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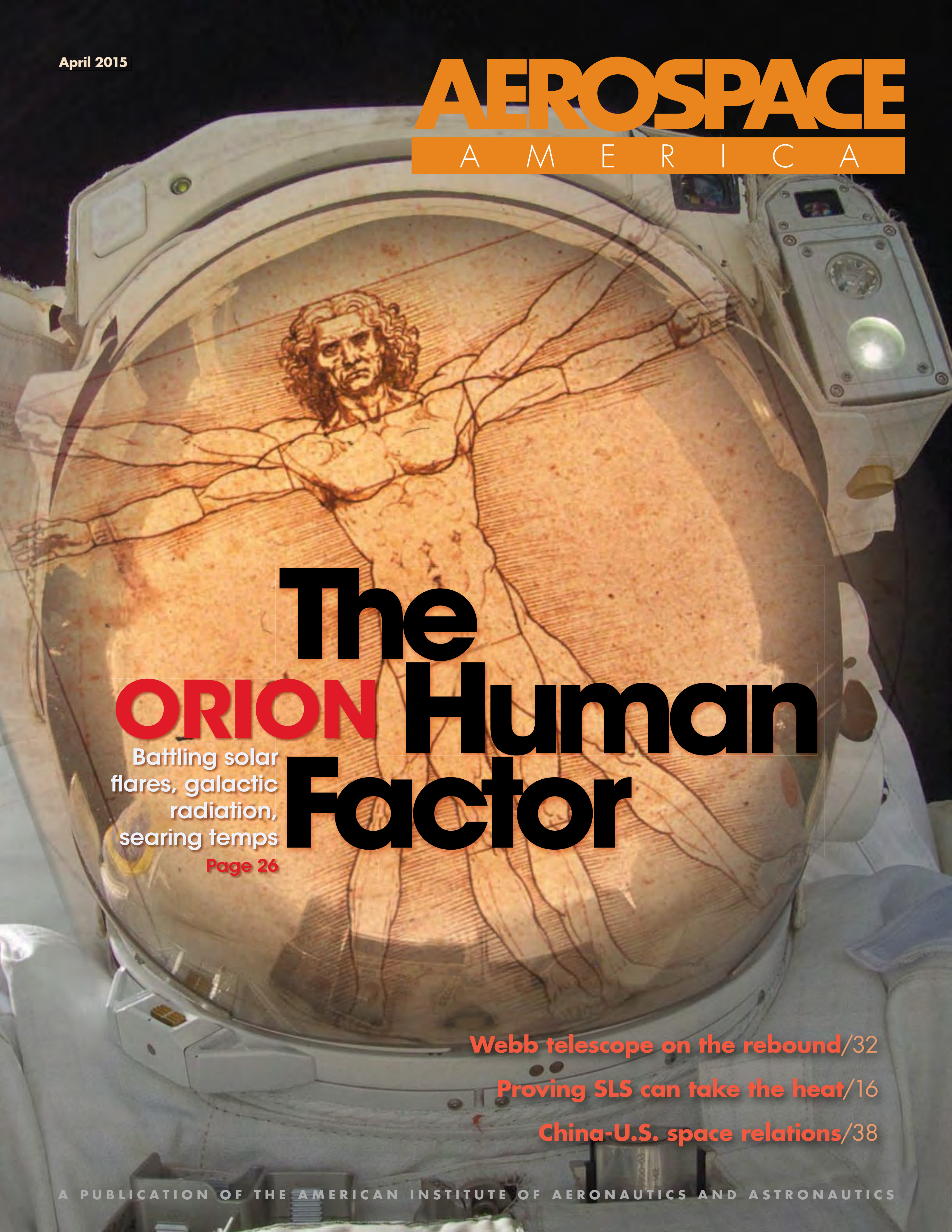

The Human Factor

ORION

Battling solar flares, galactic radiation, searing temps

Page 26

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U.S. Navy

On a human mission, a crew might need to wait about two hours for a Navy team to free them from the Orion capsule. The crew can escape through side or top hatches, if necessary. Here, a recovery team arrives at the unmanned version of Orion that splashed down in December.

The

Orion capsules will take astronauts out of low-Earth orbit for the first time since the Apollo missions. The dangers can't be taken lightly. Debra Werner explains what NASA and Lockheed Martin are doing to keep astronauts safe, and more comfortable, inside the capsule.

