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Humans and Robots in Space Exploration

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Human-crewed[1] spaceflight was the primary arena for the Soviet-American space race. It led to many flights of increasing technical achievement in low Earth orbit and then, for the United States, nine missions to the Moon. The last mission to the Moon was in 1972 (Chaikin 1995). It will be at least one-half century after that before they go any further. In fact since the end of Apollo, human-crewed spaceflight has been confined to low Earth orbit (a distance less than from Los Angeles to San Francisco). Following the space race to the Moon, the Soviet Union built Mir, an orbital space station, and the United States built the shuttle for low Earth orbit flights. In the 1990s Russia and America joined forces with the European Space Agency, Japan, and Canada to develop the International Space Station (McCurdy 2010) – also in low Earth orbit.

In this same time period, robot emissaries have travelled to all the planets and dozens of other celestial objects in the solar system (Launius 2013). One probe (Voyager 1) has even entered the interstellar medium, a region still in our solar system but where the particles of the solar wind are blocked from entering by those from interstellar sources. Voyager 2 is headed there as well along with New Horizons, following its flyby of Pluto and the Kuiper Belt object, Ultima Thule. Humans have landed on the Moon, while robotic spacecraft have landed on the Moon, Mars, Venus, Titan, and on an asteroid and comet.

Even more significant than the disparity of distance in human-crewed vs. robotic spaceflight is the pace of technological development. Human-crewed spaceflight is being planned for the 2020s with about the same general technology as it was in the 1960s. Many components are updated – but the design of space suits, life support systems, and habitats are generally the same. Conversely, robotic spacecraft has benefitted from huge changes in technology primarily brought about by ever-decreasing size and increasing capability of electronics. The widespread growth of robotic space applications into communications, remote sensing, weather monitoring, and navigation influences almost every aspect of daily life for Earth's population. Human-crewed spaceflight centers on two applications: national prestige for

[1] I use the adjective "human-crewed" in place of what was once called "manned" to describe spaceflight with a human crew onboard. I deliberately do not use just "human" for the description since (as described in this entry) all spaceflight has humans involved. In the case of robotic flight, the humans are just not onboard. I also do not use the simpler "crewed" as the adjective, since when read aloud it sounds crude.

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governments and putative commercial tourism for private companies.

The latter may speed the development of human-crewed spaceflight capability. Several companies hope to fly suborbital missions soon, and two companies are working with NASA to deliver human crews to the International Space Station. At least one entrepreneurial effort to develop a privately funded space station is also underway (Dubbs and Paat-Dahlstrom 2011). If commercial development proves viable, it could stimulate more human-crewed spaceflight development, but it should be emphasized that even one decade after the heralded X-prize award for the first privately funded human spaceflight, achievements are few and compared to government effort only rudimentary – repeating 40–50-year-old accomplishments of the United States and Russia.

The hiatus and slow pace of human-crewed spaceflight development may lead one to question if perhaps it will be replaced entirely by robotic spaceflight. Evidence points against this – not only is the United States continuing its human spaceflight program with Moon and Mars goals, but China and India have joined as new entrants to send humans to space. The geopolitical significance of human spaceflight is perhaps weaker now than it was during the Cold War, but it is still significant. It is nearly impossible to imagine the United States and Russia quitting human-crewed space development or to think that China and India would give up their aspirations in this arena. And while Europe and Japan have eschewed developing independent human-crewed flight capabilities in space, they have repeatedly reiterated their desire to partner in continuing the International Space Station and to be part of a Global Space Exploration Strategy (Laurini et al. 2015) for missions to the Moon and Mars. An intermediate step to have astronauts conduct operations in lunar orbit, in a "lunar gateway," is being designed so that it could accommodate international cooperation with human-crewed missions to the Moon by other nations should they wish to conduct their own missions there. All of the 14 nations cooperating in the Global Space Exploration Strategy have agreed on Mars as the long-range goal for human-crewed spaceflight – with still some debates on intermediate steps at the Moon, at near-Earth asteroids, or just with longer-duration flights in cislunar and interplanetary space.

