handle. It is recommended that handles be provisioned on all large mass items to facilitate their manipulation. Also, a technique is required to control the manipulation of multiple, small items.
- Of the experiments requiring extension/retraction through the Scientific Airlock (SAL) into space, it was found that the retraction forces were somewhat higher as anticipated, and that a warm-up period was required prior to final retraction and removal of experiments from the SAL to prevent formation of condensation/frost.
- Through operations of M509 and T020, the feasibility of a one-man maneuvering unit was successfully demonstrated.
- Corollary experiment T013 demonstrated that crew motion within a large spacecraft does impact its stability and guidance control and therefore, should be considered in future designs.

This section covers those experiments which were the responsibility of MSFC or required personnel/hardware support from MSFC.

B. Scientific Airlock System

The Scientific Airlock System was developed to provide access to space environment from within the OWS without having to depressurize the cabin.

1. Scientific Airlock

a. Design Description - The SAL was designed to allow deployment of experiment hardware to a point beyond the meteoroid shield of the OWS.

Two SALs were provided, one solar oriented and one anti-solar oriented. These were identified as the +Z and the -Z SALs respectively.

The SAL was a pressure vessel with an outer door closure hatch that closed against rubber seals to maintain cabin pressure. Each experiment, which used the SAL, was enclosed in a pressure vessel, the external flange of which mated with, and sealed against the inboard side of the airlock. The inboard opening of the SAL was sealed with a special metal protective plate whenever experiment pressure vessels were removed. A special metal protective plate (cover) was launched and used in lieu of the original SAL window. After installation, the pressure vessel of the experiment became part of the airlock pressure vessel and the outer door could be opened and the experiment deployed outside the spacecraft. The internal pressure of the airlock was equalized to either the cabin pressure or the external environment by a pressure valve. The basic configuration and location of the SALs is illustrated in Figure 134.

Experiments S019, S073/T027, S149, T025, and a TV camera were to use the SALs by permitting extension of hardware through the SALs to outer space. The SALs were to be used as viewing ports with the aid of windows, as in S190B, and S063, or without a window, as in the S020 experiment. Finally, the SAL was to serve as a vacuum source for the depressurization of experiment hardware for the S019, S020, S183, and T027 experiments.

b. Post Mission Assessment - The SAL system was operated efficiently and easily by one crewman, as required. Due to the deployment of the parasol thermal shield through the solar SAL, only the anti-solar SAL was available for experiment deployment and utilization.

In addition to experiment usage, the SAL vacuum source was also used for the Wardroom window evacuation (HK-84K) and for the condensate holding tank dump (HK-60B).

Table 18 is a tabulation of SAL use for the total Skylab mission.

No anomalies were reported relative to SAL operation.

On SL-2, an additional SAL tripod was launched because the original was used to deploy the parasol in the solar SAL. The

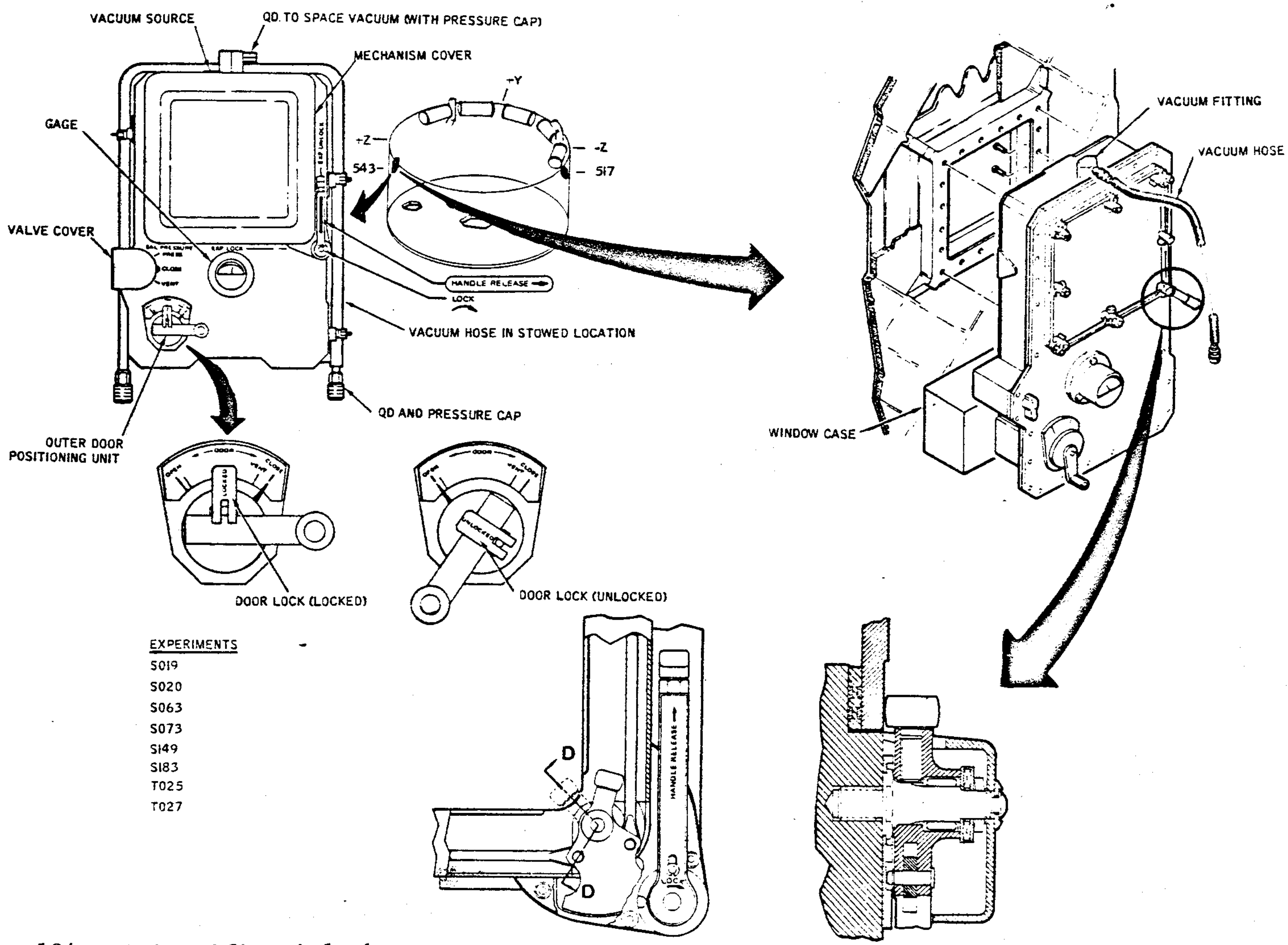


Figure 134. Scientific Airlock

+Z SAL

EXPERIMENTS	INSTALLATIONS First Mission	INSTALLATIONS Second Mission	INSTALLATIONS Third Mission	REMOVALS First Mission	REMOVALS Second Mission	REMOVALS Third Mission
T027 Photometer (Sun Shield)	1	0	0	0	0	0
Actual Total	1	0	0	0	0	0
Planned Total	7	0	0	6	0	0
% of Test Cycles	0.1%			0.1%		

-Z SAL

EXPERIMENTS	INSTALLATIONS First Mission	INSTALLATIONS Second Mission	INSTALLATIONS Third Mission	REMOVALS First Mission	REMOVALS Second Mission	REMOVALS Third Mission
S020	0	0	2	0	0	2
S190B	6	17	31	6	17	31
S019 AMS	8	16	31	8	16	31
S063	0	8	17	0	8	17
T027/S073 (Photometer)	7	2	0	7	2	0
T027 (Sample Array)	1	0	0	1	0	0
S149 (Photometer)	1	0	0	0	1	0
S201	0	0	11	0	0	11
Actual Total	23	44	92	22	44	92
Planned Total	9	43	23	9	43	23
% of Test Cycles	2.3%	4.3%	9.2%	2.2%	4.4%	9.2%

Table 18. Total Skylab Mission SAL Usage

backup SAL tripod was used at the antisolar SAL. There was an alignment problem with the backup tripod at the antisolar SAL which was solved by anchoring the left leg in its proper location and bolting the other two legs to the floor grid, after rotating them one or two grid holes. It was later determined that the backup tripod was misdrilled, causing a 2-inch offset in the alignment. A check indicated that the backup tripod would fit satisfactorily only at the solar SAL. The flight unit would fit in either SAL position, so the tripods were exchanged by the second crew. No alignment problems were encountered during the tripod exchange.

During a condensate dump, one of the crew left the SAL outer door open and the valve in the "PRESS" position. With the desiccant system valve in the "OPEN" position, this allowed cabin air to bleed overboard, through the desiccant canister, and out of the SAL. The leak was discovered during the crew sleep period. When the crew woke up the next day, they were asked to configure the SAL properly. An analysis was subsequently performed which indicated that the desiccant system still had at least a 100% margin (5000 grains of H_2O) in spite of the inadvertant atmosphere dump.

There was not enough illumination to read the SAL delta-P gauge. The crew used a penlight to obtain accurate readings. The black background and long viewing tube on the delta-P gauge made it difficult to read. The crew stated the 0-30 psia range on the gauge was excessive and not necessary. The gauge should have been designed to facilitate delta-P reading in increments of .025- psia, from 0 to a maximum of 20-psia.

No difficulties were experienced aligning experiments in the SAL and no flanges or "O"-ring seals were damaged. Experiments placed in the SAL were adequately supported by the tripod.

The crew reported that the SAL system was tight and never failed a leak check. Pressurization and depressurization of the SAL required more time than planned. Consequently, this required some lead time to set up experiments in the SAL. During crew training, actual depressurization functions were never performed by the crews. This did not prepare them with the knowledge of what to expect on-orbit, when performing this SAL operation.

C. Scientific Experiments

1. S009 - Nuclear Emulsion

a. Operations - Experiment S009 was scheduled for performance throughout the SL-2 mission to investigate aspects of cosmic radiation. The S009 detector package was removed from the OWS film vault, transferred to the MDA and installed in the S009 experiment housing. The crewman was to initiate experiment operation by setting the proper beta angle and activating the open-close cycle for the experiment. S009 was designed to operate automatically throughout SL-2 with the crew making periodic checks and/or corrections to the experiment beta angle and open-close cycle. At the completion of the experiment, the S009 detector package was to be removed from the experiment housing, and stowed in the CM, and returned.

b. Post Mission Assessment - The S009 experiment was conducted on SL-2 despite a concern of possible detector emulsion degradation due to the high OWS temperatures present during the beginning of the SL-2 mission. During the S009 detector package installation, considerable difficulty was encountered. It was determined that because of the high OWS temperatures, the emulsion package had expanded, thereby reducing the tolerances between the package and experiment housing.

After two weeks of operation, the door on the experiment housing began to bind and finally would not close properly. The crew performed malfunction procedures and concluded that the motor/drive train for the experiment door had failed. After this investigation, the experiment door was left open, the automatic open-close was inhibited, and manual pointing was maintained for data collection throughout the duration of the SL-2 mission.

At the end of SL-2, the detector package was stowed in the CSM and returned to earth. Groundanalysis of the package revealed that the emulsion layers had been fused together and the data was of little use.

On SL-4, a new emulsion package was launched. During malfunction procedures, the crew replaced the defective door motor and installed the resupplied detector package. S009 was then activated and performed satisfactorily throughout the remainder of the mission.

Experiment S009 operations, including malfunction procedures, were straightforward and no crew interface problems were experienced. The hardware unstowage and experiment activation was a one-man operation and the restraints provided in the MDA for experiment operations were considered adequate. No problems were encountered during the motor replacement and resupply of the detector package on SL-4.

2. S019 - UV Stellar Astronamy

a. Operations - The S019-UV Stellar Astronomy experiment was scheduled to be performed during 12 selected night orbits in each of the first two missions, SL-2 and SL-3.

The equipment consisted of an optical canister and the Articulated Mirror System (AMS), launched in individual stowage containers, and film canister, launched in the OWS film vault. Figure 135 illustrates the experiment operating configuration. One crewman was to set up and operate the experiment hardware in the SAL to obtain a total of 150 slides of data from a minimum of 36 starfields. Three starfields, with three exposures per starfield, were to be photographed during each operation. To maximize the scientific data return of S019, the astronaut was allowed as much flexibility in the choice of starfields and exposure times as possible.

b. Post Mission Assessment - During the initial activation of the AMS, a problem occurred in the operation of the tilt mechanism. As a result, this S019 operation was aborted and no data was acquired. Through extensive malfunction procedure checkout and finally, disassembly of the AMS tilt mechanism, the crew discovered an Allen screw binding on a small gear of the tilt mechanism. This was corrected and the unit functioned properly during the remainder of the experiment's data acquisition operations.

During the repair of the AMS tilt mechanism, the mirror was inadvertently touched leaving a finger print on the mirror. At the request of the Principle Investigator (PI), no corrective procedure was implemented to remove the print in order to prevent possible additional damage to the mirror surface. Attempting to clean the mirror may have been more degrading to the mirror's viewing function than the fingerprint itself.

During SL-3 operations of S019, it was reported that the luminescent material had come out of the engraved digits on one of the rotation dials. However, by close inspection, the operator could still distinguish the engraved impressions of the digits permitting proper operation of the rotational dial.

The S019 spectrometer mechanism jammed during retraction following an SL-3 pass. Retraction was eventually accomplished some 30-hours subsequent to the initial failure and normal operations were restored. After the retraction failure, warm-up procedures for all subsequent experiments placed in the SAL were implemented prior to exposure of their mechanism to OWS environment.

During an SL-3 S019 pass, the crew reported that the film advance/shutter lever stopped at the "CARRIAGE RETRACTED" position, and could not be moved on to the "SLIDE RETRACTED" position. This film canister was replaced with the new canister and the remaining exposures were taken as scheduled during SL-3. The failed canister was taken to an area of subdued light (the WMC, with lights out and door closed), the cover removed, and the sliding film hatch opened. Inspection, by feel, was performed on part of the carriage and shutter mechanism. The crew could not identify any apparent damage or discrepancy that could be corrected. Consequently, the film canister unit was returned to earth for malfunction analysis.

It was found, from the review of acquired data, that during performance of the S019 experiment, the system was extremely sensitive to motion and some blurs occurred on one S019 slide. It was felt that

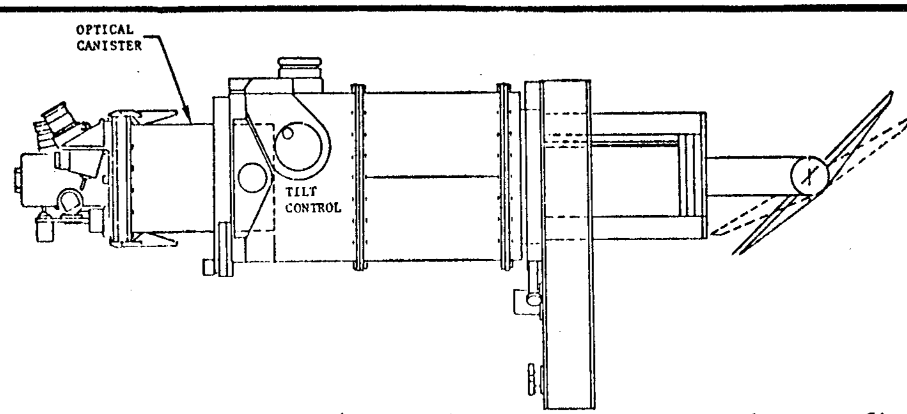


Figure 135. Experiment S019/Articulated Mirror Operating Configuration

this could have been caused when the canister was used as a writing surface. The PI requested that the S019 system not be touched when taking data. This was necessary for the acquisition of clear photography. The crew had no difficulties complying with this request except when opening or closing the shutter. At this time, momentary jiggling of the S019 system could not be prevented.

Although S019 operations were not originally scheduled for SL-4, the SL-4 mission extension created additional crew experiment time thus allowing assignment of S019. New S019 film canisters and a replacement S019 mirror were launched on SL-4. During replacement of the S019 mirror, the crew reported the new mirror was dusty and had three very narrow white streaks. The new mirror was touched by the crewman leaving a 3/4-inch long smudge which extended 3/16-inch in from the edge. This resulted when the crewmen had to remove the mirror bare handed because the special handling gloves provided were stowed under the mirror.

Numerous jamming problems were experienced with the S019 canisters during SL-4. The canister would not go into the "SLIDE RETRACTED" position. The problem was believed to be with the nylon sleeve on the film slides. The first canister that jammed was returned to stowage; however, when the second canister jammed, the crew decided to use brute force to put the lever in the "SLIDE RETRACTED" position. The canister then operated normally except higher forces were required on the operating mechanism. This canister eventually jammed again and broke when the crewman forced it into the "SLIDE RETRACTED" position. Malfunction procedures were performed, but the canister was determined to be completely broken. The first canister was obtained from stowage and was operated using excessive force. Both canisters were returned for evaluation.

There was a continuous gradual degradation of the indicator on the rotation dials of the AMS. In addition to the luminescence coming out of the units digits, the crew reported they were experiencing slippage between the mirror rotation attitude control knob and the indication dial. The belt broke and the degree indicator did not move even though the crank was turning. No repair was attempted due to the radioactivity from the luminescence in the sealed dials. For all subsequent operations, the crew had to count the number of turns of the crank to determine the rotation settings. The T002 sextant was used to check misalignment of the mirror.

A failure of the S019 reticle light occurred on one S019 canister.

The crew reported earlier that the reticle light was dim and assumed that the battery charge was too low to illuminate the bulb. The bulb and battery were not replaceable, but the reticle was for "reference only" and no data was lost due to the failure. No corrective action was necessary, however, the crew turned off the reticle light when it was not required to verify pointing accuracy.

An additional S019 operation requirement was imposed during SL-4 to reduce possible data degradation due to OWS influenced disturbances on the pointing accuracy. During SL-4, all ergometer and Mark I exerciser operations were prohibited during S019 operations.

The crew recommended that the first couple of S019 pads be relatively easy to give them a chance to re-familiarize themselves with the experiment's operations. The crew felt that 80% of all crew errors would probably occur during the first runs of the experiment. They also stated that S019 procedures needed to be updated with more exact information concerning photography exposure times.

Differences existed between the forces required to operate the controls of the different S019 canisters. Some canisters' carriage retract systems operated easily, while others were quite stiff. The PI stated that this was normal as they were not all the same. The operating controls should have been designed with appropriate "STOP" positions to eliminate the necessity of counting crank turns to the "FULL EXTENDED" of "FULL RETRACTED" positions. The crew also recommended that the locks on the shaft rotation or extension controls not be used, as they were no longer required after placing the control in the "UNLOCKED" position.

The S019 timelines were too close; therefore, the crew recommended that 30-seconds to one-minute be allocated for the operator to perform a change in pointing. They also suggested adding 15 to 30-minutes to the timeline, for the first running of the experiment, to allow for familiarization with the equipment.

The crew requested that the same crewman not be assigned to an ATM pass and an S019 pass with no time in between because any delays in the ATM pass immediately affected the S019 operations.

The crew suggested having a T-handle on top of the winding valve instead of the knob. The knob was very slippery when their hands were moist and a T-handle would have been better for winding the film.

Experiment handling was easy on-orbit compared to ground handling. The crew said that the carrying handle for the optical canister was a necessity.

The procedures for changing the viewing coordinates were very satisfactory, but there was a definite source of potential error with the sign and algebraic manipulations required to compute the rotation. The crew had not trained for these calculations and thought that they should have had training to become familiar with the calculations.

There were no problems with dark adaptation when operating S019. The critical requirements to prevent dark adaptation problems were the position of the eye with respect to the eye piece and the focus.

The repair work performed on the AMS tilt mechanism would have been aided by the addition of an Inflight Maintenance facility composed of a work bench and a high intensity light. An optics cleaning kit would have been valuable to remove the finger print contamination from the AMS mirror and should be provided on future flights.

3. S020 - UV X-Ray Solar Photography

a. Operations - Experiment S020 was scheduled to be performed on SL-3 and SL-4, employing the solar SAL to photograph x-ray and extreme ultraviolet spectrums of the sun in wavelength regions from 10 to 200 A. The spectrograph assembly is illustrated in Figure 136.

Two crewmen were to perform the setup and checkout of the experiment in the SAL. When notified that a solar flare might occur, a crewman was to point the equipment at the solar disc and obtain quiet or active sun flare exposures.

b. Post Mission Assessment - Due to the thermal shield occupying the solar SAL, additional operating methods were devised. A special EVA bracket was designed and launched on SL-3. The EVA bracket was attached to an exterior truss and successfully performed during three SL-4 EVA's and exposures up to one hour were obtained.

During deployment of the S020 camera, the crew experienced some difficulty in attaching the mount to the Deployment Assembly truss. While turning the knob to tighten the mount, the whole mount twisted. The ball joint on the mount was also difficult to adjust. The crew throught a larger ball joint would have made it easier to adjust.

During S020 preparation for the final SL-4 EVA, the crew reported a number of pin holes in each of the two filters. Some were detected by the maked eye and others were detected with a flashlight and magnifying glass. It was determined that the size of the holes, as described by the crew, would not allow enough light through to cause any problems.

The interface between the S020 equipment and the EVA bracket was well designed. The experiment hardware and procedures were adequate and experiment operations were accomplished without any anomalies.

4. S063 - UV Airglow Horizon Photography

a. Operations - Experiment S063 was scheduled to be perfomed on SL-3 and SL-4 to photograph in the visible and ultraviolet (UV) spectra the earth's ozone layers and twilight airglow.

The equipment to be used included the visible and UV cameras, with related accessories, and the respective mounting structures for the cameras at the SAL and wardroom windows as illustrated in Figures 137 through 139.

One crewman was required to attach the cameras to the SAL or wardroom window, make appropriate exposure time and shutter settings, and perform exposures during approximately 28 selected orbits of the mission.

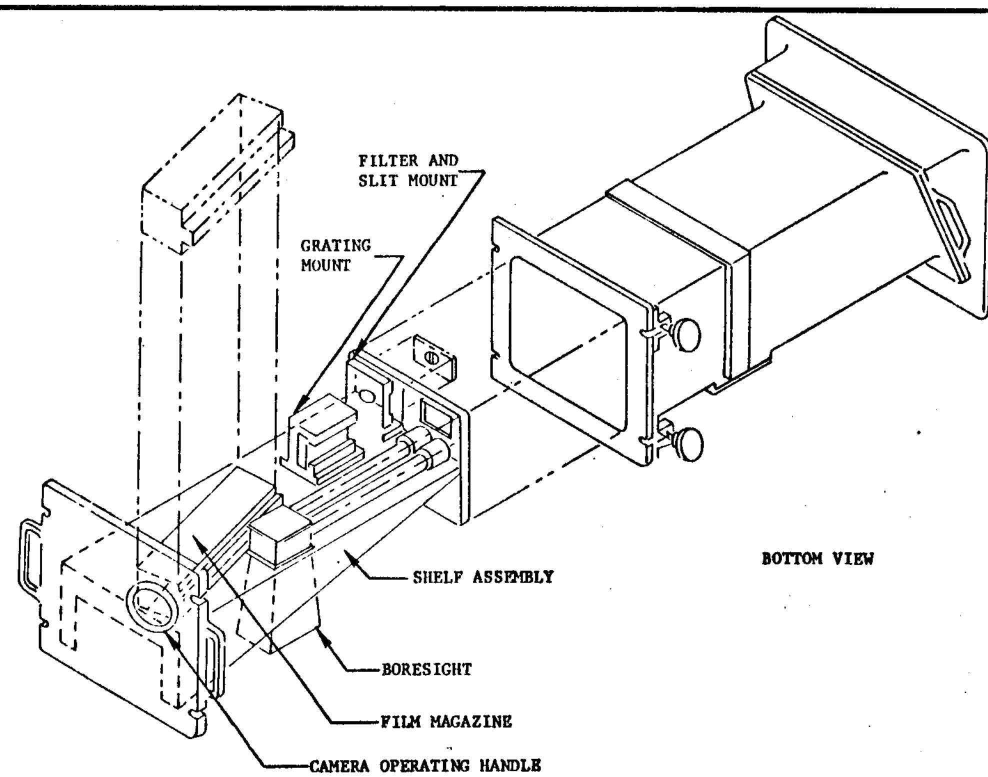


Figure 136. Spectrograph Assembly

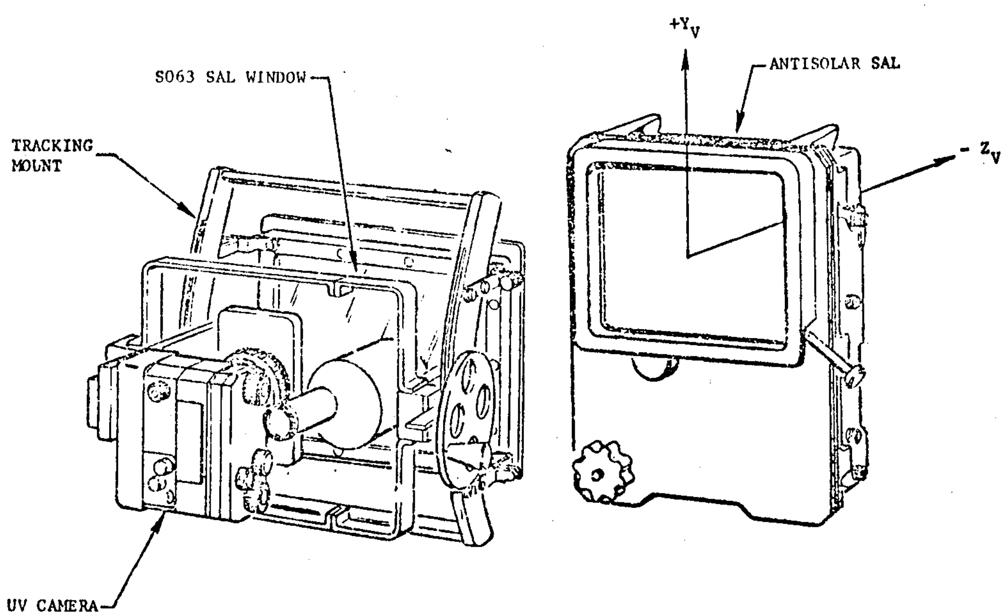


Figure 137. S063 EA-I UV Camera Operational Configuration

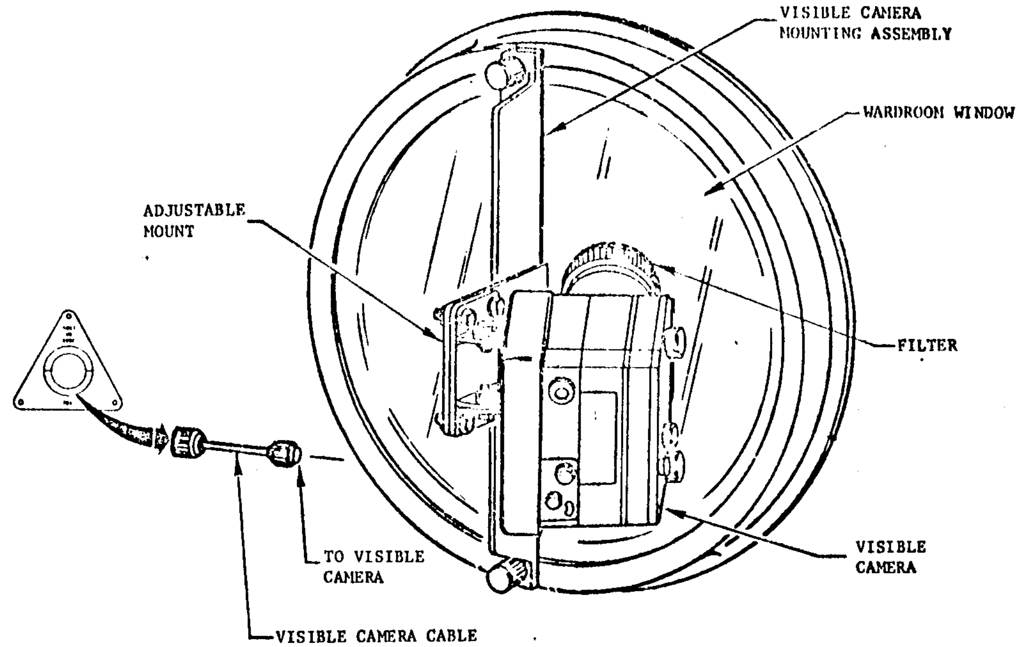


Figure 138. S063 EA-I Visible Camera Operational Configuration

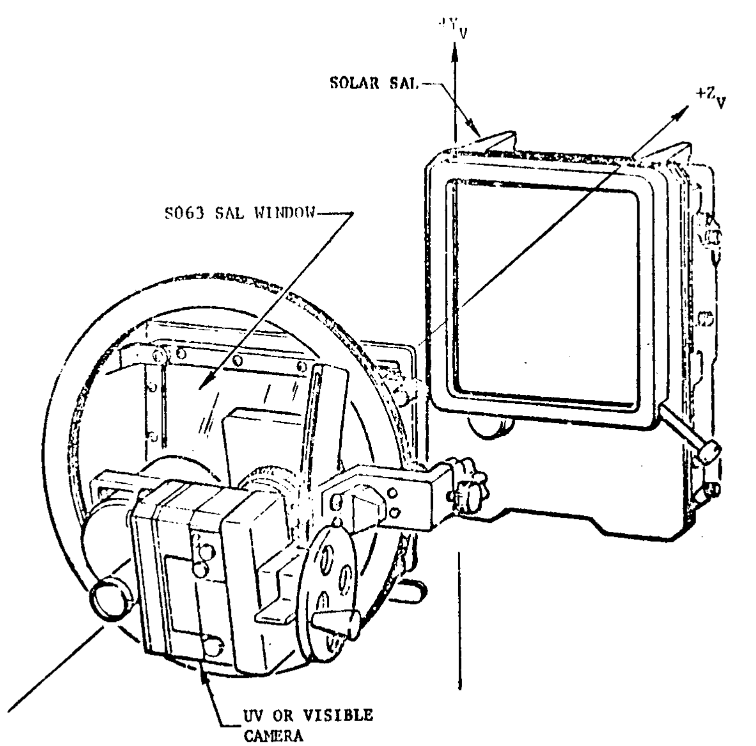


Figure 139. S063 EA-II S-SAL Operational Configuration

b. Post Mission Assessment - Some difficulty was experienced during the loading of a new Nikon camera for S063 operations. Upon investigation it was found that a bit of epoxy-like material prevented the film system from positioning properly. The crew removed this material with a knife and the camera operated satisfactorily for the remainder of the mission.

Due to solar SAL obstructions by the thermal shield, the S019 AMS was utilized to obtain some of the S063 data.

During initial operations, there was a problem as a result of a timer malfunction. Analysis established that the motor drive switch was not in the correct configuration and that the timer was being operated incorrectly. This problem required that the crewmen use their wristwatch in conjunction with the timer for all subsequent S063 operations.

The crewman had to use a flashlight to read the watch and timer. The crew requested an additional 45-seconds preparation time between exposures. At the request of the crew, information on how to interpret the S063 optical sight reticle was provided by the ground.

Due to a problem encountered in setting the viewing equipment, some exposures may have been 10-second exposures rather than the scheduled 8-second exposures. The marker on the viewing equipment had a bright edge and light glinted off the leading edge of the marker through the window. The viewing equipment was set on this leading edge rather than the white alignment mark, thereby adding approximately two-seconds to each exposure.

One visible photography portion of an S063 run was not obtained because a battery, powering the visible camera, had tape covering one terminal. This tape was removed and no further problems were encountered.

During SL-3, it was noted that an adapter between the AMS and the S063 window was missing a bolt. This missing bolt did not affect experiment operations, but a replacement bolt was provided for SL-4. The crew also reported tightening the mounting shear to the optical sight of the camera with tape, thereby providing better resolution.

During the initial SL-4 S063 operation, the remote timer did not operate.. This complicated the experiment operation because the crewman had to use manual timing, in addition to tracking and controlling the rotation and tilt settings. The timer did not operate because the crew mistakenly used a timer without any batteries. A new battery was installed in the remote timer and solved the problem. For subsequent operations, the crew removed the batteries after each use and taped them to the timer to prevent discharge of the batteries.

The crew reported the ring site was aligned in the wrong direction and that it should be aligned more towards the camera axis. Part of the sight was obscured such that the crewmen could not see the whole mirror. The crewman assumed that although his view was truncated, the camera was getting the full view. He therefore centered the sight in the circle and not in the truncated portion of the field of view. The crewman found that, by looking right below everything, straight at the AMS mirror, he could get a better field of view than looking through the sights.

A problem was experienced with the S063 reticle light when it failed to illuminate. The crew checked the prime and backup batteries and found they had an output of 1.6-volts compared to 3.1-volts pre-flight. The battery contacts were scraped clean, but neither battery would illuminate the reticle light. A substitute battery pack was fabricated from two spare "C" cells, tape, and two multimeter leads. The substitute battery pack was installed by inserting the probe ends of the leads into the female terminals of the optical sight housing. Normal reticle operation was then restored.

The S063 stowage and unstowage operations were accomplished as planned. In some instances, the crew had to hurry to get two photographs on the same target, but the tracking task time allocation was adequate. The time allocated for stowage and preparation of S063 and AMS equipment was also adequate.

The stowage location of the twin filter underneath the S063 stowage container lid was inadequate because of poor lighting and visibility in that area. This inadequacy was identified in training but never corrected.

The crew stated that they should have had one extra Nikon camera body and a minimum of six extra cassettes of 2485 fast film for photography of targets of opportunity. A great opportunity to properly photograph the Aurora, may have been missed, because these items were not on board. The crew recommended replacing the Hasselblad in the CM with a Nikon.

The crew recommended that some type of suction-cup mount be supplied for cameras used in hand-held photography. These cameras could then be restrained at any window. Such a restraint should be light, have a shutter release, and designed so that it could be moved to any position.

The crew recommended that the PI provide a small color chart identifying the different shades of night airglow gray or white as they may appear to the crew. This would make identification easier for the crew and provide a commonality point between ground and on-orbit data.

Crew training for S063 appeared to be inadequate because the timer was operated incorrectly and the crew had to request information on how to interpret the reticle.

The SL-4 crew stressed that, due to the lack of an S063 simulator, the first couple of experiment runs would have to be considered training sessions. Any operations that called for manual dexterity by the crewman could not be learned by oral communications. The crew stated they had more difficulty with S063 than with other more complicated experiments which they had trained for. Even a relatively simple task requires a couple of familiarization runs.

There was some confusion in determining the frame count on the UV Nikon camera. The frame count on the top of the Nikon read differently than the frame count on the bottom of the camera. The crew decided to use only the bottom frame count indicator. There should be only one frame count indicator per camera.

5. <u>S073/T027 - Gegenschein Zodiacal Light and ATM Contamination Measurement</u>

a. Operations - Experiment S073/T027 was scheduled for operation during SL-2 and SL-3. The purpose of S073 was to measure surface brightness and polarization of night glow in visible spectrum. The purpose of T027 was to determine changes in properties of optical samples due to deposition of contaminates and to measure sky brightness background due to solar illumination of contaminates.

The experiment employed the T027 Photometer Canister with the automatic programmer. The combined photometer system and Data Acquisition Camera (DAC) system, which was attached to the T027 Universal Extension Mechanism (UXM), was mounted to and deployed through the SAL into the space environment for acquisition of data. S073/T027 was designed for operation by one crewman.

b. Post Mission Assessment - During SL-2, the S073/T027 photometer system was activated and operated with no major difficulties. During one T027 retraction, the photometer system could not be lined up properly to allow its retraction into the SAL and the T027 canister. This was a T027 systems operations problem. The system had been driven past the desired alignment. The photometer system was bumped against the OWS and physically forced into alignment. This corrected the problem and the system was retracted into the SAL and T027 canister.

During SL-3, the first crew operation with the T027 UXM system was to retract the S149 system, which had been left extended through the SAL during the unmanned period between SL-2 and SL-3. This was accomplished with some difficulty. The final extension rod stopped about one-inch from full retraction and prevented engagement of the UXM capture latch. To solve the problem the SAL door was closed to permit the system to warm up. After warming, the final retraction was easily accomplished.

The SL-3 crew performed the T027 photometer extension and data gathering successfully, but during the retraction mode, it failed to align to the required position to permit its retraction. This had previously occurred during the SL-2 mission. All malfunction operations performed failed to allow its retraction. Consequently, the UXM, with the photometer and S073 system attached, was jettisoned on MD-8 of SL-3.

The SL-3 and SL-4 crews utilized the T025 hardware to perform some S073 Gegenschein and Zodiacal light photography. The equipment was installed upside-down in the anti-solar SAL and the occulting disc was moved out of the cameras view. No anomalies were reported with this mode of operation.

Experiment T027 handling was a one-man operation and was facilitated by the canister handle's proper location through the center of gravity. On movable items of large volume and mass (i.e. T027, S183) handles are definitely required. The handle(s) should be located such that the crewman had complete control of the object during maneuvering operations.

No problems were encountered during photometer head changeout and maintenance, despite the compressed operational envelope caused by the parasol canister/tripod protrusion. Instead of restowing T027 in its launch container between operations, the crews left the photometer attached to the launch container lid.

As T027 operations progressed, the crews noticed that the photometer UXM rods became increasingly difficult to screw together. This was thought to be caused by a buildup of moisture and contamination. Also, during rod retraction, the crews reported that the thermal gloves were required but did not hinder the crewman's rod retraction operations. The SL-3 crew indicated that the T027 system should have been checked out completely and possibly operated inside the OWS prior to its use.

6. S149 - Particle Collection

A. Operations - Experiment S149 was scheduled for performance in four different exposure periods; during SL-2, the unmanned period between SL-2 and SL-3, during SL-3, and the unmanned period between SL-3 and SL-4. Its design objective was to acquire data to assist in the determination of mass distribution of micrometeorites in near-earth space.

The S149 Motor Drive/Cassette Support Unit (MD/CSU) was to be unstowed, fitted with the detector cassettes, and attached to the T027 Photometer Universal Extension Mechanism (UXM). The T027 canister was designed to be installed in the anti-solar SAL and the S149 MD/CSU extended into space. Figure 140 illustrates the experiment operational configuration. Power was to be applied to the experiment and switches configured for ground activation of cassette exposure. In the event of a ground command failure, the experiment had a manual control capability which could be operated by the crew.

At completion of the exposure time, the crew was to retract, remove, and stow the hardware.

b. Post Mission Assessment - During SL-2, the first of four sets of S149 detector cassettes was deployed through the anti-solar SAL. Prior to crew return to earth, ground commanded the MC/CSU to "OPEN" for cassette exposure and subsequent data collection between missions.

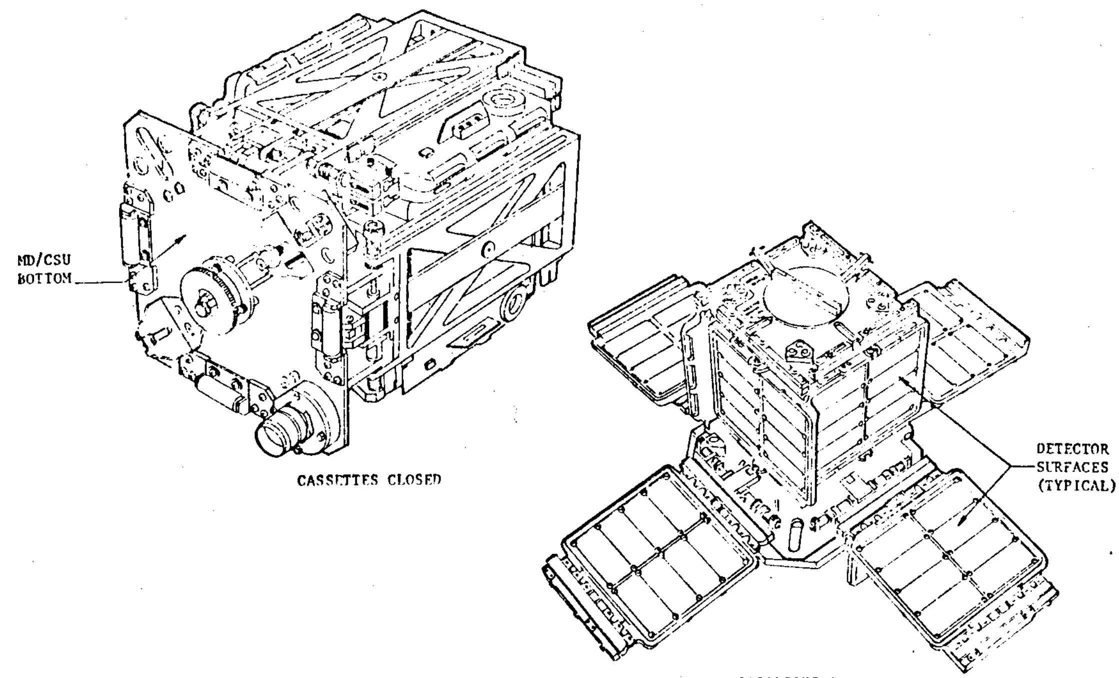


Figure 140. S149 MD/CSU With Detector Cassette Set, Operational Configuration

A problem was reported by the SL-3 crew during retraction of the SL-2 deployed S149 MD/CSU. During retraction the UXM rod tended to extend back out to space when released. The crew had to maintain a continuous retraction force on the UXM rod while the SAL door was closed (this involved a two-man effort). Once the SAL door was closed the final extension rod stopped about one-inch from full retraction and prevented engagement in the UXM capture latch. After allowing the system to warm-up, full retraction and engagement of the capture latch was accomplished. The T027 UXM system canister containing S149 was then removed from the SAL, dismantled, and stowed.

Prior to the SL-3 deployment of the second set of S149 detector cassettes, the T027 Photometer/UXM malfunctioned and was jettisoned. Thus, the hardware required to nominally deploy and expose the S149 detector cassettes was lost. As a back-up method for S149 deployment, hardware had been fabricated and launched on SL-3 for EVA deployment. Therefore, during the first SL-3 EVA, the crew mounted the S149 MD/CSU and bracketry on the ATM thermal shield lip and manually exposed the detector cassettes. It was later retrieved by EVA on SL-3 and the two sets of detector cassettes were stowed and returned to earth.

On SL-4, the third set of cassettes was deployed and later retrieved by EVA. During retrieval, the crew reported that the small discs on S149 were debonding. Several discs were lost and the others were curling up due to the bonding not holding. The experiment was stowed and no further action was taken. The fourth set was deployed during the final SL-4 EVA and has been scheduled for possible retrieval during the Apollo Soyuz Test Program (ASTP) in 1975.

S149 hardware, for both nominal and contingency operations, was well designed and operated as planned. The contingency hardware, used in EVA deployment of S149, functioned well. The bracket used in mounting the MD/CSU on the ATM thermal shield was a little loose but caused no problems. The ATM thermal shield paint was scratched as the mounting clamp was attached but this was not considered to be detrimental.

7. S183 - Ultraviolet Panorama

a. Operations - Experiment S183 was scheduled during each of the Skylab missions to obtain photographs of a wide field of view of individual stars and extended star fields in the ultraviolet.

Prior to activation of S183, the crewman was to prepare the S183 support hardware, the SAL and the S019 AMS. Once the SAL was prepared, the S019 AMS, used for S183 pointing, was to be inserted. The S183 experiment was to be unstowed and attached to the S019 AMS. The S183 film carrousel was then to be removed from the OWS film vault and installed into S183 along with a 16mm Data Acquisition Camera (DAC) to provide comparison photographic data. The crewman then was to power-up S183, open the SAL door and extended the AMS mirror. The S019 AMS mirror was to be aligned to the desired starfield and S183 photography was to commence as outlined by the checklist. Once this photographic sequence had been completed, the S183 experiment was to be deactivated, the S019 AMS retracted and the SAL closed. The experiment hardware was to be dismantled, removed from the SAL, and stowed.

b. Post Mission Assessment - Crew comments and other data related to on-orbit operations of S183 identified problems of a mechanical operational nature. After two nominal SL-2 performances, the film plate jammed and the operations were discontinued. Malfunction procedures were performed and the problem was isolated to the film carrousel. Due to this problem, all subsequent photographic data for the SL-2 and SL-3 performances was obtained by the use of the 16mm DAC. One other anomaly was reported and involved a focus problem with the 16mm DAC. Changing to another DAC did not alleviate the problem but indicated that the S183 DAC optic system was the problem.

On SL-4, a replacement DAC optic system was launched, interchanged with the original, and the focus problem corrected. In conjunction with the optics replacement, the crew performed additional malfunction procedures and were successful in correcting the film carrousel anomaly. This permitted the experiment to be operated throughout the mission to acquire S183 photographic data as originally planned.

Upon removal of the carrousel from the spectrograph during the second S183 operation on SL-4, a fragment of the SC-5 glass film plate was discovered. It was reported that the carrousel was misaligned 45° from the "00" position. A plate was protruding and the crewman pushed it into the carrousel and stowed the carrousel. Prior to the next operation, an alignment procedure was performed and no problems or loose glass fragments were reported. Pliers were used to rotate the carrousel 45^{o} to the "00" position. During the fourth operation of the spectrograph, an additional fragment of the SC-5 plate was discovered. It was concluded that the glass was jamming the carrousel. A malfunction procedure to remove the plate was unsuccessful. In addition, an "E" clip retaining a spring used to force the carrousel into the indexing detents was lost. This did not eliminate the use of the carrousel but it did require that the crewman check the orientation marks prior to each use. Extreme care had to be used when inserting the carrousel into the spectrograph. Any sudden torquing around the cyclindrical axis would misalign the unit, thus causing difficult, if not impossible, installation.

Sequence problems with the logic counter and the carrousel index, due to hardware problems and procedural errors, were experienced. The SL-3 crew had failed to reset the logic counter and the SL-4 crew cycled the plate advance reset switch and returned the reading to 01. However, the logic counter is completely independent of the carrousel indexing, and the film carrousel rotated to plate 33 and not back to plate 1. This caused plate 34 to become detached from the carrousel and exposed to cabin light. The result of the anomaly appeared to be the loss of one plate and degradation of two others. The operation of S183 spectrograph and film carrousel was not affected. In an effort to eliminate the condition which caused the film plate to slip out of place, a malfunction/synchronization procedure, to synchronize the carrousel with the logic counter, was performed.

The crew also experienced a jamming problem with the DAC camera and S183 magazine 04. After performing trouble shooting procedures, the problem was isolated to a blown fuse inside the S183 spectrograph assembly. The malfunction was duplicated on the quality test unit in France and the experiment developer recommended a work-around procedure which would bypass the blown fuse by connecting an existing wire from a DAC connector on the spectrograph assembly to an adjacent connector. The procedure was successful and S183 operations with the carrousel were resumed.

The S183 experiment activation and manipulation was easily a one-man operation. The latching technique and decals on the experiment launch stowage structure were adequate. The crew stated that for maneuvering the large mass of S183, the handholds supplied were a definite necessity. In addition, the crew recommended that on large masses (i.e. S183, T027) it would be best to have handles provided to facilitate two-handed manipulation for better control during large mass handling/maneuvering. The maneuvering technique used was for the crewman to stabilize his body, carefully push the mass in front of himself and then let the mass and himself move to the terminal location, making positional corrections while in flight. Braking was not considered a problem. This maneuvering technique was documented by experiment M151, Time and Motion Study.

The S183 operations timeline did not allow enough time between exposures. One-minute was added to these times to allow the crew to adjust pointing and timing for the upcoming exposure. The crew also complained about being rushed between an ATM pass and S183 operations. The timeline did not allow ample time to debrief the ATM pass and commence S183 operations. The crew reported no problems associated with the OWS lighting levels during S183 operations.

8. S201 - Electronographic Camera

a. Operations - Experiment S201 was performed on SL-4 to photographically collect Extreme Ultraviolet (XUV) imagery data on Comet Kohoutek.

The experiment consisted of a canister-enclosed XUV electronographic camera (with film-transport box), a second film-transport box, and an EVA bracket. The experiment was used in two operating configurations; (1) through the anti-solar SAL utilizing the S019 AMS as support equipment and (2) bracket-mounted to the ATM truss for EVA operations. Power was provided by the DAC cable during the EVA and SAL operations. Experiment S201 data was recorded on special NTB-3 film.

b. Post Mission Assessment - While performing an S201 experiment operation through the anti-solar SAL, the crew noted that the green exposure sequence indicator light was actually brownish red and very low in brightness and as a result, would probably be difficult to read during the EVA operations. During the second SL-4 EVA, three S201 data takes were performed even though the crew could not see the comet. It was hoped that the comet would be detectable on the photographic data.

Experiment S201 operations were performed as scheduled. The procedures and equipment were adequate and the crew reported no significant problems.

9. S228 - Trans - Uranic Cosmic Rays

a. Operations - Experiment S228 was scheduled for performance on SL-2, SL-3, and SL-4 to obtain knowledge of the abundance of nuclei with an atomic number greater than 26 in the cosmic radiation.

One SL-2 crewman was to deploy the detector module harness, from floor to ceiling, in the OWS experiment compartment using velcro straps as illustrated in Figure 141. Thirty-six detector modules were launched to be deployed with the harness. At the conclusion of the SL-3 mission, one module was to be removed and returned. One S228 detector module was to be launched on SL-4 and deployed during the first SL-4 EVA. It was to be retrieved during the last SL-4 EVA and returned to earth along with the remaining harness detector modules.

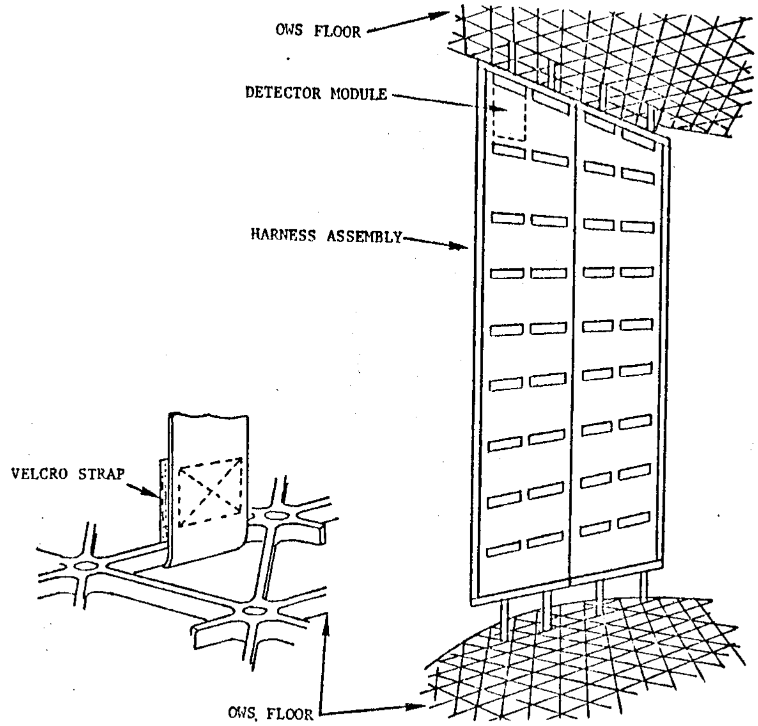


Figure 141. Experiment S228 Operating Configuration

b. Post Mission Assessment - Experiment S228 was performed as scheduled and no anomalies were reported. During the SL-4 EVA deployment, the crew observed some expansion of the experiment package, which indicated some outgassing. This was expected and was within anticipated limits. On the final Skylab EVA, this experiment package was retrieved and stowed with the remaining harness detector modules for return.

Experiment deployment and retrieval went as scheduled and no crew systems assessments were reported.

10. S230 - Magnetospheric Particle Composition

a. Operations - Experiment S230 was scheduled for performance during SL-3 and SL-4 EVA's. Its purpose was to acquire data for measuring fluxes and composition of precipitating magnetospheric ions and trapped particles through the use of a foil collection technique.

The experiment hardware was composed of two collector spools, two inner collector assemblies, two outer collector assemblies and two return pouches. The collector spools, providing support for the inner and outer collector assemblies, were launched on SL-1 to be attached to the ATM deployment truss D2 handrail. During an EVA on both SL-3 and SL-4 the crew was to retrieve one inner and one outer collector assembly for return.

b. Post Mission Assessment - On the first SL-3 EVA, the two outer collector assemblies were retrieved and a calibration shield was installed on the forward inner collector spool. During the final SL-3 EVA, the crew retrieved one of the two remaining inner collector assemblies.

On SL-4, a new inner collector assembly was launched and, on the first SL-4 EVA, attached to the empty collector spool. During a subsequent EVA for ATM film resupply and Kouhotek photography, the crew reported that the S230 calibration shield was missing. Evidently, the shield had been brushed and knocked loose by one of the crew during EVA operations. On the final SL-4 EVA, the remaining two inner collector assemblies were retrieved for return. During AM repressurization operations, one of the two samples was damaged by air from equalization valve 311. The crew reported the damage to effect approximately 10% of the sample.

The EVA procedures for the collector assembly retrievals were straightforward and no problems were reported. The crew reported that they were very careful during retrieval so as not to touch, and consequently contaminate, the collectors.

The calibration shield and the one collector assembly deployment were performed without any reported crew interface problems. The restraint/stability provisions were considered adequate for performing the S230 crew tasks.

11. S232 - Barium Plasma Observations

a. Operations - Experiment S232 was scheduled to be performed on SL-4 to obtain data necessary for determining the effects of plasma conductivity and geomagnetic activity upon the motion of barium plasma.

The experiment operations involved one crewman whose objectives were to photograph the barium cloud injected to outer space by a ground launched rocket. The crewman was notified three hours prior to the scheduled launch as to the photographic settings and procedures. A Nikon 35mm camera was attached to the universal mount and then mounted to the OWS wardroom window to obtain the photographic data. A total of seven barium rocket launches were scheduled during SL-4 with the crewman obtaining a minimum of 40 photographs.

b. Post Mission Assessment - Experiment S232 was performed as planned. Due to problems involved with the rocket launches and resulting launch cancellations, all premission planned photographic data was not obtained. The crew reported that the experiment set-up was a lengthy operation and took approximately two hours to complete. The barium injection was visible to the naked eye and was photographed by the crew using numerous time exposures. During these photographic sessions, the crew reported some difficulties with damping the oscillations of the camera/universal mount after exposure actuation. As the experiment progressed and the crew technique improved, these oscillations were reduced.