An hour before the space shuttle orbiter Atlantis carved its way back into the atmosphere at the end of a 2002 mission, astronaut Lee Morin downed 48 ounces of chicken soup to ward off any lightheadedness or fainting that might be produced by high G-loads. Space shuttle crews routinely took that precaution, known as fluid loading, because the ride subjected them to peak levels of about 2.5 times Earth's gravitational force during re-entry.

Astronauts traveling on NASA's next manned mission beyond low Earth orbit, slated for around 2021, are in for a rougher ride. They'll experience 4.5 to 5 Gs during re-entry of the Orion multipurpose crew vehicles because the trip back from deep space produces higher re-entry velocity and heat loads than shuttle's return from low Earth orbit. Plus, parachutes drop space capsules onto water with more force than winged vehicles experience during a runway landing.

NASA and Lockheed Martin have designed Orion so that the four crew members will be in a reclined position with their feet above them during the capsule's ascent and descent, which means the higher G-forces are not likely to produce any loss of consciousness. Still, Orion's crew members are likely to follow the NASA tradition of chugging chicken soup as a precaution against buffeting or any contingency operations that produce more force than expected, says Morin, who works in the astronaut office at Johnson Space Center, Houston, helping to design Orion's cockpit.

NASA and prime contractor Lockheed Martin have been developing Orion with astronauts in mind since 2006 when the company won an $8 billion contract to build the spacecraft. In spite of extensive modeling and simulation, no one knew how well the spacecraft would protect astronauts from extreme temperatures, radiation and micrometeorites until a Delta 4 Heavy rocket lifted off on Dec. 5 carrying an early version of Orion packed with instruments in lieu of a crew. Now that all the data is in, "we think the ride is going to be pretty comfortable," Morin says.

Keeping cool

The Exploration Flight Test 1 (EFT-1) version of Orion hurtled home at speeds approaching 20,000 miles per hour. Just as planned, about 20 percent of its heat shield, consisting mainly of a foamlike material known as Avcoat, melted and vaporized when its surface temperature reached nearly 4,000 degrees Fahrenheit, according to sensors mounted in the heatshield. That ablation helped dissipate lots of heat, but the exterior of the capsule was still piping hot at splashdown — the heatshield temperature varied between 140 and 220 degrees Fahrenheit and the backshell temperatures varied between 100 and 120 degrees Fahrenheit.

human factor

by Debra Werner

An early version of an Orion capsule launches from Kennedy Space Center, Florida, on Dec. 5, 2014, atop a Delta 4 Heavy rocket for a two-orbit, four-hour flight that tested many of the systems most critical to safety. Orion crews in future years are expected to explore asteroids, among other missions.

NASA

"We were concerned that when we landed, heat energy would radiate back into the capsule," Mike Hawes, Lockheed Martin vice president and Orion program manager, told reporters during a Feb. 18 briefing. "That would be extraordinarily uncomfortable for the crew."

On an actual mission, a crew might have to wait about two hours for a Navy crew to arrive, longer in an emergency splashdown. If needed, the crew can get out before the Navy arrives by opening the capsule's heavy side hatch with an explosive charge or climbing out a small hatch on top of the capsule.

To find out if a crew would be safe and comfortable during the wait, Lockheed Martin recorded temperatures inside the crew cabin for an hour after the splashdown 600 miles south of San Diego.

Orion's heat shield combined with the spacecraft's evaporative ammonia cooling system, which circulates ammonia throughout the crew cabin and around electronic boxes, keeps the temperature in the crew cabin at 77 degrees or lower during the hour after its water landing.

Astronauts aboard Orion would be wearing heavy spacesuits, so for added comfort they'll be able to control the amount of cold water pumped through their Spandex undergarments, which look like long underwear crisscrossed by IV tubes. Astronauts working outside the International Space Station rely on the same cooling garments.

Radiation exposure

Once Orion leaves Earth's orbit, its crews and electronics will be bombarded by galactic cosmic radiation and solar winds of varying intensity. Rather than trying to design the entire capsule to block what could be a rare radiation spike from a solar flare, engineers devised 42-inch by 25-inch by 28-inch aluminum lockers behind each crew member's seat. Clothes, cameras and flight equipment will be stored in these lockers, but NASA would alert the astronauts when ground-based telescopes and satellite sensors spot unusual solar activity.

