Should NASA's Human Spaceflight Strategy Be To Explore Or Pioneer?

On May 29, 2014, NASA released a white paper titled "Pioneering Space: NASA's Next Steps on the Path to Mars". The paper's first page makes an important distinction.

> Explorers go with the intent of returning to tell their story and point the way for future forays. Pioneers go with the intent to establish a permanent presence.

U.S. history abounds with examples of this distinction, but consider an early one. From 1804 to 1806, Meriwether Lewis and William Clark led their Corps of Discovery on an *exploration* of regions drained by the Missouri and Columbia Rivers. If their objective was to *pioneer*, the Corps could easily have stopped in present-day Missouri and reported to President Jefferson from there while they put down roots and lived off the land, having never seen the Rocky Mountains or the Pacific Ocean.

In June 2014, The National Academies Press issued a prepublication draft report titled *Pathways to Exploration–Rationales and Approaches for a U.S. Program of Human Space Exploration*. As part of its Congressional charter, the report's authors were to develop "enduring questions" to be addressed by human spaceflight. Such questions "provide motivations immune to external forces and policy shifts", and the report poses two and only two as follows.

- How far from Earth can humans go? and
- What can humans discover and achieve when they get there?

The *Pathways* report advocates open-ended lunar surface operations as a possible prerequisite leading to a "horizon goal" of martian surface operations. This student of history and interplanetary human spaceflight architecture suggests NASA can go farther from Earth and achieve more in space by exploring rather than pioneering. To maximize human space exploration entails a strategy devoting more effort to interplanetary human transport (including cargo logistics with supporting infrastructure) and less to operating on planetary surfaces. Surface operations, particularly those requiring specialized elements for access and habitation on major bodies like the Moon and Mars, are best left to commercial partners.

If NASA remains fixated on the martian surface as its horizon goal, it will ultimately succeed in placing humans up to 2.7 astronomical units (AU, equivalent to Earth's mean distance from the Sun) from Earth. Doing so will require all manner of specialized hardware and techniques to achieve Mars entry/descent/landing and habitation. If open-ended lunar surface operations are a prerequisite to this milestone, still more specialized hardware and techniques are necessary. All this specialized technology takes great amounts of sustained funding over a protracted interval to develop, deploy, and operate.

Now imagine NASA is unshackled from the martian surface as its horizon goal and freed to explore the martian moons and asteroids as far from Earth as possible. Although these small bodies constitute a diverse and prolific breed of potential destinations, they all pose nearly identical environments for approach, "landing", and habitation because their gravity fields and atmospheres are virtually nonexistent. Interplanetary transport technology required to reach the vicinity of Mars is therefore easily adapted and scaled to access myriads of small bodies near and far from Earth.

A bewildering number of metrics exist with which to critically assess a destination's accessibility for human spaceflight. In the interest of brevity, consider only the roundtrip change-in-velocity (Δv) required to depart a circular Earth orbit 400 km in height, arrive/depart the destination, and enter Earth's atmosphere at no more than a manageable 12 km/s upon return. This metric relates primarily to how far from Earth humans can go. For a roundtrip to the martian surface, Δv is typically about 16 km/s.

Without having to descend into and ascend out of the martian gravity well, how far from Earth could humans go with Δv = 16 km/s? Assuming a circular destination orbit about the Sun in a plane close to that of Earth's orbit, distances from Earth up to 3.7 AU would be achievable. If NASA is not burdened with developing and operating special purpose infrastructure required to access and inhabit the surfaces of the Moon and Mars, increased focus and specialization would likely permit still greater distances from Earth to be achieved in less time and with less funding than reaching the surface of Mars would entail.

It would then be conservative to stop at 3.7 AU from Earth, equivalent to a mean distance of 2.7 AU from the Sun (the mean distance of Mars from the Sun is 1.52 AU), and take stock of known asteroids lying within this frontier. To render these asteroids accessible, only those in orbits about the Sun at least as circular as that of Mars and whose planes are inclined to Earth's by less than that of Mars are considered. Furthermore, each inventoried asteroid must have an intrinsic brightness such that it is virtually certain to be at least 0.15 km in diameter. A poll of NASA's asteroid catalog on 17 August 2014 tallies 3153 known asteroids meeting these criteria. And with 60 of these asteroids discovered in the first 7.5 months of 2014, the inventory is far from complete.

The asteroid tally does not include Phobos (Δv about 7.9 km/s) and Deimos (Δv about 7.5 km/s), the two moons of Mars. These small bodies can also be accessed by systems capable of visiting asteroids because Phobos is about 22 km in diameter, while Deimos is about 13 km in diameter. From its higher orbit, humans on Deimos could control telerobotics nearly anywhere on Mars in real time, conducting any conceivable surface exploration at far less cost and risk than human "boots on the ground".

Direct and telerobotic human exploration based on small bodies in interplanetary space will produce a bonanza of scientific knowledge. It will also uncover opportunities for commercial partners to pioneer. But NASA should participate in that pioneering only through logistics support and regulation enforcement. Costs to establish and maintain pioneering infrastructure should be borne by commercial partners and their investors.

Answering the *Pathways* enduring question of what humans can do in space will remain highly speculative for years to come. But if NASA's human spaceflight strategy is to explore, what can be discovered on thousands of small bodies, including ones in proximity to Mars, is beyond even collective human imagination.

Brilliant individual imaginations, like those of Edgar Rice Burroughs circa 1912 and Wernher von Braun in the 1950s, have instilled the surface of Mars as a horizon goal in human space exploration. But these individuals were almost totally unaware of the prolific population of small bodies in our solar system and their exploration potential. It is time to move beyond their vision to one reflecting a better reconnaissance of the unexplored territory awaiting us out there.

If NASA can focus on establishing routine interplanetary human transport and resist distractions posed by pioneering in space, it will enable that pioneering by those in commercial enterprises who do it best. The Corps of Discovery served in the same capacity to open western U.S. territory to pioneers. When the U.S. Advanced Research Projects Agency established ARPAnet in 1969 to protect the flow of military information during nuclear war, none of its inventors could dream of the Internet to follow in less than 30 years. It took commercial partners to bring about that pioneering in cyberspace.