

The NASA Langley Mars Tumbleweed Rover Prototype

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The Mars Tumbleweed is a concept for an autonomous rover that would achieve mobility through use of the natural winds on Mars. The wind-blown nature of this vehicle make it an ideal platform for conducting random surveys of the surface, scouting for signs of past or present life as well as examining the potential habitability of sites for future human exploration. NASA Langley Research Center (LaRC) has been studying the dynamics, aerodynamics, and mission concepts of Tumbleweed rovers and has recently developed a prototype Mars Tumbleweed Rover for demonstrating mission concepts and science measurement techniques. This paper will provide an overview of the prototype design, instrumentation to be accommodated, preliminary test results, and plans for future development and testing of the vehicle.

I. Introduction

The surface of Mars is swept by winds averaging 2-5 meters/sec (m/s), with periodic gusting of 10-20 m/s and seasonal dust storms exceeding 25 m/s. Dr. Jacques Blamont of the National Center for Space Studies in France first discussed the use of these winds for rover mobility in the 1970s. His ideas evolved into the University of Arizona Mars Ball concept, a prototype rover using sequenced inflation and deflation of air bags to aid mobility and steer.¹ Recently, the NASA Langley Research Center (LaRC),² the Jet Propulsion Laboratory (JPL),³ Texas Tech University (TTU),⁴ and North Carolina State University (NCSU)⁵ have developed concepts for the “Tumbleweed” rover, a wind-driven vehicle that could travel great distances across varied Martian terrain, using only the Martian wind for mobility. LaRC, NCSU and TTU are studying concepts for deployable open-structure vehicles similar to kites, while JPL has developed an inflatable “beach ball” concept based on the Mars airbag landing spheres. To date, only a small portion of the Martian surface has been explored in-situ, thus the Tumbleweed provides a capability to explore scientifically interesting sites across large regions, many of which are currently inaccessible to conventional wheeled rovers. Tumbleweeds would be lightweight and relatively inexpensive, allowing multiple rovers to be deployed in a single mission to particular areas of interest and would complement other exploration missions by serving as scouts – locating areas of interest for detailed follow-on investigations by rovers, landers, or perhaps human explorers. The wind-blown character of the Tumbleweed make it an ideal platform for conducting random surveys; scouting for signs of past or present life as well as examining the potential habitability of sites for future human exploration. The Tumbleweed rovers would be several meters (m) in diameter and no larger than tens of kilograms (kg) in order to operate in the low density Martian atmosphere. To test the feasibility of the Tumbleweed concept, LaRC has developed a prototype rover for use in field tests and demonstrations. The following sections provide an overview of the prototype design, the associated construction techniques, the electronics (data system, telemetry, and sensors), and discusses plans for future development and testing.

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II. NASA LaRC Tumbleweed Concepts and Mission Scenarios

NASA LaRC has developed several notional concepts of “deployable open-structure” Tumbleweeds, for the purpose of providing a durable wind-driven vehicle with superior aerodynamic properties and open access to the Martian environment for scientific payloads. The three primary concepts (Box Kite, Dandelion and Tumble-cup) are depicted in Figure 1.² The “Box Kite” concept employs orthogonal circular hoops with fabric sails, similar in construction to some tents and automobile sunshades. Additional hoops without sails may also be included to improve the rolling characteristics of the Box kite concept. The “Dandelion” uses a spherically symmetric array of struts/legs with pads/feet at the ends to prevent sinking into soft surfaces. A variation of this concept, the “Eggbeater Dandelion,” was developed with multiple curved struts/legs resembling eggbeaters or whisks. Similar to the Dandelion, the “Tumble-cup” concept provides a spherically symmetric array; however, rather than struts/legs, open-ended cones or cylinders are used for maximizing aerodynamic surface area and thus increasing the drag force.

