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MINIMAL-HEATING THERMAL MANAGEMENT DESIGN FOR LOW-MASS, POWER-CONSTRAINED TUMBLEWEED MOBILE IMPACTORS ON MARS

Abstract

As we look to explore deep space, the development of cost-effective and low-mass solutions is becoming increasingly important. One example is the Tumbleweed mission, a low-cost Mars surface mission generating novel datasets by a wind-propelled circularly symmetrical surface exploration spacecraft swarm. However, such rovers present unique challenges, particularly in terms of thermal management due to stringent mass and energy constraints, and a high surface-to-volume ratio due to diminutive size. Miniaturized Mars surface spacecraft, such as the Tumbleweed Rover, are therefore severely energy-limited in their operation, as the majority of the available energy must be used for maintaining the internal temperature within acceptable limits. As a result, the challenge is creating a thermal management system that meets the mass and power restrictions of the Tumbleweed Rover and protects the electronic systems from Martian thermal conditions.

We examine different design options to actively and passively manage the temperature and protect the interior of a container by reusing emitted heat, as well as insulating and rejecting heat while optimizing for minimal system mass and energy consumption, which are essential for the Tumbleweed Rover. The findings are critical for exploring diverse terrains in extremely cold conditions while keeping the structure lightweight and energy-efficient, in addition to providing a protective environment for all electronics and instrumentation.

In order to determine the most suitable design, we simulate the pod's thermal properties using single-node and multi-node methods. We adjust the on-times of electronic and electrical components of the rover, the conductivity of the electronics box, and the placement of electronics components to minimize the energy required to maintain internal temperature. Furthermore, we propose a selection of insulation methods and materials, as well as operational concepts to meet the applied restrictions on system mass and energy consumption. We show novel ways to conduct a waste heat minimized active thermal management by power operation management of electronic parts, heat transfer within the electronics box and the optimal configuration of the electronic subsystems to be closely related to the operational thermal environment of the respective subsystems.

The proposed thermal management can be used across the board in space missions to minimize energy budgets required for thermal management, especially deep space missions using miniaturized spacecraft.