EVALUATING SMALL BODY LANDING HAZARDS DUE TO BLOCKS. Carolyn M. Ernst, Douglas J. Rodgers, Olivier S. Barnouin, Scott L. Murchie, and Nancy L. Chabot. Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA (Carolyn.Ernst@jhuapl.edu).

Introduction: Landed missions represent a vital stage of spacecraft exploration of planetary bodies. The access to surface materials provided by landing enables a wide variety of measurements to unravel 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, three 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]; in 2014, Rosetta’s Philae lander bounced off and later landed on the surface of comet 67P/Churyumov–Gerasimenko. All three were preceded by rendezvous spacecraft reconnaissance, which enabled selection of a safe landing site.

Two current missions have plans to land on small bodies (Hayabusa 2 and OSIRIS-REx), and landing on a small body is a component of several mission concepts. Small body landers need to land at sites having slopes and block abundances within spacecraft design limits. Due to the small spatial scale of the potential hazards, it is typically neither feasible nor cost-effective 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 spacecraft.

Methods: Many robotic spacecraft have landed safely on the Moon and Mars. Landed images of these sites along with high-resolution orbital datasets have enabled the comparison of orbital block observations to the smaller blocks imaged once landed. 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 measured from orbit to population-densities of smaller blocks. By characterizing the larger size range of the block distribution from orbital imaging, the distribution of smaller blocks is estimated. From that estimate, the probability of a lander encountering hazardous blocks can be calculated for a given lander design. Such calculations are used routinely and successfully to vet candidate sites for Mars landers [5–8].

Application to Small Bodies: To determine whether this approach will work for small bodies, we must determine if the large and small block populations can be linked. To do this, we analyze the comprehensive block datasets for the intermediate-sized Eros [9] and the small Itokawa [10, 11].

Figure 1. Measured block populations on Eros [9,*], Itokawa [10,11], and Phobos [12,*]. The [*] symbol indicates counts made for this study.

Global and local block size-frequency distributions for Eros and Itokawa are shown in Fig. 1. The distributions 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 are remarkably consistent.

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 lower-resolution counts include multiple geologic settings, they will not extrapolate to local areas containing only one setting.

A small number of high-resolution images of Phobos is sufficient for measuring blocks. These images are concentrated in the area outside Stickney crater, which is thought to be the source of most of the observed blocks [12]. Block counts by Thomas et al. [12] and performed for this study 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 (Fig. 1). Because blocks tend to be more numerous proximal to large, young craters (e.g., Stickney on Phobos, Shoemaker on Eros), and because ejecta from these large impact events likely blanketed and buried many pre-existing blocks, the block density across most of Phobos is likely to be lower than that observed in the available high-resolution images.

**Landing Hazard Assessment:** We suggest that a power-law extrapolation of Eros or Phobos large-block distributions provides a conservative upper limit for assessing the hazards faced by a Phobos lander due to blocks. To simulate selection of a safe site, we generated a 100x100 m “Phobos” block field based on the

![Figure 2](image2.png)

**Figure 2.** 100x100 meter “Phobos” block field. The ten best landing ellipses (E1–E10, 20-m diameter circles) were chosen to minimize the largest block size.

Eros block distribution (Fig. 2), assuming hemispherical blocks [e.g., 9]. Areas this size having a low regional slope are widespread on Phobos, as indicated from global shape models [13–14]. The ten best sites for a notionally 20-meter-diameter landing error ellipse are determined by minimizing the size of the largest block. The lander is randomly oriented and placed in the site (e.g., Fig. 3). Lander tilt is computed and hazards are recorded (e.g., does a block hit the leg or spacecraft body). The safest ellipse in the 100x100 m area has a 99% probability of having a tilt ≤10º, and no landing hazards (Fig. 4).


![Figure 3](image3.png)

**Figure 3.** Three-dimensional view of the local block field with simplified lander orientated on blocks.

![Figure 4](image4.png)

**Figure 4.** Cumulative probabilities for primary ellipse E1 in Figure 2 for regional slopes up to 10º. a) No-hazard (NH; no blocks touching the spacecraft body) probability distributions; b) probabilities including operational hazards (OP; blocks touching legs but not spacecraft body components); survival hazards (blocks touching spacecraft body components) for this ellipse are negligible.