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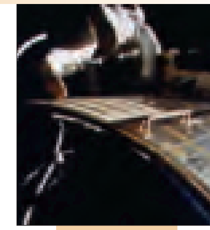


Bridge to deep space

In a fishing village off the remote north coast of Papua, New Guinea, U.S. astronaut Neil Armstrong is a household name. A young villager named Luke, who makes his living fishing and farming for his family on Wanam, one of the tropical Tami Islands, had heard the news of Armstrong's August 25 passing.

"He was first to go to the Moon," said Luke, who was born about 20 years after the Eagle landed. Questioned about my own space voyages, I had to admit that Neil, Mike Collins, and Buzz Aldrin had gone a thousand times farther into space than I had. But that didn't matter to Luke or the villagers I spoke to: I was an American 'space man,' the same as Neil. The idea that the U.S. is a nation of explorers is a concept still current in the most distant corners of the globe.

Between now and 2015, we will decide if we are to continue or abandon that premise. The space talk at the close of the year has centered on whether NASA has a new plan to match those heroic Apollo feats. The president's reelection and looming sequestration mean NASA—at best—can expect no increases in its human spaceflight budget.

ISS troubleshooting and success

Before NASA can talk of returning to deep space, it must first preserve and then build on its investment in the ISS. The closing months of 2012 saw NASA and its partners deal successfully with unexpected repairs, new cargo deliveries, and an increased operations tempo.

In September, the Expedition 33 crew—Suni Williams, Aki Hoshide, and Yuri Malenchenko—performed two unplanned EVAs to remove and replace a failed main bus switching unit (MBSU). Located on the station's S0 truss, just above the U.S. Destiny lab, the MBSU suffered a failure that took down 25% of the station's solar power capacity.

During the first EVA, Williams and Hoshide removed the failed MBSU box, about the size of a dishwasher, and replaced it with a spare delivered earlier by shuttle. During the spare installation, however, the spacewalkers were unable to drive home the long bolt that engages mechanical and elec-

Expedition 33 commander Sunita Williams participates in a 6-hr 38-min spacewalk outside the ISS on November 1, 2012. During the spacewalk, Williams and JAXA's Akihiko Hoshide ventured outside to support ground-based troubleshooting of an ammonia leak.

trical connections between the truss and the new MBSU. Mission Control in Houston had them temporarily strap down the box, reenter the airlock, and regroup for another try.

Within a week, controllers working with the crew had Williams and Hoshide back outside to try a new approach. Working at vacuum, they used a spare bolt coated with grease to capture and remove metal shavings from the threaded MBSU receptacle on the truss; engineers think the shavings were the result of galling that occurred when the MBSU was bolted onto the truss in 1-*g* during original assembly. With the threads now lubricated and clear of debris, the crew used a manual torque wrench to carefully hand-drive the bolt, securing the MBSU to the truss and engaging electrical and cooling interfaces. Flight controllers soon had full power restored.

On November 1, Expedition 33 commander Williams ventured outside with Hoshide once again, this time to isolate a minuscule leak in one P6 solar array's ammonia coolant loop. Flight controllers believe a micrometeorite or orbital debris impact punched a tiny hole in the channel 2B thermal radiator lines. To avoid a low-ammonia-coolant shutdown of the 2B power channel, Williams and Hoshide bypassed the radiator with a spare jumper line, handing over cooling duties to a long-stowed P6 radiator used during early ISS construction.

Both the bypass operation and radiator redeployment were successful.

The SpaceX Dragon commercial cargo craft is ready for release by the ISS's Canadarm2 robotic arm on October 28 to allow it to head toward a splashdown in the Pacific Ocean.

ISS controllers will look now for stable coolant levels to verify that the leak was in the bypassed radiator. If the leak persists, further EVA troubleshooting and repairs might be needed.

