DUAL-USE BALLUTE-BASED ROBUST AEROCAPTURE, EDL, AND SURFACE EXPLORATION ARCHITECTURE FOR MARS.

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Introduction: The over-arching goals of the exploration of Mars as outlined by Mars Exploration Program Analysis Group (MEPAG) are the assessment of life, climate, geology; and prepare for human missions [1]. However, prohibitive propellant requirements have traditionally inhibited mission duration, science payloads mass, and therefore mission goals. Of the five landed robotic systems on the surface, the landed masses had been less than 0.6 tons. Mars Science Laboratory will attempt to increase the landed-mass capability to 0.8t and improving the 3-σ landing accuracy to 20 km [2]. Advanced goals for Mars exploration mission will require increasing (> 2 tons) landed-mass capability (more science payloads), and human exploration of Mars will require 40-80t of exploration assets delivered within close proximity of pre-positioned robotic elements. Massive payloads will require innovative and game-changing Aerocapture, Entry, Descent, and Landing (AEDL) approaches. MEPAG have identified several crucial technical capabilities for successful long-term exploration of Mars [1]. Some of these are (1) global accessibility of Martian surface, (2) access to subsurface, (3) access to time varying phenomena, etc.

Motivation: Several innovative, game-changing AEDL and surface exploration concepts have been proposed in the last decade (see NIAC proposals [3]). For the hypersonic, supersonic, subsonic, and terminal descent regimes, we have technologies such as Hyper- and Supersonic Inflatable Aerodynamics Decelerators, Supersonic Retro-Propulsion, and the Skycrane Terminal Descent system. And for orbital, aerial, surface, and subsurface exploration, we have a plethora of instrument concepts: orbiters, rovers, landers, airplanes, airships, blimps, sondes, balloons, microbots, and subsurface explorers.

While the benefits of aerocapture as compared to direct aeroentry are relatively minor for lightweight robotic missions to Mars, aerocapture followed by EDL will be crucial for any human exploration of Mars [4].

Dual-Use Ballute AEDL Concept for Distributed Exploration of Mars: The objective of this concept is to develop a Mars exploration mission architecture by combining the advantages of Inflatable Aerodynamic Decelerators (IADs), and the benefits of a network of miniature space-based, aerial, surface, and subsurface exploration elements. Ballute aerocapture using IADs combines the benefits of non-propulsive capture with the advantages of high altitude capture, thereby reducing heat rates as compared to the case of traditional aeroshells (which have high ballistic coefficients).

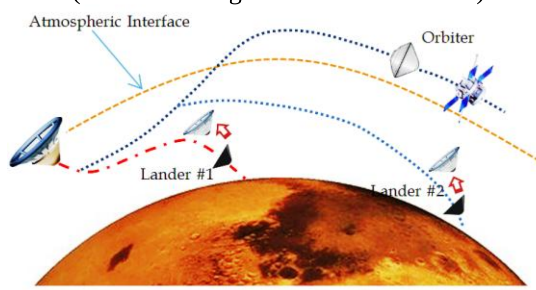

Fig. 1: Dual-use ballute aerocapture concept. It is a combination of two elements (either both landers; or one lander and an orbiter). The IAD decelerates in the atmosphere. Element 2 jettisons and either land (lander #2) or exit the atmosphere (orbiter). The main system further descends with lander #1.

There are two main systems in this architecture.

The Entry Flight System: One or two large attached ballute design IADs [5], one or two landers, and an orbiter.

The Exploration Elements: The exploration elements are a subset of the Entry Flight System, and are passive during the AEDL regime. These elements become active once the AEDL process ends. Some of the possible candidates of this set are: rovers, airplanes, airships, blimps, aerostats, sondes, balloons, microbots [6], and subsurface explorers.

Possible AEDL and Martian Surface Exploration Operations:

1. The spacecraft approaches the planetary body on a hyperbolic trajectory, deploying the ballute before entering the atmosphere. Inside the atmosphere, the ballute decelerates at a rapidly increasing rate.
2. At the point of desired velocity change, the second element is released, so that:
    a. If it is an orbiter, it exits the atmosphere, propulsively raise the periapsis, achieve the target orbit (see Fig. 1).
    b. If it is an another lander (#2), the descent trajectory is designed to land at a location with smaller or longer down-range (see Fig. 1).

3. In addition the first ballute descends with another lander (#1) onto the surface, thereby providing dual-function. (Fig. 1)
4. As the large surface lander decelerates at high altitude and after sufficient deceleration, either the lifting-IAD or an inflated airship helps the lander steer closer to target location.

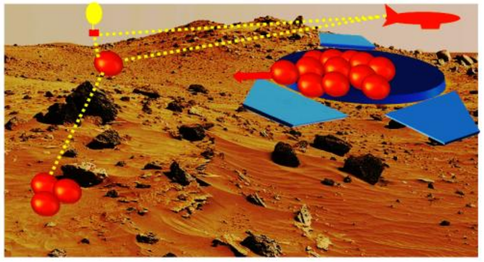

Fig. 2. Collaboratively surface operations for a Lander

For a trailing toroidal ballute configuration, with a ballistic coefficient of 5 kg/m^2, a mass of ~100 t can be delivered to the surface. Such a toroidal ballute is large with a nose radius of ~80 m [7, 8]. Consequently, the space for payloads in the system is very large.

5. Once the lander reaches the surface, various autonomous science platforms, instruments, or robots egress and start working independently or collaboratively as illustrated in Figs. 2 and 3.
6. Aerial platforms such as aerostats, balloons, airships, and blimps carry out atmospheric experiments, drop sondes, or other probes. Ultra Long Duration Balloons serve as high endurance platforms such as communication relay platforms for other geographically separated ground-based assets as shown in Figs. 2 and 3.

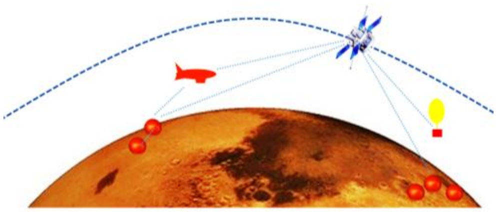

Figure 3: Collaborative exploration concept

Some of the advantages of this architecture are:

1. Increased landed-mass capability by two orders of magnitude, and increased landing accuracy by four orders of magnitude.
2. Enabling global accessibility of Mars surface from a single mission via dual-use ballute aerocapture technique—high and low latitudes, rough and smooth surfaces, low and high elevations.
3. Delivery of a wide range of exploration instruments and concepts in a single mission like orbiter, rover, aerial vehicles (airplanes, airships, blimps, balloons), sondes, microbots etc.
4. Advantages of commonality and reconfigurability will be inherent within similar exploration assets (for e.g. microbots).
5. Improve mission flexibility, robustness, and cost-effectiveness.

Thus the dual-use ballute architecture is revolutionary in the sense that with a single Earth launch, a multitude of science payloads and instruments can be delivered at different far-off locations on the surface of Mars, thus enhancing global accessibility and mission flexibility. For example, using this architecture, the Mars Exploration Rovers could have been delivered on to the surface using a single Earth launch.

Relevance of the Idea to the Scientific Goals of the Decadal Survey:

This architecture would benefit challenge area 1: *Safe and Accurate Landing Capabilities, Mars Ascent, and Innovative Exploration Approaches* in the specific areas of low cost access to the surface of Mars, Lightweight, low-cost, probes or platforms, and concepts to navigate and control entry and landing systems to improve landing accuracy.

Mars Surface System Capabilities: The exploration capabilities underlines in the concept will help to overcome some near-term of the technological roadblocks in the area of mobility on the Mars surface.

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