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Moving beyond Earth: NASA's steps through 2020

NASA's DECADE IN HUMAN SPACEFLIGHT is not off to a bracing start. The shuttle retired last year, and NASA is renting seats on Russian rockets through at least 2015. The agency faces static or declining budgets. Nothing suggests that the president or his prospective Republican opponents have new space initiatives in mind. NASA's commercial cargo providers are coping with delays, and their rockets remain locked to the launch pad.

Although NASA has direction to launch a human expedition to a near-Earth asteroid by 2025, the date is so distant that there is little public awareness of the goal, let alone excitement at the prospect. Those I meet frequently express sorrow that the space program has been canceled. The fact that U.S. astronauts Dan Burbank and Don Pettit are leading Expedition 30 at the ISS, 220 miles up, doesn't seem to counter that sentiment.

The perception of America adrift in space contrasts with China's release late last year of a national space exploration white paper. The document underlined the importance of space achievement to leaders of that rising power. Among the goals set for the next five years, the document noted that China will:

- Launch space labs, manned spaceship[s], and space freighters; make breakthroughs in and master space station key technologies, including astronauts' medium-term stays, regenerative life support, and propellant refueling; and make technological preparations for the construction of space stations.
- Conduct studies on the preliminary plan for a human lunar landing.
- Launch orbiters for lunar soft landing, roving, and surveying to implement the second stage of lunar exploration. In the third stage, China will start to conduct sampling [of] the Moon's surface matter and get those samples back to Earth.

These announced goals of orbital assembly and refueling and of robotic visits to the Moon are steps toward human lunar expeditions. It would surprise no one if China's next five-year plan made a clear commitment to a manned lunar landing, perhaps as early as 2020.

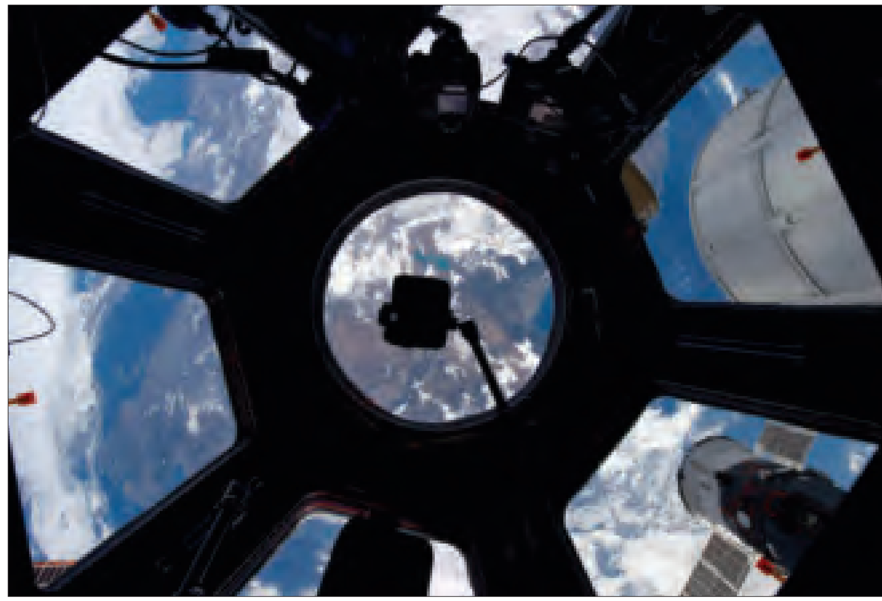
What activities could NASA reasonably undertake within the decade to preserve a U.S. technological edge in space? Recognizing budget and technical limits, can the agency make substantial progress toward leaving Earth's gravity well? Put another way, can the nation afford to remain bound in low Earth orbit for another decade?

After successfully docking with the Tiangong-1 target vehicle last fall, China's Shenzhou 8 unmanned spacecraft returned to Earth on November 7, 2011. The autonomous rendezvous and docking are steps toward China's development of a piloted space station. Credit: China News.

Why send humans to deep space?

What is our purpose in sending astronauts to the Moon or beyond? National pride is one relevant factor, especially in light of foreign ambitions, but it is by itself insufficient.

In my view, human flight beyond LEO comes at such great cost and risk that we should pursue it only because our specific objectives there demand skills and judgment that only astronauts can provide. Some skills are physical: humans bring to bear hands-on dexterity, coupled with acute visual perception. That brain-eye-hand combination can wield tools and controls in real time for exploration, or for dealing with failed systems and emergencies. Perhaps even more valuable are a human's experience and judgment, scientific and technical insight,



The Expedition 30 crewmembers took this image of Turkey through the cupola windows on the ISS on December 29, 2011. A Russian Soyuz spacecraft is docked to the station at lower right; part of the permanent multipurpose module can be seen just above it. Credit: NASA.

well-honed problem-solving abilities, and the flexibility to respond to unexpected circumstances. NASA's objectives for deep space exploration should take maximum advantage of those on-the-spot skills, backed by 50 years of in-space experience.

