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## SP-400 Skylab, Our First Space Station

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## Rendezvous and Repair

[60] First approach to the crippled Skylab by Conrad, Kerwin, and Weitz.

[61] In the afternoon of May 25, as the command and service module orbited over Guam, Mission Control in Houston heard Comdr. Pete Conrad call out:

"Tallyho, the Skylab. We got her in daylight at 1.5 miles, 29 feet per second

Sighting occurred some 8 hours following a perfect launch that morning from the Kennedy Space Center.

### Skylab Condition Predicted Correctly

As the command module closed the distance separating it from Skylab, television cameras relayed pictures to Mission Control, and the flight crew continued its description of the space station.

"As you suspected, solar wing 2 is completely gone off the bird. Solar wing I is, in fact, partially deployed... there's a bulge of meteorite shield underneath it in the middle, and it looks to be holding it down. It looks, at first inspection, like we ought to be able to get it out."

As they maneuvered for a closer look at the damaged workshop, they reported that the gold foil cemented to the skin of the space station appeared to have been discolored by solar radiation. They also reported that the scientific airlock,

through which the parasol shield was to be deployed, was clear of debris.

Initial reports also confirmed that a strap containing a row of bolts, apparently from the micrometeoroid shield, was wrapped around the solar-wing beam, preventing it from being deployed.

When the first flyaround inspection was completed, the command module docked to the Skylab's docking adapter. Joining the space station relieved the crew of the necessity to "station keep" (fly in formation with Skylab).

While ground crews studied Skylab photographs made from the television monitor, the astronauts ate their first meal, and Conrad commented on the food.

"Dinner's going pretty good, except that Paul found another one of those tree trunks in the asparagus. I had stewed tomatoes for lunch. It turned out that even as goopy as they are, they were real simple to handle, and the same way with turkey and gravy."

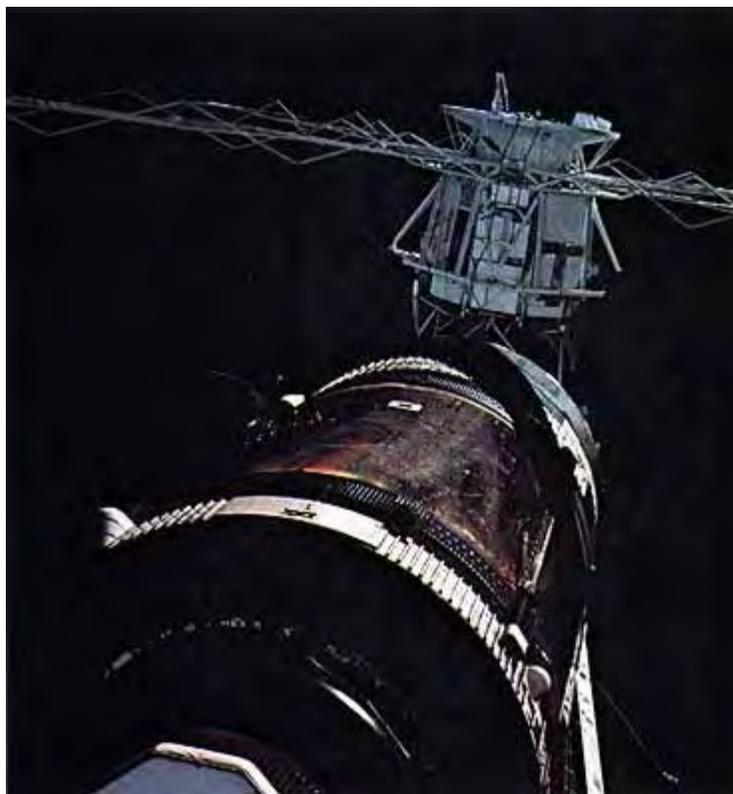
When preparations were complete, the crew "undocked" the command module for their first try at orbital repair. As Conrad maneuvered the spacecraft, Weitz leaned out its open hatch with Kerwin holding his legs. Using a 10-foot pole with a hook on the end, he attempted to pry loose the solar-wing beam.

"The tiny little strap . . . so hard that the screws in it just riveted into the SAS (Solar Array System, pronounced sass) panel. We pulled as hard as we could on the end of the SAS panel," Weitz reported. "We couldn't get it out right now. We're all trying to break it loose. It's only a half inch strip, but man, is it riveted on!"

