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Charting a Course:
Expert Perspectives on NASA's Human Exploration Proposals

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I thank the Chairman and the Committee for this opportunity to give you my thoughts on the nation's program for the human exploration of space. This testimony is my personal opinion and does not necessarily represent the views of my employer, the Universities Space Research Association.

Why are we here today? America's civil space program is in disarray, with many aspirations and hopes but few concrete, realizable plans for future missions or strategic direction. We pretend that we are on a "#JourneytoMars" but in fact, possess neither the technology nor the economic resources necessary to undertake a human Mars mission now or within the foreseeable future. What is needed is a logically arranged set of short-term, realizable space goals – a series of objectives and destinations that are not only interesting in and of themselves, but whose attainment build space faring capability in the long term.

Whatever space destinations and goals are selected, they must be such that significant milestones can be reached on a regular and recurring basis. Such a program is sustainable – progress (or its lack) can be mapped and resources allocated accordingly. Thus, any program to extend human reach beyond low Earth orbit (LEO) must be incremental, so that each step is small and affordable, yet cumulative, so that the smaller steps integrate into a coherent working program.

Demise of the Vision for Space Exploration In 2010, the United States abandoned the strategic goals for space set by Vision for Space Exploration (VSE). The Vision called for the Shuttle to return to flight, the completion of the International Space Station (ISS), the retirement of the Shuttle, a return to the Moon and a human mission to Mars, in that order. Although the first three objectives were met, the elimination of lunar return left a vacuum in space policy that has yet to be filled. The Moon served two primary purposes in the Vision: 1) a return to the Moon allowed us to develop and test the technologies, hardware and procedures needed for future human exploration beyond LEO; and 2) the use of the material and energy resources of the Moon would enable the creation of new spaceflight capabilities. Specifically desired was the harvesting of water from the poles of the Moon to manufacture propellant and life support consumables for human missions to many destinations beyond LEO, including Mars. These goals were not ancillary to the fulfillment of the VSE but rather, a critical part of the logic of the Vision.

After this loss of this strategic direction, we soon realized that few destinations beyond LEO are reachable within reasonable time-scales (decadal) for affordable cost (existing budgets). An attempt to replace the lunar surface with human missions to asteroids quickly faced the reality that given the technology constraints for human spacecraft, few accessible targets exist. Meanwhile, Congress became increasingly concerned that with the retirement of the Space Shuttle, critical national capabilities associated with that launch system were being irretrievably lost (e.g., industrial infrastructure, such as large-scale precision welding of the Shuttle External Tank, and human capital, in the form of highly skilled launch teams). Thus, Congress directed the agency to continue building the Orion spacecraft and to develop a new heavy-lift launch vehicle, the Space Launch System (SLS). The object of this direction was to ensure that we retained the capability to launch the large payloads needed for the fulfillment of human missions into deep space.

Both the Orion spacecraft and SLS rockets (being derivatives of work done previously on the now-defunct Project Constellation) are generic vehicles; they are not designed with a specific mission in mind but rather, aimed at general applicability to human missions beyond LEO. Given that the two systems come from work previously done to support lunar return, it is not surprising that they are optimized for missions to cislunar space, the zone of space between low Earth orbit and the lunar surface (which includes the Sun-Earth L-points, gravity-neutral zones in space about 1.5 million km (930,000 miles) from Earth). Cislunar space has many potential destinations of interest, but except for the lunar surface, it is all empty space. Thus, Orion and SLS – representing a potentially robust cislunar capability – have no place to go.