New cargo era

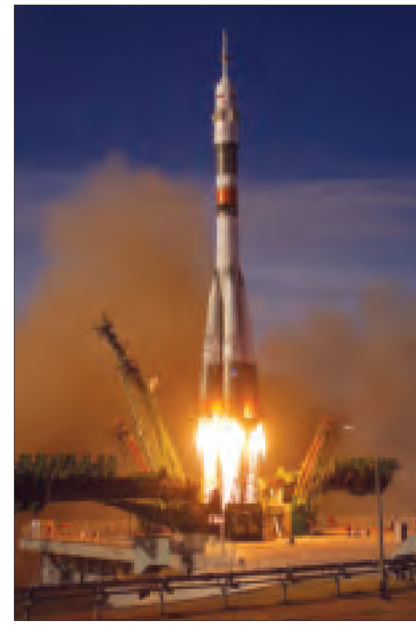
SpaceX's second Dragon cargo vehicle successfully reached the station in October, delivering 900 lb of cargo. Although Dragon's Falcon 9 booster suffered a Merlin engine shutdown during its October 7 launch, the eight remaining first-stage engines fired longer than planned and inserted Dragon into a safe orbit. After its October 10 rendezvous and berthing, the crew packed the capsule with 1,700 lb of scientific samples, obsolete gear, and trash. On October 28, Dragon departed the station and executed a successful reentry and splashdown.

Analysis of the engine failure, which shattered an aerodynamic fairing on Falcon 9's first-stage engine skirt, may delay SpaceX's next cargo run until May. NASA hopes the firm will soon be joined on cargo runs by Orbital Sciences and its Cygnus cargo spacecraft. A first test flight of Orbital's new Antares rocket is due this spring, and the company hopes to demonstrate a successful Cygnus cargo delivery to the ISS within six months.

The Dragon deliveries and a Progress cargo shipment supported the arrival of the Expedition 34 crew. Commander Kevin Ford and flight engineers Oleg Novitskiy and Evgeny Tarelkin docked their Soyuz TMA-06M at the ISS on October 25. Ford assumed command from Williams as she returned to Earth with Hoshide and Malenchenko on November 18.

In early December, the second trio of Expedition 34 astronauts was scheduled to launch from Baikonur on Soyuz TMA-07M. Chris Hadfield, Tom Marshburn, and Roman Romanenko would inaugurate Expedition 35 in March and remain on station until May.

The administration has not moved to accelerate NASA's plans for commercial astronaut transport to the outpost. The agency will remain dependent on the Soyuz, at least until 2016, to rotate expedition crews, who have maintained a continuous presence at ISS for over 12 years.

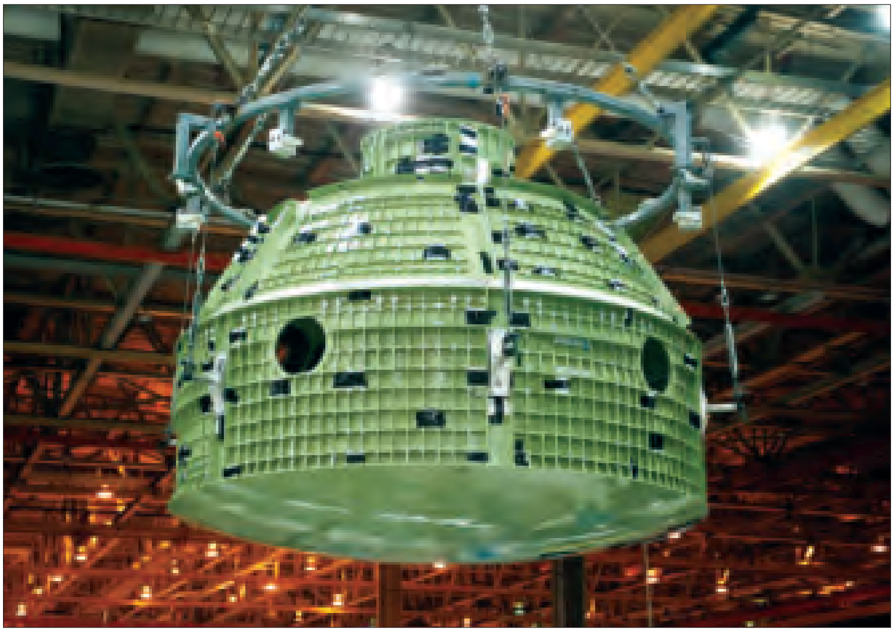


The Soyuz rocket with Soyuz commander Oleg Novitskiy, flight engineer Kevin Ford of NASA, and flight engineer Evgeny Tarelkin of ROSCOSMOS launches to the ISS on October 23, 2012, in Baikonur, Kazakhstan, on Expedition 33/34. Credit NASA/Bill Ingalls.