Each time that Weitz tugged on the strap, the....

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[62]



During the flyaround inspection of Skylab, Conrad reported: "Solar wing 2 is completely gone, and solar wing 1 is partially deployed." He also reported that debris from the micrometeoroid shield was jammed around the partially

deployed wing, holding it in place and preventing full deployment.

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[63] Apollo drew closer to the Skylab. Conrad, at the controls, had to keep backing it away to avoid a collision. This movement disturbed the position of Skylab, and caused the thruster attitude control system to operate, using a large amount of nitrogen to maintain stability.

In spite of repeated attempts to bend the strap back from the wing, it refused to budge.

As the spacecraft began to pass into orbital night, the crew reluctantly closed its hatch and maneuvered once more to dock with Skylab. This time, there was trouble. The probe capture latches failed to engage. Conrad backed the command module away and then tried again. No luck. Several attempts were made, but none of them proved to be successful.

Finally, the crew put on their spacesuits, depressurized the command module, removed its forward hatch, and disassembled part of the docking probe. Then they tried again, and now the latches worked. With the command module securely coupled to Skylab, the astronauts slept for the first time.

When they awakened, they would enter Skylab and determine what damage the searing heat of the Sun had caused to the interior of the workshop.

Would the temperatures they found be too high for them to work in? Would they find toxic gases from overheating of the insulation?



Solar wing 1 was held firmly in its partially deployed position by a strap, apparently from a portion of the micrometeoroid shield.

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## [64] Control of Skylab's Environment

The large volume inside the workshop would result in varying temperatures and the absence of gravity eliminated natural convection. Thus, considerable theoretical work had to be done to establish comfort ranges for the crew. A computerized mathematical model of the human body was developed to investigate comfort ranges.

Skylab's thermal and environmental control systems were similar in many ways to homeheating and air-conditioning systems. But a number of integrated subsystems were required to make the Skylab a comfortable home in space for the astronauts and to provide temperature control for the many experiments and the space station's equipment. These included not only means for heating and cooling the atmosphere, but also judicious applications of insulation and special surface coatings, as well as provisions for control...



This photograph of the workshop's exterior, filmed during the first crew's flyaround inspection, clearly shows the discoloration and blistering suffered by the workshop skin from prolonged exposure to the Sun. The rectangular opening at the upper center is the scientific airlock, through which the parasol was later deployed.

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[65]



To cool Skylab and its systems, it was necessary to radiate heat to space. Panels were attached to the cylindrical portion of the airlock and docking adapter. Tubes, through which liquid coolant was circulated, were welded to the interior side of the skin. These radiating devices were effective.

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...ling the atmospheric gas mixture and constituents, such as carbon dioxide and water vapor.

The primary Skylab coolant system, located in its airlock module, removed heat and moisture from the air. It provided

a comfortable environment for the crew and also provided cooling for electrical equipment. In addition, it provided low temperatures for two other cooling systems. One chilled the solar observatory control console in the docking adapter and the electrical components used for the Earth observation experiments. The other brought down the temperatures in the spacesuits worn by the crew during their work outside the Skylab.

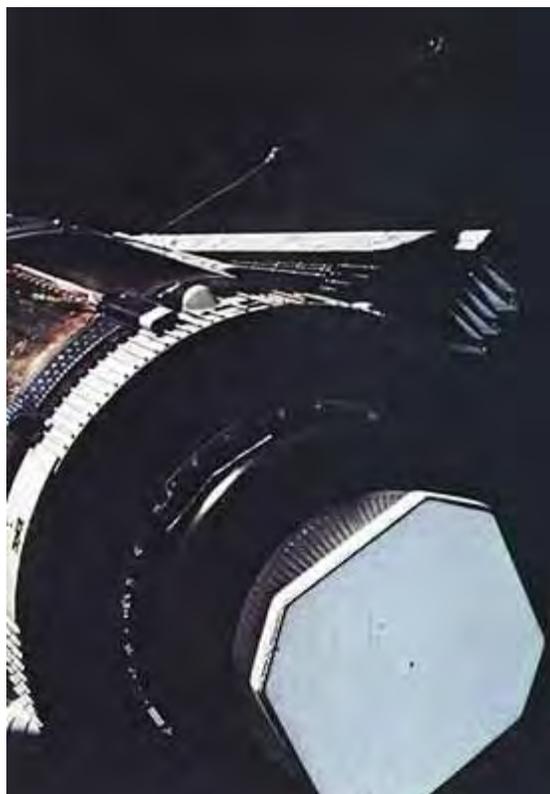
Food and certain biomedical specimens required refrigeration in the workshop, and a cooling circuit was provided which utilized a radiator at the workshop's aft end. Another cooling circuit in the solar observatory maintained the temperature of critical components within required limits.

