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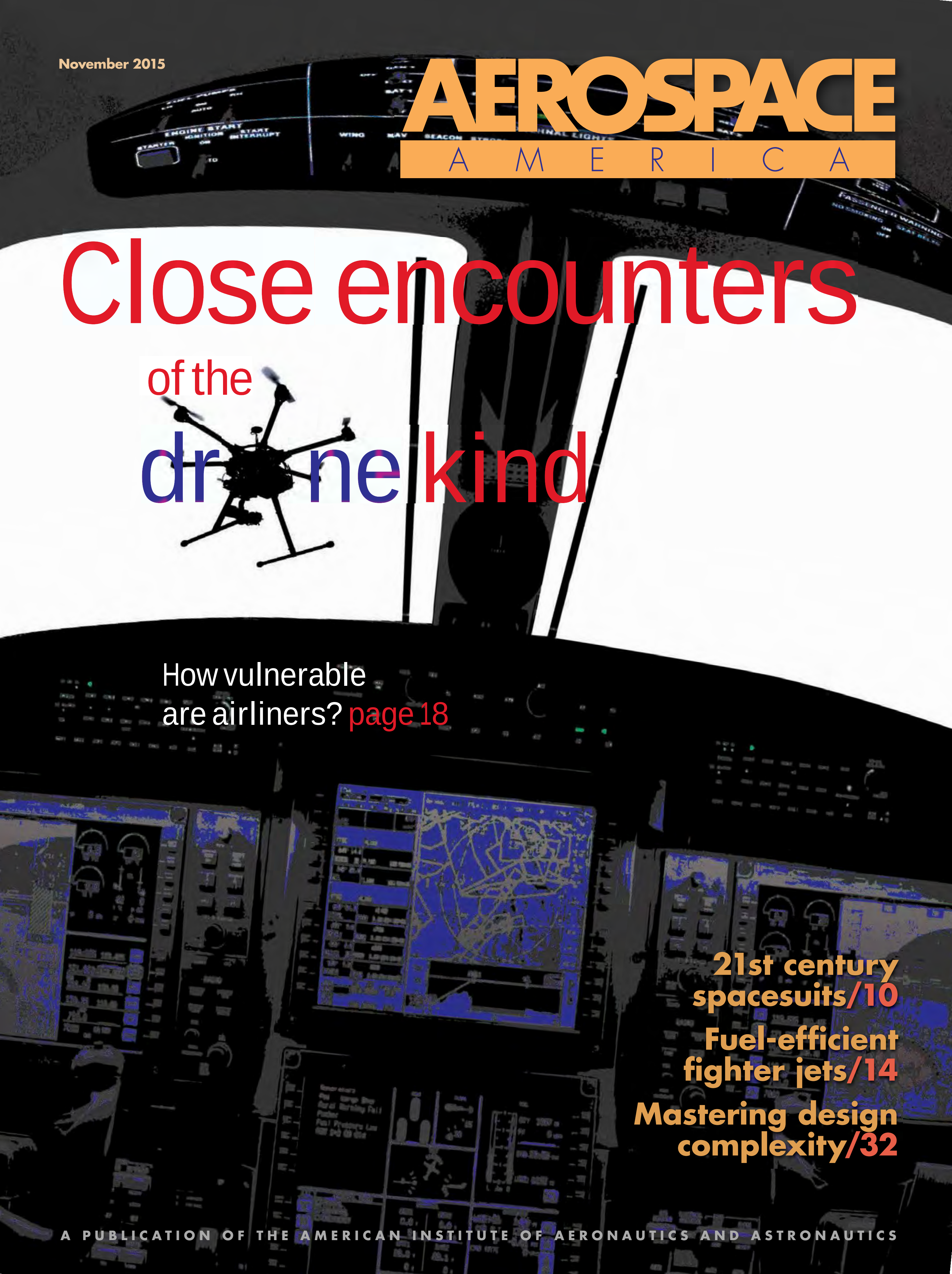

Close encounters of the drone kind

How vulnerable are airliners? page 18

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21st century spacesuits

After Luca Parmitano's near drowning during a 2013 spacewalk, NASA demonstrated how the helmet worn by the Italian astronaut accumulated water.

NASA video clip

Five decades ago, the first spacewalks thrilled the public and nearly killed two pioneers of extra vehicular activities. NASA's spacesuits today are much improved but they are in short supply and challenging to maintain. Three-time spacewalker Tom Jones examines how next-generation suits can meet the challenges of lunar, asteroid and Mars exploration.

