ACCELERON AEROSPACE JOURNAL (AAJ)
E-ISSN: 2583-9942 (Online) | Accessible at www.acceleron.org.in

Volume 5, Issue 6, (pp.1638-1642)
Article ID: AAJ.11.2106-2569
Case Study
https://doi.org/10.61359/11.2106-2569

Short Commentary: Human Exploration of Mars: Concepts, Missions, and Technological Evolution (1960–2025)

Sreedhar M *

Independent Researcher, India.

Abstract: Human exploration of Mars has long been a central objective of planetary science and aerospace engineering. Since the early space age, researchers and space agencies have proposed numerous mission architectures, technologies, and strategies aimed at enabling crewed missions to the Red Planet. Over the past six decades, advancements in propulsion systems, spacecraft design, robotics, and planetary science have significantly improved the feasibility of human Mars exploration. This article reviews the conceptual and technological evolution of human Mars exploration from 1960 to 2025. It examines early mission proposals, robotic exploration efforts, technological constraints, habitat concepts, transportation systems, and lessons learned from past missions. The study highlights the critical engineering challenges associated with long-duration space travel, planetary environments, and mission reliability. It also discusses emerging concepts such as in-situ resource utilization, underground habitats, and integrated interplanetary transportation systems. By synthesizing developments over several decades, this article provides a broad perspective on the progress and remaining challenges in achieving sustainable human exploration of Mars.

Table of Contents

1. Introduction

Mars has fascinated scientists and engineers for centuries as one of the most promising destinations for human exploration beyond Earth. Its relatively proximity, geological diversity, and evidence of past water activity make it a prime candidate for future human missions. Since the beginning of the space age in the late 1950s, space agencies and researchers have studied various mission architectures aimed at transporting humans safely to Mars and enabling long-term exploration of its surface. The concept of human Mars exploration involves multiple complex systems, including launch vehicles, interplanetary spacecraft, life-support systems, radiation shielding technologies, planetary landing systems, and surface habitats. Unlike missions to low Earth orbit or the Moon, Mars missions require astronauts to travel millions of kilometers through deep space and remain away from Earth for extended periods. As a result, mission planners must consider not only engineering constraints but also human physiological and psychological factors. Over time, numerous technological developments and robotic missions have contributed to a better understanding of the Martian environment and the feasibility of human exploration. This article reviews major conceptual and technological developments in human Mars exploration between 1960 and 2025.

2. Early Concepts of Human Mars Missions (1960–1980)

The earliest detailed concepts for human missions to Mars emerged during the 1960s, shortly after the beginning of the space race. Engineers and scientists envisioned large spacecraft assembled in

*Independent Researcher, India. **Corresponding Author:** sreedhar_m@gmail.com.
Article History: Received: 10-Dec-2025 || Revised: 20-Dec-2025 || Accepted: 30-Dec-2025 || Published Online: 30-Dec-2025.

Earth orbit and powered by chemical or nuclear propulsion systems. These early mission concepts often involved multiple launches, orbital assembly, and long-duration interplanetary trajectories. Several mission architectures proposed during this period included nuclear thermal propulsion systems capable of reducing travel time between Earth and Mars. Concepts such as Mars flyby missions were also studied, where astronauts would travel around Mars without landing on the surface. Although these proposals demonstrated the theoretical feasibility of human Mars exploration, technological limitations and budget constraints prevented their immediate implementation. During the same period, robotic exploration began providing valuable data about Mars. Early spacecraft missions helped scientists better understand the Martian atmosphere, surface conditions, and gravitational environment, all of which are critical factors in planning future human missions.

3. Robotic Exploration and Scientific Discoveries (1980–2010)

Robotic missions played a crucial role in shaping modern plans for human Mars exploration. Orbiters, landers, and rovers provided detailed information about the planet’s geology, atmosphere, and climate. Scientific observations confirmed that Mars once possessed liquid water on its surface and may have had conditions suitable for microbial life. The discovery of water ice in polar regions and beneath the Martian surface increased the scientific interest in Mars as a potential destination for human exploration. Robotic missions also helped test technologies essential for future human missions, including entry, descent, and landing systems, autonomous navigation, and long-duration surface operations. These missions significantly improved the understanding of environmental hazards such as dust storms, temperature variations, and radiation exposure.

4. Key Technological Challenges in Human Mars Exploration

Human missions to Mars face numerous technical challenges that must be addressed before such missions become feasible.

