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REPAIR OF MAJOR SYSTEM ELEMENTS ON SKYLAB

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16. ABSTRACT

In-flight maintenance, as conceived and preplanned for the Skylab Mission was limited to simple scheduled and unscheduled replacement tasks and minor contingency repairs. Tools and spares were provided accordingly. However, failures during the mission dictated complicated and sophisticated repairs to major systems so that the mission could continue. These repairs included the release of a large structure that failed to deploy, the assembly and deployment of large mechanical devices, the installation and checkout of precision electronic equipment, troubleshooting and repair of precision electromechanical equipment, and tapping into and recharging a cooling system. The repairs were conducted both inside the spacecraft and during extravehicular activities. Some of the repair tasks required team effort on the part of the crewmen including close procedural coordination between internal and extravehicular crewmen.

The Skylab experience proves conclusively that crewmen can, with adequate training, make major system repairs in space using standard or special tools. Design of future spacecraft systems should acknowledge this capability and provide for more extensive in-flight repair and maintenance.

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INTRODUCTION

In-flight maintenance, as conceived and preplanned for the Skylab mission, was limited to simple scheduled and unscheduled replacement tasks and minor contingency repair. Tools and spares were provided accordingly. The scheduled in-flight maintenance activities were held to a minimum in order to conserve crew time for maximum experiment activities. Requirements were established only where periodic cleaning or replacement of consumable, cycle sensitive or time sensitive items were necessary. These maintenance requirements were included in the crew checklists as part of the normal housekeeping tasks. Performance of the tasks was controlled by the flight plan and scheduled to accommodate crew workload. Table 1 is a list of the 16 scheduled in-flight maintenance tasks which were preplanned for the Skylab mission. Tasks performed were much the same as planned, although a number of unscheduled in-flight maintenance activities were carried out. Maintenance capability was provided for the purpose of replacing failed components, installing auxiliary and backup hardware, and servicing and repairing equipment. This service was provided in the form of spares, tools, and procedures for performing 160 different unscheduled tasks. Representative tasks are listed in Table 2. Skylab crews performed many of these unscheduled maintenance tasks during the three missions. It is interesting to note that no major problems were encountered in the performance of the preplanned scheduled and unscheduled tasks. Tools, spares, procedures, and training were adequate.

MAJOR FAILURES REQUIRING CONTINGENCY MAINTENANCE

In addition to the capability for scheduled and unscheduled in-flight maintenance, tools and materials were placed on board to provide a general maintenance capability. This capability was provided to permit repair of failed equipment for which no specific in-flight maintenance activity was anticipated. Contingencies did develop during the missions which required using the onboard support equipment but for which procedures had to be developed in real time and uplinked to the crew. Other contingencies developed for which onboard maintenance support was inadequate, thus additional tools and equipment were launched aboard the three Command/Service Modules (CSMs).

TABLE 1. SCHEDULE OF PREPLANNED IN-FLIGHT MAINTENANCE ACTIVITIES

Task Description[a]	Planned Frequency
Vacuum Clean ECS Inlet Screens	
OWS Air Mixing Chamber	7 days
MDA Fans	7 days
AM Circulating Fans	7 days
WMC Debris Coarse Filter	7 days
Replace WMC Vent Unit Fine Filter	7 days
Replace Shower Filter	7 days
Replace Mol Sieve Solids Traps	11 days
Replace Inlet CO_2 Detector Cartridges	14 days
Replace WMC Vent Fine/Coarse Filters	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 and 4 Activation
Replace ATM C&D Cooling Water Filter	Before and After EREP[b] Operation SL-2
Replace EVA/IVA Gas Coolant Separator	SL-3 and 4 Activation
Replace Urine Separator	SL-2 and 3 Deactivation
Vacuum Clean OWS Solenoid Vent Filter	SL-3 and 4 Activation

a. ECS — Electrical Control System
MDA — Multiple Docking Adapter
AM — Airlock Module
WMC — Waste Management Compartment
ATM — Apollo Telescope Mount

b. EREP — Earth Resources Experiment Package

TABLE 2. REPRESENTATIVE SAMPLING OF UNSCHEDULED IN-FLIGHT MAINTENANCE ACTIVITIES

Waste Management System
- Replace urine separator
- Replace urine separator motor
- Clean trash airlock vent valve filter
- Replace trash airlock pressure gauge seal and O-rings

Environmental Control System
- Replace ventilation fan
- Replace molecular sieve solids trap and charcoal canister
- Replace condensing heat exchanger water separator plates
- Replace WMC filter and charcoal cartridge

Instrumentation and Communications System
- Replace speaker intercom assembly
- Replace crewman communication umbilical
- Replace teleprinter assembly
- Replace AM tape recorder

Water System
- Replace hot water dispenser
- Replace ward room water hose
- Service/deservice water systems
- Replace ward room water heater

Electrical System
- Replace S190 window heater control unit and cable
- Replace general illumination flood lights
- Install Skylab to CSM contingency power cable
- Replace urine separator cable assembly

Structures System
- Contingency opening of hatches
- Replace habitation area vent plug
- Contingency opening ATM aperture doors
- Release or adjust locker and freezer doors

Experiment Systems
- Replace ATM manual pointing controller
- Replace mass measuring device electronics module
- Replace ergometer drive assembly
- Install EREP diagnostic downlink unit

Approximately 30 contingency maintenance tasks were performed by the Skylab crews; Table 3 lists these tasks by mission. Many of these involved major repairs to the cluster systems to permit continuation of the mission or to avoid significant compromises in attaining mission objectives. The locations of major repair activities are shown in Figure 1.

Six of these major system repairs have been selected for detailed discussion in this paper:

1. Release of the Orbital Workshop (OWS) solar array that failed to deploy.

2. Deployment of the parasol sun shield.

3. Deployment of the twin-pole sun shield.

4. Installation of the rate gyro package.

5. Coolant system reservicing.

6. S193 antenna repair.

These six were selected to represent the wide range of complicated and sophisticated repairs performed and include the release and deployment of a large structure, the assembly and deployment of large mechanical devices, the installation and checkout of precision electronic equipment, tapping into and recharging a closed loop fluid system and the troubleshooting and repair of precision electromechanical equipment. They also are representative of intravehicular (IVA) and extravehicular (EVA) activities requiring crew teamwork with close procedural coordination.

RELEASE OF SOLAR ARRAY WING

Sixty-three seconds after lift-off, abnormal meteoroid shield and workshop solar array indications were received showing that the shield tension straps had separated and that solar array wing 2 was in an "insecure" position. This meant the shield and solar array had deployed prematurely. Analysis of subsequent data indicated that the meteoroid shield was lost and that apparently one solar array wing was gone completely and the other was only partially deployed.

TABLE 3. CONTINGENCY MAINTENANCE TASKS BY MISSION (IN ORDER OF OCCURRENCE)

SL-2

- Parasol thermal shield deployment
- Experiment S019 extension mechanism repair
- Lubrication of ergometer pedals
- OWS solar array wing deployment
- Experiments T027/S073 backup tripod mounting
- CBRM #15 contingency procedure

SL-3

- Twin pole sail (thermal shield) deployment
- Experiment S055 door ramp latch removal
- Airlock module tape recorder disassembly
- Mark 1 exerciser repair
- Condensate system leak check
- Coolant system leak check
- Rate gyro package installation
- Experiment S082A door ramp latch removal
- Experiment S056 door ramp latch removal
- Ergometer pedal screw replacement
- OWS heat exchanger cleaning
- Video tape recorder circuit board removal
- Condensate dump probe troubleshooting
- Experiment S192 attenuator adjustment

SL-4

- Urine drawer seal replacement
- Primary coolant loop servicing
- Rate gyro package thermometer installation
- Experiment S193 antenna repair
- ATM TV monitor No. 1 replacement
- Experiment S082B auxiliary timer installation
- Experiment S009 drive motor replacement
- Mark 1 exerciser repair
- Liquid/gas separator installation in the ATM C&D coolant loop
- Experiment S054 filter wheel positioning

