THE INTERNATIONAL SPACE STATION: TESTBED FOR DEEP-SPACE MISSIONS

BY CLIFFORD R. MCMURRAY

NASA engineers are developing climbing legs for the International Space Station's robotic crewmember Robonaut 2 (R2), marking another milestone in space humanoid robotics.

Designing an improved pump for the urine reclamation system aboard ISS doesn't sound as glamorous as designing an improved rocket engine, but it's actually more important. The rocket engines we have today have room for improvement, but they can get humans to Mars and back. The life support systems we have today can't. They break down too often and need too much maintenance to be trustworthy for a Mars mission. The urine pump on ISS typically needs to be replaced every three to six months; that means the crew of a Marsbound spacecraft would need to carry a dozen spares for the three-year trip. Developing and demonstrating a much sturdier pump is just one example of why the ISS is a vital engineering testbed for long-duration flights.

As the new NASA report, "NASA's Journey to Mars: Pioneering the Next Steps in Space Exploration," says, "The ISS is the only microgravity platform for the long-term testing of new life support and crew health systems, advanced habitat modules, and other technologies needed to decrease reliance on Earth." It's not just useful for biological research like the experiments being conducted on Scott Kelly and Mikhail Kornienko during their year-long stay in space. Equally important are the lessons being learned in keeping the machinery that keeps them alive working for years at a time.

We already know how to build unmanned spacecraft to operate for decades without being touched by human hands. The Voyager probes are still sending data back to Earth 35 years after launch, and the opportunity rover has been driving over the dusty surface of Mars for a dozen years now. It's only when humans enter the picture that machinery starts breaking down. Humans put moisture into the system with their exhalations, sweat, and bodily wastes; they shed dry skin particles. Stray food particles occasionally escape from their meals. Siloxanes from their deodorants add other sticky particles to the air. Moisture and particulates are death to machinery. The two systems aboard ISS that need the most maintenance are the urine reclamation system and the carbon dioxide filter.

Successful maintenance comes from more than just having the right spare parts and tools on hand. Astronauts must know where each of the spares is located, and how to install it without having practiced with it on the ground—sometimes without having even seen it before. One of the lessons learned from the joint NASA-Russian experience with the Russian space station Mir was how easy it is to lose track of equipment in a large spacecraft in microgravity, and how much time can be wasted looking for lost tools or supplies. ISS isn't entirely perfect in this regard, but with the meticulous use of a barcode-driven computer database and RFID chips, it's much better.

The other part of the maintenance equation is knowing

The urine reclamation system in the ISS toilet is one of the systems most prone to breakdown.

how to perform a needed task, sometimes without ever having practiced it on the ground. The number of systems and subassemblies aboard the 450-ton station is simply too great for the crew to know them all in detail, and the knowledge they have gets rusty if not exercised until months after liftoff. After a water leak in the cooling system of his spacesuit flooded Luco Parmitano's helmet during an EVA in July 2013, and nearly drowned him before he could get back inside the space station, the crew discovered the leak had been caused by a clogged filter. NASA sent up a repair kit, but fixing the spacesuit wasn't anything the astronauts had been trained to do. The ground support team discovered they could upload an instructional video to teach the crew what they needed to know. Since then, instructional videos supplemented with conference calls with engineers on the ground have become a standard procedure for guiding the crew through unexpected repair tasks.

As these examples demonstrate, just keeping the ISS in operation constitutes an enormous engineering experiment. New and improved hardware replaces older hardware as it breaks down, and broken equipment, along with air and water samples, is sent back to the ground for examination that contributes to improved designs. A redesigned gear train for the urine pump, a computer called SpaceCube with improved hardening against radiation-induced errors, a Sabatier system and improved urine pre-treatment to reclaim more of the water in the life-support loop, a better carbon filter to remove siloxanes from the air, lighter-weight exercise equipment, better thermal control systems—all these and many others have been tested aboard ISS, or will be soon. There's no substitute for this kind of experience.

Not all the engineering experiments on ISS are iterative improvements of existing hardware and maintenance processes. Some of the experiments point the way to operational use of brand new technologies. The BEAM module due to be installed on ISS in 2016, for example, will be the first test of inflatable modules for human habitation. Such modules can be launched in a compact form, and when inflated will provide habitats that are both roomier and more resistant to puncture by meteorites than traditional hard-shell modules. Another new technology is laser communications, which will enable data transmission at rates 10 to 100 times faster than the radios used by present-day spacecraft. The Optical Payload for Lasercomm Science (OPALS) successfully beamed a 175-megabit high-definition video from ISS to the ground at 50 megabits per second in June 2014. That's more than twice as fast as needed for a live TV broadcast, but this experiment is just the beginning. Lasers may eventually be able to transmit tens of gigabits per second.

Additive manufacturing, aka 3D printing, opens up truly revolutionary prospects for making spare parts to order while in space, using packaged raw materials and electronic blueprints. The first 3D printer, developed by Made In Space, was launched to ISS in 2014. Using relatively low-temperature plastic feedstock, this printer produced sample items which were tested for strength and compared to identical parts printed on Earth. These experiments went well; using lessons learned from this prototype, Made In Space produced the Additive Manufacturing Facility (AMF), which will print with a wider range of polymers and be available for use by commercial customers. It will launch to ISS in 2016. So far, the prototype has printed no parts for actual use aboard ISS, but that will soon change with the printing of a plastic water gun nozzle for use in the galley.

ISS is also leading the way in a budding partnership between man and robot. Using robots for routine tasks will free up the crew for the work that requires a brain. Robonaut 2 (R2), a humanoid robot launched to ISS in 2011, began modestly by demonstrating its ability to monitor the airflow from vents to be sure the ductwork isn't clogged. It's not as fast as a human performing the same task, but it can hold the gauge more steadily than a human, and its samples aren't subject to disturbance by a human's breath. Since then, R2 has been taken through a series of increasingly complex tests, including tele-operation by the crew. R2 was launched without legs, but in 2014 a set of seven-jointed legs with grasping end-effectors was sent up and attached to the torso. Other upgrades will allow it to move about both inside and outside the station, helping spacewalking astronauts. Other ISS robotics experiments include the Interact Centaur, a rover on Earth that was controlled by an astronaut on ISS, demonstrating the ability of astronauts in orbit around Mars to operate rovers on the surface. The remote control system used by Danish astronaut Andreas Mogenson included a feedback loop that allowed him to "feel" the rover's actions from 250 miles overhead as he first steered it, then used its robotic arm to place a peg in a circuit board with a positional tolerance of only 150 micrometers.

As it enters its 16th year of continuous habitation, ISS recently got a top-to-bottom inspection for signs of wear and tear, to determine how much useful life it has left. Its international partners haven't yet committed to keep it running past 2024, but Dana Weigel, manager of NASA ISS Program Vehicle Office, says "We see no limiting factors" in the condition of the spacecraft that would preclude its occupation well past that date. Still, she says, "We're really trying to learn everything we can from this vehicle" in whatever time it has left. Before NASA and its partners retire ISS, the hardware necessary to support crewed interplanetary flights, and the techniques for maintaining that hardware without resupply from Earth, will be a lot farther down the road to maturity.

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European experts have pulled off a major advance that might one day help build new worlds in space after an astronaut in the International Space Station remotely guided a robot on Earth by feel.