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HEALTH EFFECTS of human spaceflight

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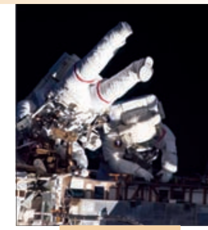


Space station repair: How it's done

Arriving at Skylab in their Apollo CSM, astronauts Conrad, Kerwin, and Weitz surveyed the damaged orbital workshop (a modified S-IVB third stage). One solar array was torn away (left, protruding wires and structure), and the starboard array was fouled by torn metal from the lost micrometeoroid shield, preventing deployment and severely limiting power levels.

Skylab 2 commander Pete Conrad eased the nose of his Apollo spacecraft toward a jammed solar array on America's crippled first space station. Maneuvering the 20-ton command and service module (CSM) from the left seat, the space-suited Conrad flew in hard vacuum. The CSM's open hatch obscured much of his view of the Skylab orbital workshop, but he had to get close enough that his two crewmates, Joe Kerwin and Paul Weitz, could free the solar array and restore Skylab's power.

The trio had launched nearly 12 hours earlier, on May 25, 1973. During launch atop the last Saturn V on May 14, the workshop's micrometeoroid shield had torn away, carrying with it the port solar array and fouling the starboard one with metal debris. Skylab was in critical condition: The lost micrometeoroid shield sent internal temperatures soaring, and without the solar arrays, the workshop was down to just 40% of design power.

Skylab 2 had two priorities: Free the starboard array wing, and deploy a solar shade to bring internal temperatures down from a scorching peak of 52 C. Sizing up the thin metal strap restraining the surviving array during his fly-around, Conrad coasted nose-first toward the 100-ton workshop. "We were well within six feet," said Weitz in a recent interview.

The Skylab 2 crew, launched May 25, 1973. Left to right: Joseph P. Kerwin, science pilot; Charles Conrad Jr., commander; and Paul J. Weitz, pilot.

Standing in the hatch with Kerwin holding his legs, Weitz extended a 10-ft-long pruning hook toward the end of the array. "We thought maybe we'd just break it loose. So we got down near the end of the solar array and I got a hold of it with the shepherd's crook," said Weitz. "I positioned the hook under the end of the wing and gave a mighty heave."

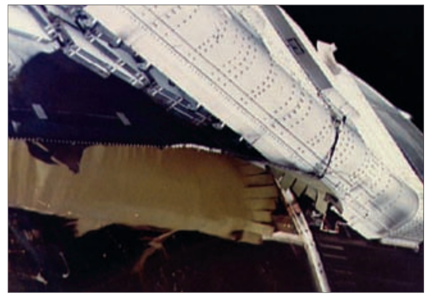
Rescuing Skylab

Weitz reported: "The wing did not move, but it pulled the CSM toward the [workshop]….So I am yanking on the pole; the CSM is being pulled in; and much to my amazement, in zero *g*, I was even moving the 100-ton lab. I could see the cold gas thrusters firing to maintain attitude, and Pete is mumbling and cursing in his attempts to maintain some sort of stationkeeping," recalled Weitz in *Homesteading Space: The Skylab Story,* by David Hitt, Owen Garriott, and Joe Kerwin.

Worried that Weitz and Kerwin's muscular efforts would bump the 20-ton CSM against the workshop, Conrad switched to an alternate approach: trying to cut through the metal strap binding the array. Beneath Weitz, Kerwin replaced the pruning hook with a lanyard-activated set of 'branch loppers.' Conrad eased back in, carefully moving the open hatch farther up the workshop near the solar array hinge. Again supported by Kerwin, Weitz tried to place the shears and cut the twisted metal strap, but "I could not get a good grip on the strap, or find enough purchase on it," he recalled. "We were trying to cut along the long way and just didn't have enough muscle with that thing, because it was about six or eight feet out ahead of me, and I was pulling on a line to try to do it; and we just could not get it through."

Performance under pressure

Defeated by geometry and an inch or two of stubborn metal, the crew backed away, vowing to succeed in a later effort. But the day's frustrations



A strip of micrometeoroid shield debris, ripped away during launch, fouled Skylab's #1 solar array wing. Skylab 2's crew could not cut the strap during a daring EVA from their Apollo command module on May 25, 1973, but freed the array and restored power during a second spacewalk on June 7, 1973.

were not over. Attempting to dock back at Skylab's axial port, Conrad found the CSM probe's capture latches would not engage Skylab's funnel-like drogue. The backup procedures didn't work either; their Apollo spacecraft could not dock with the orbiting lab.

