21st IAA SYMPOSIUM ON BUILDING BLOCKS FOR FUTURE SPACE EXPLORATION AND DEVELOPMENT (D3)
Systems and Infrastructures to Implement Sustainable Space Development and Settlement - Systems (2A)

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HIGH-DRAG UNI-DIRECTIONAL AERODYNAMIC DESIGN OF LOW-COST WIND-DRIVEN MOBILE IMPACTORS ON MARS

Abstract

Conventional Mars missions, their costs, and timelines are strongly driven by the landing and locomotion systems. To simplify conventional mission architectures and enable accessible Mars science, the Tumbleweed Mission, a low-cost Mars surface mission using a swarm of wind-driven, circularly symmetric mobile impactors employs purely passive, aerodynamic means of landing and locomotion. This enables the mission to generate planetary-scale and long-term datasets on Mars. Furthermore, it uniquely integrates the locomotion and landing functions into a single system.

As a result, the performance of the mission is strongly dependent on the aerodynamic properties of the Tumbleweed Rover both during the landing phase to sufficiently decrease terminal velocity and during locomotion. Limited developments have been done exclusively on such drag devices, especially for a circularly symmetrical, as opposed to spherical, design, meaning that the design and analysis of Martian drag-producing systems are yet to be explored.

In this paper, we discuss the development of a sail-like drag system that is attached to the structure of the impactor and provides locomotion to the rover. This system must be optimized to provide sufficient drag for a safe landing on Mars, and drag must be maximized within system constraints to maximize locomotion performance. We provide an aerodynamic configuration for a Tumbleweed Rover that is optimized for a circularly symmetrical rover structure that includes, as a core innovation, a non-rotating inner structure to which the drag devices are affixed.

Throughout the research, several types of sail configurations are considered in order to maximize drag. These configurations are analyzed using preliminary and computational fluid dynamics methods. To resolve the highly turbulent flow conditions, several different turbulence models, such as standard k-Epsilon and k-Omega SST, were used. The solutions of these simulations are used to improve and iterate the sail design to maximize drag for locomotion and landing. Subsequently, the results are validated with wind tunnel test data. Lastly, the aerodynamic design is proved in a field test of a subscale prototype.

We show that the drag performance of a wind-driven mobile impactor can be improved by more than 30% compared to legacy designs if the design is optimized for a single flow direction, and additional drag

devices enable the auto-orientation of the rover towards this orientation. Finally, we show compliance with the same aerodynamic configuration with terminal velocity requirements to enable landing.