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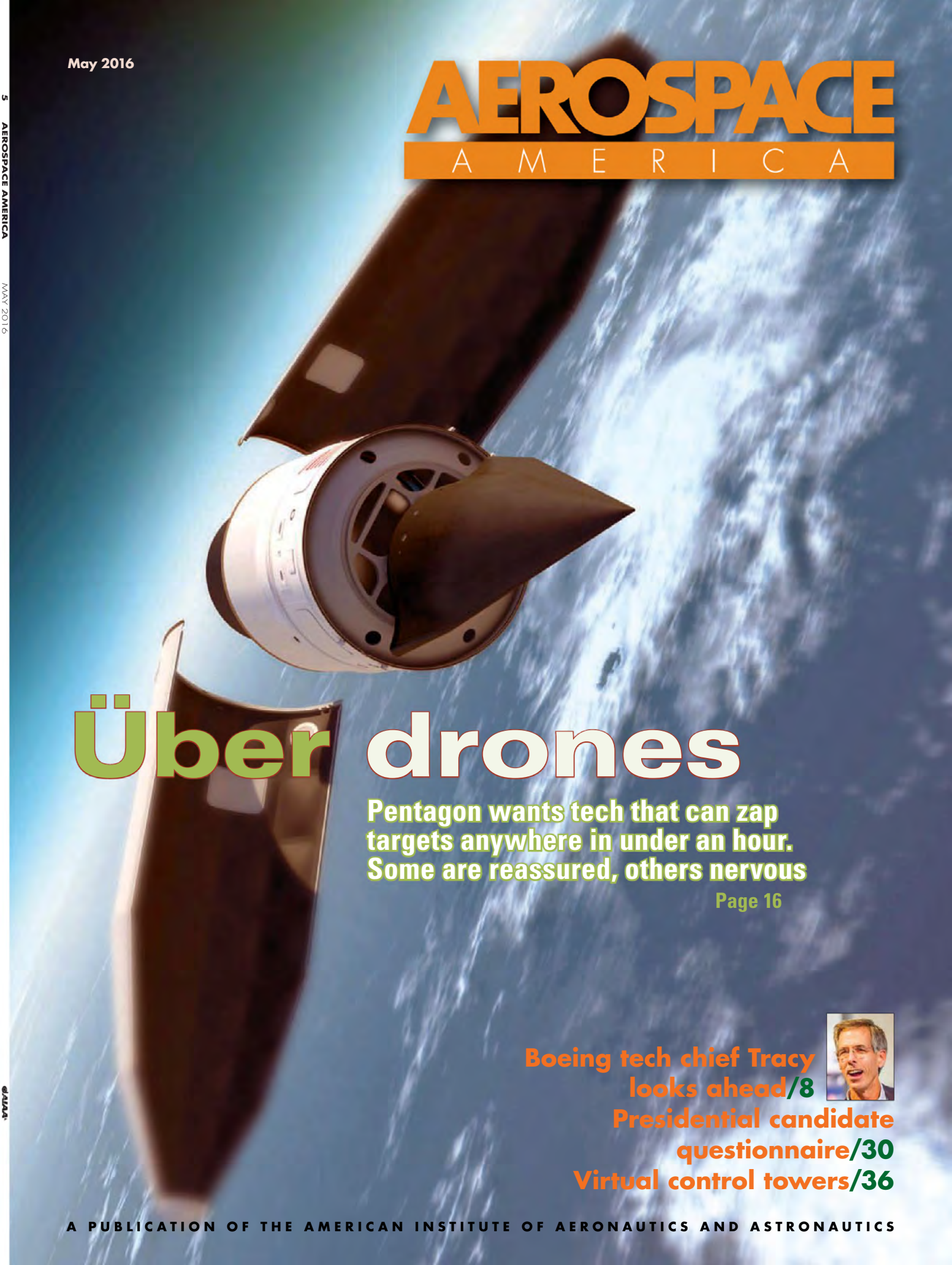

Über drones

Pentagon wants tech that can zap targets anywhere in under an hour. Some are reassured, others nervous

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Living Lunar

NASA's Orion spacecraft, left, delivers a cylindrical logistics module to an astronaut habitat in this artist's rendering.

