

Making Humans Multiplanetary, Rapidly and Sustainably

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Mars has captured imaginations for millennia as part of legends and science fiction, and more recently as a destination for scientific exploration and a possible place for people to call home. As one of our closest planetary neighbours, it provides a hospitable, albeit cold, planetary surface, a gravity 38% that of Earth, a rotational period similar to Earth's, and most importantly resources which can enable self-sustaining cities on the surface.

Through decades of robotic exploration, we have gained significant insight into the planetary history, resources, and surface conditions of Mars. And it is with that knowledge that there has been a renewed impetus for the human exploration of Mars. In 1964 Mariner 4 was the first planetary probe to fly by Mars and return more detailed images of the surface. While the planet was not covered by irrigation canals, as had been rumoured in the late 1800s, many of the features of plains, volcanoes, outflow channels, and valley networks were readily mapped to features familiar from Earth and the familiarity incited further fascination.

Through the years, additional spacecraft both in orbit around Mars and to its surface, as well as Earth-based observations, laboratory studies, and modeling, have provided increasing understanding of Mars and its processes. This understanding is an exciting start to the insights that Mars can provide on the early history of Earth and the Solar System, and a captivating new frontier for humans to become multiplanetary: for people to live, to be challenged, and to form an outpost for humanity.

With a human presence in space for the past 58 years, we have gained significant knowledge into what is required to keep people alive and productive for prolonged periods of time in this hostile environment: from people's adaptation to microgravity to the rockets required to transport them and the habitats for them to live in. Nonetheless, a human mission to Mars stretches our technical and planning abilities. A new class of affordable rockets, landers, habitats, and robotics need to be designed for what will be a long journey.

With the goal of making humans multiplanetary through the habitation of Mars, SpaceX is developing the Starship spacecraft and Super Heavy booster. A key aspect of making human missions to Mars possible is the combined capability of delivering large payloads and doing it affordably. Starship Super Heavy is being designed to those specific requirements. The key enabling technologies are full reusability of both stages to 10s and 100s of flights, in-space propellant transfer, large payload capability, and vertical landing on a variety of planetary surfaces. The full and rapid reusability of both stages will reduce the price of the launches significantly. Propellant transfer is key in the architecture, as it allows for very large payloads to be carried to planetary destinations such as Mars and the Moon. Starship Super Heavy will be able to deliver over 100 tonnes to Earth orbit; through propellant transfer, the entire 100+ tonne payload can be delivered to Mars or the Moon. The ability to land propulsively and vertically enables the payload delivery to unprepared surfaces on our neighbouring planetary bodies. The first test vehicle is currently being built, with test flights planned for the first half of this year. This will be followed by testing of the orbital Starship (2nd stage) and Super Heavy (1st

stage) through the range of relevant flight conditions. While Starship Super Heavy is being designed as a very capable vehicle for planetary exploration, it is also a very capable vehicle for cis-Earth missions. This capability in return allows for the accelerated testing and accumulation of flight heritage of its systems while delivering useful payloads to Earth orbit and the Moon.

While transportation is a necessary and key component of humans to Mars, people living on Mars requires a much larger set of capabilities to support them. One of the key qualities that makes Mars a desirable planetary body to live on is that it has key resources, such as water ice, a carbon dioxide atmosphere, and a verity of surface minerals. The need to use these resources, such as acquiring subsurface ice and atmospheric carbon dioxide to make propellants, highlights one of these key additional capabilities: acquiring (mining) resources and processing them in an extreme environment with a lengthy supply chain for spare and new parts. As in our life on Earth, all aspects of life on Mars will require power: from running the life support systems, to transportation on the surface and how to acquire and process resources. The infrastructure to generate power will have a high payload mass and human effort cost, and thus becoming extremely energy efficient will be key in allowing for growth of the outpost. The prolonged duration of the missions also requires keeping people healthy for extended periods without the sizeable infrastructure of hospitals. This will require using the latest innovations for remote medicine and miniaturized equipment. And as with any growing venture, people's time will be at a premium and the use of robotics and especially "smart robotics" enabled by machine learning will be important for the fast development of the outpost.

For humans to really be considered multiplanetary requires for Martian residents to be able to live self-sufficiently – to be okay if the ships from Earth stop coming. This requires an additional level of sophistication. Local resources will need to be used not only for propellants, but also new construction and repairs: building habitats from regolith, extracting metals to be used in additive manufacturing, making plastics out of the carbon dioxide atmosphere.

Mars has fascinated us for centuries, having been the focus of legends and of detailed space agency human exploration plans. With the decreasing price of launches and their improving reliability, the significant understanding of human physiology, and the expanding appreciation for how to utilize local resources, we are on the cusp of sending people to Mars in the next decade. Starship Super Heavy will enable that journey through its large payload capability while also being affordable. And the significant advances in many areas of human life, from efficient electric transportation to innovative medical techniques, will enable people to live there for prolonged periods of time and truly make humans a multiplanetary species.