Planetary scientist Steve Squyres, who supervised the missions of Mars rovers Spirit and Opportunity and now chairs the NASA Advisory Council, sees great rewards in having human explorers in deep space. In 2009 he told a Space.com interviewer:

"You know, I'm a robot guy, that's what I have spent most of my career doing, but I'm actually a very strong supporter of human spaceflight. I believe that the most successful exploration is going to be carried out by humans, not by robots.

"What Spirit and Opportunity have done in five and a half [now eight] years on Mars, you and I could have done in a good week. Humans have a way to deal with surprises, to improvise, to change their plans on the spot. All you've got to do is look at the latest Hubble mission to see that.

"And one of the most important points I think: Humans have a key ability to inspire, [which] robots do not."

Although putting humans on the Moon or an asteroid within a decade now seems almost impossible, fiscally and politically, NASA engineers, managers, and astronauts I've talked with think there are still ambitious things the agency can do by 2020. They hope to leverage our human, commercial, and international experience in space to push human presence beyond the Moon, and create the knowledge and momentum needed for interplanetary exploration in the decade following. Each outward step would expand operations experience and demonstrate technical capabilities, all setting the stage for asteroid expeditions and, ultimately, human expeditions to Mars.

Building on ISS

When I poll my audiences, only about one in four have actually seen the station passing overhead. Fewer still can say what scientific research is under way there. One sure way NASA can raise the station's profile is to use it as an exploration proving ground, where astronauts and engineers are testing the equipment needed to reach beyond LEO.

Let's announce what we'll need to build to reach the asteroids and Mars, and then test those systems at the ISS. Start with the new power and life support systems needed on deep-space habitats. Advanced, reliable water and atmospheric recycling systems are critical for multimonth trips to an asteroid; their operation would also help reduce demand for consumables at the outpost.

Lockheed Martin has proposed astronaut control of robotic lunar rovers on the Moon's far side, with Orion sent to Earth-Moon L2 on one-month missions. NASA is studying the feasibility of a small L2 outpost to enable lunar and interplanetary exploration. Credit: Lockheed Martin.

Within five years, NASA should fly an advanced spacesuit design to ISS, geared toward interplanetary exploration. Nothing will show we are serious about exploration better than a 21st-century spacesuit. Equip the ISS with an inflatable, deep-space habitation module, delivered by commercial or international partners. Outside, install a prototype solar electric propulsion system, using a next-generation photovoltaic array. The system could help with ISS orbit reboost as engineers test its reliability and efficiency. NASA should also equip the exterior with an EVA climbing wall, a simulated asteroid surface enabling astronauts to test anchoring tools and grappling techniques in a free-fall environment.

Earth-Moon space

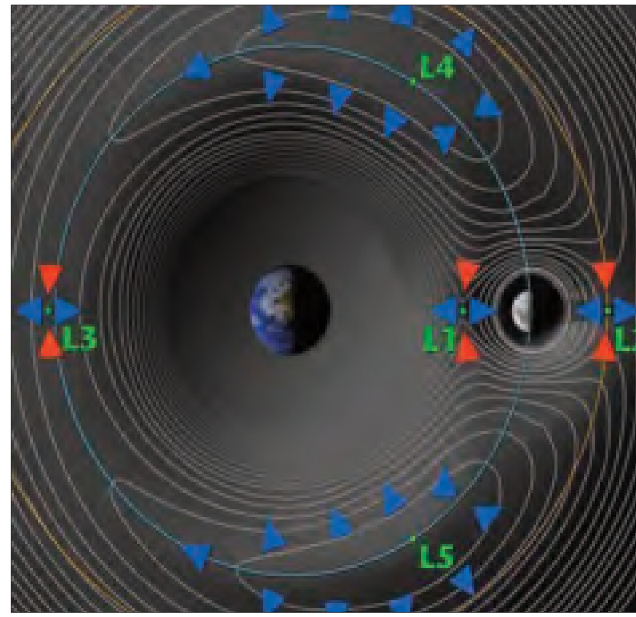
NASA announced plans last fall to begin flight tests of the Orion multipurpose crew vehicle in 2014, atop a Delta IV launcher. For its second mission, Lockheed Martin has proposed a piloted lunar swing-by, propelled by the Space Launch System (SLS) or a commercial substitute. With beyond-LEO performance, NASA could mount a series of increasingly complex missions centered on Orion, using additional components—a habitat, an airlock, a robotic manipulator arm—to create a versatile deep-space vehicle.

