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HIGH-FIDELITY SIMULATIONS OF BALLISTIC SMALL BODY LANDERS

Abstract

Small deployable landers are promising candidates to enhance the science return of minor body missions due to their relatively low cost, complexity, and risk of operation. These landers are generally passive and deployed on a ballistic trajectory, i.e. no trajectory control is available. Therefore, many challenges remain in the design of small body landers due to the complex dynamical environments near minor bodies as well as partial inelastic collisions with their surfaces.

In this research, we introduce a novel mission design toolbox that combines orbital and attitude simulations in realistic gravitational environments with a state-of-the-art contact dynamics analyzer known as "pkdgrav". First, deployment conditions are inserted by the user to initialize the numerical integration of ballistic landing trajectories for probes of different shapes and sizes. Then, trajectories are propagated with a high-fidelity numerical integrator that stops in the successful event of an impact with the surface of the target body. Right before the touchdown, pre-impact states and local acceleration values are input to the contact dynamics module, which accurately simulates the interaction between the lander and the surface of the minor body via a soft-sphere discrete element method. At the end of the contact dynamics simulations, pkdgrav generates realistic post-impact attitude and orbital conditions that can be reintegrated until the lander escapes from the system or reimpact with the surface. In the event of reimpact, pkdgrav is relaunched with the new initial conditions, and the process is iterated until the spacecraft comes to rest in its final landing site. Of course, the regolith properties of the asteroid, as well as the deployment conditions of the spacecraft, can be varied in order to explore the range of possible outcomes that can be expected for a given design domain. Consequently, the mission designer can derive and analyze scientific and engineering requirements for the mission based on the results of the toolbox analysis, including covariance ellipses on the final landing site and local regolith and gravity information.

The capabilities of the toolbox are demonstrated with a feasibility study of a cylindrical and rectangular landers to be deployed on the surface of Phobos. The results show that landing can be accomplished in both cases despite the high touchdown velocities imposed by the dynamics of the Martian system.