Facing a possibility that an Orion crew will not have anywhere to go in deep space in the near term, NASA has revived a dormant idea to build a lunar-vicinity orbit outpost. Tom Jones explains how a cislunar habitat could serve as a training waystation as astronauts prepare for future journeys to Mars.

NASA is getting serious about sending astronauts beyond low Earth orbit again. In 2012, the agency examined the possibility of stationing an outpost beyond the far side of the moon as a waystation for exploring the lunar surface and gaining experience needed for reaching Mars. But the Obama administration didn't adopt the outpost plan, proposing instead NASA's Asteroid Redirect Mission, ARM, where astronauts would rendezvous with a boulder retrieved from an asteroid.

NASA is now reviving the idea of assembling a small outpost, including a habitat module, in cislunar space between the Earth and moon or in orbit around the moon. Why? The need to acquire operational experience in deep space, meaning at the moon or beyond, coupled with widespread opposition in Congress to the asteroid mission.

NASA plans to test its Orion spacecraft and Space Launch System rocket combination in a series of flights progressing into the 2020s. First, the SLS will boost an unmanned Orion on a loop around the moon in late 2018. Then, no earlier than 2021, the rocket will launch an Orion crew into lunar orbit. After one or more additional SLS-Orion tests, NASA hopes to send a crew around the moon to rendezvous with an asteroid in 2026.

However, the federal funding outlook for the asteroid mission is very shaky. If the mission fails to win support in 2017 from the new president and Congress, Orion will have no destination a decade from now. Repeated visits to lunar orbit will look like NASA is marking time until a Mars mission sometime after 2035.

NASA thus would like to have another near-term destination for Orion in deep space. That could be an outpost near the moon, where astronauts could live and work beyond low Earth orbit for the first time since Apollo ended in 1972. The outpost would also enable visiting astronauts to conduct scientific operations

around the moon, as they would on later journeys to the Mars system. Although American Scott Kelly and Russian Mikhail Kornienko returned in March from spending nearly a year aboard the International Space Station, even extended stints in low Earth orbit can't simulate solar and cosmic radiation and other deep-space conditions that humans will encounter on journeys to Mars.

NASA is examining how it might use the SLS and Orion to assemble a bare-bones outpost near the moon. The agency is hoping it can get started on the job as early as the first Orion crewed flight in 2021, with that spacecraft providing power, life support (oxygen, water, carbon-dioxide removal), control of the outpost's orientation, or attitude, and a radiation shelter.

Next steps

Last year, NASA invited the industry to study the architectures and technologies needed for a possible cislunar outpost. The agency's Next Space Technologies for Exploration Partnerships, or NextSTEP, program aims to advance technologies for deep-space habitats and also solar electric propulsion and small satellites.

Jason Crusan, who runs NextSTEP as director of the Advanced Exploration Systems Division of NASA's Human Exploration and Operations Mission Directorate, points to the work on deep-space habitats as key for NASA.