Scientific research aboard ISS is growing, although slowly (see www.nasa.gov/mission_pages/station/research/news.html). Talented, adaptable crews, along with a well-chosen array of tools, spare parts, and robotic capabilities, have enabled astronauts and cosmonauts to overcome every systems failure and challenge encountered so far. The ISS is an invaluable asset in LEO, well positioned to serve as an exploration testbed while the partners discuss possible ventures into deep space.

Glimmers of an Earth-Moon architecture

Press reports in September revealed that NASA is evaluating a new strategy to send astronauts to the lunar vicinity and beyond. Using the Orion crew vehicle and the initial, 70-metric-ton capability of the Space Launch System (SLS) heavy lifter, the agency could



Exploration Flight Test 1 Orion, currently at Michoud Assembly Facility, will fly in 2014 to an altitude of over 3,600 mi, more than 15 times farther away from Earth than the ISS. Orion will return home at a speed of 25,000 mph, almost 5,000 mph faster than any human spacecraft. Heat shield temperatures will reach 4,000 F, higher than any crew vehicle since Apollo. Photo credit: NASA/Eric Bordelon.

reach lunar orbit or the Earth-Moon Lagrange points shortly after 2020. While not as profound an achievement as establishing a new Tranquility Base or cruising to an asteroid, the concepts under discussion offer NASA a path beyond the space station without dramatic expansion of its budget.

First come several key tests of NASA's Orion crew vehicle. Its first unmanned flight is scheduled for September 2014, atop a Delta IV-Heavy. The EFT-1 mission will test Orion systems during two high-apogee Earth orbits, ending in a reentry trajectory that will subject the guidance, heat shield, and recovery systems to the speeds and temperatures they will encounter on a future deep space return.

The second uncrewed Orion will fly atop the SLS on its first flight, late in 2017. Under current plans, astronauts would not fly an Orion until after 2020. That's just a few years before NASA is to execute a piloted mission to a near-Earth asteroid (NEA). It's hard to see how, with just a handful of deep space tests, NASA could be ready by 2025 to send astronauts several million miles beyond the Moon.

To change that calculus, the space agency appears to be seeking White House approval for an ambitious series of missions that build methodically toward a versatile deep-space capability. The building blocks of the plan come from existing, proven ISS hardware, commercial vehicles, and spacecraft in development. These include the Orion multipurpose crew vehicle, SLS, Atlas V, Delta IV-Heavy, Ariane, Proton, Dragon/Cygnus cargo vehicles, ATV/HTV cargo vehicles, spare ISS modules, build-to-print ISS structures, and inflatable habitats.

As a first step, an Orion crew would circumnavigate or orbit the Moon, as Apollo 8 astronauts did in 1968, but with an eye toward more ambitious voyages. A key piece of hardware would be a small habitat, based on Alenia's ISS MPLM cargo canister, or perhaps a new inflatable design. The SLS's interim cryogenic stage, based on the RL-10-powered Centaur, would power Orion and habitat on a lunar trajectory. Instead of a lunar orbit or landing profile, however, this bare-bones vehicle would conduct a weeks-long mission beyond the Moon to the L2 Earth-Moon Lagrange point.

L-what?

Why EM-L2? This gravitational equipotential point in the rotating Earth-Moon coordinate frame enables a spacecraft to hover some 60,000 km beyond the Moon using minimal propellant. Looping around EM-L2 for several weeks in a long, lazy halo orbit, visiting astronauts would have a direct view of the lunar far side, and could conduct intensive remote sensing investigations of that rugged hemisphere. They could also take direct 'telepresence' control of lunar farside surface rovers, taking advantage of the slightly shorter radio time delay from L2 compared to terrestrial controllers. This virtual exploration presence on the lunar surface is similar to what would be possible for Mars from a future astronaut outpost on the Martian moon Phobos.

The most challenging activities for astronauts at L2 would be rendezvous with and wide-ranging investigation of a captured NEA. A team funded by the Keck Institute for Space Studies has proposed a robotic, ion-driven spacecraft that would snare and then return a 7-m, 500-metric-ton NEA to cislunar space within a decade. The asteroid, placed into an EM-L2 halo orbit, would be available for astronaut inspection, sampling, dissection, grappling and anchoring demonstrations, and resource extraction.