Luca Parmitano, an Italian astronaut working at the International Space Station in 2013, was 45 minutes into his second extravehicular activity when he felt cold water pooling, weightless, at the back of his communications cap. Flight controllers at first assumed that the water was merely a nuisance leak from a drinking valve inside his helmet. They were unaware that the glob was creeping steadily toward Parmitano's face. Realizing the water had to be coming from the suit's life-support system, controllers ordered Parmitano and his spacewalking partner, U.S. astronaut Chris Cassidy, to go back to the airlock.

It was nearly too late.

"The water came over my head, it reached over my eyes, and it covered my eyes and my nose," Parmitano recalled in a June talk at Rice University in Houston, according to a video recording. "In one instant and one motion, I was sensorially isolated, upside down, with no light and no communications."

Breathing through his mouth, Parmitano jerked his head from side to side but couldn't shake the water from his face. Only Parmitano 's coolness during the emergency and assistance from his crew mates saved him. Parmitano managed to enter the airlock, followed by Cassidy, who quickly secured the outer hatch behind them. Immediately, their crew mates inside repressurized the chamber and scrambled into the airlock to remove Parmitano's helmet and mop the water from his face.

NASA investigators determined that water entered the helmet ventilation duct from a backpack water separator that was clogged by mineral impurities in the ISS water used to supply the suit.

Parmitano's NASA spacesuit, called an extravehicular mobility unit, or EMU, was the same kind that I wore during three spacewalks at the ISS and it is still used on the space station. Compared to the Apollo suits worn on the moon, the EMU has more flexible joints and gloves and a higher-capacity cooling system. Yet, as Parmitano's experience shows, today's spacesuits are showing the effects of being based in orbit, far from their shuttle-era home in Johnson Space Center in Houston. NASA is grappling with how to maintain these EMUs even as it invests for the long term in an entirely new suit.

Old suits, new missions

The EMU was not designed to be maintained in space for long periods. After each space shuttle mission, the suits were returned to Houston for inspection and overhaul in a clean room. But with the shuttle now retired, NASA has only limited ability to return cargo from the ISS, which means the suits must stay on-orbit for years on end. Astronauts do their best to maintain the suits, but the station lacks a clean room and all the spares and tools needed for rigorous upkeep.

Water contamination — leading to corrosion, clogging, and component failure — is among the challenges facing NASA's EVA managers. Maintenance is also constrained by the tight EMU parts supply chain. Months are required to return a suit via a Dragon cargo flight, overhaul it in Houston and launch it back to ISS. NASA currently has four EMU hard upper torsos with four Primary Life Support Systems at the ISS. Four EMUs are kept ready there for spacewalks. One spacesuit was destroyed in June's Falcon 9-Dragon launch failure.


NASA

Astronauts Stan Love and Stephen Bowen assess the Modified Advanced Crew Escape Suit for mobility, dexterity and tool handling in the Neutral Buoyancy Lab at Johnson Space Center.

A better space suit

NASA has started technology work to develop the spacesuits it will need for missions to the moon, an asteroid or Mars. At Johnson Space Center, two efforts are underway to demonstrate the improvements needed in a next-generation suit. The first effort is aimed at producing a prototype suit designed to function in the free fall environment of deep space and in low gravity environments like the surfaces of asteroids or the Martian moons. Some features of this suit could later be adapted to work on planetary surfaces.

In August, Oceaneering Space Systems, a Houston deep-sea technologies firm that has long manufactured spacewalking hardware for NASA, completed a pressure garment (the airtight portion of a spacesuit) called the Prototype eXploration Spacesuit, or PXS. The PXS was made in partnership with ILC Dover, the David Clark Co. of Worcester, Massachusetts, and several other manufacturers.

The PXS's flexible upper torso with rigid sizing frame can be adjusted to fit a broader spectrum of astronaut body sizes. Some astronauts cannot serve on ISS crews because the current EMU sizes cannot fit them. The resizing capability also means that fewer suits may be needed at the station or on deep space mis-


NASA

Technicians at NASA's Johnson Space Center in Houston test the spacesuits that will be used aboard the Orion for deep-space missions. The suits are a closed-loop version of those worn by space shuttle astronauts.

Close calls for spacewalkers

1965 Cosmonaut Alexei Leonov could have died on history's first spacewalk when his stiff suit nearly prevented him from getting back into the spacecraft's airlock. Leonov was only able to squeeze in by bleeding down his suit pressure to dangerously low levels.

1966 Gemini 9-pilot Gene Cernan became dangerously overheated during the second U.S. spacewalk. Cernan's suit cooling system was overwhelmed by his struggle to maneuver his stiff, inflated suit in free-fall conditions. With few handholds and blinded by sweat and a fogged visor, Cernan groped his way to the Gemini cabin. His heart rate soared to 180 beats per minute. At the limit of his endurance, he managed to jam himself in, but couldn't seal the hatch. His commander, Tom Stafford, levered it shut and saved Cernan's life. Cernan lost 4 pounds during his 2-hour, seven-minute EVA spacewalk.