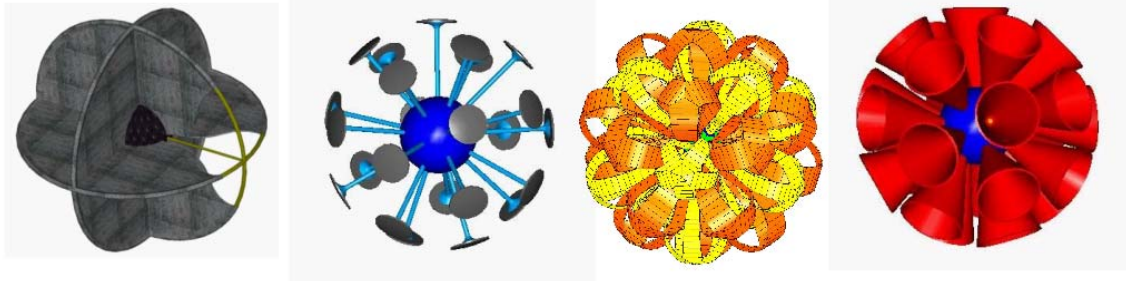


Figure 1. NASA LaRC Deployable Open-Structure Tumbleweed Concepts, from left to right: Box Kite, Dandelion, Eggbeater Dandelion, and Tumble-Cup

Candidate mission scenarios have been defined and assessed for the Tumbleweed rover concept, envisaged as an ideal platform for conducting random, in-situ surveys of the Martian surface, capable of scouting broad areas over long distances. The survey/scouting capability would fill a niche between the global surveys currently conducted using remote sensing, orbiting satellites and the highly localized, in-situ surveys conducted by conventional landers and rovers, thus developing a Mars regional survey capability. Two primary mission concepts have been explored:

1. Precursor survey of candidate landing sites for human explorers
2. Exploration of areas currently inaccessible by conventional rovers

The selection of safe landing sites on Mars for human explorers will be critical to the success of NASA’s Vision for Space Exploration. Tumbleweed rovers deployed at candidate landing sites could search for hazards (identifying potentially toxic substances, measuring radiation levels, examining the electrostatic properties of the soil, etc.) as well as identify interesting regions for human exploration, locations that may provide valuable resources such as water or contain signs of past or present life. Regional measurements for a Mars human precursor mission may include: characterizing the particulate environment, characterizing the structure of the atmosphere, finding and characterizing accessible water, and measuring the ionizing radiation environment.⁶

Many scientifically interesting sites on Mars are currently inaccessible by conventional landers and rovers. One example is the gully features discovered on numerous Martian crater walls, valleys, pits, and graben and the potential association of these features with liquid water.⁷ These gully features are of primary interest for conducting in-situ investigations because of the current strategy of “follow the water” in the search for life on Mars. Specific measurements of interest adjacent to and within gully features include: water detection, subsurface sounding for aquifers, soil composition, and gas detection / identification.⁸

III. LaRC Tumbleweed Prototype

NASA LaRC has studied the dynamics⁹ and aerodynamics¹⁰ of the notional Tumbleweed concepts and initiated development of a prototype for conducting field tests to assess the vehicle design, as well as demonstrate mission concepts and science measurement techniques. Based on the preliminary results of LaRC’s analyses, the Box Kite concept was selected for prototype development because of its high drag properties, simple design, ease of construction, and open structure for instrument access. The LaRC Box Kite prototype (Figure 2) also leveraged

knowledge gained from development of the Tumbleweed Earth Demonstrator (TED), a Box Kite prototype developed in collaboration with the NCSU undergraduate Aerospace Design class in 2002-03.^{11, 12}



Figure 2. LaRC Baseline Tumbleweed Prototype

The LaRC Box Kite Tumbleweed prototype is constructed using 3-foot length sections of 1/8-inch diameter titanium wire (6Al 4V ELI), joined by polycarbonate connectors (Figure 3) to form hoops. The LaRC Stereolithography Laboratory developed the connectors using fused deposition modeling (FDM) technology from Stratasys, Inc. Several connector configurations were developed, including 4-way and 8-way “plug-in” as well as 6-way and 4-way “snap-on.” The sails are fastened to the orthogonal hoops with Velcro™ and are made from 1.5 oz/yd rip-stop nylon sail material. Additional hoops were added between the sail quadrants to aid rolling.