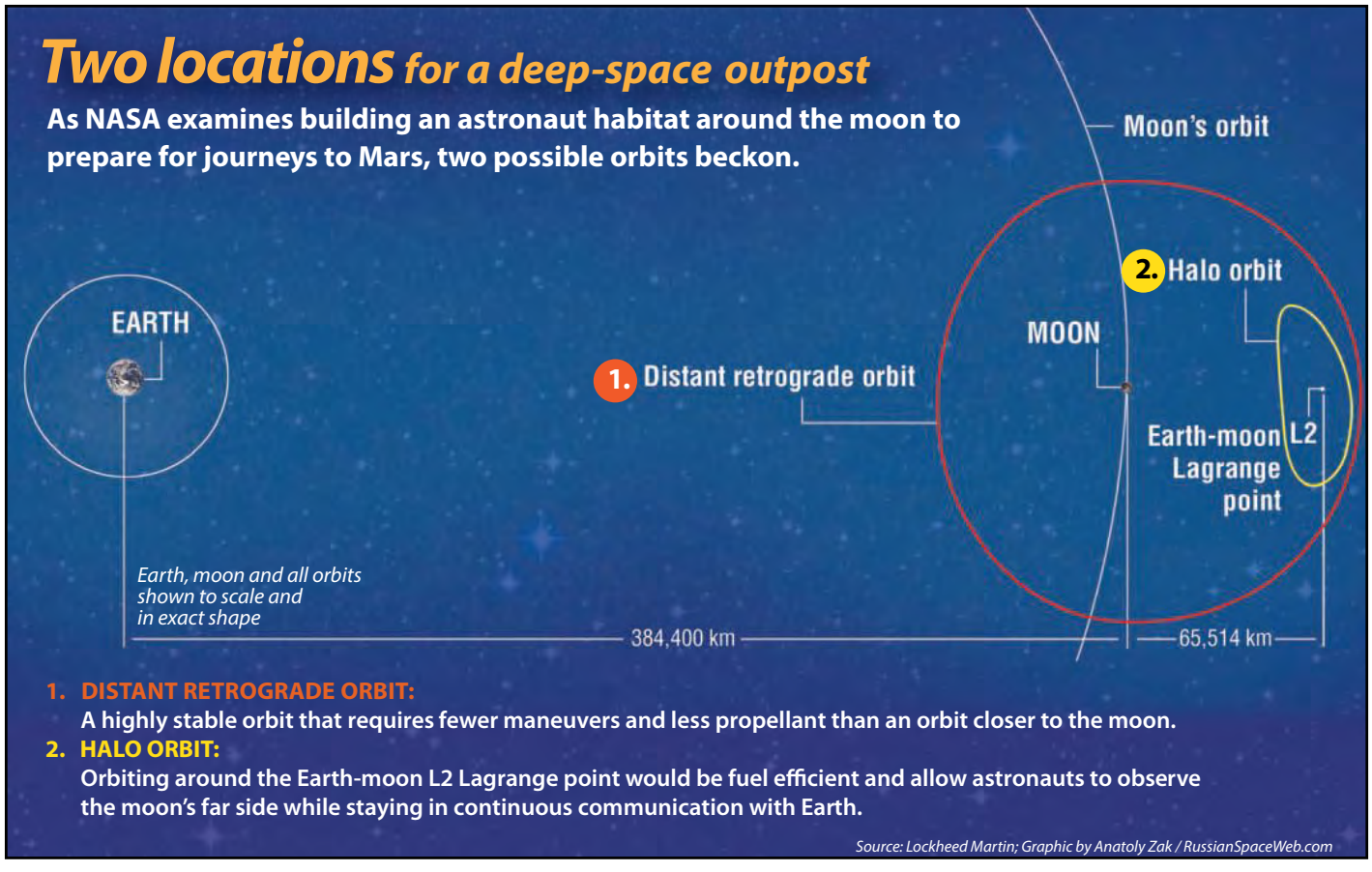
"We'll have launchers and space vehicles," Crusan says, "but staying anywhere in deep space will require a habitat. Orion itself can sustain two astronauts for 20-plus days around the moon, but we know for stays of a month or longer, we'll need a habitat."

NASA awarded seven one-year study contracts to the industry last year. Each firm received up to $1 million, which the companies had to match. Boeing, Lockheed Martin, Orbital ATK and Bigelow will develop habitat operations concepts, while Dynetics, Hamilton Sundstrand and Orbital Technologies will focus on specific life-support solutions. Each of the habitat industry partners will examine habitat technologies, operations and assembly milestones. Results are due to NASA by Sept. 30, along with a proposal from each for a phase-two study.

