Space Launch in 50 Years: Abundance at Last?

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Space travel is the next necessary step in human evolution. Ensuring that humans can live on multiple planets and be out among the stars, exploring the universe, is both key to human survival and a magnificent source of inspiration.

But current single-use rockets make getting to orbit prohibitively expensive, and the maximum transportable payload becomes vanishingly small with increasing distance. In the next 50 years, fully reusable rockets that can be refueled in space will remove these constraints, accelerating the space economy and making space travel accessible to a large sector of the population.

With launch abundance, entirely new classes of space missions will become possible, including colonization of the Moon and eventually Mars. These colonies will provide waypoints for humans to explore deep space, at first for science and industry and eventually for leisure. Learning how to live and work for long periods in space will lead to the exciting possibility of reaching other habitable planets. Perhaps one day humans will even make contact with other lifeforms that share the vast galaxy that we are just beginning to explore.

Reducing the Costs of Space Travel

Since the US Space Shuttle program's last mission in 2011, China and Russia had been the only countries carrying humans to low Earth orbit

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(LEO) and back. But this year the United States once again became capable of human space transportation under the NASA commercial crew program.

Yet getting to orbit, let alone beyond, is still extraordinarily expensive. A seat for a single person to fly to LEO on a Soyuz rocket costs more than $80 million (NASA IG 2016). The Space Launch System, NASA's newest rocket intended for spaceflight beyond LEO, is projected to cost between $876 million and $2 billion per launch (NASA IG 2019; Vought 2019).

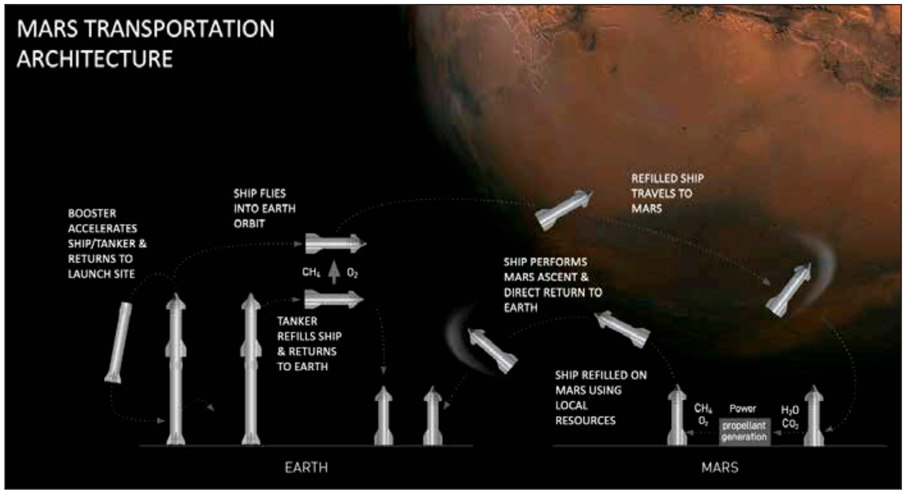

FIGURE 1 Example of in-space refueling, in situ propellant generation on Mars, and controlled landing of upper and booster stages to send unprecedented payloads to and from Mars. Source: SpaceX.

From Expendability to Reuse

One of the primary reasons for the staggering cost of space travel is that these rockets are expendable. The entire skyscraper-sized rocket is discarded after a single flight, and only the tiny capsule at the top of the stack survives launch to go on to complete a mission. Imagine what air travel would be like if the aircraft were thrown away after each flight! If it were possible to land, refuel, and refly rockets just like airplanes, the cost of the launch could theoretically be as low as the propellant cost—a 200X reduction.

In the past 5 years, spaceflight companies have spurred a renewed interest in reusable launchers. Virgin Galactic and Blue Origin are developing reusable suborbital launchers that reach the edge of the atmosphere, providing a few minutes of weightlessness. In 2015 SpaceX achieved the world's first landing of an orbital-class rocket, Falcon 9. The company has also achieved landing and reuse of the payload fairing. With over 50 successful landings, as well as 35 booster and 6 fairing reflights, SpaceX has made reuse a normal part of its business, significantly reducing the cost of spaceflight for its customers.

Breakthroughs Needed

Reusability is not enough. Space vehicles must achieve aircraft-like operations with costs approaching the lower bound of just the propellant. Five breakthroughs are needed:

1. Propulsive, precision landing of the booster stage (already demonstrated with Falcon)
2. High-performance engines that run on methane and oxygen, which can be relatively easily generated (compared to fossil fuel–based propellants) on planetary bodies (such as Mars) with the right elements (carbon, hydrogen, and oxygen)
3. In-space refueling, to "reset the rocket equation" and dramatically increase the payload that can be sent to distant planets
4. Controlled entry and propulsive landing of the upper stage, whether on a planet with a thick atmosphere (Earth), no atmosphere (the Moon), or something in between (Mars)
5. Sufficient payload volume to carry cargo and crew for long-haul flights.

SpaceX is creating a vehicle, Starship, to meet all five criteria. It will be 100 percent reusable with a payload compartment 8 m across and 17 m high, more than double that of current rockets. It will lift 100 metric tons to LEO, the surface of Mars, or Jupiter, dwarfing the capacity of today's most powerful (expendable) rockets.

Beyond Launch Scarcity

Completely reusable rockets will create a world of launch abundance rather than launch scarcity, which has been top of mind for anyone seeking to explore outer space. When every kilogram in orbit costs an astronomical sum, and when the maximum transportable payload plummets with distance, it is no surprise that spacecraft designers have been obsessed with minimizing mass and volume. Efforts to shrink payload necessarily contribute to the high cost of space missions, whose budgets exceed initial estimates as much as tenfold (Billings 2010; GAO 2019).

Relaxing or removing the constraints of launch scarcity could radically reduce mission costs:

- Exotic, ultralightweight materials can be avoided, instead using common metals such as steel.
- Off-the-shelf components can be used more readily without size and mass constraints.
- Complex or structurally intricate designs such as folding mechanisms will no longer be needed.
- Cheaper, riskier space missions can be tolerated with a reduced financial barrier to entry.

Further Options

Vehicles that meet the above criteria will make possible entirely new classes of space missions:

- Larger space telescopes that see farther with greater resolution, enabling new observations of exoplanets and the beginnings of this universe; stationing such telescopes in higher-energy orbits further improves observations by removing Earth's brightness (Gaskin et al. 2019; Mennesson et al. 2016; NASA 2019)
- Missions that travel directly to the outer planets, reducing the travel time by years compared to complex trajectories that require gravity assists from planets (Lam et al. 2015)
- Huge constellations of cheap Earth-orbiting satellites (Gristey et al. 2017)
- Long-haul transportation that leverages spaceship technology to allow the standard business or pleasure traveler to touch space en route to their earthbound destination
- Development of permanent human bases on the Moon or Mars.

The last of these is the ultimate goal: the establishment of a self-sustaining civilization off Earth. This monumental undertaking will be possible only in a future of launch abundance—which will become reality in the next 50 years.

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