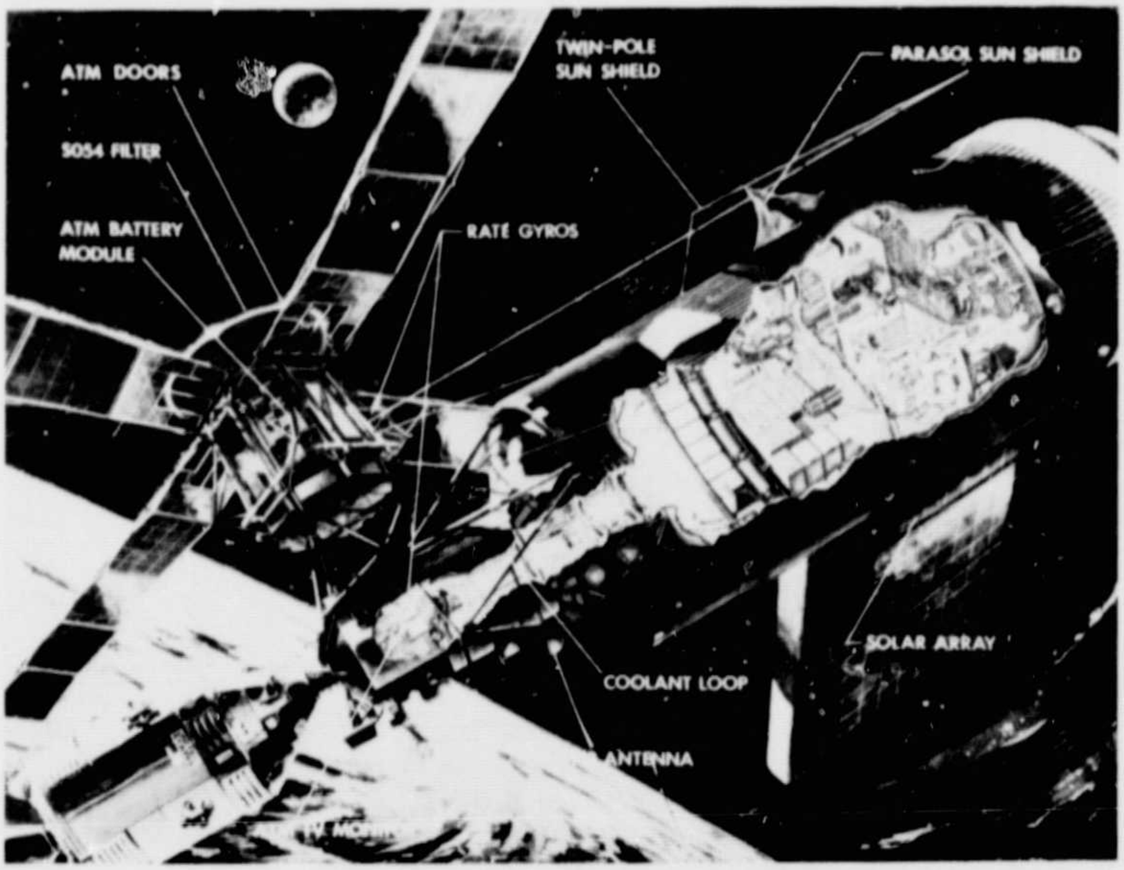

Figure 1. Locations of major maintenance activities.

While it could not be determined if the entire meteoroid shield had come off, the temperature increase in the Orbital Workshop (OWS) after orbit was reached confirmed that essentially none of the anticipated thermal protection was being provided. The Skylab, through analysis and experimentation, was placed in an attitude to minimize heating of the interior by solar radiation. In the meantime, the Apollo Telescope Mount (ATM) solar arrays were deployed successfully and provided power to maintain the spacecraft in the unactivated mode.

The launch of the first crew, on Skylab 2, was delayed 10 days to permit design, fabrication, and testing of ways to release the OWS solar array and to provide a thermal shield that would reduce the internal temperatures to a habitable level.

Work on ways of freeing and deploying the solar arary beam was begun immediately. It was speculated that the restraining debris existed in the form of bolts, sheet metal, and metal straps. Consequently, a decision was made to concentrate on shear-type sheet metal cutters and cable cutters. Tools were fabricated, tested, used for crew training and demonstration, and launched with the first CSM.

After the SL-2 crew performed their rendezvous with the Skylab, they did a fly-around inspection describing the condition of the damage and making photographs. Live TV coverage was transmitted to the ground for 15 min. The crew confirmed that the meteoroid shield was missing, OWS solar array wing 2 was missing, and that solar array wing 1 was partially deployed. Figure 2 shows a view of the damaged Skylab.

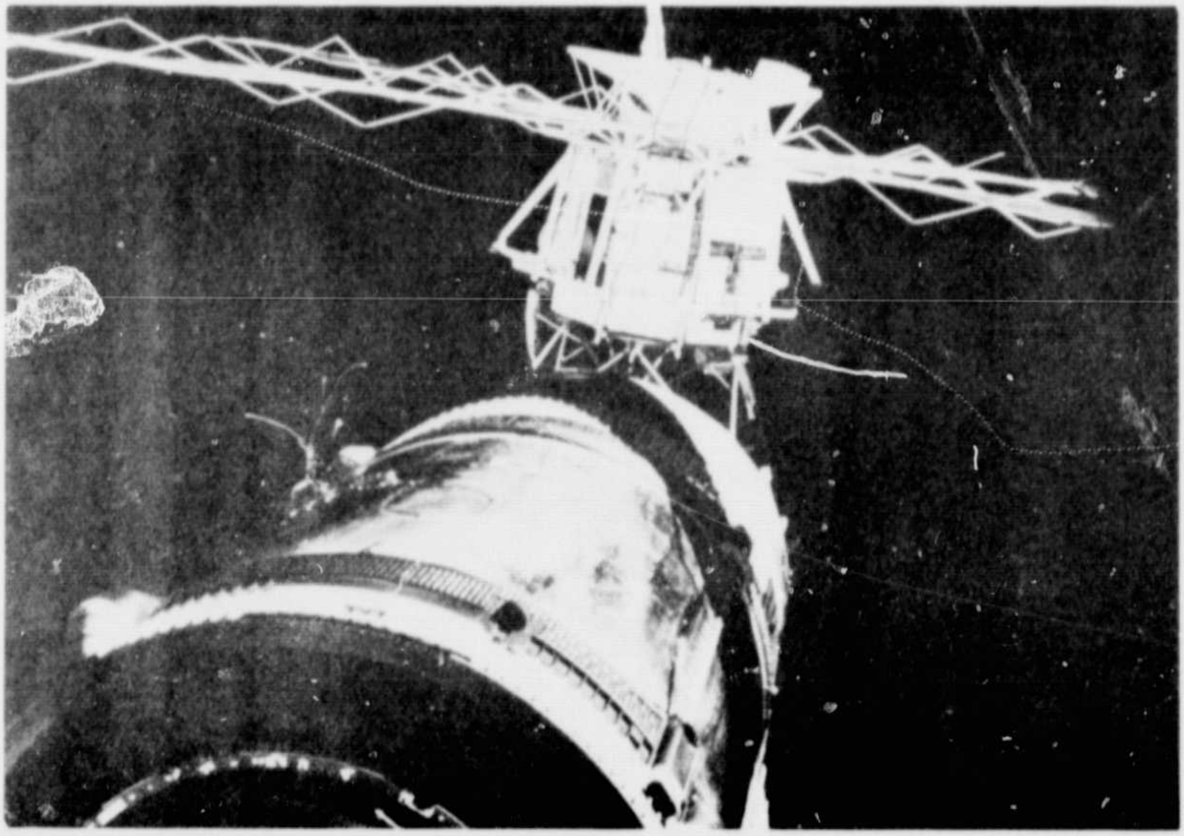

Figure 2. Skylab 2 fly-around inspection. (View of damaged workshop showing unshielded area where parasol was later deployed. The jammed solar wing is at lower right.)

Figure 3 shows solar array wing 1 partially deployed. Closer inspection by the crew revealed that the solar array beam was restrained by a small piece of aluminum alloy strap from the meteoroid shield. The crew attempted to free the wing during a standup EVA from the CSM, using a 3.04 m (10 ft) pole with a hook on the end for prying and pulling. This attempt failed and the wing deployment activities were deferred to a later EVA. Meanwhile work was still in progress on procedures to be used to free the solar array wing. The fly-around television pictures and crew description of the damage provided the basis for the procedures. This contingency repair involved releasing the beam by cutting the aluminum strap and deploying the beam to the normal operation position. The procedures were developed and demonstrated in the neutral buoyancy facility at the Marshall Space Flight Center (MSFC) with astronauts using tools identical to those on board.