"Suddenly there was a grimmer problem than the solar panel," Kerwin explained. "If we couldn't dock, we would have to come home. With nothing accomplished."

One last checklist procedure remained, labeled tersely: "Final Docking Attempt." It had come to that. Three months earlier, Conrad and Kerwin had spent an extra 15 minutes with their instructor, Jake Smith, as he reviewed an obscure, never-before-used backup procedure: Smith had showed them how they could snip wires on the probe to bypass the electrical interlock in the soft-docking capture latches, allowing the 12 main docking latches to engage.

To operate on the probe, though, the crew again had to don gloves and helmets, dump cabin pressure, remove the hatch from the CSM nose tunnel, and pull the probe into the cabin. Repressurize. Snip the proper wires. Back to vacuum. Reinsert the probe in the tunnel. Close the hatch, and repressurize for that final docking attempt.

By now the crew had been in orbit nearly 20 hours. Any chance for success now rode on Pete Conrad's flying skills. Without the probe's capture latches engaging to assure the proper alignment, could he mate the two vehicles accurately enough to close the main latches?

Weitz watched in awe as Conrad flew precisely down the docking corridor and gently pressed the CSM's nose against the smooth Skylab docking ring. Nothing held the two vehicles together except forward thruster firings from Conrad's translational hand controller. "I can't imagine anyone flying that precisely in the three-dimensional situation you find in space," Weitz said.

The crew flipped a switch to retract the probe and start the 10-second main latch engagement sequence. Kerwin recalled the tension of that moment. "We counted, 10, 9, 8, 7, 6, 5, 4, 3, 2—and a machine gun went off in our faces. That explosive rattle was the main latches engaging. We were staying!" Skylab 2 was hard-docked to its orbiting workshop.

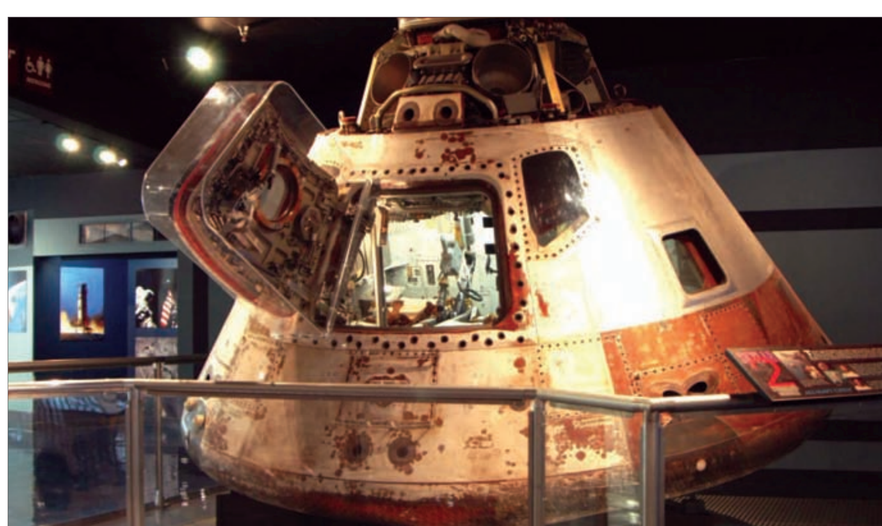
How good was Conrad's flying? When Weitz pressurized the tunnel and opened the hatch to check the latches, "By golly, 11 of those latches were engaged." Navy flier Pete Conrad had nailed it, dead-on. But someone else deserved equal credit. Wrote Kerwin: "God bless you, Jake!"

Free-fall tumble

Skylab 2 had docked successfully, but two critical repair tasks loomed. That jammed solar array could wait. First, the crew had to shade the workshop to cool its superheated interior, where food and film were degrading and insulation might be outgassing toxic fumes. Working in 15-minute shifts inside the oven-like lab, on day 2 the crew deployed a nylon-and-mylar parasol sunshade through a science airlock. Shielded from the intense solar flux, the workshop quickly cooled; by flight day 4, temperatures inside had dropped enough to allow the crew to move in and begin outfitting Skylab for science operations.

The workshop was still starved for power—the X-shaped Apollo telescope mount arrays generated only 40% of the systems and science demand. On Earth, a far-flung team led by backup commander Rusty Schweickart worked up an EVA plan to free the stuck array. Schweickart and other astronauts validated procedures through extensive underwater runs in the Marshall neutral buoyancy tank.

