EJECTA ASSESSMENT FOR OPTIMIZING NATURAL LANDING PAD SELECTION

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Introduction: As more permanent infrastructure and presence are established in pursuit of lunar resources, we must develop strategies to acquire and maintain access to regions of interest (ROI), including priority landing sites. Plume Surface Interaction (PSI) presents a challenge regarding safety near natural landing sites (sites with no constructed landing pad). Regolith particles, primarily less than a millimeter in diameter, traveling at high speeds (possibly exceeding lunar escape velocity) can directly impact and damage nearby terrain and existing infrastructure. Historically, this phenomenon occurred when regolith ejected from the Apollo 12 lander resulted in significant pitting and erosion of the Surveyor III lander, approximately 155 meters away [1]. Figure 1 shows the relative positions of Apollo 12 and Surveyor III.

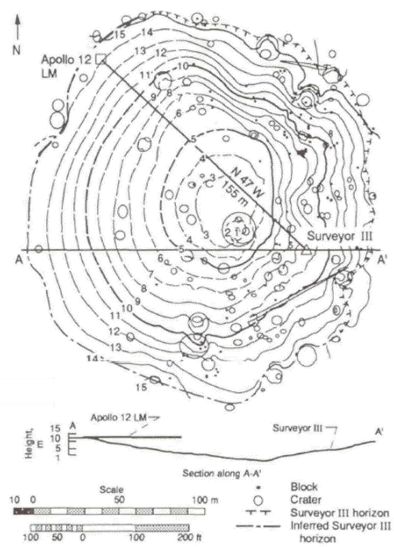

Fig. 1. Positions of Apollo 12 and Surveyor III relative to Surveyor Crater [4].

Background: This project aims to develop a tool that will provide a safety index in the product form of an aerial map overlay. Given a landing location, the overlay will show the comparative risk from a lander within a given radius of the landing site. Inversely, if we have a location we wish to protect, the overlay can show all landing locations that minimize the ejecta risk within a given radius of the protected site. In the absence of constructed landing pads to mitigate ejecta, this tool would allow for the optimization of natural landing pad selection as well as the selection of sites for planned infrastructure development.

Methods: To develop a proof of concept for our safety index tool, we used Apollo 12 as a case study. Initial data required to develop this tool are lunar elevation data which was acquired from LRO NAC DTMs [5], an estimate of the total number of particles blasted from the landing site [4], an estimated particle size distribution [3][4], and an estimate of the initial particle velocity [2][4].

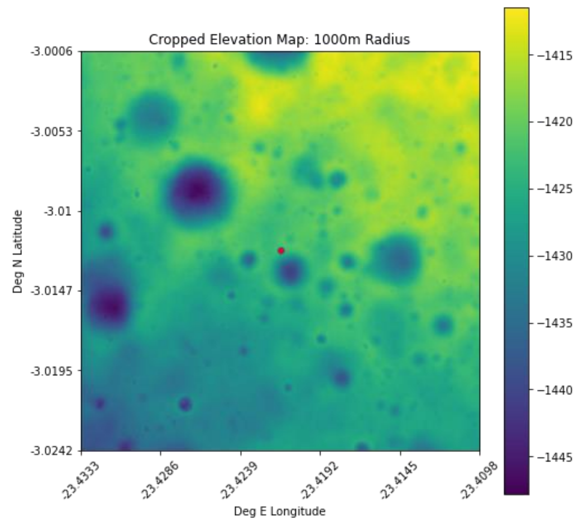

Fig. 2. DTM cropped and centered on the Apollo 12 landing site.

We assume an isotropic distribution of particles radially from the landing site and a velocity distribution as a function of particle size estimated from [2]. We used a simplified ballistic trajectory model, treating the regolith as a collection of individual spherical particles that follow ballistic trajectories without complex interactions such as collision with other particles or plume entrainment.

Using a DTM from LRO NAC (Figure 2), we determined whether the trajectories of particles, by size, are impeded by existing terrain. Figure 3 shows a cross-section of particles ranging from 0.1 µm to over 1 cm launched at an angle of 3˚ at a 315˚ azimuth.

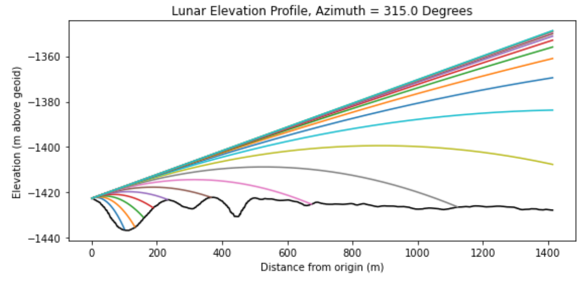

Fig. 3. Ballistic trajectories of different particle sizes.

