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A SEMI-STOCHASTIC, NUMERIC SIMULATION TOOL IN MODEL BASED SYSTEMS ENGINEERING FOR TUMBLEWEED ROVERS

Abstract

Scientific exploration of the Martian surface via a wind-driven, low-cost swarm of rovers involves a systematic design of mission-level, as well as system- and subsystem-level concepts. Risks associated with design are addressed through multiple demonstrator missions. However, the complexity and entanglement of mission- and system-level design parameters introduce cross-discipline complexities preventing demonstrator missions to be fully realized. Further, the semi-stochastic nature of the wind-driven rover creates high uncertainty in several key mission-level performance figures as well as system-level challenges which are absent in legacy missions to Mars. Finally, the historical lack of comprehensive model-based systems engineering for wind-driven spheroid rovers, makes this a unique systems challenge.

The aforementioned reasons lead to large uncertainty in early-stage mission planning as well as in the deviation of the system and subsystem-level worst-case scenarios relevant to the sizing of spacecraft subsystems and difficulty in the establishment of mass and power budgets given the lack of heritage. Furthermore, there is no research available on specific methods to estimate the mission-level performance of Tumbleweed Missions employing system-level semi-stochastic motion. Lastly, no specific methods for sizing important subsystems of a Tumbleweed Rover and for defining the operation of the mission are available.

To this end, we present an implementation of the mission in an MBSE environment using the Arcadia method, addressing performance and trajectory modeling to enable the development of guidance laws, as well as modeling of the mission on an operational, logical, and physical level to support the derivation of subsystem specifications. We show the necessity of digital, model-based systems engineering as an enabler to low-cost, swarm-based deep space missions. We also present a Monte Carlo-based performance modeling tool consisting of a 3-DOF physics model of the Tumbleweed Rover that uses system parameters, topology data, wind, and environment models. We then integrated this tool into legacy MBSE methods and tools.

As a result, we show that improvements to the early-stage design methodology of swarm missions with high levels of system-level uncertainty are relevant not only to Mars but to a host of network missions based on low-cost individual spacecraft.