Deployment and Surface Interaction of Passive Phobos Landers

*Onur Celik[1], Ronald Louis Ballouz[2], Nicola Baresi[2], Kazunori Ogawa[3], Koji Wada[4], Yasuhiro Kawakatsu[2]

1. The Graduate University for Advanced Studies (SOKENDAI), 2. Institute of Space and Astronautical Science (ISAS/JAXA), 3. Kobe University, 4. Chiba Institute of Technology

Spacecraft missions to the Martian moons have always been considered by the scientific and engineering community as a prerequisite for future manned explorations of the Martian surface. Indeed, a dedicated mission to Phobos and Deimos could finally solve the puzzle on the moons' origin and provide a better understanding of the Martian system as a whole. Moving towards this goal, JAXA is currently planning a sample return mission that will reach the surface of Phobos for the first time in history by the end of the next decade. The mission is known as the "Martian Moon eXploration" (MMX) and is scheduled to transition over Phase B in the Japanese fiscal year 2019.

Amongst the proposed payloads of MMX, a number of Deployable CAMera 5 (DCAM5) have been envisioned as promising candidates for enhancing the scientic return of the mission and supporting the landing operations of the mothercraft. The probes consist of a 0.75 kg canister equipped with a 3-axis accelerometer, two multi-band high-resolution cameras, and four close-up cameras that will study the regolith of Phobos after landing. High-resolution images of the moon surface, as well as local gravity and regolith properties are expected to be captured during the in-situ operations.

To guarantee the success of DCAM5, many challenges need to be addressed. First, the canisters have to be deployed on a ballistic trajectory with severe attitude constraints. Second, the landers have to survive the impact with the ground, relay the scientific data back to MMX, and do not escape from the vicinity of Phobos after touchdown. For all these reasons, the current baseline scenario envisions the deployment of DCAM5 during the rehearsal or actual landing operations of MMX itself. Separation from the mothercraft occurs at an altitude of 3 km from Phobos' surface and with an injection speed within 0.2 m/s and 1 m/s. These initial conditions translate in landing speeds on the order of 10 m/s, i.e., two orders of magnitude higher than MASCOT and other similar missions. Accordingly, it is still unclear whether the proposed objectives can be accomplished without failing any of the remaining operational requirements.

This research focuses on the deployment of DCAM5 through a combination of trajectory calculations and contact dynamics simulations. Our strategy is to first calculate DCAM5's trajectory in the Phobos-Mars gravitational environment right after deployment up until the point of impact. Then, the pre-impact state of DCAM5 (speed, impact angle, and attitude) is passed to pkdgrav, a parallel N-body code, which simulates the regolith surface of Phobos using spherical particles. pkdgrav treats particle collisions through a soft-sphere discrete element method (SSDEM), allowing us to model multi-contact and frictional forces using dissipative and frictional parameters that allow us to mimic the behavior of angular and rough particles of the Martian moon. DCAM5 is modeled as a rigid body made up of a combination of simple geometric shapes in the pkdgrav environment that can interact with spherical particles through SSDEM. Finally, DCAM5's post-impact properties are output to a new trajectory calculation. This two-step process of trajectory-contact simulations is iterated until DCAM5 comes to rest, allowing us to predict its final location on the surface of Phobos depending on initial conditions and simulation parameters. During the unfolding of these trajectories, geophysical quantities of interest such as the effective coefficients of restitution of Phobos' regolith are monitored and collected in order to develop a better understanding of the surface environment. Our preliminary results show that the Phobos surface is quite dissipative, with an effective coefficient of restitution between 0.1 and 0.2 for successful DCAM5 landings. These results offer new insights into Phobos' geophysical environment and should be taken into account for the design and mission operations of MMX sampling activities.

Keywords: Phobos, contact dynamics, regolith science, astrodynamics, ballistic landing