The political rationale for human-crewed spaceflight is driven in part by national technology development goals and even more by the geopolitical advantage of national prestige. That motive is subject to shifting political winds. There is also a cultural motive that might keep the program going and the vision in sight no matter how those winds shift. Mars is the only accessible world for humans to reach that has the resources to sustain life: specifically oxygen and water in its atmosphere and soil. This is not to say that its environment is hospitable to life – it is cold, dry, and toxic, more than any place on Earth, and its atmosphere is very thin. The thin atmosphere gives no radiation protection to the planet. But, still, Mars may have harbored life in the past, and it may be possible to sustain life there even now – in warmer, wetter, and more protected areas as in caves or under the surface. It represents a potential future home for humankind – if not fully settled, at least as an outpost. While few would abandon Earth for Mars, the existential threats to our home planet are at least a psychological or social motivation to develop another world. Pandemics, climate change, nuclear war, asteroid impact, and artificial intelligence run amok are five such existential threats. Knowing that humankind can continue to evolve even in their face is a strong motivation for positive human evolution and development. One hopes we will deal with earthly threats here on Earth – but being a multi-planet species creates a sense of resiliency in our efforts.

With a general political and scientific consensus for a humans-to-Mars goal, it is likely that human-crewed spaceflight will continue to develop with longer and more self-sufficient flights, increasing capabilities for the indefinite future. The pace of that development is uncertain, depending on many practical economic and political considerations here on Earth. This is not a short-range goal. Even if a human-crewed Mars landing occurs as space exploration enthusiasts hope, in the 2040s, it will take many such landings (some of which may fail) to even begin to explore the planet. The Western Hemisphere of Earth (less than half the surface area of Mars) took millennia to explore and settle – despite abundant resources. We can anticipate hundreds of years to explore Mars and perhaps thousands to really settle there (perhaps modifying its environment as we do, to increase its habitability). Human space development on Mars is open-ended.

Beyond Mars is much more uncertain. There are worlds of high interest and relevance to questions of extraterrestrial life and conditions of habitability. But those worlds, most notably the moons of Jupiter and Saturn, are very far away, with very hostile conditions. Jupiter's radiation environment is so extreme that we can't imagine humans living there if even they got that far. Saturn is almost twice as far from Earth as Jupiter and certainly beyond human-crewed reach for at least a century, more likely two. The resources needed to build life support for a human-crewed venture beyond Mars are enormous, and they would have to be mustered, while humans were busy exploring Mars. In that same period, however, human *presence* will be capable of extension way beyond Saturn – maybe even to the edges of the solar system. The human experience has already begun to be achieved through the ever-increasing robotic and information-processing technologies in our current generation. Imagine where they will be in three or four generations.

While human crews make their way to Mars in the next few decades and extend their duration for long-duration space travel from days to a few years, the robotic technologies will continue to evolve permitting decades-long space missions of increasing sophistication in smaller and smaller packages (Friedman 2015). The newer technologies of nanotechnology, biomolecular engineering, magnetic bubble memories, quantum computing, and artificial intelligence will be employed with the result that robotic space probes will have the ability to send huge amounts of data from distant worlds that, in essence, allow the recipients at home to see, hear, taste, touch, and smell those worlds. We might anticipate active payloads that interact with the sensed environment similar to what a human crew would do if they were there. The effect will be more and more to make us feel like we are extending our human presence at those distant worlds even while we remain at home, experiencing the results in some virtual exploration device. Conducting underwater investigations for life on Europa, exploring with submersibles there and on Titan, flying through the atmospheres of planets and moons in the outer solar system, and maybe even achieving fast enough speeds to exit the solar system to enable reaching interstellar distances in less than a century might all be done robotically, while human crews are still setting up the first few outposts on Mars. Concepts of these ideas are already being studied. Even commercial exploitation on the Moon or asteroids would also be done likely by such robotic vehicles rather than by costly and slow human crews – perhaps with some relatively brief human crew visits. This is not the end of human spaceflight but the beginning of a new phase with the human not as part of the crew but still as the receiver and customer for the data of exploration. Do we accept the human on Earth teleoperating a Mars rover and experiencing its received information in a virtual reality as a part of human spaceflight? That remains to be determined.

We realize then that the evolution of human-crewed spaceflight and robotic technologies removes the characterization of "humans vs. robots" as a debate in space exploration. All space missions involve both, and it is the synergy between them that conducts the missions. The human role will be more on the interpretation of information and less on its gathering – except perhaps on Mars where the humans will still be acting first as crew and then as explorers and then if it works as settlers.