12. S233K - Kohoutek Photometric Photography

a. Operations - Kohoutek Photometric Photography, experiment S233K, was scheduled to be performed during SL-4 to obtain a series of visible light photographs suitable for photometry and to provide a synoptic history of the comet Kohoutek.

Experiment S233K used the Nikon 35mm camera and mounting braketry to obtain photographs through the left viewing window of the CM and the STS window. The crewman was required to take a sequence of photographs every 12-hours throughout the comet acquisition periods.

b. Post Mission Assessment - S233K was performed throughout the designated periods of SL-4 and photographs of comet Kohoutek were obtained. All pre-mission scheduled photographic exposures could not be obtained by the crew due to window field of view limitations and faintness of the comet.

The S233K operations were straightforward and were performed as scheduled. No hardware anomalies were reported.

D. Technology Experiments

1. D024 - Thermal Control Coatings

a. Operations - Experiment D024 sample panels retrieval was scheduled for the SL-2 EVA and for the last EVA of SL-4. The equipment for experiment D024, consisting of two thermal control coated samples and two polymeric film sample panels, was mounted and launched externally on the AM support structure as illustrated in Figure 142.

Experiment D024 did not require a specific EVA for sample retrieval, but was scheduled to be performed in conjunction with the ATM experiments film retrieval. The D024 sample retrieval required two crewmen, designated EV1 and EV2. EV2 was to retrieve two sample panels, stow them in the return container, then pass the container to EV1, who was to temporarily stow it in the AM.

b. Post Mission Assessment - Experiment D024 sample panel retrieval was performed, as scheduled, on SL-2 with one thermal control coating sample panel and one polymeric film strip sample panel being returned. Due to the total time in orbit, it was decided that the remaining two sample panels had received adequate exposure by the end of SL-3 and that they should be retrieved on the last EVA of SL-3. To alleviate handling of multiple items, the crewman placed the sample into the return container prior to removing the pip pin holding the sample in place. It was noted that some of the samples were becoming slightly loose, though none were lost. After the return of the remaining two samples on SL-3, two additional sample panels with return container were launched on SL-4 for deployment on the first EVA and retrieval at the end of the mission. The crewman had difficulty deploying the sample due to poor visibility for sample alignment and the lack of tactile feed-back through the EVA gloves. However, he was eventually able to attach the panel by touching the center samples with his finger, possibly contaminating them. The samples were retrieved on the final SL-4 EVA. The problem the crew experienced with the deployment of the sample panels could have possibly been eliminated with the addition of guide pins and alignment marks on the mounting plates and the sample panels. However, the experiment as it was originally designed did not call for the deployment of the samples on orbit as they were launched in place.

The D024 samples were easily retrieved and stowed, per the checklist. A foot restraint would have been helpful at the D024 location to assist their stabilization when retrieving samples.

2. M512 (M551, M542, M553, M555) - Materials Processing in Space M479 - Zero Gravity Flammability - M518 - Multipurpose Electric Furnace System

a. Operations - The M512 experiment facility, shown in Figure 143, was designed to utilize a common spacecraft interface for a group of experiments in material science and technology. It was scheduled to be used on SL-2, SL-3, and SL-4.

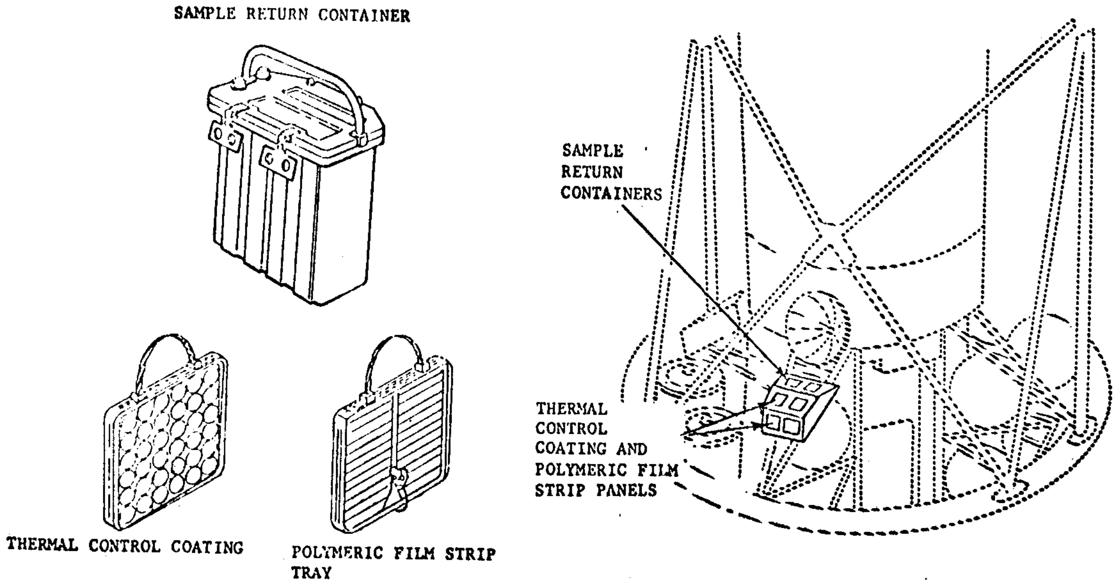


Figure 142. D024 Experiment Panels and Sample Return Container Configuration

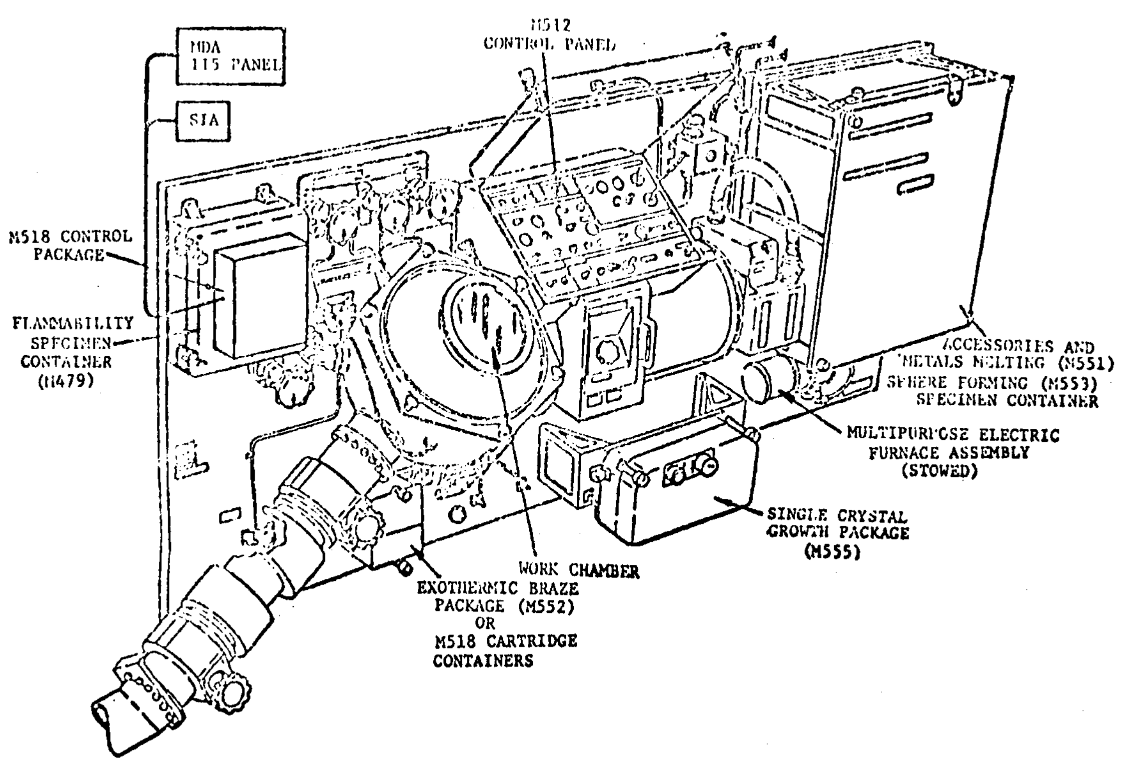


Figure 143. M512 Materials Processing Facility Stowed/Operational Configuration

The facility permitted exploration of space manufacturing applications of molten metal phenomena such as metal flow, freezing patterns, thermal stirring, fusion across gaps, and surface tension. The requirement was for one crewman to perform the experiments. The basic functions performed were; installation of the experiment equipment or specimen in the work chamber, systems control operation, observation, photography, and monitoring of the experiment, and removal and stowage of the equipment and specimen after experiment completion. Experiments M551, M552, M553, M555, M518, and M479 utilized the M512 facilities.

b. Post Mission Assessment - During initial use of the M512 facility, it was believed that the electron beam gun had shifted due to loads experienced at launch. Upon later analysis, the problem was found to be with a new mirror installed at KSC. The mirror was reversed so only one of two retaining screws could be fastened when mating it inside the facility.

During a performance of M553, difficulty was experienced with the installation of the shield over the electron beam gun. This problem was caused by a hardware installation sequence error. The shield should have been installed first, instead of last, by the crewman.

Due to M512 operational problems, the crew was asked to use the main circuit breaker to shut-off the M512 facility power when performing M553 spherical forming. During cutting of the M553 specimen stinger, the jaw of the cutting pliers broke. Wheel number one of the experiment was completed, while wheel number two had two balls that were not released and three that were released. Wheel two was returned to earth with the released specimen balls from wheels one and two.

A lengthy time period was required on-orbit to obtain a sufficient vacuum in the facility. To obtain the vacuum, the crew had to leave the vent valve in the "Vent" rather than the "Open" position during their sleep period.

Experiment M479 was performed at the end of SL-4 with the only anomaly reported being associated with the water quench system. The lower nozzle appeared to be completely plugged and the upper nozzle emitted only a dribble. The crewman completely reserviced the system but it still did not function properly. In order to get any spray at all, the crewman had to grasp the accumulator knob and pull sharply on it to force water through the system. There was not time for extensive trouble shooting, but the problem was believed to be with a water supply valve not being turned on.

While burning sample number three, the crewman stated there was an operator error in that he left the chamber repress valve in the open position. The only effect was the sample burned slightly longer. M512 experiment performance on-orbit was similar to ground training with the exception of the times required to heat or cool the experiment specimen and to obtain a sufficient vacuum in the facility. The crew stated that the training unit was excellent, just like the flight unit, but they never experienced pumping the facility to a vacuum during their training. Consequently, the first time the vacuum gauge was used on-orbit, the crew thought that the slow bleed down time indicated a faulty gauge.

During M553 operations in the M512 facility, no problems developed with the facility or accessory equipment. However, pressure build-up in the facility chamber during the firing of the electron beam gun occurred more rapidly on-orbit than experienced during training. In some instances, the balls on the M553 wheel stings formed a pear shape or did not release. The crew experienced no problems in handling the specimens as long as they observed proper cool down times.

The crew expressed enjoyment in performing the M518 Multipurpose Electric Furnace experiment because it was new and different. The equipment worked as designed and was easily installed into the M512 facility chamber. The specimen cartridges were numbered (identified) in systematic manner that permitted ease of handling and insertion. The operations were clearly defined and no problems were experienced performing the M518 series in the M512 facility.

All M479 specimen samples were in excellent condition and the burning had no effect on the view ports. The view ports remained clean throughout the experiment performance.

The M512 chamber hatch did not appear to have proper friction hinges as per the experiment design requirements. No detrimental crew comments were received, but during video downlink of M512 facility operations, the hatch was observed to be floating free.

3. T002 - Manual Navigation Sightings

a. Operations - Experiment T002 performance was scheduled on SL-2, SL-3, and SL-4. Batteries for the sextant and stadimeter were resupplied on SL-3 and SL-4. Sightings were distributed uniformly throughout the mission on a non-interference basis.

The crewman performing the experiment was to remove and stow the wardroom window cover, and obtain the sextant or stadimeter from locker W740. The batteries for the sextant and stadimeter were to be installed by the crewman during experiment activation. Wardroom lights near the wardroom window were dimmed and the reticle light adjusted before the crewman proceeded with the experiment sightings.

b. Post Mission Assessment - Experiment T002 was satisfactorily completed on all three Skylab missions. Due to a residue pattern formed on the wardroom window during SL-3 and SL-4, the operator had to reposition the instruments during his sightings to avoid viewing through this residue and expressed concern that his movements may have affected his sightings. The crew emphasized the importance of body position in obtaining accurate sightings with the T002 sextant. During an early operation, the crewman developed muscle cramps in his arms and legs. The crewman devised a restraint system to hold him in position at the window, using a long strap hooked over the S063 bar. This improved the accuracy of his sightings. He also stated that there was a distinct difference in ease, ability, and accuracy obtained, whether the stars were located up and down, left or right, relative to his body position.

The T002 window hood, which was used to shield the wardroom window from internal reflection, was considered a definite necessity. The crewman found it difficult to hold the sextant steady during sightings. He also felt it would be extremely helpful to have the sextant readout inside the reticle, in order to prevent losing sight of the star while taking readings. The stowage configuration in locker W740 was excellent, and the foot restraint provisions at the wardroom window were considered adequate.

The crew stated it was difficult to remove their fingers from the pointing control knobs on the sextant without moving it. They could get a good alignment, but when they released their fingers, the knob would move slightly. This created some mediocre scatter in the system. The control knobs should have been easy to move, but not so sensitive that they could not remove their fingers without disturbing its position. The crew also stated the knobs on the filters were poorly designed because they could not tell whether they were in or out.

The crew experienced pointing difficulties due to the shape of the case and the location of the strap. This made it difficult to hold the sextant in the proper position at the window. They believed they needed phosphorescent alignment marks to get the line of sight directed between two stars. They also suggested the use of a colored filter so that they would not lose track of which star they were sighting. This was a problem when holding the sextant at odd angles. The system should have been designed so that all controls could be operated without the crewman removing his eyes from the reticle sight.

4. T003 - In-Flight Aerosol Analysis

a. Operations - Experiment T003 was scheduled for performance on SL-2, SL-3, and SL-4. Multiple measurements were to be taken daily to determine the concentration and size distribution of particles suspended in the OWS atmosphere.

A crewman was to transport the portable self-contained aerosol analyzer (Figure 144) throughtout the OWS observing the readout and recording the data on the T003 data cards. At the completion of each mission, the data cards and the filter impactor unit from the aerosol analyzer were to be returned.

b. Post Mission Assessment - Operation of T003 went as scheduled with all functional objectives being accomplished. Results demonstrated that the OWS was cleaner than most hospital operating rooms, with a particle count of 3000 per cubic foot. The crew reported that T003 readout time was adequate for recording the data on the data cards. The only anomaly reported was a filter change which was missed due to the tardiness of a detailed pad up-linked from the ground.

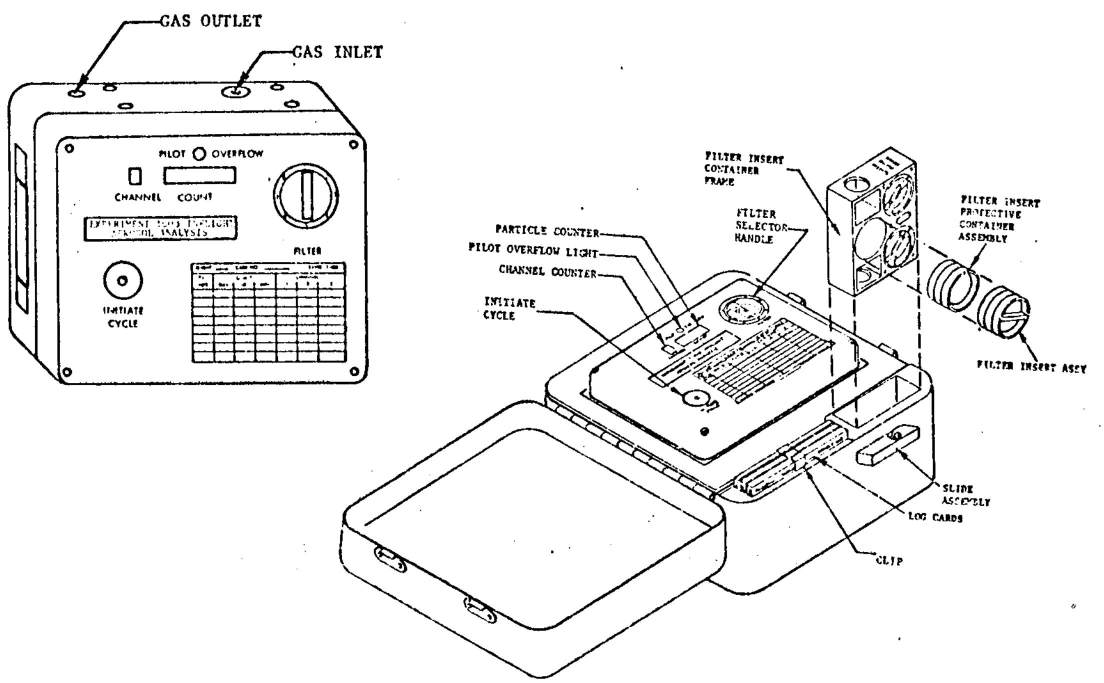


Figure 144. T003 Stowage Container

Experiment operations were straight forward and no problems were experienced in stabilizing at the various sample stations. The crew did report that the data cards were not large enough to allow sufficient area to record all the required information.

5. T025 - Coronagraph Contamination Measurement

a. Operations - Experiment T025 was scheduled to be performed on SL-2, SL-3, and SL-4, through the solar SAL, to determine the existence and presence of any changes in particle atmosphere due to transfer firings, waste dumps, vehicle orientation, and time decay of such atmospheric concentrations.

The T025 experiment equipment, illustrated in Figure 145, consisted of the coronagraph canister, including the occulting discs and extension boom assembly with the photographic equipment. One crewman was scheduled to set up the experiment apparatus in the Solar SAL and complete a 27-photographic exposure sequence during five non-consecutive orbits.

b. Post Mission Assessment - T025 was not performed as scheduled because the solar SAL was used for deployment of the parasol thermal shield. All T025 operations were cancelled for SL-2 and alternate performance methods were developed. The SL-3 crew utilized

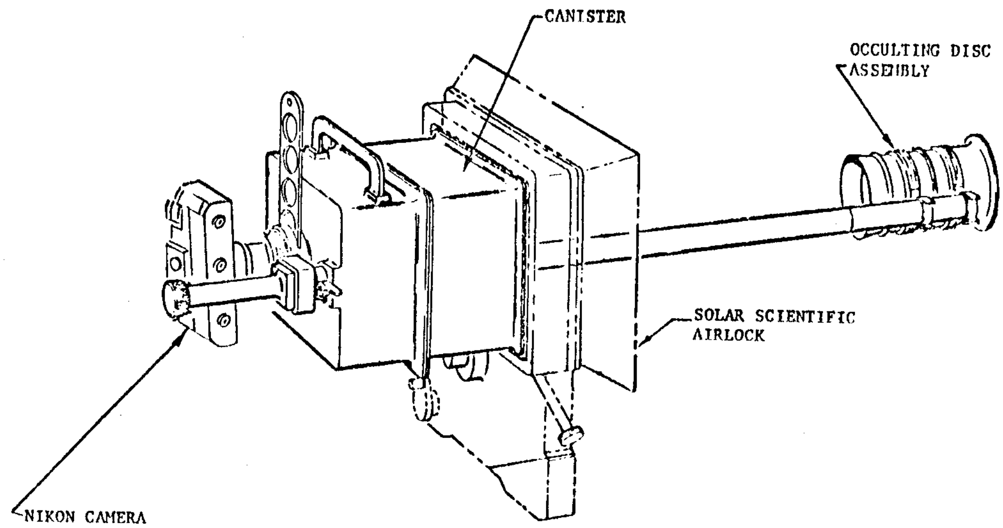


Figure 145. T025 Experiment IVA Operational Configuration

the T025 hardware to obtain some experiment S073-Gegenschein and Zodiacal light photography. The equipment was installed upside-down in the anti-solar SAL with the occulting disc positioned out of the camera's field of view. During this operation, the crewman used his finger to control the DAC shutter release. This proved to be difficult and fatiguing. In readiness for subsequent operations, the DAC was prepared for operation with the DAC push button cable. However, the crew was not directed to repeat the experiment.

As an alternate method of performing T025 and viewing the Kohoutek comet, an EVA bracket, to attach the T025 canister to an external truss, was designed and launched on SL-3. The SL-3 crew fit-checked the bracket to the T025 experiment and attached operational decals in readiness for EVA deployment on SL-4.

Problems occurred during the first SL-4 EVA operation of T025 which prohibited the acquisition of all planned data. Five photographs, out of a planned forty, were obtained. The view finder on the camera was loose and the shutter speed knob came off during operation. The crewman was able to reinstall the knob, but it did not engage enough to permit use. During EVA trouble shooting of the T025 equipment, the thermal blanket cover was removed. The T025 hardware was stowed in the AM to permit further troubleshooting at a more opportune time. After completion of the EVA, the crew successfully repaired the shutter speed knob and the T025 hardware was utilized during subsequent EVA's to obtain ultraviolet and visible photographs of the Kohoutek comet. All subsequent T025 experiment performances were performed without incident.

The T025 experiment was performed from the anti-solar SAL with only minor problems. The T025 hookup with the extension rod worked well and the procedures/checklists and hardware used for night photography were adequate. Pad updates for the experiment reminded the crew to inhibit the fire sensors prior to experiment initiation because the Caution and Warning System alarm was activated on SL-3 when the SAL was opened with T025 installed.

T025 was not originally designed for EVA use but, with the addition of the specially designed EVA bracket and filters, (illustrated in Section VI. E), ultraviolet and visible photographs of the Kohoutek comet were obtained.

6. T027 - Sample Array

a. Operations - The T027 Sample Array (SA) experiment performance was scheduled during SL-2 to acquire data for determining the change in optical properties of various transmissive windows, mirrors, and defraction gratings, cause by deposition of contaminants found about the orbital assembly.

The experiment equipment included a canister system with one extension rod, an ejection rod, and a launch stowage container. One crewman was to prepare the T027 SA experiment and then install it through the anti-solar SAL for exposure to the space environment. Upon completion of the exposure, the SA was to be retracted, removed from the SAL and restrowed in its launch container for return. Experiment hardware is illustrated in Figure 146 and 147.

b. Post Mission Assessment - The T027 experiment was installed in the anti-solar SAL and deployed as planned. Due to the parasol deployment and resulting requirements for usage of the anti-solar SAL by other experiments, the T027 SA exposure time was reduced.

The problem identified during operation of T027 occurred during the closure of the array valve prior to retraction and removal of the SA system from the SAL. When the crewman closed the array valve by turning the vane control, the valve did not seat completely. Force, in excess of that recommended during training, was applied to the vane control and the valve was closed. The problem was attributed to the low temperature of the system, causing frost to form, thus preventing normal closure.

The requirement to let the T027 SA system warm-up prior to its removal from the SAL had been eliminated from the checklist and consequently omitted from the experiment pad. This procedural information was definately necessary, as indicated by the minor problem which occurred with the array valve.

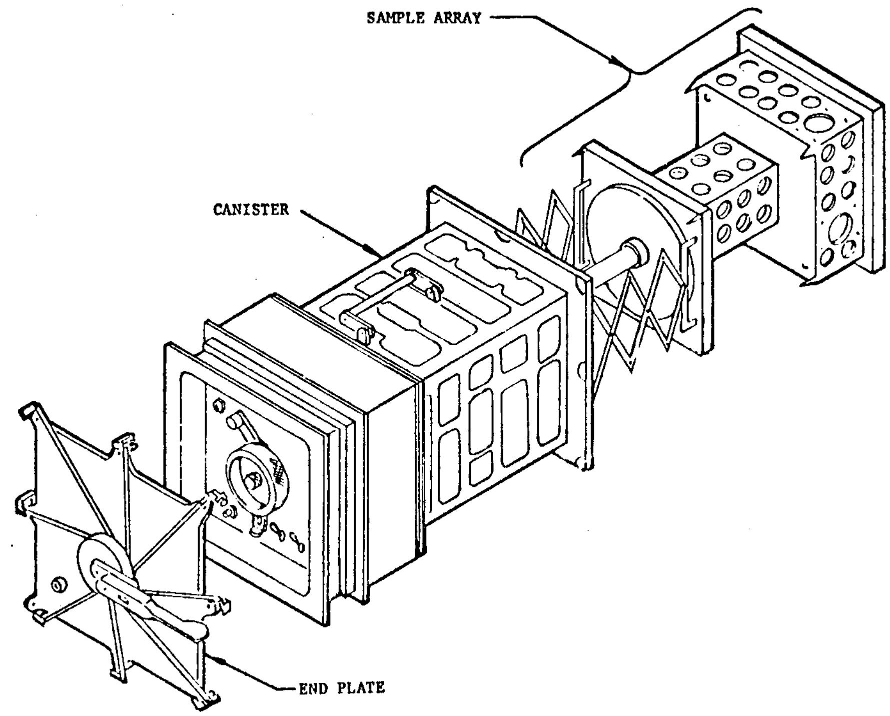


Figure 146. T027(A) Sample Array System, Operating Configuration

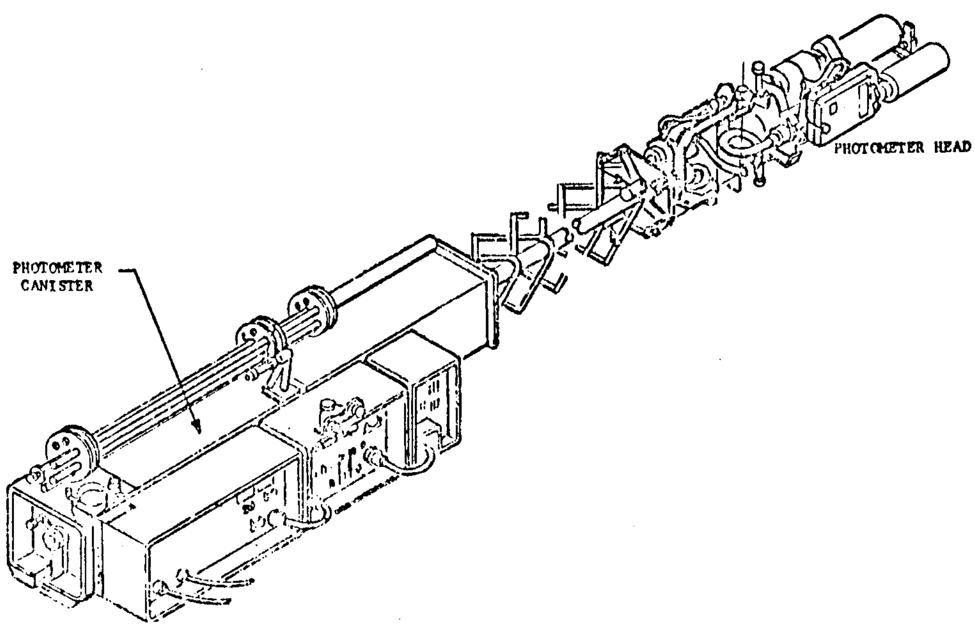


Figure 147. T027(B) Photometer System, Operating Configuration

E. Operations Experiments

1. M487 - Habitability/Crew Quarters

a. Operations - Experiment M487 was scheduled for each of the three Skylab missions for evaluating and reporting on the OWS habitability provisions.

The methods of M487 data collection were dependent primarily on the crewmen. Where possible, the experiment task was to augment or coincide with the operational activity being observed. When an activity was not scheduled or predictable, the elements of the activity were to be grouped into a staged demonstration to optimize time and effort. First the crewman was required to obtain, calibrate as required, and position the various monitoring devices throughout the OWS. The crewman then had to obtain, position, and operate the various equipment required for photography and data collection.

b. Post Mission Assessment - M487 was performed as planned throughout each Skylab mission, accomplishing all pre-mission requirements.

During the initial calibration of the sound level meter/frequency analyzer, the crewman could not obtain the correct calibration factor. A second calibration was attempted at a later time and the correct factor was obtained. The cause of the problem encountered during the first calibration attempt was undetermined.

The crews considered much of the equipment supplied to support the M487 experiment as unnecessary, as was shown by its lack of use throughout the Skylab missions. For this reason, few comments concerning the M487 hardware were available. It was reported that both the ambient and digital thermometers required a lengthy time to stabilize when measurements were made where a large change in temperature was involved. Both the digital and ambient thermometers were used over the three Skylab missions in support of other hardware evaluation and the 10-foot tape was used in several science demonstrations. These items should be included on future missions as operational support hardware.

Some crewmembers expressed annoyance toward the lengthy and time consuming on-board debriefings. They felt that this orbit time could have been better utilized and that the debriefings could have been conducted post-mission.

It is intended that the data compiled from M487 will form the basis for verifying existing spacecraft habitability criteria and will establish requirements for more advanced spacecraft.

2. M509 - Astronaut Maneuvering Equipment

a. Operations - Experiment M509 was scheduled to be performed on SL-2 and SL-3. Each test pilot was scheduled to perform four runs with the Automatically Stabilized Maneuvering Unit (ASMU) while an observer assisted. Runs 1, 2, and 4 were designated to be performed unsuited whereas run 3 was planned for maneuvers with the Skylab Extravehicular Mobility Unit (EMU).

Prior to experiment performance, the M509 hardware (Figure 148) and support hardware was to be unstowed and reconfigured for operation, including Propellant Supply System (PSS) bottle and battery charging. Once the experiment preparation was completed and the OWS forward experiment area was cleared of equipment which could impare experiment operations, the observer was to assist the test pilot in donning the ASMU (Figure 149). The test pilot was to then undock from the donning station and perform the designated M509 maneuvers. Upon completing these maneuvers, the subject was to return to the donning station and dock the ASMU, concluding the experiment performance.

b. Post Mission Assessment - The M509 performance for SL-2 was limited to operational configuration and checkout. Due to the OWS meteoroid shield problem and resulting high temperature, it was concluded that a hazardous condition might exist if the M509 batteries were discharged. If the batteries were used, an internal short might have occurred resulting in a possible explosion. The ASMU, PSS bottle rack, and AM N_2 recharge station were reconfigured to their inflight usage configurations and the PSS bottles were recharged. After reconfiguration/checkout of the M509 ASMU and the PSS bottle installation, the unit was powered-up while still in the docking station. The backpack and Hand-Held Maneuvering Unit (HHMU) thrusters were also fired.

Between missions, ground testing determined that the M509 flight batteries were acceptable for use, therefore, on SL-3 and SL-4, the experiment was successfully operated. The unit was flown in all four modes, both suited and unsuited.

One modification was made to the planned M509 activities after the first suited performance. During this performance, the test pilot noted that the Life Support Umbilical (LSU) imparted undesirable dynamic forces on the ASMU during maneuvering. To reduce/eliminate these dynamic effects, the crew stripped the LSU of most of its wiring and insulation, leaving only the O_2 line and a communications line. This modified LSU was then used on all subsequent M509 and T020 suited runs without utilizing the Secondary Oxygen Pack (SOP).

During an SL-4 suited run, battery problems arose causing the experiment run to be shortened. The batteries were being depleted much faster than anticipated due to time consuming delays during the test. One delay was experienced when the crewman encountered problems attaching the AM recharge station quick disconnect to the PSS bottle connector. Another delay was experienced when the SOP was depleted and had to be replaced by the LSU. During both these delays, the ASMU was on battery power thus draining the battery. These delays drained both M509 batteries to the 26-volt minimum and the M509 run was terminated after completing only 2/3 of the run's objectives. M509 was performed throughout the remainder of SL-4 and no anomalies were reported.

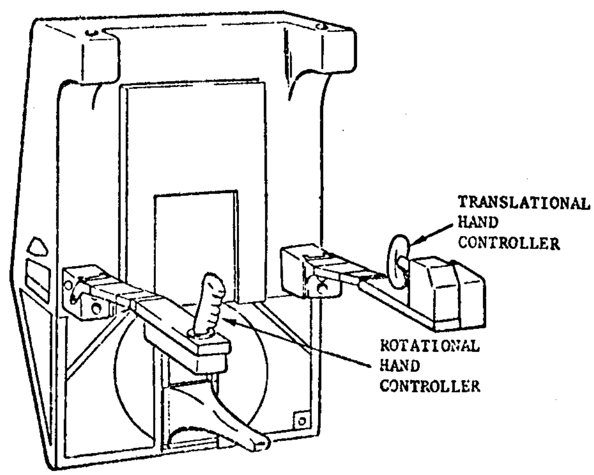


Figure 148. ASMU Operational Configuration

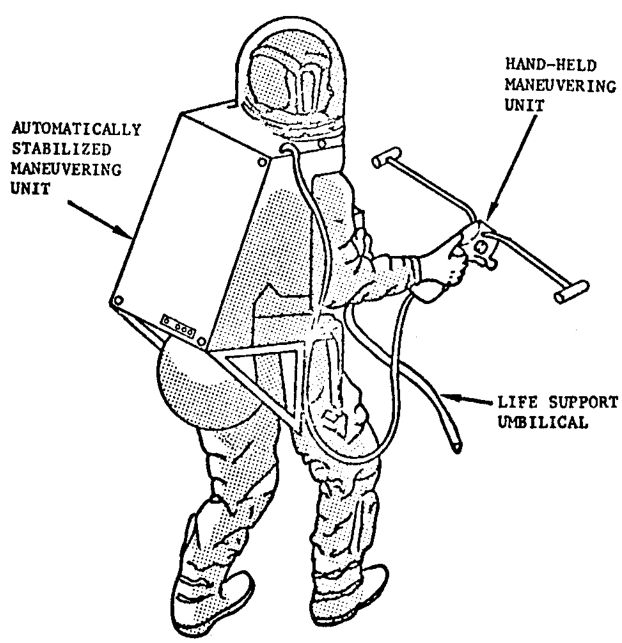


Figure 149. Astronaut Maneuvering Research Vehicle

The M509 ASMU was well designed and easy to operate. Flight training skills, common to all astronauts, was apparently readily transferred to navigating the ASMU. This transfer of training was demonstrated during an unscheduled M509 performance by a crewmember who had never trained for M509 or ever used the training simulator. His flight was performed with ease and was considered a complete success.

During the M509 maneuvers, four potential flying modes were evaluated and, in order of preference, were "DIRECT", "CMG", "RATE GYRO", and "HHMU". The "DIRECT" mode was the easiest and the more intuitive to control. The "CMG" and "RATE GYRO" modes were very good but the precision, inherent to these modes, was unnecessary and will not be required for a future EVA maneuvering device. The HHMU was given a poor rating and was recommended by the crew to be deleted from consideration as an EVA maneuvering mode. The difficulty with the HHMU was in locating the center of gravity, which turned out to be an important factor in this maneuvering mode. In future testing of a maneuvering unit, it is recommended that the HHMU be eliminated from consideration because it requires unique and undeveloped operator skills.

In flying M509, actual EVA conditions were simulated to evaluate all phases of maneuvering. Suited operations were conducted using both the LSU and SOP. The SOP configuration was preferred over the LSU configurations because of the dynamic effects present with the LSU. The LSU, due to its mass and elastic characteristics, imparted an inertia on the M509 ASMU, which proved to be annoying to the test pilot, constantly requiring guidance corrections to the unit.

Safety was a principle concern during M509 pre-mission design and planning. Due to the ease of operation and maneuverability of the ASMU, the pre-mission concern of inadvertant and possible catastrophic collisions was proven to be unwarranted. The ASMU, though very large and heavy, was handled without difficulty by the test pilot. The test pilots were confident that, even with the large ASMU mass and a maximum maneuvering velocity of 3-4 ft/sec, they could, in the event of a thruster failure, reposition themselves and absorb the energy of an impact without bodily or hardware damage.

The crews believed that the M509 hardware and supporting equipment was well designed from both a functional and integration standpoint. However, the crews one negative comment was that the ASMU had too many controls located in too many diverse and remote positions. If possible, these controls should be relocated on a common panel to facilitate crew operations. The safety goggles and ear plugs were used by all crewmen. The unstowage/stowage of the M509 hardware was straightforward with no problems occurring. PSS bottle charging required the crew to translate to and from the AM recharge station with the bottles. This entire procedure, including recharge, took less than 10 minutes to perform. It was reported that the bottles reached a temperature of approximately 100^{o}F during recharging. Translation with the bottles was accomplished by the crewman holding the bottle ahead of him, pushing off and then following along behind the hardware. Prior to reaching his destination, the crewman would reposition himself between the hardware and contact point for a safe landing.

The ASMU was an acceptable translational device but was found to be severely limited in its use as a workstation/platform for performing work related tasks. In performing relatively easy tasks, the crewman's body torques would over saturate the ASMU gyros and cause a loss of stability. To perform EVA tasks, the ASMU, as designed, would have to be docked/restrained at the designated work area to achieve the necessary stability required to perform the task.

The next generation EVA maneuvering device should be back mounted with the pilot-to-backpack restraint system providing a tight, secure, and comfortable (seat padding recommended) fit. Backpack donning/doffing should be designed as a one-man function. The backpack must have six-degrees of freedom, with the propulsion thrusters located around the center of gravity of the pilot/backpack combination, and should be hand controlled. The hand controllers should have the capability of being relocated during flight to allow multiple working postures for the pilot. The "DIRECT" mode should be selected as the maneuvering mode with a capability of a 3-4 ft/sec velocity. Restraints/docking provisions, i.e., manipulative arms must be provided to adequately stabilize the pilot and permit him to perform the designated task. A backpack spotlight should be incorporated to provide the pilot with an illumination source at his work area. Separate isolation valves/circuit breakers for each thruster, or set of thrusters, should be provided to insure against a single point failure. Ideally, backpack should contain all systems required for EVA, such as, pressure control, oxygen, and maneuvering systems, with all system monitoring displays/readouts being illuminated. Incorporation of a safety tether should also be considered.

3. T013 - Crew/Vehicle Disturbances

a. Operations - Experiment T013 was scheduled for performance on SL-3 to measure the effects of crew motions on the dynamics of manned spacecraft.

Two crewmen were required for T013 operations; one designated as the subject and the other as the observer. A third crewman was required during performance of the worst case control system input task. Data collection involved the use of the 16mm DAC, mounted in the OWS forward compartment and experiment and vehicle telemetry. The Limb Motion Sensor (LIMS) suit assembly, including the LIMS data cable, was to be unstowed, donned by the subject, and then connected to the experiment data cable between the LIMS and the Experiment Data System (EDS). Prior to start of the experiment, the observer was to don a communications headset and turn on the AM tape recorder and cameras for data collection. The Force Measurement Units (FMU) were to then be uncaged and calibrated. During the experiment performance of body and limb motions and free soaring activities, the observer was to assist in securing the subject to, and releasing him from, FMU No. 1 at appropriate times during the experiment. Experiment operational configuration is illustrated in Figure 150. Upon conclusion of the experiment performance, the cameras, AM tape recorder and the EDS were to be turned off and the FMU's caged and pinned. The EDS data cable was to then be disconnected and stowed with the LIMS suit assembly in the T013 stowage container.

b. Post Mission Assessment - T013 was performed on SL-3, as designated, by the experiment checklist.

During the first pushoff of the soaring activities, a malfunction occurred in the load cells of FMU No. 2 causing a partial loss of data. Malfunction procedures were performed on both FMU's and deformation of the load cell flexures was uncovered. As part of the malfunction procedures, a FMU calibration was performed and the results indicated that load cells 4 and 5 of FMU No. 2 had failed and were considered lost.

To satisfy the experiment mission requirements, a rerun of the T013 soaring activities was performed, but the crew failed to activate the T013 Experiment Data System (EDS), consequently, no experiment data was received.

Again, in an attempt to satisfy the experiment requirements, a third run of T013 was performed and all ATM-PCS and photography data was successfully obtained. This performance satisfied all T013 requirements.

During performance of the T013 worst case input task, only two crewmen participated instead of the required three. Since the third man, designated as observer, did not contribute to the data input and was required only for safety reasons, the omission of his participation had no effect on the experiment results.

Other than the FMU anomaly, T013 operations were straightforward and easily performed. Stowage/unstowage was simple, the LIMS suit fit well, and camera positioning was no problem. Soaring between the FMU's was quite easy. In fact, the FMU's could have been placed much farther apart without effecting the crewman's soaring accuracy. The FMU's were placed so close together that it was difficult for the crewman to soar between them and land feet first.

During the worst case task, the second performer, for some reason unknown at this time, could not soar between the film vault and the food lockers adjacent to the film vault. During the simultaneous soaring both crewmen performed their push-offs together but due to the differences in soaring distances their impacts were not simultaneous.

4. T020 - Foot Controlled Maneuvering Unit

a. Operations - Experiment T020 was scheduled for performance in the OWS forward compartment area during SL-3 and SL-4. A total of five runs by each test pilot was scheduled with the Foot Controlled Maneuvering Unit (FCMU) while a second crewman acted as observer, OWS cameraman and safety man. Of the five performances conducted by each test pilot three were to be operated in shirtsleeves and two while suited.

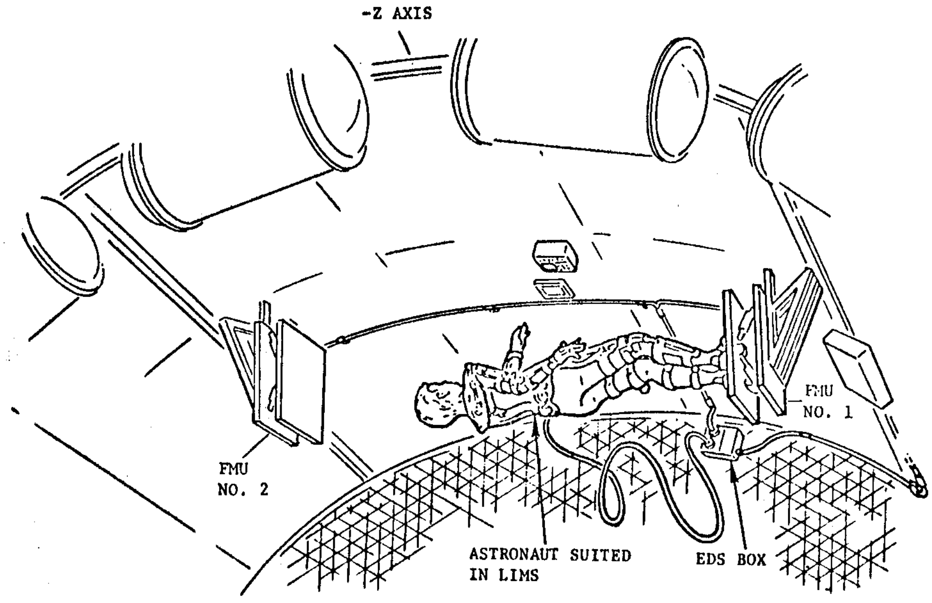


Figure 150. T013 Experiment Operational Configuration

Prior to the experiment performance, the T020 hardware and support hardware were to be unstowed and reconfigured for operation, including M509 PSS bottle and battery charging. Once experiment preparation was completed and the OWS forward experiment area was cleared according to the T020 checklist, the observer was to assist the test pilot in donning the T020 maneuvering equipment. The test pilot was then to undock from the T020 docking station and perform the required maneuvers. Upon completion of these maneuvers, the subject, with aid from the observer, was to return to the docking station and dock the FCMU, thereby concluding the experiment. Experiment configurations are illustrated by Figures 151 and 152.

b. Post Mission Assessment - Experiment T020 was performed as planned on SL-3 with the test pilots operating the FCMU five times. The first three runs were performed in shirtsleeves while the last two runs were flown suited. The two suited runs were conducted utilizing both the Life Support Umbilical (LSU) and Secondary Oxygen Pack (SOP) configurations. On SL-4, T020 was performed twice. The first run was performed suited whereas the second was performed in shirtsleeves.

Two modifications were added to T020 during its performance on SL-3. After the first maneuvering operation, it was evident that a better restraint system was needed. A modified system was devised on ground and then information was uplinked to the crew. This restraint system provided the added stability sought by the test pilot and was used throughout the remaining SL-3 T020 performances.

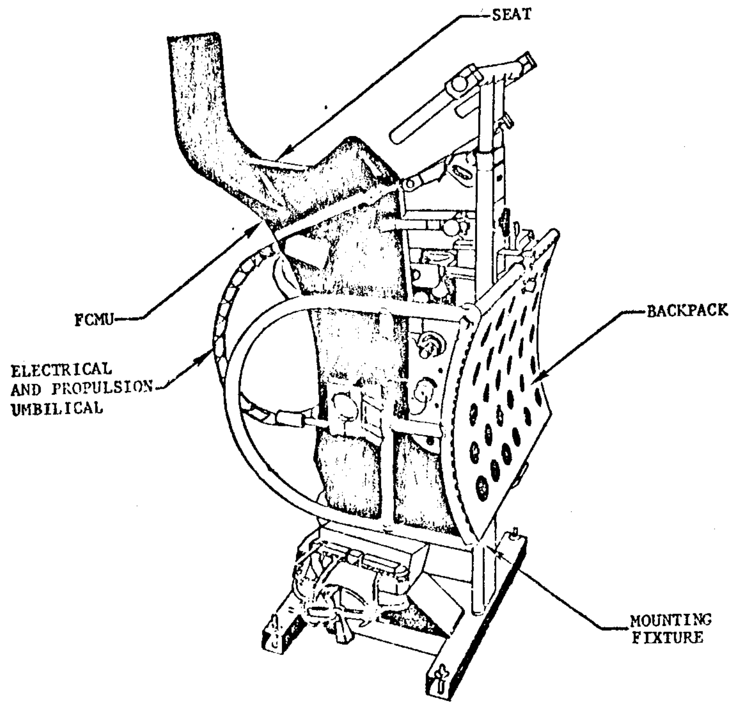


Figure 151. FCMU and Backpack Stowed Configuration

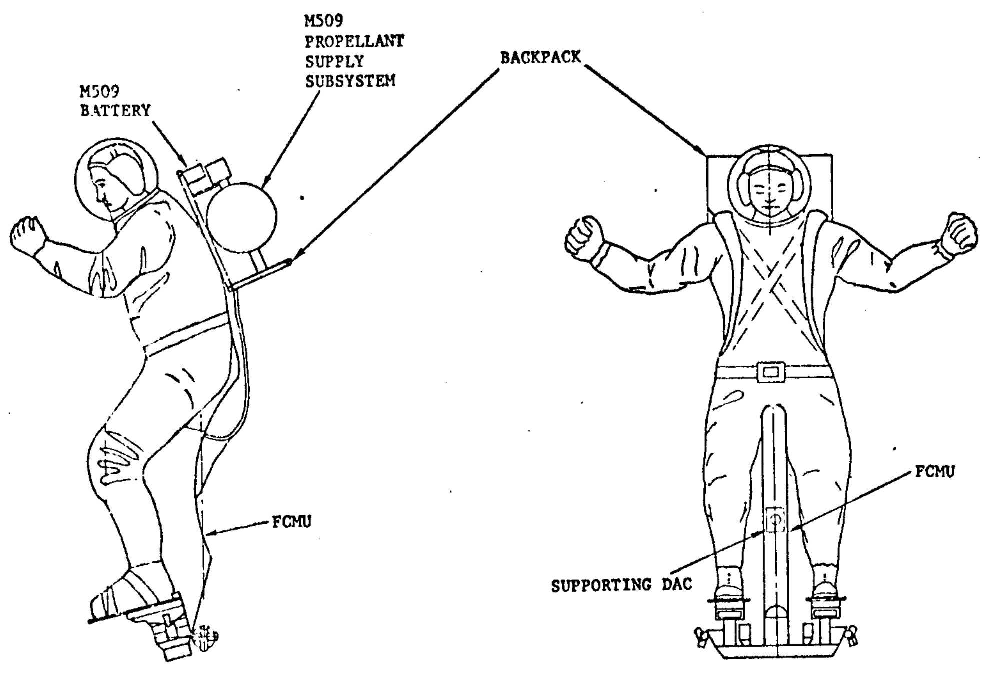


Figure 152. FCMU Operational Configuration

A second modification was performed by the SL-3 crew on the LSU in hopes of reducing or eliminating the dynamic effects it imparted on the maneuvering units. Using a scalpel and scissors, the LSU was stripped of most wiring and insulation, leaving only the O_2 line and communications line. This LSU was used on all subsequent M509 and T020 suited runs not utilizing the SOP configuration.

Because of the lack of rigidity experienced with the T020 restraint system during SL-3, a new, rigid restraint system was designed and fabricated between missions. This rigid restraint system was launched on SL-4 and used by the crew in their T020 operations.

The first SL-4 T020 run was performed suited and utilized the new restraint system. The crew reported that the system worked extremely well and reduced practically all body/backpack motions.

The second T020 performance was conducted in shirtsleeves. The crew operated T020 with both the rigid and original restraint systems. Again, the rigid system was considered highly effective whereas the non-rigid system was considered extremely poor.

This was the last evaluation of experiment T020 as scheduling considerations prohibited any additional performances.

T020 stowage/unstowage was fairly simple, although between operations it was left stowed in such a manner requiring a minimum of reactivation time...a casual type of stowage.

The T020 restraints and harness were not satisfactory. Also, seat padding was improvised and is definitely required. The restraints did not give the operator a secure or tight feeling in the unit. The harness, due to its unusual design, was difficult to don and connect. The backpack assembly was not contoured correctly and was too loose when donned. Incorporation of the required restraint system removed most of the "play" between the backpack and FCMU and gave the pilot a more secure fit with the T020 hardware.

The shoe plates seemed to work well, although it was easy to kick one's foot/shoe plate out of the FCMU. Also, the shoe plate forces required for thruster control were too high. These seemingly high shoe plate forces could be attributed to a possible deconditioning of the crew's leg muscles due to the zero-gravity environment.

T020 should have had six-degrees of freedom for fair comparison with M509 (which was not the intent of the experiment). As designed, it is unacceptable as a maneuvering vehicle and the crew saw no advantage in its concept of foot-controlled maneuvering.

F. Student Project Experiments

1. ED 23 - Ultraviolet From Quasars

a. Operations - Student experiment ED 23 was scheduled on SL-3, as an additional data pass of baseline experiment S019, to obtain spectrographic data of selected quasars.

The crew used experiment S019 as support equipment for ED 23. With S019 mounted in the SAL, ultraviolet photographs were taken of pre-designated galaxies. ED 23 data was recorded in the S019 portion of the log book and exposed film was returned in the S019 film canister.

b. Post Mission Assessment - Student experiment ED 23 was performed as scheduled, with no anomalies reported. The crew indicated that experiment training was adequate but that a decision was needed as to experiment operational priority, so as to closer approximate crew training.

2. ED 25 - X-Rays From Jupiter

a. Operations - Student experiment ED 25 was scheduled on SL-3 to detect x-rays from Jupiter.

The experiment was scheduled in conjunction with ATM experiment S054 under Joint Observation Program (JOP) 13. The vehicle was maneuvered so that the ATM could observe celestial bodies away from the sun.

b. Post Mission Assessment - Student experiment ED 25 was performed during the ATM performance of JOP 13 as scheduled, with no anomalies reported.

The crew indicated the procedures were adequate and that the hardware performed satisfactorily.

3. ED 26 - Ultraviolet From Pulsars

a. Operations - Student experiment ED 26 was scheduled on SL-3 as an additional data pass of baseline experiment S019 to search for pulsars in ultraviolet wavelengths.

The crew used experiment S019 as support equipment for ED 26. With S019 mounted in the SAL, ultraviolet photographs were taken of designated galaxies. ED 26 data was recorded in the S019 log book and the exposed film returned in the S019 film canister.

b. Post Mission Assessment - Student experiment ED 26 was performed as planned with no anomalies reported.

ED 26 used only film and S019 experiment hardware, therefore all crew interface assessments are included with the assessment of S019.

4. ED 31 - Bacteria and Spores

a. Operations - Student experiment ED 31 was scheduled on SL-3 to determine the effects of weightlessness and space radiation on the survivability, growth rate, and mutation of several vegetative bacterial species.

A crewman inoculated the 15 petri dishes containing nutrient agar. Nine cultures were incubated in the Inflight Medical Support System (IMSS) incubator and six at OWS ambient temperature. Observation and photography of these cultures were at 12-hour intervals, until the colony growth was attenuated by cooling in the OWS and chiller. The petri dishes were to be returned at the end of the mission for laboratory study.

b. Post Mission Assessment - Due to the degradation caused by the SL-2 launch delay and the elevated OWS temperatures, ED 31 was rescheduled for SL-2, afterwhich the data would be evaluated and considered for performance on SL-4, if necessary. The petri dishes were inoculated, incubated and photographed on SL-2. Petri dishes one through four had water drops but no visible growth. Photographs were not taken of dishes one through four but were taken of dishes five through fifteen. Only dishes number seven and number nine showed any growth, with three and one colonies respectively. The experiment was completed and the 15-dishes were returned on SL-2. The dishes were not chilled and were returned in a food overcan because the IMSS resupply container was not on-board SL-2. Ground studies indicated that the high temperatures experiencedon SL-2 had possibly affected the experiment results and it was decided to repeat the experiment on SL-4. ED 31 was repeated on SL-4 as planned and successfully completed.

The crew was satisfied with the experiment hardware performance and reported no difficulty in inoculating the petri dishes in a zero-g environment.

5. ED 32 - Invitro Immunology

a. Operations - ED 32 was scheduled for SL-3 to determine the effects of zero-g on the antigenicity.

A crewman was to inject each of the three immuno diffusion plates with antigen and then periodically photograph the plates throughout the incubation period. To photograph the plates, the crewman attached them to OWS light number 1 using the photo clip supplied in the ED 32 hardware.

b. Post Mission Assessment - Antigen injection of the three diffusion plates was accomplished early in the SL-3 mission. Ten days later, the plates were attached to the OWS light and photographed with the 35mm Nikon camera. This constituted completion of the ED 32 experiment requirements.

