**Quick change artists:** Astronaut Edward M. (Mike) Fincke, Expedition 9 NASA ISS science officer and flight engineer, donned a Russian Orlan spacesuit as the American issue spacesuits were out of commission. He installed hardware associated with Europe's Automated Transfer Vehicle (ATV), scheduled to launch on its maiden voyage to the ISS next year.
*Image Credit: NASA*

# The Mother of Invention

## By James Oberg

NASA officials have been publicly extolling the amazing in-flight repair work of recent crews aboard the International Space Station (ISS) as demonstrating skills that will be called upon for future flights deeper into space. The work of the flight crews is indeed worthy of praise, as is NASA's new awareness of the fundamental challenge of hardware maintenance while far from Earth.

But the celebration is premature—and should only begin after NASA completely restructures the way it designs, builds, certifies and operates its crew systems hardware. Until NASA makes that conceptual breakthrough and gets the support it needs from Congress, what we've learned from recent experience will remain useless, and humanity will remain tied down to low earth orbit by the fundamental nature of the technology we build and use to get into space.

The last two years have seen several impressive space repair jobs by the astronauts and cosmonauts aboard the ISS, and they were forced to perform them largely because of the station's semi-isolation that resulted from the grounding of the shuttle fleet following the Columbia disaster. But a closer look shows that few, if any, of these successes would have been possible if the equipment had broken down in total isolation from Earth—say, for example, on a mission to Mars.

Now, as the space shuttle fleet prepares to return to work, it is critically important that mission operators not slip back into old habits regarding in-flight maintenance and repair. The space team had better not forget these lessons identifying the need for new attitudes and abilities, unless it wants to remain tied to the apron strings of ground-based support.

The Russians were champion "space tinkerers" aboard their long-term Salyut stations in the 1980s and especially aboard Mir in the 1990s. They always stressed "systems training" rather than "task training" for their crews, realizing that once in space they would be confronted by technical demands that simply could not have been anticipated prior to launch.

The work their cosmonauts have done with their Elektron oxygen generators has set a new high standard for in-space repair. These units have been installed aboard Mir and the ISS for more than a decade, and as each one becomes unfixable, a more advanced model (or the major components of one) is sent up. Worn-out hardware that accumulates becomes a spare parts inventory for future repair work.

Russian engineers have been struggling with the technological difficulty of delivering an electrical current to a medium that includes water, splitting that water into gaseous oxygen and hydrogen, and then separating the gas from the liquid without the convenience of the Earth's buoyancy forces. Impurities in the water or bubbles can contaminate and jam the sensors which control the process and prevent potentially catastrophic failures. Electrical conductors—both metallic and liquid—degrade over time, eventually becoming so impaired that the unit won't operate. Other factors, still largely unknown, sometimes require delicate fiddling with settings on the control panel, and sometimes require very high power settings to initiate the desired reactions.

However, the only factor that has allowed cosmonauts to keep the Elektron units working for more than a year is the constant stream of parts and new tools and techniques from Earth. The limiting factors on the device's lifespan remain unclear, as are the proper technologies needed to overcome them without the lifeline from Earth. The design has proven to be "good enough" for a space station about 250 miles (400 kilometers) from its home planet, and might even function for human spacecraft throughout Earth-Moon space—but for destinations beyond, it simply isn't good enough.

To a large degree, the American side has now caught up to Russia's attitudes regarding space repair. But both teams have only just begun the journey towards the level of maintainability and repair that an interplanetary spacecraft will demand.

Consider the treadmill. The one on the space station is no ordinary health club model. Called the Treadmill Vibration Isolation System (TVIS), it's a high-tech health maintenance and monitoring apparatus containing a computer-controlled, gyroscopically-stabilized, shock-isolated moving belt. Even when in full heart-pounding mode, it doesn't disturb the rest of the spacecraft.

