Evaluating small-body landing hazards due to blocks

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Introduction: Landed missions represent a vital stage of spacecraft exploration of planetary bodies. Landed science allows for a wide variety of measurements essential to unraveling the origin and evolution of a body that are not possible remotely, including but not limited to compositional measurements, microscopic grain characterization, and the physical properties of the regolith.

To date, two spacecraft have performed soft landings on the surface of a small body. In 2001, the Near Earth Asteroid Rendezvous (NEAR) mission performed a controlled descent and landing on (433) Eros following the completion of its mission [1]; in 2005, the Hayabusa spacecraft performed two touch-and-go maneuvers at (25143) Itokawa [2]. Both landings were preceded by rendezvous spacecraft reconnaissance, which enabled selection of a safe landing site.

Three current missions have plans to land on small bodies (Rosetta, Hayabusa 2, and OSIRIS-REx); several other mission concepts also include small-body landings. Small-body landers need to land at sites having slopes and block abundances within spacecraft design limits. Due to the small scale of the potential hazards, it can be difficult or impossible to fully characterize a landing surface before the arrival of the spacecraft at the body. Although a rendezvous mission phase can provide global reconnaissance from which a landing site can be chosen, reasonable a priori assurance that a safe landing site exists is needed to validate the design approach for the spacecraft.

Method: Many robotic spacecraft have landed safely on the Moon and Mars. Images of these landing sites, as well as more recent, extremely high-resolution orbital datasets, have enabled the comparison of orbital block observations to the smaller blocks that pose hazards to landers. Analyses of the Surveyor [3], Viking 1 and 2, Mars Pathfinder, Phoenix, Spirit, Opportunity, and Curiosity landing sites [4–8] have indicated that for a reasonable difference in size (a factor of several to ten), the size-frequency distribution of blocks can be modeled, allowing extrapolation from large block distributions to estimate small block densities. From that estimate, the probability of a lander encountering hazardous blocks can be calculated for a given lander design. Such calculations are used routinely to vet candidate sites for Mars landers [5–8].

Application to Small Bodies: To determine whether a similar approach will work for small bodies, we must determine if the large and small block populations can be linked. To do so, we analyze the comprehensive block datasets for the intermediate-sized Eros [9,10] and the small Itokawa [11,12]. Global and local block size-frequency distributions for Eros and Itokawa have power-law slopes on the order of -3 and match reasonably well between larger block sizes (from lower-resolution images) and smaller block sizes (from higher-resolution images). Although absolute block densities differ regionally on each asteroid, the slopes match reasonably well between Itokawa and Eros, with the geologic implications of this result discussed in [10].

For Eros and Itokawa, the approach of extending the size-frequency distribution from large, tens-of-meter-sized blocks down to small, tens-of-centimeter-sized blocks using a power-law fit to the large population yields reasonable estimates of small block populations. It is important to note that geologic context matters for the absolute block density — if the global counts include multiple geologic settings, they will not directly extend to local areas containing only one setting [10].

A small number of high-resolution images of Phobos are sufficient for measuring blocks. These images are concentrated in the area outside of Stickney crater, which is thought to be the source of most of the observed blocks [13]. Block counts by Thomas et al. [13] suggest a power-law slope similar to those of Eros [9] and Itokawa global counts, with the absolute density of blocks similar to that of global Eros. Because blocks tend to be more numerous proximal to large, young craters (e.g., Stickney on Phobos, Shoemaker on Eros), the block density across most of Phobos is likely to be lower than that observed in the available high-resolution images. We suggest that a power-law extrapolation of Eros or Phobos large-block distributions provides upper limits for assessing the block landing hazards faced by a Phobos lander.

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