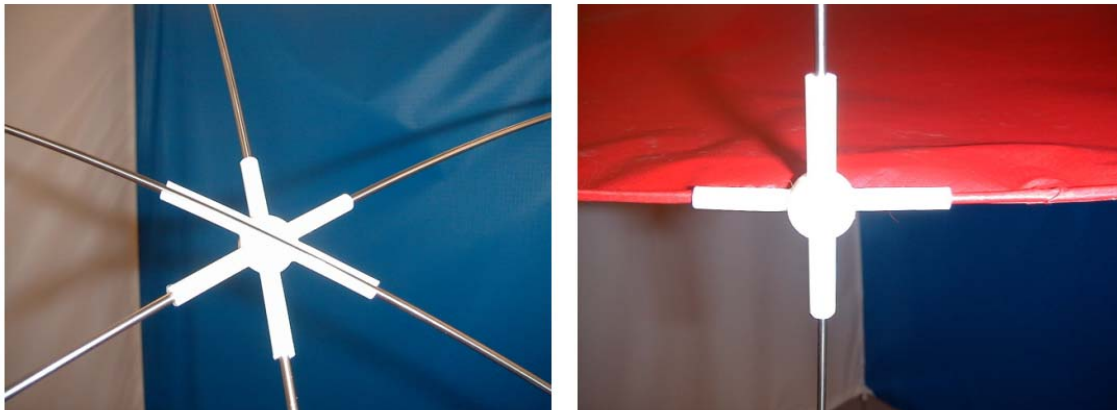


Figure 3. Polycarbonate (Lexan™) connecting nodes

The instrument/payload core, which is located in the center of the vehicle, is a duplicate of the NCSU TED stereolithography core created by Fineline Prototyping, Inc. of Raleigh, NC (Figure 4). Use of the same core as the NCSU TED allows for future collaboration and exchange of instrumentation between the two vehicles. The 10-inch diameter core provides protection for the data/telemetry system as well as select sensors and is attached to the sails by Velcro™. Two removable hatches provide access to the core interior where the data/telemetry system (including power) and sensors are located. The thermocouples, pressure sensors and the Global Positioning System (GPS) antenna protrude through the core to access the exterior environment.



Figure 4. Instrument / payload core¹³

The data/telemetry system is a commercial off-the-shelf (COTS) kit designed for unmanned aerial vehicles (UAVs), the Radio Controlled Aircraft Telemetry System (RCATS™) (Figure 5). The RCATS™ provides a 20MHz micro-controller based data system with 11 channels of input, powered by a 3-cell, 12V Lithium Ion battery. A 900MHz (100mW) frequency hopping, spread spectrum transmitter provides a range of 5+ miles (line-of-site).¹⁴

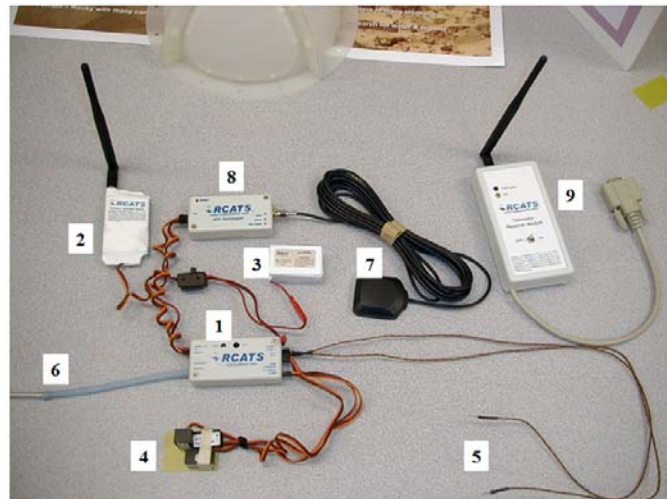


Figure 5. RCATS™ - (1) data system, (2) transmitter, (3) lithium-ion battery, (4) accelerometers, (5) thermocouples, (6) pressure sensor, (7) GPS antenna, (8) GPS data logger, and (9) ground station receiver

The sensor suite of the Tumbleweed prototype, which demonstrates fundamental measurement capabilities and provides engineering data on the vehicle, includes several COTS sensors from the RCATS™: three (3) accelerometers, two (2) thermocouples for temperature measurements, pressure and temperature sensors built-in to the data system, and a Trimble™ GPS antenna (Table 1).