Heat generated by Skylab equipment and the crew themselves was removed by a combination of systems.

An atmosphere temperature control system....

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[66]



A large octagonal radiator on the aft end of the workshop also radiated heat to space.

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...picked up excess heat from the compartments and transferred it through heat exchangers into the primary Skylab coolant system where it was radiated to space through a radiator on the cylindrical forward portion of the airlock and the docking adapter.

An onboard thermostat operated four heat-exchanger fans and duct-heater elements to provide conditioned air inside the workshop. Another four duct-heater elements could be turned on manually if sufficient electrical power was available. Eight radiant wall heaters heated the workshop before the astronauts entered it and also were intended to maintain the workshop above 40° F during the unmanned phase of the mission. The loss of the micrometeoroid shield made these unnecessary, however. Thermostatically controlled heaters were also provided for other walls, docking ports, tunnels, water tanks, overboard vents, and windows to maintain the temperatures within the required limits.

Heat leakage through the structure was controlled by careful selection of coatings and insulations. In the solar environment, coatings with a low ratio of absorptivity to emissivity (white coatings) provide a cold surface; coatings with a high ratio of absorptivity to emissivity (gold coatings) provide a hot surface.

During the first 10 days of the mission, low temperatures developed in some locations within the airlock due to maneuvers necessary to reduce peak temperatures and provide adequate electrical power.

Skylab's design included special coatings and insulations, carefully located on the assumption that the vehicle would be in an attitude in which the solar panels faced the Sun most of the time. When this attitude was changed for long periods to reduce solar heating in the workshop, temperatures in the spacesuit cooling water loops decreased until the water was very close to freezing. Frozen water could have broken lines but, even more serious, water freezing in the heat exchangers would have caused failure of the primary coolant system. This system was vital to the cooling of electrical equipment and to providing a comfortable environment for the crew.

This potentially serious problem further complicated the maneuvering of the space station. After trying many space station attitudes, ground controllers found one which provided the most energy from the Sun without further increasing workshop temperatures. Temperatures in the system which provided spacesuit cooling did remain dangerously close to freezing for several days, but then began climbing slowly.

Skylab's planned 9-month flight posed a unique problem. While the space station orbited the Earth, the Earth's axis tilted as the seasons changed. The net result was that the orbital angle with respect to the Sun (called the beta angle) changed from 0 to +73.5 degrees. The corresponding change in the length of time that the space station would be in [67] the Sun each orbit varied from 61.5 to 100 percent of the time. Thus, Skylab had to be designed to a much wider variation in the external environment than previous Earth-orbiting manned spacecraft. Also, it had to be designed to fly predominantly in a solar inertial attitude so that one side of the spacecraft faced the Sun for solar observations and to acquire power from its solar wings. Short excursions of one to two orbits were planned for the Earth observation experiments where the other side of the space station faced the Earth, and special maneuvers were planned to view stars and obtain other scientific information and, subsequently, to view the Comet Kohoutek.

Two separate and redundant coolant loops were provided through most components with the control valves, pumps, and some heat exchangers duplicated in each loop. Normally, one pump was running in each loop; however, all cooling functions could be provided by operating two pumps in either of the loops. The coolant fluid, the pumps, and many of the other components were the same as those used in the Gemini program.

Prior to launch, excess heat was rejected through a ground heat exchanger. Once in orbit the coolant loop rejected its heat to space through a radiator. Two thermal capacitors at the outlet of the radiator provided additional peak capability. These were aluminum-honeycomb boxes filled with a wax which melted at 22°F. They were penetrated...