This entry focuses on the long term, where human and robotic space exploration are headed. The decisions that are made about space missions are influenced by vision and rationale but governed by budgets and politics – short-term decisions. In the United States, there is disagreement and debate about whether going back to the Moon is a detour or a step on the way to Mars. In either case a new heavy-lift rocket and crew life support module are required. To that end the US program is now building a new rocket, the Space

Launch System (SLS), which is being planned to grow into a larger vehicle capable of human-crewed Mars missions. They are similarly building a new human-crewed capsule (Orion) – with a European service module – to extend astronaut missions to support weeklong durations in cislunar space. The rocket and crew capsule are intended for cislunar missions.[2] Human-crewed low Earth orbit missions and transportation to the International Space Station are to be assigned to the private sector. NASA is now supporting the development of the SpaceX Falcon rockets and Dragon crew vehicle and the Boeing Commercial Space Transportation (CST) Starliner crew vehicle. Those companies and Blue Origin with its New Glenn rocket are now developing human-crewed systems for commercial ventures in space. Space tourism is a commercial goal. Privately funded human exploration beyond low Earth orbit remains a more distant goal – although it is the inspiration behind entrepreneurs like Elon Musk and Jeff Bezos who seek to develop commercially profitable human space travel while personally making new achievements in space exploration and extending the human presence into the solar system (Pyle 2019).

NASA will resume human-crewed missions in the early 2020s with SLS/Orion missions to lunar orbit and SLS/Starliner and Falcon/Dragon to the International Space Station. The United States, with European, Japanese, and Canadian partners, has a goal of humans reaching the Moon in the mid-2020s. China has announced a similar goal. Longer-duration missions going into interplanetary space will require a larger rockets and a new habitation module with extended life support. The journey to Mars will require a decade-long series of steps, probably first to Mars orbit (and perhaps a rendezvous with one of its moons, Phobos or Deimos) and ultimately to landing on the surface.

[2]Specifically to the "lunar gateway," originally proposed as a destination for a robotically retrieved asteroid as a place to conduct human space operations. The asteroid retrieval project was cancelled, but the lunar gateway destination remained – probably as a site for a human-tended space platform.

There are many technical challenges for a human-crewed Mars mission (Pathways to exploration: rationale and approaches for a human space exploration 2014). A closed-loop ecological life support system will be necessary for the several year duration of mission. Astronauts will have to undergo a rigorous regimen of exercise and other countermeasures to deal with weightlessness (zero gravity). Alternatively, artificial gravity with a rotating structure might be required. The astronauts will also have to be protected from cosmic ray radiation and solar coronal outbursts. Some think the physiological dangers to humans are so great that human-crewed Mars missions will be impossible – but this is something that will either be overcome or learned in the series of steps in cislunar space. Robotic missions to Mars during the same time period will add to our knowledge about the dangers of the Martian environment and the requirements for measures to protect Mars from contamination by earthly organisms. This planetary protection will be necessary so long as the possibility for investigating extant or extinct Martian life exists.

A measured approach is also evident in the buildup of China's and India's space programs. Both are developing human spaceflight capabilities, but each is going about it steadily in a step-by-step approach of increasing capabilities. China's space station goal seems to be for the early 2020s.

Russia still maintains lunar and Mars goals for human spaceflight, but their funding barely keeps their rocket program going. They have not conducted even a robotic mission to any solar system destination since reaching the orbit of Mars in the 1980s. Their only human-crewed missions since their space stations, Salyut and MIR, have been to the International Space Station. Europe and Japan have elected to have no independent human spaceflight capability but to support and participate in international efforts.

Almost all space missions can be accomplished at lower cost robotically. There are special cases when human piloting is necessary or at least more valuable. In the past these have included landing a spacecraft in a dangerous terrain or in selecting a particular navigation route or site to explore on the Moon. But even those tasks are increasingly capable of automation by artificial intelligence in the spacecraft computer system. Space applications like communications and remote sensing are totally robotic. Future applications, possibly even including bases on the Moon and mining of asteroids, will also be likely robotic, perhaps with an occasional human crew short-duration visit. Robotic missions, without the difficult requirements of crew safety and life support, are far less expensive and demanding. A human-rated spacecraft system would be much heavier (and more expensive to launch) and demand many more redundant and high reliability spacecraft components than its purely robotic counterpoint.

But as we noted above, human-crewed spaceflight will not just continue; it will grow – with more earthly participants and with greater achievements away from Earth. It is a symbol of national prowess – important to both developed and developing nations. It also helps to develop a desired indigenous technical infrastructure for countries to pursue their other space ambitions in education, science, communications, remote sensing, commercial development, and technology. This is the reason that the United States, Russia, Europe, and Japan will maintain the human-crewed programs and China, India, and other industrialized nations will develop theirs even in the face of other national priorities. Beyond the tangible political importance lies the popular appeal of space exploration and the vision of extending the human presence beyond Earth, perhaps to even becoming a multi-planet species. Human-crewed spaceflight continues to excite the imagination with both adventure and discovery, inherent in the Journey to Mars.

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