"They would remove components from the lockers and hook them to various points around the crew cabin because all of the hardware helps absorb radiation," says Lockheed Martin's Blaine Brown, the crew module deputy director. "Then they

NASA

Spacesuit engineers demonstrate how the four crew members would be arranged for launch inside the Orion spacecraft. NASA and Lockheeed Martin have designed Orion so that crew members will be in a reclined position with their feet above them during the capsule's ascent and descent, preventing loss of consciousness from the higher G-forces.

would climb into the lockers, which are a little safe haven."

Apollo, Shuttle and ISS had lockers. Orion's are different because they are integrated with the primary structure in the aft bay of the capsule to maximize use of available volume. The lockers used by astronauts aboard the Apollo missions were not designed to protect the crew during a large solar radiation event. And because the Shuttle and International Space Station operate in low Earth orbit, they benefit from the Earth's magnetic field shielding, so their exposure is not as risky as deep space exploration, and their lockers aren't designed for that purpose.

Orion astronauts would have plenty of incentive to cram into the tight space. Since exposure to high levels of radiation can increase a person's risk of developing cancer, NASA keeps close tabs on how much radiation astronauts encounter. The agency bans them from space missions when doctors determine their U.S. government work has increased their risk of getting cancer in their lifetime by 3 percent compared with the population at large.

"Your career is over as an astronaut when you hit that level of exposure," says Morin, whose own radiation exposure included his medical work on a U.S. Navy nuclear submarine.

During EFT-1, officials at mission control in Houston monitored radiation levels with battery-operated detectors developed by NASA Johnson and the University of Houston. "From the measurements we made, everything stayed within the expected range," according to Hawes. [NASA and Lockheed Martin are not yet ready to offer detailed information on Orion radiation levels recorded in the crew cabin but may be after they submit the report on EFT-1 to NASA, which was scheduled for March 5.]

Aside from the threat to astronauts' health, deep space radiation can jeopardize the performance of the computers and communications equipment, causing data corruption, locking up processors or damaging spacecraft electronics. The capsule's walls made of an aluminum-lithium alloy will block some radiation, but the electronics will have to keep running through levels higher than experienced by electronics in low Earth orbit, which are protected to a degree by the Earth's magnetosphere. NASA and Lockheed Martin monitored those systems closely during EFT-1.

Orion's avionics computers continued to function even though EFT-1 took the spacecraft through the Van Allen Belts, regions of charged particles trapped by Earth's magnetic field. "We flew through one of the worst radiation environments

Seats to save the spine

Astronauts are in for quite a jolt when the Orion multipurpose crew vehicle splashes down. The spacecraft's parachutes are designed to slow the space capsule from 480 kilometers (300 miles) per hour in the upper atmosphere to less than 30 kilometers per hour at impact.

To prevent injury, NASA and Orion prime contractor Lockheed Martin are working with Safe Inc., a company based in Tempe, Arizona, that is known for producing energy-absorbing helicopter seats. Orion will be equipped with crew seats that slide a few inches along the axis of the astronaut's spine.

"When Orion hits the water, there will be forces in several different directions," says Tony Herrmann, subsystems manager for the Orion Crew Impact Attenuation System in NASA Glenn Research Center's Crew Service Module Mechanisms Group. "The human body is pretty resilient except the spine. You don't want spines to be compressed."

Initially, NASA and Lockheed Martin tried to reduce the force of impact by mounting each astronaut's seat to a pallet below using seven struts to absorb energy in different directions. Data retrieved during Orion's Exploration Flight Test-1 on Dec. 5 proved that NASA could simplify the design and reduce weight by replacing the struts with metal that slides a few inches along a single axis.

It's not yet clear what metal Safe Inc. will use in the new design. NASA gave the company its crew protection requirements and Safe Inc. will determine the best way to develop the system, Herrmann says.

"It turns out we did not need struts going in every direction," Herrmann says. "We just needed them going in one direction to prevent spinal injury."

The new Orion Crew Impact Attenuation System is expected to weigh less than 18 kilograms (40 pounds) per seat, compared with roughly 64 kilograms for the previous design, Herrmann says.

The Orion space capsule's mass is limited to 20,500 pounds by the parachutes used to slow its descent in Earth's atmosphere. Because of that ceiling, NASA and Lockheed Martin are searching for ways to reduce mass to make room for additional flight equipment.

Debra Werner

and the system performed exactly as designed," says Paul Anderson, Lockheed Martin's Orion avionics director.

