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The Small Mars System

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ABSTRACT

The Small Mars System is a proposed mission to Mars. Funded by the European Space Agency, the project has successfully completed Phase 0. The contractor is ALI S.c.a.r.l., and the study team includes the University of Naples "Federico II", the Astronomical Observatory of Capodimonte and the Space Studies Institute of Catalonia. The objectives of the mission are both technological and scientific, and will be achieved by delivering a small Mars lander carrying a dust particle analyser and an aerial drone. The former shall perform *in situ* measurements of the size distribution and abundance of dust particles suspended in the Martian atmosphere, whereas the latter shall demonstrate low-altitude flight in the rarefied planetary environment. The mission-enabling technology is an innovative umbrella-like heat shield, known as IRENE, developed and patented by ALI. The mission is also a technological demonstration of the shield in the upper atmosphere of Mars. The core characteristics of SMS are the low cost (120 M€) and the small size (320 kg of wet mass at launch, 110 kg at landing), features which stand out with respect to previous Mars landers. To comply with them is extremely challenging at all levels, and sets strict requirements on the choice of the materials, the sizing of payloads and subsystems, their arrangement inside the spacecraft and the launcher's selection. In this contribution, the mission and system concept and design are illustrated and discussed. Special emphasis is given to the innovative features and to the challenges faced in the development of the work.

1. Introduction

The robotic exploration of Mars has yielded a dramatic increase in knowledge about the Martian system. Since 1976, the surface probing of Mars has been carried out with a series of landers: Viking 1 and 2 [1], Mars Pathfinder [2], the two Mars Exploration Rovers [3], Phoenix [4] and Mars Science Laboratory [5]. The majority of these missions belong to NASA's Mars Exploration Program whose goals are to determine whether life ever developed on Mars, to characterize the climate, to understand the geology, and eventually to prepare for the human exploration of the planet. As a complement, NASA's Discovery Program, started in 1992, focuses planetary science investigations by launching smaller missions using fewer resources and shorter development times. The Discovery Program includes Mars Pathfinder and the geophysical Mars lander InSight planned for 2018 [6].

Establishing if life ever existed on Mars is one of the outstanding scientific questions of our time. To address this important goal, the European Space Agency (ESA) has established the ExoMars program to investigate the Martian environment and to demonstrate new technologies paving the way for a future Mars sample return mission in the 2020's. ExoMars comprises two missions: ExoMars 2016 has recently delivered the Trace Gas Orbiter [7], whereas the second mission features a rover and has a launch date in 2020 [8].

The Small Mars System (SMS) is being designed as a European technology demonstration and science mission in the category of small, low-cost landers. It was proposed by ALI S.c.a.r.l. to ESA with the aim of experimenting an innovative deployable heat shield (DHS), whose first version, known as IRENE (Italian ReEntry NacellE, [9]), is conceived for terrestrial applications, such as returning payloads from the International Space Station. The mission objectives of SMS were

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later extended to include two payloads: a dust particle analyser (DPA) and an aerial drone (AD). The DHS, developed and patented by ALI, is a modular atmospheric entry shield. Its main characteristics are the umbrella-like opening mechanism and the innovative off-the-shelf ceramic material. The DHS is lightweight, hence suitable for a low-mass spacecraft. The DPA is a scientific instrument developed at the Astronomical Observatory of Capodimonte (INAF-AOC). Heritage of previous experiments (DREAMS, [10]; MEDUSA, [11]; GIADA, [12]), the DPA measures the concentration and size distribution of the dust grains present in the atmosphere, key elements in the study of the Martian climate and in the definition of the entry-descent-landing requirements of future exploration missions, including manned ones. The AD is being designed at the University of Naples “Federico II” and aims at demonstrating low-altitude flight in the rarefied atmosphere of the red planet. During flight, an imaging camera on board the AD shall take high-resolution pictures of the surface, thus enhancing the scientific return of the mission.

In its current configuration, SMS has a wet mass just above 300 kg, 110 kg constituting the mass of the lander. The cylindrical envelope of the spacecraft has a size of 2 m (diameter) ×3 m (height). Current estimates for the total mission cost are close to 120 M€ including launch and operations. Such a low value will be made possible, on the one hand, by relying on the heritage of previous missions, by implementing recently developed technology (e.g., the DHS), and by adopting commercial-off-the-shelf (COTS) hardware and lightweight materials, and by making a strong effort in terms of design optimization, synergy among the several subsystems and efficiency in mission planning, on the other. The short duration of the operations (eleven months of interplanetary transfer plus a few days of scientific activity on the surface) and the reduced mass and volume of the spacecraft (which comply with the performance characteristics of the Vega rocket, the European launcher for small payloads) further contribute to the cost reduction. The majority of past missions of the kind were much bigger in size and mass, and more expensive, the cheapest being Mars Pathfinder worth 265 M$ and the high-end being Mars Science Laboratory (2500 M$). These missions had a much wider scientific reach and engineering dimension, though. SMS aims at proving the technical viability of a Mars lander of smaller size and the possibility of retrieving scientific data of relevance to the international community. The Phase 0 of the project, conducted between November 2015 and May 2016, has proven the feasibility of SMS. All mission design elements have been addressed and developed at an appropriate level for this preliminary phase.