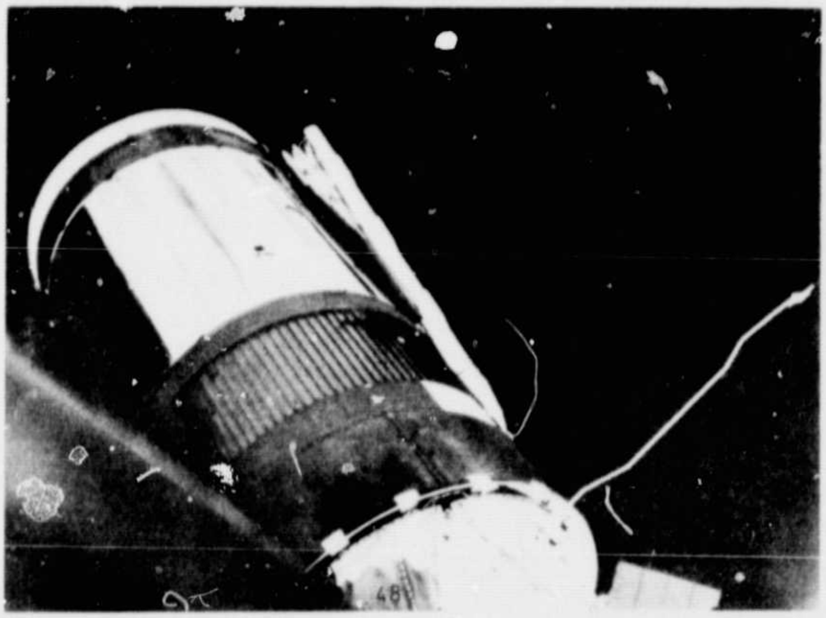

Figure 3. Solar array wing 1 partially deployed.

On June 7, 1973, the Commander and Science Pilot spent nearly four hours in perhaps the most difficult and daring of all orbital repair jobs. The task was especially complicated by the absence of EVA aids in the area of the solar array beam. Figure 4 shows the aluminum strap holding the beam. The crew translated to the fixed airlock shroud area and assembled a tool made up of a 7.6 m (25 ft) pole with a rope operated cutter on one end. Figure 5 shows this cutter tool being tested by MSFC engineers. The cutter end was attached to the debris and the Commander, using the pole as an aid, translated to the cutter end. Then, with the Commander managing the cutter, the Science Pilot cut the aluminum strap using the rope for control. A typical sample of the aluminum strip that held the solar wing is shown in Figure 6.

After release, the beam deployed out to about 20 deg and stopped. This was predictable since the beam damper-actuator was below the freezing temperature of its fluid. In anticipation of this the crew had installed a tether between the vent module and a strut in the fixed airlock shroud area. A crewman then stood up under the tether as shown in Figure 7. The tension thus applied to the solar wing broke loose the frozen damper-actuator that still held the wing, permitting the wing to swing out and lock into place.

PARASOL DEPLOYMENT

Many viable schemes for recovering the lost thermal control were postulated. During the 10 day period between May 15 and May 25, 1973, a herculean effort was mounted, not only by NASA but by contractors as well.

Johnson Space Center (JSC) designed a parasol thermal shield to fit in a small canister that had been designed to house an experiment to be deployed through the scientific airlock. It operated much as a normal parasol, having four legs and a center post. The center post was held by the crew in the workshop, and the telescoping legs were shoved out through the canister extending through the +Z scientific airlock. The legs were spring loaded so that all four legs extended when they cleared the canister. Another JSC concept was to let the crew rig a shield while standing in the open Command Module hatch. The crew was to take a fabric shield and, using poles with hooks at their ends, attach pulleys and ropes to the Saturn Workshop to rig up a shade. This concept seemed simple, but the necessity for keeping the Command Module close to the Saturn Workshop and uncertainty of the crew's being able to tie the shield firmly using a pole led to retaining this concept only as an alternate method.

MSFC developed a thermal shield concept which required the crew to perform an EVA, going outside and hanging a fabric thermal shield from a twin-pole A-frame. The top of the A-frame would be attached at the solar observatory work station, then the 16.76 m (55 ft) long poles would be extended down the side of the workshop, and the thermal shield would be stretched between the poles.

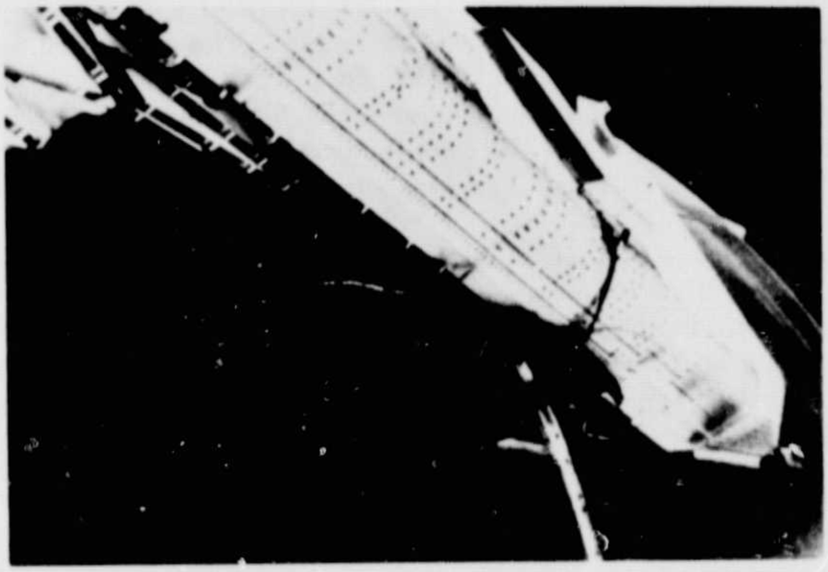

Figure 4. Aluminum strap restraining solar array beam.

Figure 5. Cutting tool being tested.

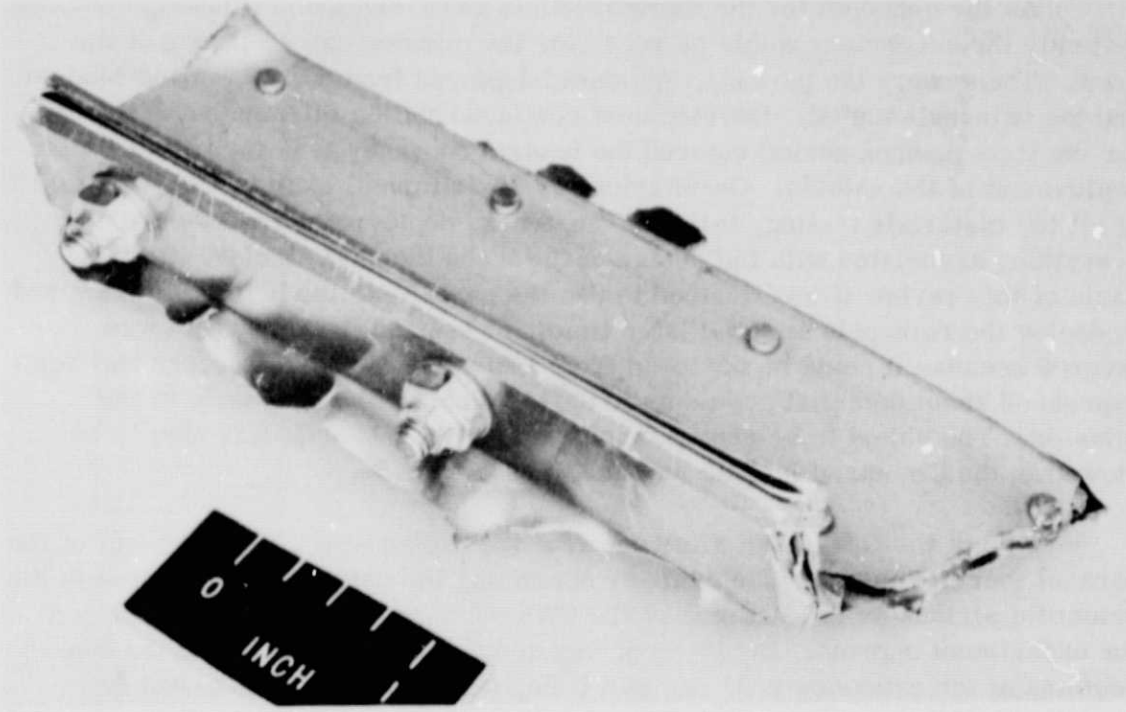

Figure 6. Sample segment of the aluminum (Al 7075-T6) strip that held the solar wing.