Before the flight, Orion engineers screened parts to eliminate ones that could be damaged permanently by radiation. They also took the bold step of relying on commercial processors instead of radiation-hardened processors, which often slow computations. To make up for any vulnerability, Lockheed Martin worked with Honeywell International to equip the spacecraft with pairs of computers designed to monitor each other and correct problems.

"The fantastic surprise was how well that operated," Anderson says. "There were some events that caused upsets as expected, but the system self-corrected."

A bigger test will come during Orion's Exploration Mission-1, when the spacecraft spends 21 days in a distant retrograde orbit near the moon.

Micrometeorites

Orion also must protect crews from micrometeorites. Even a tiny pinprick could cause the air inside the capsule to rush out into the vacuum of space. During Orion's initial flight, micrometeorites struck the spacecraft and penetrated its thermal protection system but stopped before reaching the crew cabin just as the spacecraft's engineers expected, says Jim Bray, Lockheed's Orion crew module director.

Orion's exterior tiles absorbed the first strike of micrometeorites, slowing their velocity. Debris created by micrometeorites then passed through the tiles and spread out in the air gap between the tiles and the crew module, where the spacecraft's computers and cables are housed. The exterior of the crew module, which is composed of an aluminum-lithium alloy, then absorbed the smaller, slower debris particles.

"Since Apollo, we have learned that protection from radiation and micrometeorite debris is critical, especially for long duration missions," Bray says. "Apollo was designed for seven-day missions. Our requirement is for 21 days. We are going to be out there longer and need to survive greater radiation and greater exposure to micrometeorites."

Comforts of home

For any journey beyond 21 days, Orion would need to be linked to a larger service module packed with food, equipment and supplies. For shorter missions, Orion is designed to afford more comfort and privacy than Apollo. Apollo capsules offered 70 cubic feet of habitable volume per person, compared with Orion's 78 cubic feet or about twice the passenger volume of a Ford Explorer. Lockheed Martin seeks to use every bit of that space.

After ascent, Orion's seats fold down, which helps make room for many of the amenities Apollo did not have, including a water dispenser, food warmer, toilet, exercise equipment and a small curtained area where astronauts can change clothes privately or take a sponge bath.

"Apollo was designed to go to one place and its mission duration was


NASA

Heat shield: As expected, about 20 percent of Orion's Avcoat shielding melted and vaporized during re-entry in December. NASA experts inspected the shield after it arrived at Marshall Space Flight Center in Alabama.

known," Bray says. "We've got to be able to accommodate any destination for ranges much longer than Apollo did. Having access for the crew to be able to be safe, to be able to be hygienic, and to be able to live, eat and breathe is what we are about."

Flight crews

NASA does not plan to select astronauts for Orion's first manned flight until about two years before takeoff. Nevertheless, 20 astronauts already are becoming familiar with the spacecraft through extensive flight simulation exercises. Every couple of months, two astronauts, one commander and one pilot, come to Building 9, the Vehicle Mockup Facility at Johnson Space Center, to fly in a static simulator.

The astronauts don flight suits, gloves, headsets and spend approximately four hours going through various flight scenarios, including most recently an ascent full of problems. "We take them through countdown and launch," Morin says. "They see the displays and respond to the malfunctions."

One hallmark of NASA's astronaut training program is its ability to test how well prospective flight crews tackle problems and stressful situations. About two years before Morin was selected for his 2002 Space Shuttle mission, he and five colleagues spent 10 days in a tent in Northern Canada's Arctic region. NASA mission control gave them assignments, which included early frequent treks into the Arctic night and temperatures as low as 30 degrees below zero Fahrenheit.

"They would give us map coordinates and send us five miles to get essential supplies," Morin says. "The essential supplies were a case of frozen broccoli to go with the case of frozen broccoli they had us get at 3 o'clock in the morning the day before. Or they would ask us to observe some stars and take readings, but the stars weren't visible from the Northern Hemisphere."

This type of expedition, like much of astronaut training, is designed to test a person's response to exhaustion, stress and discomfort. No matter how well-designed Orion is, spending seven days journeying to the Moon or 21 days investigating an asteroid will mean leaving behind the comforts of home.

That type of hardship doesn't deter them, Morin says. "Getting the privilege of riding on Orion, being in deep space for the first time since the 1970s, perhaps rendezvousing with an asteroid or being on the way to the moon or Mars, people are prepared to put up with a little discomfort for that."