Thermal control system.

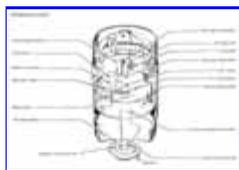
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[68] ...by coolant passages which transferred the heat from the coolant to the wax, and vice versa. Since the radiator was subjected to variable thermal conditions throughout each orbit, a larger radiator than that provided would have been required to assure an acceptable outlet temperature at all times. When the radiator outlet temperature rose above 22°F, some or all of the wax melted and the coolant at the outlet of the capacitor could be maintained at approximately

the desired temperature. During orbital operation, the capacitors were to be normally solid on the night side of the orbit and partially molten on the day side, depending upon how much the radiator outlet exceeded the melting point of the wax.

The workshop refrigeration system cooled perishable food and biomedical samples and chilled the drinking water. The workshop was equipped with five food freezer compartments, a food and water chiller, and a urine chiller and freezer. Two independent coolant loops, using a common ground heat exchanger and thermal capacitor unit, were provided. An octagonal radiator at the aft end of the workshop dissipated heat from this system in orbit. A thermal capacitor similar to that used in the primary Skylab cooling system provided cooling during ascent. Temperatures were automatically controlled by a radiator bypass valve, and other controls were provided which could switch from one pump to another or from one loop to another should temperatures or pressures in the system indicate the need to do so.

The ventilation and atmosphere control systems provided adequate flow for crew comfort, maintained carbon dioxide levels below 5.5 mm Hg for normal operations, maintained the dewpoint between 46°F and 60°F, and removed objectionable odors. Molecular sieves removed carbon dioxide, odors, and moisture. Each sieve unit contained two beds filled with material which absorbed water vapor and carbon dioxide. Every 15 minutes an automatic controller switched the atmosphere flow....



Refrigeration system.

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[69]



Environmental control system.

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...over to a fresh bed and vented the saturated bed to space. The concept did not require replacement of filter elements, a feature of early short-duration manned space missions.

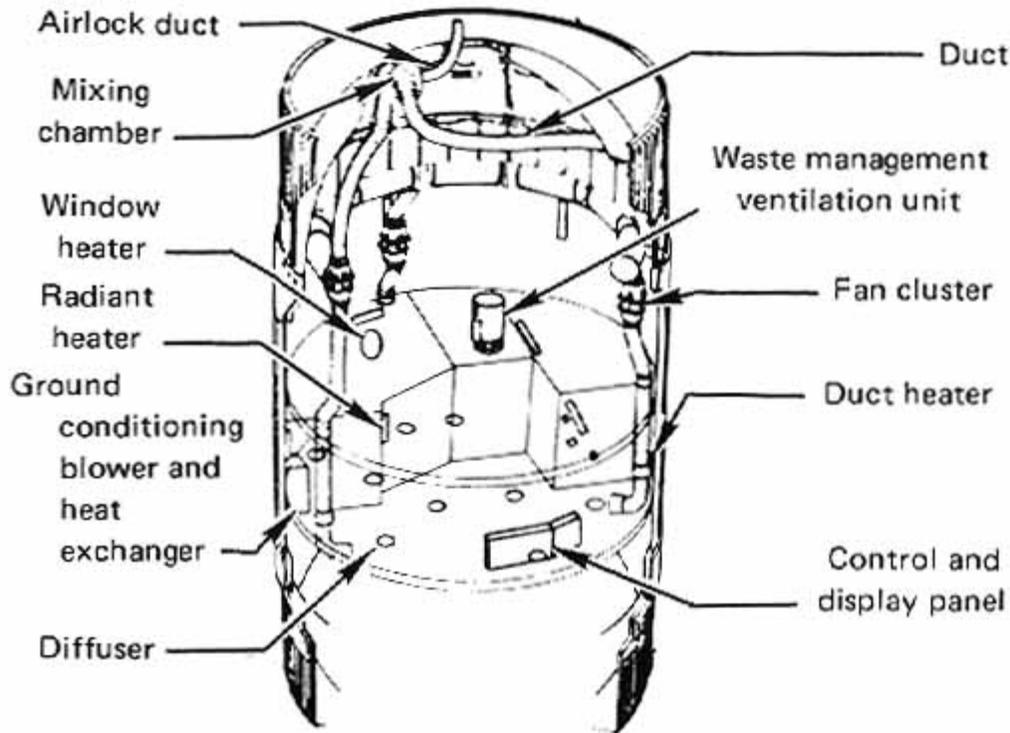
Since there was no gravitational force to drain the condensate from the heat exchangers, this function was accomplished by a suction line connected to a tank whose pressure bellows had been evacuated by venting to space. Once the tank filled with water, valves were manually switched so that the bellows could be pressurized by the cabin atmosphere. This forced the water into the waste tank at the aft end of the workshop.

