SCIENCE OBJECTIVES OF THE TUMBLEWEED MISSION - SWARM-BASED, WIND-DRIVEN ROVER MARS EXPLORATION.

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Introduction: Thorough characterization of Mars requires global surface observations, which are currently achieved by large, infrequent, risky and relatively high-cost space missions that gather localized, detailed data. However, limited resources on Earth inevitably suggest that a significant reduction of cost, risk and schedule is needed to reach the ultimate Mars exploration goal of establishing a habitat on the red planet in the coming decades.

Most recently these issues have been addressed by the proposed mission architecture of a swarm of autonomous, wind-driven, solar-powered mobile impactors (rove

rs) that are built to provide large scale surface observations over long periods of time [1]. The Tumbleweed Mission concept has been already explored by a team at the NASA Langley Research Center [2], and it is currently being developed by Team Tumbleweed (www.teamtumbleweed.eu).

We discuss the scientific objectives of the mission and its required instrumentation.

Mission Design: The mission consists of 90 large, spheroidal mobile impactors (Figure 1), that unfold following mid-air deployment and land on the surface close to one of the poles (Figure 2, points 3-6). From there, the rovers spread across the Martian surface propelled by strong wind towards the equator for approximately 90 sols, until a desired distribution is achieved, and are then stopped for an undefined period (Fig. 2, pt. 7-10).

Scientific data is collected during both the rolling and stationary phases, allowing different types of measurements. The 5-meter diameter rovers can host up to 5 kg of scientific payload each, as well as provide electrical power, data processing, and location determination in-situ.

Science Objectives: The scientific opportunities presented by the Tumbleweed Rovers contribute to NASA's Mars Exploration Program Analysis Group (MEPAG) goals [4] in an unprecedented way. A wide range of previous and current Mars missions, varying from orbiters and landers to rovers and aerial vehicles, have collected indispensable data about the red planet. However, none of them have been able to provide a detailed surface-measurements based global picture of Mars, which is the overarching goal of the Tumbleweed Mission. It is further split into primary and opportunistic/secondary objectives.

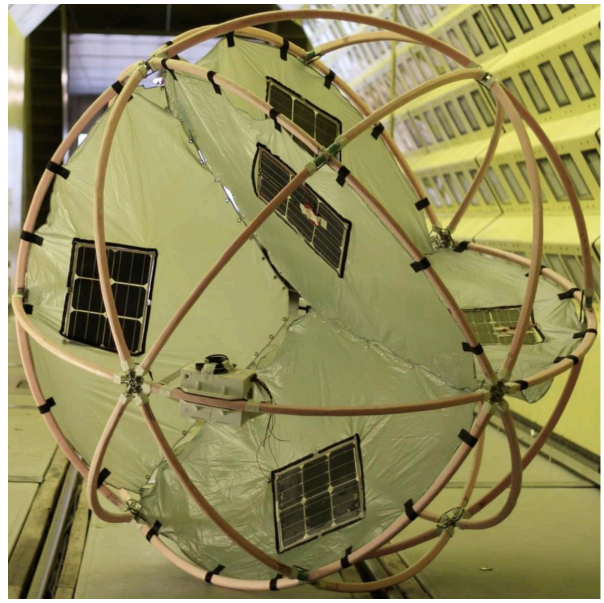

Figure 1. The Tumbleweed Rover prototype V3, tested in Negev Desert in 2021 [3].

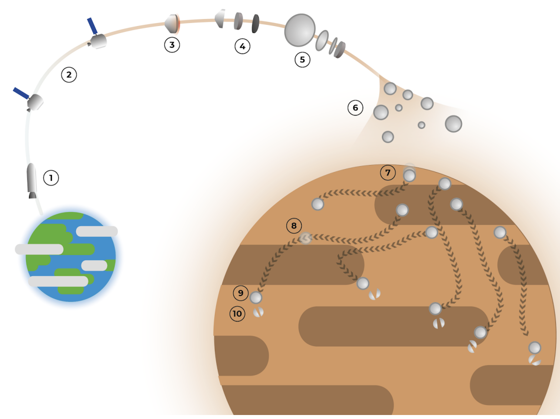

Figure 2. A visualization of the mission architecture, showing landing, rolling and deployment stages of the wind-driven rovers.