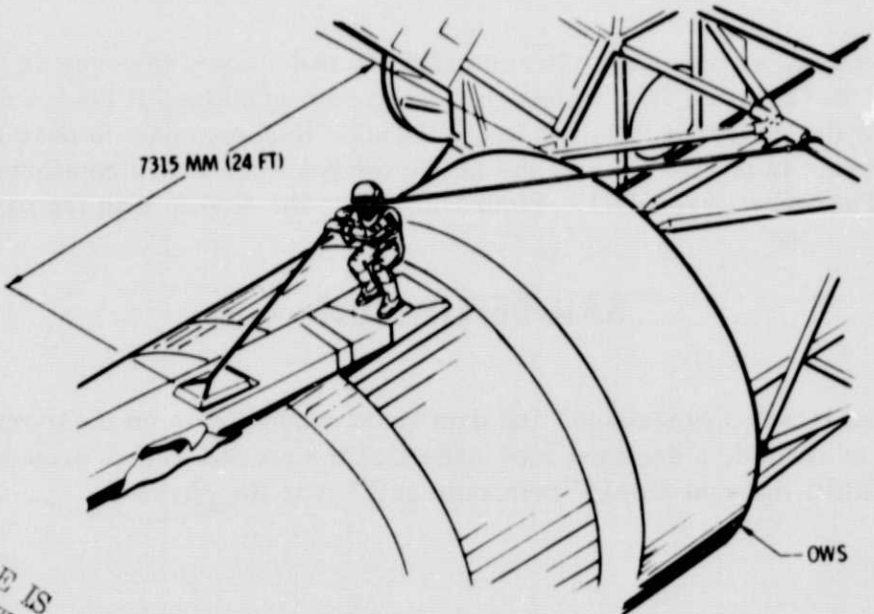

Figure 7. Standup operation used to finally erect the wing.

As the concepts for the thermal shield were developed it became obvious that only three versions would be ready for the mission day 12 launch of the crew. These were the parasol, the shield deployed from the Command Module, and the twin-pole shield. Development continued and on mission day 9 the crew for the first manned period entered the neutral buoyancy tank for training in deployment of the shields. On mission day 10, a formal examination was held of all the materials testing, failures, analyses, deployment procedures, and everything associated with the design of the three thermal shields. On the basis of this review it was decided to use the parasol as the primary device and to deploy the twin-pole at some later time, if required. The parasol was favored because it could be deployed from inside the Skylab. Concern had been expressed about potential problems in performing an EVA too early in the mission. The shield to be rigged from the Command Module was also to be stowed in the Command Module as a contingency device.

One of the first tasks after entering the Skylab was the deployment of the parasol thermal shield. The canister containing the parasol was mounted to the scientific airlock on the sun side of the OWS supported by the tripod provided for experiment support. Deployment was accomplished by attaching the five sections of the extension rod, one at a time, until the parasol extended far enough out of the scientific airlock to permit release of the four telescoping rods, which in turn deployed the shield. After the shield was deployed, the extension rod was pulled back inside, securing the parasol next to the OWS external surface. The extension rod was removed and stowed. Figure 8 shows the deployment sequence in cutaway views and Figure 9 shows the sequence of deployment as viewed from the outside.

The shade, or parasol as it was called, was designed to cover an area 6.70 by 7.31 m (22 by 24 ft). Although it had a few wrinkles, it covered about 90 percent of the proposed area and brought inside temperatures to near normal in about 2 days. In about 11 days, the inside temperature was a comfortable 75 degrees Fahrenheit (23.9°C). Figure 10 shows the Skylab with the parasol in place.

SAIL DEPLOYMENT

As the mission progressed and data from ground tests on the thermal shield were evaluated, a decision was made that the second Skylab crew should deploy the MSFC thermal shield "twin-pole sail" over the parasol.

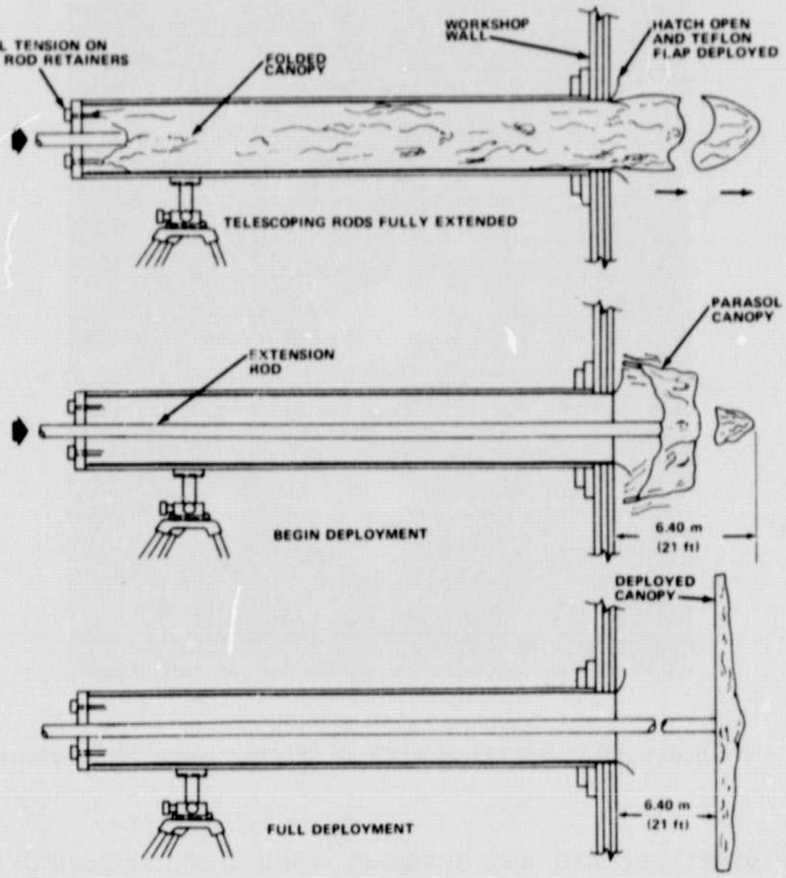

Figure 8. Development sequence of the parasol canopy inside the OWS.

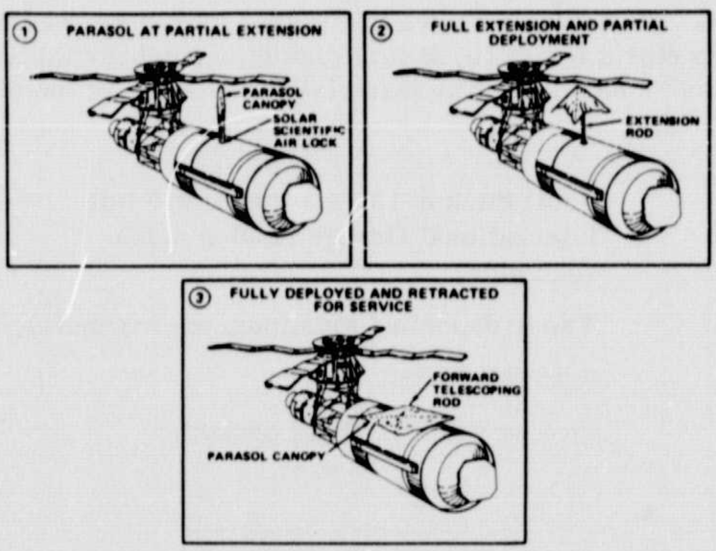

Figure 9. Deployment sequence of the parasol canopy as it appeared outside the OWS.

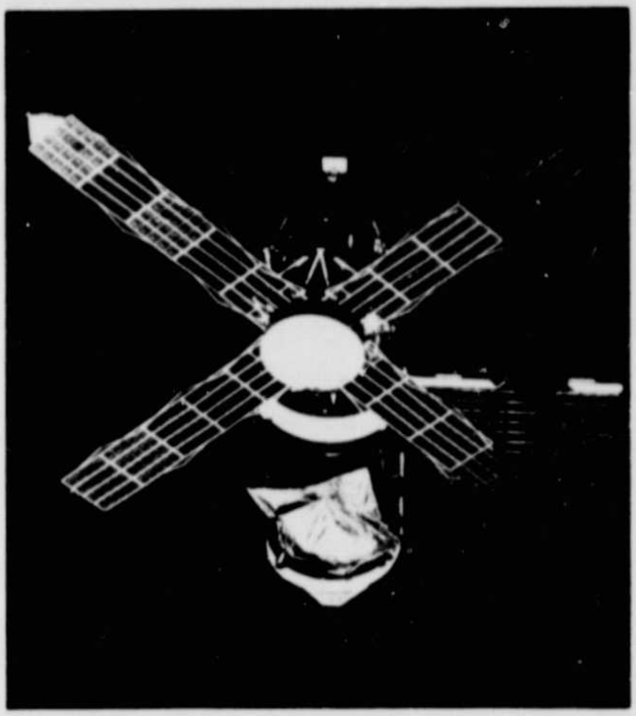

Figure 10. External view of Skylab showing parasol.