Crusan says that on deep-space missions, crews will need a module that provides living space, exercise gear and life support capacity. Building a cislunar habitat would firmly establish NASA in deep space, stretching its abilities toward Mars while helping the industry transition from supporting the space station to building commercial stations in LEO.

Habitat on a budget

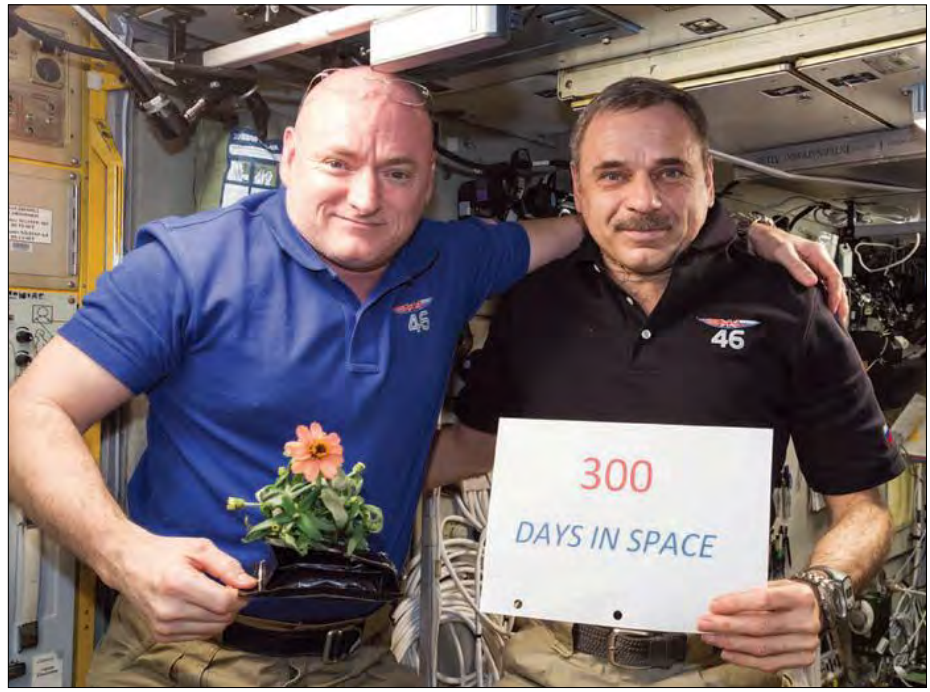
The habitat effort results from "a rare alignment in human exploration priorities between the [Obama] administration and Congress," Crusan says. "They both agree the habitat is the



next thing we need to do in engineering for deep space."

Congress has agreed to fund $53 million in habitat studies in fiscal 2016; NextSTEP is part of that package. NASA envisions a lunar-vicinity habitat that would be tended by astronauts visiting for a few weeks a year, rather than manned continuously like the International Space Station. Crusan says the outpost would start small, be adaptable and affordable, and serve as a science platform as astronauts gain experience in deep-space operations. What NASA does not want is a costly, complex duplicate of the space station — this time around the moon.

For habitat designers, there's good news and bad news around the moon. The thermal environment in a high lunar orbit is more benign than in low Earth orbit or in a lower, Apollo-style lunar orbit, where radiated heat from the Earth or the moon requires larger radiators and cooling capacity. The lunar vicinity is devoid of man-made space debris, but natural micrometeoroids are still a hazard. Among the negatives, there are no quick abort options from lunar orbit. Getting home takes days, not the hour or two needed for an emergency return to Earth from the space station. A cislunar outpost is also at the end of an expensive and tenuous supply chain, requiring careful management of consumables and spare parts. The biggest challenge is radiation: A cislunar outpost, unlike one in low Earth orbit, is exposed to solar proton storms and a steady stream of galactic cosmic rays. Yet with each problem solved, NASA will be that much closer to understanding how to get crews to and from Mars.



