Grain-Scale Morphology and Initial Aspect Ratio Effect on Granular Avalanches

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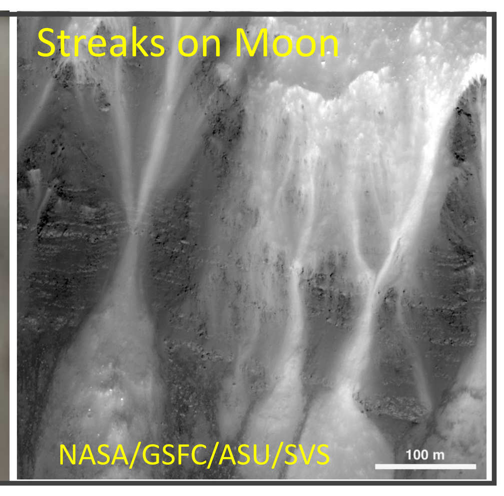
Key Results

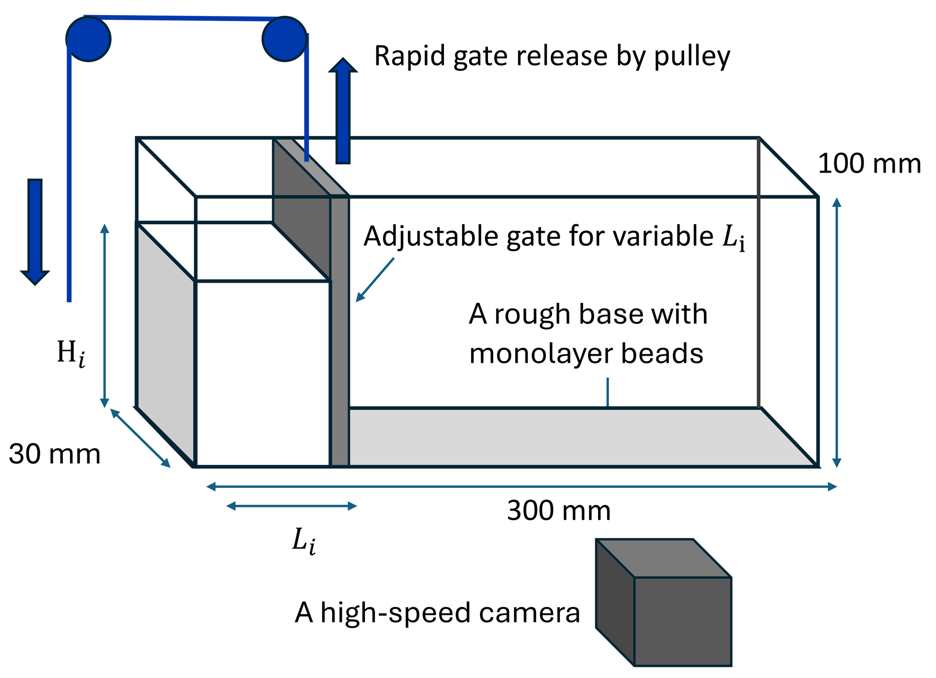
- **Relative importances of controlling factors on deposit geometry: Initial aspect ratio (a) ≫ Grain angularity > Grain size (d) > porosity.**
- **Porosity effect may be small, suggesting potential bypass of geological history diversity on planetary bodies.**

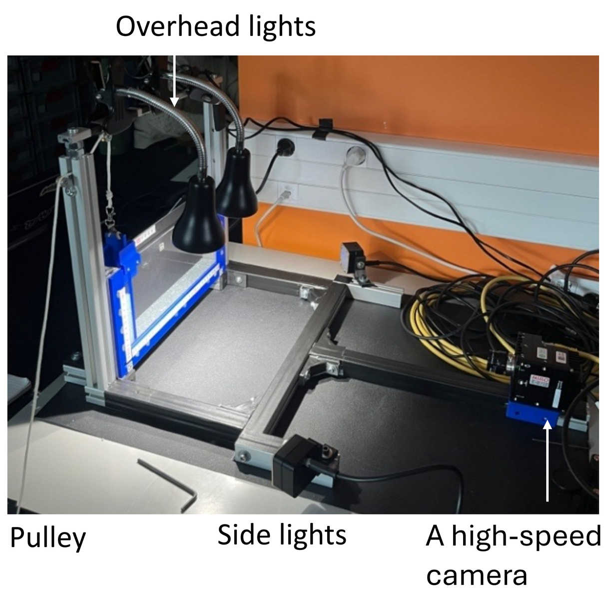
Planetary Relevance & Motivation

- **Planetary Observations:** Recent missions have revealed ubiquitous granular mass wasting and complex regolith movements on planetary surfaces (e.g., Ryugu [1], Bennu [2], Deimos [3], and 67P/Churyumov–Gerasimenko [4]).
- **Global Material Transport:** Mass movements spanning 100s meters to several km could cause global resurfacing and mass transport on small bodies (e.g., ≲ 10 km in diameter).
- **Goal:** Clarify how physical conditions, such as grain morphology and porosity, govern avalanche transition regimes and runout dynamics to help interpreting surface exploration data and future in-situ missions.