The MSFC sail had been designed, tested, and shipped to KSC in the hectic 10 day period after the Skylab launch on May 14, 1973, and was launched with the first crew for possible future use. Although a number of designs and material combinations were constructed and tested, the final sail configuration was rectangular, measuring 6.78 m (22 ft 3 in.) by 7.4 m (24 ft 5 in.). Around the perimeter a 6 mm (0.25 in.) diameter polybenzimidazole (PBI) rope was sewn into a channel. The material composition of the sail is given below:

Top	5 mil thick S-13G applied to 2.5 mil International Orange ripstop nylon (sun side)
Middle	Vapor deposited aluminum approximately 2000 Å
Bottom	0.25 mil Mylar
Weight	19.5 kg (43 lb) (flight packed)

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On August 5, 1973, the SL-3 crew began preparation for an EVA which would involve retrieving and installing film and also attaching the MSFC twin-pole solar sail. Prior to the EVA, the parasol was lowered as close to the Workshop wall as possible. The deployment procedure for the sail began August 6, 1973, with the Pilot translating himself through the airlock hatch to the ATM side, parallel to the damaged side of the Workshop, and mounted temporary foot restraints to the ATM hand rails (near an outrigger). When the foot restraints were in place and the Pilot was properly positioned, the Science Pilot, using the onboard extendible boom (for use on other EVAs), transferred to the Pilot a base plate fitting especially designed to hold the two sail poles in position over the Workshop. While the Pilot was clamping the base plate to an ATM outrigger, the Science Pilot, standing near the open airlock hatch, began assembling a 16.76 m (55 ft) pole from eleven 1.52 m (5 ft) sections, feeding the pole as he built it to the Pilot, who by this time was ready to receive it. The Pilot's position during this entire procedure was only slightly different from the one occupied during a normal EVA for replacing film canisters. After receiving the first pole, he positioned the base end into one of the two receptacles, or sockets, ("V" shaped) on the base plate. The second pole was received and attached in like manner in the other socket. As can be seen in Figure 11, a simple sketch of the pole, the end of the outward section of each pole has an eyelet through which is threaded a continuous loop rope. After the Science Pilot had transferred the sail package to the Pilot, he then hooked two corners of the folded sail onto the pole ropes (attach rings on rope). He then gradually pulled the ropes, alternately, sending the sail out along the poles in a manner similar to raising a flag. After full extension of the sail, the other two remaining ends of the sail were extended and tied off with ropes to the ATM outrigging.

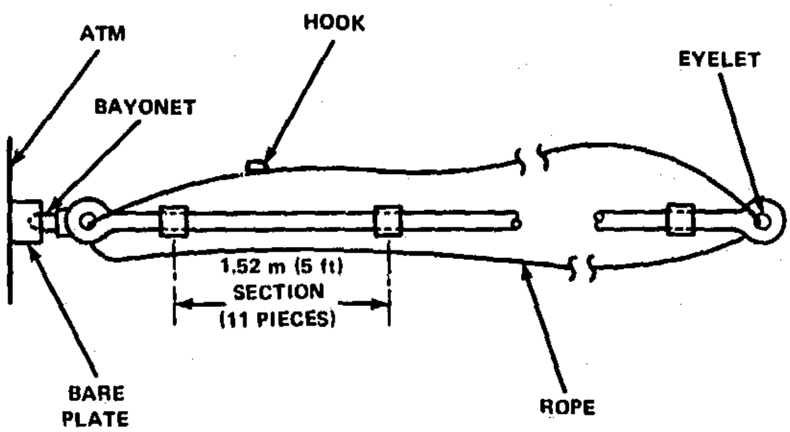

Figure 11. Sail pole as it appears attached to the base plate on the ATM strut.

Figure 12 is a sketch of the deployed sail and Figure 13 is an actual view of the attached sail.

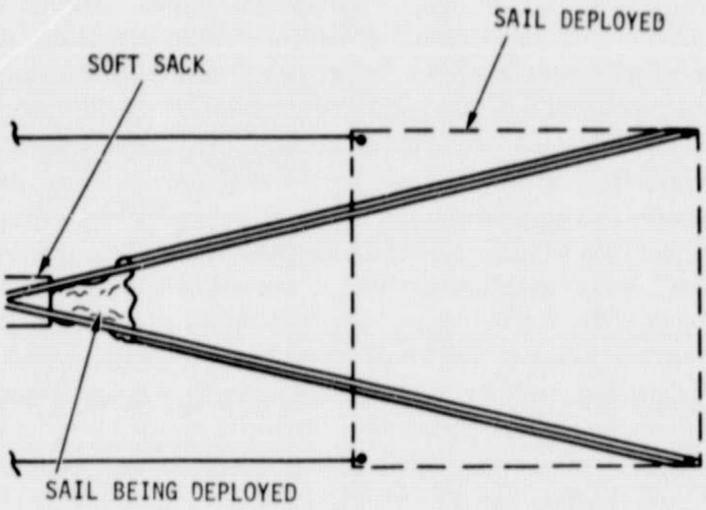

Figure 12. Sketch of sail deployment.

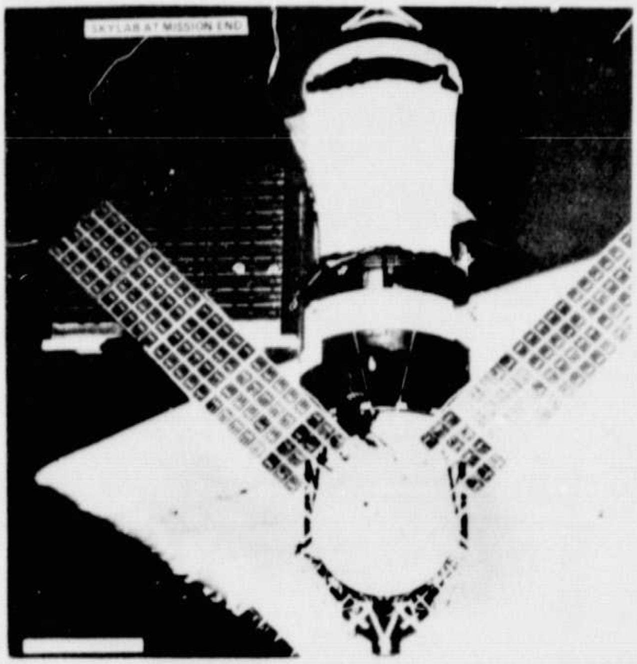

Figure 13. Skylab cluster with attached sail.

RATE GYRO PROCESSOR

The attitude and pointing control system (APCS) used integrating rate gyroscopes to sense spacecraft attitude rates. The gyros were mounted individually in a rate gyro processor (RGP) which contained, in addition to the gyro, a power supply, heater and control, 4800 Hz generator, three-phase inverter, ac amplifier, demodulator and torque driver. There were three of the RGPs per vehicle axis used in a compare-and-spare redundancy management scheme.

Following switchover from launch vehicle attitude control to Skylab control, it became apparent that some of the RGPs were behaving abnormally. The redundancy management rate integral discompares showed that several RGPs had out-of-spec drift. Additionally, telemetry showed that the Z_1 RGP was excessively hot. The drift rates were as high as 18 deg/hour, two orders of magnitude above specification. The high drift rates made it difficult to maintain the correct attitude for thermal control during the first 10 days after SL-1 launch. The high drift rates were compensated for by changes in the ATMDC software uplinked from the ground; however, the drift rates often changed suddenly. This caused difficulty until the new rates could be measured and compensated. As time passed in the mission, the magnitude of the drift rate changes decreased. Eventually the X_1, Y_1, and Z_3 RGPs became stable and were used through the remainder of the mission.

After considerable investigation, it was found that the high drift rates were caused by gas bubbles in the rate gyro flotation fluid. The formation of bubbles in the fluid was apparently caused by a design deficiency which exposed the float chamber bellows to the hard vacuum of space and by entrained gases present in the flotation fluid. Corrective action included tests to verify the theory of bubble formation and a design modification which sealed the float cavity from the hard vacuum of space. The design modification consisted of replacing the vented bellows end up cap with an unvented end cap so that internal float pressure would remain near the original float fill pressure despite external pressure changes.

Within the first 21 hours of the mission, four RGPs were overheating. Subsequently, two more showed identical symptoms. A detailed thermal analysis was performed relating RGP base plate heat sink temperatures of RGP temperatures. It was determined that base plate temperatures of 14° C corresponded to RGP temperatures of about 110° C. Also, a hot RGP was powered down, allowed to cool, and then powered up. The RGP temperature was seen to increase and become off-scale high. It was concluded that the six RGPs in question had experienced heater control failures and that the RGP temperatures were about 108° C. There was much concern that as the RGP temperatures increased, the RGPs would become unstable and cause loss of control. Test and analysis dat indicated that the RGP stability margin expected at 67.8° C would disappear at 110° C because of the reduction in float damping fluid viscosity. It was expected that normal increases in solar elevation angle during the mission would cause increased RGP base plate temperatures and higher RGP temperatures.

