Stepping-stones to Mars—An Alternate Strategy
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While the most obvious progression of deep-space voyages is to the surface of the Moon and then to the surface of Mars, for decades some space planners have recommended a different strategy. They urge that the next human expeditions beyond low Earth orbit scout out the "offshore waters," then nearby islands, later the islands near the final destination, and only then aim for Mars.

Now the latest and most persuasive exposition of this plan has appeared. Wesley Huntress, emeritus space scientist for NASA, president of The Planetary Society, and now director of Carnegie's Geophysical Laboratory in Washington, D.C., had originally disclosed details of one study in his testimony before the Senate committee overseeing space, in October 2003. He described a private effort he was then involved in, under the auspices of the International Academy of Astronautics (IAA), called "The Next Steps in Exploring Deep Space." The latest version of this plan is to be unveiled in early December, and it is a serious alternative to NASA's current interpretation of the Vision for Space Exploration.

This strategy identifies several specific "destinations" beyond low Earth orbit (LEO) but short of the ultimate Mars landing. First is a "gateway" zone at the Sun-Earth Lagrangian Point L2 (about 1.6 million kilometers "down-sun" from Earth); then, there would be sorties to one or more of the small asteroids known as near-Earth objects. Next are visits to the two moons of Mars, Phobos and Deimos. Reaching the surface of Mars is at the limit of its vision. "There is no single destination for human exploration, as was the case during the Apollo era," the report explains. "There is a set of destinations that is scientifically and culturally compelling." And perhaps the most controversial aspect of this strategy is that the surface of the Moon is not on the path to Mars.

And in one of the study's most innovative creative leaps, for each step, the development of only one fundamentally new type of space vehicle is required. "This approach requires incremental investments to maintain progress, rather than huge new budgets," he explained to the Senate committee. It would allow the program to exist under a relatively constant "budget roof," not requiring peaks (and valleys) or roller-coaster funding.

Buzz Aldrin, Apollo 11 Moonwalker, believes that breaking a "20-year space plan" into bite-size chunks may also offer profound political advantages. "You have no idea how important I really believe [this approach] to be," he told me. Because space goals are set by whomever is in the White House, he believes that "we should design a series of four-year programs" as part of long-range strategy. From time to time, he continues, "you may slide some of the objectives due to delays, wars, politics—but you can't slide who makes the decisions, and that's the President." Projects with well-defined short-term goals would be politically much more advantageous than one big project with a far-distant single goal.

The International Space Station can be useful for research and testing, but despite NASA's initial claims, it cannot serve as a jumping-off point for more distant missions. "Its orbit inclination creates a severe penalty for station-launched missions to the Moon and planets," Huntress explained, referring to the sharp north-south flight path necessitated by making it accessible to Russia's spaceports. Combined with a crippling 20–25 percent performance penalty of U.S. space shuttles launched into the station's inconvenient orbit, these considerations suggest it will remain a space voyage dead end.

In contrast, the IAA study focuses first on a region of empty space as the first human destination beyond LEO. It is located about 1.6 million kilometers from Earth (four times the distance to the Moon), away from the Sun, and is designated "SEL2," or Sun-Earth Lagrange-2. It is a gravitationally neutral zone where spacecraft are metaphorically swept along in the gravity wake of Earth, and thus can maintain position there at very little cost in steering rocket firings.

Space astronomers have already had their eyes on this region. This is because of the unrestricted view of most of the celestial sphere, and of the benign thermal conditions (no rapid day-night cycles as in LEO), and of the uniform gravitational forces that allow widely scattered spacecraft to maintain very precise relative positioning. NASA's Webb Space Telescope will be located here, as well as its Constellation-X and Terrestrial Planet finder instruments. The European Space Agency is developing a range of observatories—named after scientists Herschel, Planck and Darwin—that are also to be deployed in this region. In years to come, the need may grow for human servicing and even human-assisted deployment and calibration for follow-on instruments such as those now being imagined to map the surfaces of extrasolar planets.

By lucky coincidence, this region also offers a unique view of the Earth. The angular size of Earth at this range is nearly the same as that of the Sun, providing properly positioned observatories with a continuous annular eclipse that backlights Earth's atmosphere whose profile can be monitored. And since objects in the zone are not really in orbit around Earth, they can transition from it into orbits around Earth with any desired inclinations to access, inspect, repair or otherwise control any object in Earth-Moon space.