Charcoal canisters in the molecular sieves and a charcoal canister in the waste management compartment ventilation unit of the workshop removed odors from Skylab. A fan filter in the waste management compartment removed particulate matter, such as hair and lint, from the workshop atmosphere.

Purified air from the molecular sieves could be diverted to either the workshop or the multiple docking adapter compartments or divided between the two, as desired. Ambient atmosphere in the structural transition section of the airlock module was mixed with this revitalized atmosphere and combined with the outlet flow from the four workshop

heat exchangers before dissemination. A flexible duct was connected to a mixing chamber at the forward end of the workshop where the flow...

[70]



Ventilation system.

...was mixed with a portion of the workshop atmosphere. The flow was then channeled into three ventilation ducts. Four fans in each of these ducts routed the atmosphere to a large distribution chamber at the aft end of the workshop. The crew quarters floor was equipped with adjustable diffusers which circulated the air through the crew quarters and back to the forward end of the workshop. A portion of the atmosphere flowed through the hatch and the airlock tunnel, returning to the molecular sieves for reconstitution. The remainder was drawn into the mixing chamber and recirculated in the workshop.

### Thermal Control of the Solar Observatory

The solar observatory was exposed to the Sun throughout most of the Skylab mission. To maintain optical stability of its instruments, the temperature of its components required careful control.

An octagonal structure, known as the rack, supported the experiment canister. It also served as a mounting structure for more than 140 electrical and mechanical components designed for operating temperature ranges from  $-4.6^{\circ}\text{F}$  to  $121.4^{\circ}\text{F}$ . Additionally, all hardware used or touched by astronauts during spacewalks had to be maintained at acceptable temperatures. This was accomplished by several methods. Surfaces were painted white to reduce solar heating. Thermal shields protected sensitive components with low internal heating from cold environments; these shields were covered with varying thicknesses of multilayer insulation to control heat losses. All major mounting panels, except

those containing high-heat dissipating components such as batteries, were isolated from the rack structure and covered with multilayer insulation on the canister side. Components were located so that power distribution in major zones around the rack sides was reasonably uniform. Components dissipating heat at high rates were mounted on external panels. Finally, a rackmounted Sun shield prevented continuous direct solar impingement on rack components.

The canister, an insulated cylinder shielding the eight telescopes, provided a uniform and nearly constant internal environment and served as a stable platform. All instruments were mounted on a cruciform-shaped spar, an isolated structure that divided the canister interior into four longitudinal compartments. The spar was supported by a girth ring that connected to a gimbal system. Spar thermal isolation minimized spar temperature changes and prevented optical misalignment. Thermal isolation was achieved by using low-conductance mounts where the instruments attached to the spar and where the spar attached to the girth ring. In addition, the aluminum spar was covered with multilayer insulation. The canister exterior was covered by a multilayer insulation to protect its cold plates. This insulation, originally developed for the Apollo program, is used in making rescue blankets.

The canister's interior walls, painted black to minimize reflections and maximize radiative coupling between instruments and liquid-cooled "cold plates," were maintained at a nearly constant temperature by a closed-loop fluid, heat-transfer system. Heat generated by the instruments was absorbed by the cold plates, transferred to the radiator by a fluid, and then radiated to space.

Separate thermal design of each telescope was required to satisfy individual pointing stability requirements and maintain focal lengths within specified tolerances.

### First Visit to the Workshop

When Conrad, Weitz, and Kerwin awoke, their most pressing activity was to make sure that the atmosphere inside the workshop was suitable for occupancy. Engineers at the various NASA centers had taken special precautions to assure that the heating to which the insulation had been exposed did not cause a gaseous residue in the workshop.