4.1 Interplanetary Transportation

Transporting humans safely between Earth and Mars requires spacecraft capable of sustaining long-duration missions in deep space. Travel time typically ranges from six to nine months using conventional propulsion systems. Researchers have explored various propulsion technologies, including chemical propulsion, nuclear thermal propulsion, and electric propulsion systems. Reducing travel time is critical for minimizing astronaut exposure to cosmic radiation and microgravity. Advanced propulsion systems could significantly improve mission efficiency and safety.

4.2 Radiation Protection

One of the most serious hazards in deep-space travel is exposure to cosmic radiation and solar particle events. Unlike Earth, Mars lacks a strong magnetic field capable of shielding astronauts from radiation. Spacecraft and habitats must therefore incorporate effective radiation protection strategies. Proposed solutions include water shielding, hydrogen-rich materials, and underground habitats that use Martian soil as natural radiation protection.

4.3 Life Support Systems

Long-duration missions require reliable life-support systems capable of recycling air, water, and waste materials. Closed-loop environmental control systems are essential for maintaining sustainable living conditions during interplanetary travel and surface operations. These systems must operate autonomously for extended periods with minimal maintenance.

4.4 Entry, Descent, and Landing

Landing large spacecraft on Mars presents significant engineering challenges. The thin Martian atmosphere makes it difficult to rely solely on parachutes for deceleration, while the planet’s gravity still requires substantial propulsion during landing. Researchers are investigating advanced technologies

Volume 5, Issue 6, pp (1639-1642)
E-ISSN- 2583-9942
https://dx.doi.org/10.61359/11.2106-2569

such as supersonic retropropulsion and inflatable aerodynamic decelerators to enable safe landing of large payloads.

5. Habitat Concepts for Human Settlement

Long-term human presence on Mars will require robust habitats capable of protecting astronauts from the harsh Martian environment. One promising approach involves constructing subsurface or underground habitats. These structures could provide natural protection from radiation, temperature fluctuations, and micrometeoroids. Martian regolith may also be used as shielding material. Another important concept is in-situ resource utilization (ISRU), which involves producing essential resources directly on Mars. Technologies under development aim to extract water from ice deposits and convert carbon dioxide from the Martian atmosphere into oxygen and fuel. ISRU could significantly reduce the amount of material that must be transported from Earth.

6. Mission Architecture and Transportation Systems

Mission architecture studies aim to determine how different components of a Mars mission can be integrated into a cohesive system. These architectures typically include multiple spacecraft elements such as cargo vehicles, crew transport systems, and surface infrastructure. One common strategy involves launching cargo missions ahead of the crewed mission. These cargo spacecrafts deliver habitat modules, power systems, and scientific equipment to Mars before astronauts arrive. This approach reduces mission risk and ensures that necessary infrastructure is available upon arrival. Some proposed architectures also involve orbital stations around Mars or staging points in cis-lunar space, which could serve as logistical hubs for deep-space missions.

7. Lessons from Mars Mission Failures

Historically, a significant proportion of missions to Mars have experienced partial or complete failure. These failures have occurred due to various technical issues, including propulsion system malfunctions, navigation errors, and communication failures. Analyzing these failures provides valuable insights into improving mission reliability. Engineering redundancy, improved software validation, and rigorous testing procedures are essential for minimizing mission risks. Understanding past failures is particularly important for human missions, where the consequences of system failures could be catastrophic.

8. Emerging Strategies for Future Mars Missions (2010–2025)

In recent years, renewed interest in Mars exploration has led to the development of new mission concepts and technologies. Both governmental space agencies and private aerospace companies are actively exploring strategies for sending humans to Mars.

- Current research focuses on several key areas:
- Development of heavy lift launch vehicles
- Reusable spacecraft systems
- Advanced propulsion technologies
- Autonomous robotic construction systems
- Long-duration life-support technologies

These advancements may significantly improve the feasibility of human missions to Mars within the coming decades.

9. Conclusion

Human exploration of Mars represents one of the most challenging and inspiring endeavors in the history of space exploration. Over the past six decades, scientific discoveries and technological innovations have gradually transformed the concept of human Mars missions from speculative ideas into realistic engineering objectives. Robotic exploration has provided crucial knowledge about the Martian environment, while advances in propulsion systems, life-support technologies, and habitat design have improved the feasibility of long-duration missions. Despite these developments, significant challenges remain, particularly in areas such as radiation protection, transportation efficiency, and sustainable surface operations. Continued research and international collaboration will play a critical role in overcoming these challenges. As technological capabilities continue to evolve, the prospect of humans setting foot on Mars may move from theoretical possibility to practical reality, marking a major milestone in humanity's expansion into the solar system.