A human mission to SEL2 would involve launching a spacecraft just a little faster than the Apollo missions during the Moon race, and would take about 15 days to get there. The velocity change, or delta-V—the propulsion maneuver—to stop in the zone, and later to depart it for the return to Earth, would be about 20 percent greater than that needed by Apollo 8 in December 1968 to enter lunar orbit and then head back to Earth a day later.

The IAA plan calls for the development of a crew-carrying spacecraft with capabilities similar to those of the Orion Crew Exploration Vehicle. The U.S. would also have to build a reusable "service module" for the propulsion and power. Between missions, this vehicle would be parked in LEO. There it could be serviced and refueled—and the vehicles could also be used for human missions to lunar orbit and to 24-hour geosynchronous orbit.

This strategy does not require a lunar landing phase on the way to Mars. Huntress had testified that the Moon itself "is not necessarily on the critical path to Mars," and the draft report elaborated on this theme: "The Moon is a destination with important scientific and cultural benefits that make it worthy of human exploration," it stated, "but from a technical standpoint it is not necessarily in the critical path to Mars." There could well be good reasons for humans returning to the Moon, the report concludes—but preparation for Mars is not among them.

The term “gateway” as applied to the SEL2 zone means that objects parked there—and it does take significant propulsive energy to get there—can trade that energy back in to be applied to pathways to other destinations. A vehicle could depart SEL2, dive back towards Earth and, while swooping by it, fire its engine again to attain an extremely efficient escape trajectory.

For humanity’s first sortie beyond the Earth-Moon system, Huntress and the IAA team had a consensus—visit a passing asteroid. “There is no doubt that a one-year human mission to a near-Earth object (NEO) would serve as an excellent intermediate step before any mission to Mars,” he told the Senate committee. The full report elaborated: “NEOs are ideally situated to provide an important stepping-stone to Mars. They are accessible with flight times that are intermediate between SEL2 and Mars, and will provide us with an opportunity to exercise many of the required transportation elements in a relatively low-risk manner.”

There are powerful reasons for stand-alone interest in these particular objects. “I find it a very refreshing approach,” noted Apollo astronaut Rusty Schweickart. “I am especially supportive of their recognition of the critical role asteroids will likely play in our future in space.” The incremental approach also appealed to him: “The step-by-step logical progression leading to real capability for human presence in deep space will also be more attractive to the public than one-shot grasp for a human Mars landing.”

“By far the strongest imperative for human missions to NEOs arises from consideration of their utility as an intermediate step to Mars,” the report argues. “Their locations and physical characteristics will stretch the capabilities of human exploration just enough to greatly reduce the risk of the Mars missions to come. NEOs will thus play an important architectural role as a bridge between Earth’s neighborhood and Mars.” And later, if the choice at Mars is to first visit its moon Phobos, “a precursor mission to a near-Earth asteroid would allow demonstration of almost the entire mission at a destination closer to Earth, with ample solar power availability, high communications rates and relatively short return-to-Earth flight times that provide an extra measure of safety.”

Matching orbits with a speedy passing asteroid is a challenge when launched from LEO. The strategy proposed in the IAA report is to stage such a mission from the SEL2 gateway. There, reusable space tugs initially developed for access to that point can deliver the asteroid-bound space vehicle and, in the end, its crew. The energy required to assemble the vehicles here is acquired piecemeal through reusable tugs over a period of months, and is then expended efficiently during a brief launch maneuver in which the total required launch energy has already largely been “pre-invested.”

Since the flight time increases from a few weeks to many months, neither a modified Apollo vehicle nor the SEL2 human-access spacecraft could keep a crew alive long enough for an asteroid round-trip. So the elegance of the IAA plan pays off again. Following the principle of “one major new vehicle per step,” it calls for development of an interplanetary transfer vehicle to carry a crew for a long mission (a year or more) with a delta-V capability of about 6 km/sec (to be increased to 8 km/sec for later Mars missions). This spacecraft “is most significant development that will be required for this step,” the report states. “This will represent a substantial investment and must be designed with the ultimate destination [Mars] in mind."