Section 2 illustrates the mission concept and time frame. Section 3 describes the two payloads. Section 4 deals with the selection of the launcher, the choice of the launch date, the definition of the launch profile, the design of the interplanetary trajectory and the approach to Mars. Section 5 contains a description of the entry, descent and landing (EDL) phase. This is followed by the illustration of the design of the DHS (Section 6). The subsystems design is outlined in Section 7. Conclusions are drawn in Section 8.

2. Mission concept and time frame

SMS has the twofold objective of demonstrating the effectiveness of a deployable thermal shielding technology for planetary entry and the capability of a small, low-cost system to deliver scientific and technological payloads to Mars. The spacecraft consists of three main parts, as shown in Fig. 1 (left) illustrating the launch setup in the payload fairing of a Vega rocket: the Lander stowed inside the DHS (in retracted configuration), the cruise stage (CS) and the propulsion module (PM). The PM shall act as an additional (fifth) stage at launch. Its presence is necessary because Vega does not achieve Earth escape. The PM will separate from the spacecraft after executing the injection into interplanetary trajectory, leaving a total mass of 304 kg (including propellant). The CS shall provide telecommunications, photovoltaic power and propulsion (see Section 7) during interplanetary transfer and will be jettisoned shortly before atmospheric entry, leaving a mass of 150 kg. The Lander contains the payloads (i.e., the AD and the DPA) and the avionics and has a mass of 110 kg at touch down, resulting from the release of the DHS and the parachute.

According to the baseline mission profile, SMS shall be placed on a direct transfer from Earth to Mars and shall enter Mars atmosphere from a direct hyperbolic trajectory. Since no Mars orbit insertion is foreseen, SMS will not deliver an orbiter and shall rely on the availability of an existing one for telecommunications. Upon entering the atmosphere, an umbrella-like mechanism will unfold the shield, stowed at launch and during the interplanetary cruise (see Fig. 1 center and right). In this way, the shield occupies little space in the payload fairing, a feature which allows the adoption of a small launcher. The descent phase will exploit the DHS and a subsonic parachute to reduce speed. Soft landing will be aided by a vented airbag stowed in the nose of the capsule. Once on ground, the cover of the lander will unfold (Figs. 2 and 3) exposing the payloads and the antenna. Operations on the surface of Mars should last from a few days to a few weeks.

Thermal and safety considerations affect the choice of the landing site and the selection of launch and arrival dates. Fig. 4 shows the daily average maximum and minimum atmospheric temperatures close to the ground as functions of time (represented by the solar longitude L_s from 0° to 360° over one Martian year) and geographical latitude (from the South pole at −90° to the North pole at +90°). The strong variations (absolute minimum temperatures are close to −130 °C, whereas the maxima can reach 20 °C) are closely associated to the relatively high eccentricity (0.0934) of the orbit of Mars, which causes an appreciable variability of the solar irradiation received by the planet. The figure shows that the most favorable thermal conditions occur in winter (solar longitude between 270° and 360°) in the southern hemisphere. However, the Martian meteorological conditions are severe at this epoch because the heat transport in the atmosphere causes strong air currents and winds which raise the dust from the ground causing devils and even planetary-scale storms. Therefore, landing close to the equator (the milder region on a yearly basis) at solar longitude earlier than 180° (beginning of autumn) is desirable. These considerations have been assumed in the form of requirements on the design of the trajectory and on the selection of launch and arrival dates (see Section 4). The exact location of the landing site has not been decided yet. It will be the object of further analysis and discussion at more advanced stages of the project.

3. The payloads

SMS exploits a modular architecture consisting of two main elements: the Lander, including the payload and avionic modules, and the DHS. The payload module hosts the AD in folded configuration, preserving its integrity during the transfer and allowing for its release after landing. The avionic module contains the DPA.

3.1. The aerial drone

Several studies in the open literature suggest that the next stages of Mars exploration will take advantage from the adoption of aerial drones [13–22] since they can overcome some limitations inherent to rovers, such as the limited mobility and the difficulty to explore rough terrains or canyons. Indeed, in an ideal scenario the exploration task should be distributed among drones and surface rovers. Drones provide higher flexibility, multi-mission and sample return capability by exploiting vertical takeoff and landing, and allow for local and/or regional-scale coverage and high-resolution imaging of Mars surface. Actually, low-altitude flight and multi-mission capability, as well as the use of swarms, would allow providing high-resolution imaging and wide area coverage at the same time. In this framework, the experiment designed for SMS aims at demonstrating the feasibility of releasing and