10. References

[1] Hoffman, S. J. (1997). *Human exploration of Mars: the reference mission of the NASA Mars exploration study team* (Vol. 6107). National Aeronautics and Space Administration, Lyndon B. Johnson Space Center.

[2] Biswal M, M. K., Kumar, R., Basanta Das, N., & A, S. (2022). A Review on Human Interplanetary Exploration Challenges. In *AIAA SCITECH 2022 Forum* (p. 2585).

[3] Lindemann, R. A., Bickler, D. B., Harrington, B. D., Ortiz, G. M., & Voothees, C. J. (2006). Mars exploration rover mobility development. *IEEE Robotics & Automation Magazine*, *13*(2), 19-26.

[4] Biswal M, M. K., Ayyappan, S., Thomas, A., Kumar V, R., & Das, N. B. (2021). A baseline strategy for human mars exploration. In *ASCEND 2021* (p. 4238).

[5] Biswal M, M. K., & Annavarapu, R. N. (2021). Human Mars exploration and expedition challenges. In *AIAA Scitech 2021 Forum* (p. 0628).

[6] Simonsen, L. C., Wilson, J. W., Kim, M. H., & Cucinotta, F. A. (2000). Radiation exposure for human Mars exploration. *Health physics*, *79*(5), 515-525.

[7] Biswal M, M. K., Das, N. B., & Kumar V, R. (2021). Biological Risks and its Implications for Crewed Interplanetary Missions. In *ASCEND 2021* (p. 4133).

[8] Biswal M, M. K., & Ramesh Kumar, V. (2025). Integrated Human-Crewed Mission Architecture for Multiplanetary Exploration of Mars and Ceres. *LPI Contributions*, *3090*, 2101.

[9] Hubbard, G. S., Naderi, F. M., & Garvin, J. B. (2002). Following the water, the new program for Mars exploration. *Acta Astronautica*, *51*(1-9), 337-350.

[10] Biswal M, M. K., & Kumar V, R. (2021). Power Options for Human Mars Mission. In *AIAA Propulsion and Energy 2021 Forum* (p. 3260).

[11] Biswal M, M. K. (2025, March). Nuclear-Powered Propulsion Systems for Multiplanetary and Deep Space Exploration. In *Lunar and Planetary Science Conference (LPSC) 2025* (p. 2368).

[12] Biswal M, M. K., Basanta Das, N., & Kumar, R. (2022). Conceptual Design of Lunar Underground Habitation System for Advanced Human Civilization on Moon. In *AIAA SCITECH 2022 Forum* (p. 2004).

[13] Biswal M, M. K., Basanta Das, N., & Annavarapu, R. N. (2021). Orbital and Planetary Challenges for Human Mars Exploration. *arXiv e-prints*, arXiv-2101.

[14] Biswal M, M. K., A, D., & Kumar, R. (2022). Conceptual Design of Mars Underground Habitation System for Human Settlement on Mars. In *AIAA SCITECH 2022 Forum* (p. 0720).

[15] Bharti, N. P. S., & Alexander, M. A. M. (2024). Prospective Celestial Destinations: A Comprehensive Review for Human Exploration. *Acceleron Aerospace Journal*, *2*(3), 209-225.

[16] Biswal M, M. K., & Annavarapu, R. N. (2021). Conceptual Design of Mars Octastrut Lander for Large Scale Mass Landing. In *AIAA AVIATION 2021 FORUM* (p. 2787).

[17] Biswal M, M. K. (2025, March). Advancing The Lunar Gateway for Multiplanetary Missions to Mars and Ceres. In *Published in the Conference Proceedings of Lunar and Planetary Science Conference (LPSC) 2025* (p. 2235).

[18] Biswal M, M. K., & Bheemavarapu, R. (2025, March). Conceptual Design of a Multiplanetary Mission Architecture for Human Exploration of Mars and Ceres. In *Lunar and Planetary Science Conference (LPSC) 2025* (p. 2429).

[19] Biswal M, M. K. (2025, March). Nuclear-Powered Propulsion Systems for Multiplanetary and Deep Space Exploration. In *Lunar and Planetary Science Conference (LPSC) 2025* (p. 2368).

11. Conflict of Interest

The author declares no competing conflict of interest.

12. Funding

No funding was issued for this research.