2013 Luca Parmitano, a European Space Agency astronaut, managed to get back to the International Space Station's airlock after a glob of water covered his eyes and nose. "Because of capillarity, [the water] went inside my nose — completely plugged my nose. It also got inside my ears," Parmitano recalled in a June talk. Parmitano's spacewalking partner, U.S. astronaut Chris Cassidy, peered inside Parmitano's helmet and saw on his head what "looked like half of a grapefruit-sized blob of water, kind of jiggling like a bowl of Jell-O." Parmitano was stoic about the real possibility of drowning. "It was fairly uncomfortable to have that water standing in front of your face," he said. Parmitano pictured "an Italian newspaper headline declaring, 'Italian Astronaut Drowns in Space.'"

sions, reducing stowage and supply chain demands.

Such a free-fall suit won't be ready by 2025, when an Orion capsule is scheduled to carry astronauts to a piece of an asteroid in NASA's Asteroid Redirect Mission. Therefore, NASA plans to use an upgrade of the shuttle's launch-and-entry suit, called MACES for the Modified Advanced Crew Escape Suit. MACES will be equipped with the EMU's gloves and an advanced life support system backpack.

"By giving the astronaut a super-snug fit in the MACES, we've shown it can give crews adequate dexterity for the ARM EVA tasks," says Steve Stich, director of exploration integration and science at Johnson Space Center. ARM astronauts will perform two EVAs with this suit as they examine and sample a boulder retrieved robotically from a near-Earth asteroid.

Last year, astronauts tested MACES suits under water in the Neutral Buoyancy Laboratory at Johnson, running up to four hours of simulated asteroid EVA jobs, such as sample retrieval and moving around a boulder's surface.

In a parallel effort, a Johnson-industry team, including ILC, is developing the Z-2 suit prototype pressure garment, aimed at testing mobility technologies for planetary surface work, such as on the moon or Mars. The Z-2 also adjusts to different-sized crew members but features a hard upper torso.

"We need to start down-selecting the best features offered by these two suits to build one down the road that we'll fly," Stich says. Stich has an annual budget of just over $30 million to maintain the current EMUs and develop its successor, but an operational suit is still years away. Stich says his team is eager to fly its follow-on design at the ISS, working out its operational kinks in low Earth orbit before it must perform at lunar distance and beyond.