No assessments or recommendations were received from the crew concerning ED 32. Therefore, it is assumed that the experiment hardware, procedures and interfaces were well designed and all functioned as planned.

6. ED 41 - Motor Sensory Performance

a. Operations - ED 41, Motor Sensory Performance, was scheduled on SL-4 to obtain motor sensor performance data which could be used in planning, training, and equipment development for future manned space missions.

The method of measuring motor sensory performance used in ED 41 was a standardized eye-hand coordination test using a maze with a 119-hole aiming pattern, stylus, and cable assembly as illustrated in Figure 153. During operation, the unit was attached to the wardroom window shelf by velcro strips and the cable was connected to the speaker intercom assembly connector. The experiment was performed once early and again late in the mission by the same astronaut. No activities, imposing either intense physical exertion or mental/emotional strain, was to precede performance of the experiment. Inflight performance was compared with pre-flight and post-flight tests performed by the same subject.

b. Post Mission Assessment - Student experiment ED 41 was performed as scheduled with no anomalies reported. Procedures for ED 41 were straightforward and the hardware performed satisfactorily.

7. ED 52 - Web Formation

a. Operations - Experiment ED 52 was scheduled on SL-3 to observe the web building process of the Araneous Diadematus (Cross) Spider in a zero-gravity environment and to compare this process with one performed in a one-g earth environment. A prime and backup spider were launched.

The crewman performing the experiment deployed the experiment enclosure which permitted observations of spider activity. The spider was released from her vial into the experiment enclosure and allowed to spin her web. During the experiment performance, a crewman periodically provided food and water for the spider. Still photographs were made with the 35mm Nikon camera and correlated to Ground Elapsed Time (GET) by voice recorded comments. Movie photographs were to be made with the 16mm DAC camera utilizing the automatic camera actuator which detected spider motion to start/stop the motion picture camera. Experiment operational configuration is illustrated by Figure 154. Upon completion of the experiment the spiders were to be disposed of through the trash airlock.

b. Post Mission Assessment - Prior to releasing the prime spider, Arabella, the crew reported a problem with the automatic camera actuator. Malfunction procedures were conducted on the automatic

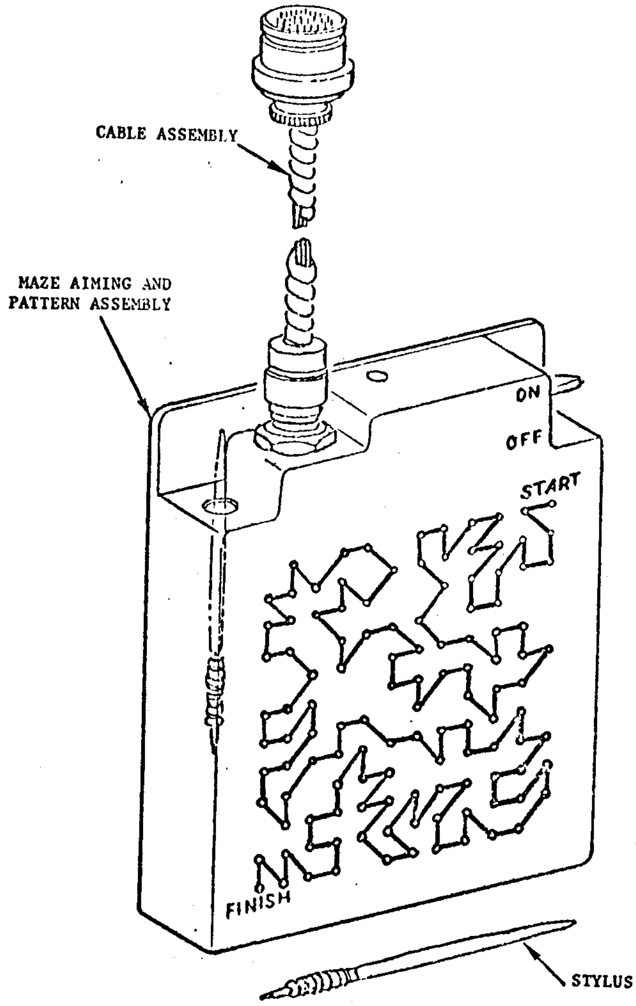


Figure 153. ED41 Experiment Configuration

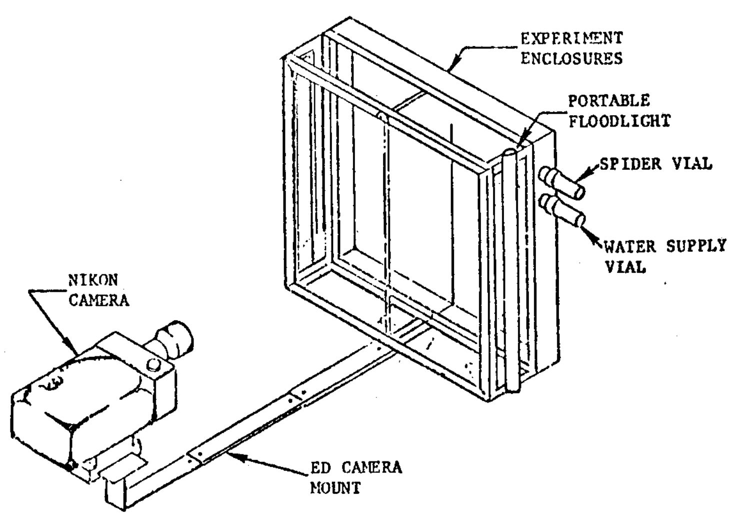


Figure 154. ED52 Experiment Operational Photographic Configuration

camera actuator with no results. The actuator was considered failed and therefore the web forming photography objective was not met. Photographs were taken periodically by the crew using the hand-held camera. Due to the actuator failure, some additional crew time was spent taking hand-held photographs. Both the prime and backup spiders died in-orbit and were returned to earth along with web samples.

8. ED 61/62 - Plant Growth/Plant Phototropism

a. Operations - ED 61/62 was scheduled on SL-2 to observe the difference in root and stem growth of rice seeds germinated in the zero-g environment. Eight seed groups were implanted, by the crewman, with the seed planter into a compartmental container filled with clear agar. This container was filled with neutral density filters to enable a variation in the total light impinging on the eight separate seed groups. Following implantation, the crewman photographed the seed groups daily, for 14-days, using the 35 mm Nikon camera. Experiment hardware is shown in Figures 155 thru 157.

b. Post Mission Assessment - Due to the high OWS temperatures after launch, and subsequent on-ground testing, the ED 61/62 performance was cancelled for SL-2. Resupply and performance of ED 61/62 was accomplished during SL-4. Prior to seed implantation, the experiment was relocated because existing light levels were felt to be too low for adequate growth. In addition, the portable light was incorporated to provide additional lighting to insure growth. The seeds were implanted and photographed as scheduled with no anomalies reported.
No assessment or recommendations were received from the crew concerning ED 61/62.

9. ED 63 - Cytoplasmic Streaming

a. Operations - Experiment ED 63 was scheduled on SL-3 to observe the effects of zero-g on cytoplasmic streaming in plants. Crew activation of ED 63 consisted of restraining the ED 63 transparent container, containing the elodea water plants, near a specific light in the OWS wardroom to maintain photosynthesis during the mission. Once early in the mission and again late in the mission, crewman detached a leaf from the elodea plant, and with use of the Inflight Medical Support System (IMSS) microscope and associated hardware, examine the leaf for cytoplasmic streaming. The 16mm DAC was to be used to document the data. Experiment hardware is depicted in Figure 158.

b. Post Mission Assessment - ED 63 was performed as scheduled during SL-3. During the first performance, the crewman reported that all three plant vials had a sulphurous smell and that the leaves from the three plants showed no resistance when detached. Two slides were prepared from one of the plants and no cytoplasmic streaming was observed.

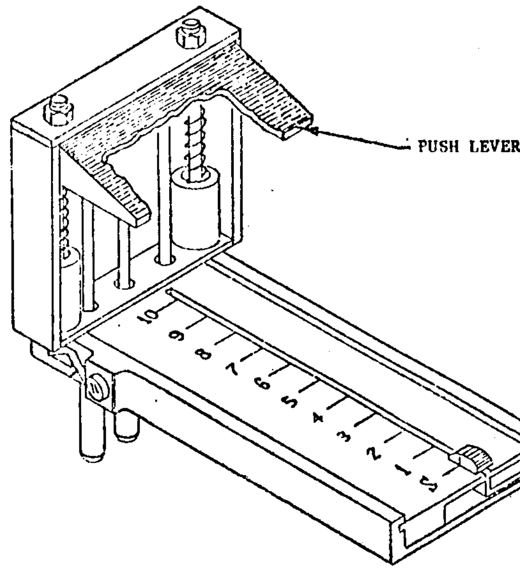


Figure 155. ED61/62 Seed Planter

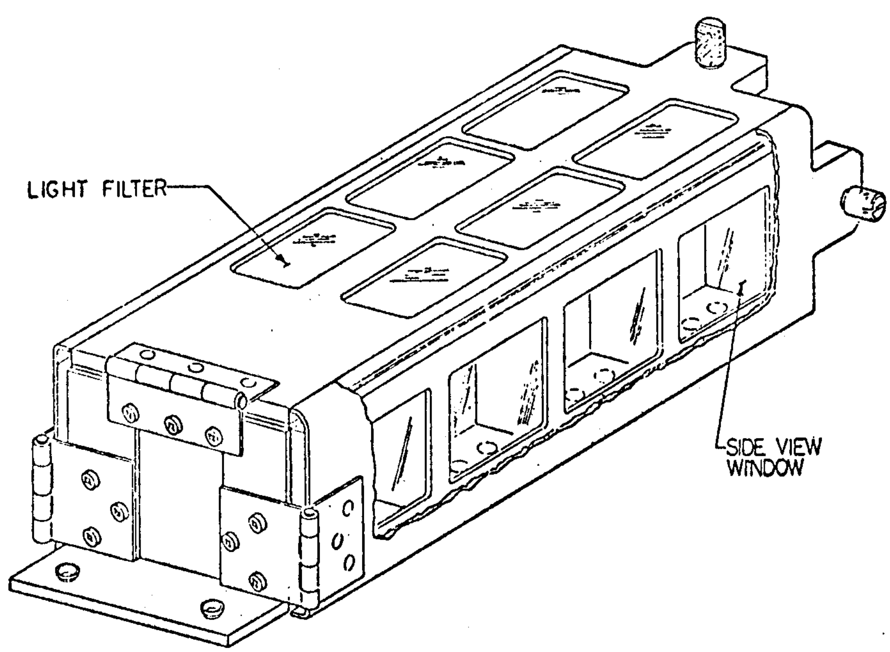


Figure 156. ED61/62 Container Assembly

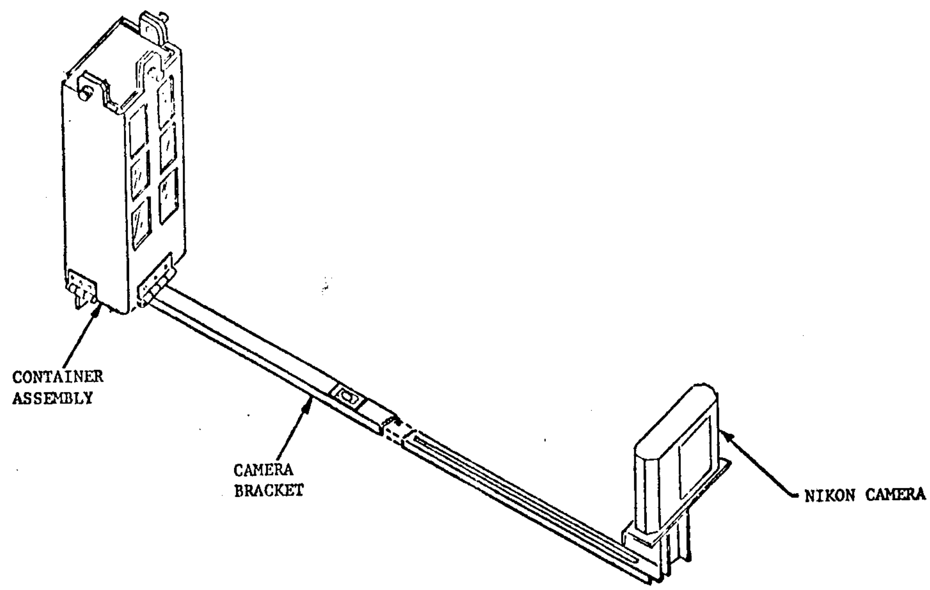


Figure 157. ED61/62 Operational Photographic Configuration

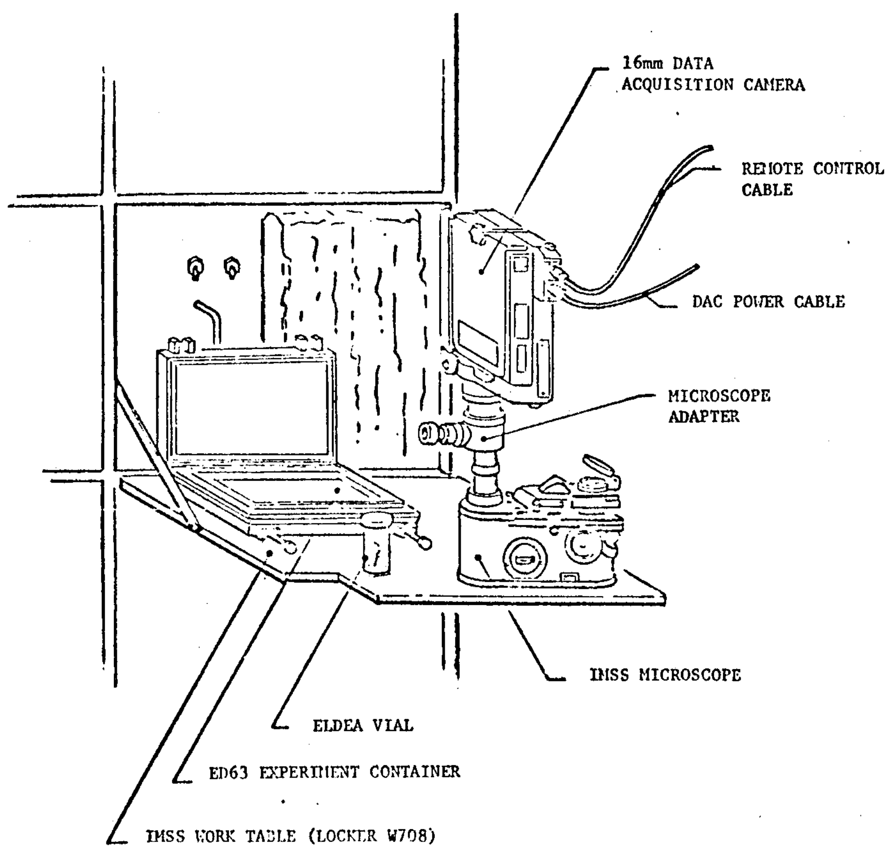


Figure 158. ED63 Experiment Operating and Data Acquisition Configuration

In conjunction with performance of ED 63, a ground based test was performed. A sample slide was prepared on each of the three plants and observed under a microscope. Two of the three elodea plants appeared to be totally dead, the third appeared normal and exhibited good cytoplasmic streaming. The vials containing the two dead plants smelled of hydrogen sulfide and the leaves showed no resistance when detached. Based on this, it was considered probable that one or more of the plants in-orbit were dead. From a later on-ground performance of ED 63, it was discovered that a previously considered dead plant had exhibited some cytoplasmic streaming. Therefore, the crew was requested to prepare slides on all three plants and examine for possible streaming. The crew complied; however, no streaming was detected. This resulted in termination of the experiment for SL-3 and an eventual resupply for a SL-4 performance.

During the SL-4 performance of ED 63, a hardware anomaly was reported concerning the DAC camera/IMSS microscope adapter. The crewman examining for cytoplasmic streaming could not acquire a full field of view. It was his assessment that the adapter was the cause of the problem.

The SL-4 performance of this experiment approximated the results obtained from SL-3. During the first cytoplasmic streaming observation, one plant provided some evidence of streaming. In subsequent observations, the elodea plant leaves showed no resistance when detached, there was a sulphurous smell present and no cytoplasmic streaming was observed. It was decided that the plants were dead and the experiment was terminated. The plants were removed from their vials and placed in the trash airlock.

Other than the DAC camera/IMSS microscope adapter anomaly, the ED 63 performances were conducted as planned. The crew reported that the experiment procedures and hardware functioned well and that everything possible was done on their part to acquire usable data. From the results of this experiment, it was concluded that zero-g has an undesirable effect on cytoplasmic streaming in plants.

10. <u>ED 72 - Capillary Study</u>

a. Operations - Experiment ED 72 was scheduled on SL-4 to demonstrate capillary action as a liquid pumping mechanism.

The experiment hardware consisted of two separate capillary tube modules and an additional capillary wick module. Each capillary tube module contained a reservoir, lever valve system and three transparent capillary tubes of graduated sizes. One module contained water, the other Krytox oil. The capillary wick module contained three capillaries of twill and mesh screens. The crewman activated the lever valve of the capillary tube modules and photograph the capillary action of the fluid. The entire experimental sequence was photographed, beginning with the actuation of the capillary valve and ending with the time that the slowest fluid volume reached the end of the capillary tube.

b. Post Mission Assessment - The wicking segment of ED 72 was successfully performed, as scheduled, with photographic data and crew sketches obtained.

The capillary segment of ED 72 was unsuccessful. During the preparation of this portion, the crewman observed that both the oil and water had leaked from their reservoirs. When the lever valves were operated, no capillary action was observed. The failure was attributed to the reservoir leakage. Mission Control later suggested attempting to refill the reservoirs but the crew had already disposed of the modules through the trash airlock. The leakage was documented on film.

The wicking portion of ED 72 was successfully completed with the hardware functioning as designed. However, the capillary segment was unsuccessful due to the hardware failure resulting in the leakage of the capillary modules.

11. ED 74 - Mass Measurement

a. Operations - Experiment ED 74 was scheduled on SL-3 to demonstrate the use of harmonic motion to measure the mass of an object.

To operate ED 74, a crewman removed ED 74 from launch stowage in the OWS film vault and then bolted it to the film vault. The device was calibrated using the calibration weights included with the ED 74 hardware. Next, the mass of four small objects was determined through use of the ED 74 hardware.

b. Post Mission Assessment - During SL-3, ED 74 was perfomed twice instead of once, as scheduled. It was decided that this experiment was a good candidate to be downlinked by real-time TV coverage.

During both performances, the hardware functioned as planned with no anomalies reported. The crew stated that during the final performance, ED 74 worked very well.

12. ED 76 - Neutron Analysis

a. Operations - Student experiment ED 76 was scheduled for operation during all three Skylab missions. Its objective was to acquire data for measurement of the ambient neutron flux at Skylab orbital attitudes.

Experiment hardware was comprised of ten neutron detectors and stowage containers. During SL-2, the ten neutron detectors, consisting of chemically coated films, were deployed on the inboard surfaces of the OWS. At designated times during SL-2 and SL-4, the crew deactivated certain detectors and stowed then for return.

b. Post Mission Assessment - During SL-2, the ten neutron flux detectors were deployed as planned. At the end of this mission, four detectors were deactivated, stowed and returned. The remaining six detectors continued data collection throughout the Skylab missions and were deactivated and stowed in the CM by the SL-4 crew just prior to their return.

The SL-4 crew stated that detector Bravo 3 was poorly placed, in that, as they came through the hatch from the forward compartment to the experiment compartment, it was in a very natural place to grab. If touching degraded it, it was definitely degraded as it was touched numerous times.

No assessments or recommendations were reported by the Skylab crews concerning ED 76. Therefore, it is assumed that the experiment hardware, procedures, and interfaces were well designed and functioned as planned.

13. ED 78 - Liquid Motion

a. Operations - Experiment ED 78 was scheduled on SL-3 to study the dynamic response of a liquid/gas interface when subjected to an impulse in zero gravity.

The crewman was to excite a gas bubble, surrounded by a liquid, by activation of the calibrated force supplied by the ED 78 piston/spring mechanical system. Photographs were to be supplied to the student investigator to provide ED 78 data interpretation.

b. Post Mission Assessment - Experiment ED 78 was set-up and initiated during SL-3, but the hardware did not operate properly. The piston/spring mechanism did not function when activated. Several unsuccessful corrective procedures were attempted. It was determined that the diaphragm in the piston/spring mechanism was ruptured and that corrective actions were impossible. The ED 78 hardware was disassembled and stowed.

During SL-3 and SL-4, liquid motion scientific demonstrations were performed and data from these demonstrations were provided to the ED 78 student investigator. This data provided sufficient information to satisfy the requirements on ED 78.

SECTION V. INFLIGHT MAINTENANCE

Initial design concepts excluded inflight maintenance as a requirement for Skylab and incorporated the use of highly reliable hardware to insure mission success and provide for maximum utilization of crew time. This philosophy gradually changed throughout the program, evolving from a minimum maintenance concept to one of extensive planning and provisioning of inflight maintenance support.

The change in maintenance philosophy was brought about as the result of increasing complexity and magnitude of the Skylab systems and the realization that even with high hardware reliability, failures could occur which would have an adverse effect on the crew and mission objectives. Because of this change in philosophy, an extensive design and hardware analysis was initiated to determine the maintenance capability necessary to support the hardware most critical to the mission and most likely to fail. The end result was the high level of maintenance capability provided on-board Skylab.

A. Scheduled IFM

1. Design Description - Scheduled IFM activities were held to a minimum in order to conserve crew time. Requirements were established only where periodic cleaning or replacement of consumable, cycle sensitive or time sensitive items were necessary. The requirements were included in the checklists as part of the normal housekeeping tasks. Performance of the tasks as controlled by the flight plan and scheduled to accommodate crew workload. Table 19 is a list of the scheduled inflight maintenance tasks which were planned for the Skylab missions.

2. Post Mission Assessment - The feasibility of performing inflight maintenance and the value of this capability to the success of space missions was effectively demonstrated during the Skylab missions. Success of the inflight maintenance accomplishments during SL-2 coupled with continued degradation of some systems and equipment resulted in planning of many additional inflight maintenance activities which were executed during SL-3 and SL-4. Procedures were written and the crews were trained to perform maintenance tasks which were previously thought not to be practical or feasible or were not even conceived prior to SL-1/2.

Scheduled maintenance activities as conducted during the Skylab missions are identified in Table 20. The tasks performed were much the same as planned. However, a number of additional tasks were added and the frequency of performance was varied based on the results obtained as the missions progressed and as a consequence of extending the SL-4 mission to 84 days.

No significant difficulties were reported in performing the scheduled inflight maintenance tasks. On-board tools, spares and procedures were adequate for all tasks. The crew indicated that the tasks could have been performed efficiently with little or no maintenance training. Another crew comment was that a more powerful vacuum cleaner would be desirable for cleaning tasks.

TASK DESCRIPTION	PLANNED FREQUENCY
Vacuum Clean - ECS Inlet Screens	
OWS Air Mixing Chamber	7 days
MDA Fan Inlet Screens	7 days
WMC Vent Upstream Filter (Coarse)	7 days
Replace - WMC Vent Unit Upstream Filter (Fine)	7 days
Replace - Shower Filter	7 days
Lubricate - LBNP Waist Seal Zipper	7 days
Replace - Mol Sieve Solids Traps	11 days
Replace - Inlet CO_2 Detector Cartridges	14 days
Replace - WMC Vent Unit Upstream Filter (Coarse)	28 days
Replace - Fecal Collector Filter	28 days
Replace - Urine Separator Filter	28 days
Replace - Mol Sieve Charcoal Canister	28 days
Replace - WMC Filter and Charcoal Cartridge	28 days
Replace - Outlet CO_2 Detector Cartridge	28 days
Replace - PPO_2 Sensor	SL-3 & 4 Activation
Replace - ATM C&D Cooling Water Filter	Before and After EREP Operation SL-2
Replace - EVA/IVA Gas Coolant Separator	SL-3 & 4 Activation
Replace - Urine Separator	SL-2 & 3 Deactivation
Vacuum Clean-OWS Solenoid Vent Filter	SL-3 & 4 Activation
Replace - M487 Batteries	SL-3 & 4 Activation

Table 19. Scheduled IFM - Planned

TASK DESCRIPTION	PLANNED FREQUENCY	SL-2 FREQUENCY	SL-3 FREQUENCY	SL-4 FREQUENCY
Vacuum Clean - OWS Heat Exchanger Vanes				6 days
Vacuum Clean - ECS Inlet Screens				
OWS Air Mixing Chamber	7 days	7 days	3 days	2 days
OWS Heat Exchanger Fans		7 days	3 days	2 days
MDA Fans	7 days	7 days	3 days	2 days
AM Circulating Fans	7 days	7 days	3 days	2 days
WMC Debris Coarse Filter	7 days	7 days		
WMC Debris Coarse/Fine Filter			3 days	
WMC Debris Fine Filter				2 days
Replace - WMC Vent Unit Fine Filter	7 days	7 days	12 days	12 days
Replace - Shower Filter	7 days	Following Crew Showers		
Replace - Mol Sieve Solids Traps	11 days	11 days	11 days	11 days
Replace - Inlet CO_2 Detector Cartridges	14 days	14 days	14 days	14 days
Replace - WMC Vent Fine/Coarse Filters	28 days	On MD-28	On MD-59	On MD-28
Replace - Fecal Collector Filter	28 days	28 days	28 days	28 days
Replace - Urine Separator Filter	28 days	---	---	---
Replace - Mol Sieve Charcoal Canister	28 days	28 days	28 days	28 days
Replace - WMC Filter and Charcoal Cartridge	28 days	On MD-28	On MD-59	On MD-27
Replace - Outlet CO_2 Detector Cartridge	28 days	28 days	28 days	28 days
Replace - PPO_2 Sensor	SL-3 & 4 Activation		Activation	Activation
Replace - ATM C&D Cooling Water Filter	Before & After EREP Operation SL-2	On MD-4 On MD-25	On MD-58	On MD-50
Replace - EVA/IVA Gas Coolant Separator	SL-3 & 4 Activation		---	---
Replace - Urine Separator	SL-2 & 3 Deactivation	Deactivation	Deactivation	
Vacuum Clean - OWS Solenoid Vent Filter	SL-3 & 4 Activation		Activation	Activation

Table 20. Scheduled IFM - Conducted

B. Unscheduled IFM

1. Design Description - Unscheduled IFM capability was provided on board the SWS for the purpose of replacing failed components, installing auxillary and backup hardware, and equipment servicing and repair. This capability was provided in the form of spares, tools and procedures for performing 160 different unscheduled tasks. These tasks are listed in Table 21.

Skylab crews performed many unscheduled maintenance tasks during the three missions. These were anticipated tasks for which on-board tools, spares and procedures had been provided on SL-1. The crew had been trained to perform each of the tasks; and the checklists containing the required procedures were available in the flight data file. Table 22 is a listing of the unscheduled maintenance tasks accomplished during the missions.

2. SL-2 Activities

a. M074 Specimen Mass Measuring Device (SMMD) Electronics Module Replacement - On MD-9 (DOY 153), the M074 Electronics Module from the Wardroom SMMD was removed and reinstalled in the WMC SMMD. The changeout was a result of an earlier failure of the WMC unit and was a pre-planned IFM capability to provide an interim solution for the specific failure which occurred. Per the IFM planning, a spare Electronics Module was carried up and installed during SL-3.

b. Color TV Camera Replacement - Failure of the Color TV Camera on MD-10 (DOY-154) required use of the spare camera for the remainder of the mission. The crew disassembled the camera in an attempt to repair it, but determined it was not repairable.

c. Urine Separator Filter Replacement - Hydrophobic filter was replaced in the CDRs Urine separator during MD-12 (DOY 156). This filter was scheduled to be replaced after the first 28 days of SL-3 and SL-4. The filters were also changed out at the end of each mission as an integral part of the Urine Separators. The unscheduled replacement of the filter reduced the number of spares available to support SL-3 and SL-4 to 5 units. Six spares were required to perform the scheduled replacements. As a result, it was necessary to eliminate one of the mid-mission replacement requirements.

d. Manual Opening of S054 Aperture Door - Release pins were incorporated into the design of the ATM aperture doors to provide the capability for manually opening and restraining any of the individual aperture doors during EVA in the event that the door drive mechanism failed. During the MD-14 (DOY 158) EVA, the S054 Aperture Door was manually opened after a failure in the drive mechanism had occurred. No problems or difficulties were noted in performing this activity.

TASK DESCRIPTION SPARES	ON-BOARD SPARES
Replace-TV Monitor	1
Replace-TV Camera/Monitor Cable	1
Replace-TV Power Cable	1
Replace-OWS ECS Flowmeter Transducer	0(1)
Install-IFM Contingency TV System Cables	
RF Cable Assy. -009	0(1)
RF Cable Assy. -010	0(1)
RF Cable Assy. -019	0(1)
RF Cable Assy. -020	0(1)
Replace-Communications Carrier	3
Install-Command Transfer Unit	1
Replace-MDA No. 2 Control Umbilical	1
<u>Water System</u>	
Replace-WMC Hot Water Dispenser	1
Replace-Drinking Water Dispenser	1
Replace-Food Reconstitution Water Dispenser Valve	1
Replace-Flush Water Dispenser	1
Replace-Water System QD-615	1
Quick Disconnect Coupling O-Ring	3
Replace-Water System QD-631	1
Replace-Wardroom Water Hose	1
Replace-Water System Sample Port QD O-Ring	3

TASK DESCRIPTION SPARES	ON-BOARD SPARES
Service/Deservice-Cluster Water Systems	
LSU/PCU	N/A
ATM C&D Coolant Loop	N/A
Suit Umbilical System	N/A
Replace-Wardroom Water Heater	1
Replace-WMC Water Heater	1
Replace-Wardroom Water Heater With WMC Water Heater	N/A
Replace-Food Reconstitution Water Dispenser O-Ring	
O-Ring -503	3
O-Ring -511	6
<u>Electrical System</u>	
Replace-S190 Window Heating Control Unit	0(1)
Replace-S190 Window Heater Cable	0(1)
Replace-AM Light Bulb (20 Watt)	24
Replace-AM Light Bulb (10 Watt)	120
Replace-MDA/OWS General Illumination Floodlight	6(6)
Replace-MDA Power Umbilical	1
Install-MDA/CSM Contingency Power Cable	1
Replace-Urine Separator Cable Assy	1

NOTE: Number in parenthesis indicates spares available on ground for resupply

Table 21. Unscheduled IFM - 3 of 5

TASK DESCRIPTION SPARES	ON-BOARD SPARES	TASK DESCRIPTION SPARES	ON-BOARD SPARES
WASTE MANAGEMENT SYSTEM		Replace-Trash Airlock Vent Valve O-Ring/Plug Subassy.	1
Replace-Waste Management Unit Power Module		Replace-Waste Processor Door Seal (Quad-X-seal)	3
-Vacuum Cleaner Power Module	1	Replace-Waste Processor Control Panel	1
-Shower Power Module			
-Suit Drying Station Power Module		Replace-Washcloth Squeezer Bal-Seal	1
		Replace-Washcloth Squeezer Flapper valve	1
Replace-Dump Probe Assy.	1	Replace-Urine Separator	1
Replace-Trash Airlock Inboard Hatch Seal	3	Replace-Urine Separator Dump Line Flex Hose	1
Replace-Trash Airlock Torsion Bar Seal		Replace-Urine Separator Motor -Shower Separator Motor	2
O-Ring - 1	4	Replace-Urine Separator Cover Seal	3
O-Ring - 501	2	Replace-Urine Separator Support and Filter (Scheduled Mainten-ance Spares)	6
Replace- Trash Airlock Pressure Gauge Seal		Replace-Waste Processor Screen	1
O-Ring-509	2		
O-Ring-511	2	Replace-Fecal Collector Bellows	1
		Replace-Waste Processor Pressure Mechanism	1
Release-Jammed Trash Airlock Ejector	N/A	Replace-Fecal Collector Liner	1
		Replace-Waste Processor Filter Saver Valve O-Ring	2
Clean-Trash Airlock Vent Valve Filter	N/A	Replace-Urine Separator Air Return Hose (Molded)	1

NOTE: Number in parenthesis indicates quantity of spares available on ground for resupply

Table 21. Unscheduled IFM - 1 of 5

TASK DESCRIPTION SPARES	ON-BOARD SPARES	TASK DESCRIPTION SPARES	ON-BOARD SPARES
Replace-Urine Collector Drainer Pressure Plate Assy.	1	Replace-Portable Timer Timing Batteries	4
Replace-Urine Volume Determinator	1	Replace-Portable Timer Tone Generator Batteries	12(24)
Replace-Urine Bag Housing Assy.	1	Replace-Video Switch	1
Replace-Crimper/Cutter/Door Assy.	1	Replace-Fire Sensor Assy.	6
Remove/Clean-Trash Airlock Cylinder Assy. Screen	N/A	Replace-Crewman Communication Umbilical	2
<u>Environmental Control System</u>		Replace-Teleprinter Cartridge	1
Replace-ECS Ventilation Fan	8(1)	Replace-Teleprinter Assy.	1
Replace-MOL Sieve Fan	1	Replace-TV Input Station	1
Replace-MOL Sieve Solids Trap	2Pair	Replace-Fire Sensor Control Panel	2
Repair-MDA/CSM Flexible Duct	N/A	Replace-Teleprinter Paper spool	1
Replace-WMC Odor Control Filter	1	Replace-LCC Control Head and Cable Assy.	1
Replace-MOL Sieve Charcoal Canister	0(2)	Replace-CO_2 Detector End Plate (Inlet)	1
Repair - OWS ECS Duct	N/A	Replace-CO_2 Detector End Plate (Outlet)	1
Replace-WMC Filter and Charcoal Cartridge	0(1)	Replace-GMT Timer	1
Replace-OWS Thermal Control Heater	1(1)	Replace-Fire Sensor Control Panel Indicator Lamp	8
Replace-WMC Vent Upstream Filter	1	Replace-Dosimeter Mounting Assy.	1
Replace-WMC Vent Upstream Filter (Inner)	1	Replace-Video Tape Recorder	
Replace-Condensing Heat Exchanger Water Separator Plates	4	Electronics Unit	1
Replace-Condensate Tank Module	1	Transport Unit	1
<u>Instrumentation and Communication System</u>		Replace-AM Tape Recorder	4
Replace - Speaker Intercom Assy.	2(2)	Install-Video Switch Power Cable	1
		Replace-Color TV Camera	1

NOTE: Number in parenthesis indicates spares available on ground for resupply

Table 21. Unscheduled IFM - 2 of 5

TASK DESCRIPTION SPARES	ON-BOARD SPARES	TASK DESCRIPTION SPARES	ON-BOARD SPARES
<u>Structure</u>		Disassemble-SAL Tripod Expando Grip Pin	N/A
Contingency/Open-MDA Docking Port Hatch	N/A	Manual Decinch-ATM Solar Arrays	N/A
Repair-Structural Leakage	N/A	Adjust-Food Freezer Door Hinge	N/A
Replace-OWS/MDA Habitation Area Vent Plug	1	<u>Crew Equipment</u>	
Replace-OWS/MDA Habitation Area Vent Plug O-Ring	4	Replace-Shoe Indexing Cleat	Cannibalized
Release-Jammed Stowage Locker Doors	N/A	Repair-Shoe Indexing Cleat	N/A
Contingency Open-OWS Entry Hatch	N/A	Maintain-EMU Seals and O-Rings	N/A
Contingency Open AM Forward Hatch	N/A	Repair-EMU Bladder	N/A
Contingency Open-ATM Aperture Doors	N/A	Clean/Antifog Treat-EMU Helmet	N/A
Contingency Open-Film Vault Doors	N/A	Lubricate-Sleep Restraint Zipper	N/A
Contingency Open-Ring Container Doors	N/A	Replace-Food Trays	2
Contingency Open Urine Collection Drawer	N/A	<u>Experiment Systems</u>	
Replace-MDA Docking Port Hatch Seal	1	Replace-ATM Manual Pointing Controller	1
Contingency Remove-Expando Grip Pins	N/A	Replace-ATM Control and Display Console Precision Clock	1
Contingency Release-Docking Latches	N/A	Replace/Interchange-Mass Measuring Device Electronics Module (M074/M172)	0(1)
Install-AM Viewing Port Cover Mechanism Cap Assy.	N/A	Replace-VCG Cable (M093)	3
		Replace-Electrode Harness (M093)	3 Kits
		Replace-Magazine Drive Assy.(S190)	1
		Replace-Cooler/Dewar/Detector(S192)	1
		Replace-Dessicant Assy.(S190)	18

NOTE: Number in parenthesis indicates spares available on ground for resupply

Table 21. Unscheduled IFM - 4 of 5

TASK DESCRIPTION SPARES	ON-BOARD SPARES	TASK DESCRIPTION SPARES	ON-BOARD SPARES
Connect-EREP Tape Recorder Spare	Installed	Install-Shutter Override Actuator (S054)	4
Connect-Backup Digital Address System Input Unit	Installed	Install-Signal Attenuator (S192)	
Connect-Backup Radio Noise Burst Monitor	Installed	Primary	1
Replace-Subject Interface Box (M092/M093)	1	Secondary	1
Install-Thruster Cap (M509)	4	Install-EREP Diagnostic Downlink Unit	1
Replace-Film Magazine (S190)	1	Replace-Optical Sight Battery (S063)	2
Replace-Film Cassette (S190)	1		
Replace-Size D Batteries (M487)	15		
Repair-Battery Vent Line (M512)	N/A		
Remove/Install-FMU Foot Restraint (T013)	N/A		
Disconnect-Shutter Drive (S190)	N/A		
Install-Camera Filter (S020)	2		
Replace-BTMS Probe (M171)	3		
Replace-Valve Assembly (M171)	3		
Replace-Mouthpiece (M171)	3		
Replace-Breathing Hose (M171)	1		
Activate-Backup Inverter Lighting Control Assy.	Installed		
Replace-Ergometer Drive Assy. (M171)	1		
Replace-Lower Body Negative Pressure Waist Seal	1		
Replace-Sextant Batteries (T002) -Stadimeter Batteries (T002)	2		

NOTE: Number in parenthesis indicates spares available on ground for resupply

Table 21. Unscheduled IFM - 5 of 5

TASK DESCRIPTION SPARES	ON-BOARD SPARES	RESUP-PLIED SPARES	SPARES USED/ TASKS PERFORMED		
			SL-2	SL-3	SL-4
Waste Management System					
Replace-Dump Probe Assy.	1	-	-	1	-
Replace-Washcloth Squeezer Bal-Seal	1	-	-	1	-
Replace-Urine Separator Support & Filter	1 (From Scheduled Replacement Spares)	-	1	-	-
Environmental Control System					
Replace-ECS Ventilation Fan	8(1)	-	-	1	1
Replace-MOL Sieve Fan	1	-	-	1	-
Instrumentation and Communication System					
Replace-Speaker/Intercom Assy.	2(2)	-	-	1	1
Replace-Portable Timer Tone Generator Batteries	12(24)	-	-	3	-
Replace-Teleprinter Cartridge	1	-	-	-	1
Replace-Teleprinter Assy.	1	-	-	1	-
Replace-TV Input Station	1	-	-	-	1
Replace-Teleprinter Paper Spool	1	-	-	-	1
Replace-Video Tape Recorder					
Electronics Unit	1	-	-	1	-
Transport Unit	1	-	-	1	-
Replace-Fire Sensor Assy.	6	-	1	-	-
Replace-Color TV Camera	1	1	1	1	-
Replace-TV Camera/Monitor Cable	1	-	-	1	-
Replace-TV Power Cable	1	-	-	1	-
Replace-AM Tape Recorder	4	2	1	3	2
Water System					
Replace-WMC Hot Water Dispenser	1	2	1	-	-
Service/Deservice-Cluster Water Systems					
LSU/PCU.	N/A	N/A	1	1	1
ATM C&D Coolant Loop	N/A	N/A	-	-	1
Suit Umbilical System	N/A	N/A	-	-	1
Electrical System					
Replace-AM Light Bulbs (10 Watt)	120	-	-	9	-

NOTE: Number in parenthesis indicates spares available on ground for resupply

Table 22. Unscheduled IFM Activities--1 of 2

TASK DESCRIPTION SPARES	ON-BOARD SPARES	RESUP-PLIED SPARES	SPARES USED/ TASKS PERFORMED		
			SL-2	SL-3	SL-4
Structure					
Contingency Open-ATM Aperture Doors	N/A	N/A	1	-	2
Crew Equipment					
Clean/Antifog Treat-EMU Helmet	N/A	N/A	2	3	4
Experiment Systems					
Replace/Interchange-Mass Measuring Device Electronics Module (M074/M172)	0(1)	1	1	1	-
Replace-Magazine Drive Assy. (S190)	1	-	-	-	1
Replace-Cooler/Dewar/Detector (S192)	1	1	-	1	1
Replace-Dessicant Assy. (S190)	18	-	18	-	-
Replace-Film Magazine (S190)	1	-	-	-	1
Replace-Size D Batteries (M487)	15	-	3	2	-
Install-Camera Filter (S020)	2	-	-	-	2
Install-Shutter Override Actuator (S054)	4	-	-	-	1
Install-Signal Attenuator (S192)					
Primary	1	-	1	-	-
Secondary	1	-	-	-	-
Install-EREP Diagnostic Downlink Unit	1	-	-	1	-
NOTE: Number in parenthesis indicates spares available on ground for resupply					

Table 22. Unscheduled IFM Activities--2 of 2

e. AM Tape Recorder Replacements - AM Tape Recorder No. 1 failure was reported after completion of the trouble-shooting procedure on MD-15 (DOY) 159). The recorder was replaced with one of the four spares provided for unscheduled IFM support of the three AM Tape Recorders. On MD-29 (DOY 173), a second recorder failure was reported after splashdown. The second recorder was replaced by the SL-3 crew. Two additional spares were flown on SL-3 to replenish the units expended during SL-2.

f. S190 Desiccant Replacement - Six S190 desiccant units were replaced in the S190 camera assembly on MD-17 (DOY 161) due to evidence of possible moisture contamination in the camera assembly. A total of 18 spare desiccant units were provided on-board for unscheduled replacements. The CDR noted that the color of the removed units was the same color as the new units installed. The replaced units were baked out in the waste processor to remove all the moisture and to insure thoroughly dry units would be available. All 18 of the spares were alternately installed, removed and baked out throughout the missions.

g. Fire Sensor Control Panel Replacement - Failure of Fire Sensor Control Panel 392 in the AM was confirmed on MD-17 (DOY 161). The panel was replaced with one of the two spares on-board. The failure involved only the Fire Sensor No. 2 circuit. Two panels in the OWS use only the Fire Sensor No. 1 circuit. Consequently, the failed panel was retained for further use as a spare.

h. WMC Water Dispenser Valve Replacement - Replacement of the WMC Water Dispenser Valve was necessary when the valve became plugged. The one on-board spare was installed on MD-22 (DOY 166). Two additional spares were provided on SL-3 to insure adequate water supply in the WMC. The failed unit was returned on SL-2 in order to determine the exact nature of the failure.

3. SL-3 Activities

a. M074 Electronics Module Replacement - The wardroom SMMD Electronics Module was moved to the WMC SMMD during SL-2. A replacement unit was supplied on SL-3 and installed during activation.

b. AM Tape Recorder Replacement - Three AM Tape Recorders were replaced during SL-3. On MD-4 (DOY 212) a recorder, which failed after SL-2 deactivation, was replaced. A second failed recorder was replaced on MD-48 (DOY 256). A third recorder was replaced on MD-52 (DOY 260) because the remaining recorder had exceeded its operating life limitation. Four spare recorders were initially launched on SL-1 and two additional spares were provided on SL-3.

c. EREP Downlink Unit Installation - The EREP Downlink Unit was installed on MD-6 (DOY 214). This maintenance activity involved installation of auxiliary hardware and was not the result of a failure. The Downlink Unit provided capability of patching between EREP and the video system to provide direct down link of data from EREP to ground.

d. Video Tape Recorder Replacement - Replacement of the Video Tape Recorder was accomplished on MD-11 (DOY 219) after failure of a circuit board occurred in the electronics unit. All necessary tools, spares and procedures were available on-board to perform this task. During the replacement operation a faulty 3/16-in. allen bit was discovered and was replaced with a spare from the spare tool inventory on-board.

e. Teleprinter Replacement - Failure of a drive roller in the Teleprinter head assembly resulted in replacement of the Teleprinter. The replacement was performed on MD-11 (DOY 219). Only one spare Teleprinter was provided and as a result procedures were developed for repair of the failed unit using on-board materials in the event a second failure occurred on SL-3. A teleprinter repair kit was developed for SL-4 and included replacements for the failed parts.

f. Mol Sieve Fan Replacement - On MD-12 (DOY 220) one of the two fans in Mol Sieve B was replaced. The failure was isolated to the fan after a malfunction procedure was performed on the Mol Sieve. One spare fan was provided on-board to support the four fans installed in the two Mol Sieves.

g. STS Light Bulbs Replacement - Three 10-watt light bulbs in the STS were replaced on MD-12 (DOY 221). A total of twenty-four 20-watt and one hundred twenty 10-watt spare bulbs were provided in the AM. These were incandenscent, bayonet base bulbs. Tools were not required for replacement. A total of nine of the 10-watt bulbs were replaced during the mission. No 20-watt bulb usage was reported.

h. Speaker Intercom Assembly Replacement - The Speaker Intercom Assembly located at the -Z SAL (PNL-540) was replaced on MD22 (DOY 230) as a result of an apparent failure of the "push to talk" switch. Two spare units were provided on-board.

i. TV Camera Replacement - The malfunction procedure performed on the video system resulted in identification of a failed TV camera. The camera was replaced on MD 28 (DOY 236) with the spare provided on-board. One camera was returned at the end of SL-3 and a new camera was provided on SL-4.

j. Condensate Dump Probe Replacement - The problem associated with dumping condensate into the waste tank was isolated to the dump probe. Suspected heater failure resulted in replacement of the probe on MD-36 (DOY 244) and an accumulation of ice was found in the probe.

k. TV Power Cable Replacement - The TV Power Cable was replaced on MD 48 (DOY 256) after a malfunction procedure was performed on the video system to determine the cause of noise generated in the system. One spare cable was provided on-board. Later investigation by the crew revealed an open in the center conductor of the coaxial cable.

l. Washcloth Squeezer Bal—Seal Replacement - Leakage of the Washcloth Squeezer resulted in replacement of the squeezer plunger seal (Bal-Seal) on MD 56 (DOY 264) with the spare seal provided on-board. The seal had apparently folded back after striking the edge of the cylinder during operation. Procedures were developed for removing contamination which had collected around the piston and shaft and may have caused seal damage.

m. TV Monitor Cable Replacement - The spare TV Monitor Cable was installed on MD 56 (DOY 264). Failure was detected when the crew was unable to acquire a picture on the TV Monitor. The problem reoccurred when the spare monitor was connected. The cause was finally isolated to the cable when it was flexed at the camera connector and produced an intermittent picture.

4. SL-4 Activities

a. Manual Opening of the Hα 2 Door - The Hα 2 door on the sun end of the ATM was pinned open during the EVA performed on MD 7 (DOY 326). The door was designed with a pin which, when removed, permitted manual opening the door and latching it in the open position. Excessive drag in the door mechanism made it necessary to perform this activity.

b. Speaker Intercom Replacement - On MD 15 (DOY 334) the Speaker Intercom Assembly located in the MDA, Panel 131, was replaced as a result of failure of the channel select switch. The failure occurred in the Channel B position. The second of the two on-board spares was used for this task.

c. Teleprinter Cartridge and Paper Spool Replacement - The spare Teleprinter Cartridge and spare Paper Spool were used to correct an apparent failure of the Teleprinter on MD 19 (DOY 338). The failure was resolved after it was determined that the paper was improperly loaded in the Teleprinter.

d. Manual Pinning of the S082A Door - Failure of the S082A door to respond to open/close commands on several occasions made it necessary to manually latch the door open during the EVA on MD 40 (DOY 359). The S082A door is located on the sun end of the ATM. The capability to latch the door open was a feature incorporated into the design of the door mechanism.

e. S054 Shutter Override Actuator Installation - The S054 Shutter Override Actuator was installed on MD 40 (DOY 359) during the EVA operations in order to perform the S054 malfunction procedures and aid in the contingency task to manually position the filter wheel. The Shutter Override Actuator was launched on-board SL-1.

f. SUS Loop Servicing - Servicing of the Suit Umbilical System was accomplished on MD 43 (DOY 362) after a low reservoir level had been detected. All necessary equipment and procedures were available on-board for this task. The low level in the reservoir was determined to be the result of coolant loss into the LSU/PCU's which had not been serviced prior to the first SL-4 EVA.

g. TV Input Station Replacement - A failed TV Input Station at location 642 in the OWS was replaced on MD 45 (DOY 364). One spare unit was provided in the MDA for inflight maintenance support of the TV system. Replacement was required because of a broken pin in connector J-3.

h. ATM C&D Coolant Loop Servicing - Low coolant level in the ATM C&D Coolant Loop Reservoir resulted in servicing the system with water from the OWS on MD 50 (DOY 004). Equipment and procedures were available on-board to accomplish this task. Replacement of the ATM C&D Coolant Loop Filter was accomplished in conjunction with the servicing activity.

i. S190 Magazine Drive Replacement - The spare S190 Magazine Drive was installed on MD 57 (DOY 011) after the installed assembly failed. The spare assembly and the necessary tools were provided on SL-1.

j. S192 Mark XV Detector Replacement - On MD 61 (DOY 015) the S192 Cooler/Detector/Preamp was replaced with a unit which was launched on SL-4. Replacement of the detector was necessary for proper alignment and to insure acquisition of accurate data. Malfunction or out of tolerance condition was indicated on the EREP C&D Panel. One spare was initially launched on SL-1 along with the necessary tools required for installation but the spare was not used.

k. OWS Heat Exchanger Fan Replacement - On MD 63 (DOY 017) one of the four OWS Heat Exchanger Fans was replaced in an attempt to correct a degraded airflow condition through the heat exchanger. This was accomplished in conjunction with vacuum cleaning of the heat exchanger vanes. An acceptable flowrate resulted from this activity. The crew modified the vacuum cleaner adapter with cardboard, tape and mosite in order to adequately vacuum the heat exchanger vanes.

1. AM Tape Recorder Replacement - AM Tape Recorder No. 3 was replaced on MD 66 (DOY 020) with one of the two remaining spares. The recorder was replaced because it had exceeded the 1000 hour life limitation. At the time of replacement the unit was still operating and had 1,579 operating hours in flight and 241 operating hours during ground test. AM Tape Recorder No. 2 failed on MD 67 (DOY 021) and was replaced with the remaining spare on-board. The failure occurred after 1446 operating hours. Two resupply spares were provided on SL-3 and an AM Tape Recorder Repair Kit was launched on SL-4. The repair kit was not used during SL-4.

5. <u>Post Mission Assessment</u> - No significant problems associated with unscheduled maintenance were reported by the crew. Tools, spares, and procedures were adequate for performing all of the required tasks.

C. Contingency IFM

1. Design Description - In addition to the capability provided for scheduled and unscheduled inflight maintenance, tools and materials were placed on-board Skylab to provide a general maintenance capability. This capability was provided to permit repair of failed equipment for which no specific inflight maintenance activity was anticipated. Items such as tape, wire, "C" clamps, various types of pliers, a vise, twine, hammers and tweezers were included in the Skylab tool inventory for this purpose.

Additional maintenance tools and equipment were launched on-board the three CSM's to provide capability to correct equipment malfunctions which were unanticipated. These were tasks for which on-board maintenance support was inadequate. Other contingencies developed during the missions which required maintenance action using the on-board support equipment but for which procedures had to be developed real time and uplinked to the crew.

2. SL-2 Activities

a. Skylab Parasol Deployment - Following launch and orbit achievement of SL-1, flight data revealed that an apparent failure of the meteoroid shield had occurred. On SL-2, MD 2 (DOY 146) the crew successfully deployed a parasol sun shield from the OWS solar SAL in order to lower the OWS temperature and make the SWS habitable. The parasol was designed and fabricated following the meteoroid shield failure and carried up on SL-2.

b. S019 Extension Mechanism Repair - Jamming of the Articulating Mirror Tilt Gear mechanism resulted in a disassembly task on MD 7 (DOY 151) involving the use of on-board tools to free the jammed drive gears. Jamming was caused by a metal tab which was interferring with the gears. This condition was corrected by bending the tab back out of the way.

c. Lubrication of Ergometer Pedals - On MD 11 (DOY 155), the M171 ergometer pedals were lubricated with the general purpose lubricant provided in the tool kit. This task was performed to alleviate squeaking which occurred during operation.

d. OWS SAS Wing Deployment - On DOY 134 telemetry data indicated that the OWS solar arrays did not deploy. It was postulated that Wing 2 was completely missing and that Wing 1 had been jammed and prevented from deploying. The fly-around by the SL-2 crew verified that Wing 2 was in fact missing and that Wing 1 had been restrained by debris from the failed meteoroid shield. Attempts to free Wing 1 during a standup EVA from the CSM were unsuccessful.

On MD 14 (DOY 158) using tools which were carried up in the SL-2 CSM for the standup EVA and other on-board tools and equipment, the crew successfully deployed Wing 1. Procedures and tools for deploying the wing were developed at MSFC and verified in the Neutral Buoyancy Tank. The procedures were then uplinked to the SL-2 crew.

e. T027/S073 Backup Tripod Mounting - Due to differences in the backup unit which was flown on SL-2, it did not interface correctly with the mounting provisions in the OWS. On MD 18 (DOY 162), the tripod was mounted using attaching hardware salvaged from the throw-away items used as launch restraints and removed during activation. The flight tripod was used to support the parasol at the solar SAL.

f. CBRM #15 Contingency Procedure - During the EVA on MD 28 (DOY 172), a contingency procedure was successfully performed on CBRM #15 to free a stuck relay. The procedure, which was developed by MSFC, consisted of striking the CBRM with a hammer at a predetermined location that would impact a maximum impulse to the relay.