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The solar observatory was designed for full exposure to the Sun throughout most of the Skylab mission. The temperature of its components was carefully controlled.

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Maneuvering of the spacecraft had held temperatures to a level which prevented decomposition of the insulation. The pressurization and depressurization cycle, which had been carried out for several days, had effectively removed any undesirable atmospheric elements which might have been present.

As Weitz donned a gas mask and began sampling the atmosphere, he found no evidence of noxious or toxic gases. Satisfied that the atmosphere was safe for occupancy, Weitz and Kerwin entered the workshop and began its activation. The temperature inside was 130°F, but the humidity was so low that they could work inside for as long as 5 hours.

Using procedures worked out carefully in engineering laboratories, the crew erected the parasol thermal shield.

First, they attached the canister to the scientific airlock. Then Conrad and Weitz, working cautiously to be sure that they did not force structural members out of shape, extended the folded shield through the opening and into space. Slowly, the struts extended and the sunshade took shape. Although one corner did not extend fully, the trapezoidal-shaped shield was in place over the workshop outer surface. Almost immediately, temperatures inside the workshop began to drop.

With the parasol shield deployed, Conrad and his crew continued workshop activation. Temperatures...

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[72]



Sequence of parasol deployment. (a) Parasol operation from interior of airlock. (b) Parasol at partial extension. (c) Full extension and partial deployment. (d) Fully deployed and retracted for service.

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...of the outer wall decreased rapidly, and about an hour later, ground controllers returned the Skylab to the solar inertial attitude. The result was an immediate increase in electrical power as the full force of the Sun's rays fell on the solar observatory solar array.

Even though most of their activities had been of an emergency nature, and temperatures inside the workshop were still high, the crew adjusted quickly to their new environment.

Temperatures inside the workshop dropped to about 90°F, but for the first few nights the crew slept inside the docking adapter, where the temperatures were a comfortable 68°F.

### A Sense of Up and Down

"You do have a sense of up and down," Scientist Pilot Kerwin reported. "And you can change it in two seconds whenever it's convenient. If you go from one module into the other and you're upside down, you just say to your brain, 'Brain, I want that way to be up.' And your brain says, 'Okay, then that way is up.' And if you want to rotate 90 degrees

and work that way, your brain will follow you. I don't think it's vestibular at all. I think it's strictly eyeballs and brain. And it's remarkably efficient."

The crew quickly established a normal routine....

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[73]



Orientation in the space station was never a problem. As the crew adjusted to its new environment, Scientist Pilot Joe Kerwin reported that there was, indeed, an up and down in space. It was simply a matter of telling yourself which was which, he observed. In this photo taken by Astronaut Weitz on the final day of the mission, Kerwin is shown in the hatch between the Multiple Docking Adapter and the Apollo spacecraft.

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...of carrying out experiments, housekeeping, eating, sleeping, and exercising. A careful schedule, worked out between flight and ground crews, was maintained to assure the proper performance of routine maintenance tasks and experimentation. The crew's typical day consisted of 16 hours of activities and 8 hours of sleep. All crewmen slept at the same time.

In scheduling their activities, the crew had to allocate time for observations of the Earth and the Sun, taking into account Skylab's orbital position. After these observation periods were scheduled, other activities could be accommodated.

Since virtually all electrical power came from the solar observatory power system, the experiment program was stretched out, but it was still carried out almost as planned. Six experiments could not be performed as planned, since they had been designed to make use of the Sun-facing scientific airlock, now occupied by the parasol. But the flight crew modified the program and conducted three of the experiments using the scientific airlock in the Earth-facing side of the workshop. Two of the remaining three experiments were mounted on the solar observatory truss and the other on the solar observatory Sun shield by the crew during extravehicular activity.

Even without power from the workshop solar array, there was an average of about 800 to 1000 watts available for experiment purposes over that needed to maintain essential functions in Skylab. But the solar observatory batteries were being overworked. To fulfill all mission objectives, the workshop solar array would have to be deployed.

As the flight crew continued its work in space, ground teams worked around the clock to develop....

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[74]



Kerwin extended the long-handled cable cutter while Conrad affixed the cutter jaws to the strap holding the solar wing. Together, they cut the strap, which freed the wing and then they extended it to its full position.