During SL-2 an expedited effort was begun to prepare a package of RGPs that could be added to the APCS should additional failures threaten the program. This package containing six RGPs became known as the "six-pack." The gyros in this package contained a design fix for the bubble problem encountered in flight. It was decided to mount the six-pack in the MDA on a mount provided for an experiment. This location was close to the center of gravity, could be aligned within limits, was close to the ATM control and display console for system interconnect, and was near a high power outlet. The installation required IVA and EVA with participation of all three crewmen. The rate gyro six-pack was mounted in the MDA as shown in Figure 14 and was connected to the ATM control and display console.

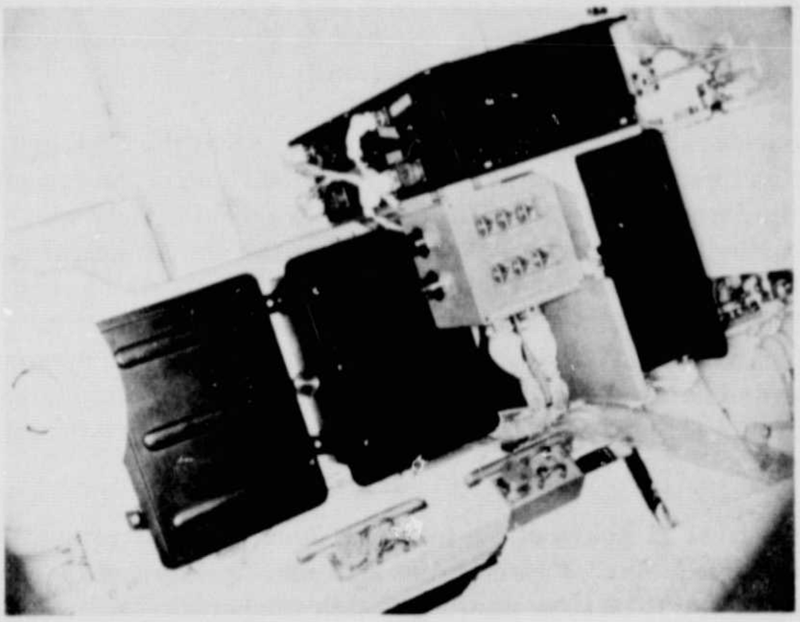

Figure 14. The six gyros mounted in the backup MDA hardware.

The Commander remained inside while the Science Pilot and Pilot went outside to complete the installation which required the disconnecting of three cable connectors and the installation of the new cable and rate gyro selector box which required connecting four connectors. The external cable and selector box are shown in Figure 15. The internal and external cable connections are shown in Figure 16.

The first connection broken was at the trunnion plate. The APCS was turned off by the Commander just prior to disconnecting this cable and was turned on again after the installation was complete. A special set of pliers for use in disconnecting and connecting the electrical connectors had been developed and was on board. The installation was accomplished successfully permitting the APCS to return to normal operations.

COOLANT SYSTEM RESERVICING

On the ninth day of SL-3, a coolant leak in the primary coolant loop was indicated by a low pump inlet pressure warning. Ground analysis indicated a long term decrease in pressure. The crew attempted to ascertain the location of the coolant leak by removing panels and unwrapping insulation from suspect lines. Wrapped lines were visually inspected for bulging, color changes, and wetness but no evidence of leakage was found. During EVA, the crew inspected the accessible exterior areas, especially the radiators, for evidence of coolant leakage but none was found.

On the 27th day of SL-3 the primary loop was shut down to prevent pump cavitation and possible damage after the pump inlet pressure had reached a low of 3.45 N/cm^2 (5 psia). Flight data also indicated that the secondary loop possibly was leaking but was still operational and providing the required cooling. The leakage rate was determined to be so small that the coolant loops could remain operational by replenishing the coolant. Since the coolant loops were not designed for onboard reservicing, efforts were initiated by ground personnel to devise a way to reservice the loops, develop the hardware and demonstrate its capability in time for launch of SL-4.

The procedure developed included stripping insulation from a coolant line near the cabin heat exchanger in the airlock module, piercing the line with a saddle valve assembly (Fig. 17) which had a quick disconnect for attaching a service hose and forcing coolant from a small storage tank by applying pressure from a 24.13 N/cm^2 (35 psi) source through a bellows arrangement. Parts for the reservice equipment were primarily qualified by similarity to equipment used in other Airlock Module applications. The tank was adapted from a

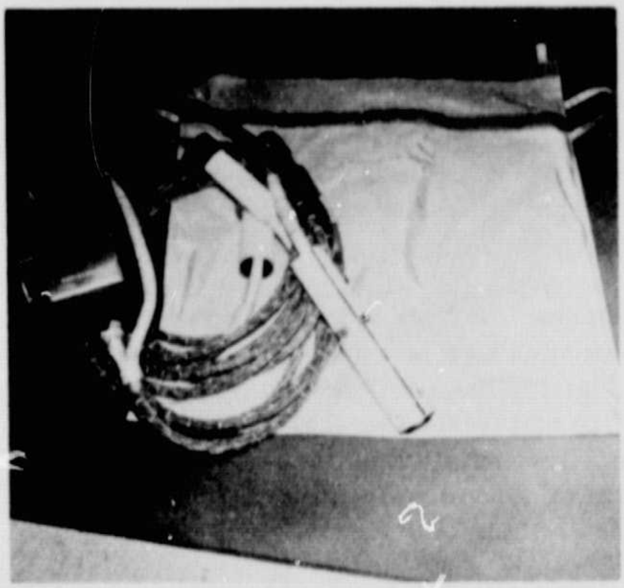

Figure 15. RGP EVA cable assembly and selector box.

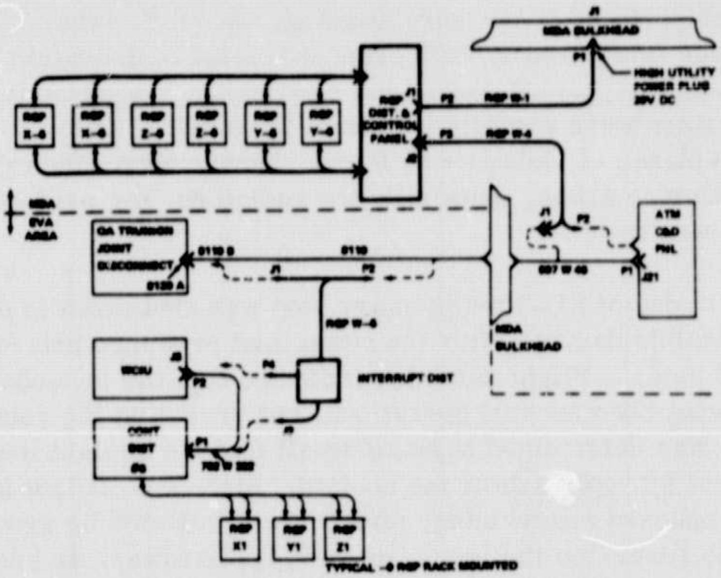

Figure 16. RGP six-pack connection schematic.

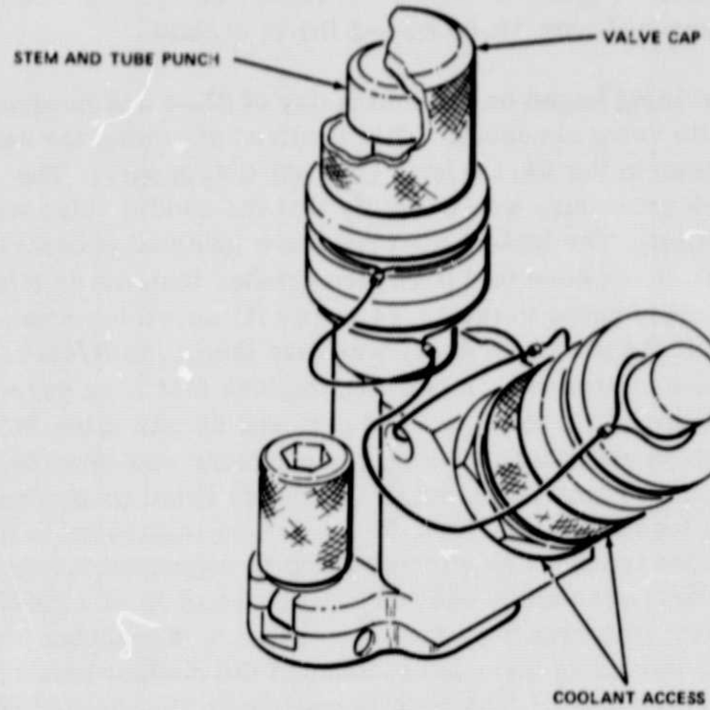

Figure 17. Saddle valves.