Assembled in LEO, the stack could then rendezvous with and service geosynchronous communication or imaging satellites, replacing ailing components or refilling empty fuel tanks. Crews would return to Earth in Orion, but the SEP system could reposition the habitat/airlock hardware for reuse. Such a demonstration by astronauts would be a pathfinder for follow-on commercial services that would use robot spacecraft.

After the lunar circumnavigation, Orion could move up another notch in capability, to an advantageous pair of gravitational equilibrium points, Earth-Moon L1 and L2. As at the other three Lagrange points, the effective forces at L1 and L2 are in equilibrium, and a small body placed there can theoretically remain stationary in that rotating reference frame.

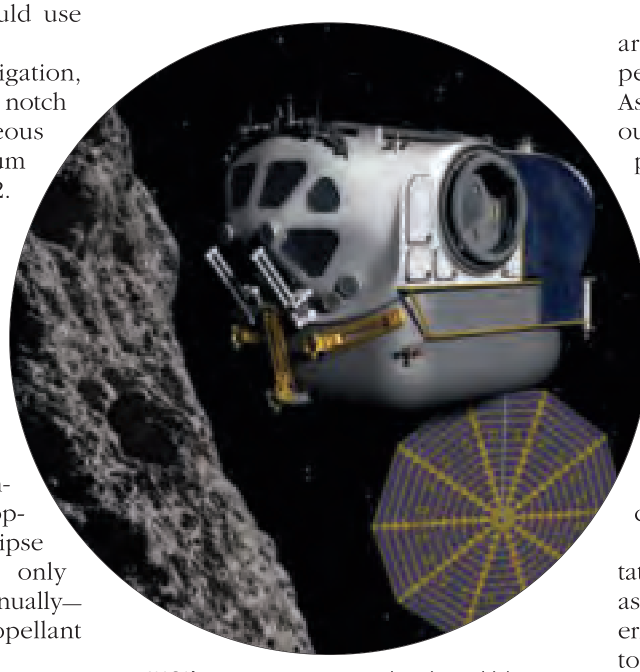
Staying precisely at these two points, which are dynamically unstable, requires substantial maneuvering fuel. But looping around them in a lazy ellipse called a halo orbit requires only about 100 m/sec of delta-V annually—a figurative drop in the propellant bucket.

L1 point is on the Earth-Moon line, 325,000 km from Earth and 56,000 km from the Moon. L2 is on the extended Earth-Moon line, another 67,000 km beyond the Moon; it takes about eight days and 3,450 m/sec to get there from LEO. From an L2 halo orbit, astronauts would have a direct view and radio link to Earth, because that orbit would be far larger in angular extent than the Moon's disk. A craft in such an orbit could also serve as a relay between Earth and the lunar far side.



Contours of the effective gravitional potential in the Earth-Moon two-body system show the five Lagrange points. Arrows show the potential gradient: red is 'downhill' toward the L-point; blue is downhill away from it. Credt: NASA.

Using early SLS test launches (which have to go somewhere, after all), NASA could autonomously assemble in an L2 halo orbit a sort of 'line shack,' a human-tended facility useful for a variety of exploration tasks. Components would be copies of ISS designs or actual station spares to minimize the cost of development. For example: a build-to-print ISS solar array, a small SEP unit for orbit maintenance, a modest MPLM-derived habitat, supply vehicles from ISS partners, or even an old orbiter airlock.


NASA's two-person space exploration vehicle concept, here free-flying at a near-Earth asteroid, is one of the deep-space systems that could be deployed and tested at ISS. Credit: NASA.

The L2 line shack would host an array of science-oriented activities performed by visiting Orion crews. Astronauts could assemble and check out a series of lunar or NEO probes, piggybacked on SLS, commercial, or international partner supply runs. Farside rovers could be commanded by astronauts or, more routinely, by relay from Earth. Lunar samples rocketed from the surface to L2 could be collected, stored, and returned to Earth, again by visiting Orion crews. Lunar, Earth, and astrophysical observations would continue under remote command between crew visits.

Because of its advantageous gravitational perch, L2 could also be used as a gateway for assembling and delivering robot probes or space telescopes to lunar orbit, the lunar surface, the Earth-Sun L-points, near-Earth objects, or even Mars. These assembly activities could be enhanced by delivery of an inflatable, pressurized hangar where astronauts could put together large telescope elements or spacecraft, free of bulky pressure suits and gloves (inside the low-pressure envelope, crews would have to breathe supplemental oxygen through a mask).

Opportunity at the Moon

L1 and L2 are very close to the Moon. The latter, 67,000 km from the far side, is a superb vantage point for remote sensing, and an ideal relay station for commanding far-side rovers from Earth. Enabling visiting astronauts to operate those same rovers from L2 would demonstrate how future crews could explore Mars by teleoperating rovers from a Phobos outpost.