NASA

Scott Kelly, left, of the U.S. and Mikhail Kornienko of Russia set a record in March 2016 after spending 340 days aboard the International Space Station. Even extended stints in low Earth orbit can't fully prepare astronauts for deep-space conditions they would encounter on the way to Mars.

Room for four

Lockheed Martin's Josh Hopkins, acting space exploration architect, and Bill Pratt, the company's manager for NextSTEP habitat work, say that their team is examining a human-tended, cislunar outpost with an operational life of at least 10 years. It would consist of a habitat module, airlock, and propulsion and power modules with thrusters, solar arrays, and batteries. Four-person Orion crews could visit the habitat for 30-day stays, eventually extending that to two months or longer.

Because Orion was designed with circumlunar missions in mind, its systems can supply some of a habitat's initial needs for heating and cooling, power, attitude control and life support, Hopkins says. Using Orion, NASA could start visiting a habitat more quickly and cheaply than if it waited for a fully outfitted version. The module the astronauts would occupy could be built from modified versions of space station cargo transports like Europe's Automated Transfer Vehicle or Japan's H-2 Transfer Vehicle. Subsequent Orion visits would add solar arrays, propulsion and more capable environmental control systems.

The outpost would travel in either a lunar distant retrograde orbit or a halo orbit around the Earth-moon L2 Lagrange point. The highly-stable distant retrograde orbit would require fewer maneuvers than an orbit closer to the moon. In the L2 option, balanced gravitational forces would allow the habitat to orbit with little fuel expenditure some 65,000 kilometers beyond the moon's far side.

Astronauts could teleoperate rovers down on the surface. The rovers would explore geologically intriguing features such as the ancient South Pole-Aitken impact basin, and perhaps undertake the layout of sensitive radio-astronomy antennae on the radio-quiet lunar far side. Similar telescience operations would be possible between astronauts on the Mars moons, Phobos and Deimos, and rovers on the red planet.

Habitat as a stepping stone

If ARM does deliver its asteroid boulder to lunar orbit by the mid-2020s, the fragment could be docked at the cislunar habitat, where a visiting Orion crew could use the habitat airlock to conduct multiple spacewalks to probe and sample the asteroid. By contrast, the current ARM plan includes just one or two spacewalks conducted from Orion's depressurized crew cabin. Should ARM be canceled, the cislunar habitat would still give

NASA a place to practice its deep-space skills in the 2020s.

Lockheed's Pratt notes that a single 45-day crew stay in lunar orbit would surpass the entire deep-space experience of the Apollo era. His colleague Hopkins says: "Over time, we can work our way up to a year-long stay in deep space. We won't need to do many like that, but it's probably a box we'll need to check before we head for Mars."

Getting real

Even with nearly flat budget projections, NASA's Crusan is optimistic that the agency can fund the incremental construction of a cislunar habitat. By the mid-2020s, the sun will be setting on International Space Station operations, and development costs for Orion and SLS will be winding down, too. The first SLS to fly with an Exploration Upper Stage could launch Orion and an additional 10-ton habitat element to a distant retrograde orbit around the moon. Subsequent annual SLS-Orion launches could then expand the habitat and support 30- to 60-day stays by the late 2020s. Hopkins is eager to get started.

"NASA has told us they want to get a toe-hold in cislunar space as soon as possible, perhaps as early as" Exploration Mission 2, the first Orion-crewed mission planned for around 2021.

A natural question is whether this round of habitat planning will prove any more fruitful than the cislunar waypoint idea that failed to get traction in 2012, or the now-shaky prospects for retrieving an asteroid boulder. How will these current outpost studies survive the shock of first contact with a new administration's space priorities?

Answers Crusan: "If we're going to Mars, you'll still want to test [solar electric propulsion] and a hab in deep space, no matter what happens to ARM. Both ARM and the cislunar habitat are essential elements in NASA's plan to establish humans in deep space."

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