On June 7, Conrad and Kerwin exited the airlock and assembled a 25-ft



On May 25, 1973, a Saturn IB rocket launched the Skylab 2 command and service modules into orbit with Charles Conrad, Paul Weitz, and Joseph Kerwin. After making substantial repairs, including deployment of a parasol sunshade that cooled the inside of Skylab to 75 F, the workshop was in full operation by June 4. After 404 orbits and 392 experiment hours, the crew returned on June 22, 1973; their command module is displayed at the National Museum of Naval Aviation, Pensacola, Florida. Photo courtesy Smithsonian Institution.

pole topped by the rope-activated power company shears. Kerwin's task was to guide the pole and cutter down to the metal strap restraining the array, firmly seating the jaws on the strap. Conrad would translate down the stable pole to the array wing, hooking a rope called the beam erection tether (BET) to openings on the array wing. Once Conrad was clear, Kerwin would cut the strap. Both men would then pull on the BET to extend the array.

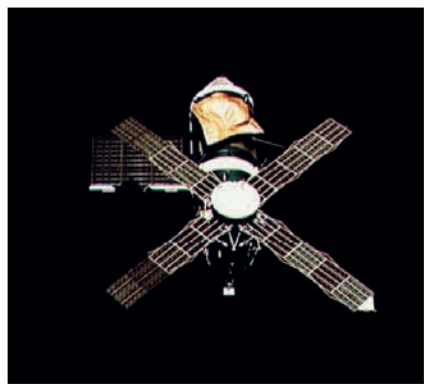
Simple tasks in free fall become major challenges if an astronaut cannot maintain a stable body position using handholds and tethers. The upper workshop furnished few tether points and no footholds; with his body only loosely tethered to an antenna strut, Kerwin struggled to guide his long pole and cutter onto the strap. Finally, Conrad helped him double his chest tether through an eyebolt on the workshop surface, snapping it back to his suit. Now Kerwin could 'stand' in a three-point stance—a tether and two boots. Three minutes later the cutter was firmly clamped on the offending strap.

Conrad inched out and attached the BET to the hinged array beam. Kerwin tied the BET's near end to structure, the tensioned rope lying parallel to the workshop hull. From his post on the fixed airlock shroud atop the lab, Kerwin yanked the cutter lanyard with all his strength. The cutter sliced the debris strap in two, but the freed array lurched up only a few inches, then stopped. A hydraulic damper, now frozen, kept the spring-loaded beam from popping fully open.

Back to the ropes. Conrad and Kerwin maneuvered under the taut BET, suits aligned with the rope, facing the hull, with boots toward the array. "Pete gave the word and we both pushed away with our hands and got our feet under us," Kerwin wrote. "We pushed and straightened up. Suddenly…I felt the pop. The rope was loose, and we were free in space, tumbling head over heels and floating away."

Tossed into space by the sudden release of the BET tension, the pair grasped their gold-coated umbilicals and hauled themselves back, hand-over-hand, to the workshop. With the three photovoltaic panels in the array deployed, power levels rose to 70%. Skylab was in business.

Skylab 3 and 4 followed; the three crews racked up 171 days of experimental work in orbit from May 1973 to February 1974.



As the crew of Skylab 2 departed their orbiting lab on June 22, 1973, they looked back at the starboard solar array and the parasol sunshade they had successfully deployed, salvaging the space station.

Right stuff at the ISS

The quick reaction and EVA heroics of the Skylab 2 crew were surely on the minds of the ISS Expedition 35 crew this spring. On May 9, astronauts sighted a steady, slow-moving stream of ice crystals escaping from the far port-side P6 truss. The sparkling snowflakes were the latest manifestation of a persistent leak first seen last summer in the 2B ammonia coolant loop.

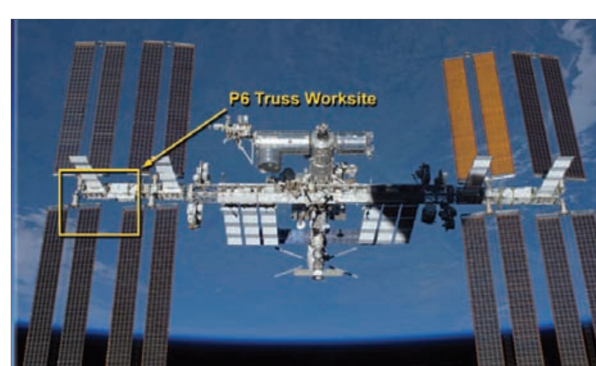
The loop cools electronics for half the 32.8-kW P6 solar arrays; when full, it contains 55 lb of ammonia. The engineers suspected that the loop, which originally was leaking at a slight 1.5 lb a year, had been damaged by a micrometeoroid or debris strike on its silvery, 6x50-ft radiator, which cools both ammonia systems on the array.