3. SL-3 Activities

a. Twin Pole Solar Sail Deployment - The Twin Pole Solar Sail was deployed during the first SL-3 EVA on MD 10 (DOY 213) over the top of the Parasol which was deployed during SL-2. The procedure involved EVA erection of two poles from the ATM center work station extending to the aft radiator section of the OWS. The sail was then deployed by means of clothesline ropes attached at the end of each pole and positioned over the habitation area of the OWS. The two poles were assembled from 22 specially designed pole sections, each five feet in length. The sail and all equipment necessary for deployment was launched on-board the SL-2 CSM.

b. S055 Ramp Latch Removal - On MD 10 (DOY 218) the latch ramp was removed from the S055 aperture door latch mechanism. This task was accomplished during EVA and involved use of a 7/16-inch openend/box wrench to remove two bolts securing the latch ramp and shims. Removal of the ramp was necessary to alleviate binding of the door during opening and closing.

c. AM Tape Recorder Disassembly - AM Tape Recorders were disassembled on MD 15 and MD 20 (DOY 223 and DOY 228) to determine the cause of failure. In both instances the failure was isolated to a worn drive belt. All tools necessary for disassembly were on-board.

d. Mark 1 Exerciser Repair - On MD 23 (DOY 231) the crew reported that the rope on the Mark 1 Exerciser had broken. A procedure was developed on the ground to replace the rope and uplinked to the crew. The crew successfully replaced the rope but experienced some difficulty. The Skylab tool inventory did not contain a 9/64-inch Allen wrench which was required to tighten the rope clamp screw. A 1/8-inch Allen wrench, cocked to one side in the socket head screw, was used to tighten the clamp.

e. Condensate System Leak Check - A leak check procedure was accomplished on the Condensate System on MD 24 (DOY 232) in an attempt to isolate air leakage into the system which caused loss of differential pressure in the Condensate Dump Tank. The system was pressurized to 35 psi and the plumbing joints bubble checked with a soap and water solution. The leak was not isolated as a result of the procedure but stopped after replacement of the dump probe.

f. Coolanol System Leak Check - A leak inspection procedure was performed on the Coolanol System after excessive loss of coolant was detected. The procedure was accomplished in two phases on MD 24 and MD 26 (DOY 232 and DOY 234) and required the removal of a number of structural panels to gain access to plumbing lines and fittings. The leak check consisted of a visual inspection of the lines and fittings. No internal leakage was detected as a result of the inspection.

g. Rate Gyro Package Installation - The Rate Gyro Package (six pack) was installed on MD 28 (DOY 236). The gyro package and the installation procedures were developed during the SL-2/SL-3 unmanned phase. The procedure required EVA and IVA mating and demating of connectors, handling and alignment of large components and check-out using the multimeter. All of the tools and equipment necessary for installation and checkout were included with the Rate Gyro Package.

h. S082A and S056 Door Ramp Latch Removal - During the second SL-3 EVA, MD 28 (DOY 236) the S082A and S056 Door Ramp Latches were removed to eliminate binding which occurred during opening and closing of the doors. The same procedure used to remove the S055 Door Ramp Latch was used for the S082A and S056 ramp latches.

i. Ergometer Pedal Screw Replacement - A screw from one of the ergometer pedals became lost and was replaced with a substitute screw from on-board spares on MD 32 (DOY 240). The first substitute screw was broken during installation and had to be extracted. The file blade of the Swiss Army Knife was used to slot the head of the broken screw so that it could be unscrewed with a screwdriver. A second screw was cannabilized from the spare Urine Separator and successfully installed in the pedal.

j. OWS Heat Exchanger Cleaning - Low air flow through the OWS ECS ducts was corrected on MD 36 (DOY 244) by vacuum cleaning the OWS Heat Exchangers. Air flow returned to normal after the cleaning operation.

k. Video Tape Recorder Circuit Board Removal - Four circuit boards were removed from the Video Tape Recorder Electronics Unit on MD 42 (DOY 250) to be returned for failure analysis. Two screwdrivers were used to extract the circuit boards after removal of the electronics unit cover.

l. Condensate Dump Probe Troubleshooting - On MD 42 (DOY 250) a troubleshooting procedure was performed on the Condensate Dump Probe which was removed on MD 36 because of ice accumulation in the probe. Checkout of the probe heaters using the digital multimeter revealed that the heaters had not failed. The probable cause of the ice buildup was determined to be inadequate heating of the probe prior to dumping and abnormally frequent dumping due to system leaking. The probe was restowed for use as a spare after the troubleshooting procedure was completed.

m. S192 Attenuator Adjustment - The S192 attenuator was adjusted on MD 38 (DOY 246) to correct the over exposed condition of the S192 data which occurred during SL-2. The 3/32-inch blade screwdriver would not fit the attenuator adjustment screw and had to be modified. The modification consisted of reducing the thickness of the blade using the Swiss Army Knife file blade. The adjustment was successfully performed using the modified tool.

4. SL-4 Activities

a. Urine Drawer Seal Replacement - During SL-3 deactivation, one of the three urine drawer seals became unbonded. The seal acts as an interface between the centrifugal separator outlet line on the urine drawer and the dump line in the waste management unit. The seal is engaged when the drawer closes and prevents leakage at the urine outlet/dump line interface. Three spare seals were carried up on SL-4 and the failed seal was replaced on MD 2 (DOY 321) during activation of the urine system. The replacement seal was specially designed in order to permit replacement without the need for adhesives or tools. The remaining spares were not used during SL-4.

b. Primary Coolant Loop Servicing - The Primary Coolant Loop pumps were turned off due to degradation of pump inlet pressure caused by Coolanol leakage from the system during SL-3. Contingency procedures were developed for removing coolant from the refrigeration system in order to service the Primary Coolant Loop during SL-3. Because the Secondary Coolant Loop remained operative, the servicing activity was not performed. Servicing equipment was developed during SL-3 and the SL-3/4 unmanned phase and was launched on SL-4. On MD 4 (DOY 323) the Primary Coolant Loop was successfully reserviced and returned to operation. The procedure involved stripping the insulation from one of the coolant lines, installing a saddle valve on the line and refilling the system with Coolanol from a pressurized accumulator type reservoir. The tools required to assemble and connect the servicing equipment were on-board.

c. Rate Gyro Package Thermometer Installation - Liquid crystal thermometers backed with pressure sensitive adhesive were installed on each of the six rate gyros on MD 6 (DOY 325) in order to monitor the gyro temperatures. The rate gyro temperatures were monitored every two days throughout SL-4.

d. Disabling of S193 Antenna Pitch Gimble Motor - A failure in the pitch control electronics of the S193 Antenna resulted in a maintenance activity to disable the Pitch Gimble Motor and pin the pitch gimble at a zero degree pitch angle. The task was performed during the EVA on MD 7 (DOY 326) and involved installation of a jumper box and inhibit switch in the antenna circuitry and installation of a gimble lock assembly on the pitch gimble. In order to reach the antenna it was necessary for the crew to translate around the FAS to the -Z axis of the MDA. This was accomplished without the use of preplanned translation aids and restraints since the path was not along the normal EVA route. The OWS portable foot restraint was mounted at the antenna location using a special foot restraint in order to provide a fixed crew restraint. The equipment necessary for performing the task was provided on SL-4.

e. ATM TV Monitor No. 1 Replacement - The ATM TV Monitor failed during SL-3 and was replaced with the spare provided on SL-4 on MD 10 (DOY 329). Since inflight replacement of the TV monitor was not planned prior to the failure, procedures, special extension cables and a special screwdriver to remove the attaching hardware were developed and provided with the spare monitor.

f. S082B Auxiliary Timer Installation - During SL-3 it was determined that more accurate XUV slit timing was required and that an auxiliary timer would be provided and installed during SL-4. An attempt to remove the ATM C&D Console Kickplate during SL-3, in preparation for this activity, was unsuccessful. As a result a special tool was developed during the SL-3/4 unmanned phase to remove the Hi-Torque screws from the kickplate. On MD 10 (DOY 329) the timer was successfully installed and the cable connectors mated without the need for removing the kickplate. This was done by using a pair of special connector pliers with a 90-degree nose.

g. S009 Drive Motor Replacement - The S009 drive motor failed during SL-2 when the crew attempted to deploy the detector package. The motor failure was apparently caused by interference between the detector package and the housing. A replacement motor was launched on SL-3 and was installed on MD 11 (DOY 330).

h. Mark I Exerciser Repair - The Exerciser Repair Kit, consisting of a spare rope, spring, and a 9/64-Allen wrench, was used to repair the Mark I Exerciser on MD 20 (DOY 339). The rope on the exerciser was broken during SL-3 and had become abraded at the ends. A temporary repair was made during SL-3 but proper tools and spares were not available for complete refurbishment. The repair kit was assembled and launched on SL-4.

i. Liquid/Gas Separator Installation in the ATM C&D Coolant Loop - A drop in pump flowrate in the ATM C&D Console Coolant Loop was corrected on MD 33 (DOY 352). This action involved temporarily installing one of the spare Liquid/Gas Separators in the coolant loop to filter out possible contamination and gas bubbles in the system. The coolant was circulated through the separator which was installed in place of the system filter. After removing the separator and installing a replacement ATM C&D Coolant Filter, flowrates of 295 lbs/hr for pump B and 280 lbs/hr for pump C were reported. These rates were slightly above the nominal rates at which the system had initially operated. The procedure was repeated with the same success on MD 50 (DOY 004).

j. S054 Filter Wheel Positioning - A maintenance activity was performed during the MD 40 (DOY 359) EVA to manually position the S054 Filter Wheel to the "clear aperture" position (Filter No. 3) The procedure required working through the open S054 door using an inspection mirror and flashlight and a long 1/8-inch screwdriver. The mirror and flashlight were used for visual observation while the screwdriver was used to puncture the filter segments in order to rotate the filter wheel.

5. Post Mission Assessment - As a result of the contingency activities performed, the crew recommended that a number of different tools be provided; including a hacksaw, drill and drill bits, and a larger screwdriver. The recommendations stem from the problems associated with extracting the broken screw from the ergometer pedal.

The need for some type of work bench was also expressed as a result of the AM tape recorder disassembly and the AMS Tilt Mechanism repair tasks which were performed. According to the crews' comments the work bench should include features for holding tools and small parts as well as the components requiring repair or disassembly. It was also suggested that the work bench be insulated so that electrical checkout and repair of components could be conducted without the possibility of electrical shock.

The need for accessibility to equipment, other than that for which failure was anticipated, was also demonstrated as a result of the contingency inflight maintenance activities. Specific examples of this need were installation of the rate gyro package, the leak checks performed on the condensate and coolanol systems and the attempt to remove the ATM C&D Console kick plate.

EVA inflight maintenance capability should be given the same consideration during inflight maintenance planning as IVA maintenance.

Contingency EVA inflight maintenance conducted during the missions substantiate the need for adequate planning in this area. Prior to the SL-1 launch, EVA inflight maintenance was intentionally avoided. During the three manned missions, the EVA inflight maintenance performed not only initially saved the Skylab program but kept the spacecraft systems and experiments functioning even longer than the planned program duration.

D. Tools and Equipment

1. Design Description - The tools and equipment on-board Skylab were provided to support not only inflight maintenance, but also activation, operation and deactivation of the Cluster systems and experiments. Lubricants, safety wire, twine, tape, Velcro and other like materials were included for general use throughout the Cluster and for contingency maintenance.

Due to limited stowage capability the majority of tools in the Skylab tool inventory were selected to perform specific identified tasks. As a result, full sets of wrenches, sockets, Allen wrenches, and screwdrivers were not provided. Spare tools were provided in some instances where justified by the number of applications and susceptibility to loss or breakage.

The tool/maintenance equipment complement on-board Skylab was primarily contained in five kits located throughout the SWS. Figure 159 depicts the five kits and their locations in the spacecraft.

a. Skylab Tool Kits 1 and 2 - Located in the OWS Stowage Lockers, E623 and E624, and contained most of the tools and materials required for maintenance.

b. Activation/Contingency Tool Kit - Located in the MDA, locker M144, and contained tools and materials which were required or potentially needed during periods when the Skylab Tool Kits 1 and 2 were not accessible; such as, prior to OWS activation and during EVA. Some duplicate tools were included for use during activation when the same tool was simultaneously required by two crewmen.

c. Hatch Tool Kit - Located on the forward side of the MDA Axial Docking Port Hatch and contained the tools required to disassemble the hatch in the event that the latching mechanism became jammed.

d. Repair Kit - Located in the OWS, locker E620, and contained materials necessary to patch leaks in the habitation area of the Cluster and miscellaneous fastening materials and devices; such as, tape, Velcro, and snap assemblies.

Additional special purpose tool kits, tools, materials and equipment were located at various places in the spacecraft. These included the CSM Tool Kit, S190 Tools, EMU and PGA Maintenance Kits, Water System Servicing Equipment, and spare tools plus a number of miscellaneous tools and maintenance equipment items. Table 23 is a complete listing of the tool/maintenance equipment inventory initially launched on-board the SWS.

The Skylab tool/maintenance equipment inventory was supplemented on all three missions with items necessary to install auxiliary hardware, support contingency inflight maintenance, and to replace tools which were lost or broken during previous missions. Table 24 is a listing of these supplemental and additional tools and equipment items.

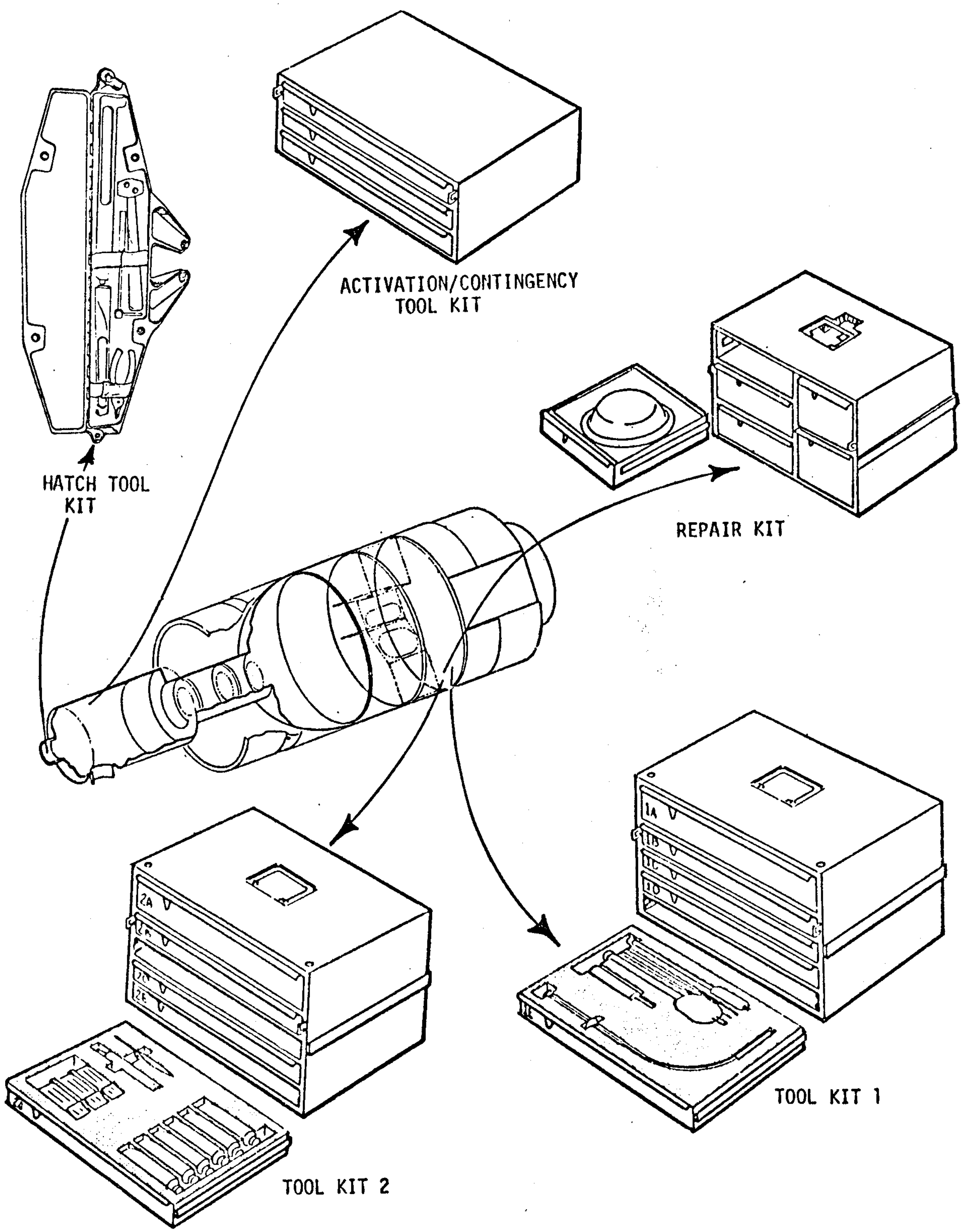


Figure 159. Skylab Tool Kits

SKYLAB TOOL KITS 1 and 2	5/32 ALLEN BIT-MODED	CONNECTOR PLIERS
TORQUE HANDLE	3/16 ALLEN BIT	PIN STRAIGHTENER PLIERS
TORQUE WRENCH	3/16 ALLEN BIT-MODED	3/32 BLADE DRIVER
SPIN HANDLE	3/16 X 3-1/2 ALLEN BIT	3/16 BLADE DRIVER
RATCHET HANDLE	3/16 LONG ALLEN BIT	PHILLIPS DRIVER 1
SPEEDER HANDLE	3/16 LONG ALLEN BIT-MODED	PHILLIPS DRIVER 2
EXPERIMENT HANDLE	3/16 90 DEG ALLEN BIT	PHILLIPS OFFSET DRIVER
4 INCH EXTENSION	1/4 ALLEN BIT	HAMMER
8 INCH EXTENSION	UNIVERSAL JOINT	1/16 PUNCH
12 INCH EXTENSION	11/16 CROWFOOT WRENCH	3/32 PUNCH
SOCKETS	3/4 CROWFOOT WRENCH	3/16 PUNCH
1/4 8 POINT STD SOCKET	1 CROWFOOT WRENCH	O-RING EXTRACTOR
1/4 STD SOCKET	1-1/8 CROWFOOT WRENCH	KNIFE
5/16 STD SOCKET	1-3/8 CROWFOOT WRENCH	TWEEZER
3/8 STD SOCKET	5/16 WRENCH	RETRIEVAL MIRROR
7/16 STD SOCKET	11/32 WRENCH	RETRIEVAL HOOK
SOCKETS	3/8 WRENCH	MECHANICAL FINGERS
5/16 DEEPWELL SOCKET	7/16 WRENCH	PINCH BAR
3/8 DEEPWELL SOCKET	1/2 WRENCH	VISE
7/16 DEEPWELL SOCKET	9/16 WRENCH	C CLAMP
1/2 DEEPWELL SOCKET	11/16 WRENCH	VELCRO-PILE
9/16 DEEPWELL SOCKET	3/4 WRENCH	VELCRO-HOOK
3/8 BLADE DRIVER BIT	13/16 FLARENUT WRENCH	3/4 INCH NEUTRAL TAPE
HI-TORQUE DRIVER BIT 1	ADJUSTABLE WRENCH	1 INCH RED TAPE
HI-TORQUE DRIVER BIT 2	3/64 ALLEN WRENCH	2 INCH NEUTRAL TAPE
HI-TORQUE DRIVER BIT 3	5/64 ALLEN WRENCH	SAFETY WIPE
1/16 ALLEN BIT	3/32 ALLEN WRENCH	LACING TWINE
3/32 ALLEN BIT	SLIP JOINT PLIERS	LUBRICANT
7/64 ALLEN BIT	CHANNEL LOCK PLIERS	H20 SYSTEM LUBRICANT
1/8 ALLEN BIT	NEEDLE NOSE PLIERS	SCISSORS
5/32 SQ ALLEN BIT	VISE GRIP PLIERS	
5/32 ALLEN BIT	CUTTER PLIERS	

Table 23. Skylab Tool/Maintenance Equipment - 1 of 3

ACTIVATION/CONTINGENCY TOOL KIT
SPIN HANDLE
RATCHET HANDLE
4 INCH EXTENSION
1/4 DEEPWELL SOCKET
5/16 STD SOCKET
3/8 DEEPWELL SOCKET
7/16 DEEPWELL SOCKET
HI-TORQUE DRIVER BIT 3
3/64 ALLEN WRENCH
1/4 WRENCH
1/8 ALLEN BIT
5/32 SQ ALLEN BIT
3/16 90 DEG ALLEN BIT
3/16 LONG ALLEN BIT
ACCUTRON TIMER KEY
1/16 ALLEN WRENCH
7/16 WRENCH
CONNECTOR PLIERS
PHILLIPS DRIVER 2
1/8 BLADE DRIVER
3 INCH FLAT PATCH
5-3/4 BLISTER PATCH
7-1/4 INCH BLISTER PATCH
8-1/2 INCH BLISTER PATCH
UNIVERSAL SEALANT
1 INCH RED TAPE
2 INCH NEUTRAL TAPE
SCISSORS
PINCH BAR
TOOL CADDY
UTILITY BELT
3/4 WRENCH (DELETED)
STOWAGE BAGS (DELETED)

HATCH TOOL KIT
SNAP RING REMOVAL TOOL
PUNCH
MALLET
SEAL LOOSENING TOOL

REPAIR KIT
DUCT TAPE
REPAIR PATCH, FLAT
REPAIR PATCH, DOME, 5-IN.
REPAIR PATCH, DOME, 7-IN.
REPAIR PATCH, DOME, 8-IN.
POLYBUTENE SEALANT
PLUMBERS TAPE
VELCRO (HOOK AND PILE)
SNAP ASSEMBLY

CSM TOOL KIT
TOOL B (RATCHET)
TOOL E (HANDLE)
TOOL F (END WRENCH)
TOOL L (CDC DRIVER)
TOOL R (DRIVER)
TOOL V (U-JOINT DRIVER)
TOOL W (RATCHET)
TOOL 1 (SOCKET)
TOOL 2 (SCREWDRIVER)
TOOL 3 (TORQUE TIP 8)
TOOL 4 (TORQUE TIP 10)
TOOL 5
TOOL 6 (TORQUE TIP 6)
CSM TETHER
CSM JACK SCREW

S190 TOOLS
S190 LARGE SPANNER WRENCH
S190 SMALL SPANNER WRENCH
S190 SCREWDRIVER
S190 SCISSORS
S190 TAPE

WATER SYSTEM SERVICING EQUIPMENT
HOSE ASSEMBLY
JUMPER HOSE ASSEMBLY
ADAPTER ASSEMBLY
HOSE ASSEMBLY
DEIONIZER ASSEMBLY
ADAPTER ASSEMBLY
ADAPTER ASSEMBLY
HOSE ASSEMBLY

MISCELLANEOUS TOOLS AND EQUIPMENT
VACUUM CLEANER
DOCKING LATCH TOOL
LATCH RELEASE TOOL
SEAL ASSEMBLY
ORIFICE CLEANING TOOL
BIOCIDE WIPES

Table 23. Skylab Tool/Maintenance Equipment - 2 of 3

UTILITY WIPES
WET WIPES
ELECTRODE KIT WET WIPES
TISSUES
PGA MAINT KIT
OWS MAINT KIT, EMU
TOOL CADDY
UTILITY BELT
MECHANICAL FINGERS

SPARE TOOLS
7/16 STD SOCKET (1)
7/64 ALLEN BIT (1)
5/32 ALLEN BIT (3)
3/16 ALLEN BIT (1)
3/16 LONG ALLEN BIT (1)
1/4 ALLEN BIT (2)
3/4 WRENCH (1)
3/64 ALLEN WRENCH (3)
3/32 ALLEN WRENCH (1)
3/32 BLADE DRIVER (1)
3/16 BLADE DRIVER (1)
SWISS ARMY KNIFE (1)

Table 23. Skylab Tool/Maintenance Equipment - 3 of 3

SL-2 Mission	SL-3 Mission	SL-4 Mission
SEVA Tools End Grip, MSFC Pole SAS HOOK Double Prong Adapter Cable Cutter Shear Assembly Pole Tether Restraint Tool Extender Rods (3) Waist Tether (L) Waist Tether (R) Release Mechanism Claw Assembly **Parasol Tools** Strap Wrench (2) Screws/Allen Tools **Miscellaneous** Swiss Army Knife	**Resupplied Tools** Ratchet Handle, 3/8 Drive Swiss Army Knife **Rate Gyro Package Tools** Ratchet Handle, 3/8 Drive 9/16 Deepwell Socket, 3/8 Drive No. 3 Hi-Torque Bit, 1/4 Drive (2) Ratchet Handle, 1/4 Drive Screwdriver Bit, 3/16 Hex, 1/4 Drive Universal Joint, 1/4 Drive Extension, 4 inch, 1/4 Drive 3/8 Open End/Box End Wrench RGP Connector Pliers (2) 90 Degree Nose Connector Pliers **Parasol Tools** Hex Head Wrench (2) Rod Disconnect Tool	**Resupplied Tools** Screwdriver Bit, 3/16 Hex, 5 inch 3/16 Blade Screwdriver Swiss Army Knife (3) Red Tape, 1 inch Diagonal Cutter Pliers, 6 inch General Purpose Tape (2 Rolls) **Miscellaneous** 9/16 Flarenut Wrench 7/8 Crowfoot Wrench Sharpening Kit 9/64 Allen Wrench (2) Screwdriver Bit, 9/64 Hex Hi-Torque Screw Removal Tool S193 Repair Screwdriver EPC DRC Connector Pliers Capture Latch Release Tool ATM TV Installation Tool

Table 24. Additional/Resupplied Tools

2. Usage - According to the crew's comments, nearly all of the tools in the tool kits were used during the missions. Table 25 is a listing of these usages based on review of flight planning data, voice and dump tape transcripts, checklists, real time contingency and maintenance procedures, and crew debriefings.

3. Losses and Failures - During the course of the three missions, one ratchet handle failed, the 4 inch diagonal cutters and one 5-inch long, 3/16-hex screwdriver bit were broken and one pinch bar was lost.

A retaining ring was either missing or was lost from the ratchet directional control lever and the mechanism fell apart during SL-2 Activation. Procedures were developed to repair the ratchet but were not performed. A replacement ratchet handle was launched on SL-3.

The diagonal cutters were broken during an attempt to remove the spheres from the M553 sphere forming wheel. The 4-inch cutters were inadequate for this purpose and jaws yielded when the task was attempted. A larger, 6-inch, set of diagonal cutters were provided on SL-4. The SL-4 crew reported that the 6-inch cutters were dull after only a few uses.

During the SL-2 crew debriefing, the crew stated that one of the 5-inch long, 3/16-hex screwdriver bits was defective. The bit shank turned in the socket adapter. Since a spare bit was provided on-board, resupply was determined not to be necessary. The same defective tool was reported by the SL-3 crew during replacement of the Video Tape Recorder. The SL-3 crew acquired the spare bit and completed the task. Because of some confusion with the exact tool description a spare modified type, 5-inch long, 3/16-hex screwdriver bit was launched on SL-4. The 3/16-hex screwdriver bits were high usage tools on all three Skylab missions.

The pinch bar which was used during the OWS Solar Wing deployment activity was left tethered to the wing. A replacement was determined not to be necessary due to limited usage identified for the pinch bars and the fact that there were two initially stowed on-board. During SL-4 the soft inserts in the jaws of the connector pliers became loose and had to be taped in place.

4. Post Mission Assessment - Sufficient tools were provided on-board to perform all planned activation, operational and maintenance tasks. The on-board tools also proved to be adequate for support of most of the contingency maintenance tasks. Some additional tools were required to perform specific tasks, since complete sets of Allen wrenches, sockets, and open end wrenches were not proved. The SL-3 crew also expressed a need for a hacksaw, drill, drill bits, larger screwdrivers, and a sharpening stone. Special purpose tools were required for support of the Standup EVA, Parasol deployment, OWS Solar Wing deployment, Rate Gyro Package installation, and installation

TOOL NOMENCLATURE
APPLICATION

Adapter Assembly (61A830387-1)
- Service/Deservice Cluster Water Systems

Adapter Assembly (61A830387-2)
- Service/Deservice Cluster Water Systems

Adapter Assembly (61A830357-7)
- Service/Deservice Cluster Water Systems

Adapter, Double Prong
- Deploy OWS Solar Array

Bar, Pinch
- Deploy OWS Solar Array

Belt, Utility
- General Usage

Bit, Screwdriver, 3/32 Hex, 3 1/2 in. Shank
- Adjust M074 Transducer
- Adjust M172 Zero Crossover, Axial
- Repair S019 Extension Mechanism
- Replace S009 Drive Motor

Bit, Screwdriver, 7/64 Hex, 3 1/4 in. Shank
- Remove M554 Composite Casting Specimens
- AM Tape Recorder Disassembly

Bit, Screwdriver, 5/32 Hex,
- Replace Dump Probe Assembly
- Replace Teleprinter Assembly
- Replace Fire Sensor Control Panel
- Replace M074 Electronics Module
- Activate Fecal/Urine Collector
- Remove Dump Hose Launch Restraints
- Activate Vacuum Cleaner
- Plenum Bag Stowage
- Close M171 Metabolic Analyzer Sample Inlet Valve
- Refrigeration System Vent Valve Operation
- Adjust M172 Zero Crossover, Lateral
- Shower Activation
- AM Tape Recorder Disassembly

Bit, Screwdriver, 5/32 Square
- Replace Speaker Intercom Assembly
- Replace WMC Filter and Charcoal Cartridge
- Replace Video Tape Recorder
- Relocate MDA Intercom Assembly
- Install CSM/MDA Air Interchange Duct
- Unstow OWS/VCS Duct
- Relocate M168 Stowage Container
- Remove VC Tree from Film Vault

Bit, Screwdriver, 3/16 Hex, 2 in. Shank
- Replace Video Tape Recorder
- Remove Food Tray Launch Restraints
- Remove Food Table Cover Launch Restraints
- Suit Drying Station Activation
- Wardroom Window Activation
- Remove Portable Fan Launch Restraints
- Remove OWS/AM VCS Duct Launch Restraints
- Relocate Food Container

Table 25. Skylab Tool/Equipment Usage - 1 of 9

TOOL NOMENCLATURE

APPLICATION

- Remove OWS Film Vault Launch Restraints
- S063 Experiment Pre-Preparation
- Unstow M509 AME from Launch Configuration
- M074 SMMD Preparation
- M172 BMMD Preparation
- Remove H_2O Dispenser Launch Restraints
- Remove ED74 Camera Mount
- Remove ED74 Mass Measurement Assembly
- Adjust M172 Zero Crossover, Axial
- Adjust M172 Zero Crossover, Lateral
- Remove Circular/Conical Shoe Cleat from ATM C/D Chair
- Replace Ergometer Pedal Screw

Bit, Screwdriver, 3/16 Hex, 2 in. Shank, Modified

- Replace Video Tape Recorder

Bit, Screwdriver, 3/16 Hex, 3 1/2 in.

- Primary Coolant Loop Servicing

Bit, Screwdriver, 3/16 Hex, 5 in. Shank

- Replace Urine Separator
- Replace Urine Separator Motor and Filter
- Replace Urine Separator Support and Filter
- Replace Video Tape Recorder
- Unstow OWS/AM VCS Duct
- Activate Fecal/Urine Collector
- Remove Trash Airlock Launch Restraints
- Remove Portable Fan Launch Restraints
- Remove Dome Locker Launch Restraints
- Install T027 Tripod
- Relocate T027 Sample Array Container
- Relocate T027 Photometer Container
- Remove T025 Launch Restraints
- Perform Wardroom Water Purge
- Unstow ED74 Mass Measurement Beam Assembly
- Remove Urine System Separator
- Deploy Skylab Parasol
- Remove Video Tape Recorder Circuit Boards

Bit, Screwdriver, 3/16 Hex, 1/4 in. Drive, RGP Tools

- Install Rate Gyro Package

Bit, Screwdriver, 3/16 Hex, 90 Degree

- Replace Video Tape Recorder
- Activate Fecal/Urine Collector
- Remove Trash Airlock Launch Restraints
- Activate Wardroom Window
- Relocate S149 Container
- Relocate S183 Stowage Rack
- Remove Video Tape Recorder Circuit Boards

Bit, Screwdriver, 1/4 Hex

- Shower Activation
- Open/Close M171 Vacuum Valve

Bit, Screwdriver, Hi-Torque No. 2

- Configure SAL for S063 Operation

Bit, Screwdriver, Hi-Torque No. 3

- Replace Video Tape Recorder

Table 25. Skylab Tool/Equipment Usage - 2 of 9

TOOL NOMENCLATURE
  APPLICATION

  Coolanol System Leak Inspection

Bit, Screwdriver, Hi-Torque No. 3, 1/4 in.
Drive, RGP Tools
  Install Rate Gyro Package

Bit, Screwdriver, Standard, 3/8 Blade
  Replace WMC Filter and Charcoal Cartridge
  Relocate Spare Condensate Module

Caddy, Tool
  General Usage

Cleaner, Vacuum
  General Usage
  Clean OWS Air Mixing Chamber
  Clean ECS Fan Inlet Screens
  Clean WMC Ventilation Unit Filters
  Clean OWS Heat Exchanger Vanes
  Clean OWS Solenoid Vent Port Filter

Cutter, Cable
  Deploy OWS Solar Array

Deionizer Assembly, Water System Servicing
  Service/Deservice Cluster Water Systems

End Grip, MSFC Pole (Mushroom)
  Deploy OWS Solar Array

Extension, 4 in.
  Replace Hot Water Dispenser Valve
  Replace TV Input Station
  Replace Urine Separator
  Replace Video Tape Recorder
  Clean Solenoid Vent Port Filter
  Primary Coolant Loop Servicing
  Remove Video Tape Recorder Circuit Boards
  Replace OWS Heat Exchanger Fan

Extension, 6 in. 1/4 in. Drive, RGP Tools
  Install Rate Gyro Package

Extension, 8 in.
  Replace Video Tape Recorder
  Relocate Spare Condensate Module
  Remove Dome Locker Launch Restraints
  Unstow M509 AME from Launch Configuration
  Relocate T027 Sample Array Container

Extension, 12 in.
  Relocate S149 Container
  Relocate T027 Sample Array Container
  Relocate T027 Photometer Container
  Relocate S183 Stowage Rack
  Relocate Wardroom and WMC Spare Hotwater
    Heaters

Extractor, O-Ring
  Replace Wash Cloth Squeezer Bal-Seal

Fingers, Mechanical
  General Usage

Table 25. Skylab Tool/Equipment Usage - 3 of 9

TOOL NOMENCLATURE
  APPLICATION

Hammer, Ball Peen, 8 oz.
- Free Stuck CBRM #15 Relay

Handle, Experiment Wrench
- Relocate T027 Sample Array Container
- Relocate S183 Stowage Rack

Handle, Ratchet
- Replace WMC Odor Control Filter
- Replace Teleprinter Assembly
- Replace TV Input Station
- Replace Urine Separator
- Replace Urine Separator Motor and Filter
- Replace Video Tape Recorder
- Clean OWS Solenoid Vent Port Filter
- Unstow OWS/AM VCS Duct
- Activate Fecal/Urine Collector
- Remove Food Tray Launch Restraints
- Remove Food Table Cover Launch Restraints
- Relocate OWS Electrical Panel Support
- Remove Portable Fan Launch Restraints
- Remove OWS/AM VCS Duct Launch Support
- Remove WMC Vent Cover
- Remove Dome Locker Launch Restraints
- Replace OWS Heat Exchanger Fan
- Primary Coolant Loop Servicing
- Install T027 Tripod
- Shower Activation
- S063 Experiment Pre-Preparation
- Unstow M509 PSS Stowage Rack
- Unstow M509 AME from Launch Configuration
- M172 BMMD Preparation
- Remove H_2O Dispenser Launch Restraints
- Configure SAL for S063 Operation
- Relocate T027 Sample Array Container
- Relocate S183 Stowage Rack
- Remove S190B Launch Restraints
- Remove T025 Launch Restraints
- Wardroom Window Purge
- Remove Window Cover from ATM C/D Console Foot Restraint
- Remove SAL Window Covers from M512 Foot Restraint
- Relocate Wardroom and WMC Spare Hotwater Heaters
- Remove Circular/Conical Shoe Cleat from ATM C/D Chair
- Unstow ED74 Mass Measurement Beam Assembly
- Deploy Skylab Parasol
- Coolanol System Leak Inspection
- Replace S009 Drive Motor
- Remove Video Tape Recorder Circuit Boards

Handle, Ratchet, 1/4 in. Drive, RGP Tools
- Install Rate Gyro Package

Handle, Ratchet, 3/8 in. Drive, RGP Tools
- Install Rate Gyro Package

Handle, Speeder, Brace Type
- Remove Trash Airlock Launch Restraints
- Activate Wardroom Window
- Relocate S149 Container

Table 25. Skylab Tool/Equipment Usage - 4 of 9

TOOL NOMENCLATURE

APPLICATION

- Remove Film Vault Launch Restraints
- Relocate T027 Photometer Container
- Remove ED74 Camera Mount
- Remove ED74 Mass Measurement Assembly

Handle, Spin Type

- Replace Dump Probe Assembly
- Replace WMC Filter and Charcoal Cartridge
- Replace Fire Sensor Control Panel
- Replace M074 Electronics Module
- Relocate MDA Speaker Intercom Assembly
- Install CSM/MDA Air Interchange Duct
- Activate Fecal/Urine Collector
- SAL Window Initial Installation
- Remove Dump Hose Launch Restraints
- Activate Wardroom Window
- Activate Vacuum Cleaner
- Relocate M168 Stowage Container
- Relocate Spare Condensate Module
- Shower Activation
- M074 SMMD Preparation
- Install Urine Separator
- Relocate T027 Sample Array Container
- Relocate S183 Stowage Rack
- Plenum Bag Stowage
- Remove M554 Composite Casting Specimens
- Refrigeration System Vent Valve Operation
- Adjust M074 Transducer
- Adjust M172 Zero Crossover, Axial
- Adjust M172 Zero Crossover, Lateral
- Remove VC Tree from Film Vault
- Remove Urine Separator
- Repair S019 Extension Mechanism
- AM Tape Recorder Disassembly

Handle, Torque, 5-150 in.-lbs.

- Replace Urine Separator Support and Filter
- Replace Video Tape Recorder
- Relocate Food Container
- Close M171 Metabolic Analyzer Sample Inlet Valve
- Open/Close M171 Metabolic Analyzer Vacuum Valve
- Wardroom Window Moisture Removal
- Replace Ergometer Pedal Screw
- Primary Coolant Loop Servicing

Hook, SAS

- Deploy OWS Solar Array

Hose Assembly, Water Servicing Deionizer

- Service/Deservice Cluster Water Systems

Hose Assembly, Jumper

- Service/Deservice Cluster Water Systems

Hose Assembly, Water Separator Plates

- Service/Deservice Cluster Water Systems

Hose Assembly, Water System Servicing (61A830355-13)

- Service/Deservice Cluster Water Systems

Table 25. Skylab Tool/Equipment Usage - 5 of 9

TOOL NOMENCLATURE	APPLICATION
Joint, Universal	Replace TV Input Station Replace Video Tape Recorder Relocate S183 Stowage Rack
Joint, Universal, 1/4 in. Drive, RGP Tools	Install Rate Gyro Package
Kit, Cluster Leak Repair	General Usage
Kit, OWS Maintenance, EMU	Maintain EMU Seals and O-Rings
Kit, PGA Maintenance	Clean/Antifog Treat EMU Helmet
Knife, General Purpose	General Usage Replace M487 Battery S183 Malfunction Procedure Replace Ergometer Pedal Screw Primary Coolant Loop Servicing
Lubricant, O-Ring, General Purpose	General Usage Lubricate M092 LBNP Waist Seal Zipper Lubricate Ergometer Pedals
Lubricant, O-Ring, Water System	General Usage
Multimeter, Digital	Checkout Rate Gyro Package DAC Camera Checkout TV Power Cable Checkout S183 Malfunction Procedure Condensate Dump Probe Checkout
Pliers, Connector, Electrical	Replace Mol Sieve Fan Replace WMC Filter and Charcoal Cartridge Replace TV input Station Replace Fire Sensor Control Panel Replace Video Tape Recorder Shower Activation Replace WMC Vent Filter Replace OWS Heat Exchanger Fan
Pliers, Cutter, Diagonal, 4 in.	Remove M553 Sphere Specimens from Disc
Pliers, Needle Nose	Activate Vacuum Cleaner
Pliers, Pin Straightener, Electrical Connector	Replace S009 Drive Motor Primary Coolant Loop Servicing
Pliers, Vise Grip Type	Deploy OWS Solar Array Remove Hi-Torque Screws

Table 25. Skylab Tool/Equipment Usage - 6 of 9

TOOL NOMENCLATURE
  APPLICATION

Removal Tool, Cable Plug, RGP Tools
  Install Rate Gyro Package

Remove Tool, Cable Plug 90 Degree, RGP Tools
  S082B Auxillary Timer Installation

Scissors, S190
  Replace S190 Cassett

Scissors, 6 in.
  General Usage

Screwdriver, Phillips No. 1
  Repair S019 Extension Mechanism
  Replace S009 Door Drive Motor
  Adjust S192 Attenuator
  Engage M133 Tape Recorder Pinch Roller

Screwdriver, Phillips No. 2
  Install S054 Shutter Override Actuator
  M133 Post Operation Activities

Screwdriver, Standard, 3/32 Blade
  Adjust Fire Sensor Sensitivity
  M487 Sound Meter Level Frequency Analyzer Calibration
  Adjust S192 Attenuator

Screwdriver, Standard 1/8 Blade
  S054 Filter Wheel Positioning

Screwdriver, Standard, 3/16 Blade
  Replace AM Tape Recorder
  Replace EVA/IVA Liquid Gas Separator
  Replace Portable Timer Tone Battery
  Disassemble S054 Film Magazine
  AM Tape Recorder Disassembly
  Remove Video Tape Recorder Circuit Boards
  Install Gas/Coolant Separator in ATM C&D Coolant Loop

Screwdriver, S190
  Replace S190 Magazine Drive Assembly
  Disconnect S190 Shutter Drive Mechanism

Sealant, Universal (Polybutene Putty)
  Seal Condensate System Connections

Seal Assembly
  Replace Dump Probe Assembly

Grid Snaps
  General Usage

Socket, Deepwell, 7/16 in.
  Unstow M509 PSS Stowage Rack
  Unstow M509 AME from Launch Configuration
  Remove Window Cover from ATM C/D Console Foot Restraint
  Relocate Wardroom and WMC Spare Hotwater Heaters
  Replace OWS Heat Exchanger Fan

Socket, Deepwell, 1/2 in.
  Replace WMC Odor Control Filter

Table 25. Skylab Tool/Equipment Usage - 7 of 9

TOOL NOMENCLATURE
  APPLICATION

Socket, Deepwell, 9/16 in.
  Wardroom Window Moisture Removal

Socket, Deepwell, 9/16 in., Thinwall, RGP Tools
  Install Rate Gyro Package

Socket, Standard, 1/4 in.
  Relocate T027 Sample Array Container
  Coolanol System Leak Inspection

Socket, Standard, 5/16 in.
  Relocate T027 Sample Array Container
  Relocate S183 Stowage Rack

Socket, Standard, 3/8 in.
  Replace TV Input Station
  Clean Solenoid Vent Port Filter
  Coolanol System Leak Inspection
  Primary Coolant Loop Servicing

Socket, Standard, 7/16 in.
  SAL Window Initial Installation
  Relocate OWS Electrical Panel Support
  Remove WMC Vent Cover
  Shower Activation
  Unstow M509 PSS Stowage Rack
  Remove S190B Launch Restraints

Tape, S190
  Replace S190 Cassette
  Disconnect S190 Shutter Drive

Tape, Pressure Sensitive, 2 in.
  General Usage
  Deploy OWS Solar Array
  Wardroom Window Moisture Removal
  ATM Door Ramp Latch Removal
  Primary Coolant Loop Servicing

Tape, Pressure Sensitive, 1 in. Red
  Condensate System Leak Check
  S183 Malfunction Procedure
  Failed Component Identification

Tape, Pressure Sensitive, 3/4 in.
  Remove OWS SOP Launch Restraints
  Plenum Bag Stowage

Vise, Bench Type
  Replace Ergometer Pedal Screw

Wire, Safety
  Deploy OWS Solar Array

Wrench, Adjustable
  Condensate System Leak Check

Wrench, Allen, 5/64
  Remove Video Tape Recorder Circuit Boards

Wrench Allen 9/64
  Mark I Exerciser Repair

Table 25. Skylab Tool/Equipment Usage - 8 of 9

TOOL NOMENCLATURE
APPLICATION

Wrench, Allen, 3/16
- S082B Auxillary Timer Installation

Wrench, Crowfoot, 1 3/8 in.
- Condensate System Leak Check

Wrench, Open End, 5/16 in.
- Replace Video Tape Recorder
- Install H_2O Gun Resupply
- Remove H_2O Gun Resupply

Wrench, Open End, 11/32 in.
- Replace Video Tape Recorder

Wrench, Open End, 3/8 in.
- Replace Video Tape Recorder
- M074 SMMD Calibration

Wrench, Open End, 3/8 in., RGP Tools
- Install Rate Gyro Package

Wrench, Open End, 7/16 in.
- Relocate Portable Water Tank
- M172 BMMD Preparation
- Remove SAL Window Covers from M512 Foot Restraint
- ATM Door Ramp Latch Removal

Wrench, Open End, 9/16 in.
- Replace TV Input Station
- M172 BMMD Preparation
- Remove OWS SOP Launch Restraints
- Wardroom Window Moisture Removal
- Condensate System Leak Check

Wrench, Open End, 11/16 in.
- Condensate System Leak Check
- Wardroom Window Moisture Removal

Wrench, Open End, 3/4 in.
- M172 BMMD Preparation
- Connect Radio Noise Burst Monitor Antenna
- Disassemble S054 Film Magazine
- Condensate System Leak Check

Wrench Strap
- Deploy Skylab Parasol

Wrench, S190 Spanner, Small
- Replace S190 Dessicant Assembly
- Replace S190 Magazine Drive Assembly

Wrench, Torque, 0-600 in.-lbs.
- Replace WMC Hotwater Dispenser Valve
- Condensate System Leak Check

Table 25. Skylab Tool/Equipment Usage - 9 of 9

of the ATM TV Monitor. Redundant tools were provided in some instances, such as with the Rate Gyro Package where fit and access were possible problem areas and the tools could be fit checked on the ground with flight and backup hardware.

Only a small number of tools were required to perform any of the specific tasks and, as a consequence, the crewmen did not exercise the option of removing the tool kits from their stowage lockers for transportation to the worksite.

The tool caddies were used on several occasions but proved to be inadequate except for retaining the tools at the worksite. This was due primarily to failure of the Velcro to restrain the tools during translation. Most of the tools were carried to the worksite in the crewman's trouser pockets.

The Hi-Torque screwdriver bits proved to be inadequate for removal of the Hi-Torque type screws. Crewmen finally resorted to use of the Vise Grip pliers to remove some of the fasteners; however, this procedure proved to be time consuming and tedious. A special screw removal tool was developed and launched on SL-4 for this purpose but was not required for any task.

Specialized tool nomenclatures were misleading and in some instances were responsible for the crew not using tools for purposes other than those specified. As an example, the tool developed for removal of Hi-Torque screws was identified for stowage purposes as a C&D Kick Plate Tool. The tool was developed to resolve the problem of removing the Hi-Torque screws from the kickplate. However, the SL-4 crew encountered difficulty removing Hi-Torque screws in order to gain access to the Primary Coolant Loop lines for servicing and was unaware that the special removal tool was available.

The SL-4 crew indicated that they had problems with ice building up behind the inner food freezer door and did not have the proper tool for its removal. An ice scraper would have been useful for this purpose but was not available on-board. They also found that some QD's were very difficult to mate and demate when adequate access was not provided. Future spacecraft design should insure sufficient clearance for operation of quick disconnects. The crew recommended that a tool be developed to aid in mating and demating quick disconnects.

Arrangement of tools in the tool kits and the method of retention were criticized by the Skylab crewmen. One main complaint was that specific classes of tools; such as sockets and socket drive accessories, open end wrenches, Allen wrenches, screwdriver bits etc. were not located in separate drawers. It was recommended that this would be desirable even if larger tool kits were required. Another complaint was that some tools fit tightly into the drawer cutout's while others were so loose that they were not restrained at all.

The crewmen also indicated that the placement of tools and tool kits at numerous locations throughout the cluster was undesirable and they recommended that all of the tools be grouped in one specific area.

A tool summary or listing was not available on-board for crew visibility of the entire tool inventory. As a consequence the crews were unaware of the availability of certain tools unless they were specified in a procedure and their location spelled out. This included the tools initially provided as spares and those stowed throughout the cluster other than in the main tool kit in the OWS. The SL-4 crew stated that they would like to have had the tools displayed on the OWS wall the same as a work shop would be layed out in order to provide visibility of the tool inventory.

None of the tools in the initial tool inventory were designed for EVA use. As a consequence, tool handle sizes had to be enlarged by wrapping them with tape. Tape was also used to attach the necessary tethers, since the tools were not equipped with tethers or tether attach points. The tools proved to be adequate for EVA after the handles were taped and the tethers attached. An adaptable EVA handle for standard tools and tether attach points would be desirable for any future tools required for EVA inflight Maintenance use.

The Velcro patches on the tools were of very little value. In some cases the patches came loose and they did not hold tight enough to retain the tools on the tool caddy during translation. The main usage was for retaining tools in the area of the SAL where patches of velcro pile had been installed.

E. IFM Summary and Conclusions

Skylab experience demonstrated that preplanned maintenance capability resulted in relatively problem free, easily executed maintenance tasks, when coordinated with design. However, unanticipated maintenance activity created excessive resupply requirements for special tools, spares and equipment, as well as consuming a great deal of crew time and effort. Installation of the Rate Gyro Six Pack, leak check of the coolant and condensate systems and attempted removal of the ATM Control and Display Console kickplate are examples of maintenance tasks unanticipated but accomplished on Skylab. Excessive numbers of fasteners had to be removed, some types of fasteners were unacceptable for maintenance purposes, not all tools were available on-board and accessibility was poor. Special tools, jumper cables and installation hardware had to be developed on a real time basis and provided on revisit missions.

Initial design concepts need to include inflight maintenance provisions which must be developed concurrently with hardware design. This philosophy permits incorporation of the necessary design features to facilitate failure detection, isolation, corrective action and verification of repair. Stowage provisions for tools, spares, maintenance, equipment and space for maintenance work areas, must be incorporated in the initial design. This is necessary to optimize spacecraft maintenance support with available weight and volume; to permit orderly arrangement of tools and equipment; and, facilitate performance of bench repair.

Experience gained during Skylab has proven that extra-vehicular maintenance is not only feasible, but is also a necessary capability for success of space missions. The Skylab crewmen demonstrated that tools could be effectively manipulated, equipment erected, electrical connectors mated and demated and components removed and installed, when the necessary procedures, tools and equipment items were made available. All of these capabilities were required in order to deploy the solar shade, connect the rate gyro package, deploy the OWS solar wing and remove the ATM door ramp latches. Skylab experience also demonstrated that EVA time could be extended beyond that anticipated, in order to accomplish necessary tasks. Most of the extra-vehicular maintenance on Skylab was unanticipated and was accomplished based on real time planning, without the assistance of built in translation aids, restraints or tools intended for EVA applications.

Design criteria for maintainable spacecraft must include provisions for extra-vehicular inflight maintenance. This criteria must insure that translation and restraint capability is provided for all potential work areas; i.e., predetermined attaching points for handrails, restraints and tethers.

Accessibility to equipment, attaching hardware, electrical connections and plumbing is imperative, even in areas where maintenance is not anticipated or is highly unlikely. All failures and contingencies cannot be anticipated, but with adequate design criteria, corrective maintenance action can be taken.

Skylab crews expressed a preference for Calfax type quick release fasteners and magnetic door latches as opposed to dial latches, pip pins and Expando-Grip pins. Internal wrenching (Allen head) screws and hex head bolts were the preferred types of attaching hardware. Hi-Torque and slotted type screws were unacceptable for inflight maintenance purposes.

The experience gained on Skylab indicates that the astronauts are capable of performing complicated maintenance tasks during EVA and bench repair of major components on IVA. Handling, alignment and manipulation of large heavy items presented no problems in zero gravity. Small items such as bolts, screws, washers, nuts, etc., did present some problems because they tend to float away and become lost. However, these items usually found their way to one of the ECS inlet screens. Methods and techniques must be developed on future space programs to enable the astronauts to handle and control these small items in an effective manner.

Selection of spares to support inflight maintenance capability should include consideration of non-critical and redundant hardware. Skylab experience demonstrated the desirability of replacing or repairing all failed equipment. With the exception of the contingency maintenance performed, nearly all of the items replaced during the missions were identified as non-critical or redundant hardware. The tape recorders, speaker intercom assemblies, water dispenser, mass measuring device electronics, cameras and fans are just a few examples. Without these spares and many others of the same type, the Skylab mission would still have been successful, but the degree of success would have been reduced.

Spares selection for IFM should include repair parts for certain items whose design permits inflight bench repair as well as replaceable assemblies. Skylab has proven that the crew, when provided the proper tools, procedures and parts, is capable of performing bench repair of failed assemblies.