International and commercial entities could send their own robotic craft to sample and process the water, metals, and other light elements in the asteroid. This accessible resource, similar in composition to carbonaceous chondrite meteorites, could kick-start an entire venture into using asteroidal material to lower the cost of future exploration. The NEA exploitation would thoroughly prepare astronauts and flight controllers for expeditions to larger, more distant asteroids.

The proposed deep space transportation system, modest at first but growing as budgets and partnerships expand, would be flexible enough to take on other cislunar missions. Astronauts could rendezvous with robotic sample return missions from the Moon, asteroids, and Mars, using

Orion to shepherd the samples on the final leg to terrestrial laboratories.

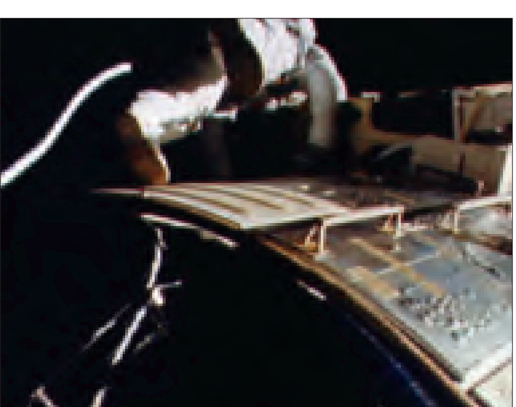
Should human explorers return to the Moon, astronauts could use the EM-L2 or L1 halo orbits to outfit, check out, and dispatch a lander down to the surface. A returning lander could also rendezvous with Orion there to return the crew to Earth, and to be serviced for another lunar sortie. Commercial services would play a key role, providing much of the logistical, consumable, and propellant support needed for L2 halo, robotic lunar, and captured NEA missions. This deep space activity would also open up commercial opportunities for robotic NEA prospecting and commercial-scale water, volatile, and metal resource extraction.

ISS as testbed

The international space station, used wisely, should be a bridge to these deep space ambitions. Habitats, life support, and power systems for the deep space vehicles should be evaluated and proof-tested at the ISS. Prototype resource extraction processors, using simulants or actual meteoritic material, could blaze a path toward eventual large-scale propellant production in cislunar space.

Upgraded spacesuits could be phased in to replace the 1980s shuttle version currently in use. Rugged yet flexible, the new models would then be ready for work at a captured asteroid or L2 halo activities. NASA should also develop and test-fly at the ISS a prototype space exploration vehicle, a one- or two-person space pod for inspection, maintenance, and NEA surface exploration.

Such testing at ISS would engage the attention of taxpayers and policymakers, showcasing the station as a knowledge-driven springboard to deep space. It's *the* place to demonstrate that NASA and its partners are serious about moving beyond LEO.



On August 5, 1971, Apollo 15 command module pilot Al Worden carried out the first deep space EVA from the Endeavour crew module. His all-too-brief EVA lasted 38 min 12 sec. Photo credit NASA.

Deep space

In his autobiography, *Falling to Earth*, Apollo 15 astronaut Al Worden describes the first-ever deep space EVA, 196,000 mi. from Earth, as the command and service module Endeavour coasted homeward following the fourth lunar landing in August 1971. Worden, retrieving film magazines in the harsh sunlight slanting across the module's instrumentation bay, stole a few seconds to take in the view.

"All around me, there was—*nothing*....This wasn't deep, dark water, or night sky, or any other wide open space that I could comprehend. The blackness defied understanding, because it stretched away from me for billions of miles.

"...I could see the entire Moon if I looked in one direction. Turning my head, I could see the entire Earth. The view is impossible to see on the Earth or on the Moon. I had to be far enough away from both. In all of human history, no one had been able to see what I could just by turning my head."

Al Worden experienced what all of us would hope to see, if only vicariously. He lived suspended between worlds, just as NASA now seems suspended between its brilliant past and an uncertain future. If the U.S. can take small but real steps now toward exploring and exploiting cislunar space, we can turn a glimmer of deep space travel into a limitless reality. And people around the globe would learn the names of a new generation of explorers.

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