AN UPDATED SECONDARY LUNAR METEOROID EJECTA MODEL FOR ENGINEERING DESIGN.

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Introduction: The surface of the Moon is constantly being bombarded by a flux of meteoroids of various sizes. Impacts due to these meteoroids produce secondary ejecta material at much lower speeds but with a total mass larger than the original impactor. Details about the secondary ejecta are important for planning missions on the lunar surface. In this work, an updated ejecta model is presented called the Meteoroid Model of Secondary Ejecta (MeMoSeE), to replace the Apollo-era ejecta model, NASA SP-8013 [1], in the SLS-SPEC 159 Design Specification for Natural Environments (DSNE) [2]. The model produces secondary eject flux environments for a user-specified location on the lunar surface, and sorts the incoming secondary flux by angular direction and speed.

Methods: MeMoSeE is broken into three parts: the inputs, the conversion step, and integration of fluxes. Inputs to the model include the primary meteoroid fluxes and the primary near-Earth object (NEO) fluxes. Meteoroid fluxes, both asteroidal and cometary, are calculated using the Meteoroid Engineering Model (MEM3) [3] for different locations on the Moon. For each surface location, an ephemeris is generated using the JPL HORIZONS System [4] that feeds into MEM3. The NEO fluxes are approximated by the high-density population of MEM3 (i.e., only the directionality), where the speed distribution of the NEO fluxes is renormalized to match observations [5]. The regolith properties are used as defined in the DSNE [2].

The conversion step utilizes scaling laws given by Housen & Holsapple 2011 [6] to convert the primary impactor flux to the total mass of secondary ejecta. The ejecta distribution, at the point-of-impact (POI), is separated into a zenith angle and azimuthal angle distribution. The zenith angle distribution follows a beta distribution where the peak depends on the impact altitude angle and the impact azimuth [7]. We employ an ejecta azimuth distribution that is based on Rival & Mandeville 1999 [8] which focuses ejecta in the downstream direction for more oblique impacts.

Finally, during the integration step, we sum secondary ejecta number fluxes at a particular region-of-interest (ROI) that originated from many POI locations over the entire surface of the Moon. We keep track of both altitude and azimuth angle bins as well as a range of speed bins, following the igloo gridding as done in MEM3 [9]. The ejecta particle size distribution and density is assumed to be the same as the lunar regolith [10, 2].

Results: The primary fluxes are computed for one Metonic cycle (19 years) for various locations over the lunar surface with a fixed orientation. Both the angular and speed distributions of the primary fluxes are dependent on the latitude and longitude. The overall primary fluxes show a roughly 13% increase from the eastern limb to the western limb.

In general, the speed distribution of the secondary fluxes span from a user-defined minimum speed to the escape speed of the Moon (2.38 km/s), roughly following a power-law relation [6]. Different parts of the speed distribution come from different primary impact locations on the Moon. The secondary ejecta is dominated by the slowest speeds, where these particles originate nearby the ROI. For speeds around 71% of the escape speed, the secondary ejecta originates from locations near the antipodal point. On the other hand, secondary ejecta speeds that exceed roughly 90% the escape speed, the ejecta particles come from all over the lunar surface to the ROI.

Comparing the secondary ejecta fluxes from MeMoSeE with NASA SP-8013 [1], there is a reduction by about 2-3 orders of magnitude for secondary ejecta particles greater than 1 µg. These estimates agree with recent findings from Bjorkman & Christiansen 2019 [11]. The secondary ejecta fluxes are also compared with the primary fluxes, where the ejecta fluxes are roughly an order of magnitude greater than the primary fluxes.

References: [1] Cour-Palais, B. G., (1969) NASA SP-8013. [2] NASA SLS-SPEC-159 Rev. H (2020). [3] Moorhead, A. V., et al. (2019) *JS&R*, 1-17. [4] Giorgini, J. D., (2015) *IAUGA*, 29, 2256293. [5] Moorhead, A. V., (2020) Memo OSMA/MEO/Lunar-001. [6] Housen, K. R., and Holsapple, K. A., (2011) *Icarus*, 211(1), 856-875. [7] Gault, D. E., and Wedekind, J. A., (1978) *L&PSCP*, 9, 3843-3875. [8] Rival, M., and Mandeville, J., (1999) *Space Debris*, 1(1), 45-57. [9] Moorhead, A. V., (2019) MEM3 User Guide. [10] Carrier, W. D., (1973) *The Moon*, 6(3-4), 250-263. [11] Bjorkman, M. D. & Christiansen, E. L., (2019) *ODC*