Tools selected for Skylab were primarily those required for specific tasks that were approved for inflight accomplishment. A few contingency type tools were included such as a pry bar, a hammer and the Swiss Army knife, which proved to be valuable assets. Allen wrenches of certain sizes were provided for specific application, all sizes were not provided. The same applied to open end wrenches, sockets, etc. The crews have expressed a desire for complete sets of these tools. It has also been indicated that regular off-the-self type tools are adequate and no special finish is required for use in space. A tool caddy for carrying tools from place to place should be developed with the purpose in mind of facilitating the location of the needed tool after arriving at the work station. Crew comments indicated a "see through" material would be desirable. The caddy should also provide a capability to hold small parts such as washers, screws, bolts, nuts, etc., since containing and locating these items was a problem in zero gravity.

The crew of SL-3 indicated that a portable leak detector should be considered for future missions. This need became evident when coolant leaks and vacuum leaks were suspected and verified, but not isolated to a specific location. A desire of all crews was a dedicated work bench or table with a capability for holding things that tend to float away. This, with the availability of repair parts, would enhance the repair of failed assemblies. Future spacecraft design should include a maintenance package, incorporating bench repair capability and containing a complete selection of general purpose tools and the necessary special tools and equipment to maintain the spacecraft and payload systems. For future missions, tools should be equipped with tether attach points to restrain them during EVA maintenance activities.

The astronauts have indicated that the tasks and procedures were so well planned and documented that many of the maintenance tasks could have been performed efficiently with little or no maintenance training. In the future, the engineers and technicians must continue to work out the procedural details, verify the tasks on trainers and flight hardware, and provide accurate and concise procedures in order to reduce and/or eliminate maintenance training for the astronauts.

Training for inflight maintenance should be limited to complex repair tasks which involve unusual equipment disassembly techniques, or tasks which could present a hazard to the crew, or result in damage to spacecraft equipment.

SECTION VI. EXTRAVEHICULAR ACTIVITY

Extravehicular operations were performed during all three manned Skylab missions. These operations included nominal tasks (ATM film retrieval), major contingency operations (Solar Array System deployment and twin-pole sail deployment), and several other minor tasks. Each of these categories is discussed below with regard to equipment design and usage, anomalies, and an overall assessment of the EVA system. For reference to specific EVA tasks, Table 26 contains information regarding the appropriate paragraph number, mission number, and the particular EVA during which each task was performed.

A. Skylab EVA System Development

Skylab EVA system development was initiated when the requirement for EVA was established during the mission definition phase of the Apollo Telescope Mount. The ATM, an orbiting solar observatory capable of high resolution telescopic photography of different solar phenomena, was officially included in the cluster design in December 1966. Extravehicular activity was defined at that time, as a requirement for meeting the ATM scientific objectives. The astronauts would be required to service the ATM experiments by retrieving and replacing the film during EVA's performed at intervals throughout each mission. Corollary experiments requiring EVA (D024 and S230) were added, placed so that the astronaut could gain access to them without leaving the ATM EVA work envelope. Additionally, the ATM EVA system was used for several off-nominal tasks that were added after launch, including Skylab salvage operations and experiment operations stemming from the discovery of the Comet Kohoutek.

Upon establishment of the requirement for EVA, studies were conducted to identify the EVA requirements necessary to support each mission. For example, number, frequency, purpose of each, duration, and tasks to be performed were identified. Analyses were then initiated to define specific crew tasks and, simultaneously, to derive a set of EVA design guidelines and constraints. The remainder of the EVA systems development focused on integrating the tasks with the hardware subsystems to provide an EVA capability that satisfied the mission objectives.

There were two distinct Skylab EVA system development periods between conception in 1966 and delivery in 1973 which reflected the two overall Skylab cluster concepts: (1) the Wet Workshop concept, and (2) the Dry Workshop concept.

1. <u>Wet Workshop Development</u> - The primary Skylab EVA objective was to deploy and recover solar astronomy experiment film magazines. The first guidelines specified that EVA would be conducted from the Airlock Module, using an A6L Block II Apollo pressure suit with a 60-foot umbilical as the primary life support system (Figure 160). The Portable Life Support System (PLSS), used on Apollo, was specified as a backup mode of operation. The LM/ATM forward hatch would be considered for backup ingress and egress. Seven film cassettes were to be exchanged at 14-day intervals.

EVA TASK / MISSION - EVA	SL-2		SL-3			SL-4			
	1	2	1	2	3	1	2	3	4
<u>ATM FILM RETRIEVAL</u>									
Hα		VI.B.2		VI.B.2	VI.B.2		VI.B.2		VI.B.2
S052		VI.B.2		VI.B.2	VI.B.2		VI.B.2		VI.B.2
S054		VI.B.2		VI.B.2	VI.B.2		VI.B.2		VI.B.2
S056		VI.B.2		VI.B.2	VI.B.2		VI.B.2		VI.B.2
S082A		VI.B.3		VI.B.3	VI.B.3				VI.B.3
S082B		VI.B.3		VI.B.3	VI.B.3				VI.B.3
SAS BEAM DEPLOYMENT	VI.C								
TWIN POLE SAIL DEPLOYMENT			VI.D						
D024 SAMPLE RETRIEVAL		VI.E.1						VI.E.1	
S230 SAMPLE RETRIEVAL			VI.E.2		VI.E.2	VI.E.2			VI.E.2
T025 CAMERA OPERATIONS						VI.E.3			
S201 CAMERA OPERATIONS							VI.E.4		
S149 DEPLOYMENT	VI.E.6		VI.E.6			VI.E.6			
ATM DOOR RAMP REMOVAL			VI.E.7		VI.E.7				
S052 DISC CLEANING		VI.E.8			VI.E.8				
ATM DOOR OPENING	VI.E.9							VI.E.9	
CBRM REPAIR		VI.E.10							
RATE GYRO PACKAGE CABLE INSTALLATION				VI.E.11					
SAIL SAMPLE INSTALLATION/RETRIEVAL					VI.E.12				
S193 REPAIR						VI.E.13			
VEHICLE EXTERIOR INSPECTION			VI.E.14						
MATERIAL SAMPLE RETURN								VI.E.12	
S054 LENS POSITIONING							VI.E.15		

Table 26. EVA Task-Mission Reference

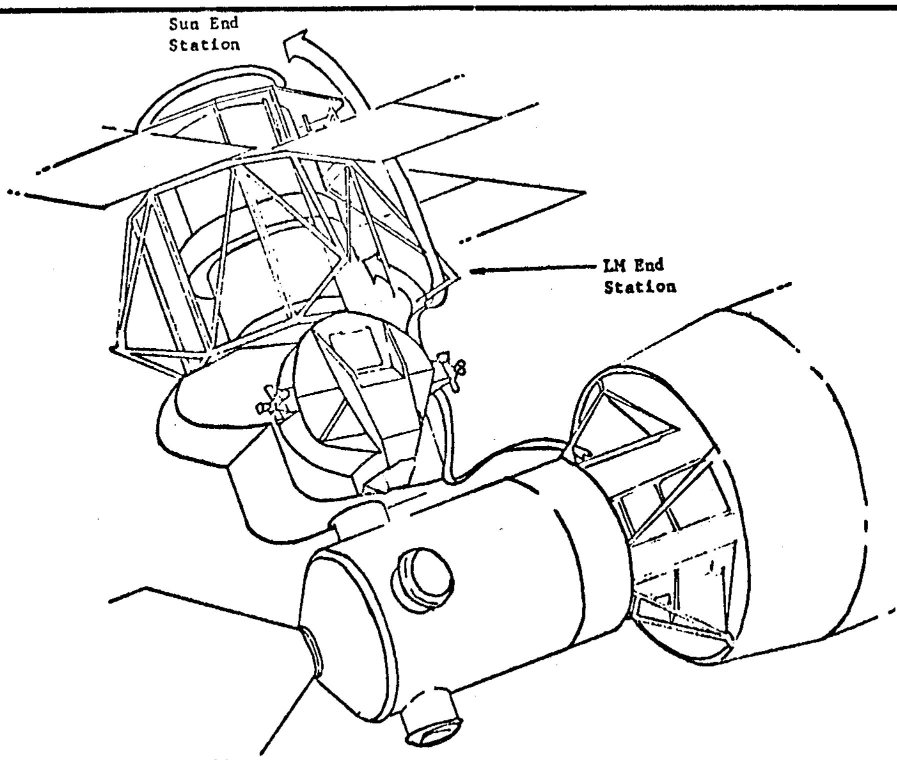


Figure 160. AAP 3/4 Cluster Configuration and Film Retrieval EVA Routes

The first conceptual studies were conducted using limited fidelity, inexpensive, one-g part-task mockups with a six degree-of-freedom mechanical simulator to investigate ATM canister access, determine optimum locations and configurations for ATM film retrieval workstations, and to develop and evaluate alternative design concepts for astronaut translation and film transfer.

Four ATM experiments required film packages located in the side of the canister; three required film packages at the sun end. Rather than having the astronaut maneuver to each camera, it was decided that the canister roll capability would be used to bring the camera access points to the crewman positioned at a fixed worksite. Two LM/ATM workstations would be developed; one providing access to the film positioned in the side of the canister and the other located at the sun end of the canister. These workstations were named "LM-End Workstation" and "Sun-End Workstation", respectively.

In order to shorten the astronaut translation and film transfer distances to and from the AM hatch and realizing the capabilities already built into the LM/ATM (it contained the ATM experiment controls, had its own independent power source, and astronauts could egress the LM forward hatch for EVA), it was recommended, in the summer of 1966, that film retrieval be conducted from the LM/ATM forward hatch rather than from the AM hatch. In view of this anticipated change, the system throughout 1967, 1968, and the first half of 1969 was designed using the LM/ATM hatch for EVA egress/ingress. The film magazines to be exchanged were stowed in the LM/ATM cabin instead of inside the AM. A workstation located just outside the LM/ATM EVA hatch, designated the LM Hatch Workstation, was developed.

At the time, there was very little experience with the Apollo EVA System, and the Gemini EVA experience had created a concern for the total workload to which the crew would be subjected. Egress from the LM/ATM forward hatch improved the EVA route, but considerable translation distance still existed between the LM Forward Hatch and the two ATM Workstations. Therefore, the LM-End Workstation was moved to a position between the ATM +Y and +Z axis, putting it nearly adjacent to the LM hatch. The Sun End Workstation was moved to a position directly underneath the LM Hatch Workstation at the +Z axis. These workstation locations were retained throughout the remainder of the Wet Workshop design. During the time that the EVA egress location and general workstation configuration were changing, work was proceeding on the ATM canister access and on detail design of the film cameras and their telescope-mounted receptacles. Using preliminary "one-g" mock-ups, Figure 161, reach envelopes, general door size (based on expected camera configurations), and door locations were identified and designs prepared. Requirements had been defined for camera designers, and evaluations had begun on the camera-to-receptacle interface. Necessary guides and aids for correct positioning of the cameras were defined. Using these mockups, requirements were established for detent forces, latching flags and locking mechanisms. Upon the receipt of preliminary camera configurations, which had now decreased from 7 to 6 with the change of one camera to a video display, work proceeded on film transfer concepts.

The greatest challenge in developing the EVA system lay in finding a solution to the astronaut and film transfer problem: How to get the crewman and his delicate cargo to and from the workstations unharmed, without damage to the vehicle exterior, without physically taxing the crewman, and without exceeding the specified 4-hour EVA duration. Many factors combined to complicate the task but the main source of difficulty was the seemingly contradictory requirements for optimization of each workstation (in terms of reach and visibility) not just individually, but with respect to each other workstation and, in particular, with respect to the crew and cargo transfer system. Interactions between workstations and transfer systems, especially in the "domino" effects of small changes became extremely difficult to predict analytically. Thus, frequent simulations, both suited and shirtsleeve, and "one-g" and reduced gravity began to play an increasing role in the conceptual design function.

Many concepts for getting the astronaut and film from the EVA egress/ingress hatch to the film retrieval/replacement workstations were investigated and applied, in simulations, to the existing workstation concepts. Generally as development progressed, and as understanding of man's ability to conduct orbital EVA increased, the complexity of the concepts for the Skylab EVA decreased; prediction of results and interactions became more intuitive and the emphasis in simulation shifted from one of searching for potential solutions to one of verification of candidate concepts. These candidate concepts, presented herein, provide an overview of EVA system evolution.

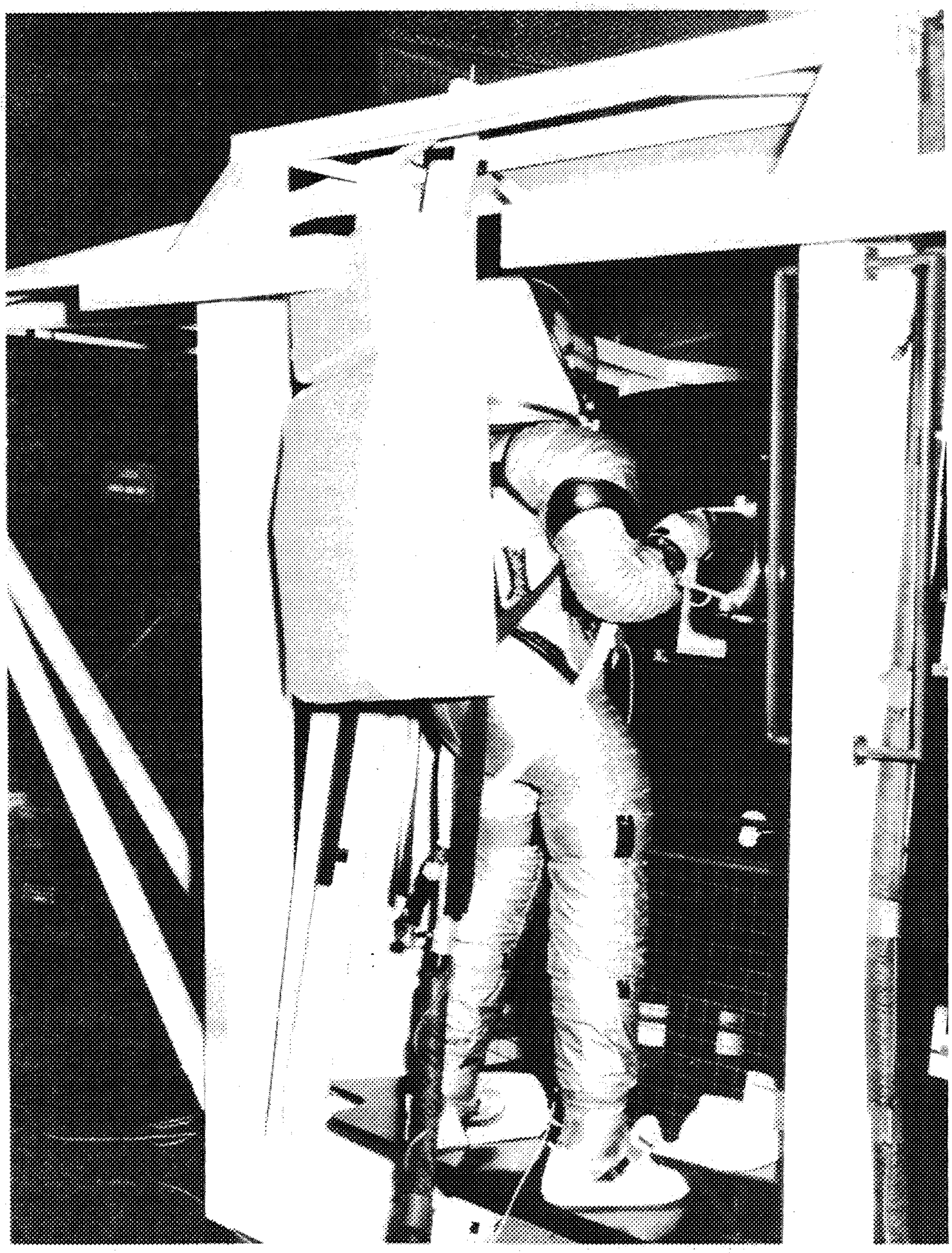


Figure 161. One-g Mockup Simulation

In the early Wet Workshop configuration, using the AM as the EVA egress point, design centered around the use of telescoping booms of various types. Because of the preoccupation with crew workload, early concepts were relatively highly automated. The serpentuator (Figure 162), a segmented, highly automatic system for transfering both the crewman and the film magazines, was considered. Although quite heavy and complex, it offered considerable savings in crew workload and was, therefore, given initial emphasis. Also considered at this time was the use of "roll up" booms (Figure 163), which formerly had been used principally as antennas on unmanned satellites. At the time of the decision to use the LM hatch as the baseline EVA egress hatch, the simpler extendible booms were being considered for film magazine transfer.

Two methods of crew transfer were under investigation: 1) using the booms themselves, and 2) using fixed handrails on the exterior of the MDA and the LM/ATM. Handrails were ultimately selected for two reasons: 1) lack of sufficient bending stiffness in the booms and 2) the potential hazards related to the sharp edged tapes forming the boom elements.

When the decision was made to use the LM hatch for primary EVA egress, attention shifted to the use of rail systems of simpler design and construction than the boom or serpentuator concepts. Several "aided" rail systems, either powered or manually controlled, were considered. In addition, pivoting arms operated through a linkage which would swing packages to workstations were given heavy emphasis.

The initial rail system was named the "trolley" (Figure 164), and provided the capability to transfer both crew and film simultaneously. The crewman provided the motive force by pulling himself and the trolley along the rail. A prototype trolley was designed and fabricated and was evaluated in neutral buoyancy simulation. Although the trolley system provided excellent control of astronaut body position and could allow simultaneous transfer of both crew and equipment, it was quite complex, rather heavy, and the simulations indicated considerable development would be required to provide an easy rolling system. Difficulty with this system was due to cocking in the roller system from off-center loads applied by the crewman (especially in negotiating curves).

Helping to make the decision not to go ahead with the trolley was the reclock of the workstations to provide a more direct line from the LM hatch to the LM End Workstation and the Sun End Workstation. The equipment transfer design configuration at this point consisted of a pivoting arm (Figure 165), actuated by a handle at the LM Hatch Workstation, which swung down to the LM End Workstation with appropriate cameras. For the Sun End Workstation, the S082A and B film magazines were to be carried on a rail device, nicknamed the "skateboard", which rolled on the dual handrails provided for translation to the sun end. Two concepts of the skateboard were pursued initially. One could be pushed in front of and actuated by the crewman. Another concept had a simple cable system operated by a handcrank at the LM Hatch Workstation, allowing transfer of the equipment separately from the crewman translating to the sun end.

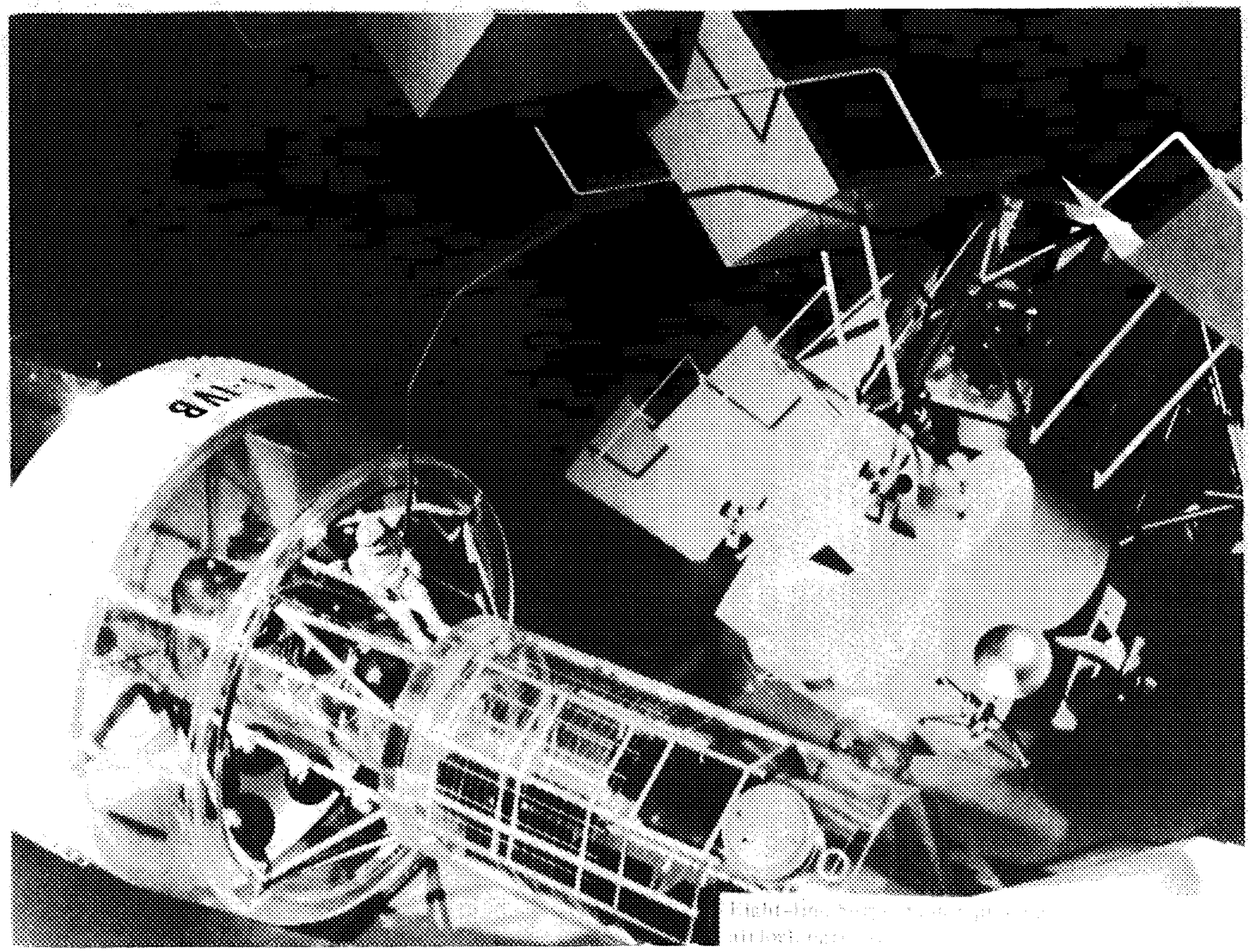


Figure 162. Serpentuator

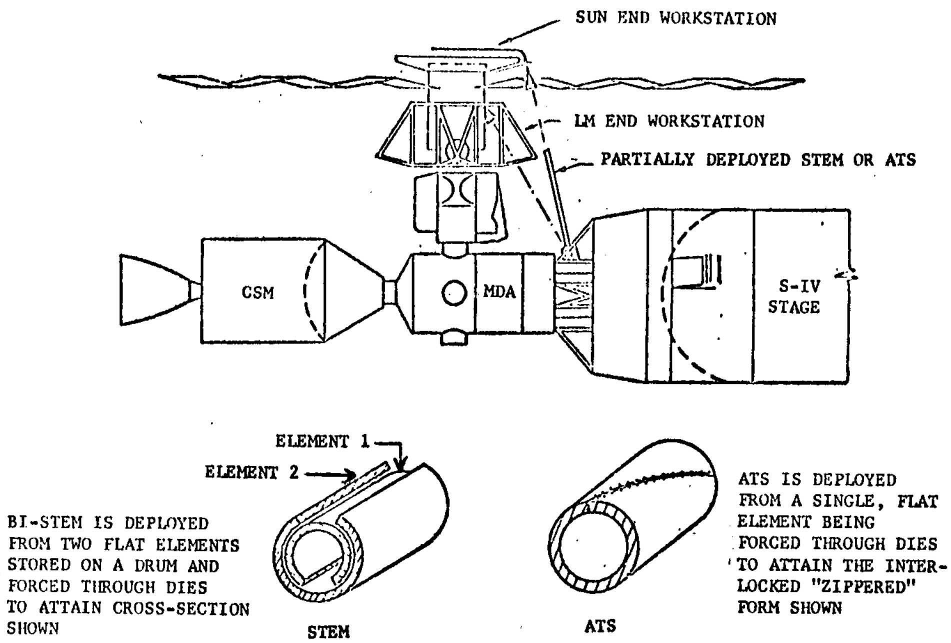


Figure 163. Extendible Booms

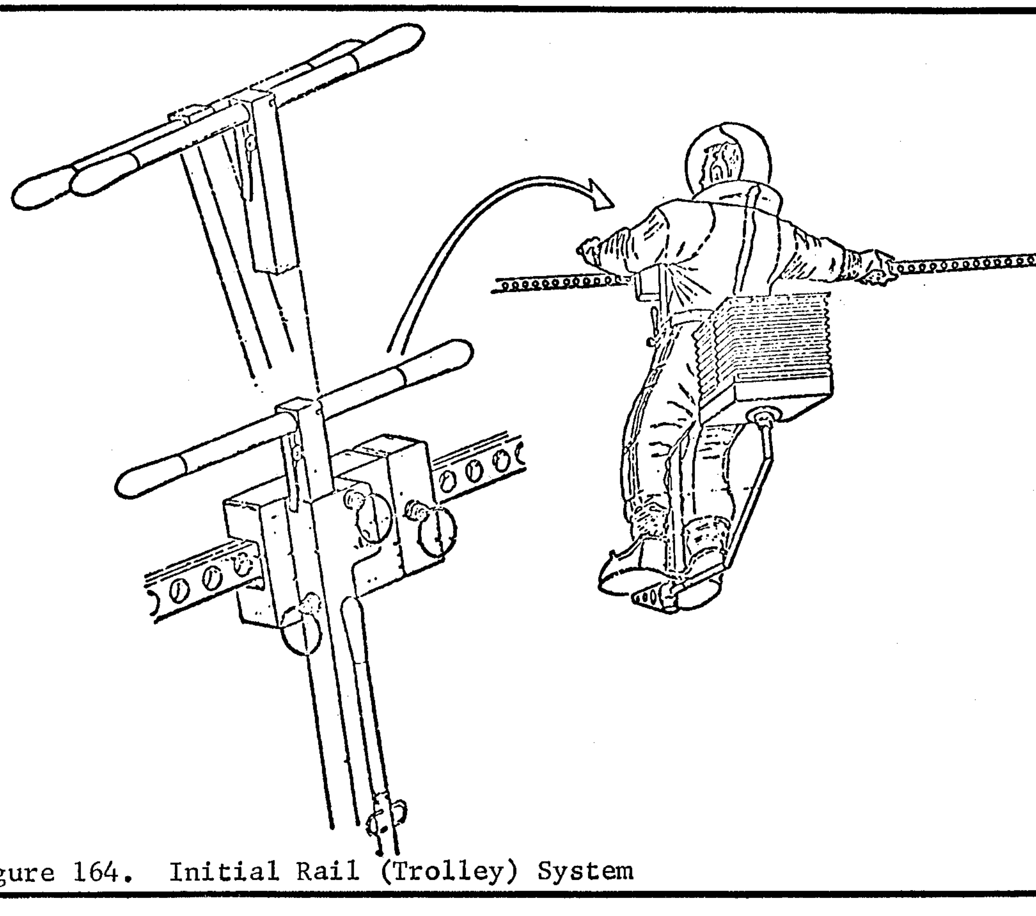


Figure 164. Initial Rail (Trolley) System

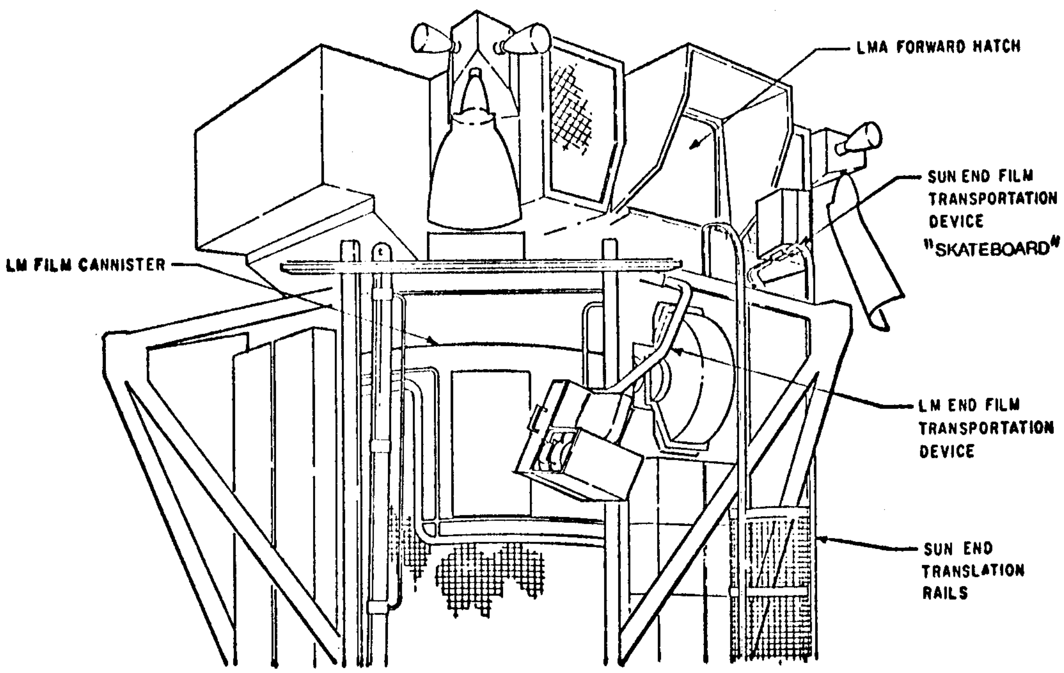


Figure 165. ATM LM End Workstation

The dual rail system was provided to maintain better body stability during translation through the solar panels. There was some worry of damage to the solar panels or to the crewmen by inadvertent contact. To assist in body stabilization, an early concept of the dual rails provided a trough-like gridwork ("Coal-Chute") which formed essentially a key-slot where the crewman could insert his feet and thereby stabilize his lower body during translation (Figure 165).

This system of a flipover arm to the LM End Workstation and skateboard and dual rails to the Sun End Workstation was the design at the time of the Wet Workshop CDR, just prior to the decision to go to the Dry Workshop configuration. Both one-g and neutral buoyancy simulations were used effectively during the development of this final Wet Workshop concept.

2. Dry Workshop Development - With the advent of the Dry Workshop, the LM was eliminated and the ATM was launched already attached to the rest of the Cluster, causing the location for EVA egress to be returned to the AM. With egress from the AM and with the ATM being oriented in the same manner as in the Wet Workshop concept (but without the LM), cargo transfer and translation routes were not as accessible as before. Of the possible alternatives, it was determined that the Sun End Workstation could be brought within 45^{o} of a direct line from the AM and the LM End Workstation, although 90^{o} from the best location was still accessible for direct cargo transfer, and crew translation was not

seriously hampered. Under Dry Workshop design, the LM End Workstation of the ATM was renamed the Center Workstation (with the acronym VC) and the Sun End Workstation was given the acronym VS (in keeping with the JSC selection of two letter nomenclature for all external workstations). The Dry Workshop film retrieval concept resulted in the development of a workstation in the fixed airlock shroud area, (Figure 166), designated VF. This station would be occupied by the first crewman out during an EVA. It would provide stowage locations for all the ATM film, a temporary stowage hook for equipment, sufficient handrails for use of the foot restraints, general mobility in the area of the workstation, and access to whatever transfer equipment was to be provided. Thus, one crewman was to provide a general management role for film equipment and umbilicals, and the other crewman was to actually translate to the ATM and exchange the film.

Some initial studies considered the use of a skateboard device for film transfer to the ATM from the fixed airlock shroud. It became obvious, however, that any rail concepts, being discontinuous across the ATM/MDA interface (to allow ATM deployment), faced unjustifiable difficulties in alignment during deployment and were, therefore, dropped. Extendible booms mounted at the fixed airlock shroud and "pre-aimed" at the ATM workstations, were next to be considered for equipment transfer, with separate crew transfer and equipment transfer being baselined. A simple, endless clothesline system was selected as a back-up to the booms. The alternative of carrying film magazines, one at a time, by the crewman performing the film retrieval was considered and rejected because of the higher probability of damage to the film magazines and the increased translational workload required.

The fixed airlock shroud workstation was developed using the combination of one-g and neutral buoyancy mock-up hardware. Concepts were generated in one-g and, if they appeared reasonable, were fabricated and installed in the neutral buoyancy development article. Using the combination of one-g and neutral buoyancy development, and simulation to determine the most effective positioning for the VF foot restraints and the best utilization of the space around the VF workstation (again with the selection of extendible booms for film transfer) proved very effective. There were to be three booms provided: one to the Sun End Workstation, one to the Center Workstation, and one spare. The positions of these booms were selected initially using one-g hardware. Their accessibility for replacement and for positioning at the ATM workstations was then verified in neutral buoyancy simulation.

The clothesline assemblies (alternate film transfer system) were designed to be mounted to approximate the travel path of the booms as closely as possible. This took advantage of the previous work done in positioning the booms for good access to the film packages at both the airlock and the ATM ends of the transfer. Since the VS Workstation was not visible from the airlock and since neither selected method of film magazine transfer would go around the corner, an intermediate workstation named the Transfer Workstation (VT) was developed (Figure 167).

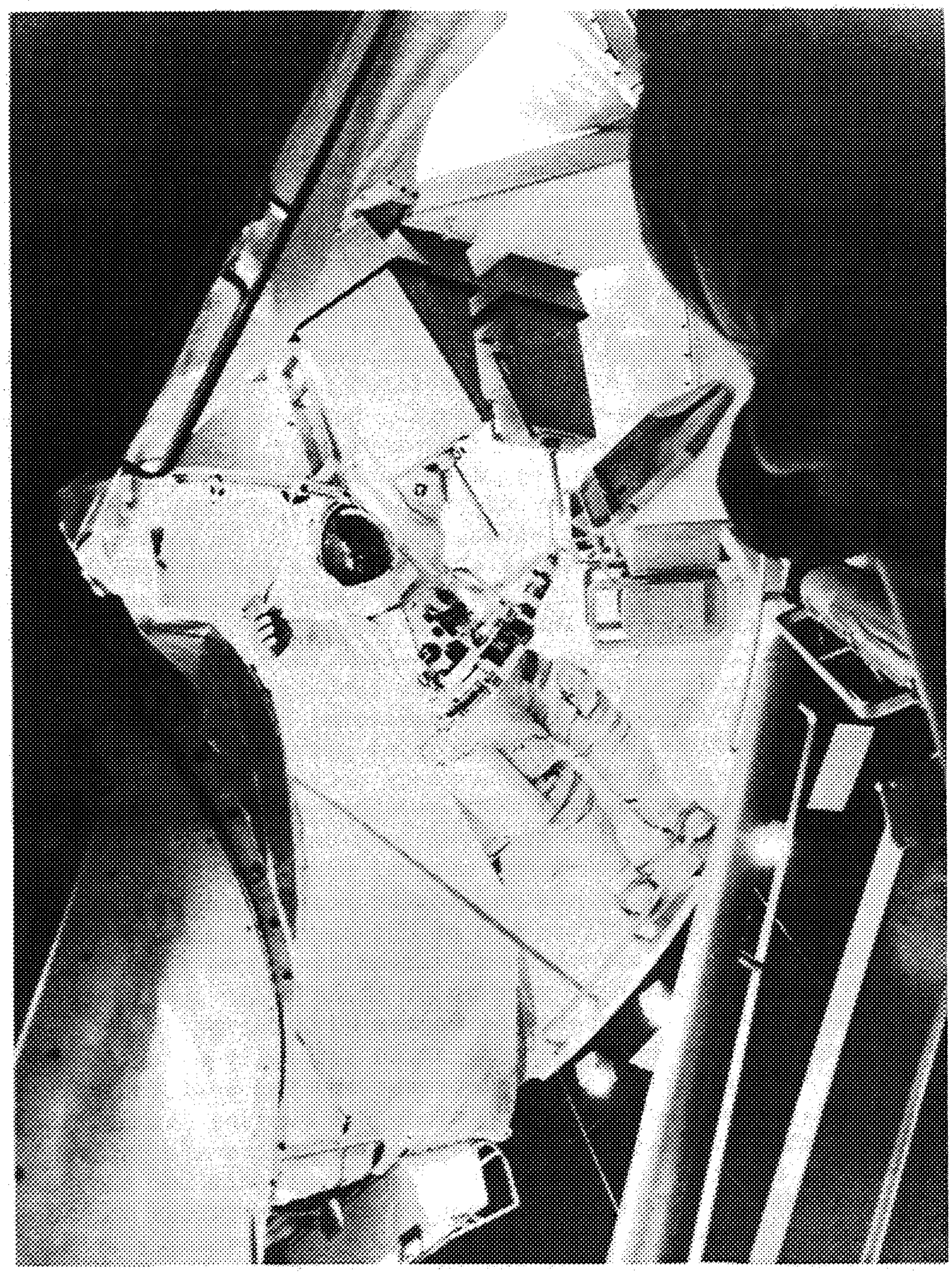


Figure 166. Fixed Airlock Shroud (VF) Workstation

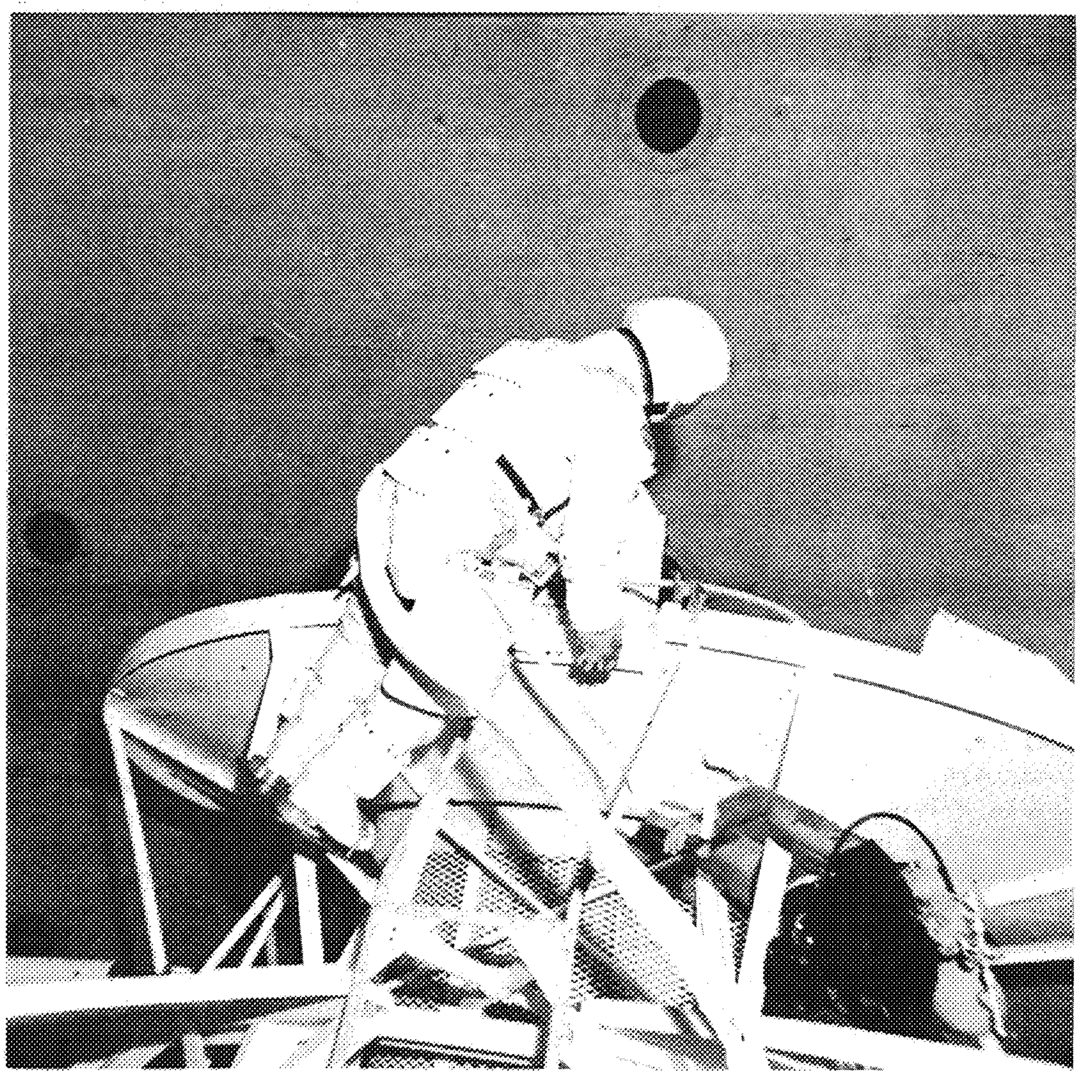


Figure 167. Transfer Workstation

Because of its unique location and position with respect to the other components, this workstation was developed entirely through the use of neutral buoyancy simulation. With the establishment of the Transfer Workstation and the concomitant selection of the position for stowage of the S082A and B magazines on their film transfer tree, along with the selection and location of a temporary stowage device for the S082 cameras during film exchange, the ATM EVA system development was essentially complete. The system described above was evaluated during the EVA CDR in November 1970 and was accepted with little modification.

3. Final Systems Development and Verification - Two major changes to workstations occurred during final concept verification, procedures development, and early training. The first change involved simplification of the Center Workstation and its guard rail due to the deletion of the requirement for a mechanical lock to ensure that the canister would not inadvertently roll while a crewman was in the process of transferring film. It was determined that due to the design of the canister and its drive logic this mechanical brake was not required. The second change was required when it was found that the film transfer booms as originally designed could not carry the film transfer boom hook during launch without extensive redesign. Early vibration testing of the booms pointed out this problem and, consequently, a quick-release attachment to the boom was designed and a stowage box was provided near the VF workstation, from which the SL-2 crew could install the boom hooks.

To aid in the replacement of failed film transfer boom, a temporary workstation, designated the replacement workstation (VR), was developed. This consisted of a handrail and a small section of aluminum channel which served, respectively, as a toe bar and heel restraint and was mounted near the airlock tunnel in such a position that all three of the film transfer booms could be reached and exchanged from that position.

Umbilical clamps, which were the subject of much discussion during the early development of the EVA, were placed at the Sun End Workstation, the Center Workstation, and in two places (one for each crewman) just outside the EVA hatch, accessible from the VF Workstation. This was a considerable decrease from the number of clamps originally discussed in the early days of EVA development. Ultimately the use of the clamps at the two ATM workstations became optional at crew discretion. The primary umbilical management position became the fixed airlock shroud workstation (VF) with its two umbilical clamps.

Minimal procedural changes occurred during training. This was a result of the detailed, iterative development performed on the system and the consistent participation by the flight crew.

4. Summary - The Skylab EVA system design was initiated at a time when orbital EVA capabilities were not clearly known and the program, which was to become Skylab, was exhibiting considerable fluidity. These factors encouraged the consideration of many possible design solutions.

In particular, the changes in the EVA egress position created very different transfer requirements, thus spawning new options with each change. The final result was a system which had undergone thorough evaluation of alternatives and provided a conservative, simple, and flexible design.

Note: For further details, see MSFC TMX-64855, Skylab EVA Systems Development.

B. ATM Film Retrieval

The ATM experiments, with the exception of S055, collected solar astronomy data on photographic film. This film was enclosed in magazines which were to be periodically removed and replaced by an EVA crewman. The hardware described in this section includes all major EVA equipment required for the removal and replacement of film magazines from the ATM experiment canister. The EVA hardware subsystems included are the Fixed Airlock Shroud Workstation (VF), the Center Workstation (VC), the Transfer Workstation (VT), the Sun End Workstation (VS), and the mobility aids and other equipment (EVA lights and umbilical clamps, for example) along the EVA translation path. The hardware at these four EVA Workstations is discussed in the sections below with regard to the hardware design, its on-orbit use, any anomalies that occurred during its use and an assessment of its design. The functions and interrelationships of each hardware subsystem are also identified.

1. Fixed Airlock Shroud Workstation (VF) - This workstation, together with the adjacent center lock compartment of the Airlock Module, served as "base camp" for all nominal and contingency EV operations by providing stowage locations for all hardware and tools, prime and back-up transportation devices for ATM film magazines, and foot restraints from which one crewman (EV1) could monitor the other (EV2) during Center Workstation and Sun End Workstation film retrieval operations. Within reach of the crewman in his foot restraints were stowage locations for the ATM film magazines, Film Transfer Booms (FTBs), the boom hook stowage box, the boom control panel (Panel 321), Life Support Umbilical (LSU) clamps, data acquisition camera attach points, a temporary stowage hook, clothesline film transfer systems (back-up), and sufficient fixed handrails for ingress, egress and translation to and from other EV workstation on the cluster. Also in the immediate vicinity were the D024 experiment, the FTB replacement workstation (for exchanging a failed FTB with the spare), and the S230 experiment.

a. Film Transfer Booms (FTB), Boom Control Panel, and Boom Hooks - The Film Transfer Booms were tubular extendible devices, which, under the control of EV1 (using the boom control panel), were capable of being extended to and retracted from the Center Workstation (VC) and Transfer Workstation (VT). These were used to transport film magazines on a clamp-type hook attached to the end of each boom. The boom used for VC operations carried individual film magazines to a location near the VC, so EV2 could remove spent film magazines from the ATM canister and replace them with fresh magazines from the FTB. The FTB used for Sun End operations transported the VS tree with both S082A and B film magazines attached, and terminated near the Transfer Workstation where EV2 removed the tree from the boom and stowed it in a convenient location for use from the Sun End foot restraints. The

FTBs were electrically driven and had a manual deployment/return back-up capability. In the event of total operational failure of a FTB, a spare unit, located in the VF area, was available as a back-up unit and could have replaced either the VC or VS film transfer boom. The FTBs were capable of being operated by EV1 with one hand and required no auxiliary equipment other than the FTB hooks. Electrical power was supplied to the FTBs on redundant Airlock Module buses. If a failed FTB had to be replaced, the zero-g connector on the FTB could be removed by the crewman and replaced on the spare FTB.

The film transfer boom hooks were attached to the end of the FTBs with a connector adapted from a quick-disconnect fluid coupling. The hooks were designed to accept the standard handle configuration found on all film magazines and film trees and exert a clamping force on the handle so that the connection was semirigid. A lock-lock prevented inadvertent release. Both hooks were one-hand operable, in that once a handle was inserted, it was retained securely until clamping force was applied and the lock-lock was engaged. The boom hooks were stowed in a box forward of the VS tree receptacle and were secured on the booms prior to the first film retrieval tasks.

During EVA operations, the FTB and boom control panel operated flawlessly with the exception of the second EVA on SL-2. After the VS FTB was extended to the VS the first time, the retract switch had to be cycled once to make the boom retract. This problem did not occur again, and no other problems occurred with the FTB, boom panel or FTB hooks. During the SL-3 third EVA, however, 1 in. scratch marks from four to six inches apart were noticed on the VS boom element.

The VS and VC FTBs were effective methods of translating large, massive equipment during EVA. This method is desirable when the on-orbit time savings or safety considerations can justify its expense compared with manual or clothesline type translation devices.

The FTB hooks were adequate to secure the VC film magazines and VS tree and hold them at their proper orientation. These hooks are recommended for similar application without any design changes.

b. Temporary Stowage Hook - A locking stowage hook was provided at the VF for temporary stowage and restraint of loose equipment. This hook was one-hand operable, and incorporated a lock-lock.

No problems were encountered with operation of the temporary stowage hook. The VF temporary stowage hook is an effective method of stowing loose equipment during EVA. No changes are recommended for future use.

c. Film Transfer Boom Replacement Workstation - The FTB replacement workstation consisted of a simple toe-bar foot restraint which positioned EV1 in the optimum position for exchanging a failed FTB for the spare. It was located along the edge of the AM hatch (opposite the hinge side).

During the last EVA of SL-4, one crewman used the foot restraint during deployment of the film retrieval clotheslines. No problems occurred with its use.

d. VF Handrails - The VF contained sufficient handrails to assist all required operations. Handrails were anodized blue and were numbered to provide easy identification and correlation with checklists. The handrails were fabricated by compressing a 1.125 in. tube to 1.42 in. X 0.62 in., and were designed to withstand a load of 200 lbs. in any direction. They were mounted with stand-offs 3.25 in. away from the mounting surface.

During EVA operations, the crew noticed that the handrails had turned turquoise from the original blue color. All EVA handrails were adequate for crew stability and translation. Their use on future EVA missions is recommended.

Although some of the EVA handrails at the other workstations were smaller (1.25 in. X 0.63 in.), their general configuration was the same. Since the handrails at all EVA workstations were basically the same, the comments concerning design description, on-orbit use, and recommendations for VS handrails is also applicable for handrails at other workstations.

e. Film Trees and Receptacles - Two pallets (trees) were used to transfer film magazines from the AM where they had been placed during EVA prep., to the VF through the EVA hatch. Each tree was inserted into a tree receptacle located within reach of the VF foot restraints. These receptacles consisted of a metal plate designed to hold the film trees. Each receptacle had a locking hole that would accept a spring loaded latch on the tree's base. The VS film tree secured both S082 film magazine containers as a unit and was extended to the Transfer Workstation on the VS film transfer boom. On the other hand, the VC tree secured the S052, S054, S056 and Hα1 magazines as a cluster for handling only within and between the AM and the VF; film magazines were transferred individually to the VC, while the tree remained in the FAS receptacle. Both the VC and VS film trees were one-hand operable for both camera attachment/removal and tree mounting/removal.

During EVA operations, VC and VS film trees worked satisfactorily, and no problems were encountered with the VF tree receptacles. The ATM film trees are convenient methods of transporting several pieces of equipment simultaneously. Positive latching of the separate hardware items on the tree is desirable. The film tree receptacle is an effective method for securing the tree with a minimum of time and effort.

Since the film tree receptacle, located at the Sun End (VC), was identical to the receptacle at the VF, all comments concerning other operation of the VF tree receptacle apply to the VS receptacle also.

f. Life Support Umbilical (LSU) Clamps - Two spring-loaded LSU clamps were located adjacent to the EVA hatch as temporary restraint for the Life Support Umbilical (LSU) of each crewman. Shortly after each crewman's egress from the lock compartment into the EVA bay, each LSU was inserted into a clamp with predetermined amounts of slack, depending on the activity to be performed.

The VF LSU clamps operated satisfactorily during EVA and were easier to operate than they had been in the neutral buoyancy trainer. They are acceptable, as designed, for future use.

Comments concerning operation of the VF umbilical clamps apply to the clamps used at other workstations since they were identical.

g. EVA Foot Restraint - The EVA foot restraint located at the VF consisted of a toe-bar and heel plate for each foot. To secure his feet in the restraint, the crewman inserted each boot toe under the toe-bar and slid the boot heel clip under the heel plate. To disengage the boot from the restraint, the crewman slid the heel to the inside and withdrew his toe from the toe-bar. The VF foot restraint was identical to the foot restraints used at other workstations, except for the orientation of the restraints on the mounting plate.

The foot restraints at the VF and other workstations provide an adequate crew restraint when used in combination with a handhold or handrail. The existing foot restraint design is recommended for future applications.

h. VF Area EVA Lights - The EVA lighting system provided illumination to the VF area by means of five EVA lights. Primary control of the VF lights as well as all other EVA lights was from Panel 316 located in the AM lock compartment. Each light was encased in a wire-grid enclosure to protect its light bulb from damage.

In addition to illuminating the VF area, one of the five EVA lights was mounted on the D024 sample panel handrail to illuminate that area for sample panel retrieval. The lighting system was powered by two independent buses with each light set capable of providing adequate lighting for all EVA operations.

During one EVA, the lights failed to come on when commanded from Panel 316 in the center lock compartment. Approximately 10 minutes after sunset, when the problem had become evident, the lights were successfully commanded on from the ground. No satisfactory cause for this problem has been established.

Otherwise, the EVA lights provided adequate illumination. The lights are recommended for use on future missions without changing the illumination characteristics, basic design, or redundant wiring philosophy. Glare shield configuration will depend, however, on the location of each light at the workstation.

Since the VF EVA lights were identical to those used at other workstations, the above comments apply to all EVA lights.

i. Photographic Equipment - During certain portions of the EVAs, a 16mm data acquisition camera was used to obtain motion picture records of EV activities. For mounting this camera, using a modified universal mount, portions of several VF handrails were marked with aluminum tape. Positions for placement of the camera were readily accessible to the EVA crewman, who mounted the camera at the beginning of some EVAs, made a film record of selected activities at the VS or VC, and recovered the camera at the end of the EVA.

During EVA operations, both the Data Acquisition Camera (DAC) and video cameras were difficult to mount, point, and operate. If cameras are to be used during future EVAs, they should have separate, firm mounting brackets located to minimize accidental contact with the crewman in the workstation. The crewman should also have adequate foot restraints and handrails for stability. All camera operations should be one-handed.

j. Clothesline Film Transfer Units - Two clothesline film transfer units were available as back-up to a failed spare FTB and for nominal ATM film retrieval during the last SL-4 EVA. Each clothesline unit consisted of a "Brooklyn" type endless clothesline with appropriate hooks and hardware for attachment to special brackets located at the VF, VC and VS. In the event of the spare FTB failure, a clothesline could be manually deployed to continue film magazine removal/replacement operations. The free end of the appropriate clothesline (VC or VS) would be carried by EV2 to the VC or VT and attached to the clothesline bracket, the other end having been attached prior to launch. Each clothesline had two tether hooks for securing the film magazines. Both the VC and VS clotheslines were operable with one hand, were simple in design, and needed no special handling equipment other than the clothesline attach brackets.

No problems occurred with the clothesline or stowage box operation. However, the SL-4 crew had to be careful when ingressing the AM hatch at the end of the fourth EVA to prevent getting their umbilicals entangled around the deployed clothesline. No changes are recommended for future use.

k. VC and VS Clothesline Containers - Stowage containers were provided for the VC and VS clotheslines on the side of the FTB housing. The containers were made of anodized aluminum and fiberglass and had velcro fasteners to hold the cover closed. The clotheslines were installed in the container in such a way as to provide a slight resistance to deployment, so that as EV2 (carrying the free end of the clothesline) moved from the VF to either the VC or VT, a light tension was maintained which prevented entanglement.

No anomalies occurred with use of the clothesline container. Similar designs may be used on future EVA missions.

