Impact drag force exerting on a projectile penetrating into a fragile granular bed

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When a solid projectile impacts onto a granular bed, drag force decelerating the projectile motion finally results in the cessation of the projectile. Fundamental understanding of the mechanics of such granular impact drag force is crucial to properly predict the touchdown behavior of the planetary explorer. So far, rigid particles such as sand and/or glass beads have been used as model target granular beds. However, grains returned from asteroid Ryugu indicate that the asteroidal surface grains have extremely low density [1]. Such porous grains could be deformed and/or crushed by the impact. Then, the drag force exerting on the projectile impacting onto a granular bed consisting of such fragile particles might be significantly different from that of conventional one consisting of rigid particles.

Therefore, we performed a set of low-speed impact experiments between a solid projectile and a granular bed consisting of fragile particles. Fragile particles used in this experiment were formed by binding tiny glass beads monomer (5 micrometer in diameter). The aggregated particles of diameter ranging in 2-4 mm were used for the target granular layer. To control the strength of fragile particles, particles were sintered. By controlling sintering temperature and time, aggregate strength was varied from 10^0 to 10^4 kPa. Then, a solid projectile of diameter 12.7 mm was dropped from various heights (10-320 mm) and the impact penetration was filmed by a high-speed camera at 12,000 fps and 0.036 mm/pixel resolution. From the acquired data, instantaneous penetration depth z and velocity v were computed. The obtained v(z) relations were fitted by the granular impact drag force model [2]. Then, the fitted values of two parameters characterizing inertial drag and depth-proportional force were compared between rigid-grain case and fragile-grain case. As a result, we found that the inertial drag was almost identical between them. However, the depth-proportional drag parameter showed a significant difference. This difference results from the effect of particle crushing. Details on the quantitative analysis of this difference will be discussed in the presentation.

[1] Yada et al., Nat. Astron. https://doi.org/10.1038/s41550-021-01550-6 (2021).
[2] Katsuragi & Durian, Phys. Rev. E 87, 052208 (2013).

Keywords: Impact drag, fragile particles

