MODELING THE PROPAGATION OF SPACECRAFT EXHUAST PLUME VOLATILES ON THE MOON.

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Background & Motivation: Understanding the mechanisms that control the origin, abundance and distribution of lunar volatiles is integral to understanding the history of the inner Solar System and the in situ resources available for planetary exploration. Motivated in part by these scientific questions, there is international interest in returning to the lunar surface over the next decade. However, any soft landing on the lunar surface will involve the release of non-indigenous volatiles into the lunar exosphere during descent. Modeling the exospheric transport and deposition of exhaust plume gases is critical to constraining the degree to which exhaust gases may contaminate measurements aimed at characterizing the extant lunar volatile inventory. Powered landings also present valuable opportunities to further our understanding of how volatiles interact with and migrate over the lunar surface. For instance, previous modeling of the propagation of the Chang'e 3 exhaust plume, combined with LADEE observations of the lunar exosphere, provided useful constraints on the degree of thermalization of water molecules upon contact with the lunar surface [1]. In this work, we explore the fate of exhaust plume volatiles in further detail.

Approach & Implications: We model the propagation of exhaust plume volatiles through Monte Carlo simulations, by tracking the transport, deposition and loss of a large number of representative molecules released during a nominal landing – based on the trajectory followed by Chang'e 3 during the most recent controlled lunar landing [2], but at a higher latitude, where volatiles are likely to remain in the vicinity of the lander for longer. Preliminary calculations indicate that in the near-field, the exhaust plume is sufficiently dense (see *Figure 1*) that collisions between gas molecules are likely to play a role in determining the far-field velocity distribution – which in turn may affect how much of the exhaust remains gravitationally bound, as well as the initial distribution of volatiles along the ground track. We use a Direct Simulation Monte Carlo (DSMC) code [3] to model collisional gas dynamics in the near-field. The DSMC method accommodates the transition from collisional to collisionless flow in the far-field, and the subsequent migration of volatiles deposited on the lunar surface. We focus on water in the exhaust plume, as a volatile of interest. The interaction of water molecules with the lunar surface is highly sensitive to surface temperature; we include several representative polar cold traps in our model, and account for the small-scale temperature gradients caused by surface-roughness in a stochastic manner [4]. We also model water loss due to gravitational escape and photodissociation.

This approach allows us to investigate several questions of interest; for instance: What is the initial distribution of exhaust volatiles near the landing site? How far would a rover have to traverse to reach uncontaminated terrain? What fraction of exhaust volatiles reach polar cold traps? We will report on our progress towards addressing these questions.

References: [1] Hurley et al., 2014, *LPSC.* [2] Liu et al., 2014, *Res. Astron. Astrophys*. [3] Stewart et al., 2011, *Icarus.* [4] Prem et al., 2018, *Icarus*. [5] Roberts, 1966, *NASA TRS*. [6] Lee, 2017, *PLOS One*.

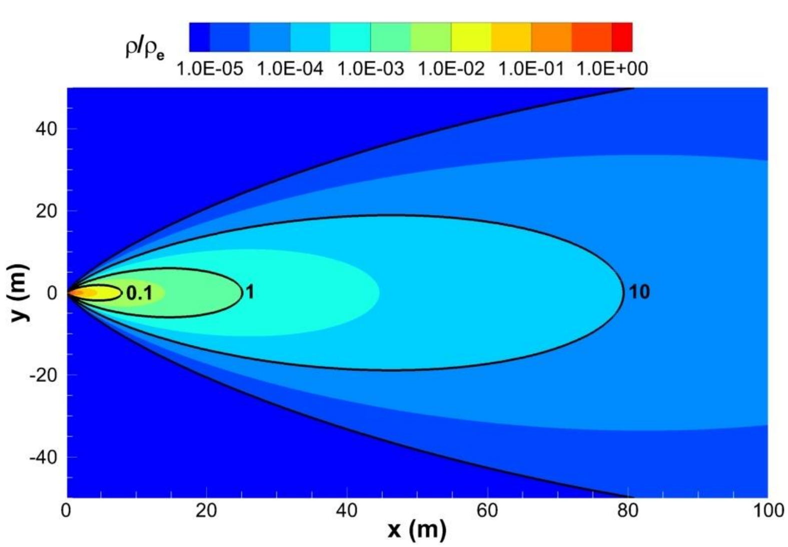

Figure 1. Estimated density field in the vicinity of a 60 cm (exit diameter) nozzle, visualized in terms of the ratio ρ/ρ_e, [5] where ρ is density and ρ_e is density at the nozzle exit (0,0). The labeled black contours indicate the Knudsen number (Kn), defined in this case as the ratio of the mean free path (between molecular collisions) to the nozzle diameter, computed for a representative mixture of exhaust gases [6]. Kn ~0.1-10 typically indicates a rarefied but collisional flow.