Tumbleweed: Wind-propelled Measurements for Mars. K.R. Kuhlman[1], A. Behar[2], J. Jones[2], M. Coleman[2], P. Boston[3], C.P. McKay[4], L.J. Rothschild[4], M.G. Buehler[5], D. Northup[6], D.S. Choi[7], Planetary Science Institute, Suite 106, 1700 E Fort Lowell, Tucson, AZ 85719, kim@psi.edu. [2]Jet Propulsion Laboratory, [3]New Mexico Institute of Technology, [6]NASA Ames Research Center, [7]Decagon Devices, Inc., [8]University of New Mexico, [9]University of Idaho.

Introduction: Tumbleweeds are wind-propelled, long-range, autonomous vehicles based on well-developed airbag technology (Figure 1), which could survey Mars for variations in habitability using the Mars exploration paradigm, "Follow the Water" or to survey for in-situ resources (ISRU) [1]." Tumbleweed seeks to expand our ability to obtain ground truth from large areas of an environment to determine the nature and distribution of habitable environments. Tumbleweed fills an important niche between *in-situ* rover-based measurements and measurements from orbit. The sampling strategy is not random. Rather, it is downwind. The trajectory of the vehicles can be modeled given documented wind patterns and topography. Inexpensive and numerous, such units could cost-effectively provide data across an extremely broad area unavailable by other strategies.

Inflatable Tumbleweeds. In 2000, Jack Jones of NASA JPL was testing a three-wheeled inflatable rover in a windy sand dune area in California's Mojave Desert when one of the wheels broke off and took off over the sand dunes, while Jones' crew chased the ball with a dune buggy [2]. The renegade 1.5 m diameter ball was able to climb steep slopes, over large boulders, and through the jagged brush without hesitation. This seemingly unlucky incident produced the inspiration for the current Tumbleweed vehicle [3]. JPL then went on to measure performance of a 1.5 m sphere in the Mojave Desert [2], which was confirmed by theoretical analyses performed by the University of Southern California [4]. The inflatable Tumbleweed has since successfully been tested in Greenland in 2003 and in Antarctica in 2004 (**Error! Reference source not found.**). The latest version of the rover was deployed in Greenland in May 2004, where it autonomously traveled more than 200 km across an ice sheet during a 4-day period. Communicating via the Iridium satellite network, the vehicle successfully and reliably relayed live GPS, temperature, and pressure data to a ground station at JPL.

Habitability: Soil and atmospheric moisture, biologically relevant gases and other elements of interest can be mapped using relatively simple instruments onboard multiple Tumbleweeds during transects of the deployment site. The instruments currently proposed for use on Tumbleweeds are either relatively mature instruments that have been developed through NASA funding or are modifications of available commercial handheld instruments. Many other instruments are currently under development for *in situ* extraterrestrial applications using minimal power and mass through various NASA programs and the commercial market-place. We anticipate that within a few years, these more sensitive instruments will be readily deployable on Tumbleweeds. Such instruments include gas chromatograph mass spectrometers (GC-MS), quantum cascade tunable diode laser (QC-TDL) gas sensors and ground-penetrating radar (GPR).

The inflatable Tumbleweeds have been tested by NASA JPL in Greenland and Antarctica carrying a complete central internally suspended payload consisting of batteries, inflation/deflation pumps, communications, and a winch. The winch can be used to pull on one or more of the central payload tension lines while the ball deflates. This will create a "turtle" shape and allow the ball to stop, forming a volume underneath that can be used to collect gases emanating from the soil that might indicate hidden subsurface reserviors of gas (Figure 2). This chamber is very conducive to the collection of gases because its volume to basal area ratio can be very small, providing more rapid feedback to the concentration gradient that drives molecular diffusion across the surface [5].

In-situ Resource Utilization: A suite of instrumentation can be envisioned for a fleet of Tumbleweeds for deployment on Mars for *in situ* resource surveys. An example instrument suite would include surface mounted soil moisture sensors (SMSMS), ground penetrating radar to characterize subsurface layering, aquifers and voids, sensors for a variety of useful gases, a miniature X-ray fluorescence spectrometer for elemental analysis of martian regolith and a multispectral imaging system for characterizing grain size and shape distributions as well as surface mineral composition. Other suites of instruments could be envisioned based upon the requirements of specific survey scenarios. More detailed descriptions of these possible instruments can be found in Kuhlman, et al, 2010 [1].

Conclusion: Tumbleweeds will be particularly useful for long-range surveys for habitable environments or in-situ resources that require intensive, global geological exploration suggested by Taylor, 2001: sedimentary deposits, hydrothermal deposits, and differentiated igneous provinces. Taylor (2001) suggests that these global searches for resources be started early in the process in order to attract capital for martian investment [6]. Fleets of low-cost Tumbleweeds could play an integral role in such reconnaissance.

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Figure 1. NASA JPL Tumbleweed test deployment in Antarctica in 2004. Image courtesy Alberto Behar, NASA JPL.

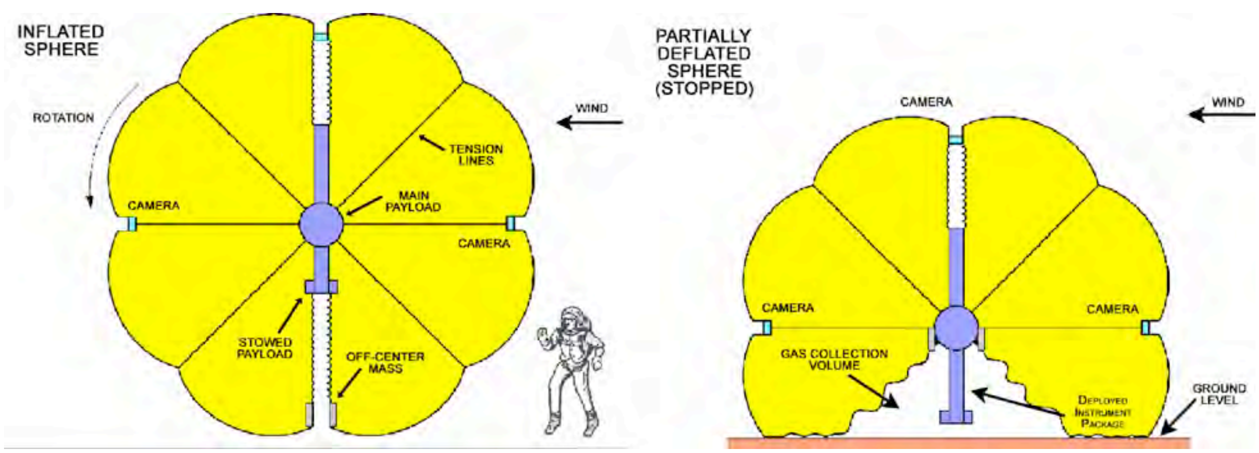

Figure 2. An inflatable Tumbleweed can be stopped by partially deflating the ball and pulling on one of the central payload tension cords to create the “Turtle mode.” This mode of stopping also creates a collection chamber for gas measurements [2].