Experiment Setup





Experimental setup for 2D granular column collapse: Schematic diagram (left) and photograph of the setup (right). Granular column collapse is initiated by the rapid lift of the gate via a pulley system, with avalanching processes recorded by a high-speed camera.

Particle Morphology

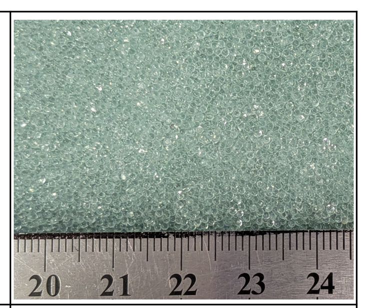
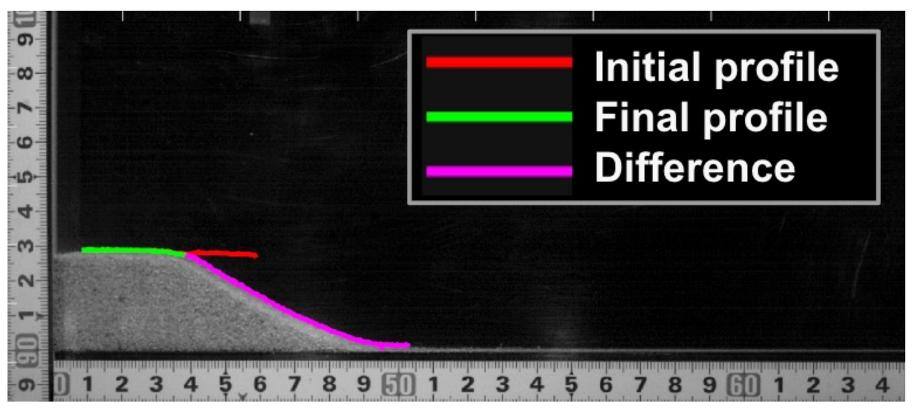
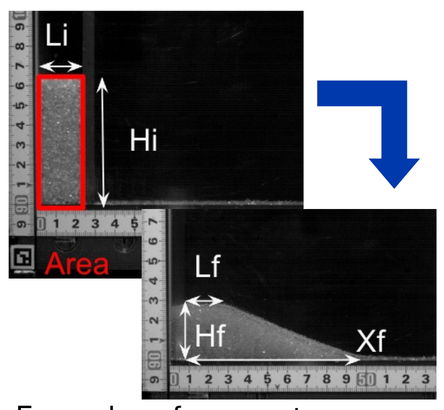
Glass beads	
Sand	
Glass grit	

Image Processing & Analysis

1. **Optical Distortion Correction:** Undistorted raw images using pre-calibrated camera intrinsic parameters.
2. **Profile Extraction**: Isolated the granular bed via frame-differencing, refined binary masks with morphological filtering, and traced the top surface coordinates.
3. **Parameter Extraction:** Converted pixels to metric to quantify initial geometry and physical dimension of deposits.



Surface profile extraction from initial and final deposit states.