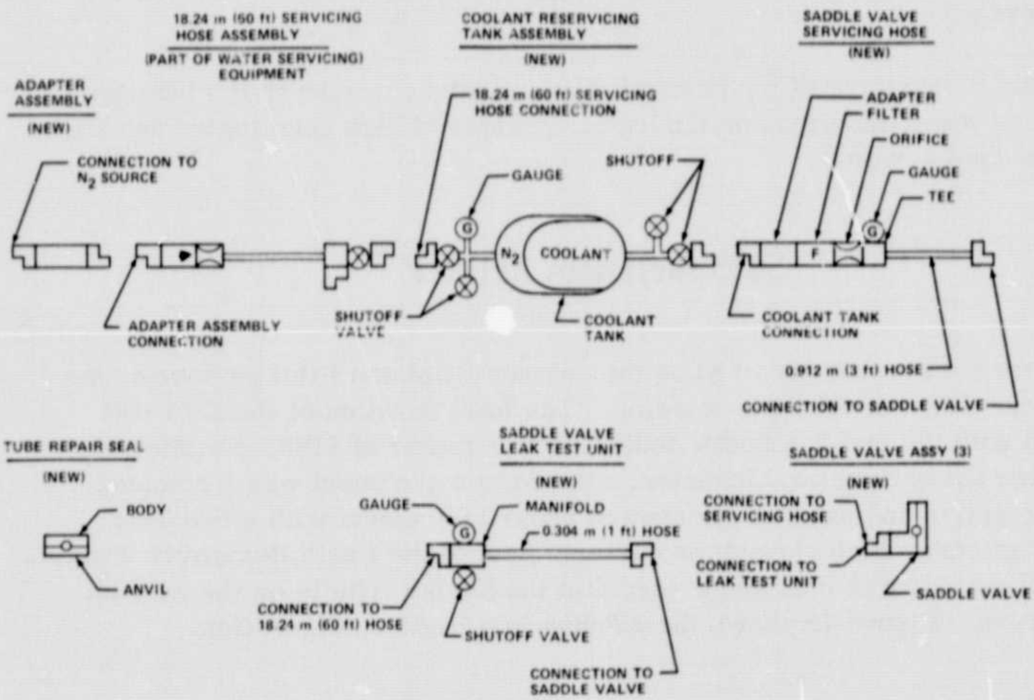

Figure 18. Coolant reservicing equipment.

Command Module fuel tank. Figure 18 shows the reservice system schematically. The tank was launched with 19.05 kg (42 lb) of coolant.

The in-flight servicing began on the fourth day of SL-4 and progressed smoothly through a saddle valve checkout. This involved attaching the saddle valve and the leak test hose to the 24.1 N/cm^2 (35 psi) GN_2 supply. The purpose of the leak check procedure was to verify that the saddle valve was not leaking prior to penetration. The leak check procedure involved pressurizing the saddle valve and leak check hose to a pressure greater than 20.68 N/cm^2 (30 psig), closing the supply valve in the 18.24 m (60 ft) servicing hose, and monitoring for 30 min. If the pressure decay was less than 1.38 N/cm^2 (2 psi), the servicing was to proceed. However, the leak test hose gage indicated an initial pressure of 22.75 N/cm^2 (33 psi) and 35 min later 21.03 N/cm^2 (30.5 psi). After an additional 20 min, the pressure was down to 17.23 N/cm^2 (25 psi). Thus, a leak was indicated in the saddle valve or the leak check hose. To determine the location of the leak, the crew was instructed to disconnect the leak check hose from the saddle valve and to repressurize the leak check hose. The leak check hose alone showed a pressure drop of 1.38 N/cm^2 (2 psi), indicating a leak. The crew was then instructed to disconnect the leak check hose from the servicing hose and to connect the coolant servicing tank and the coolant servicing hose. The system was carefully checked out and the coolant valves were then opened to supply coolant to the saddle valve under pressure prior to piercing of the coolant line. No coolant leakage was observed; the primary coolant line was then pierced and the servicing proceeded satisfactorily.

The reservicing of the primary loop permitted return to the two loop operation of the coolant system during the periods of high beta angles and EVA (high heat load periods).

S193 ANTENNA REPAIR

On the seventh day of SL-4 the Science Pilot and Pilot performed the first of four EVAs of the SL-4 mission. The total duration of the EVA was 6.5 hours with the last 3.5 hours dedicated to a repair of S193, the Microwave Radiometer Scatterometer Altimeter. The S193 experiment was a complex electronic active and passive microwave radar instrument with a two-axis gimbaled antenna which viewed the earth as part of the Earth Resources Experiment Package. It was mounted external to the Skylab vehicle on the Airlock Module truss. Figure 19 shows the antenna in a flight configuration.

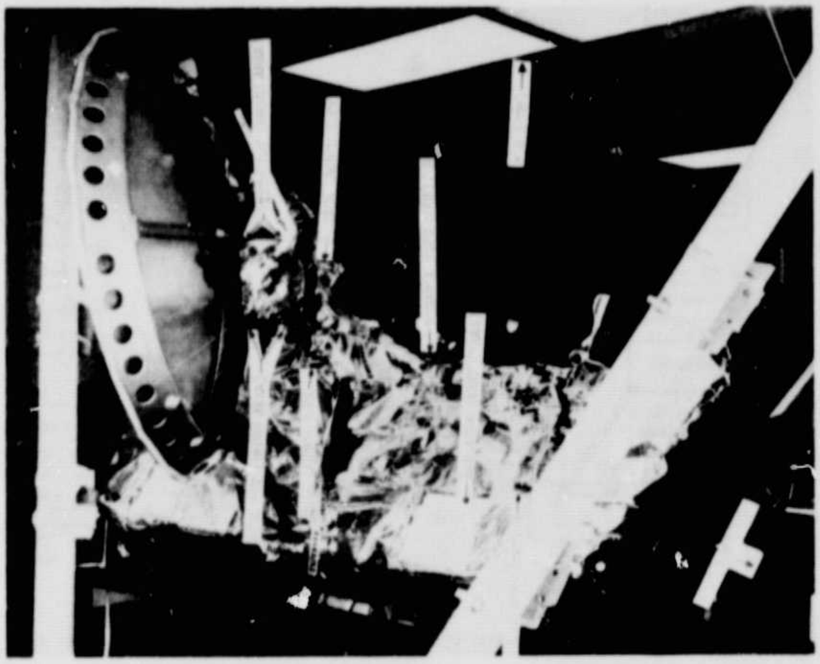

Figure 19. S193 antenna.

A failure occurred earlier during EREP pass 40 on mission day 49 of SL-3 which manifested itself by erratic antenna motion. A subsequent in-orbit SL-3 telemetry test gave ground engineers additional data to analyze the problem and begin working toward a solution. A -10 volt reference in the gimbal servo system was found to be at -1.0 volt. Circuit analysis indicated that the failure was most likely a short in either the pitch or roll gimbal potentiometers, or both. These potentiometers were accessible from outside the experiment (Fig. 19). Following the analysis, NASA decided to perform an EVA to attempt to correct this problem and at least get partial use of the S193 experiment.

A procedure was developed and tested by the SL-4 astronauts in the neutral buoyancy tank at MSFC. Specialized hardware was prepared which included a jumper box for isolation of the short, a tool pouch with appropriate repair tools, and astronaut restraints. When the EVA occurred, the three astronauts worked together very closely. The Science Pilot and Pilot shared the work outside. From the inside, the Commander advised them of the best work position and nearness to such delicate items as the antenna feed and the S190A window. He also assisted in the functional testing by operating the EREP control switches from inside the vehicle. The astronauts followed the procedure as written, based on the planned logic diagram shown in Figure 20. The actual steps followed are shown in Figure 21.