2. <u>ATM Center Workstation (VC)</u> - The VC provided the equipment necessary to accomplish the task of removal and replacement of the S052, S054, S056, and Hα1 film magazines. Specifically, this equipment included Rotation Control Panel 160, experiment access doors, a clothesline attach bracket, EVA lights, cameras and receptacles, a protective screen, handrails, an LSU clamp, and an EVA foot restraint, each of which is separately discussed below.

a. Rotation Control Panel (160) - Rotation Control Panel 160 provided the means for rotating the experiment canister to position each of the camera access doors at the Center Workstation. Panel 160 was also used to rotate the canister to the proper orientation for Sun End EVA operations. The S082A and B experiment aperture door switch and status indicators were used to open the S082A and B doors for VS operations. The control panel hand controller provided two speeds in each rotation direction. The handle had ±40 degrees of right or left motion with a maximum torque of 26 inch-pounds, and was compatible with pressure suit gloved-hand operation. In order for the translation from "Low" to "High" speeds to be obvious, a detent cam was used. The "Roll Enable/Inhibit" switch empowered a solenoid to release the mechanical brake on the roll drive and brake assembly when placed in the "Enable" position. The "Inhibit" switch position allowed the spring loaded brake to operate at 80 foot-pounds of break-out torque. Primary and secondary power switches were used to either enable or inhibit redundant electrical power busses. The S082A and B aperture door switch was a three position (center-off) momentary switch. A five watt light in the adjacent talkbacks displayed "Open" or "barber pole" by means of back lighting. During EVA operations the rotation control panel operated satisfactorily, and its use is recommended for future applications without modification.

b. VC EVA Lights - The five VC lights provided a minimum of five ft-lamberts of light. If one power bus had failed, sufficient light would still have been available if either of the two buses had become inoperable.

Lights at the VC were adequate for all crew operations and even provided enough illumination for good photographs at night (see VI.B.1.h for a detailed description of the EVA lights).

c. VC Protective Screen - The VC protective screen was made from sheet aluminum perforated with 1 in. holes and prevented contact between the ATM gimbal rings and canister launch lock arms and the crewman's legs and feet during canister rotation. A standard cross section handrail along the edge of the screen at waist level added to the complement of handholds at this workstation.

The screen kept the crewmen away from the canister roll ring and other canister-mounted equipment. No interference or significant loss of mobility due to the screen was evident for nominal EV operations (film retrieval). For one of the contingency operations, however, absence of this screen may have been preferable.

A screen is acceptable for separating the crewman from dangerous or delicate hardware. However, if this hardware has to be examined or serviced, the screen should be removable or hinged to provide access.

d. VC Clothesline Attach Bracket - The VC clothesline attach bracket incorporated the VC temporary stowage hook and was mounted on a boom located to the right of the VC. The boom was manually deployed from its launch position (where the clothesline attach point and temporary stowage hook were inaccessible) to any one of three deployed positions at the option of the crewman. This allowed the crewmen to optimize the clothesline and temporary stowage hook positions according to their height variations.

This bracket was deployed on SL-2. No problems occurred with its operation. The clothesline boom is acceptable for future use as designed. This is the attach bracket of choice, given compatible spacecraft structure.

e. VC Film Access Doors - There were five doors in the side of the canister. Four doors were provided for film retrieval by the crew during EVA from the Center Workstation. The fifth door was for ground access to the S055A experiment only. The canister was rotated into position using Rotation Control Panel 160. The doors were all manually operated and had no remote position indication. The S052 door was a double door with a latching mechanism on one side and a fixed handle on the other. All doors incorporated a launch lock mechanism, mechanical latch mechanism, door position indicator (white flag), magnetic latches, and rim seal. The door was opened by pushing the handle into a dust boot, which rotated a bellcrank and retracted two latch dogs. The mechanism included a spring loaded launch lock pin (in shear) to hold the latch dogs in the locked position. The launch lock release was a spring loaded D-handle which was actuated by pulling and folding the latch into a retention spring. The door had to be pulled open against magnetic latches at the top and bottom of the door. A friction device kept the door open, using the friction of a spring against a curved rod. When the door was opened, a spring loaded pin in the doors "Closed" indicator was released allowing the white flag to drop into the housing, out of view. With the door closed, the pin was depressed and the flag was made visible indicating "Door Closed". Pulling out the handle rotated the bell-crank in the opposite direction, forcing the latch pins outward into holes in the door sill.

All VC film access doors operated as expected with one exception. During SL-2, the mechanical latches on the S054 door would not engage, so the door was held closed by only the magnetic latches. When the SL-3 crew first used the door, however, the mechanical latches were reported to be engaged. All other door operations were nominal.

The film access doors were marginally acceptable. In the original door design, the magnetic latches were intended as the primary orbital door retention devices; the white flags serving only to indicate firm closure of the door. The latch dogs and push-pull handle operation were designed for launch retention only; the only orbital use being the first "push-to-unlock" operation on the first EVA.

When the capability of the magnetic latches to withstand docking transients was questioned later in the program, the latch was modified to permit re-use on-orbit but retained the "easy to unlock, but difficult to relock features inherent in the basic design.

Future programs might benefit from the following guidelines:

- Magnetic, or friction latches, may well be sufficient for orbital use depending on docking loads, etc.
- "First-line" mechanical latches, even if intended only for launch, should be designed for re-use as though intended for nominal orbital use.
- "Second-line" mechanical latches (lock-locks, launch pins, etc.), if required only for launch, may be designed for "one-time only" use.

f. VC Film Magazines and Receptacles - The film magazines which were used at the VC were the S052, S054, S056, and Hα1 magazines. Each film magazine could be mounted into the ATM canister receptacle with one hand, and each magazine/receptacle incorporated visual and tactile feedback of position and locked status. Such things as alignment stripes, flags, positive detents and end of travel hard-stops, were used in various combinations. Magazine/entry guides were included to provide a self-align function thus reducing the requirement for fine alignment on the part of the pressure suited crewman. Presence of these guides also served to prevent contact with more delicate portions of the experiments.

No problems occurred with installation of the film magazines into the experiment receptacles or with their removal after the film was used. All of the film magazines and receptacles are acceptable for future use.

g. VC Foot Restraint - The EVA foot restraint used at the VC was similar to the restraint used at the VF, and all earlier comments concerning the VF foot restraint apply also to the VC foot restraint. The individual boot restraints were identical; the alignment of each boot, however, positioned the crewman slightly counterclockwise (in roll) in order to center him for the leftward-biased movements required at the VC.

The foot restraints provided adequate crew restraint during all VC tasks.

h. VC Handrails - Handrails located at the VC include the solar panel back-up structure handrail, protective screen handrails, the outrigger hairpin handrail, and the lateral handrail. See VI. B. 1. d for a detailed description of the EVA handrails.

The handrails were adequate to provide crewman stability at the VC. Their use on future mission is recommended.

i. LSU Umbilical Clamp - An umbilical clamp identical to the one located at the VF was provided at the VC for umbilical management.

The VC LSU clamp operated adequately. One crewman did not use the LSU clamp at the VC, but encountered no entanglement problems.

3. <u>ATM Sun End (VS) and Transfer (VT) Workstations</u> - The VT was included as a part of the Sun End Workstation (VS) and contains no separate equipment, except for the standard EVA foot restraint. Since the VS is "around-the-corner" from the VF and therefore inaccessible to the boom, the VT served to bridge this gap by providing a position for acceptance of the Sun End film magazines. Prior to the Sun End film removal and replacement operations, EV2 ingressed the VT and received the loaded VS tree from EV1 via the Sun End boom. EV2 then placed the tree in a receptacle located on the ATM solar shield. The VT was also used for deployment of the VS clothesline attach bracket and clothesline during SL-4.

The VS was provided to support removal and replacement of the S082A and B film magazines at the ATM Sun End. Equipment located at the VS included the S082A and B experiment access doors, handrails, EVA lights, and the S082 film magazine temporary stowage container, the VS clothesline bracket, the VS foot restraint platform, and the S082A and B cameras and receptacles.

a. VT and VS EVA Lights - One EVA light was used at the VT and six were used at the VS. The lights are physically identical to those located at the VF and CC. See paragraph VI.B.1.h for a detailed description of the EVA lights and their on orbit operation.

b. Temporary Film Stowage Container - The S082A and B temporary stowage container was a box like unit with four flexible retaining flaps, and was used to secure the unexposed S082 film magazines while the exposed film magazines are removed from the experiment receptacle and placed in the S082 containers. The S082 containers were secured by the VS tree during VS film handling operations.

The S082A and B temporary stowage container was used with no problems. The temporary stowage box is simple, easy to use, and is an effective method of retaining packages temporarily. Its use is recommended for future application without modification.

c. VS Clothesline Attach Bracket - The VS clothesline attach bracket is a two part folding boom mounted on the solar shield. The boom was unlocked and deployed from the VT by releasing a pip-pin and swinging the boom into position where "one-time" latches held the boom in place.

During SL-4, the clothesline bracket was used to support the VS clothesline. The only problem noted was that of a "sticky" pip-pin holding the bracket in its launch position. This stickiness which yielded to presistent efforts, was probably due to a combination of close tolerance fit and an awkward position.

The VS clothesline boom operated satisfactorily and, except for the "sticky" launch lock pin, was easy to deploy. Although the weight and volume penalty paid for this particular hardware was severe, it must be operationally recommended as acceptable for future use, at least in the concept of a folding, deployable structure (see VC clothesline bracket, above). Its use is recommended on future missions.

d. S082A and B Film Access Doors - Film retrieval access doors were provided at the VS for S082A and B. These doors could be opened with one gloved hand, by rotating a handle with a mushroom shaped pushbutton lock-lock. Friction hinges held the doors at any desired point between the closed and open positions. The experiment Sun End aperture doors, which in their closed position covered the access doors, had to have been opened from Panel 160 at the VC before the film access doors could be opened and the S082 film magazines removed.

The S082A access door performed nominally. The S082B door also performed nominally until the second EVA of SL-3 when the crewman had difficulty pulling the door from the door well after unlocking. During the third SL-3 EVA the crewman had to place both knees on the canister surface and pull the handle with both hands to free the stuck door. The problem persisted throughout the other EVAs but did not prevent the crewmen from opening the door. During the SL-4 fourth EVA, the crewman had to place his hand inside the aperture opposite the hinge and pull the door open after exposure to the sunlight for several minutes. This procedure had been suggested to the crew after 1-G simulations had been performed. Possible explanations for the anomaly might be:

- Thermal warping of the door within the well
- Incomplete retraction of some of the four door latches (S082A had two)
- Adherence of the rubber door seal caused by environmental conditions.

The S082A and B doors are generally acceptable. Before they are used again, however, some precautions should be taken to prevent the sticking problem observed on the S082B. Either the hinge, latching mechanism, seal configuration, or a combination of these, should be modified prior to future use.

e. S082A and B Film Magazines and Receptacles - Each film magazine could be inserted into the ATM canister receptacle with one hand, and each magazine used flag indicators, detents, and hard stops for position and locking status. The magazines also provided alignment arrows where needed for alignment with the receptacle. As with the VC, receptacle alignment/insertion guides eliminated fine positioning requirements on the part of the crew.

The film magazines and receptacles are satisfactory, and they could be used on future missions without modification.

f. S082A and B Containers - The S082 containers were designed to provide thermal and contamination protection for the S082A and B film magazines. The film magazines were mounted in the containers, and the containers, in turn, were mounted on the VS tree. The operation of the container doors was similar to the VS access doors except that the handle rotation was 180 degrees instead of 90 degrees and the lock-lock was a finger tab rather than a push-button. As with other insertion/removal tasks, visual and tactile feedback was provided. Due to weight and volume requirements, however, alignment/insertion guides were not provided to the degree found elsewhere.

The film magazine containers operated satisfactorily. Their current design is sufficient to provide thermal and contamination protection to film or samples during EVA operations.

g. VT and VS Handrails - Handrails located at the VT and VS include the solar shield handrail and the VS handrail. All handrails were similar to those at the VF. See Section VI. B. 1. d for a description of EVA handrails and their on orbit operation.

h. VT and VS Foot Restraints - EVA foot restraints used at the VT and VS are identical to the one discussed for VF operations. (Section VI. B. 1.g). All comments concerning on orbit operation apply to the VT and VS foot restraints also.

i. VS Tree Receptacle/Tree - The VS tree receptacle was a sheet metal bracket designed to accept the latching mechanism on the base of the VS tree. The receptacle was identical to the VS tree receptacle located at the VF. All comments concerning operation and specifications of the VS tree and tree receptacle located at the VF are also applicable.

4. EVA Translation Path - Astronaut translation path hardware consisted of single handrails from the FAS Workstation (VF) to the ATM Center Workstation, with a dual rail "ladder" to the Sun End Workstation (VS). Each workstation was equipped with combinations of single handrails for ingress/egress and movement about the particular station. An EVA lighting system and umbilical clamps were included in the translation system. These hardware items are discussed below.

All translation path handrails used the standard Apollo cross section. Aluminum handrails were finished with blue anodize and all stainless steel handrails were painted blue.

EVA lighting illuminated the EVA translation paths to each workstation to approximately 1.0 ft-Lamberts. Workstations were generally illuminated with a 5.0 ft-Lambert level minimum. EVA lighting was provided as follows:

AM EVA lights - five (5)
DA EVA lights - six (6)
ATM EVA lights - fourteen (14)

Each light unit used an 18.75 watt incandescent lamp. The EVA lights were supplied by AM bus 1 and AM bus 2 through "EVA Lights 1" and "EVA Lights 2" circuit breakers on Panel 202. Control of all EVA lighting was provided on Panel 316 in the AM lock compartment by switches labeled "Lighting-EVA: AM, DA, and ATM". Switch commands were redundant. They provided AM bus 1 and AM bus 2 power to their respective lights in such a manner that loss of a single bus would disable only half of the lighting in a given area. All EVA lights except those at the DA were enclosed in a wire grid and contained a glare shield. The DA lights were enclosed in a metal box with a hole provided for directional lighting.

Two LSU clamps were located adjacent to the EVA hatch to facilitate life support umbilical management during EVA. The clamps was made up of two jaws: one fixed, the other movable. The movable jaw was spring loaded to maintain a slight clamping force on the LSU. When not in use, the spring, being over-centered, maintained the movable jaw in the "Open" position for easy insertion of the umbilical. In the event that the LSU experienced side loads due to a crewman's activity, the spring loaded jaw would open, freeing the LSU, and preventing possible LSU damage due to its restraint in the clamp. The LSU could also be manually released from the clamp. One LSU clamp is located in each ATM workstation.

All equipment along the EVA path was designed without sharp corners or edges which might damage the PGA in case of contact by the crewman. All ATM equipment drawings of hardware along the EVA path were evaluated to verify that EVA safety consideration had been reasonably satisfied, and that all drawings contained statements about the minimum radius of corners and edges, the finishing process used, the deburring of milled edges, and the potting or buffing of screw heads.

During EVA operations all translation route handrails were adequate for crew translation. Lighting was also sufficient, and the LSU clamps were adequate for umbilical management. This hardware may be used on future EVA missions without modification.

C. Solar Array System (SAS) Beam Deployment

Approximately 63 seconds after launch of Skylab 1 (SL-1) on May 14, 1973, the Orbital Workshop (OWS) Micrometeoroid Shield malfunctioned, resulting in the loss of essentially the complete Micrometeoroid Shield and the #2 SAS Wing Assembly. The #1 SAS Wing Assembly remained intact, although it was partially deployed and jammed. The loss of the Micrometeoroid Shield left the OWS without adequate thermal protection, while the loss of the #2 SAS Wing and minimal deployment of the #1 SAS Wing reduced the orbital assembly power capability by about 50%. After SL-1 orbit was attained and the anomaly had been investigated, an attempt was made to deploy the remaining SAS Wing Assembly (#1) from the ground, but this attempt failed.

In preparation for SL-2 launch, the primary area of concern was the development of a thermal shield capable of reducing the extreme temperatures inside Skylab. A parallel effort was also initiated to investigate feasible methods for the deployment of the #1 SAS Wing Assembly. This section describes the activities performed to develop the hardware and crew procedures necessary to deploy the SAS Wing.

1. Standup EVA (SEVA) From the Command Module - The primary concept for deploying the SAS Wing was to have the crewmen perform a stand-up EVA (SEVA) from the Command Module (CM). The development of hardware and crew procedures to perform this task and the on-orbit SEVA operations are discussed below.

2. Hardware/Procedures Development - Based on the assumption that there was debris of some sort keeping the SAS Wing from fully deploying, engineering personnel began developing tools for clearing away this debris. On a recommendation by McDonnell Douglas Astronautics Co., Eastern Division, the A. B. Chance Tool Company (of Centralia, Missouri), a manufacturer of tools for use on overhead transmission lines for utility companies, was contacted. On May 16, an engineer from Chance Tool Co. was flown to MSFC to demonstrate a number of tools that could be used for clearing debris from the remaining SAS Wing. After evaluation of the available tools, three tools were selected for the SL-2 SEVA. These were: cable cutters, sheet metal cutters, and a two-pronged universal tool. (The sheet metal cutters had to be fabricated by MSFC because there was no commercially available product of the desired size.) The tools were sent to JSC for further evaluation. Simultaneously, MSFC and JSC coordinated an effort to adapt these tools to the poles being designed for use with the MSFC Thermal Shield, i.e., adaptation of the tools/poles connection fittings, and handle and leverage mechanisms.

a. SAS Deployment Analysis - MSFC and JSC also jointly performed a detailed analysis of the problems associated with SAS deployment and how it should be attempted. Areas of concern were as follows:

- What types of debris were preventing the SAS Wing from deploying?
- Which of the tools selected would be best for specific cutting and prying jobs?
- What would be the most feasible approach angles for attempting to cut the debris?
- If the debris were removed, what might be expected as the result of SAS Wing dynamics?
- What hardware would be required for one-g and neutral buoyancy testing?

b. Cutting Tool Concepts - While these tools were being designed and developed, and the above areas of concern were being investigated, two cutting tool concepts were sent to MSFC by Martin-Marietta Aerospace Corporation. One of these concepts was a nibbling tool adapter to the Lunar Drill, and the other was a concept for a pair of manual cutting shears. Because of the size, weight and time restrictions for SL-2 launch, these ideas were not given serious consideration.

c. Bench Review and Delivery of Selected Tools - Tool and adapter fabrication, along with the MSFC Twin Pole Sail fabrication, were completed on May 22, 1973. A combined Bench Review, Crew Compartment Fit and Function (C^2F^2) and one-g training session were conducted that same day at MSFC, attended by the SL-2 prime crew. Included in this review were the tools supplied by JSC, including a "shepherd's hook" for pulling on the aft end of the SAS Beam, and a "mushroom" fitting for the proximal end of the tool poles. The OWS mission support mockup was used during the training session. A prototype SAS Wing assembly had also been fabricated to simulate the envelope and the bending characteristics of the actual beam fairing assembly. The following day, May 23, the MSFC Twin Pole Sail, and the MSFC and JSC Solar Array System Wing deployment tools were shipped to Kennedy Space Center for SL-2 Command Module stowage.

3. <u>On-Orbit Operations</u> - On May 25, SL-2 was launched with three shield concepts and the SAS Wing deployment tools. The decision had been made, prior to launch, that Solar Array System deployment would be attempted by Command Module stand-up EVA (SEVA) if the Commander deemed it feasible.

a. Damage Inspection - Upon rendezvous with the Skylab cluster, a fly-around inspection of the Orbital Workshop was conducted. The following is a summary of the crew's comments based on their initial damage inspection:

- #1 SAS Wing looked good and appeared to be deployed about 15 degrees.
- Nothing was left of the #2 SAS Wing except some protruding tubes and wires.
- The vent module covers on the #1 SAS Wing were still intact.

- The remaining portion of the Meteoroid Shield was pushed under the SAS Beam and wrapped slightly around the edge of the beam from the underside.
- There was a "strap" that looked like it contained a row of bolts which had wrapped over the edge of the beam fairing.

After the fly-around inspection, the crew soft docked to the Multiple Docking Adapter (MDA). A review of the fly-around TV transmission was then conducted at MSFC and JSC to determine the best approach for attempting deployment of the remaining SAS Wing. Based on this reivew, it was felt that the piece of metal bent over the SAS Wing fairing was a piece of angle, which the crew would probably not be able to cut but would have to bend in order to free the wing. It was recommended that the tools be configured as follows:

- One pole with the shepherd's hook
- One pole with the cable cutter
- One pole with the mushroom and tether

b. Initial Deployment Attempt - During the SEVA, the crew first attempted to lift the end of the SAS Wing fairing using the pole with the shepherd's hook. This was unsuccessful, so they maneuvered the CM to a stationkeeping position next to the SAS Wing where the piece of debris strap was wrapped over the beam fairing. Using the two-pronged universal tool, the crew attempted to pry the strap away from the beam fairing; however, after several attempts, this also proved to be unsuccessful. Summarizing these SEVA attempts, it was determined that the piece of metal wrapped around the fairing was only about 1/2-in. wide, but the screws in it seemed to be "riveted" into the SAS Beam fairing with such force that they could not remove the strap with the available tools. Because they were losing daylight, the crew was forced to abandon the deployment effort and dock with the MDA to prepare for entry into the Orbital Workshop.

c. Crew Debriefing - Several days after the SEVA, a conference was held with the crew. This conference was held to further define the debris strap and configuration of the SAS Wing. The most significant items discussed by the crew included the following:

- The end of the debris strap was firmly attached on top of the SAS Beam with what appeared to be a row of bolts in the strap. These bolts seemed to be cutting into the beam skin.
- The debris strap was bowed out along the side of the beam two to three inches.
- Debris from the Micrometeoroid Shield was visible under the SAS Wing.

Based upon the data received from this discussion with the crew, a neutral buoyancy mockup of the #1 SAS Wing Assembly was prepared and is illustrated in Figures 168 and 169.

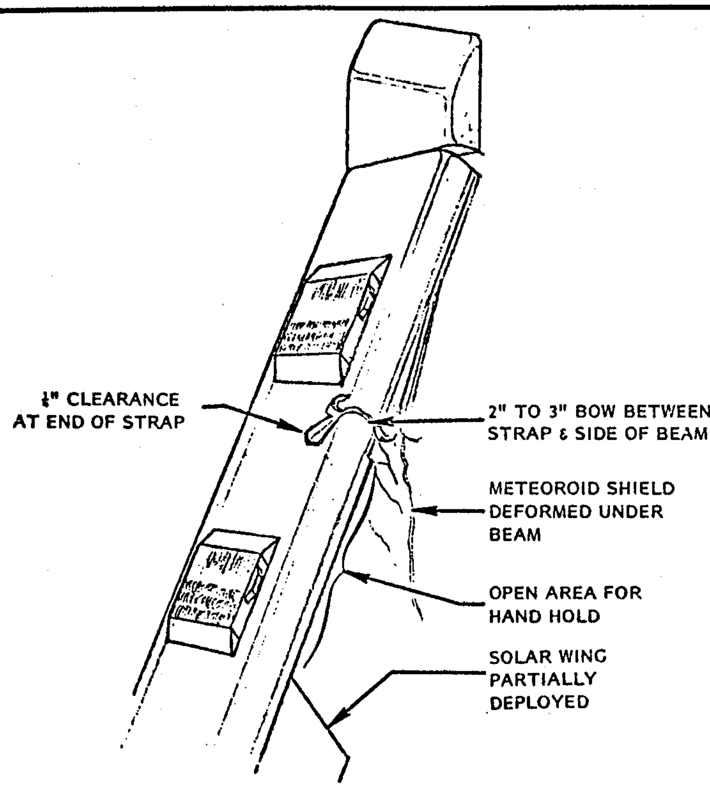


Figure 168. SAS Beam and Debris Strap

4. EVA From the Airlock Module - After the unsuccessful attempt to deploy the #1 SAS Wing by means of the SEVA, the Crew Systems Mission Support Group began developing a method of freeing the wing during an EVA from the nominal Airlock Module EVA hatch. This procedures development activity was predicated on two assumptions: (1) the aluminum angle strap was the only debris preventing the SAS Wing from being deployed, and (2) on board tools would be sufficient to cut the strap or pry it loose. The sections below describe the hardware and procedures developed for this task and the EVA operations performed to deploy the SAS Beam.

5. Hardware/Procedures Development - The paragraphs below describe the activities that occurred from the inital definition of the problem through the selection of tools and development of crew procedures for the beam deployment EVA.

a. Description of the Deployment Problem - It was determined by review of flight hardware drawings that the strap described by the crew was probably a section of the micrometeoroid Shield composed of two pieces of aluminum angle and an extrusion (Figure 170). By using the fly-around video tape and the Skylab Mission Support Mockup, this strap was determined to be approximately 25 ft. below the top of the FAS and 1-1/2 ft. below the first vent module (Figure 171). For the SAS beam to be erected, this strap would have to be either cut or pried away from the beam skin.

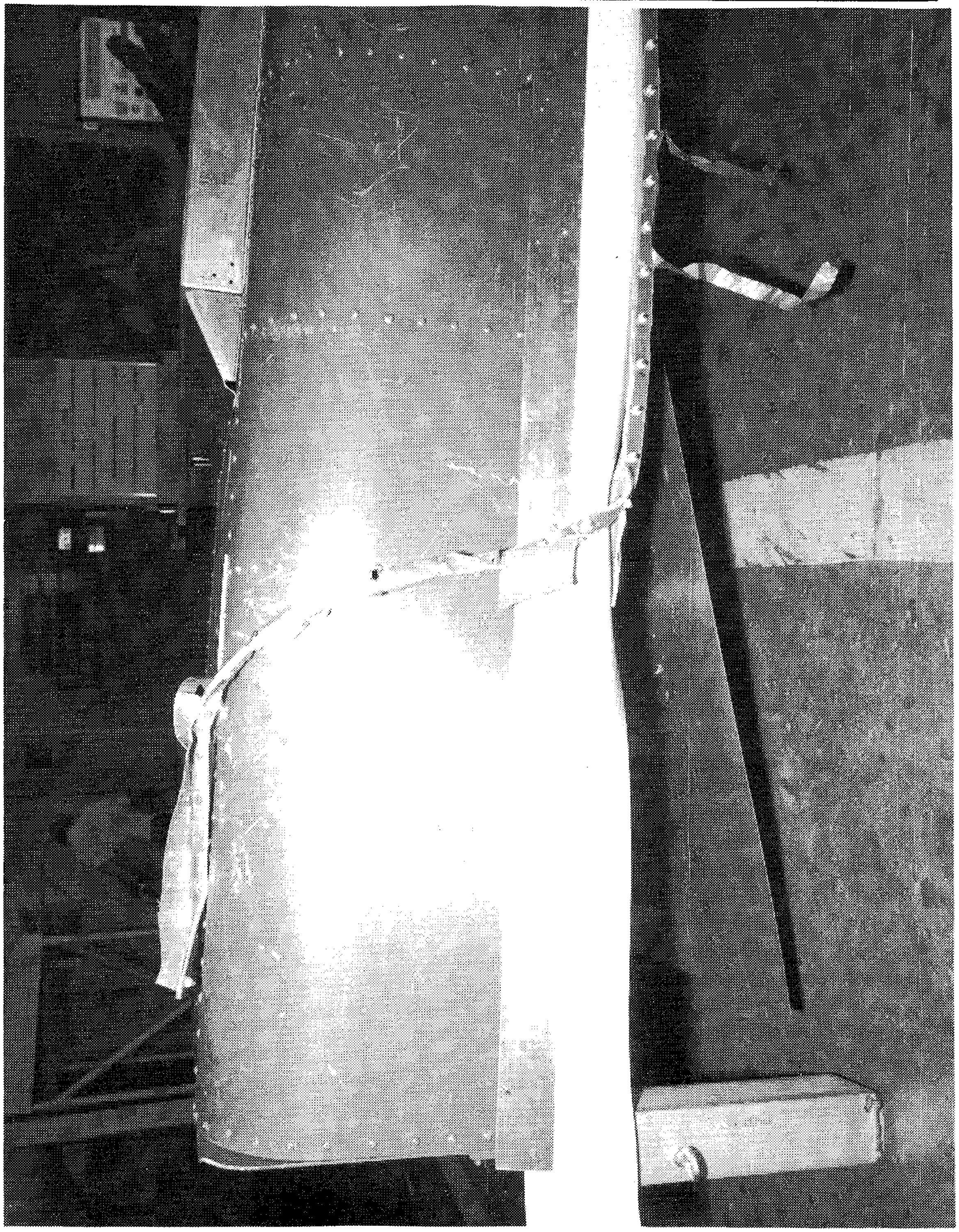


Figure 169. SAS Beam Neutral Buoyancy Mockup

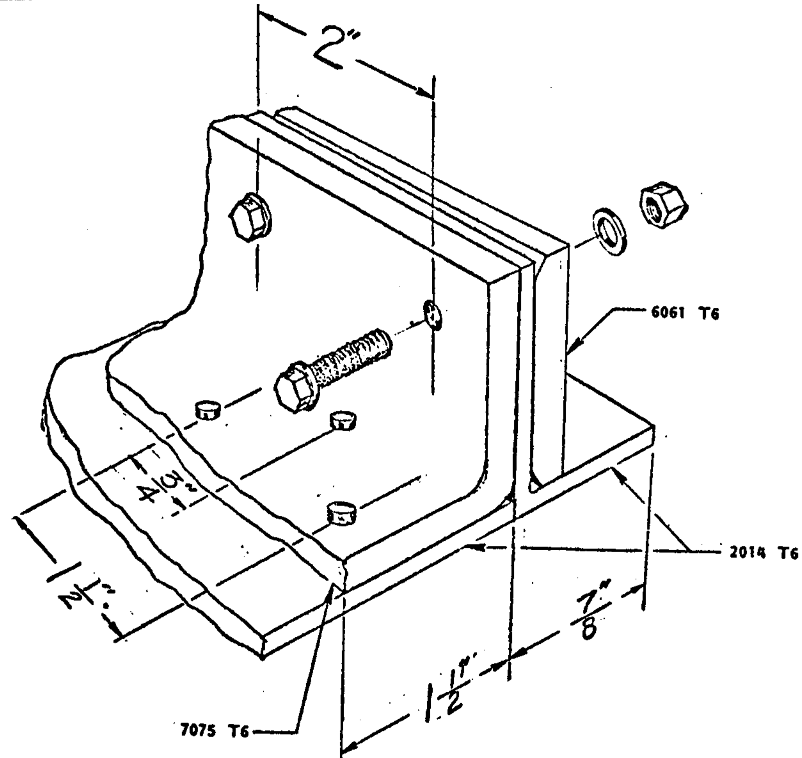


Figure 170. Debris Strap Cross Section

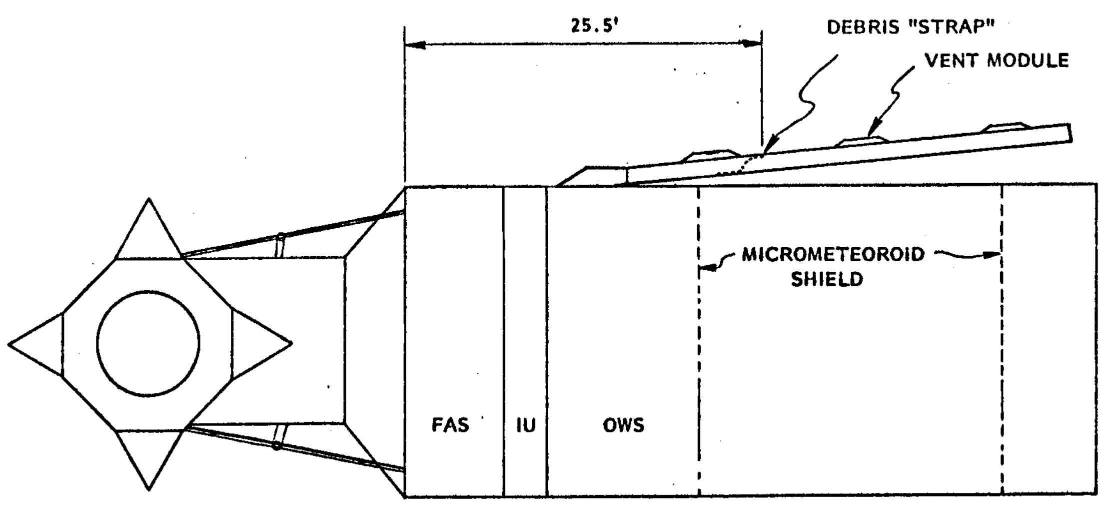


Figure 171. SAS Beam Configuration After Launch

It was also predicted that if the strap were removed, the SAS beam would rise approximately two feet at that point on the beam and would then stop because of frozen oil in the damper/actuator. The beam would then have to be pulled up with a force of approximately 15 lbs. (measured at beam end) to break the damper/actuator mounting bracket in the beam hinge mechanism.

From the definition of the overall problem, it became obvious that four separate problem areas would have to be addressed:

- Translating one or two crewman to the FAS area above the SAS beam and possibly translating one crewman to the debris strap
- Restraining a crewman at the FAS above the beam and possibly restraining a crewman in the strap area
- Cutting the strap or prying it loose
- Pulling the beam to an erect position

In order to study the SAS wing problem more accurately, the back-up SAS Wing was shipped from TRW to MSFC. A review of this wing was conducted on June 2, 1973. It was learned that what were thought to have been scratch marks on the top of the beam caused by the debris strap were actually two rows of bolts. Also, two bend-relief holes were found on the base of the vent module. These relief holes were later selected as tether attach points for manual beam deployment.

b. Identification of Candidate Deployment Hardware and Procedures - The four problems identified above are discussed in this section along with hardware proposed for their solution.

(1) Crew Translation and Restraint - Two methods of translating to the FAS area above the SAS Beam were identified. These were: 1) translation over the ATM Deployment Assembly and around the top of the FAS to the discone antenna boom, and 2) translation through the AM trusses to the antenna boom. The latter appeared more advantageous, because several handrails and other equipment would be available for use as translation aids.

Several methods of translating from the FAS ring to the debris strap were identified, all of which involved using some type of handrail from the discone antenna boom area to the strap. These translation methods included:

(a) Attaching four sections of the OWS fireman's pole (21-ft.) to the FAS ring with C-clamps or tethers. The crewman could translate to the strap area and use a set of EVA foot restraints which had been taped to the EREP foot restraint grid mounted to the strap end of the fireman's pole.

(b) Translating a fully extended FTB (30-ft.) from the VF to the FAS above the strap, and attaching the FTB motor end to the FAS ring. The crewman could then use the FTB as a handrail to aid him in translating to the strap.

(c) Assembling three SEVA tool poles and two spare MSFC sail poles (27-ft.) at the VF with the cable cutter on one end and the mushroom on the other end, and then translating to the discone atenna area. The crewman could hook the cable cutter snugly on the strap and use the pole as a handrail while he translated to the strap, with the other crewman holding the mushroom end.

Methods for restraining the EVA crewmen at the FAS ring and at the debris strap also had to be developed. The crew restraint methods identified for the FAS ring area were:

(a) Holding the discone antenna with one hand while placing the feet against the O_2 bottles

(b) Using the OWS N_2 purge line at the FAS ring as a handhold while placing the feet on the FAS ring

(c) Attaching the OWS EVA foot restraints at the FAS ring with C-clamps and using this as the only restraint

The first and second options had the advantage of requiring no equipment setup. The first also had the advantage of being directly above the strap on the SAS Beam. The third option would offer better restraint but would require a difficult setup task.

The problem of restraining a crewman at the SAS Beam appeared to be a more serious problem because of the possibility of sharp edges on the debris strap and on the remaining section of Micrometeoroid Shield. The problem solution was also hampered by the fact that there was no equipment on the SAS Beam that could be used as a handhold or foot restraint. Therefore, any crew restraint would have to be extended by the crewman at the FAS.

The restraint methods proposed for solution of this problem included:

(a) Use of the translation aid from the FAS ring to the SAS Beam strap as a handhold at the strap area. This translation aid could be the fireman's pole, extended FTB, or SEVA tool poles and sail poles. The last option had the advantage of being attached at the strap end by mounting the cable cutter to a SEVA tool pole and then securing the cable cutter around the debris strap.

(b) Attachment of the OWS EVA foot restraint to the fireman's pole and letting the crewman at the debris strap use it as a single stability aid. This method would allow use of both hands, but it had the disadvantage of requiring ingress of the foot restraint with no handholds. Second, it would require the EVA crewman at the FAS ring to manage the fireman's pole with extreme care, and, finally, the fireman's pole was only 21-ft. long, while the debris strap was 25-ft. below the FAS ring.

(2) Debris Strap Cutting/Prying Tools - Four onboard tools were identified for cutting the debris strap or prying it loose. These included the SEVA cable cutter, the dental kit bone saw, the pry bar, and the SEVA universal tool.

(a) Cable Cutter - The cable cutter (Figure 172) had several significant points in its favor. First, it could be attached to the debris strap by a crewman at the FAS, thus allowing the other crewman to use the SEVA tool poles and sail poles as a translation aid attached at both ends. Second, the tool had a high shear cutting force and could probably cut through the strap. Third, the cutter could be operated remotely by one or two crewmen at the FAS ring.

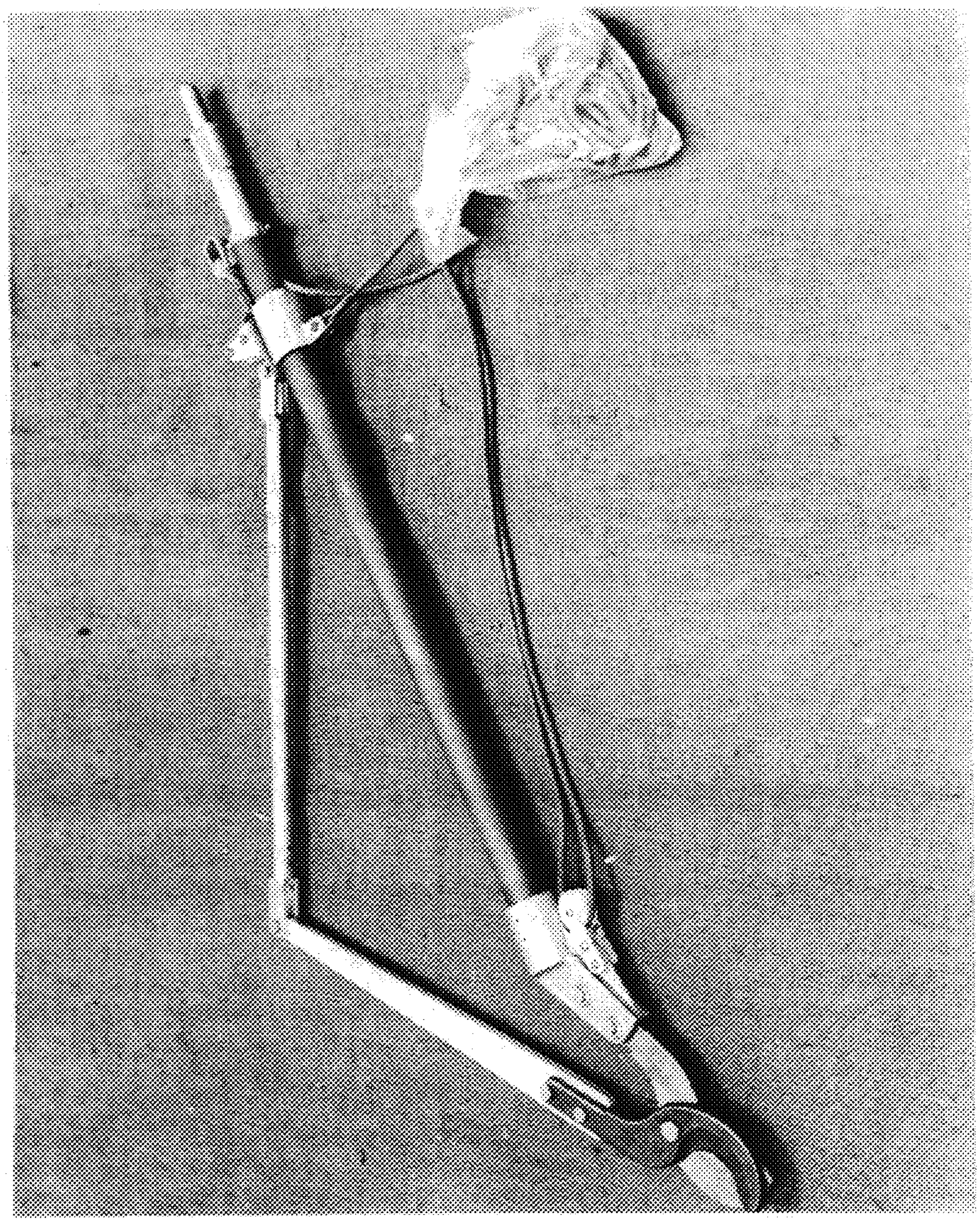


Figure 172. Cable Cutter

(b) Pry Bar - The pry bar had the advantages of being simple to use, small, easily carried by a crewman, and operable one handed. However, the crewman would have to work very close to the strap and other debris, thereby exposing his PGA to any sharp edges that might be present. Also, if the bolts in the strap were sufficiently embedded into the SAS Beam skin, the crewman might not be able to generate enough force to move the strap. The strap also might spring back into the SAS solar panels after being pried from the beam.

(c) Bone Saw - The dental kit bone saw, a flexible length of wire with rings at each end and cutting teeth bonded along the wire surface, had the advantage of being small and easy to carry. In addition, it was found to be a good cutting tool, provided that the crewman could be restrained sufficiently. The bone saw could be used with the crewman's thumbs in the rings at each end, or it could be mounted between two standoffs on a pole and used as a hand saw.

(d) Universal Tool - The universal tool (Figure 173) could be mounted on the end of the SEVA tool poles (3) and twin sail poles (2) and could be used by the crewman at the FAS to grasp the debris strap and pull it loose. However, this method did not work during the SEVA and probably would not be successful during another EVA.

(e) Urine Separator Saw - Another concept evaluated was the electric motor from the urine separator adapted to a flattened M512 sample disc with edges filed and shaped into saw teeth. This modified tool was found to be capable of cutting the metal strap retaining the SAS Wing, but it would require electrical power. In the light of the availability of other cutting devices (bone saw, cable cutter) it was not given serious consideration beyond this point.

(3) Manual SAS Beam Deployment Methods - Two primary methods of deploying the SAS Beam after the strap was cut were identified. These involved: 1) pulling the beam up with a tension line, or 2) forcing the beam up by placing an OWS washcloth squeezer bag under the beam and inflating it with the portable H_2O tank (filled with N_2). These methods are discussed below.

(a) Use of a Tension Line - This method of deploying the SAS Beam involved very little hardware and procedural complexity. This method is described in the steps below:

- Prepare tension line and two waist tethers as shown in Figure 174 (IVA operation).
- Affix end of line to A-frame crossmember above discone antenna boom area.
- Translate to first vent module on SAS Beam.
- Install two waist tether hooks into relief holes in bottom of vent module (Figure 175).
- Pull line snug at A-frame end using the cleat on the apex hook (Figure 174).
- Place feet on SAS Beam forward fairing (near hinge) and lift line until damper bracket breaks and beam deploys (Figure 176).

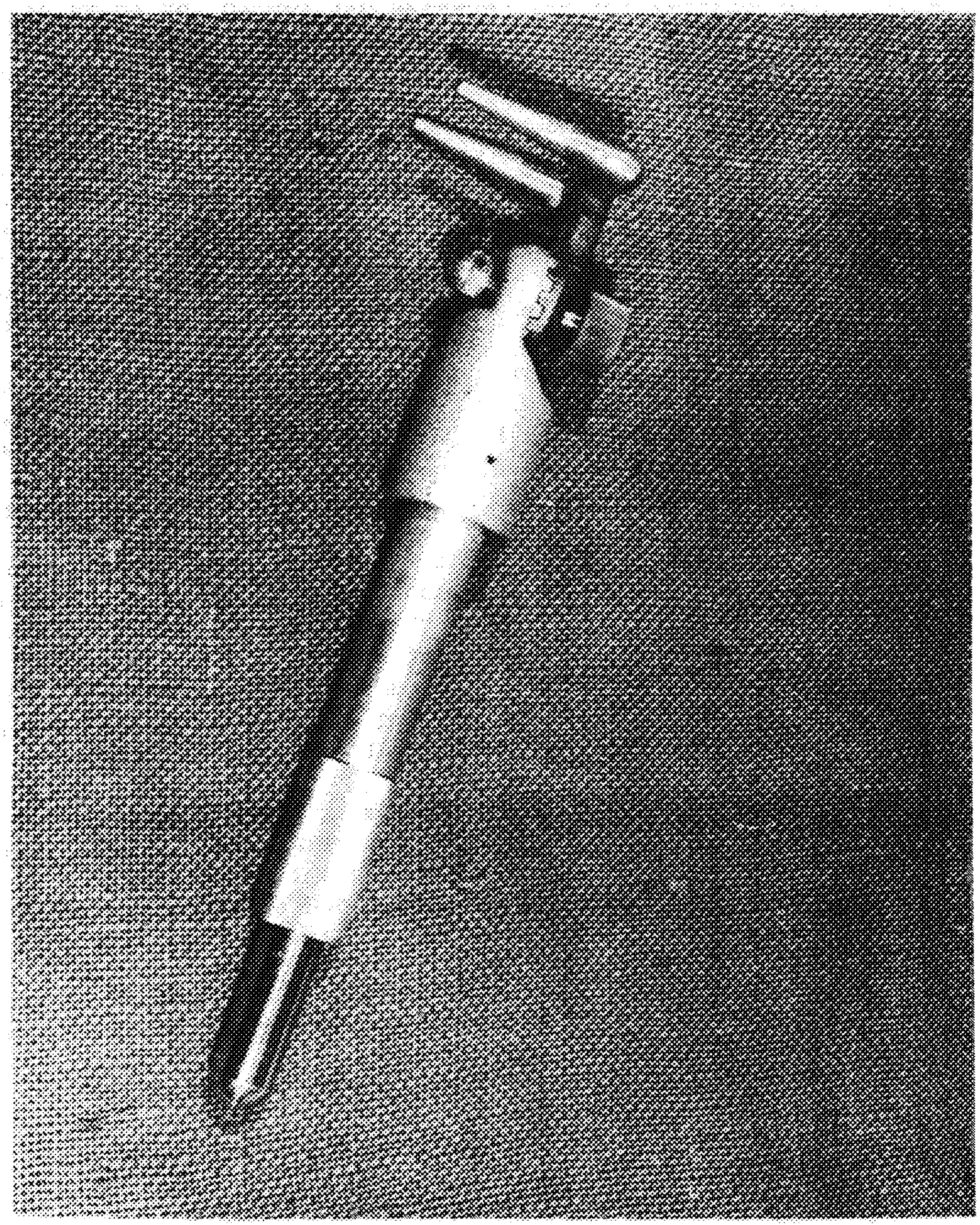


Figure 173. Universal Tool

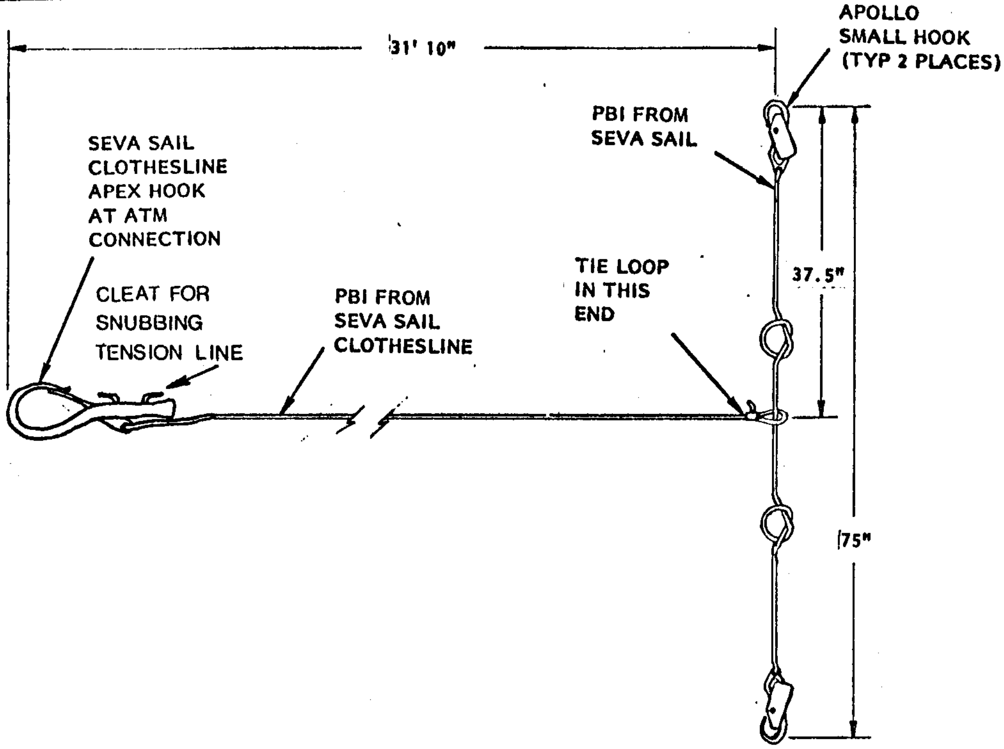


Figure 174. SAS Deployment Tether/Harness - Part of EVA Prep

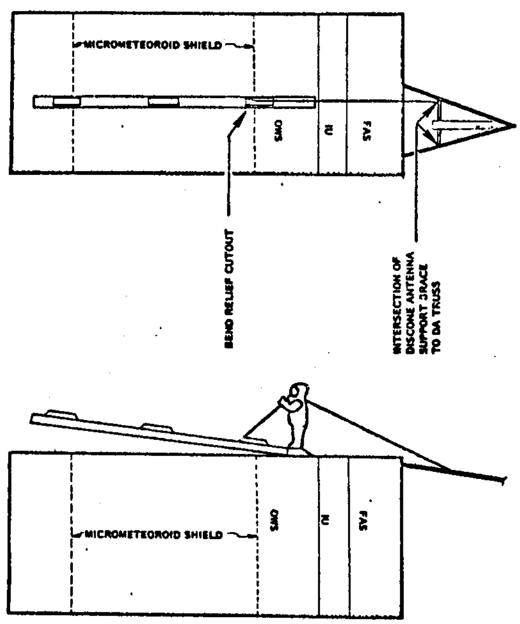


Figure 176. SAS Beam Deployment Configuration

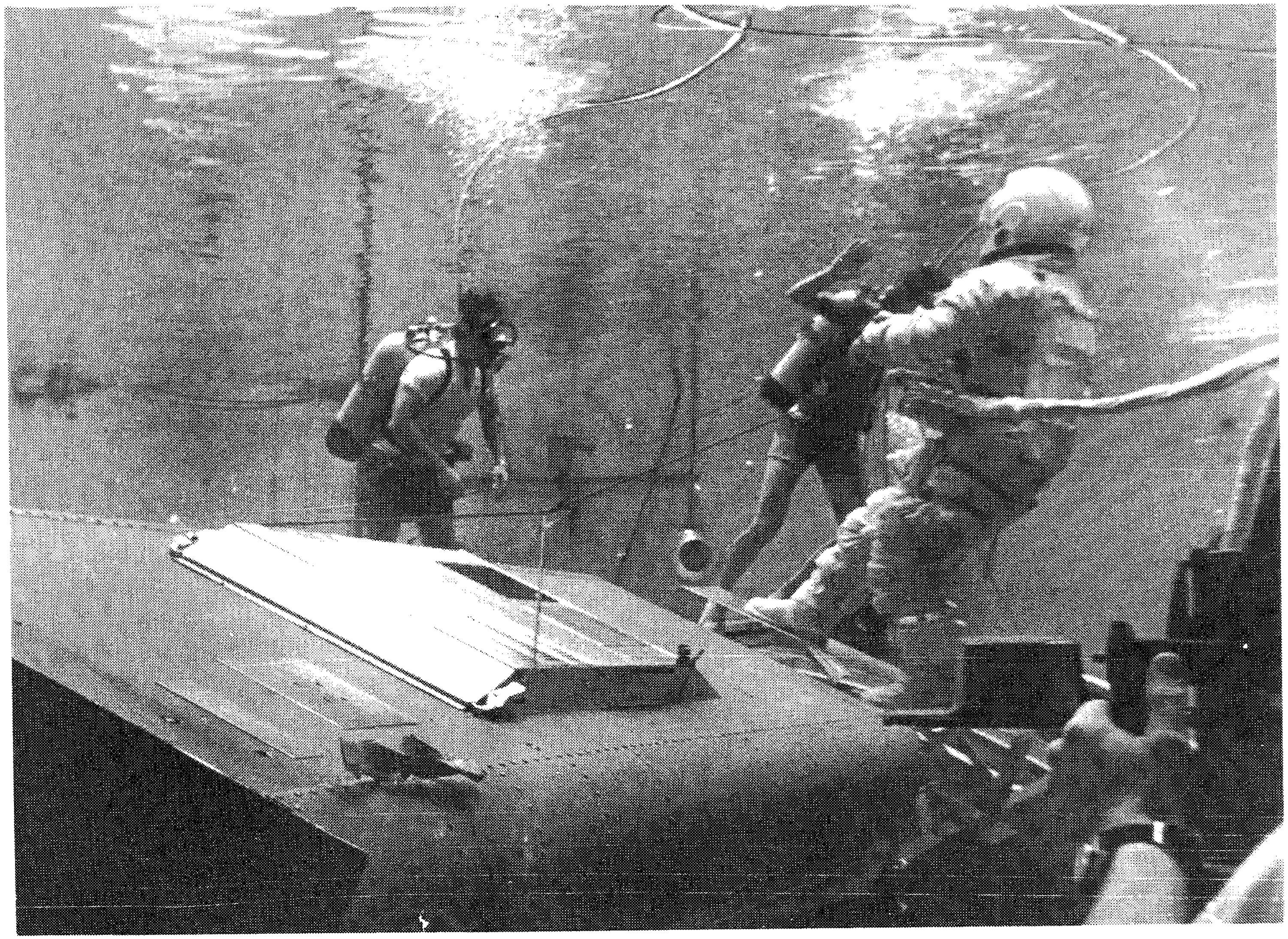


Figure 175. SAS Beam With Hooks Installed in Vent Module Relief Holes

(b) Use of OWS Squeezer Bag - A second method of deploying the SAS Beam involved using the OWS washcloth squeezer bag inflated with nitrogen from the portable water tank. This involved the IVA tasks of pressurizing the gas side of the portable water tank to 35 psia from the pressure panel on the water bottle ring in the OWS and attaching the 25 ft. condensate dump hose and the 15 ft. condensate tank vacuum hose between the squeezer bag and the water tank. The EVA procedures necessary to deploy the SAS Beam by this method included:

- Install folded bag under SAS Beam near hinge; retreat to FAS ring.
- Crack valve on water tank to pressurize bag.
- Observe SAS movement and close valve as soon as release is assured.