So, with the first two stepping-stones now achieved—SEL2 with its fleet of science observatories, and the variety of passing asteroids now also within reach—and with a Mars landing the ultimate goal, where next will human footprints be planted?

"Our philosophy of incremental development as a means of managing cost and risk suggests that a human mission to one of Mars's moons, Phobos or Deimos, may be an important precursor to a mission to the planet's surface," the report continues.

In the IAA plan, one other major space vehicle is needed even before the new human Mars landing craft itself can be built. This final intermediate step is to develop hardware to provide a means to get large cargoes to distant destinations where future travelers can use them. As the report states, "A robust cargo delivery capability is a key element of a sustainable human exploration program."

This plan suggests developing high-efficient low-thrust engines—probably powered by nuclear reactors—to send most of the mission's cargo out ahead of the crew. This concept, again, isn't unique to the IAA study, but it is in keeping with the study's philosophy: "Only one major new capability is required for each step, coupled with evolutionary progress in existing capabilities."

Being close to Mars has many scientific advantages. "The removal of the light-time delay to Earth would make it feasible to actively manage experiments and react to discoveries," the IAA report points out, "thus helping to define the role of humans when they eventually reach the surface." A human-in-the-loop real-time control of the recent twin Mars rovers, for example, could have increased their surface speed by a factor of 50, and allowed months of science investigations to be accomplished in a few days. Instead of creeping along at inches per hour, and taking days to properly align instruments over rocks of interest, surface rovers (as well as flying vehicles) directly controlled by people on Phobos could operate at astonishing speeds and thus harvest even more astonishing results.

With in situ refueling on Phobos, spacecraft based there can make sorties into lower orbits around Mars to rendezvous with robot payloads sent up from the surface with carefully collected samples. Such samples can initially be studied and cataloged in the habitat imbedded safely under the radiation-shielding dirt of Phobos.

How long will human visitors to Mars have to wait before going down to the surface? "A large suite of very capable hardware elements will have…progressively evolved through each destination," the report says. "There will, however, be a large number of unique elements that are required for the Mars surface mission."

Funding their development, and testing them—including space tests, perhaps near the Moon, perhaps even at Mars—will take a long time. It could be a decade or more between the arrival of humans at Mars and the first human footsteps on Mars.

One argument heard against such a step-by-step strategy is how frustrated astronauts might feel orbiting Mars but unable to land (as if the space program were designed for the psychological satisfaction of astronauts—as some cynics have long suspected). But when asked, experienced astronauts have expressed no such objections.

“Some crewmember candidates will say ‘If I spend years in preparation and then a couple of years in space, I must go to the surface to justify my time investment,’” pioneering space station astronaut Owen Garriott has admitted. But he suspects that other potential crewmembers would not: “Other fully qualified candidates will be just as anxious to contribute to this magnificent opportunity to make a meaningful, early contribution to our exploration of the solar system and to the Mars vicinity,” he continued. “This is a case in which ‘self-selection’ provides a quite valuable discriminator.”

Garriott appealed to historical precedent, to which he was a direct eyewitness. “Consider selection of the early Apollo crews in the 1960s,” he explained. “Probably everyone in the Astronaut Office would have wanted to go to the Moon's surface. But some more than willingly accepted roles in lunar orbit or in LEO, or as backup crews which were essential to the Moon landings, or even reached for other important objectives, as in Skylab. I would expect Mars to be a similar situation.”

The logic of this strategy may be persuasive, but as of now it still goes counter to conventional wisdom. For many spaceflight theorists this stepping-stone approach is nothing but an overcautious temptation that distracts from the main goal, Mars itself. Instead, it replaces that goal with what could become a series of stumbling blocks that would bankrupt a space budget and stretch out flight schedules beyond the attention spans of the public and political leadership.

The details of that final step are another topic entirely, since what is most innovative about the new strategic plan is how people get to that point. “This architecture gradually builds capability to explore the solar system through a series of carefully selected steps, each one designed to eventually enable humans to reach the Martian surface,” the IAA study concludes. “Ultimately it will be the continuing sense of exploration, along with the scientific discoveries and technical progress of the preceding steps, which will sustain public interest and international political support and make human presence on Mars a reality.”