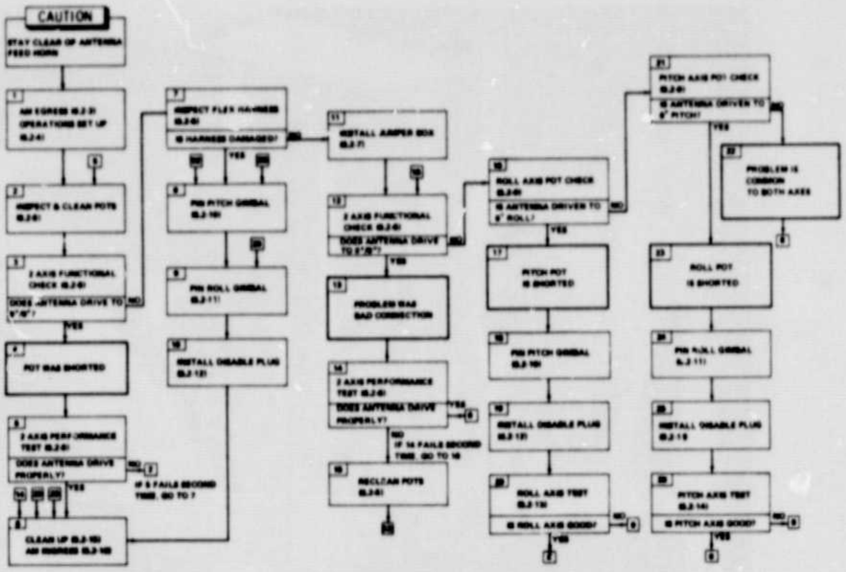

Figure 20. S193 antenna malfunction planned logic diagram.

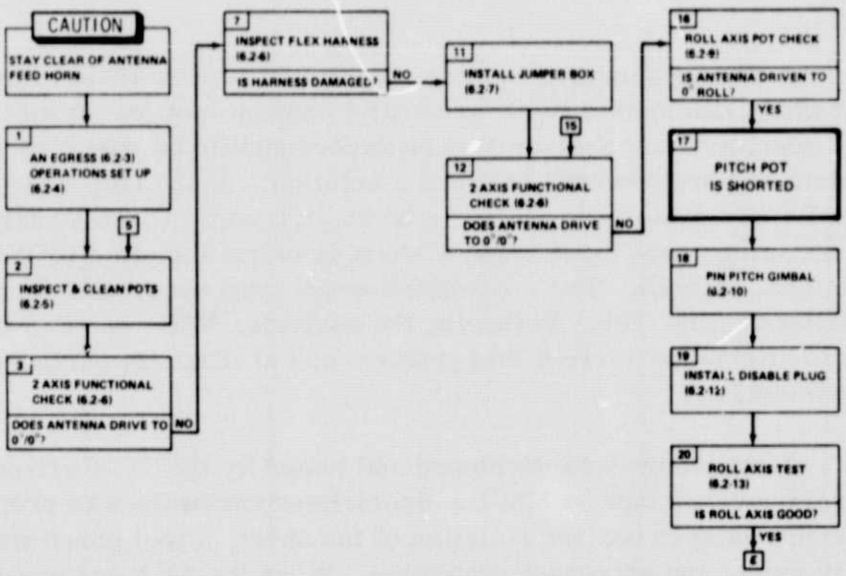

Figure 21. S193 antenna malfunction actual logic diagram.

Chronological highlights of the procedures were that the astronauts translated to the area near the S193 gimbals, inspected them and removed a sliver of insulation material from inside the pitch gimbal. They performed functional testing to see if the removal of the sliver corrected the problem. When they found it had not, they removed three flight cable connetions and installed the jumper box (Fig. 22) for isolation of the short. They ran another malfunction test which isolated the short to the pitch axis only. With this determination the procedure required removal of a launch pin and installation of a manual gimbal lock (Fig. 23). To free the launch lock, they had to tap it with a hammer a few times. This two-man operation required visually aligning a hole in the pitch gimbal housing with a hole in the pitch gimbal shaft by rotating the antenna to a mechanical null position. Additionally, they put a disabling plug (Fig. 24) on the launch lock circuit which prevented power from being applied to the pitch electrical circuitry during operation of EREP for the rest of the mission.

During the repair operation it was necessary to uncover the surfaces of the experiment of the aluminized Mylar thermal insulation for access to the hardware. The insulation was held in place by means of 19 mm (0.75 in.) aluminized tape and velcro. The tape adhesive froze, rendering the tape useless during replacement of the insulation, but the astronauts commented on how well the velcro worked. Throughout the operation, although they had foot restraints, it was ncessary for them to physically move each other around to provide the best access to the work at hand. On completion of this task the S193 experiment had approximately 80 percent of its preflight functions restored.

CONCLUSIONS

The Skylab experience in the successful conduct of planned and contingency repairs proved conclusively that man in space can make major systems repairs using standard or special tools. Essentially, any repair or maintenance that logistically fits an operations activity can be performed. Procedures for contingency repairs can be developed and demonstrated on the ground, transmitted to and satisfactorily performed by the crew already in space.

Design of future spacecraft should acknowledge this almost limitless capability and provide for more extensive in-flight repair and maintenance.

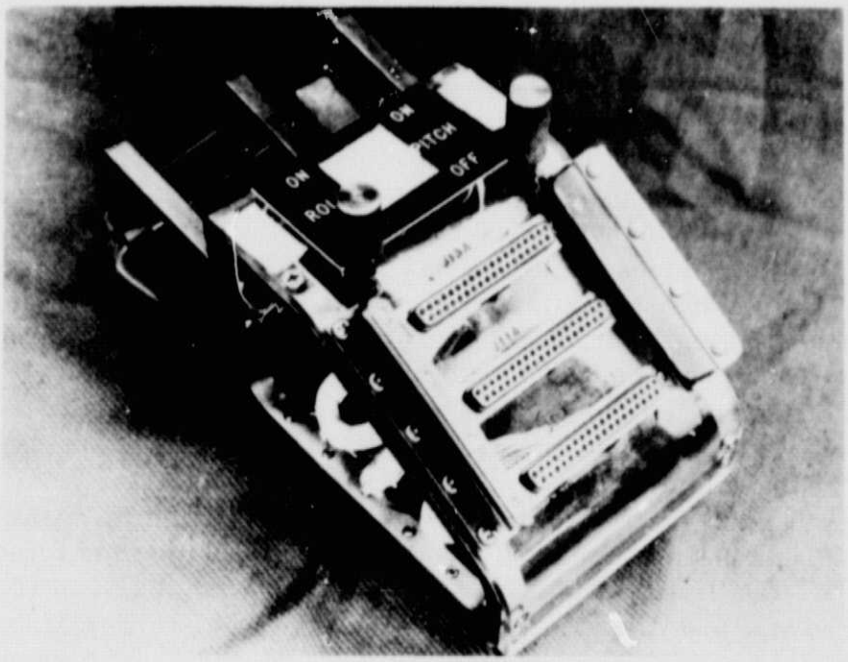

Figure 22. Junction box.

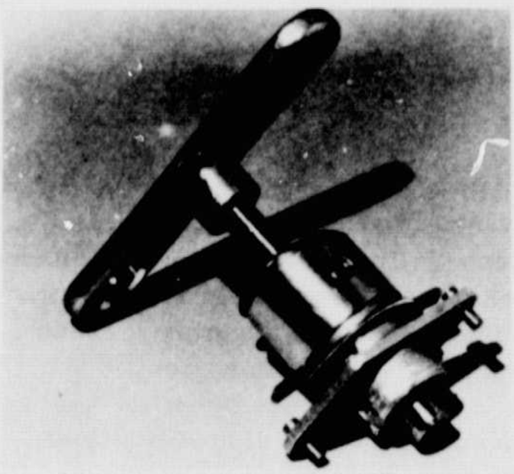

Figure 23. Manual gimbal lock.

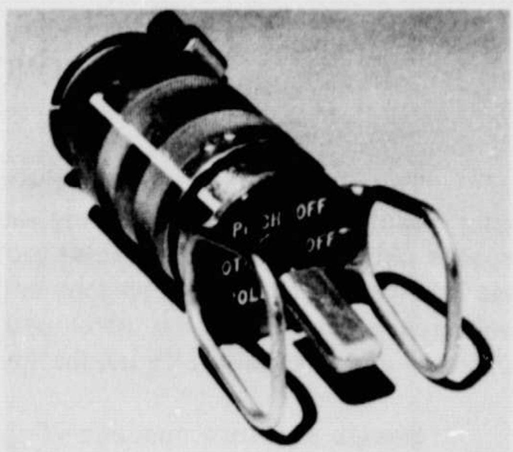

Figure 24. Disabling plug.

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APPROVAL

REPAIR OF MAJOR SYSTEM ELEMENTS ON SKYLAB

By Robert E. Pace, Jr.

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

R. J. Schwinghamer

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