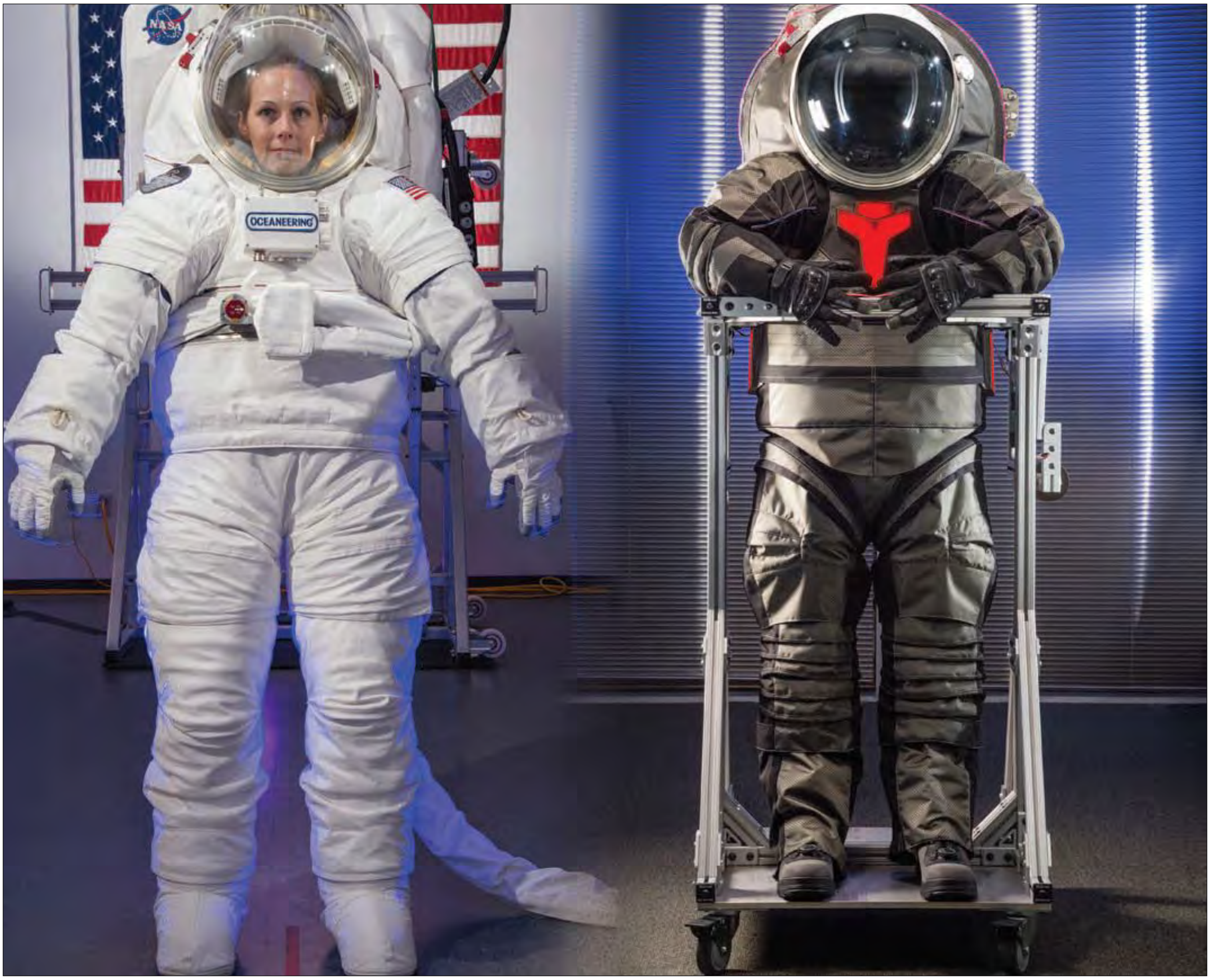
Seven areas of innovation

The technologies NASA will evaluate in trials of both suits include:

•Advanced Heat Rejection: Keeping a working astronaut cool on an EVA is the job of a new Spacesuit Water Membrane Evaporator. The current EMU relies on a device called an ice bed sublimator. Warm water from the astronaut's cooling loop runs through an ice bed formed in a porous metal block. The ice sublimates into the vacuum outside, taking heat from the cooling loop with it, but the porous block can become clogged by contaminants. The new system circulates body-warmed water to the evaporator, which vaporizes water into the vacuum outside, carrying the heat into space. The membrane evaporator promises to be less vulnerable to water contamination than the sublimator.

•Improved Backpack Maintenance: Astronauts have replaced the fan/pump/separator units — Parmitano's nemesis — as well as gas and water filters, and emergency oxygen tank assemblies of the EMUs aboard the ISS. Making future backpack systems easier to inspect, remove, upgrade, and repair is critical for long expeditions into deep space or on Mars.

•Modern Avionics: On my EMU, I pushed and pulled a cable to select the correct pressurization setting, and used a stovetop-style knob to control temperature. The 1970s-vintage fault-detection computer, displays, and mechanical control linkages on the EMUs will be upgraded to digital electronics for suit monitoring and control.



NASA Johnson Space Center

NASA's two spacesuit prototypes are the Prototype eXploration Suit, left, meant for use in free fall and low gravity, and the Z-2, which is testing mobility technology for surface exploration on the moon or Mars.

•Regenerable CO2 Removal: The current EMU uses metal-oxide cartridges to remove CO2 from the suit atmosphere, but these cartridges must be replaced and renewed inside the ISS. These might be replaced by a chemical-bed scrubber containing organic nitrogen compounds, called amines, to remove CO2 and water vapor. The scrubber would then vent these gases overboard during a heating cycle. The amine bed-system would operate continuously and eliminate the need for cartridge replacement.

•Simplified Suit Donning: A rear-entry hatch under the backpack, as on the Russian Orlan suit, would enable an astronaut to slip easily inside, considerably reducing the time needed to don the spacesuit. Rear-entry suits might also be designed to attach to a suit port outside a vehicle, simplifying EVA operations from a surface habitat or rover where dust is a concern.

•Thermal Protection: On Mars, the thin atmosphere (about 0.5 percent Earth surface pressure) can still conduct heat between the suit's outer insulation layer and the interior, and vice versa. Better thermal insulation systems will be needed to protect astronauts from temperature extremes.

•Higher Operating Pressure: A higher suit pressure would reduce the time astronauts must spend breathing oxygen before an EVA to reduce risk of decompression sickness, also known as the bends. The EMU operates at 4.3 pounds per square inch and the Russian Orlan at 5.7 psi; engineers would like a future suit to function at up to 8 psi. The design challenge is to keep the suit's limb joints and glove fingers flexible enough at these higher pressures to preserve dexterity and reduce fatigue.

NASA is gathering testing data from life-support and astronaut trials in the new suits. The agency is particularly interested in an astronaut's dexterity and ability to work in the suit, as worn on treadmills, in vacuum, thermal chambers and simulated free fall. If NASA's technology efforts succeed, the well-dressed astronaut's wardrobe will include a new EVA suit sometime in the mid 2020s.

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