In a May interview, ISS deputy program manager Kirk Shireman said that "the leak rate last September rose to 7-9 lb of ammonia per year." Responding in a November EVA, astronauts Suni Williams and Aki Hoshide had bypassed the suspect radiator, routing coolant back through an unused early thermal control system backup. By February, the leak rate was stable at 5 lb of ammonia annually. By contrast, pressure in the bypassed radiator "was rock solid," said Shireman: The leak had to be somewhere else.

When the visible leak appeared in early May, engineers had their evidence. "The ammonia snowflakes did not appear to be coming from a point source," said Shireman. Rather than a micrometeoroid impact, engineers now suspected an internal leak in the loop's pump flow control subassembly (PFCS), which circulates ammonia through cold plates in the array electronics and out through the radiator.

This larger leak, estimated by flight controllers at 5 lb a *day*, threatened to drop the 2B cooling loop below the 40-lb threshold that would trigger an automatic shutdown of the array electronics. Controllers shifted ISS loads to the other seven power channels, then shut down the 2B cooling system.

In less than two days, station engineers had put together an EVA repair plan. Though spacewalker Tom Marshburn was just four days from boarding a Soyuz for return to Earth, he put aside packing and joined flight engineer Chris Cassidy in a day of intense study, tool preparation, and spacesuit checkout.



The site of the ammonia coolant leak repaired by Expedition 35 astronauts is on the far left P6 truss. The P6 arrays were the first U.S. solar arrays deployed at the ISS, in December 2000. Courtesy NASA.

Expedition 35 flight engineers Chris Cassidy (right) and Tom Marshburn completed a space walk on May 11, 2013, to inspect and replace a pump controller box on the ISS's far port truss (P6) leaking ammonia coolant.

On May 11 Marshburn and Cassidy, who had spacewalked together in 2009 on STS-127, translated to the far end of the P6 truss, then removed the dishwasher-sized PFCS. They saw no signs of frozen ammonia: "It looks really clean, surprisingly so," reported Cassidy. The astronauts parked the faulty pump, then installed a spare, older PFCS that had driven the loop for the first few years of ISS operations. Using pistol-grip power tools, the pair bolted the spare PFCS into the truss, then drove two shafts that tightly mated it to the 2B ammonia lines.

The reconnection went smoothly; ground controllers started the pump and checked the loop's integrity as the astronauts observed for half an hour. "I've had eyes on it and haven't seen a thing," Marshburn radioed. The system appeared to be holding. Their mission accomplished, the astronauts returned to the Quest airlock after five-and-a-half hours outside.

Shireman noted that the spare, "slightly used" space PFCS came with an unexpected bonus: Surplus ammonia in its accumulator partially replenished the leak losses. He said it would take several weeks of observing the 2B loop pressures, sifting out noisy, temperature-induced fluctuations, to assess the system's integrity. By May 22, all eight power channels were back online, and ISS program manager Mike Suffredini confirmed that the 2B leak had been eliminated.

Meanwhile, ammonia pressure in the suspect PFCS dropped to zero, consistent with an internal leak. But without the space shuttle, the ammonia-contaminated PFCS can't be returned for forensic examination. It will remain stowed on the P6 truss.

Before reentering the airlock on May 11, Marshburn radioed Mission Control with thanks. "I just have to say, it is incredible what we've done in just 48 hours. By 'we' I mean all of operations at Johnson [Space Center] and around the country." He and crewmates Chris Hadfield (Canada) and Roman Romanenko (Russia) returned to Earth safely on May 13, aboard Soyuz TMA-07M. Cassidy completes his Expedition 36 tour this month.

Expect the unexpected

In the hostile and unforgiving space environment, no mission goes completely as planned. Extending our reach into deep space will be neither easy nor trouble free. To cope with the unexpected and ensure safety and mission success beyond LEO, we will need decisive leadership, a top-notch team, and adequate resources.

As Kerwin put it, "…it is possible for humans to live and work in space for extended periods—but only with a terrific 'Home Earth' team to support them." The Skylab team set an extraordinary long-duration example, and the ISS partnership upholds and expands that heritage.

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