The squeezer was tested and found to be capable of exerting enough force to break the damper bracket and deploy the SAS Beam. However, it involved complex crew procedures and detailed equipment setup.

c. SAS Wing Deployment Test Program

(1) Neutral Buoyancy Testing - The first neutral buoyancy test run was made on May 29, 1973, to evaluate the two candidate translation routes and to verify the distance to the SAS debris area using the three tool poles and two sail poles with the cable cutters attached.

The second neutral buoyancy run was made on May 30, 1973, using the SEVA hook, cable cutters and the same five pole sections. The cable cutters were determined to be a good method of restraining the pole at the debris strap. The other end could also be restrained with a tether to the discone antenna bracket. The discone antenna boom provided a restraint for a suited subject with his waist tether attached to the antenna bracket. The run went well; more study was required, however, on tool/equipment transfer from the nominal EVA FAS work area to the discone antenna area.

On May 31, 1973, two neutral buoyancy runs were performed to evaluate crew translation and restraint and strap cutting methods. Two FAS work areas were studied: the N_2 Purge Line (upper EVA Bay) and the discone antenna area. The discone antenna work area proved more feasible. A flight bone saw was used to cut the debris strap in approximately three minutes. Restraint of the crewman at the SAS work area and hardware logistics presented the biggest problems.

During the debriefing it was decided that the particular method for removing the debris strap should be left to the real-time judgment of the SL-2 crew (pry bar, cable cutters or bone saw). It was also suggested that the crew translate under the DA trusses from the VF to the discone antenna over the thermal capacitor using the Molecular Sieve duct for a handrail, and then using one of the two manual deployment methods for deploying the SAS Beam if the damper/actuator was frozen.

Another neutral buoyancy run was conducted on June 1, 1973, to study various debris removal tools and the manual SAS Beam deployment method.

On June 2, the neutral buoyancy SAS simulation hardware was reconfigured based on information received from the crew debriefing on June 1, and on review of the flight back-up SAS (shipped to MSFC from TRW).

An EVA Hardware/Equipment Bench Review and EVA prep was also held at the Neutral Buoyancy Simulator. A suited simulation run was made that afternoon with two Skylab crewmen as subjects. Preliminary EVA crew procedures were used, and translation of crewmen and equipment went much more smoothly. The cable cutters with five pole segments and mushroom head were then the prime method for translating the SAS work area. Cable cutters were attached to the debris strap and the mushroom end was tethered to the discone antenna bracket at the FAS work area. It was noted that more work was needed on methods of crew restraint and EVA preparation. Total EVA time was approximately 2 hours, 25 minutes.

On June 3, 1973, another bench review was held with the Skylab crewmen doing their own EVA preparation, subsequent to which the final neutral buoyancy simulation run was made using near final EVA procedures. The suited run went smoothly. Equipment and hardware transfer was well executed. The crew debriefing on June 1, and review of the flight backup SAS Wing provided data that was used to develop better crew restraints at the debris strap work area. Attaching the cable cutters to the debris strap was successful on the second attempt. The crewman tethered himself to the cutting pole with a chest tether during translation while taking the PBI tether (BET) which he attached to the two aft corners of the vent module (bend-relief cutouts). The other end was attached to the discone antenna launch support truss on the deployment assembly. The crewman's chest tether, attached to the cutter pole, provided adequate restraint during translation. Restraint at the work area was provided by the waist tether remaining attached to the cutting pole and using the BET as a handhold after being attached to the relief cutouts in the aft corners of the vent module. The three debris removal tools (cable cutters, pry bar and bone saw) were used, and it was decided that the tool chosen for debris removal would be a real-time option of the SL-2 crew.

(2) One-g Testing - On June 1, 1973, a SAS Beam deployment test was conducted to verify that a crewman could exert enough force on a tension line to break the deployment bracket in the beam hinge. The SAS Beam mockup was held by a support stand on the hinge end and by a counterbalance/pulley system on the other (Figure 177). A tension line, fabricated of SEVA clothesline (PBI), was attached to the vent module and a fixed point that simulated the discone antenna launch tray. A load cell was mounted in the line to record the tension.

During the test, the bracket broke at 167 lbs of tension which was lower than the maximum tension (309 lbs) that the suited crewman could generate.

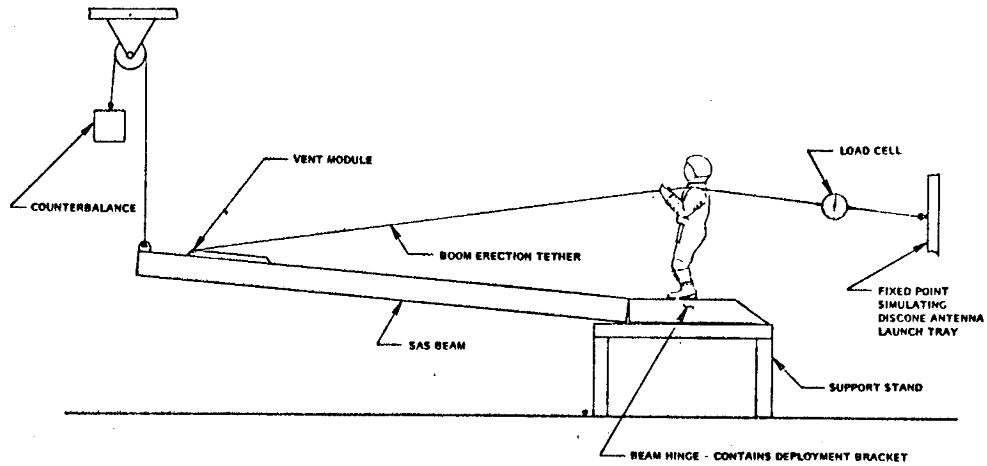


Figure 177. One-g SAS Beam Deployment Test Setup

Additional tensile strength tests were performed on the two tethers being considered for use as the tension line. The OWS Adjustable Tether (fireman's pole tether) broke at 240 lbs. The SEVA sail line (PBI) broke at 375 lbs. Therefore, the PBI was selected as the Beam Erection Tether (BET).

(3) Tool/Procedures Selection - As a result of the one-g and neutral buoyancy testing, a set of tools and crew procedures was selected for deployment of the jammed SAS Wing. The best translation route from the VF to the FAS ring above the Solar Array System Wing was determined to be through the AM trusses. The discone antenna boom was also found to be the best crew restraint at the FAS ring. The five pole sections were selected as a translation device with the mushroom mounted at one end and the cable cutter attached to the debris strap at the other end. The best strap cutting tool was judged to be the cable cutter, although the bone saw and pry bar would also be taken. The SAS Beam deployment method selected was to have the crewmen: 1) fabricate (as part of EVA Prep) a tether from SEVA sail line, the SEVA hook, and Apollo wrist tether hooks, 2) attach the tether at the SAS Beam vent module and discone antenna launch bracket, and 3) position himself on the SAS forward fairing and lift the tether.

6. <u>On-Orbit Operations</u> - The primary purpose of the first EVA from the Airlock Module was deployment of the SAS Wing, as described below.

SAS Beam deployment was accomplished with very little deviation from the procedure sent to the crew. Equipment setup (IVA) and pole assembly (EVA) were performed without any problems or changes to the recommended procedures. Translation to the discone antenna boom also presented no problems. Attachment of the cable cutter to the debris strap was difficult and required several attempts. However, this had been expected due to the similar difficulty encountered during the neutral buoyancy tests. The Commander translated to the debris strap area, and attached one BET hook to the vent module relief hole with moderate difficulty. He was unable to attach the second hook. In anticipation of this problem, "figure-eight" knits had been tied in the harness portion of the BET on either side of the loop forming the end of the main tether (see Figure 174). This eliminated the requirement to have both tether hooks attached to the vent module. He then returned to the FAS area.

Cutting the debris strap with the cable cutter provided some exciting moments. With both crewmen at the FAS, the Science Pilot attempted to pull the cable cutter rope to cut the debris strap. After several pulls, the cutter jaws appeared to be spreading without cutting the strap. The Commander, therefore, decided to translate to the debris strap to examine the cutter jaws. Upon his reaching the cutter scissors mechanism, however, the cutter severed the strap. When this occurred, the cutter came free from the strap; the SAS Beam came up about two feet, and the BET became slack. This obviously resulted in an unstable restraint situation for the Commander. He, therefore, grabbed the BET and pulled himself to the FAS while performing "whifferdills" along the way. Although this particular operation was not anticipated, it did not result in damage to the crewmen or hardware, but it did prevent the crewmen from observing the initial SAS Beam release.

The crewmen pulled the slack from the Beam Erection Tether (BET), and attempted to pull the SAS Beam up by pulling on the BET from the FAS. When this was unsuccessful, the Commander translated to the SAS Beam hinge and lifted the BET to his shoulder facing the FAS. At this point, the Science Pilot was also pulling the BET from the FAS. When both crewmen were applying significant force to the BET, the beam released causing slack in the BET. As both were using the BET for a restraint, this resulted in another unstable restraint condition. This was no serious problem, however, and they were soon restrained at the discone antenna boom area, but without benefit of having observed the beam deployment.

The return to the VF and disassembly and stowage of the SAS deployment hardware in the Airlock Module went according to the procedures with no difficulty.

Because this EVA is obviously not planned for other Skylab missions, the crew did not comment on improvements that could be made to the SAS Beam deployment equipment or procedures. They did, however, recommend a change in the EVA checklist regarding the Airlock Module fire sensors. When the sun shone in the AM aft lock compartment, the fire sensors were activated. This caused serious concern to the Pilot during the EVA. Therefore, the crew recommended that these sensors be deactiviated during future EVAs.

D. Twin Pole Sail Deployment

1. Concepts for Orbital Workshop Thermal Shielding - On May 15, 1973, soon after the failure of the Skylab 1 Micrometeoroid/Thermal Shield, efforts were made to devise a method to shield the OWS from the intense heat generated by the sun's rays in this area. Marshall Space Flight Center, other NASA centers, and private contractors began developing candidate concepts to repair the vehicle. All concepts proposed used some type of thermal covering structured to cover the exposed area and lower the temperature that was making the Orbital Workshop uninhabitable.

Many concepts for deploying the shield necessary to insulate the Orbital Workshop from the sun's rays were presented to NASA as possible solutions to the problem affecting Skylab. All possible shielding methods were evaluated closely and compared to the constraints and requirements (e.g., storage volume, weight, ease of installation) needed to remedy the problems.

The concept selected and pursued by MSFC, entitled the Twin Pole Sail, is described in this report. This concept utilized a covering of aluminized mylar coated with S-13g paint. The deployment assembly for this concept consisted of a simple mounting bracket "base plate" which attached to the ATM A-frame (Figure 178). Eleven interlocking poles, each 5-ft. in length were joined to make each of two 55-ft. sections, and inserted in the base plate. The two 55-ft. sections stretched down the OWS to hold the thermal shield. The 22 X 24-ft. thermal sail (packed much as a large cargo parachute was packed in a retaining bag) was unfurled by attaching the forward edge of the sail to a clothesline ring on each pole. Next, the sail was hoisted by drawing the clothesline until the forward edge of the sail was butted against the far end of the extended poles. The trailing edge of the sail, with attached reefing lines, was stretched and tied tautly to the ATM outrigger where the Payload Shroud attach fitting was located. The sail was adjusted to the proper elevation for clearance of the existing parasol. This sytem was installed during the first EVA of SL-3 to backup the parasol system.

Contained in the following sections of this report are specific descriptions of the stages of design, development, and crew/system evaluation involved in the overall development and implementation of the twin pole sail concept in the Skylab Program.

2. Twin Pole Sail Hardware Design and Description - Soon after the twin pole sail had been selected as the MSFC concept, the major elements were designed and modified as concurrent real-time simulation and evaluations were conducted. The evaluations were carried out by MSFC, JSC Crew Systems personnel, and both prime and back-up crew members. Described below are the equipment elements which make up the total twin pole sail assembly.

a. Base Plate Assembly, 10M22055 - The base plate assembly, shown in Figure 179, consisted of an aluminum plate with two adjustable receptacles which were designed to hold the supporting poles, and

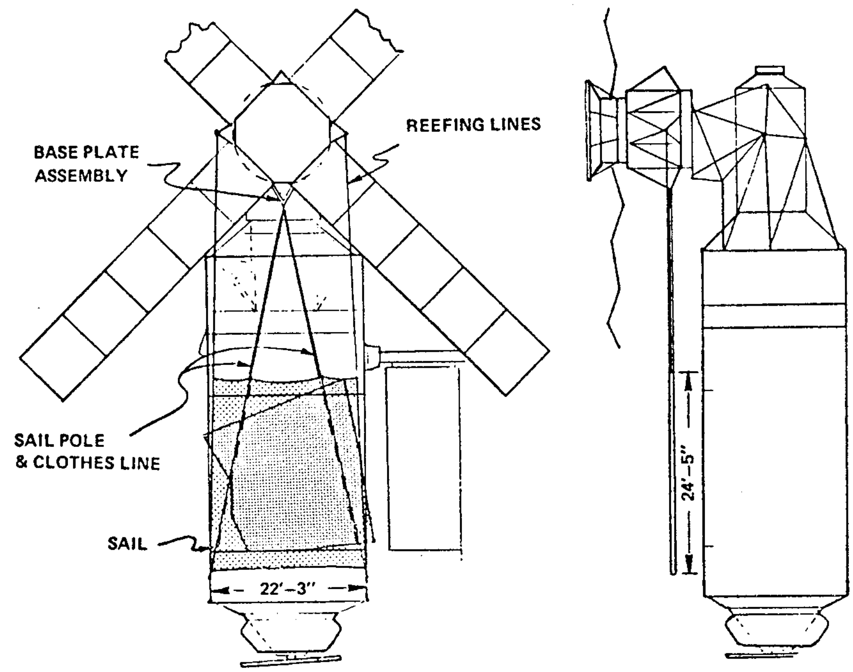


Figure 178. Thermal Shield Deployment Configuration

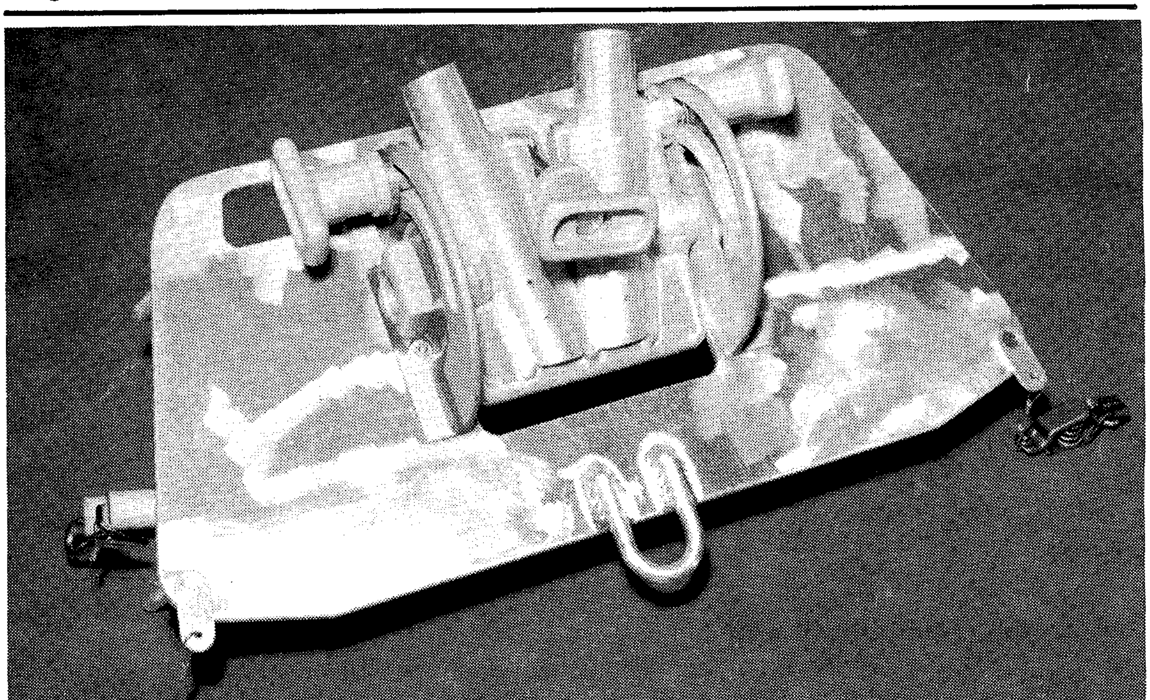


Figure 179. Thermal Sail Base Plate Assembly

provide a means of attaching the assembly to the vehicle structure. In addition, the adjustable receptacles were hinged to allow positioning of the sail against the OWS after deployment. The assembly was attached to the A-frame structure by two hinged clamps and mating side braces. The clamps were positioned around the tubular A-frame structure and torqued with the threaded end of the clamp and knurled knob (Figure 180). Also attached to the base plate were alligator clips for securing the clothesline after the sail was deployed. The crew incurred no problems in using this piece of hardware.

b. Sail Poles and Pallet Assembly, 10M13316 - 10M13314 - The sail poles and the sail-pole pallet are shown in Figure 181. The sail pole pallet consisted of a flat aluminum sheet with elastic loops on both ends to secure the sail poles. Each of the sail poles was 5-ft. long with a .75-in. diameter. They were joined together using a bayonet joint and a locking collar. It took 11 such poles to make each 55-ft. long section of the deployment assembly. The pallet configuration provided ease in translating the poles from the AM to the FAS area.

c. Thermal Sail Assembly, 10M50464-1 - This thermal sail was constructed of aluminized mylar coated with S-13g. The sail, shown in Figure 182, is a 22 X 24-ft. rectangle, designed to cover the exposed area on the OWS vehicle. Four spring clamps (dog leash clamps) were located on the leading and trailing edges of the sail as attach points for deployment. The sail was folded in the horizontal and then in the vertical direction (like a large cargo parachute) to the dimensions 14 X 13-1/2 X 9-in. to fit in a sail bag. This bag was equipped with a draw cord for closure and air holes to prevent entrapped air. Special care was taken to ensure that no air was trapped in the folds during packing; vacuum chamber tests were conducted to check for expansion of trapped air in the sail and bag by reducing pressure to 20 torr in 80-sec., and ultimately to 5^{-2} X 10 torr. Included in the bag design was a safety hook that attached to the base plate to prevent loss during installation. No problem occurred in the use of this equipment.

d. Clothesline and Restraint Bracket, 10M13318-3 - The clothesline assembly and restraint bracket consisted of a continuous clothesline made of Polybenzimidazole (PBI) .25-in dia. and approximately 55-ft. in. length, two end fittings for the line to pass through, and an aluminum restraint bracket for retaining the clothesline for stowage. One end fitting was attached to the first sail pole and a second end fitting was attached to the last sail pole, thus stretching the clothesline along the 55-ft. length of the sail poles.

After attaching the second end fitting to the pole assembly, it was inserted and locked into the base plate assembly. The clothesline was deployed by pulling 1.5-ft. sections from under each elastic retaining loop. The crew experienced no problem with this equipment.

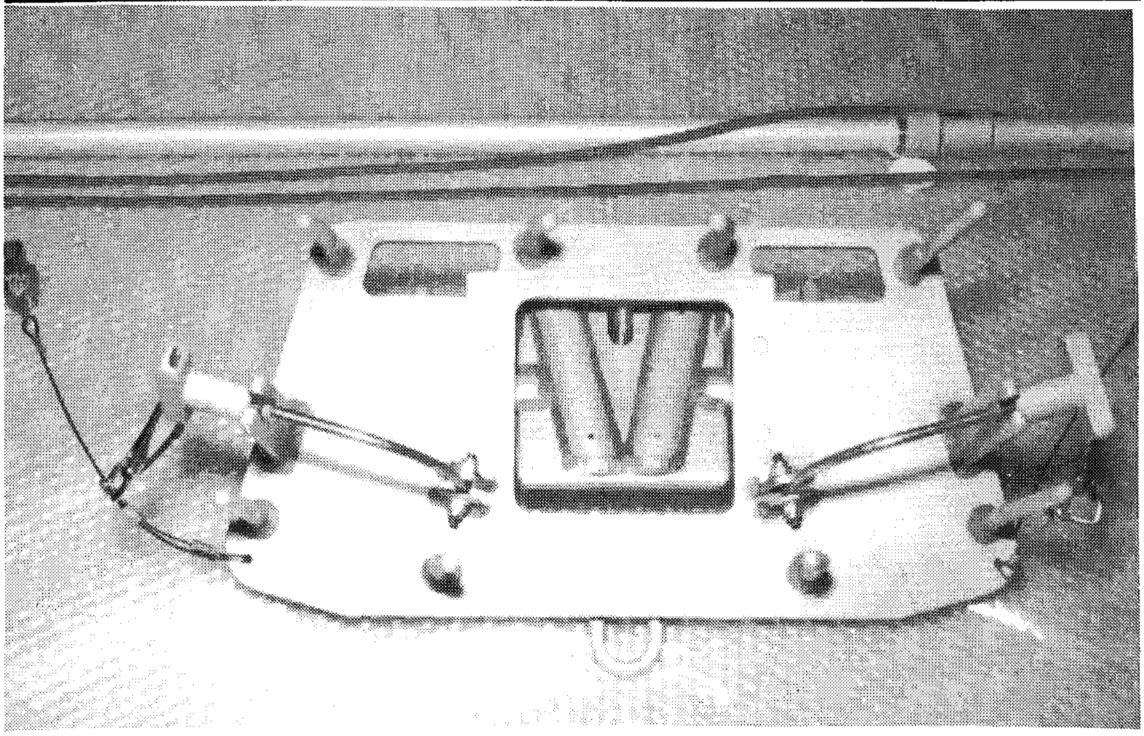


Figure 180. Bottom Side of Base Plate Assembly (Vehicle Attachment)

Figure 181. Sail Pole and Pallet Assembly

Figure 182. Neutral Buoyancy Sail Deployment, SL-2 Crew Members

e. Foot Restraint and Adapter Assembly, 10M50445-1 - The foot restraint and adapter plate assembly consisted of the workshop portable foot restraint, located on board, and an adapter plate made of stainless steel (Figure 183).

This assembly was required in order for the EVA crewman's lower body to be adequately restrained in the proper attitude in the structure of the A-frame on the ATM (from which EV2 could deploy and adjust the sail).

3. Crew Hardware Evaluation - Upon selection of the sail configuration, the related hardware was designed and fabricated. The crew participation during this time was extremely valuable and expedited the time required for producing finished, workable hardware. The prime and back-up crews participated in both one-g and neutral buoyancy evaluation of the finished hardware.

The neutral buoyancy testing program was conducted to evaluate the sail's design and to provide simultaneous training of the flight crew. The MSFC neutral buoyance simulator, with the full scale Skylab mockup, was fitted with the sail hardware necessary for evaluation activities. The first neutral buoyancy evaluation of the thermal sail concept was performed on May 18, 1973.

The sail material selected for neutral buoyancy simulation was .5-in. nylon netting. This material was chosen to minimize the dynamic drag incurred while moving the sail through the water. Figure 182 depicts the neutral buoyancy operations in one of the simulation runs.

On May 21, 1973, a one-g demonstration/evaluation, shown in Figure 184, was conducted with prime and backup SL-2 crew members, and engineering personnel. The purpose of this 1-g demonstration was to validate the sail configuration's method of deployment, and to familiarize crew members with hardware and procedures.

As a part of equipment qualifications, the crew conducted a Crew Compartment Fit and Function (C^2F^2) test prior to flight equipment acceptance.

Figure 185 illustrates the C^2F^2 activities upon completion of MSFC thermal sail design and development.

4. Twin Pole Sail Deployment - Deployment of the twin pole sail was accomplished by two crewmen, EV-1 and EV-2. After loading all the equipment in the Airlock Module (AM), EV-1 ingressed the VF foot restraints. EV-2 then passed out the following equipment which was stowed in the FAS area: the two Sail Pole Stowage Plates, the Sail Bag, the Base Plate, the two Clothesline Assemblies, and the Foot Restraint.

EV-2 egressed the AM and translated to the double handrail near the outrigger on the ATM. The Foot Restraint was passed to EV-2 on the ATM Film Transfer Boom and locked in place on the outrigger structure. After EV-2 was in position in the Foot Restraint, the Sail Pole Base Plate was passed out on the boom and was also installed on the outrigger. The Sail packaged in the sailbag was then transferred in the same manner and tethered to the Base Plate.

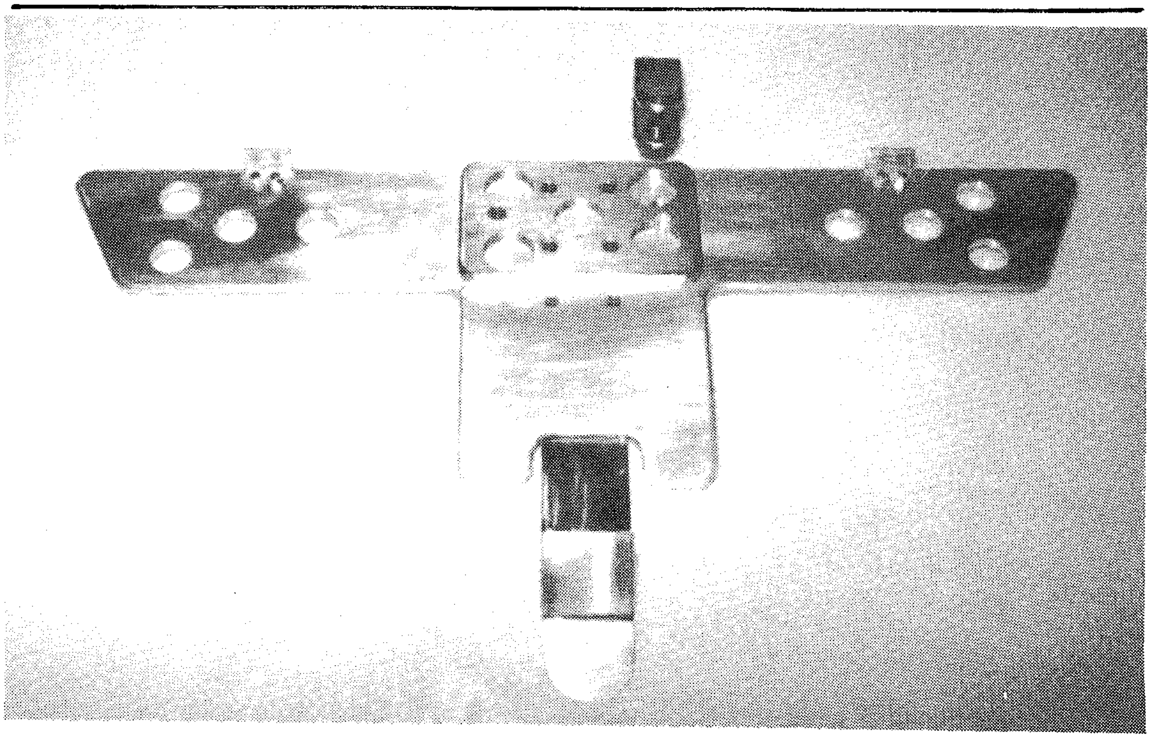


Figure 183. Foot Restraint Adapter Plate

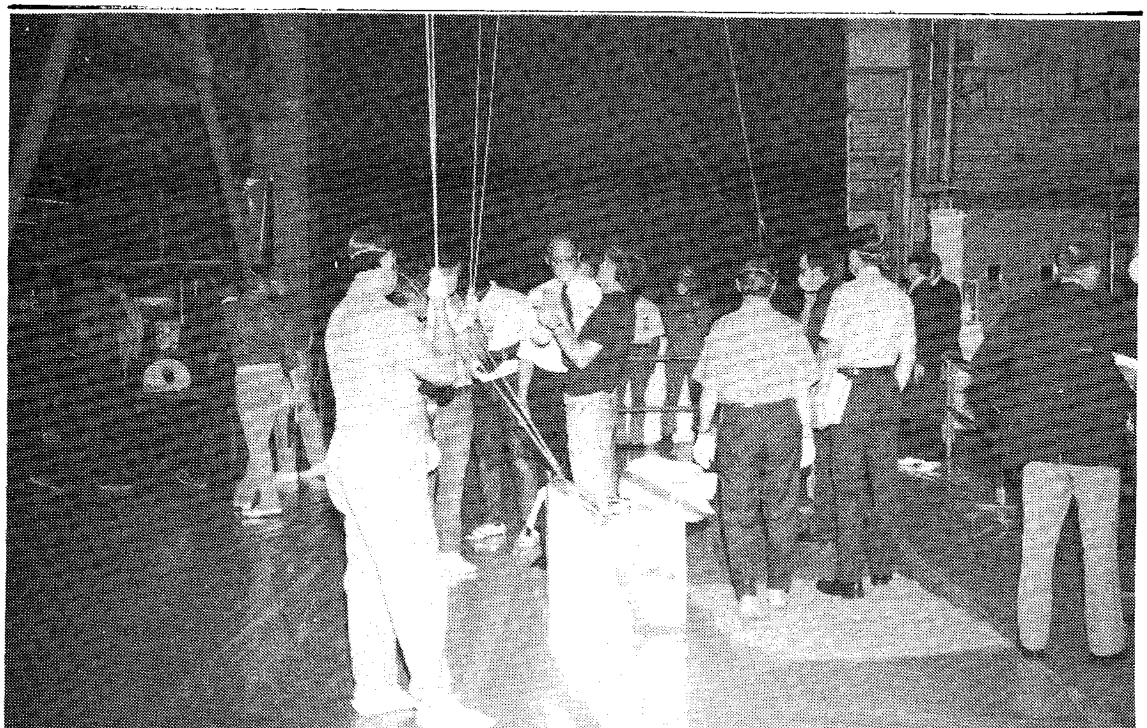


Figure 184. One-g Sail Deployment Demonstration

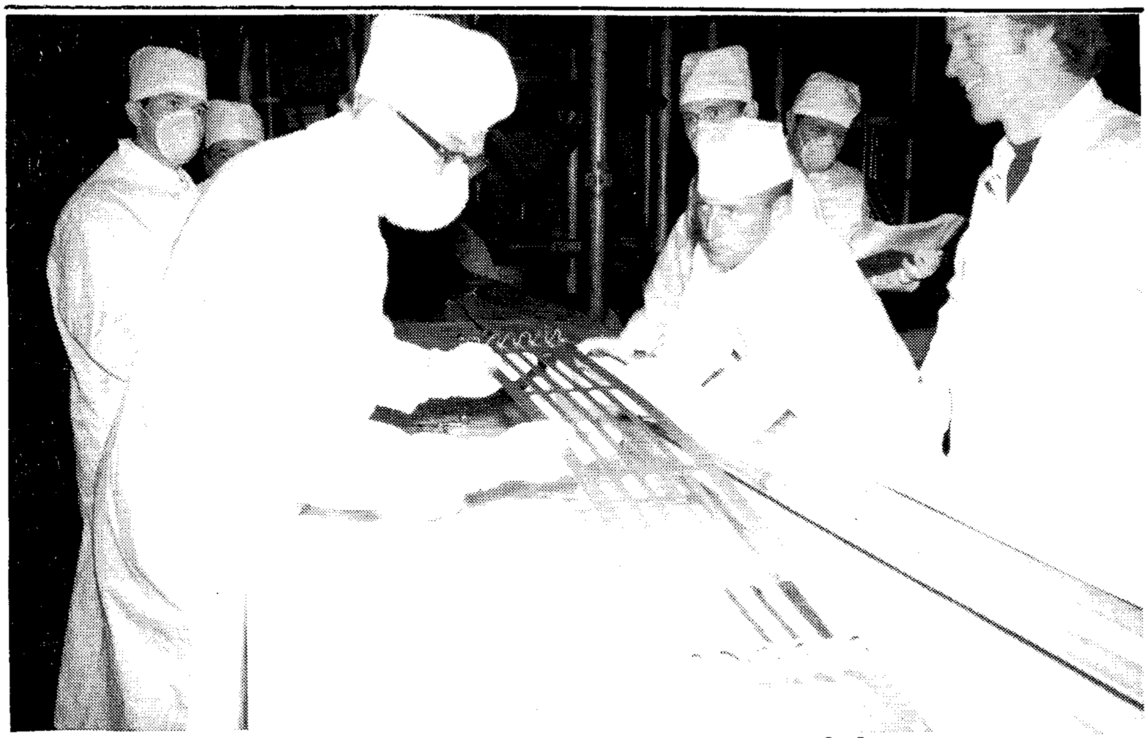


Figure 185. Thermal Sail Design and Development C^2F^2 Activities

EV-1 assembled the Sail Poles by first attaching the clothesline and fitting to the first pole section. Each section was locked together (11 sections plus a second end fitting) to complete one pole. EV-2 assisted by guiding the joined sections. After eleven sections were joined to form a single pole, EV-2 locked it in place in the Base Plate. The same procedure was followed for the second sail pole.

EV-2 opened the Sail Bag, removed the leading edge of the sail, and attached 2 sail hooks to the clothesline rings. A portion of the sail was then removed from the Sail Bag, and the slack was taken up with the clothesline. This action was continued until the second set of attach hooks on the sail was reached. These hooks were attached to the second set of rings on the clothesline. The sail was then hoisted to the end of the sail poles. After full deployment, the sail was swung toward the exposed area of the workshop, and the rotating portion of the base plate was locked in place.

Two reefing lines were provided to extend the corners of the sail nearest the ATM.

EV-2 translated with one reefing line to the ATM outrigger where the Payload Shroud attach fitting was located. He secured the line to stretch one corner of the sail. This step was repeated for the other reefing line which completed the sail deployment.

5. Crew/Equipment Interface Anomalies - Crew/equipment interface problems included those discussed below:

- A procedural problem occurred during installation of the clothesline pallet on the temporary stowage hook; the stowage hook was reversed which required the order of pallet installation reversed from that given in the checklist.

- The crew encountered some difficulty in removing the 5 ft. sections of sail poles from the pallet. The elastic bands holding the poles were placed behind the threaded locking collars instead of on the collar. Because of this, the poles needed to be rotated so the elastic would roll up on the collar for easy removal. This problem was encountered with both sail pole pallets.
- The folds in the sail during deployment had a tendency to cling together. This was thought to have been due to the tackiness of the painted surface. After receiving photos of the SL-4 fly around, it appeared that the sail had a memory due to the folding and packing of the sail in the sail bag. The crew attempted to remove the folds during deployment without complete success. However, the sail covered the exposed area and served the purpose for which it was designed.
- While assembling the poles, a twist in the clothesline was encountered. The solution to this problem was to disjoin two sections of poles and pass the line between them, then reassemble the poles, thus removing the twist.

6. Summary - Installation of the MSFC sail to aid in protecting the exposed OWS from the sun's rays was not difficult. The EVA crew of SL-3 did not encounter any major problems during the entire performance of this task. This activity provided conclusive data supporting the effectiveness of man in a spacecraft system. If it had not been for the presence of crewmen, the entire Skylab Mission could have been substantially compromised. In eleven days, from the discovery of the system failures on SL-1 launch day to May 25, the date of the launch of SL-2, engineers, scientists and technicians utilized every appropriate resource to develop this concept.

E. Other EVA Activities

Although the major EVA tasks were ATM film retrieval, SAS beam deployment, and twin pole sail deployment, various other tasks were performed during the Skylab EVAs. These planned and contingency tasks are described below.

1. D024 Sample Retrieval - The Thermal Control Coatings Experiment (Figure 186) consisted of two sample panels which were to be retrieved by the SL-2 and SL-3 crews during ATM film retrieval EVAs. These samples were mounted adjacent to the Fixed Airlock Shroud (FAS) ring just outside the normal FAS workstation (VF). The sample panels, held in place by snap fasteners, were to be released by the crewman, placed in return containers, and stowed in the AM. Since this was to be a one-handed operation, no foot restraints were provided; rather, a continuous handrail around the D024 experiment hardware was provided for crew restraint.

The sample retrieval operations were somewhat more difficult than expected. Although the crewmen had minor difficulty maintaining their positions, the samples were successfully retrieved.

After the samples returned by the SL-2 crew were examined, the Principal Investigator requested that an additional sample panel be installed by the SL-4 crew during their first EVA and retrieved during the third EVA. This task proved to be very difficult because of the problem of attaching the panel to four "blind" snaps without foot restraints. If a similar fine alignment task is planned for future EVAs, adequate foot restraints should be provided. Installation guides would also be desirable.

2. S230 Sample Retrieval - The purpose of experiment S230 was to measure fluxes and composition of precipitating magnetospheric ions and trapped particles through the use of a foil collection technique. The experiment apparatus was mounted on an AM Deployment Assembly (DA) truss under the D-2 handrail. This apparatus consisted of four foil collector cuff assemblies mounted on two collector mounting spools (Figure 187) with the first pair of cuffs mounted beneath the second pair. Each of these collector cuffs contained six foil samples mounted on an armalon backing, and each was held to the mounting spool with a velcro strip along two edges. These samples were collected during EVA operations of SL-3 and SL-4 and were returned for evaluation. No problems occurred with removal or return of the cuffs.

3. T025 Camera Operations - Experiment T025, the Coronagraph Contamination Measurements experiment, was to be used to collect data around Skylab and solar corona data from the Scientific Airlock (SAL). As the JSC Parasol was installed through the solar (+Z) SAL, plans were made to obtain as much of the original experiment data as possible by taking the T025 instrument out on regularly scheduled SL-4 EVA's. However, in addition, the experiment objectives were modified to obtain photographic data about the comet Kohoutek.

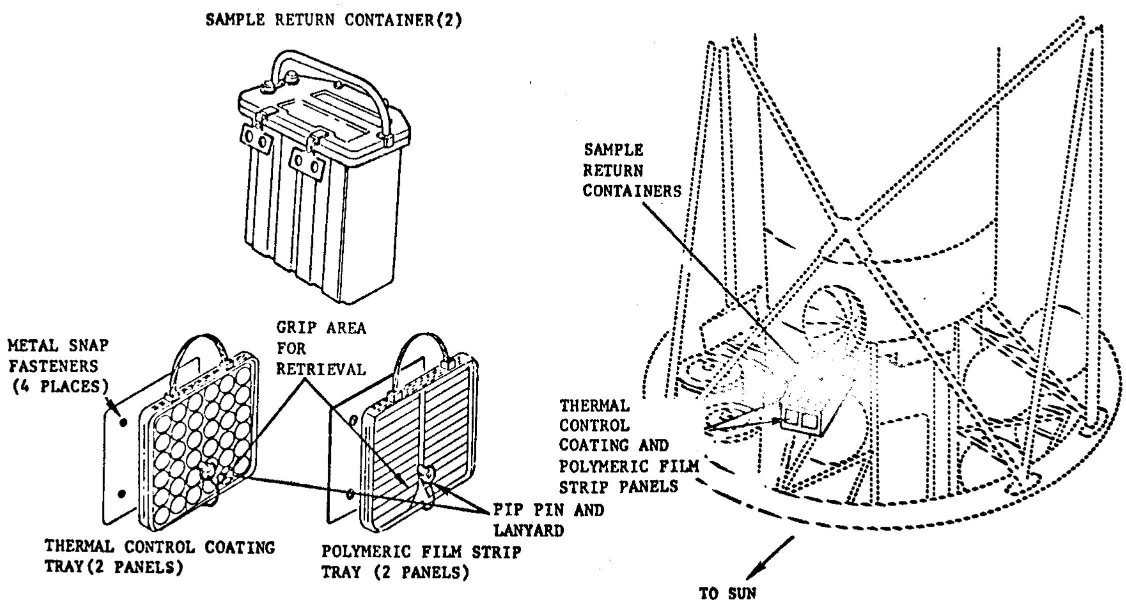


Figure 186. D024 Experiment

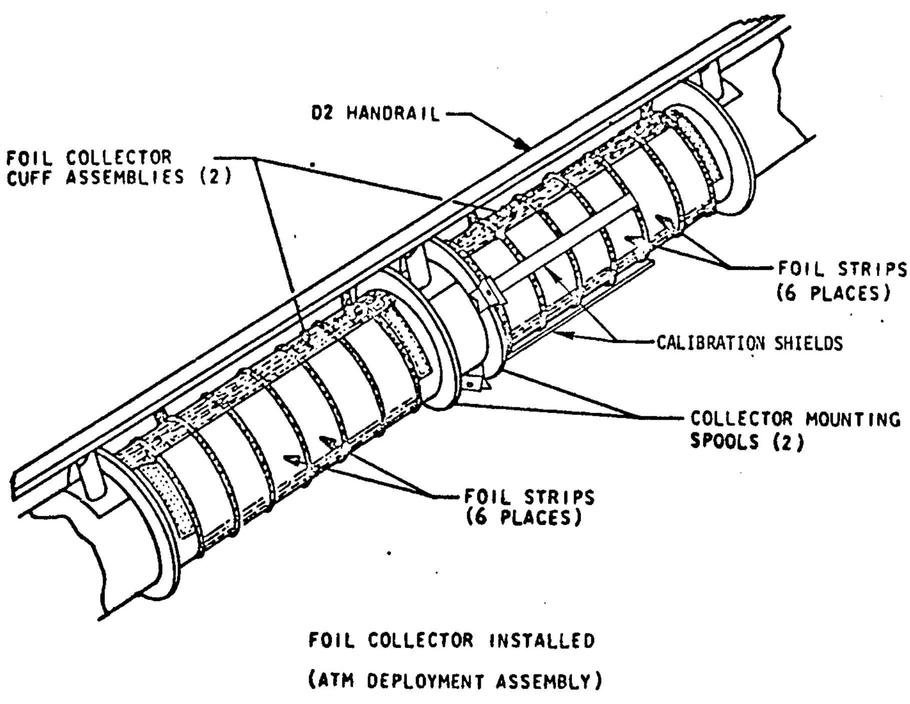


Figure 187. S230 Experiment

The experiment apparatus consisted of a newly designed and built adjustable EVA bracket, the coronagraph canister and camera, and an occulting disc mounted on a boom (Figure 188). The EVA bracket was to be mounted on a DA truss near the D-1 handrail at the Fixed Airlock Shroud workstation (VF).

For the first EVA of SL-4, the T025 apparatus was mounted at the VF. During camera operation, the shutter speed control knob became loose. Only five photographs out of a planned 40 were obtained.

Instead of trying to repair the camera during EVA, the picture taking sequence was stopped, and the equipment was returned (after removal of the thermal blanket cover) to the AM. There, following the EVA, the T025 hardware underwent troubleshooting, and the crew successfully repaired the shutter speed knob. The T025 hardware was used during subsequent EVAs to obtain ultraviolet and visible photographs of Kohoutek. Throughout the remaining three EVAs, no problems occurred with operation of the camera or EVA bracket, and subsequent T025 experiment performance was without incident.

4. S201 Camera Operations - Experiment S201, XUV Electronographic Camera, was developed to collect extreme ultraviolet (XUV) photographic data on Comet Kohoutek. Investigations of the comet's halo were to be made in the hydrogen lyman α line, and the XUV lines of oxygen and carbon monoxide. The experiment consisted of a canister enclosed camera, a film transport box, and an adjustable EVA bracket that attached to an AM Deployment Assembly truss at the same point that T025 was installed near the Fixed Airlock Shroud workstation (VF).

Pointing the camera during EVA was to be accomplished by sighting through two frame finder circles on the wide side of the canister. The two circles were designed to fold down between the canister ribs behind the handles on the canister side. When released by a latch, the two circles were to spring up perpendicular to the canister side, the larger ring forward of the smaller one. With his eye about six inches behind the center of the rear ring, the crewman could see both rings merge to outline the full 20 degrees field of view of the camera.

Two toggle switches were provided for activating main power and initiating a 205 second sequence of eight exposures. Two status lights were also provided to indicate a sequence in progress (green light) and a film advance in progress (white light).

S201 EVA operations were performed during the SL-4 second, third and fourth EVAs. Prior to EVA operation the crew noticed that the green "sequence in progress" light was actually reddish-brown, and the light intensity was low, but this caused no problem during EVA operations. No problems were encountered during experiment mounting or operation.

5. S020 Solar Photography - Experiment S020, UV X-Ray Solar Photography, was scheduled to be performed on SL-3 and SL-4 through the solar Scientific Airlock (SAL) to photograph X-ray and extreme ultraviolet spectra of the sun in wavelength regions from 10 to 200 Å. Due to the JSC Parasol occupying the (+z) SAL, the S020 experiment,

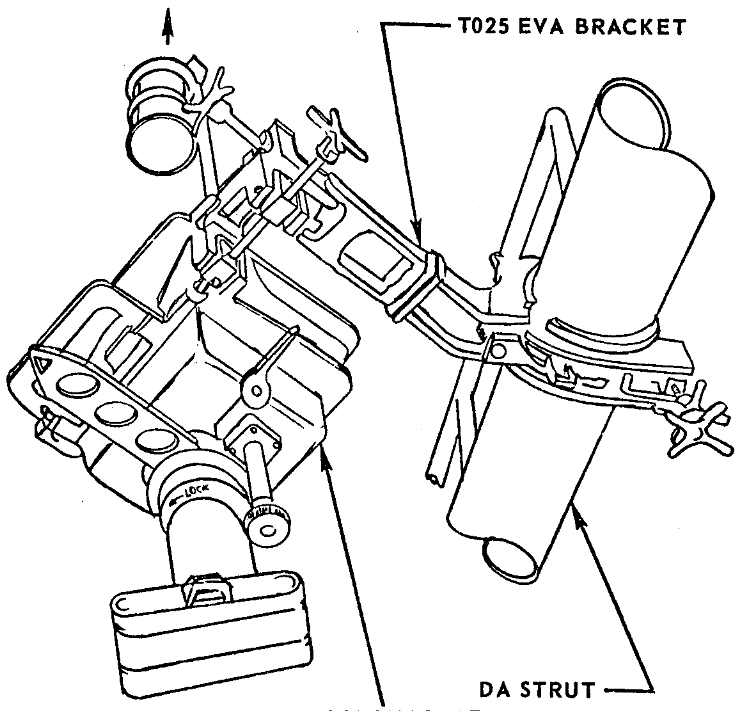


Figure 188. T025 EVA Configuration

along with the preceding S201 and T025 experiments, was mounted on the DA truss on the opposite side of the truss from the other two experiments. A special EVA bracket was designed and installed on the S020 equipment. S020 was successfully performed on three SL-4 EVAs with exposures up to one hour being obtained.

During deployment of S020, the crew experienced slight difficulty in attaching the mount to the DA truss. The mount twisted during the tightening operation. In addition, the ball joint on the mount was difficult to adjust, and the crew felt a larger ball could have made adjustments easier.

The SL-4 crew reported a number of pinholes in each of the two filters during preparation for the final EVA. It was felt, however, that the size of the holes as described would not allow enough light through to cause any problems.

6. S149 Deployment - The purpose of the S149 Particle Collection experiment was to determine the mass distribution of micrometeorites in near-earth space by a study of impact phenomena on prepared surfaces. The experiment apparatus consisted of a motor drive/cassette support unit, detector cassettes and an EVA adapter bracket (Figures 189 and 190). This bracket provided a method for mounting and positioning the experiment on the rim of the ATM solar shield (Figure 191) using a two jaw mechanism (one fixed, one movable) which was activated by a clamp locking handle. This EVA bracket was developed after the JSC Parasol was installed in the Scientific Airlock (SAL) window, thereby precluding nominal S149 operations through the SAL. The experiment apparatus also contained a crank handle for manually deploying the four cassette arms.

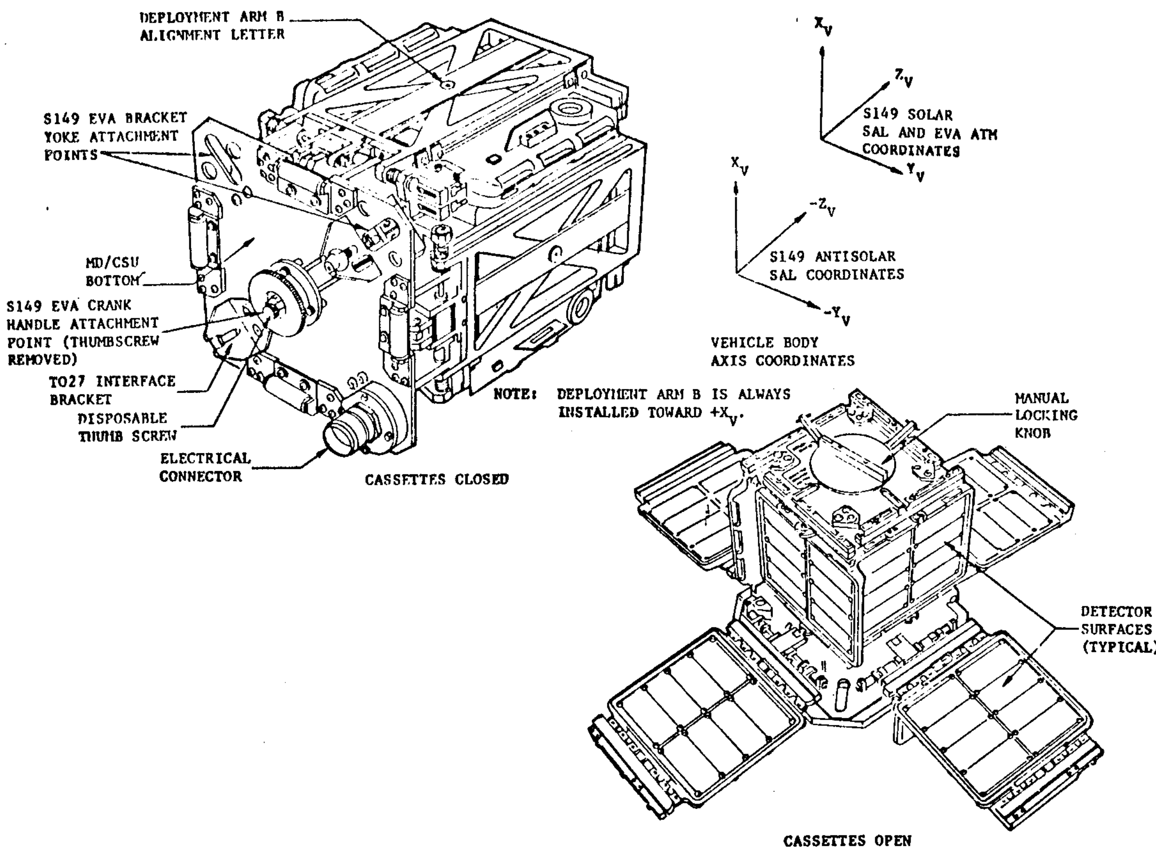


Figure 189. S149 Experiment

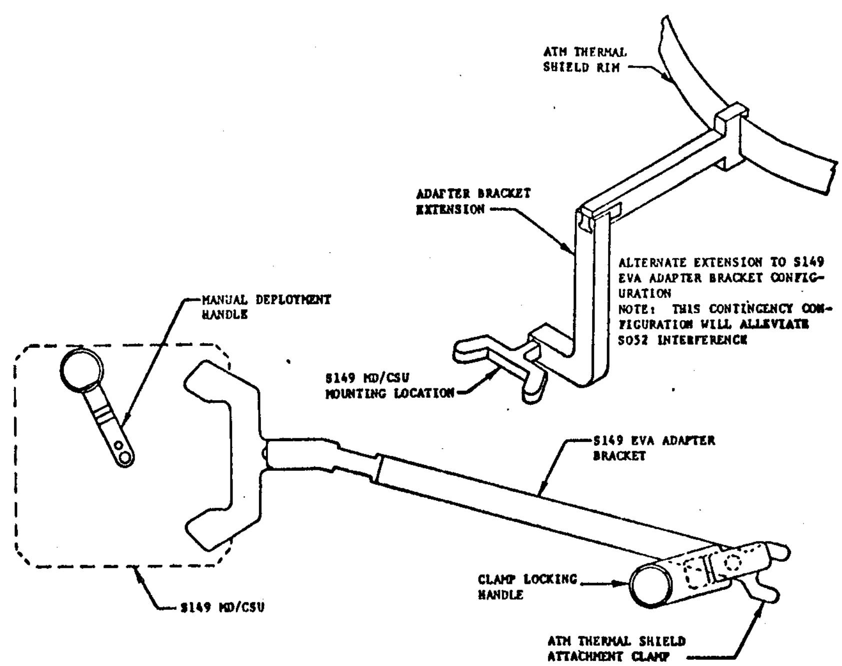


Figure 190. S149 Solar Shield Bracket

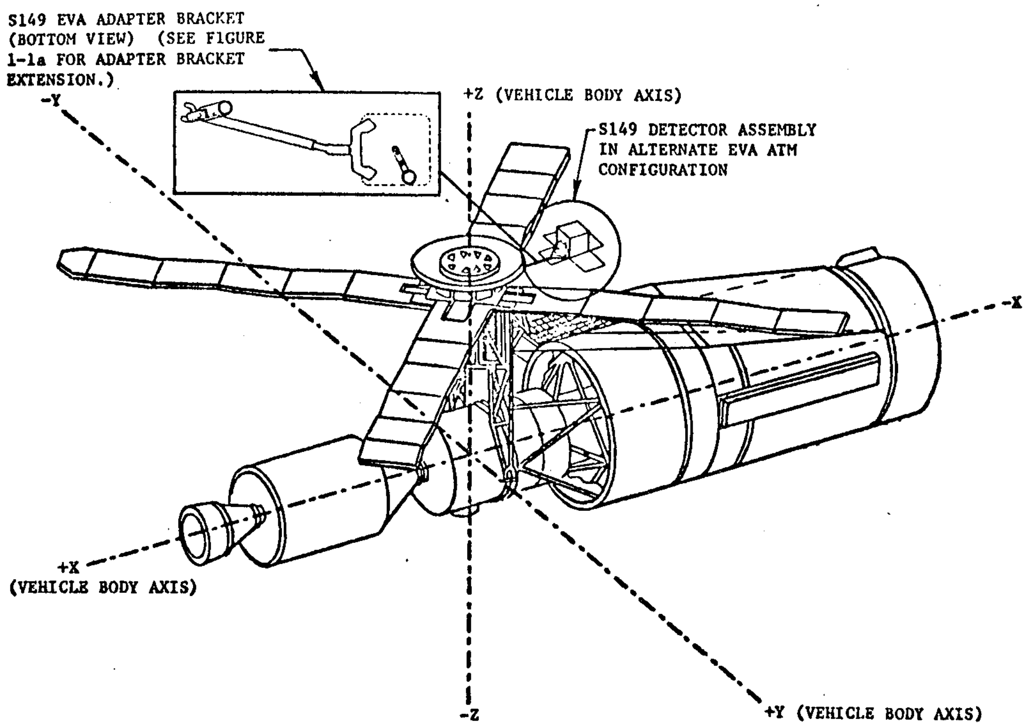


Figure 191. S149 Mounting Configuration

During EVA operations the S149 operated as planned with no major problems. The EVA bracket and cassette deployment mechanism operated satisfactorily.