At the Moon, NASA could deploy a series of landers and rovers to pursue high-value lunar science. These probes could sample ancient rocks from the South Pole-Aitken Basin, prospect for ice deposits in shadowed craters, and scout sites for future human exploration.

I am intrigued by recent Lunar Reconnaissance Orbiter images of skylights, cave-in openings into ancient lava tubes. One skylight in Mare Ingenii (appropriately, the Sea of Cleverness), is 130 m across; a rover could trundle up to its rim and take a detailed peek inside. Such lava tubes might be excellent sites for outpost habitats, shielded from radiation yet in the middle of a fascinating geological setting.

Science aside, a detailed assessment of lunar resources such as water, oxygen, and metals is a necessary step in opening up cislunar space to commercial development. The LCROSS impact experiment in 2009 revealed that its target crater, Cabeus, holds an estimated billion gallons of water, enough to fill over 1,500 Olympic-size pools. Similar ice deposits could feed many decades of LOX/LH_2 propellant production for lunar and in-space use.

By the year 2020, NASA could be leading a multinational lunar science campaign, using robots to explore the most promising regions of the Moon. The discoveries they make could put the U.S. at the forefront of lunar exploration, while American astronauts at L2 prepare for true deep-space expeditions.

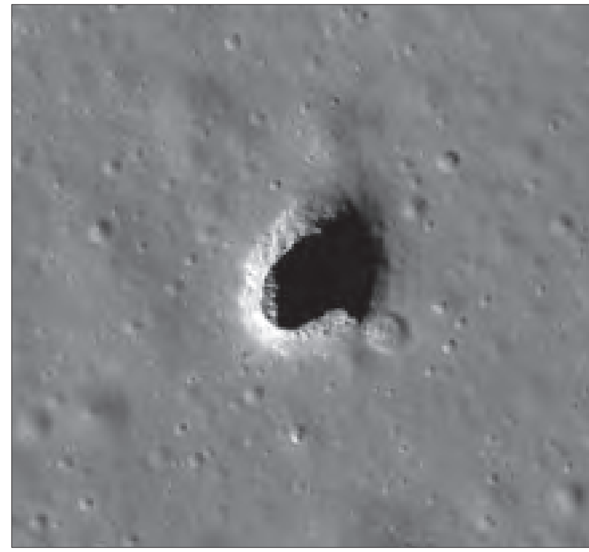
Gateway to the NEOs

From a perch at L2, the mesmerizing view takes in the rugged lunar far side, backdropped by a delicate blue Earth hanging in a velvet-black sky. Building on ISS expeditions and a series of month-long visits to this L2 gateway, we would be ready by the early 2020s to reach even farther into deep space.

By that point we should have enough evidence from a space-based search telescope, and a series of near-Earth object (NEO) precursors, to select several likely targets for human exploration. Ancient, unprocessed, water-rich NEOs should be of prime interest: meteorite evidence indicates that those with hydrated silicate surfaces contain up to 20% water by weight. If confirmed by probes like JAXA's Hayabusa II and NASA's OSIRIS-REx, then a 100-m asteroid, weighing about a million metric tons, could harbor 200,000 tons of water.

A resource of that magnitude would be almost impossible to ignore, and would invite a NASA-industry effort to figure out how to extract it and get it back to useful locations in cislunar space. Human expeditions could demonstrate ore handling and extraction processes, then give way to robotic exploitation of a handful of promising NEOs. The same robot and human explorers would return extensive remote sensing data and physical samples, revealing much about the origin, composition, and history of these ancient remnants of planetary formation.

A decade of study would also yield the collective knowledge and operations experience needed to divert a NEO from a collision course with Earth.



This skylight into a probable lava tube is in Mare Ingenii, the 'Sea of Cleverness,' on the lunar far side. The opening is about 130 m in diameter, and the image is 550 m across. Illumination is from the upper right. Credit: NASA Goddard/Arizona State University.

Taking flight

NASA's outlook in the face of static budgets and national deficit struggles is challenging, but there are some bright spots: The ISS is complete, commercial launch partners are making progress, and the agency has Orion and SLS in the pipeline. By using the space station as a testbed, capitalizing on commercial innovation to lower launch costs, bringing in contributions of hardware and expertise from its international partners, and harnessing bright ideas from its own engineers, managers, and flyers, NASA can execute a series of small but concrete steps to put the U.S. at the threshold of deep space.

It's a modest but appealing program that can take us to the Moon and beyond by 2020. We'll need stable funding, smart thinking, and politicians who won't turn the space effort upside down every four years. But if NASA's leaders can convince the White House and Congress to turn its explorers loose, this decade should see us move beyond Earth for the first time since 1972, when we last knew how to carry out truly epic journeys of exploration. It's time to get started.

Thomas D. Jones
Skywalking1@comcast.net
www.AstronautTomJones.com