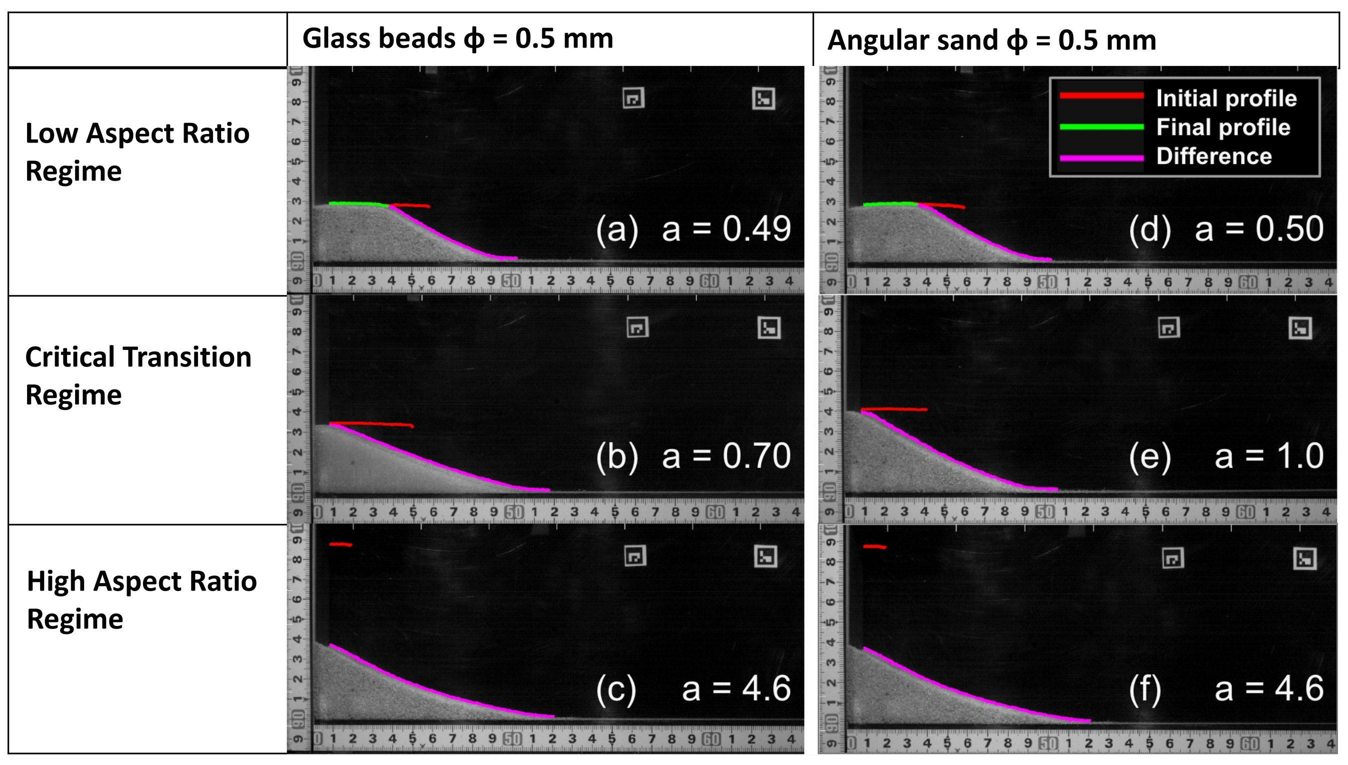


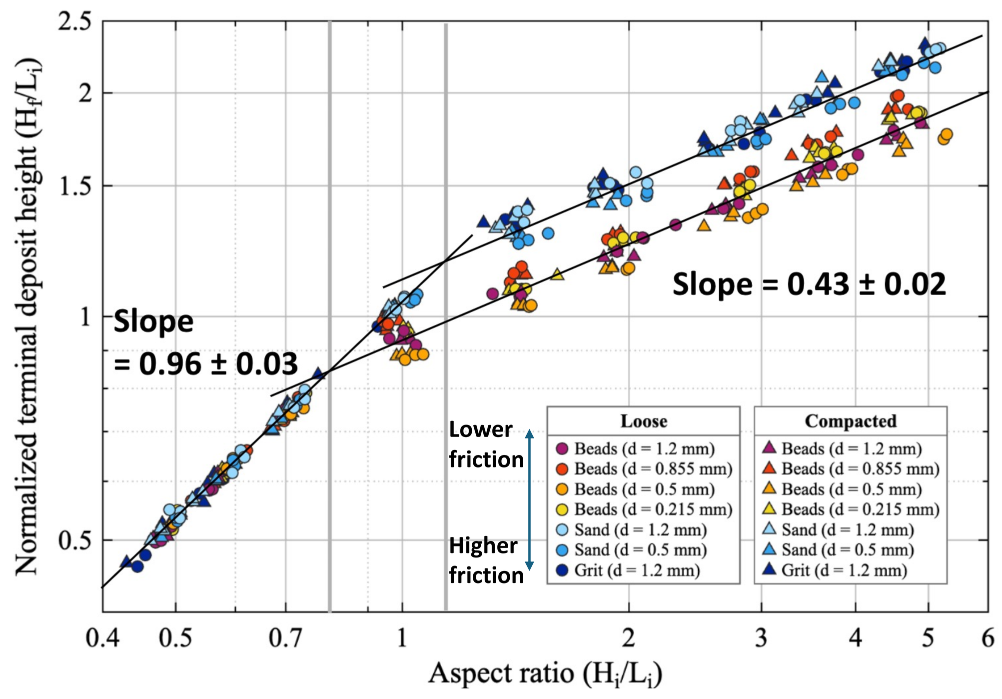
Examples of parameters extracted.