Table 1. RCAT™ Sensor Specifications¹⁴

Measurement	Specification	Resolution
Temperature (Thermocouples, K-type)	32 to 1875 °F	0.5 °F
Temperature (Ambient)	-102 to 302 deg F	0.5 °F
Acceleration	Up to +/- 25 G	~1/16 G
Altitude (barometric pressure)	0 to 30,000ft	~8 ft

The total weight of the prototype, including the structure, sails, sensors, and payload core is 10.5 lbs, measured using a Zebco Deliar 228 fish scale.

Preliminary field-testing of the Tumbleweed prototype was conducted at the NASA LaRC in May 2005 (Figure 6). The data/telemetry system performed as expected and acceleration, temperature, pressure and position information were transmitted to the RCATS™ receiver and downloaded to a PC Notebook computer, where it was viewed in real-time using the RCATS™ ground station software. Wind speed measurements indicate that the vehicle achieved motion in 3 – 4 mile per hour winds, despite the “soft” structure that resulted in a larger footprint and hence more rolling resistance than anticipated. Additional, extensive field-testing is planned for Summer 2006 in cooperation with NCSU students who have developed a second generation TED.



Figure 6. LaRC Tumbleweed Prototype Field Testing

IV. Next Generation Tumbleweed Prototype

An advanced Tumbleweed prototype is proposed that would include a packagable and deployable structure, solar power generation (for battery charging) and the LaRC developed Micro Flight Computer (MicroFC) data/telemetry system. Additional sensors, to conduct sample measurements like those discussed in the mission concepts of Section II, would also be incorporated into the next generation prototype, and could include a wheel electrometer (derived from the Mars Environmental Capability Assessment (MECA) electrometer) to measure the electrostatic properties of soil, an x-ray fluorescence (XRF) spectrometer to examine soil composition, a tunable diode laser (TDL) for water vapor detection, and a wideband electromagnetic sensor for subsurface surveys. Sensors such as the wheel electrometers would be located on the connecting nodes of the Box Kite hoops (Figure 7). This prototype will be used to demonstrate the measurement capabilities of the Tumbleweed at Mars analog sites on the Earth.

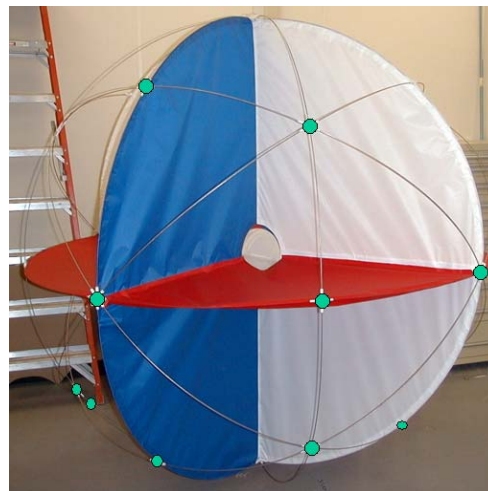


Figure 7. Potential sensor locations on the "nodes" of the LaRC Box Kite Tumbleweed prototype

V. Summary

The Tumbleweed rover concept is an ideal platform for conducting random, in-situ surveys of the Martian surface, scouting broad areas over long distances, and filling a “regional” niche between the global measurements of remote sensing orbiting platforms and localized, in-situ measurements of landers and rovers. A baseline prototype Box Kite Tumbleweed was developed at NASA LaRC for assessing the concept and demonstrating measurement techniques. Preliminary field tests were conducted with acceleration, pressure, temperature, and position measurements acquired. Additional tests are planned for varied terrain and conditions. A next generation prototype with an advanced sensor suite is proposed for demonstrating measurement capabilities at Mars analog sites.

Acknowledgments

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