The Particle Accretion in Microgravity Free-Float Experiment: Protoplanetary Aggregate Formation

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I. Introduction

The fundamental mechanical properties of the dust that makes up protoplanetesimals in the solar nebula are critical to understand if we are to inform accretion hypotheses regarding early stage terrestrial planet formation [1]. The mineralogy of this dust is similar to the surfaces of primitive asteroids and comets and it's critical to exploration science to characterize properties such as cohesion, aggregation, porosity, and coefficient of restitution in order to better inform the design and operation of spacecraft and ISRU technology. The objective of the upcoming experiments is to determine the effects of the material/mechanical properties on the accretion of dust-scale grains in microgravity conditions. **The primary objectives of the proposed work are to:** (1) determine the effects of particle size; (2) number density; and (3) composition on the aggregation of dust-scale grains in microgravity conditions.

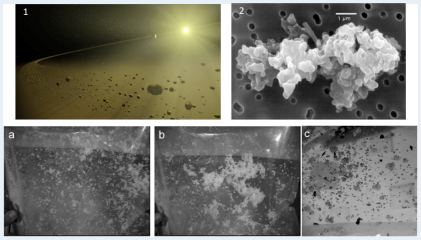


Figure 1: (1) Artist impression of a protoplanetary disk. (2) SEM image of a ~10 µm interstellar dust particle. (a) Images from Don Pettit's ISS experiments (Figure 1 from Love et al., 2014). NaCl crystals in a bag (b) Contents after shaking. (c) Seconds later, showing particle aggregation.

II. Experiment

We conducted a campaign of parabolic flight experiments in 2018 and 2019 to study the dependence of fundamental properties of different relevant analog minerals on the growth of porous clusters (aggregates) in microgravity using our new free-float design (Figure 2). Our dust aggregation experiments are a follow-up to experiments like the "Saturday Morning" free-float experiments initially performed by astronaut Don Pettit aboard the ISS, and later published by co-author Love [2], and also experiments performed by co-author Durda aboard parabolic aircraft. In Pettit's experiments, bags of finely grained materials were agitated and left to free-float immediately showing the aggregation of the highly cohesive materials (Seen in Figure 1 a, b, c). The clusters that formed did so due to surface forces such as van der Waals electrostatic forces. In a low-gravity environment these and other secondary forces dominate over the self-gravity of the cluster; this is the case in the nascent protoplanetary disk where small mm- to cm-sized protoplanetesimals form, as well as on comets and asteroids.

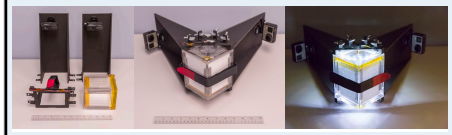


Figure 2: The experiment frame (rig) that holds the acrylic box with the dust inside. The LEDs illuminate the the dust for the two cameras (GoPro) that have a 90 degree offset to allow 3D visualization of the forming aggregates.

Cargo bay and free-float

Figure 3 (left): Images showing: a) the cabin of the Zero-G aircraft with all team's experiments bolted to the floor; b) Durda, Tsang, and Whizin performing free-float experiments during a parabola; and c) the team smiling for a selfie during a much needed break.

IV. Results

GoPro footage

Figure 4 (left): Each GoPro mounted to the frame of the box filled with analog materials possesses a field of view like this one. The two fields of view provide three-dimensional footage of the aggregates during their time in microgravity. The black material of the camera arm helps reduce glare from cabin lighting. Each camera is activated during the 2-g pullout and records the entire parabolic arc, roughly 17-20 seconds.

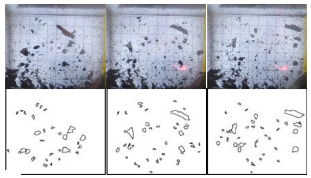


Figure 5 (right): Time-sequence frames taken from the GoPro footage. During the parabola the dust is agitated and free-floats inside the acrylic box, as seen here, clumping immediately. The data are analyzed by taking thresholds of the frames and running particle tracking in ImageJ software to obtain the pixel areas of the aggregates.

Aggregate size dependence on grain size

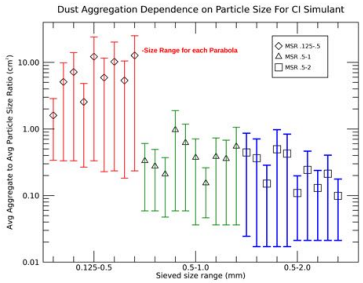


Figure 6 (left): The pixel areas of the aggregates are scaled to cm^2 and saved from each frame in experiments with varies PSDs. The red error bars represent the mean size range determined over all frames. The shapes indicate the mean dust aggregate size determined over all frames in each experiment. Three size ranges were flown 0.125-0.5mm, 0.5-1.0mm, 0.5-2.0mm. Each of these boxes were free-floated 5 times each (the 0.125-0.5mm box had one failed parabola).

Aggregate size dependence on dust composition

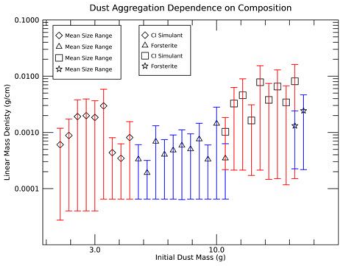
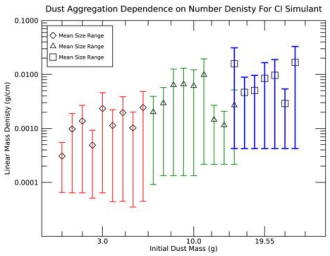


Figure 7 (last two): We varied three primary initial conditions, mass of the dust (number density), the grain size (PSD), and the composition (meteorites, a CI simulant, olivine, and enstatite). Here we show our aggregation rates during the experiments with varied compositions and mass.

Aggregate size dependence on number density



V. Conclusions

- During our first flight we observed dust aggregate growth is dependent more heavily on PSD and number density rather than composition.
- We observed large clumps compared to initial grain size for tiny grain PSDs.
- We observed filament-shaped aggregates in some parabolas with the crushed meteorites, and some electrostatic effects from charged spots on the wall caused interesting aggregate behavior.

VI. Future Work

Future analysis of this data will include finishing the cluster tracking for the final two flights. Our final flight campaign is nominally scheduled for summer or fall 2020 and we plan to fly our remaining dust samples. Careful analysis of the images is underway to determine collisional properties, *e.g.* bouncing. We plan on eventually flying mixtures of olivine and pyroxenes, as well as meteorites, to determine if and the degree heterogeneity plays in clump formation. The wide array of materials and initial conditions will allow us to determine detail of the clustering of dust that will aid astrophysical models of PPDs.

References

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[3] Love, S., D. Pettit, and S. Messenger (2014) *Meteoritics & Plan. Sci.* **49**, 732–739.

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