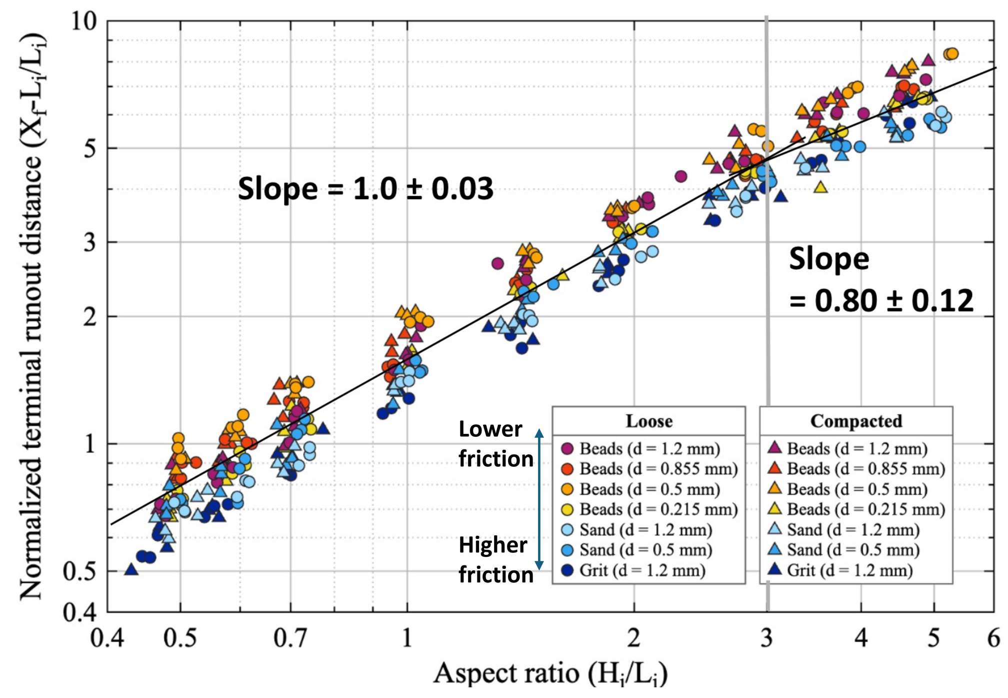
Experimental Results: Collapse Regimes & Controlling Factors

Three regimes of avalanche motion **(Consistent with previous studies [5-7]):**

1. **Low Aspect Ratio (a) Regime (a, d):**
   - Retains a static, undisturbed plateau at the top ($H_f = H_i$).
2. **Critical Transition Regime (b, e):**
   - Plateau disappears as the failure plane reaches the left wall.
   - Transition occurs at lower a for spherical beads (a~0.7) than for angular particles (a~1.0).
3. **High Aspect Ratio Regime (c, f):**
   - The top surface drops entirely ($H_f < H_i$).







Hierarchy of controlling factors on H_f/L_i:
Aspect ratio ≫ Angularity > Grain size > Porosity

1. Aspect ratio: A clear transition dependent on aspect ratio.
2. Particle angularity: Spherical beads transition at lower a(~0.7), whereas angular grains (sand & grit) transition around a~1.0.
3. Grain size (d) : Despite a ~ 6x difference in bead diameter (0.215 mm to 1.2 mm), variation in H_f/L_i is minimal with no apparent systematic dependence on size.
4. Porosity (initial packing): A ~ 3 % variation in initial packing (loose vs. compacted) yields no noticeable deviation across all tested materials.

Physical Mechanism

- **Governing factor of final height transition:**
  - Aspect Ratio: Scaling transitions across varied a align with previous studies
  - Angularity: Influential factor shifting the transition point, as grain interlocking directly controls the angle of internal friction.
  - Grain Size: Ineffective on the static collapse threshold due to testing coarse, cohesionless grains.
  - Porosity: Shows negligible impact on deposit morphology for coarse (~ mm) particles.
- **Governing factor of runout distance:**
  - Complex behavior with AR and grain size
  - Frictional Dissipation vs. Thin-Layer Mobility

Conclusions and Future Study

- **Our experiments reveal the following key insights:**
  - Integrated hierarchy of morphological controls: Aspect ratio a << angularity < grain size < initial porosity.
  - Limited sensitivity to initial compaction for coarse grains.
- **Future study**
  - Wider parameter: Test broader grain-size and porosity ranges to bridge coarse regolith and fine-grained environments. Test cohesive materials.
  - Simulation comparison: Integrate findings with numerical simulations to validate internal stress distributions and micro-mechanics.

Planetary Implications

- The initial packing range tested (~3% variation) shows negligible effect on deposit geometry and runout. This suggests that morphological analyses may be relatively robust against uncertainties in past compaction history within this range.
- Mass-movement morphologies on coarse rubble-pile asteroids like Ryugu [1], Bennu [2], 67P/Churyumov-Gerasimenko [4], and Hera/Ramses targets (Didymos, Apophis) are expected to be primarily controlled by slope geometry and angularity, not local porosity.
- For bodies with fine dust (~ μm; Moon, Ceres, Deimos targeted by MMX), interpreting streamers and mass flows requires extending experiments to smaller, cohesive grain sizes.

References & Acknowledgements

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