Objective A): Martian Climate and Atmospheric Sciences. Following MEPAG Goal II (Understand the processes and history of climate on Mars), the mission will be able to provide imaging of transient Mars weather phenomena, characterize the visible and near-visible light radiation environment on the Martian surface, improving constraints to computational models and overall understanding of Martian climate and weather. Wind and dust cycles', as well as atmospheric chemical properties' observation capabilities are still under consideration.

After completing the rolling phase, the rovers would serve as weather stations, providing weather data from up to 90 surface points of Mars until their decommission.

Objective B): Interior Geophysics. The second science objective corresponds to MEPAG Goal III (Understand the origin and evolution of Mars as a geological system). The Tumbleweed Mission enables novel network science, which would be one of the biggest novelties in Martian interior studies yet. The autonomous rovers will also be able to reach previously inaccessible areas, such as the Tharsis region and, potentially, the north and south poles. The primary application of the large network setup is to constrain Mars mantle properties through continuous measurements of nutation, precession, tidal deformation, gravimetry, etc. of Mars.

Objective C): Surface Geology. As the previous objective, surface geology is covered by MEPAG Goal III, with the mission focusing on the landform modification processes on Mars. The surface imaging and spectroscopy from multiple locations allows to determine the regolith composition and study the terrain to a great detail.

Secondary Objectives: Enabling Human Exploration and Searching for (Signatures of) Life on Mars. The opportunistic objectives of the mission are connected to MEPAG Goals I (Determine if Mars ever supported life) and IV (Prepare for human exploration). They include investigating mantle plume strength through direct measurements of surface deformation, search for structures associated with life in surface or subsurface environments, identifying the geologic evidence for the location, volume, and timing of ancient water reservoirs, among others. The results from the primary objectives contribute as well, with one of the most important being that the surface-measurements from up to 90 places on Mars can be used to map future landing sites.

Scientific Payload: The Tumbleweed Rovers will mostly employ legacy instruments, however, some modifications are expected due to the system's power requirements, limitations of the rover shell, and the predicted rolling behavior. Currently, a combination of a radio beacon and laser retroreflector (In-situ MArs Geodetic Instrument NEtwork – IMAGINE [5]) is being adapted for the rover. While the exact instrumentation is currently under investigation, it is worth mentioning the preliminary list, which consists of (but is not limited to):

1. Camera - to be used for (near-) visible spectrum imaging.
2. Thermometer, barometer, sensors for humidity, wind and solar irradiance - to be used to model the near-surface atmosphere.
3. Spectrometer - to be used for atmospheric and chemical properties and surface parameters.
4. Radiobeacon - to be used in interior structure observations.
5. Laser retroreflector - to be primarily used for location determination, however, it will also serve as part of the IMAGINE instrument and will be critical in surface mapping of the potential landing sites.

Apart from validation of critical rover mechanisms, the next stage of the development also includes testing the proposed instrumentation in Mars analogous environments.

Summary: By providing wide and long scale data sets using rover swarms, the Tumbleweed Mission offers the opportunity to make deep space more accessible to all. The associated science objectives, once reached, will fill some of the crucial gaps in the current knowledge of Mars required to enable human exploration on the red planet. It does so by providing atmospheric data over various spatial and temporal scales, investigating surface geology, and more.

The presentation will briefly explain the mission concept, review the most desirable science applications, and discuss the instrument recommendations and main limitations.

References: [1] Rothenbuchner, J. et al. (2022) *73rd IAC,* Abstract #IAC-22,A3,IP,x72458. [2] Antol, J. and Hajos, G. A. (2012) *LPSC,* Abstract #4142. [3] Groemer, G. et al. (2022) *Austrian Space Forum, AMADEE-20 Mission Report.* [4] Banfield, D. et al. (2002) *Mars Science Goals, Objectives, Investigations, and Priorities: 2020 Version.* [5] Rothenbuchner, J. et al. (2022) *73rd IAC,* Abstract #IAC-22,A3,IPB,35,x72466.