The Asteroid Retrieval Mission (ARM). Asteroids circle the Sun in orbits independent of Earth and Moon. When planning a mission to an asteroid, one must select a target using fairly stringent constraints, including its distance from the Sun, the inclination of its orbital plane, and the timing between the positions of Earth and asteroid (in both directions). Given these limitations, few asteroids suitable for human exploration can be identified and none of them are very large. With the lunar surface having been ruled off-limits, the problem of identifying cislunar missions became one of finding something for astronauts to do. In 2011, the Keck Institute for Space Studies came up with the idea of bringing a "destination" to cislunar space: find a small asteroid, attach a solar electric propulsion (SEP) module to it, bring it back to cislunar space and place it where it can be reached by the Orion spacecraft. The concept was sketched out in a 50-page report, but the mission was neither fully developed conceptually nor was its value vetted through the scientific advisory structure that we maintain to review and judge mission concept proposals.

Embraced by NASA as the "next step" towards a human Mars mission, the ARM offers few scientific and scant operational benefits. With additional study, the planned size of the returned object has continually decreased: initially, it was planned to return an asteroid about 7 meters across, but it is now planned to return a small 1-2 m boulder. Virtually all asteroids (~85%) are ordinary chondrites, a rock type so renowned for its uniformity that it is used as a compositional standard in cosmochemical studies. Moreover, we already possess (literally) tons of ordinary chondrite meteorites, as they continually fall onto the Earth every day. With limited power and minimal loiter time near the object, the Orion spacecraft does not possess the capabilities necessary to experiment with resource utilization. Thus, the ARM does not contribute to learning how to process and use the material resources of space. The ARM will be conducted in microgravity and it will not prepare us for human operations on the surface of Mars, where a significant gravity field exists (approximately one-third the gravity of Earth). Although it is claimed that the ARM develops technology needed for future Mars missions, many of its alleged technological benefits (e.g., solar electric propulsion) can be developed just as well by other cislunar missions and at the same time, emplace transportation infrastructure for future use.

The ARM offers no unique benefits beyond providing a place for Orion to visit. In terms of scientific and operational importance, it is barren of real accomplishment and irrelevant to future human deep space missions. And for learning how to use space resources, it can only perform rudimentary reconnaissance of the type already accomplished or planned by a variety of robotic missions, past (e.g., NEAR), present (e.g., Dawn) and future (e.g., OSIRIS-REx).

Cislunar Development – An Alternative to ARM. By focusing on the development of cislunar space, we will build something of utility and lasting value. This zone of space contains more than 95% of all of our scientific, economic and national security satellite assets. Low Earth Orbit (LEO, 160-2000 km or 100-1200 miles) is the home of the ISS and a multitude of scientific and Earth-monitoring satellites. Middle Earth Orbit (MEO, ~2000-35,000 km or 1200-22,000 miles) is where the satellites of the global positioning system (GPS) reside. Geosynchronous orbit (GEO, 36,000 km or 22,500 miles) is the altitude at which one orbit coincides with one rotation of the Earth (so that the satellite appears to stay in one location in the sky); it is prime real estate in space, the location of most of the world's communications and weather satellites. Highly Elliptical Orbits (1000-36,000 km or 600-22,500 miles) are used for various national security missions. Lagrangian points (L-points, 350,000-1,500,000 km or 220,000-930,000 miles) contain few spacecraft at the moment, but are useful locales for loiter/storage and staging nodes for future missions to more distant destinations. Modern technical civilization is critically dependent on the satellite assets deployed throughout cislunar space.

At present, we can reach these various orbital levels only with unmanned systems. When a satellite becomes obsolete or stops functioning, the only solution is replacement. If we could move people and machines throughout the various locales of cislunar space, we would be able to emplace, construct, upgrade and maintain satellites. Large, distributed space systems could be built that would provide complete hemispheric coverage and create virtually unlimited bandwidth for all types of communication devices. To access the various levels of cislunar space, we need to develop a permanent space faring infrastructure, including transport vehicles, staging nodes, deep space habitats, power stations, and fuel depots. In terms of the energy expended, all destinations in cislunar are essentially equal – if we can go to-and-from the Moon, we can go to-and-from all of the other locales in cislunar space. Such a system creates not only routine access to the Moon and to all of cislunar space, but also enables human missions to the planets beyond.

