Mission architecting, technology development, and operations strategies for long-term human and robotic missions to Mars—Lessons learned from the NASA Mars Exploration Program

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***Abstract*— The NASA Mars Exploration Program (MEP) has decades of experience in operating robotic systems—orbiters, landers, rovers, and aerial vehicles—at Mars. Some of this experience is applicable to potential future human missions, especially when those missions involve collaborative efforts between the human explorers and robotic systems. This paper describes key lessons-learned in the areas of mission architecting, technology development, and operations strategies for applications in long-term human and robotic missions to Mars.**

***Index Terms*—mission architecting, technology development, operations, Mars, robotics, rover, lander, orbiter**

Figure 1: Human- rover cooperation at Mars (Credit: NASA)

I. Introduction

NASA has been sending robotic missions to Mars since the 1970's. The two Mars Viking orbiter/lander missions in 1976 cemented NASA's legacy in long-duration orbital and landed missions at the Red Planet. After mixed success over the next two decades, NASA restructured its Mars Exploration Program (MEP) in the early 2000's to take a more integrated approach to Mars mission architecting, technology development, spacecraft development, and mission operations.

This new approach by NASA resulted in the last two decades of successful Mars orbiter, lander, rover, and helicopter missions--many of which are still in operation. The lessons learned from these missions (some expensively) may be applicable to future long-duration missions to Mars, both robotic and human.

II. Mars Exploration Program Approach

The NASA Mars Exploration Program strategic approach [1] is for a long-term enterprise of integrated missions, which offers some significant advantages over a series of independent missions such as those executed under the NASA Discovery and New Frontiers programs. Because there is a regular cadence and succession of Mars missions, it is possible to utilize elements of earlier missions to contribute to later missions. These contributions can come in the form of collecting technical data in the unique Mars environment (atmosphere, gravity, temperature, radiation) to influence the design of future missions, or demonstrating new technologies before committing them to a high-stakes flight mission, or utilizing orbital assets to serve as members of a communication relay network for surface assets (landers and rovers).

As NASA begins to formalize its approach to potential human missions to Mars (including high-performance robotic systems that may operate independently or in support of those human missions), some of the MEP's strategic approaches may also be applicable. Furthermore, while there is little or no overlap for human life support applications, the approaches and architectures developed for Mars robotic mission power, communications networking, and entry, descent and landing are potentially relevant.

The unique attributes of the Mars orbit, environment, and access to other applicable assets (e.g., for comm relay) will play major roles in mission design for long-term human and robotic missions. As an example, Earth-Sun-Mars conjunctions will result in communication dropouts for several weeks per year. These periodic communication dropouts will need to be factored into operations planning to ensure crew safety and robotic system operations efficiency.

Another example is the Earth-Mars communication time delay, which can be several minutes in length depending on the relative positions of the two planets in their respective orbits around the Sun. Command and control strategies developed for ISS and Lunar applications may become untenable. These considerations are well-appreciated by the mission operators in the Mars Exploration Program, and can be integrated with other considerations for human missions (i.e., life support, abort scenarios, critical system

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redundancy) when transitioning from Lunar to Martian applications.

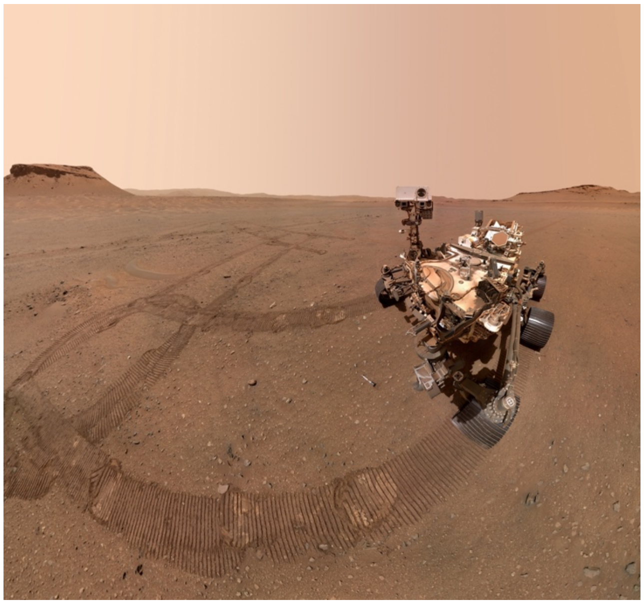

Figure 2: NASA Perseverance rover at Three Forks site, depositing sample tubes for potential Earth return (Credit: NASA/JPL-Caltech/MSSS)

III. Conclusion

The spectacular successes (and, occasionally, painful failures) of NASA's robotic Mars exploration missions represent a deep reservoir of knowledge than will undoubtedly benefit future long-term human and robotic Mars missions.

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References

[1] https://mars.nasa.gov/files/mep/Mars_Exploration_Program_Future_Plan.pdf