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RELIABILITY ANALYSIS OF MULTI-LAUNCH SAMPLE RETURN MISSIONS USING THE SPACE MISSION ARCHITECTURE AND RISK ANALYSIS TOOL (SMART)

Abstract

Over the past decade, international space agencies displayed a growing interest in sample return missions (SRM). SRM concepts exhibit many advantages compared to exploring geophysical characteristics of the Moon, Mars and asteroids remotely by rovers. For instance, scientific instruments installed on spacecraft are generally accompanied by higher masses and development costs than similar instruments on Earth. Furthermore, communication delay makes prolonged operations costly and inefficient.

The design of SRM concepts, however, proves to have their own sets of challenges. Due to the complexity and long mission durations, multi-launch mission architectures have been proposed – in which each mission fulfills its own objectives and contributes to the overall mission success. This leads to variations in possible launch sequences and operation strategies of consisting missions, resulting in an extensive trade space. Evaluation of these architectures and assessment of the driving factors for mission success is revealed to be difficult in early design stages.

In the context of these system engineering challenges, a multi-launch mission scenario for potential sample return from Mars was investigated with the Space Mission Architecture and Risk Analysis Tool (SMART). SMART is a modeling interface which employs Disjunctive Normal Form and Monte-Carlo simulations for risk assessment of robotic and human spaceflight missions. In this model, relations within the mission concept are established via Boolean parameters. Spacecraft are modeled as assets with decaying reliability as mission duration increases. Permutations of the mission architecture are compared to a baseline architecture.

The results indicate Entry, Descent, and Landing Systems, Power Subsystems, and Sample Accessibility to be a few of the driving factors for the sample return scenario. Overall mission success can be improved by one of two methods: selection of a specific mission architecture, and technological maturation of the driving factors. Both aspects are significant for mission design since a mission architecture with a high comparative reliability, but a high sensitivity to a subsystem, can still be prone to failure. Providing relaunch options is one approach to enhance system robustness to such failures while increasing overall mission success. Furthermore, launch sequence plays a critical role not only for mission success, but also influences the magnitude and order of the driving factors. The findings agree well with the overall understanding of the mission concept and demonstrate SMART's capabilities to provide a first comparative analysis of complex multi-launch mission architecture in early mission design stages.