Soldering in space holds surprises

There is nothing routine about working in space, as astronaut Mike Fincke found out when he did some soldering onboard the International Space Station (ISS).

Richard Grugel, a materials scientist at NASA Marshall, watched his video monitor in disbelief. A transmission from the ISS was playing. The scene: Astronaut Fincke touches the tip of a soldering iron to a wire wrapped with rosin-core solder.

The solder, heated, becomes a molten blob with a droplet of rosin clinging tightly to the outside. As the solder melts, it is the behavior of the rosin that amazes Grugel. As the temperature increases, the droplet begins to spin, round and round, faster and faster, like a miniature carnival ride.

"What a surprise," says Grugel. "I have never seen anything quite like it."

Grugel is the principal investigator of the In-Space Soldering Investigation (ISSI). Fincke was conducting the ISSI program at the time of the discovery. The program's purpose is to find out how solder behaves in a weightless environment. This is important information for astronauts: If something breaks during a long trip to Mars, they will likely reach for a soldering iron to repair it.

The solder Fincke used for ISSI is a mixture of lead, tin, and rosin. The purpose of lead and tin is to form an electrically conducting connection, but the rosin also plays an important role. Grugel explains: "When metals are exposed to air, they become coated with oxides." Iron, for example, rusts, forming iron oxide. "One purpose of rosin," he says, "is to wash away any oxides before the lead and tin solidify, clearing the way for a good strong connection."

Astronaut Mike Fincke, Expedition 9 NASA ISS science officer and flight engineer, works on the ISSI in the station's Destiny laboratory.

Rosin also has another purpose. On Earth and in space, surface tension tends to hold solder in awkward blobs. Rosin breaks the tension, an action called "wetting," allowing molten solder to flow.

However, as the video shows, weightless rosin does not always behave as expected, which could be a problem.

To find out more about this behavior, Grugel plans to slice the solder blobs created by Fincke and examine what lies inside. He will be able to see whether the solder made a clean connection to the wire. He will also look for tiny bubbles of vaporized rosin inside the blobs. Such bubbles, which also appear in solder joints on Earth, lessen the electrical and thermal conductivity of the connection.

Grugel says that the ISSI experiments are complete. No more are presently planned. The astronauts conducted 86 separate experiments in all, spanning four increments. He says that the samples are still on the ISS and hopefully will be returned with the next shuttle flight. He expects that much information will be acquired from examining the ISS processed coupons. He adds that the group gained considerable insight regarding melting kinetics, equilibrium shape formation, and thermocapillary convection effects from the real-time and downlinked video observations.

Meanwhile, Grugel and his colleagues are brainstorming, trying to understand what causes the rosin to twirl. "We almost have it," Grugel says, but he is not yet ready to announce a solution. He does, however, have some advice for astronauts bent on soldering: Wear goggles, and watch out for flying rosin.

Changing forces and effects

NASA scientists have been concerned about the behavior of solder materials in weightlessness for some time. The ISS will not return to Earth should something need to be repaired—the astronauts will have to make the repair in space. The ISSI program was formed to examine the soldering issue.

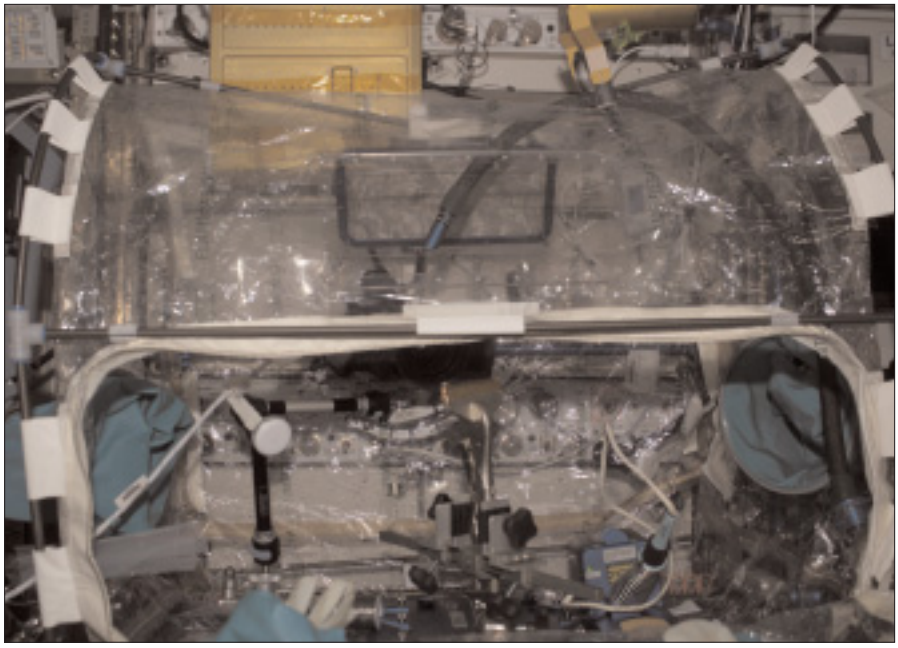
Many of the methods used to build and repair equipment on Earth must now be adapted for space. ISS crews have tools for making small repairs, but little research has been conducted on the best ways to manufacture and repair equipment in space.