To become space faring, it is vital that we learn the skills necessary to harvest the material and energy resources of space. Such technology allows us to launch only the most technically advanced and critical equipment from the Earth while large-mass, low-information materials (e.g., propellant, life-support consumables) can be obtained from local sources, wherever we are. Thanks to a variety of robotic missions over the last decade, we now know that the Moon possesses these resources in abundance. The poles of the Moon contain billions of tons of water. In its liquid form, water supports human life and when broken into its component hydrogen and oxygen gas and then liquefied, it becomes the most powerful chemical rocket propellant known.

Within the next decade, near-term activities having long-term significance can be performed in cislunar space through the creation of a permanent, space-based transportation system. Elements of such a system can be delivered with solar electric propulsion vehicles to various locations in cislunar space, including the L-points. An example of a simple (but extremely useful) technology development mission would be to launch several tons of water from Earth and experiment with transforming and using it for various applications in space. Rechargeable fuel cells combine gaseous hydrogen and oxygen into water, generating electricity; this process makes water, that can be then cracked back into its elemental form using electricity generated by solar panels. By generating solar power at the highly illuminated peaks near the poles and then using the fuel cells to generate power during eclipse, the development of this technology will permit us to stay for extended times on the surface of the Moon. Radiation shielding, a critical requirement to keep crews safe from cosmic rays and solar particle events during months-long, interplanetary voyages, is another important use of water in space. Experimentation with water in deep space prepares us to handle and utilize the water produced in the future from extraterrestrial sources (e.g., lunar polar ice, the hydrated minerals of asteroids, and martian ground ice).

American Leadership in Space. With considerable justification, the United States thinks of itself as a world leader in space. But the current lack of focus and strategic confusion in our civil space program undermine that claim. News coverage of recent and planned space efforts documents a worldwide interest in the Moon, with specific lunar surface mission plans and programs announced by Europe, India, Russia and China. These missions are not being undertaken to merely plant flags on another world, but to reap all of the benefits offered by the exploration and utilization of the Moon. As the world beats a path to the Moon, we stand aside. How can we claim leadership in a technological and scientific movement in which we have no participation and seek no ownership?

There is another dimension to the abdication of our leadership in space. China is rapidly developing the capability to access and use all regions of cislunar space. The Chang'E-2 spacecraft first went into lunar orbit in 2010 and mapped the entire surface over the course of a year. It then left lunar orbit and traveled to Earth-Moon L-2 (a point 60,000 km (37,000 miles) above the center of the lunar far side) and loitered there for 8 months. Leaving L-2, it flew by the Moon and intercepted the near-Earth asteroid Toutatis, sending images back to Earth, then entered an orbit around the Sun, from where it is still in radio contact. The mission profile of Chang'E-2 documented China's ability to travel, loiter, rendezvous with and intercept any target in cislunar space.

China has demonstrated their capability in anti-satellite (ASAT) warfare, most notoriously with the interception and destruction of a target satellite in low Earth orbit in 2007, creating a hazardous cloud of space debris that threatens the satellites of all nations. A future Chinese ASAT loitering at an L-point could fly to satellites in lower orbits from the Moon, an approach direction not normally monitored. Close contact could neutralize a satellite, either with a robotic arm to cut a power or communications cable or by deploying a sun shield, putting the solar arrays of our satellite in shade and cutting off their electrical power. We would have no recourse to this type of action and few alternatives short of war. In such a scenario, we would be starting at a decided disadvantage as a result of our lack of commitment to establishing a strong national presence in cislunar space.

America is at a critical juncture in the history of its space program. Congressional leadership is needed to set us back on the correct strategic path. The development of the Moon and cislunar space answers critical national needs. It is an incremental, affordable and useful strategic direction, a sustainable path that creates new capabilities in space faring. A return to the lunar surface allows us to use the enabling asset of the Moon to journey to and explore the planets beyond.

I thank the Committee for its attention, I welcome your comments and thoughts and I am happy to answer any questions that you might have.