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Author: Dr. George Lordos
Massachusetts Institute of Technology (MIT), United States

Prof. Jeffrey Hoffman
Massachusetts Institute of Technology (MIT), United States
Dr. Olivier de Weck
Massachusetts Institute of Technology (MIT), United States

MODELING ROBUST MARS SURFACE ARCHITECTURES OVER A BROAD RANGE OF MISSION SCALES

Abstract

NASA and its international and commercial partners are returning to the Moon, with a human mission to Mars following in the late 2030's. Orbital mechanics dictate that once a crew departs for Mars, they will be on their own, potentially for two years or more. From the 1960's until the present day, all Mars exploration architecture concepts studied by NASA have been constrained to between 4 and 6 crew, because of a widespread perception that crew size directly drives costs, and because low volumes and the use of single-use rockets leads to a vicious circle of spiraling high costs. However, the advent of reusable rockets, including but not limited to Falcon 9, Starship and New Glenn, motivates the rigorous, quantitative study of significantly larger human missions to Mars so as to compare small and large missions side-by-side in terms of total cost, crew safety, science return, national posture and the potential for international and commercial participation. In this work, we describe how to generate and compare Mars architectures over a broad range of mission scales, from 4 to 60 crew. We start by deriving a family of robustly scalable architectures, and model its elements, cost and performance as a function of crew size, number of nearby sites and surface endurance. New metrics include the Robustness Composite Indicator, which measures the presence of 15 known vulnerabilities, and the Lifecycle Cost per Non-Logistics Full-Time Equivalent person on Mars per year, which is a proxy for the true economic cost of fielding a scientist on Mars. Major findings are that a NASA-led, long-endurance, dual-site mission to Mars with 30 to 40 crew is significantly more robust than a 4-person, 1-month mission, has two orders of magnitude more potential for science return, and costs about the same in average annual costs to NASA ($1B / yr over 28 years), after accounting for extensive international participation in the larger mission where each Artemis Accords member nation or commercial entity funds its crew on a "subscription cost" basis. The work is relevant to decision-makers planning technology development and international collaboration to support human missions to Mars. Specifically, it shows that technology roadmaps and plans for future international collaboration aligning with significantly larger human missions to Mars should be put in place starting now, to support the Mars missions of tomorrow that will follow after the first mission to the Red Planet.