Figure 4 shows a cross-section of the potential ground surface damaged by a 320 µm particle launched at 3˚. From [4], the estimated number of particles blasted by Apollo 12 was 2.05x10^{16}, and from our particle distribution, approximately 3.16x10^{13} of those particles were between 320-323 µm in diameter. The maximum distance traveled by a 320 µm particle is 1124m, shown in Fig. 4. Using estimates for the number of particles dispersed per azimuth angle around the landing site, we calculate that approximately 5.63x10^{6} (320-323 µm) particles per m^2 impact between the landing site and maximum distance (traveled at 315˚ azimuth) with an impact momentum of 6.79x10^{-6} kg m/s per particle (38.2 kg m/s per m^2).

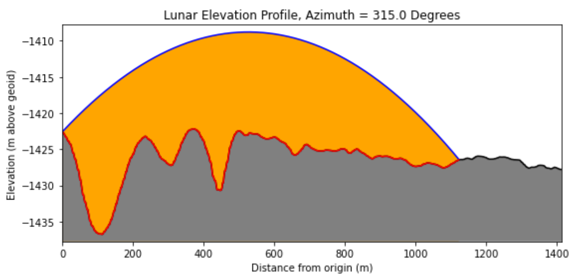

Fig. 4. Surface damaged by 320 µm particles (shown in red).

When this process is performed for an array of particle sizes for every pixel within a predetermined radius of the landing site, we can produce a map overlay similar to Figure 5.

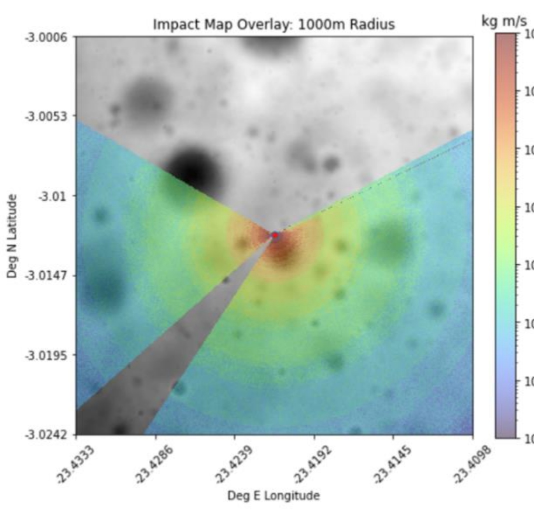

Fig. 5. Index overlay showing comparative compiled ejecta impact momentum from the Apollo 12 landing site.

Discussion: This index tool aims to provide mission planners with a simplified method of downselecting potential natural landing sites optimized toward minimizing localized erosion risks to terrain, infrastructure, and equipment. Figure 6 shows an inverse version of the overlay, centered on the Surveyor III location, representing the risk to Surveyor III had Apollo 12 landed at any surrounding point within 100 m.

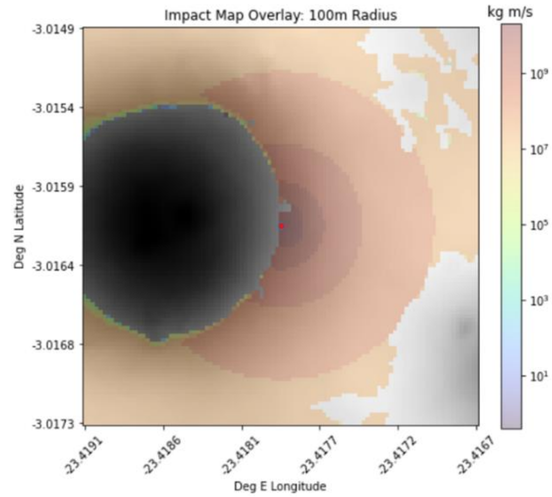

Fig. 6. Optimized Landing Location centered on Surveyor III. Overlay shows landing locations that would have minimized damage to Surveyor III from ejecta.

Ideally, a finalized version of this proposed tool would allow users to input high-resolution DTM (less than 5 mpp) of the lunar surface, coordinates for the potential landing or protected site, and the mean and standard deviation of particle size at the site (if known). The tool would also allow for the construction of simulated infrastructure (e.g., berms, habitats) to understand the benefits and drawbacks of protected and unprotected structures. If building material is known, the estimated penetration depth of pitting ejecta into infrastructure could also be estimated and used as an additional indicator of risk [6]. An additional variable to be considered as an input is lander type, which can influence the number of particles blasted from the landing site as a function of thrust [4].

References: [1] Immer et al. (2011), *Icarus*, 211(2), 1089-1102. [2] Lane & Metzger (2015), *Acta Geophysica*, 63(2), 568-599. [3] Graf (1993), *NASA Reference Publication 1265*. [4] Katzan & Edwards (1991), *NASA Contractor Report 4404*. [5] Henriksen et al. (2017), *Icarus*, 283, 122-137. [6] Beckmann & Gotzmann (1981), *Wear*, 73(2), 325-353.