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Conceptual study and key technology development for Mars Aeroflyby sample collection ☆

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ABSTRACT

Conceptual study of Mars Aeroflyby Sample Collection (MASC) is conducted as a part of the next Mars exploration mission currently entertained in Japan Aerospace Exploration Agency. In the mission scenario, an atmospheric entry vehicle is flown into the Martian atmosphere, collects the Martian dust particles as well as atmospheric gases during the guided hypersonic flight, exits the Martian atmosphere, and is inserted into a parking orbit from which a return system departs for the earth to deliver the dust and gas samples. In order to accomplish a controlled flight and a successful orbit insertion, aeroassist orbit transfer technologies are introduced into the guidance and control system. System analysis is conducted to assess the feasibility and to make a conceptual design, finding that the MASC system is feasible at the minimum system mass of 600 kg approximately. The aerogel, which is one of the candidates for the dust sample collector, is assessed by arcjet heating tests to examine its behavior when exposed to high-temperature gases, as well as by particle impingement tests to evaluate its dust capturing capability.

1. Introduction

Mars Exploration with Landers and Orbiters Synergy (MELOS) is currently entertained in Japan Aerospace Exploration Agency (JAXA) in collaboration with a large number of planetary science groups over Japan [1]. As its name suggests, the MELOS mission is designed as a conglomerate mission, in which orbiters, landers, rovers, and/or airplanes are used for aeronomical, meteorological, and geoscientific researches [2–7] as well as life search [8] to reveal *why Mars is now in red* – the fate of ancient water and carbon dioxide on the course of Martian history.

In the mission scenario, the landers and the orbiters are transported to Mars and initially inserted into an extended elliptic orbit altogether, then the landers are transferred into the atmospheric entry orbit by using the orbiter as the entry service module, after which the orbiters are maneuvered to their respective final orbit [1,9]. Such a mission scenario has great potential for a variety of probe vehicles incorporated into the MELOS mission. In this article, as one of the candidate subsystems for the MELOS mission, a Mars Aeroflyby Sample Collection (MASC) system using the aeroassist orbit transfer (AOT) technologies is proposed.

2. Concept of MASC

Mars sample return missions commonly entertained may require a gigantic and complex system, consisting of an atmospheric entry vehicle, a lander to collect samples

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on the ground, a launcher to take them to a Martian orbit, and a return vehicle to transport them to the earth. Meanwhile, it is widely known that small particles of several micrometers in diameter, or dust particles, in which global and averaged geological information of the Martian surface is expected to inhere, are frequently blown up from the Martian surface and kept suspended in the atmosphere up to 40 km altitudes. If such dust particles as well as Martian atmospheric gases are collected during the aeroflyby and brought to the earth, valuable geological and aeronomical information on climatic vicissitude of Mars may be obtained at reasonable cost. Such a concept was first proposed by Leshin et al. [10] as one of the candidates for the Mars Scout mission, namely the SCIM mission, based on sample return technologies of STARDUST and GENESIS.

Although the concept of Leshin et al. is essentially worthwhile, the mission plan originally proposed seems to be difficult to actualize from several engineering standpoints. To overcome such difficulties, a conceptual study and a feasibility assessment of the Mars Aeroflyby Sample Collection (MASC) are conducted in JAXA by introducing aeroassist orbit transfer technologies, as a part of MELOS mission. The basic scenario of MASC is illustrated in Fig. 1. The MASC system covered with the aeroshell equipped with the thermal protection system (TPS) is flown into the Martian atmosphere, makes a 30–40 km altitude pass through the atmosphere, and collects dust samples as well as atmospheric gases during the guided atmospheric flight. After departure from the Martian atmosphere, the MASC system cast off the aeroshell and is inserted into the parking orbit as an orbiter. During several months of trajectory modulation to minimize the ΔV required for earth return, the orbiter collects ionized gas samples in the ionosphere in addition. Finally, the orbiter with dust and gas samples departs for the earth from the parking orbit. On arriving at the earth, the orbiter ejects a reentry capsule with samples in its container into the earth atmosphere, and the reentry capsule is recovered in a capsule recovery operation on the ground.

The conglomerate interplanetary system of MELOS is currently designed to arrive at Mars with an approach velocity of 3.8 km/s at infinity, and to be inserted into the primary elliptic orbit having a 300 km periapsis altitude and a 7 R_m apoapsis altitude where R_m is the Mars average radius. In such a mission scenario, two trajectory plans may be possible for MASC:

1. The MASC system is separated from the MELOS system before the MELOS system is inserted into the primary elliptic orbit, and flown into the Martian atmosphere for sample collection directly from an interplanetary orbit.
2. The MASC system is separated from the MELOS system after the MELOS system is inserted into the primary elliptic orbit, and flown into the Martian atmosphere from the primary elliptic orbit.

To decelerate the MASC system and insert it into the parking orbit, the aerocapture technology is used in the first plan, while the AOT from the primary elliptic orbit is performed in the second plan. In the first plan, since the MASC system is flown into the Martian atmosphere directly from the interplanetary orbit, higher entry velocities are available than in the second plan. Such higher entry velocities allow the MASC system to be inserted into higher parking orbits, resulting in a smaller ΔV required for earth return from the parking orbit. Consequently, mass of the orbiter can be reduced in accordance with the propellant mass needed for Mars departure. In addition to this, higher entry velocities allow the MASC system to reach lower altitudes where dust particles having larger diameter are more available. In typical cases under consideration, the accessible lowest altitude is 31 ± 5 km in the first plan, while it is 34 ± 5 km in the second plan, depending on the entry conditions and the final orbit into which the MASC system is inserted after atmospheric flight.

On the other hand, from a mission operational standpoint, the second plan is considered to be much superior

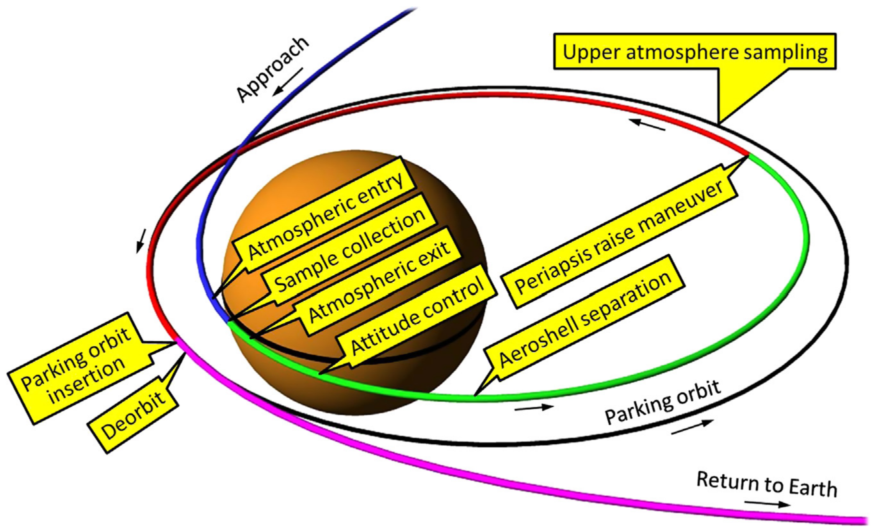

Fig. 1. Conceptual view of Mars Aeroflyby Sample Collection (MASC).