**Mr. Fix-It:** Cosmonaut Alexander Y. Kaleri, Expedition 8 flight engineer, performs in-flight maintenance (IFM) on the Treadmill Vibration Isolation System (TVIS) in the Zvezda Service Module on the International Space Station (ISS). *Image Credit: NASA*

A year ago, the station crew completed a major repair of the device, which had suffered a series of hardware glitches over the previous three years. They weren't originally supposed to be able to do this—but without the exercise device, there were questions about their health being good enough for the extended two-man missions necessitated by the loss of shuttle transportation.

"The treadmill was to be removed from the floor (the 'pit') and its chassis opened up to allow access to the roll-stabilizing gyroscope for removal of its flywheel," a NASA internal status report stated. "The failed gyro bearings are then replaced, followed by reassembly of the gyro with careful torque calibration. This requires measuring shims, small metal wedges to hold a mechanism gap at a precision width, and building a new shim stack, while verifying the running torque for the fasteners."

Using a set of tools sent up on a Russian supply ship, they took the unit apart, replaced a broken component, and then reinstalled the shaft with a precision that had been thought only possible in a fully-equipped Earth-side workshop.

Both crewmen worked two full days on this, "longer than expected," according to NASA. But in a message to the crew celebrating the completion of the repair, Mission Control indicated it understood the long-range significance of the success. "You are expanding the [in-flight maintenance] envelope," the message said, "something that will be increasingly important as we plan and execute missions farther and farther from home."

"The crews have shown repairing hardware in space with as few supplies and equipment as possible," noted program manager William Gerstenmaier when discussing this success. "Missions far from Earth will benefit from their work." Later, he reiterated the theme: "We have already learned a lot about long-duration remote operations on the ISS with limited resupply."

**Deep space solutions**

The key word is "limited." There is still the option of waiting for small components to be sent up, on demand, from Earth. Whether in large quantities or small, this is still an unsevered umbilical cord to the home planet.

In many cases, not only have station crewmembers frequently discovered that they did not have the correct tools, they didn't even have the correct diagnostic equipment. For example, while trying to discover the cause of the cooling system failure in one of the NASA space suits, Mission Control thought that it would be helpful to attach a microphone to the outside of the unit and then send the detected noises down to Earth for analysis, i.e., to differentiate between a pump that was stuck, unprimed, clogged or something else all together.

This was a creative and potentially helpful idea—but the space station hardware wouldn't cooperate. In order to save bandwidth, the voice communication system used a compression algorithm that filtered out noises unusual for human voices. It was impossible to turn this off, even if desired, and so no usable hi-fidelity transmission of mechanical noise was possible.

Still, the crew did succeed in repairing the U.S. space suits. As astronaut Mike Fincke prepared to return to Earth in October 2004, he described his own assessment of the significance of the work. "It is very important that—as it turned out—our space suits can be repaired on orbit," he explained. Contamination in the coolant water lines had rendered all of the U.S. suits unusable earlier in the year. Designed to be serviced only back on Earth, two of the three backpacks were opened, cleaned, serviced with new rotor pumps and other parts sent up from Earth, reassembled and retested.

This remaining dependence on Earth—on the transport of small spare parts and special tools after an equipment failure has occurred—is now what NASA must learn to wean itself from. Impressive as the repairs of the treadmill and the space suits were, they still could not have been accomplished if the spacecraft had been halfway to Mars.

Over the next decade, NASA needs to design and build space hardware that is even more diagnosable, repairable and recertifiable than any of the gear now aboard the space station—or for that matter, any gear awaiting delivery from Earth for the foreseeable future. It must build equipment that can be handled by a limited set of diagnostic equipment and tools, and with enough commonality so that pieces can be cannibalized as needed to serve in other devices.

In another crucial break with tradition, operations and logistics, experts need to be intimately involved from the very beginning of the development of the hardware. Hardware must be designed from scratch with in-flight repair in mind, so that the impressive accomplishments of recent space station crew repairs become obsolete.

The most obvious application for these enhanced abilities—which have not yet been achieved, despite the hurrahs from NASA spokespeople—is going to be aboard space missions beyond Low Earth Orbit, out where the options of quick re-supply and ground-based workshop access no longer apply. In the last two years, space operators have unexpectedly and unwillingly been forced to try this approach. It is a process that needs to continue.