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...procedures for freeing the workshop solar-array wing. The flyaround television pictures of the restrained beam fairing underwent continuous study. Tests continued in the neutral buoyancy simulator, where Astronaut Russell "Rusty" Schweickart used tools and equipment identical to those on board Skylab to practice procedures for freeing the jammed beam. The simulated solar-wing beam structure in the tank was fitted with debris resembling the actual situation on the Earth-orbiting space station as shown on the photographs relayed from space.

Along with fellow Astronaut Edward Gibson, who would be the scientist pilot of the third crew, Schweickart tried cutting the aluminum strap holding the wing in place, using the pry bar, a bone saw, and the cable cutter. Each method was successful. Deploying a pole from the hatch of the airlock module, and using the cable cutter on the outboard end as a clamp, one astronaut used the pole as a handrail to maneuver the solar-array panel. This new procedure was described in detail to Conrad and his crew aboard Skylab.

On June 7, Conrad and Kerwin opened the hatch on the airlock module and moved out on the airlock shroud to assemble their tools and equipment. Weitz remained inside. Schweickart, with his simulator experience, talked to the crew from Mission Control at Houston. Engineers at Houston and Huntsville listened intently to the operation, ready to give advice if needed.

Standing outside the workshop, Conrad and Kerwin assembled the 25-foot-long aluminum pole from its five sections. They then attached a cable cutter tool to one end and carefully maneuvered the pole until the cutter jaws were clamped on the debris on the solar-wing beam. While Schweickart relayed instructions, they fastened the other end of the pole to the solar observatory truss structure.

Attached to a tether, Conrad worked his way hand over hand to the wing beam. Once at the beam, he determined that the cutter jaws were correctly positioned on the debris.

Now, orbital night stopped them, but as the...

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Extension of the solar wing became a problem, even after the offending strap had been cut. With one end of a rope attached to the vent module on the wing and the other to the deployment assembly truss, Conrad stood up stretching the rope over his shoulder. This provided sufficient leverage to deploy the wing.

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[75] ...spacecraft moved back into daylight, they were ready once more.

Kerwin pulled hard on the lanyard, which operated the cutter jaws. "Man, am I pulling," he exclaimed.

Nothing happened.

He pulled even harder. Since the cutter jaws appeared to be spreading without cutting the strap, Conrad made his way back along the beam to examine the cutter jaws.

As he reached the scissors-type mechanism, the cutter severed the strap, and the beam, now free, moved suddenly. The unexpected action propelled Conrad tumbling into space, where the tether restrained him. The excitement caused him to miss seeing what happened as the wing deployed some 20 degrees.

Now the problem facing Conrad and Kerwin was to deploy the beam the full 90 degrees so that the solar arrays could be extended. This problem had been anticipated, and procedures for deploying the beam had been carefully worked out on the ground and tested. Before cutting the metal strap restraining the beam, Conrad had hooked a tether to a vent module relief hole on the beam. The other end of the tether was firmly secured to an antenna support truss on the solar observatory.

Both Conrad and Kerwin tugged on the tether to move the beam, but without success. Conrad then worked himself along the beam to where it hinged to the workshop. Standing at the hinge, he lifted the tether to his shoulder and stood erect, while Kerwin pulled on the tether again.

Suddenly, the clevis bracket on the actuator broke, freeing the beam. As Conrad and Kerwin again tumbled into space, restrained by their tethers, the beam swung out to its fully deployed position.

As the two astronauts began disassembling the tools and stowing their gear, the Sun's rays warmed the deployment mechanism. Slowly, the three panel sections began extending. Now, ground controllers maneuvered Skylab to allow solar heating of the fluid in the wing section actuator-dampers. Within 6 hours after the beam was freed, the individual wing sections were fully deployed and functioning. This increased the power capability from 4000 to 7000 watts, thus assuring that Skylab would be able to carry out its mission completely.

Conrad, Kerwin, and Weitz had kept their word. They had demonstrated that, properly trained and equipped, man could carry out difficult repairs in space.

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Shading of the workshop and deploying the solar wing made Skylab fully operable. The addition of the workshop solar array provided much-needed electrical power and the parasol shielded the workshop from high temperatures.

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