In the low-gravity environment inside the orbiting space station, surface tension influences materials and fluids more strongly than it does on Earth. Fluids that would splatter and spill to the ground on Earth form drops held together by surface tension. Left uncontained, these drops float through the air in space.

Convection and surface tension are two forces that influence how a fluid moves or flows. Both play roles in fabrication and repair techniques such as soldering and welding. Soldering involves melting a metal or metal alloy, usually lead or tin. The molten material is applied and flows between surfaces or joints of materials that are being held together. When it cools and solidifies, the solder joins the materials together. On orbit, however, gravity is balanced by the equal but opposite centrifugal force or orbital rotation, thus eliminating convection and leaving surface tension to be the dominant force influencing flow.

On Earth, gas bubbles that form inside solder are lighter, and convection causes them to rise to the surface and separate from the molten fluid. In space, a different method must be used to remove the bubbles from the soldering metal. If too many bubbles become trapped, the solder is weakened and joined parts can separate.

The goal of the ISSI study is to investigate solder flows and the quality and strength of solder connections formed in the absence of convection.



Astronauts performed the ISSI experiments in the Maintenance Work Area.

Workbench investigation

The investigation uses hardware already available on the space station. For small on-orbit repairs, the astronaut toolkit includes a battery-operated soldering iron that heats up to 600 F. The device has special safety features, such as a holder that protects the user from burns.

The experiment is conducted inside the ISS Maintenance Work Area, a portable workbench with a tabletop that measures 36×25 in. When not in use, it is folded and stored inside a drawer.

The Maintenance Work Area can be used almost anywhere onboard the ISS. An astronaut unfolds it and clamps it to a slotted mechanism similar to seat tracks found in cars or airplanes. The tracks are located on the sides of most of the floor-to-ceiling racks inside the station.

To contain debris during cutting, drilling, filing, or soldering, a clear plastic cover can be placed around the workbench. Gloveports on the sides and ends of the workbench's plastic cover and a front flap that unzips allow both crewmembers to use the soldering iron or other tools at the same time. The station's vacuum cleaner can be attached to capture and dispose of particles or liquids that are 6 µm in diameter or larger.

One challenging aspect of soldering in space is that any smoke created during the heating will not easily disperse, possibly leaving the operator unable to see the work piece. In the work area, this problem will be avoided by using the vacuum.

The crew performed several tests connecting metal alloy wires of various configurations together with solder. These test pieces, or coupons, are designed to evaluate the effectiveness of different geometries typical of the kinds of operations that might be required in the future.

Investigators on Earth monitored the experiment from the Telescience Center at NASA Marshall. By viewing video, they can observe the soldering operation as the crew works on samples.

When the samples return to Earth for examination, the tests will include a microscopic evaluation of the structures of the solder joints. The tests will also compare the joints made in space with those done in the laboratory on Earth. The tensile strength will be measured in specially designed coupons.

Challenges of space repairs

The ISS must be maintained for its lifetime of a decade or longer. Since this orbiting home and workplace never returns to the ground, all repairs must be made in space.

Conducting repairs in space is challenging—tools and loose materials must be tethered or restrained so they do not float away. Crewmembers must anchor themselves so they have a steady hand when making repairs. Particles of debris created during drilling, filing, and other operations must be collected and disposed of so they do not contaminate the crew's living environment.

Besides the soldering iron, other tools used for repairs inside the space station include ratchets, sockets, screw drivers, wrenches, pliers, hacksaws, chisels, files, hammers, and even a sewing kit. Special tool kits allow astronauts to repair electronics, fiber optics, and fluid lines.

Experiments like the ISSI provide a systematic method for studying how to improve tools and repair procedures. This information can be used to design future tools and develop the best procedures for repairing equipment in the unique environment inside an orbiting spacecraft.

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