7. ATM Door Ramp Latch Removal - On several occasions prior to the SL-3 first EVA, the aperture door failed to open when commanded during operation of the S055 experiment. This problem was overcome by simultaneously commanding both windings of the redundantly wound motor amature to open the door. It was suspected that the problem was the result of the door ramp latch lubricant's being worn off by normal cycling of the door. Since the ramp latch was needed only for supporting the door during launch and served no useful function afterwards, a proposal was made to have a crewman remove the latch during the next EVA.

The Mission Support Mockup (MSFC Bldg. 4619) and the ATM back-up unit were examined to determine what would be required to remove the latch. It was found that the latch was mounted to the ATM canister with two hex-head screws which could be removed with an on-board combination wrench. Although one screw was accessible to a socket/ ratchet tool, the other bolt was shrouded and could be removed only with a 7/16 in. open-end wrench. Consequently, it was decided that the on-board 7/16 in. combination wrench should be used to remove both screws. The wrench was modified for use with the EVA glove using on-board materials (tape, etc) to increase the handle diameter. The ramp latch had been installed with three adjustment shims between the latch and the canister. These shims, along with the latch, two screws, and two lockwashers, were to be retrieved to prevent them from floating into the ATM canister or distracting the star tracker; on-board tape was selected to affix the various parts to the ATM Sun End (VS) film tree for return to the Airlock Module.

Another question arose with regard to the position of the S055 ramp latch relative to the crewman in the Sun End workstation (VS) foot restraints. With the experiment canister in position for S082A and B film replacement, the crewman could not reach the S055 ramp latch. The ATM mission support mockup was used to determine the roll angle (in this case, +3000 arc min) on the ATM Control and Display Panel (Counter No. 1) which would position the ramp latch optimally for the crewman.

During the first EVA, after nominal film retrieval operation at the Sun End, the experiment canister was rolled to +3000 arc min for removal of the S055 ramp latch. The door was cycled open and closed several times, and a slight, jerky motion was noticed as the door engaged and disengaged the ramp latch. The bolts, washers, ramp latch, and two shims were then retrieved and mounted under the tape on the VS tree. One shim escaped in a direction away from the canister surface. The other ramp latch gear was successfully returned to the Airlock Module taped to the Sun End film tree.

The latch was returned with the crew for optical testing of the S-13G paint. Except for the difficulty of gathering eight small pieces of gear simultaneously, no problems occurred. After removal of the ramp latch, the door was cycled open and closed. No binding or jerking motions were observed.

Later, during the SL-3 Mission, the S056 and S082A doors began to malfunction, exhibiting the same symptoms as the S055 door had earlier. Because of that similarity, and because of the disappearance of the sticking problem with the S055 door after latch removal, it was decided to remove the ramp latches on the S056 and S082A doors. As the latches, bolts, and shims were identical to those on S055, the only change in the removal procedure was the recommended roll position of the experiment canister. The ATM Mission Support Mockup was again used to determine the best canister roll angles. These were found to be +3000 for S056 and -7200 for S082A. The procedures sent to the crew were identical to the procedures sent for S055 latch removal.

During the third EVA, after nominal Sun End film retrieval tasks, the experiment canister was rolled to +3000 arc min for S056 ramp latch removal. The door was cycled open and closed for crew observation. A jerky motion was noticed during opening and closing. Removal was performed with no difficulty. Nevertheless, as the ramp latch gear was being taped to the Sun End film tree, all four shims and one screw departed into their own near-Skylab trajectories.

The canister was then positioned for removal of the S082A ramp latch. The door was cycled open and closed. The same jerky motion noticed on S056 was also observed during S082A door movement. During removal of the first latch screw, the crewman removed one foot from the foot restraint to extend his reach envelope. During removal of the second screw, the crewman removed both feet. All latch gear was retrieved and taped to the VS tree.

The major problem associated with the removal of the ramp latches was the collection and stowage of the shims, bolts, washers, and latches after their removal. The use of tape to restrain these pieces (8 per latch) was not totally successful; four shims and two bolts were lost. Potentially, each of these hardware pieces, unrestrained, could have interfered with star tracker operation, ATM observations, etc. A dependable stowage method should be developed for use in future EV operations in instances where small hardware must be removed and retrieved.

8. S052 - Disc Cleaning - During operation of the S052 experiment on SL-2, optical glare was observed on one of the occulting discs. It was postulated that this glare was caused by a small (1mm dia.) piece of contamination on the outermost external occulting disc (D1). If this were true, it was felt that a crewman could remove the debris with an onboard brush and return the S052 experiment to its original condition.

It appeared from a review of the Mission Support Mockup in Bldg. 4619 and the flight back-up unit in Bldg. 4708 that a crewman could easily reach the D1 disc and would have adequate visibility to identify the contamination and remove it. The disc, however, had a sharp outside edge, so the crewman would have to be careful not to cut his glove. An adequate lens cleaning brush was identified from stowage container F524, and a cleaning stroke of center-to-outside was recommended to prevent cutting the brush bristles on the disc.

The position of the ATM canister for normal VS operations was not adequate, however, because the crewman could not reach S052 from the VS foot restraints. Therefore, the Crew Systems ATM Mission Support Mockup was used to determine the best position of the canister for the S052 cleaning operation. Disc inspection and cleaning procedures, including a canister position of +6600 arc sec, were transmitted to the crew for use during the second EVA.

During that EVA, the ATM experiment canister was rolled to the recommended required roll angle with the door open. Crewman EV2 located the contamination and removed it with the optics cleaning kit brush. The S052 aperture door was then closed.

During SL-3, contamination was again noticed on the occulting disc. The disc cleaning procedures used during SL-2 were again sent to the crew for use during the third EVA, and the contamination was removed with no problems. The lens cleaning brush was judged to be adequate for the task.

9. ATM Contingency Door Opening (S054, S082A) - During SL-2, the crew had difficulty opening the S054 aperture door. The door was first commanded open unsuccessfully with the S054 "DOOR OPEN" switch on the ATM Control and Display Panel, and then through the ATM Digital Address System (DAS). When these commands failed to open the door, the DAS was used to activate, simultaneously, both circuits of the aperture door drive motor's redundantly wound armature. This action appeared successful--the S054 door talkback indicated that the door had opened. The door was left open in case it could not be opened again.

Two solutions were proposed. The planned method of manually opening the aperture door at the Canister Sun End during an EVA was initially proposed. This procedure had been established before the mission as a contingency procedure, and the crew had been trained for it. The procedure involved removing a pin from the door "hub" (the pin was the only solid connection between the door axle and the door itself). When the pin was withdrawn (by rotating its "tee" handle), the door and the axle were free to rotate independently. This allowed the door to be held open by a latch without affecting the rest of the door actuation system. The disadvantages were that the open door would allow contamination to enter the ATM experiment canister, that it presented a potential thermal problem, and that the procedure was irreversible (it was virtually impossible to reinsert the pin once it had been withdrawn). There was also some doubt as to whether or not the door had actually failed. The alternate procedure consisted of jamming the S054 "DOOR OPEN" switch (on the ATM C&D Console) to the open position with either a pencil or a section of wire, thereby preventing the "DOOR SHUT" command from closing the door. This method would have allowed more time for evaluating the problem, and for developing a solution which did not irrevocably lock the door open. But, eventually, the original plan was chosen and was included in planning for the first EVA.

During the SL-2 first EVA, after the Solar Array System beam had been deployed, EV2 translated to the ATM Sun End to open the S054 door. The door pin was unscrewed and the door was rotated and latched open with no difficulty.

On SL-4, a similar problem occurred with the S082A aperture door, and during the third EVA, it too, was latched open. No problems occurred with the opening of either the S054 or S082A doors.

10. <u>CBRM Repair</u> - Early in the SL-2 Mission, Charger-Battery-Regulator Module (CBRM) Number 15 malfunctioned, causing a decrease in electrical power available for Skylab. An evaluation of the telemetry measurements associated with the CBRM indicated that the malfunction was probably caused by a relay contact having become stuck in the open position. The only method of solving this problem, without replacing the entire CBRM, appeared to be to have an EVA crewman strike the CBRM cover near the relay with a hammer or other appropriate tool in the hope that the shock would free the relay.

The first task the crew performed during the second SL-2 EVA was the release of the stuck relay. EV2 translated from the VF to the ATM Rack bay adjacent to the Center Workstation (VC). He then described the CBRMs to the Capsule Communicator and to EV3 to verify identification of CBRM No. 15 and the target screw in particular. EV2 then struck the screw several times until EV3 observed current flow through the regulator. Although some paint was knocked from the CBRM cover and the ATM oscillated several times after the screw was struck, no other hardware or procedural problems occurred.

11. Rate Gyro Package Cable Installation - In the early part of the SL-2 mission, the orbital attitude rate gyros had begun to give faulty and sometimes erratic indications. To correct this problem, an extra set of gyros was assembled into a Rate Gyro Package (RGP) "Six Pack" and was flown aboard SL-3. The "Six Pack" was to be mounted in the Multiple Docking Adapter (MDA). To integrate these rate gyros into the cluster attitude control system, however, a new cable would have to be installed between an ATM trunnion plate and the ATM Workshop Computer Interface Unit (WCIU). A set of procedures was provided in the Saturn Workshop (SWS) Cue Cards. Special connectors with extended backshells that enabled the EVA crewman to mate the connectors by hand were used on the RGP cable. A set of connector pliers was also developed for use in disconnecting the old RGP cable. These pliers were similar to standard connector pliers, but had a tether ring and a handle orientation compatible with the EVA gloves.

The RGP cable was installed during the SL-3 second EVA. The installation required that the Skylab attitude control system be disabled from the time the connections were broken at the ATM trunnion until after the connections were complete. Because the area around the WCIU and the Deployment Assembly trunnion area were not illuminated by EVA lights, the crew inspected both areas during the first dayside pass to verify crew restraint methods, connector accessibility, and the cable routing scheme. The connector pliers were fitted to the connectors and found to be the proper size. The adjacent wire bundles were then inspected and found to allow sufficient clearance for removing the connectors. Body restraint was also determined to be satisfactory at both locations. The cable routing scheme was discussed among the crewmen and was not considered to be a problem. Other EVA activities were subsequently performed during the orbital night and are discussed in the sections below.

Prior to the next sunrise, the cable connection was made at the trunnion, the cable was routed to the ATM WCIU area, and EV2 restrained himself at the WCIU for the cable installation operations. Immediately after sunrise, he began breaking and making the connections at the WCIU and trunnion while EV3 read the installation procedures. Less than four minutes later, all connections had been made. No problems were encountered with use of the tool, connector backshells, crew restraint, or positioning of the connectors.

12. Sail Sample Installation Retrieval - After the JSC parasol was deployed on SL-2, a study was performed to determine the effect of solar radiation on the parasol material. It was discovered that there might be some material degradation with extended exposure. As a result of this study, the SL-2 crew was requested to cut an 18 inch square section from the Stand-Up EVA (SEVA) sail (made from the same type of material as the parasol except with a layer of Kapton) and mount it to an ATM Deployment Assembly (DA) truss. The procedure transmitted to the crew was to sew velcro along two sides of the parasol sample prior to EVA. The sample was then to be wrapped around a tubular truss near the Fixed Airlock Shroud Workstation (VF) where it would be exposed to direct sunlight.

During the second EVA of SL-2, EV2 installed the JSC sail sample to a truss near the ATM deployment motor. As no foot restraints were available, and as wrapping a flimsy article around a truss is essentially a two-hand task, crew stability was severely limited. But, with EV1 holding EV2's feet, the sample was eventually deployed. If such tasks are required during future EVAs, adequate restraints should be provided.

During the third EVA of SL-3, the sample was retrieved. No problems occurred.

In order to obtain more data on the effects of the space environment on the JSC parasol material, two additional material samples were carried aboard SL-3. These were attached to old crew procedures Cue Cards, and the Cue Cards were mounted on a clipboard attached to a universal mount. This mount could be attached to an EVA handrail and adjusted to expose the material samples to direct sunlight.

During the EVA, EV2 attached the universal mount to the S-10 handrail while his feet were held by EV1. Except for the lack of adequate restraint, no problems occurred.

The samples were retrieved during the third SL-4 EVA without difficulty.

13. <u>S193 Antenna Repair</u> - The purpose of experiment S193, Microwave Radiometer/Scatterometer Altimeter was to investigate active and passive microwave sensing systems from an orbital altitude. The experiment included a mechanically driven parabolic reflector (Figure 192) that scanned in several programmed modes.

During SL-3 the antenna began to malfunction and would not scan properly. To correct this problem, hardware and procedures were developed to enable two EVA crewmen to check out and repair the antenna or its associated electronics package. Several major problems had to be solved: (1) the S193 antenna was on the side of Skylab where nominal EVA operations were not performed and no EVA lights, handrails, or foot restraints were available near the antenna, (2) the antenna was large (44.5 in. x 21.2 in.) and massive (294 lbs), (3) the electronics were located beneath the antenna and would not be very accessible to the crewmen, and (4) attempts to diagnose the problem from the ground were only partially successful.

It was determined that crew translation to the S193 antenna from the EVA hatch could be accomplished by using the mole sieve vent duct along the exterior of the Multiple Docking Adaptor (MDA). The major problem, however, was restraint of the crewmen at the antenna; development was begun on a "universal" foot restraint that would attach to a variety of external hardware, including the trusses around the S193 antenna. After several iterations, a design was evolved which would secure the OWS portable foot restraint to round trusses from 1 to 6 in. in diameter, to the Fixed Airlock Shroud (FAS) ring, to the solar panel back-up structure, and to various other external points which included adjustments in roll and pitch to position the crewman at the worksite.

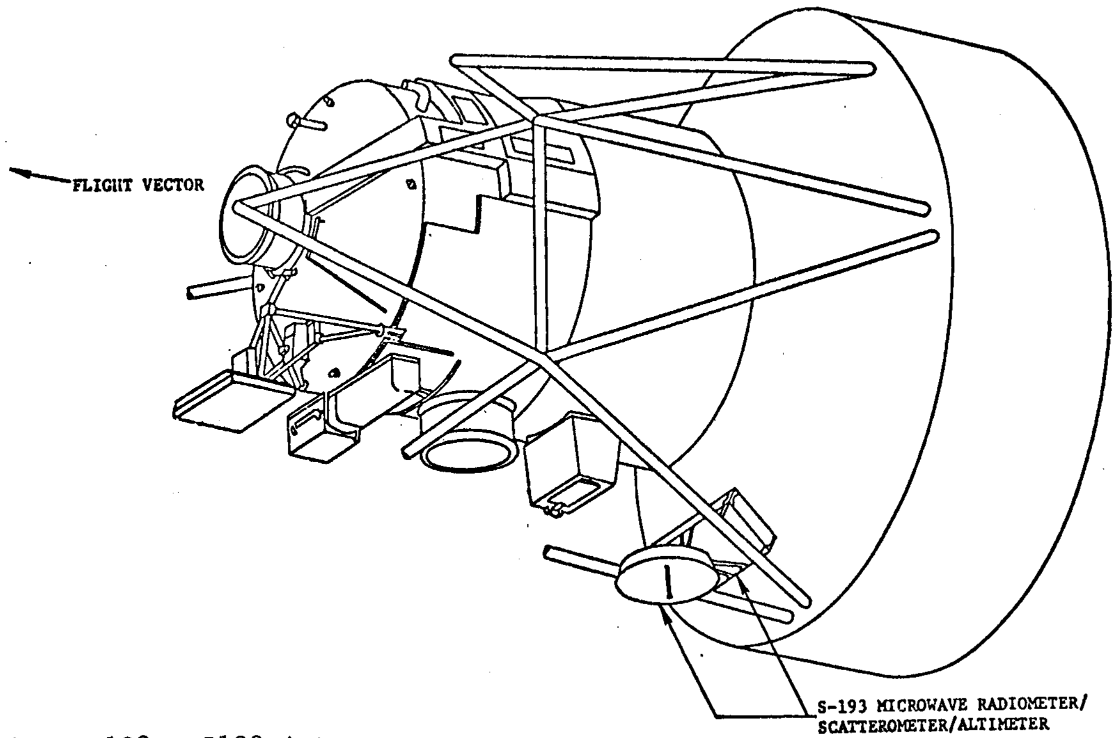


Figure 192. S193 Antenna

Two sets of foot restraints were developed for experiment S193--one at MSFC and one at JSC. The JSC set was selected for use. This foot restraint was not universal, but was designed to fit into a lightening hole on the discone antenna launch tray near the S193 antenna. The JSC foot restraint was lighter than the MSFC concept, and was therefore selected to be carried aboard SL-4 for the antenna repairs.

An antenna inspection/repair procedure fashioned after the Orbital Workshop malfunction procedures was developed (Figure 193). Additional crew instructions on separate pages were provided for each block of the flow diagram. The tools and electronic equipment necessary to repair the antenna were identified and packaged into a tool caddy. These tools consisted of vice grips, hammer, screwdriver, allen bit, ratchet and connector pliers.

Neutral buoyancy tests verified that the antenna repair tasks could be performed, but, because of the antenna's mass and size and the inaccessibility of the electronic components, the task would be both difficult and long.

During the first EVA of SL-4, two crewmen performed the inspection/repair tasks. EV2 translated to the S193 antenna and installed the foot restraint. EV1 then translated to the antenna, ingressed the foot restraint and mounted the tool caddy on a deployment assembly truss. EV2 began the inspection/repair task with EV1 holding EV2's feet for stability and passing tools as they were needed. During the task, the two crewmen pinned the antenna's pitch gimbal and installed a disable plug and jumper box. This locked the antenna in a fixed pitch position and permitted operation of the antenna in a roll-scan only mode. No major problems were encountered.

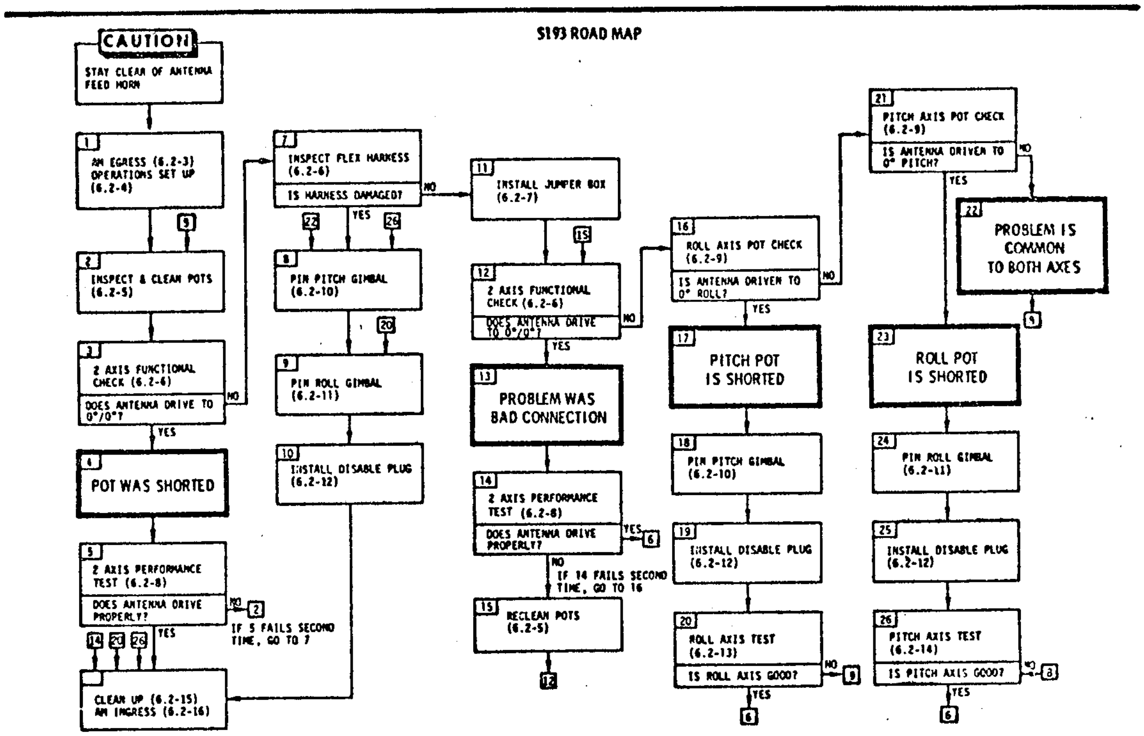


Figure 193. S193 General Repair Procedures

14. Skylab Vehicle Exterior Inspection - Prior to the first SL-3 EVA, several anomalies occurred on one bus of the ATM electrical power system. In order to determine whether a short circuit had developed in the electrical power distributor, the crew was asked to inspect the Power Transfer Distributor, which is 90 degrees to the right of the ATM Center Workstation. Scorched posts near the fuse modules and gray residue near the vent ports would be convincing evidence of such a short circuit.

As part of a troubleshooting exercise to locate a coolant leak, the crew was requested to examine the Multiple Docking Adapter (MDA) exterior to identify any signs of leaks. The crew was advised of locations to check and was told what types of deposits and discolorations would be present if a leak had occurred.

These two inspections were performed during the SL-3 first EVA. During inspection of the Power Transfer Distribution box, no residue or discoloration was observed around the gas ports, and the gas port screens appeared clean. Also, no scorching was found around the fuse module mounting screws.

The crewman (EV2) then described the exterior of the Command Module (CM) and the MDA. The CM was a tan color where it was exposed to the sun with a darker brown color around the hatch. A dark tan line was also observed extending from under the CM hatch to the docking window. The MDA was examined for any discoloration or streaks which would indicate a coolant leak. No evidence of a leak was observed.

15. S054 Filter Wheel Positioning - During SL-4, the S054 filter wheel jammed. Neither ground commands nor onboard commands from the ATM Control Panel could move the wheel. Since telemetry indicated that the wheel was jammed between two filters, film data would be severely degraded until the wheel was positioned at one of the six filters.

An examination of the ATM back-up unit indicated that the filter wheel could be turned manually be a crewman at the ATM Center Workstation (VC) with a long blade screwdriver. However, several significant problems had to be solved.

- First, none of the SL-4 crewmen had ever seen the filter wheel or the surrounding hardware, nor were there on-board photographs or drawings.
- Second, during the EVA, the crewman would not be able to see the filter wheel without the aid of a mirror and additional lighting.
- Third, the filter wheel could not be moved without destroying the filters with the screwdriver.

The first problem was solved by giving the crew a detailed verbal description of the filter wheel and the surrounding hardware. To solve the visibility problem an onboard penlight was taped to the extension mirror (Tool Kit No. 1). This mirror/light could be held by the crewman over the aperture to enable him to see the filter wheel. The S054 experiment personnel determined that the wheel should be positioned at the blank (no filter) position to avoid taking photographs through a broken filter.

The procedure sent to the crew was to: (1) remove the exposed S054 film magazine from the experiment canister receptacle at the VC, (2) place a new film magazine in the receptacle with a shutter override mechanism attached to the base (this latched the shutter open to permit access to the filter wheel), (3) remove the new film magazine, and (4) insert the screwdriver through the shutter opening into the filter wheel, while using the mirror and light to provide adequate visibility. The crew was then to insert the screwdriver blade into a filter and force the wheel to the right until another filter could be seen on the left. This procedure was to be repeated until the blank filter was positioned in the optical path.

During the second EVA, this task was performed. The used film magazine was removed, and the new magazine with the shutter override mechanism was installed, opening the shutter. The film magazine was removed and, as the filter wheel was being turned, the shutter unexpectedly closed on the screwdriver blade. After repeated attempts to reopen the shutter failed (due to distortion of the blades), and after consultation with ground controllers, the blades were forced apart, clear of the light path. EV2 then proceeded with the rotation of the filter wheel until the blank position was centered. The film magazine was then replaced.

Although this task was difficult and the crew had not been trained, the repair operations were successfully performed.

VII. TEST DATA

This section contains test data on select hardware items for historical and informational purposes only.

A. Waste Management

1. Waste Management Design and Development Reviews - The Preliminary Design Review of the Waste Management Subsystem was presented at MSFC August 27-28, 1969. The same methods for basic fecal collection and processing, contingency fecal collection and processing, and vomit collection and processing presented at the PDR existed in the final design. There was one exception. Vomit was to be collected in a separate bag. It was changed so that contingency fecal collection and vomit collection utilized the same bag.

The urine collection and preservation system presented at the PDR utilized a bag for each collection. Each bag, after collection, was placed in the processor where the urine was vacuum dried, then stored, and returned via the command module for analysis.

Subsequent to the PDR, the preservation scheme for urine was changed for vacuum drying to chilling during collection and sampling; and freezing of the sample obtained after each 24-hour collection period. The original system utilized a single collection bag. After each collection, the gas in the bag was expelled through a zitex filter membrane, and the bag containing the urine was held against a chill plate to maintain the urine below 59°F.

Just prior to the Critical Design Review in September 1970, a failure of the original urine collection method occurred. The filter in the collection bag clogged, and would not permit air flow after being in contact with the urine for a period of time during chilling.

The Critical Design Review of the Waste Management Subsystem, except for urine collection and preservation, was presented at MDAC September 14-17, 1970. The same basic system was presented that was presented at the PDR. The only significant difference was the utilization of a 6 drawer processor instead of a nine drawer processor, due to the elimination of vacuum drying urine.

At that time three methods of collecting urine were under design and test: (1) a one-bag collection system which used a modified collection bag with a larger filter which allowed holding the bag open during the 24-hour collection period to limit filter exposure, (2) a two-bag collection system where the urine was collected in one bag; then transferred to a holding bag that did not have a filter, for chilling the urine, and (3) a centrifugal separator system that separated the urine from the air and pumped the urine into a holding bag for chilling the urine.

The Critical Design Review of the Urine collection and preservation system was presented at Fairchild Industries March 31, April 1, 1971. All three systems were presented at the CDR.

Subsequent to the CDR, the one- and two-bag schemes were cancelled and the separator system implemented.

At that time, the modifications to the urine system, to include the separator, were as follows:

- Addition of a new 24-hour urine pool holding bag which incorporated 2000 ML capacity, a recirculation line to mix urine with the lithium chloride secondary volume determination agent contained in the bag, a urine receiver capable of receiving urine and connecting to the recirculation line, and use of a screw on adaptor also capable of cuff contingency mode collection.
- Urine Separators.
  Folding teflon urine receiver and inlet hose and valve assembly.
- A rectractable pressure plate capable of exerting a pressure equivalent to 6-inches of water on the urine holding bag. It also would keep the bag in intimate contact with the cold plate in order to chill the urine pool. The pressure plate was actuated through the airflow valve handle on the urine drawer front panel. This plate connected mechanically to the volume measurement indicator dial gage.
- The drawers were modified to accommodate the urine separators, urine collection bag, and pressure plate, etc.
- Additional equipment like hose rollers, UTCA adaptors, new urine sample bags, etc.

During the SMEAT test conducted at JSC, Houston, during July and August of 1972, it was determined that the 2000 ML capacity of the urine system was not adequate. As a result, the final design parameters of the urine system were established during a meeting on September 26, 1972 at JSC.

The final iterations were as follows:

- Primary volume determination chemically using the lithium chloride tracer.
- Elimination of recirculation by use of manually shaking of the urine pool.
- Design of a 4000 ML urine holding bag capable of alternate cuff mode operation.
- Modification of the urine sample bag.
- Design of a urine bag container box and spring actuated pressure plate.
- Elimination of the mechanical dial gage volume measurement system by a micrometer gage plate system used in conjunction with the urine bag box assembly and the manual squeezer handle assembly used to take samples.

- Design of a hard-metal cone-reciever in place of the old teflon folded cone construction, and associated inlet hose.
- Design of a combination urine sample bag holder and crimper/cutter assembly for use in sampling and sealing the sample.
- Design of a urine bag box support mechanism capable through use of sqeezer handles of applying additional pressure on the urine collection bag to assure adequate filling of the urine sample bags. This device is also used in conjunction with the micrometer volumetric plate for mechanical volume measuring.
- Modification and simplification of the urine drawer to accommodate the new hardware.
- Design of new adapters for use with interface equipment such as the UTCA's and the urine dump system.

There are no open action items from the Preliminary and Critical Design Reviews.

2. Subsystem Conclusions

a. Waste Processor

(1) Summary of Capabilities versus Design Requirements - The processor module had demonstrated its capability of attaining the design requirements. The unit had:

(a) Demonstrated its ability to process feces, diarrhea, and vomitus to an inactive state in which bacterial growth was prevented.

(b) Demonstrated that the leakage rate from the cabin atmosphere through the processor was well within the 0.27 lb/day allowance.

(c) Demonstrated that it could be operated with a minimum of crew time, effort, and maintenance.

(d) Successfully completed qualification unit vibration testing (at MDAC).

(e) Met the touch temperature requirement of 105°F (except for indicator lamps).

(f) Successfully met the electrical requirements such as over and undervoltage, input transients, and reversed polarity.

(2) Summary of Open Problems and Plans for Corrective Action - There were no open problems or plans for corrective action associated with the processor module. All problems generated during the development and design phases were resolved satisfactorily.

(3) Long Duration Operational Capability - The unit as a whole had been subjected to life testing of 140-cycles of operation of each of the six processing chambers to simulate one chamber operation per day during a 28-day mission and two 56-day missions. A cycle involved opening and closing the chamber door, vent valve, and locking handle; the pressure plate assembly and damper were also operated by virtue of their connection to the chamber door. Some failures of indicator lamp filaments (each lamp had two filaments) and timer skipping of 1/2-hour increments occurred. Voltage surges due to the test set-up were believed responsible for lamp filament failures.

Timers were reworked to the production configuration, employing aluminum rather than stainless gears for reduced inertia. A second 140-cycle operational life test was completed.

b. Collection Module

(1) Summary of Capabilities Versus Design Requirements - The Fecal/Urine Collection Module demonstrated its capability of attaining the design requirements. The unit:

(a) Successfully completed prototype vibration testing.

(b) Been able to supply the necessary airflow.

(c) Been able to accommodate the necessary coolant flows.

(d) Successfully met the electrical requirements.

(e) Attained the necessary accuracies for volume determination.

(f) Demonstrated the ability to collect in a zero G environment.

(g) The capability for efficient man interface.

(h) The ability to prevent bacteria contamination in the airstream introduced by collection.

(2) Summary of Open Problems and Plans for Corrective Actions - There were no open problems or plans for corrective action associated with the Fecal/Urine Collection Module. All problems generated during the development and design phases were resolved satisfactorily.

(3) Long Duration Operational Capability - The unit as a whole was subjected to life testing and several of the more critical components successfully underwent life tests in excess of the requirements. The more important components and their capabilities were as follows:

(a) Blower Assembly - Two endurance tests were run on the blower, one for 2000-hours and another for 630-hours, successfully, although the requirement was 250-hours.

(b) Odor Control Filter - Development tests showed that the odor control filter had an operational lifetime in excess of 54-days or nearly twice the lifetime required (28 days). These tests were run absolutely dry which made the results extremely conservative. The odor control filter did demonstrate a greater life expectancy during qualification.

(c) Time Delay Relay - Any one time delay relay was required to undergo 840 cycles while in orbit. During qualification testing, two units were subjected to 3000-cycles each without deleterious effects. This was well in excess of the requirement.

c. Vacuum Cleaner and Power Module

(1) Summary of Capabilities Versus Design Requirements - The power module and vacuum cleaner demonstrated the capability of attaining their respective design requirements. The units were:

(a) Successfully completed vacuum cleaner qualification testing.

(b) Provided the necessary airflow for zero-g collection with specified power consumption limitations.

(c) Successfully met all electrical and electomagnetic interference requirements.

(d) Successfully completed prototype vibration testing.

(e) Met the touch temperature limitation of 105°F.

(f) Demonstrated an operational life and cycling capability in excess of specified requirements during prototype testing of the vacuum cleaner and testing of its most critical time dependent item, the blower.

(g) Demonstrated one-handed operation with a minimum of crew time, effort, and maintenance.

(h) Demonstrated the performance of the blower at the habitation period pressure and atmospheres.

(i) Demonstrated the ability of the blower to sustain orbital storage without subsequent degradation in performance.

(j) Was able to demonstrate acceptable levels of acoustical noise generation during power module operation.

(2) Summary of Open Problems and Plans for Corrective Action - There were no open problems or plans for corrective action associated with the power module or vacuum cleaner. All problems generated during the design and development phases were satisfactorily resolved.

(3) Long Duration Operational Capability - The operational life requirement of the power module was 250-hours of running time with a minimum of 7000-cycles. The operational life requirement of the vacuum cleaner was a minimum of 980-cycles for a total running time of 94-hours.

This latter operational life requirement was demonstrated in the vacuum cleaner qualification test. In addition, the life cycle test on the supplier prototype vacuum cleaner verified that the unit was capable of meeting the specified operational life requirements. The vacuum cleaner was operated for 1963-cycles of 6-minutes each; the canister was removed and reinstalled on the power module 100 times; the hose from the vacuum cleaner was attached and detached 980 times; the accessory tools were attached and detached at the vacuum cleaner, and at the end of the hose, a total of 980 times at each location (the cycling was divided evenly between the three tool attachment); the debris bag was changed a total of 280 times.

Two endurance tests were run on the blower, the most critical time dependent item in the power module.

(a) In order to validate the solution of premature bearing failures, a test program was undertaken to demonstrate the compressor reliability. A compressor was modified to incorporate the recommended changes and subjected to a pre-qualification test which included vibration, vacuum, acoustic noise, aerodynamic performance, and extended life. The compressor was operated successfully for 600-hours without signs of degradation in performance. The results of this testing are documented in AiResearch Report Number 71-7693, dated July 28, 1971. Based on the results of this inspection, 1400-hours of additional endurance testing seemed to be a viable goal. Therefore, this additional testing was undertaken and completely successful. The results of this additional testing are documented in AiResearch Report Number 71-7962 dated November 12, 1971.

(b) Prior to completion of endurance testing, a blower assembly was subjected to qualification testing successfully. In the course of testing the unit experienced 7,000 starting surges over a period of 630-hours of operation. The results of this testing are documented in AiResearch Report Number 71-7886, dated September 30, 1971.

Based on the foregoing test results, the capability of the power module and vacuum cleaner to meet and exceed their operational life requirements is deemed to have been clearly demonstrated.

d. Collection Bags

(1) Summary of Capabilities Versus Design Requirements - The collection bags demonstrated their capability of attaining the design requirements.

(a) The Fecal and Fecal Contingency Bag demonstrated:

- Their ability to collect in a zero-g environment.
- Their ability to prevent bacteria contamination from escaping into the atmosphere during collection, mass measurement and processing.
- Their capability to collect the maximum required volume of feces, diarrhea and vomitus.
- Their compatibility with the operational requirements of the 1B79136-1 Waste Processor Module.
- Their capability to provide sanitary conditions for the collection, retention and sealing of feces, diarrhea and vomitus.
- Their ability to prevent mixing of and cross-contamination of collected feces, diarrhea and vomitus.
- Their capability to be disposed of through the trash airlock and withstand the airlock depressurization.

(b) The Debris Collection Bag:

- Demonstrated the ability to contain waste matter particles and liquid while installed in the Vacuum Cleaner with the power module shut-off.
- Provided sanitary conditions for the collection, retention and sealing of debris by the crewman.
- Demonstrated its ability to prevent bacteria contamination from escaping into the atmosphere.
- Demonstrated its ability to interface with the vacuum cleaner interlock to prevent operation unless a bag is installed.
- The capability to collect 350 ml and contain liquids at 20 inches of water pressure with no leakage.
- The capability to be disposed of through the trash airlock and withstand the airlock depressurization.

(2) Summary of Open Problems and Plans of Corrective Actions - There were no open problems or plans for corrective action associated with the Collection Bags. All problems generated during the development and design phase were resolved satisfactorily.

(3) Long Duration Operational Capability - The collection bags completed the shelf life test as recorded in MS115T0047 ("Test Plan and Procedure for Shelf Life Tests of Collection Bag Adhesive Materials", dated January 15, 1971).

(a) Trash Collection Bags - Two line item tests were performed to establish the adequacy of the trash bags:

- Line Item HS-67 Trash Bag Deployment Test
- Line Item ST-35 Trash Airlock Functional Capability Test

The Trash Bag Development Test consisted of tests to evaluate concepts of trash bag materials and designs and to verify proper operation of the final selected configuration under simulated on-orbit conditions. Part I of the test included leakage, burst and stowage tests on materials and bag designs. Part II verified the operational interface of the trash disposal airlock/trash bag concepts and included life cycle tests of parts of the Trash Disposal Airlock Assembly.

Based on the design requirements established for the Waste Management, Trash Collection Subsystem, it was concluded that the materials and design configurations selected would meet the above requirements.

The interface of the Trash Disposal/Trash Bag concepts was verified and the life cycle tests of the ejector detent and inboard hatch latch assembly were successfully completed.

The objectives of the ST-35 test were to evaluate the compatibility of the TALs internal trash cyclinder and its ejection system when subjected to various contingency anomolous configurations of filled trash, urine and disposal bags. This test consisted of airlock depressurization and ejection cycling of armalon bags containing combinations of stowed items that may have presented an ejection problem during habitation. The ejected equipment items were compiled from the OWS Stowage Location Usage Report.

All testing was completed successfully. None of the bagged specimens became lodged within the airlock cylinder, and no problems were experienced with bag breakaway tabs and rejection forces were low to moderate.

No problems were encountered with bag tape and snap fastener even during degraded bag modes, therefore all specimens ejected through trash airlock within the limitations of the test objectives were thereby qualified for use in the Orbital Workshop.

e. Centrifugal Urine Separator

(1) Summary of Capabilities Versus Design Requirements - Based on the successful completion of all special feasibility testing, Design Verification Testing, and Production Acceptance Testing of each unit, it was concluded that the CUSA was compliant with all of the applicable SCD design requirements.

(2) Open Problem and Resolution Summary - None

(3) Time/Life Cycle Limitations - The SV748753-1 Support and Filter was a time/life cycle limited component. Based upon the Design Verification Testing and resultant data obtained, Hamilton Standard recommended the Support and Filter be replaced after 28-days of use.

f. Trash Airlock

(1) Summary of Capabilities Versus Requirements - Based on analytical results, it was determined that actual factors of safety exceeded required factors of safety. Therefore, the structural integrity of critical components of the trash disposal airlock was verified analytically.

It was concluded from the analytical and test results that the trash disposal airlock met all design requirements for use on the OWS.

The trash airlock development test (line item HS-24) was completed successfully and verified the design requirements for leakage, proof and burst pressures, vibration, and repeated functional cycles under orbital differential pressure and temperature environments.

3. <u>Subsystem Certification</u>

a. General - Design maturity of the OWS Waste Management Subsystem was predicated on the results of the extensive and methodical testing. The test results demonstrated that:

(1) The method of achieving waste management in a zero-g environment was valid.

(2) The functional capability of the WMS system/components was not degraded after exposure to simulated flight level environments.

(3) The system/component endurance capabilities were adequate for the proposed OWS flight program.

(4) The materials used in the WMS were compatible with crew safety.

(5) The methods used in the WMS were compatible with crew safety.

Specific major component certification is given below.

b. Waste Processor

(1) Basic for Certifying Design Maturity and Manned Flight Safety - Design maturity of the waste management fecal and vomitus processor was based on extensive and methodical development spanning a period of at least six-years. Development was started on the MOL program and finalized on the Skylab program.

Initial development established basic design parameters such as temperature, vacuum line sizing and pressure plate force. Further refinements incorporated such features as pressure plate and door damper, temperature controls for operational and over temperature modes, time delays and timers. Hardware incorprating these features was subjected to severe laboratory tests such as vibration and cycling to evaluate its flight worthiness.

Allflight units underwent a comprehensive acceptance test prior to installation. Design safety criteria was emphasized during the design phase. Safety features inherent in the design and processor were:

(a) A safety interlock preventing opening of the chamber when vented to vacuum.

(b) Burn hazards were eliminated by stringent temperature control and limitations.

(c) Shock hazards were eliminated by use of low voltage.

(d) Electrical fire hazards were eliminated by design and construction under strict Quality Control supervision.

c. Collection Module

(1) Basis for Certifying Design Maturity and Manned Flight Safety - Design maturity of the waste management fecal and urine collection module was based on an extensive and methodical development period spanning at least six years. Development was started on the MOL program and finalized on the Skylab program.

Initial development established basic design parameters such as airflow, orifice size and orientation, and man interface. Further refinement of the system was accomplished by flight testing in a KC-135 in a zero-g environment using a simulated fecal dispenser. The system was finally man-rated by operating in a zero-g flight test program using human subjects.

The Skylab hardware, beside incorporating all the parameters established during the development program, had been subjected to severe laboratory tests such as vibration and cycling to evaluate its flight worthiness.

All flight units underwent a comprehensive acceptance test before being installed.

Design safety criteria was emphasized and carefully monitored during the design phase. Safety features inherent in the design of the collector module were:

(a) Supports and restraints safety retained the crewman in position during collection in zero-G.

(b) Noxious odors and gases were filtered out of the collection airstream by an odor control filter.

(c) Fecal bacteria were prevented from escaping into the Skylab atmosphere.

(d) All controls were guarded against inadvertent actuation.

(e) Shock hazards were eliminated by the use of low voltage.

(f) Redundancy, spares, and the ease of replacement enhanced the safety and reliability of the collector.

d. Vacuum Cleaner and Power Module

(1) Basis for Certifying Design Maturity and Manned Flight Safety - Design maturity of the waste management vacuum cleaner and power module was based on extensive and methodical development spanning a period of at least six years. Development was started on the MOL program and finalized on the Skylab program.

Initial development established basic design parameters such as airflow and orifice size. Early zero-g flight tests were conducted on the MOL program to refine these basic parameters. Further refinements incorporated such features as varied attachments including a surface tool, crevice tool, brush and hose.

Hardware incorporating these features was subjected to severe laboratory tests such as vibration and cycling to evaluate its flight worthiness, safety and performance.

All flight units underwent a comprehensive acceptance test prior to installation. Design safety criteria were emphasized during the design phase. Safety features inherent in the design of the vacuum cleaner were:

(a) A safety interlock prevented operation as a vacuum cleaner if a debris bag was not installed, preventing contamination of the power module.

(b) Overload hazards were eliminated by use of a circuit breaker integral with power module.

(c) Shock hazards were eliminated by use of low voltage.

(d) Electrical fire hazards were eliminated by design and construction under strict Quality Control supervision.

e. Collection Bags

(1) Basis for Certifying Design Maturity and Manned Flight Safety - Design maturity of the waste management collection bags was based on an extensive and methodical development period spanning at least six years. Development was started on the MOL program and finalized on the Skylab program.

Initial development established basic design parameters such as bag element arrangement, pressure differential and filter material.

Further refinements resulted in adaptation of the basic parameters to the different bag configurations. Sealing methods were developed and extensively tested. Various filter materials were selected and tested for processing optimization. Time line tests were conducted for substantiating statistical data.

Flight hardware incorporating all these features were subjected to severe laboratory tests to evaluate its flight worthiness from a safety and performance criteria.

Each flight bag underwent a comprehensive acceptance test before being installed.

(a) Trash Collection Bags - All testing was completed successfully. None of the bagged specimens became lodged within the airlock cylinder, no problems were experienced with bag breakaway tabs, and rejection forces were low to moderate.

No problems were encountered with bag tape and snap fastener even during degraded bag modes, therefore all specimens ejected through trash airlock within the limitations of the test objectives were thereby qualified for use in the Orbital Workshop.

f. Trash Airlock Subsystem Certification

(1) Basis for Certifying Design Maturity and Manned Flight Safety - All stress analysis and structural demonstration tests relative to the trash disposal airlock were satisfactorily completed to verify structural integrity.

(2) List of Open Items - None.

(3) List of Waivers and Deviations to Specifications - None.

4. <u>HS and ST Test Summaries</u> - The fecal/urine collection system successfully passed all Qualification Tests. The specimen demonstrated satisfactorily performance and compliance with design requirements.

Note: Redesign of the urine system from 2000 ml capacity to 4000 ml capacity shortened some of the testing. This testing was picked up later by HS-90.

The portable vacuum cleaner, waste processor, stowed urine separator, urine dump compartment, fecal bag dispenser bag bundles, and collection bag return assembly all successfully passed their individual qualification test requirements with no failures or problems noted. Each specimen tested demonstrated satisfactory performance and compliance with its design requirements.

B. Whole Body Shower

1. Testing - Various tests were conducted by MSFC on the whole body shower (WBS) to develop and qualify the equipment and techniques needed for successful body cleaning.

a. Development - A study was made of a zero-g, whole body shower for use during the extended, manned orbital flights of the Skylab series. Subsystem components were developed and tested to verify conceptual proposals and to provide engineering data for system design. A large effort was devoted to the development of an air-water phase separator. Three concepts of air-water phase separation were investigated with a mechanically driven centrifugal design chosen over two passive types. A functionally high fidelity shower system was assembled using a plexiglass shower enclosure for laboratory testing. Shower water was collected using a vacuum pick-up system and subsequently removed from the airstream for disposal with the centrifugal - type air-water phase separator. The system was tested in earth gravity and at both atmospheric and reduced air pressures. Test results indicated that the system design was feasible for the orbital workshop environment, and that an effective shower system could be assembled largely from modified OWS components.

b. Qualification - The qualification test was performed on the Orbital Workshop Whole Body Shower, Water Bottle Module Assembly (MSFC Dwg. No. 20M32509, S/N 002). These tests were performed to determine if the Water Bottle Module Assembly could meet the requirements established by the MSFC Specification Control Dwg. 20M33020 and detailed in test procedure DOP-TMM-72-11.

Two components malfunctioned during the qualification testing. During the life cycle test of the relief valve, the reseat pressure decreased from the required 29-psig down to 22-psig. After 20 cycles of the required 100 installation cycles, a retaining spring in one of the quick release fasteners failed; however, the test was completed without further malfunctions.

In addition, an apparent leak in the diaphragm was caused by entrapped air which required approximately 3-hours to disperse. This condition was verified by S&E-QUAL.

The CCOH and destructive tests were performed after the system tests. Results of these tests were satisfactory.

The failure of the quick release fastener spring was considered insignificant since the water bottle could still be mounted satisfactorily. Also, there are three quick release fasteners on the bottle and one was sufficient to hold the bottle in zero "G". The low reseat pressure on the relief valve is also a minor problem; therefore, the water bottle was considered qualified and recommended for use on the Orbital Workshop Whole Body Shower System.

c. KSC Testing - The KSC activity consisted of leak checking the shower, the inter-connect tubing, and the pump. The pump was functionally verified by operation and the whole system was stowed aboard the OWS. The testing was completed and all results were satisfactory.

C. Suit Drying

1. Development Tests - The test specimen, essentially identical to the production unit, was subjected to all environments expected through the Skylab mission from launch to on-orbit requirements. The following environments were tested:

- Proof Pressure, Leakage, and Flow vs Δp.
- Functional Test of Power Module.
- Functional Test of Zitex Desiccant Container.
- Acoustical Measurement Tests.
- Vibration Test of Zitex Desiccant Containers.
- Functional Life Cycle Tests.
- Post Test Inspections.

2. Qualification Test - Not applicable.

3. Acceptance Test - Not applicable.

4. Special Tests - During the first and second week in June, 1972 an actual PGA was loaned to MDAC so that development-type tests could be performed on two desiccant assemblies proposed for use in a semi-closed loop drying system. The following basic procedure was followed:

a. The PGA drying system, including the PGA, was installed in an environmental chamber that was controlled to the highest air dewpoint expected for Skylab habitation area (60^{o}F). The temperature was controlled at $83 {}^{+2}_{-0}{}^{o}$ F to test the thermal characteristics of the Electronic Controller of the power module. The dry weight of the PGA and desiccant assemblies was recorded just prior to the drying test. Five hundred grams of water were added to the liner of the PGA and PGA closed immediately thereafter. During the drying operation, the continuous decrease in PGA weight was to be recorded but data was lost due to the electronic setup. In one case,only was the continuous decrease in PGA weight obtained.

5. Problems and Corrective Actions

a. Problem - During the initial functional air flow test, the power module failed to exhaust a minimum of 5 ACFM to the two PGA. Flow rate as measured was below calibration of the flowmeter.

(1) Solution - A rubber duct was added to the power module exhaust port and routed to the non-propulsive vent. At the non-propulsive vent a rubber seal was added to prevent air leakage and to channel the air into the manifold assembly. After this duct addition, the air flow versus Δp exceeded the design requirement of 5 ACFM to each PGA.

b. Problem - During the initial ten-hour functional test where the test chamber was controlled at 83$^{+2}_{-0}$F, the power module electronic controller overheated.

(1) Solution - A small orifice (.130/.134 DIA.) was cut in the rubber duct previously added and air flow channeled across the electronic module. This orifice provided 1.3 ACFM to the electronic module which reduced the temperature approximately 12^{o}F. To reduce the temperature further, another orifice was cut to increase the air flow but during the test verification run, the new orifice did not reduce the temperature any appreciable amount. Therefore, all remaining tests (life cycle) was run with one orifice only. The resulting temperature was acceptable to the manufacturer of the power module.

c. Problem - During a functional drying test performed at JSC/NASA where approximately 6.85 ACMF (70% O_2/30% N_2, and 90^{o}F and 60^{o}dp), was channeled through the PGA, approximately 75 grams of moisture (water) remained in the suit after 5-1/2 hours of drying using an open loop system. The excessive moisture (75 grams) was considered by JSC/NASA to be not adequate for control of Fungal contamination resulting in degradation of PGA materials.

(1) Solution - Change concept from drying two PGA's at one time to one PGA at a time. Also, after drying PGA with air flow power module, place in the PGA a sufficient amount of desiccant to absorb the remaining moisture. A 6 1/2 foot length of Zitex Dessiccant Assembly was added to the drying technique. Test data that uses a PGA simulator (1/10 volume of actual PGA) and a desiccant bag manufactured out of Zitex material and Silica Gel was tested with satisfactory results. Two vacuum drying tests using the wet desiccant bags resulted in the desiccant being dried completely after ten hours.

6. Subsystem Conclusions

a. Summary of Capabilities Versus Requirements - Based on the test results and the power module performance after life cycles the air flow rate and moisture removal has been demonstrated. Removal of moisture remaining in the PGA after dynamic drying was also demonstrated.

It is concluded from test results that the PGA Drying Station will meet all design requirements for use on the OWS.

b. Summary of Open Problems and Plans for Corrective Action

None.

c. Long-Duration Operational Capability - Not applicable.

7. Subsystem Certification

a. Basis for Certifying Design Maturity and Manned Flight Safety - All functional demonstration tests have been satisfactorily completed to verify that moisture removal from PGA will be accomplished.

D. Stowage

The Stowage subsystem provided provisions for containment/restraint for loose equipment in the OWS during the launch/boost phase and zero-g. Stowage provisions consisted of containers, lockers, cabinets, film vault, food freezer/chiller and miscellaneous restraint provisions. Checkout for the Stowage subsystem consisted of 1B96422, Stowage Procedure, plus eighteen additional procedures, mostly experiments and water subsystem hardware.

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

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

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

- Launch pressure - Support of equipment deemed satisfactory.
- Orbital pressure - Design changes were required on M-487 stowage box. These changes were accomplished.

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

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

Six (6) procedure change requests (PCR's) were written due to stowage changes. Three (3) bench reviews were conducted with crew participation and all components or representative samples were reviewed. There were 1,255 deviations written and 231 IDRs generated during the total test run. None of these were any major problem and all were closed or upgraded to DRs.

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

E. Crew Systems

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

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

No significant problems were encountered during checkout

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

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

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

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

1. KS-0010A - Integrated Crew Compartment Fit and Functional Test - The Crew Compartment Fit and Functional Test (CCFF) at KSC was performed to accomplish the verification of fit check and functional sequences that were not satisfied during the first CCFF (1B86424) at Huntington Beach due to lack of hardware or non-acceptable equipment requiring modification and subsequent review. The specific tasks performed by the Flight Crews, under the direction of assigned Test Conductors were:

- Verification of the accessibility and operational suitability of the previously non-verified stowed and installed OWS module equipment provisions.

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

APPROVAL

MSFC SKYLAB CREW SYSTEMS MISSION EVALUATION

By

Man-System Integration Branch

Systems Analysis and Integration Laboratory

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 been reviewed and approved for technical accuracy.

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