

Aggregate Accretion from Dust Particles in Free-Float Microgravity Experiments A. D. Whizin¹, D. D. Durda², C. S. Tsang², and S. G. Love³, ¹Southwest Research Institute, ²NASA JSC. (email:awhizin@swri.edu)

Introduction: During the early stages of terrestrial planet formation in the solar nebula the accretion of dust aggregates that make up the protoplanetesimals occurred in a microgravity environment. In order to better inform accretion processes and planet formation models we need to understand the mechanical properties of the aggregates in these environments [1]. The low-gravity mechanical processes and mineralogic composition of this dust is also 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 objectives of the experiments are to determine the effects of particle size, number density, and composition on the accretion of dust-scale grains in microgravity conditions.

This work, which is funded by a NASA ROSES Emerging Worlds Grant, is based upon previous microgravity free-float experiments initially performed by astronaut Don Pettit aboard the International Space Station (Figure 1) [2], and later performed by co-author Durda. In the Pettit experiments bags of finely grained materials like coffee and sugar were agitated and left to free-float immediately showing the aggregation of the highly cohesive materials.

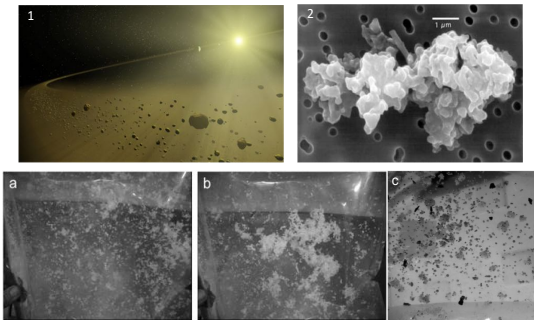


Figure 1: (1) Artist rendering of an early solar nebula. (2) SEM image of IDP dust aggregate of many small sub-micron particles. (a, b) Aggregates and individual particles of sugar and (c) other materials that were allowed to float for several hours aboard the ISS (a, b, c figures from Love et al 2014).

The clusters that formed did so due to surface forces such as van der Waals and 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.

During our flights we observed the formation of clusters in these size regimes.

Materials: In this experiment we used finely crushed dust powders made up of olivine (San Carlos peridot gems) and simulants. In this flight, for ease of use and cost we used UCF-1, a CI carbonaceous chondrite asteroid simulant with a high chemical fidelity [3]. We sieved the simulant and olivine powders to three size distributions each (0.125 – 0.5 mm, 0.5 – 1.0 mm, and 0.5 – 2.0 mm), covering masses (i.e. number densities) of 3 g, 10 g, and 20 g.

Experiment: We designed a parabolic flight experiment to study the dependence of fundamental properties of different relevant analog minerals on the growth of porous clusters (aggregates) in microgravity. To accomplish this, we built frames capable of holding interchangeable plexiglass boxes filled with the experimental samples (Figure 2). Each frame has two camera arms mounted with wing nuts for easy assembly during the zero-g flight, and has a GoPro camera mounted on each end. The GoPros offer a reliable and easy-to-use recording method for this experiment, which is not overly complex by intention, as free-floating an experiment during a parabolic flight campaign is quite challenging in and of itself. To not burden the user and to ensure the best fidelity data collection (low residual g-forces on the samples inside the boxes) we opted for this strategy.

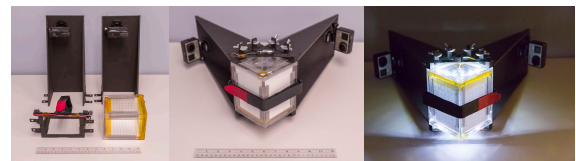


Figure 2: The experiment frame and camera arm mounts used in the parabolic flight experiments. GoPro's are mounted on each arm for a stereoscopic view. LED lights are activated during flight for extra illumination to observe the fine-grained dust's behavior.

In our experiment we take nine 10 x 10 x 12 cm Plexiglas boxes, each filled with different minerals or mixtures of minerals. During each parabola a single box is removed from the storage case and allowed to free-float for the ~20 seconds of microgravity. The boxes are then shuffled between the three flyers for a streamlined and rehearsed rotation method so that all boxes fly equal time (Figure 3 shows the three flyers operating the experiment during the parabolic flight). Experiments on the ground and aboard the ISS have shown that this is

more than enough time to allow for the rapid formation of aggregates of the dust [4], and this was indeed the case as observed during our ~17 second free-float times. The formation and subsequent collisions of the aggregates were filmed and the aggregation's characteristics and behavior later analyzed.



Figure 3: From top left clockwise: (1) An image of the Zero-G plane cabin with the experiments bolted down. (2) Our team (Whizin, Tsang, and Durda) prepared for weightlessness. (3) Team members entering microgravity. (4) The team having a good time pausing during a break. (5) Action shot of data collection during a good parabola.

Results: We used the open source tracking software ImageJ to track the particles and clusters. For brief periods of time there were no residual g-forces on the boxes, and this section of footage was clipped and then analyzed (Figure 4). The aggregate pixel areas were determined and plotted for each frame, and for each of the CI-simulant boxes (Figure 5).

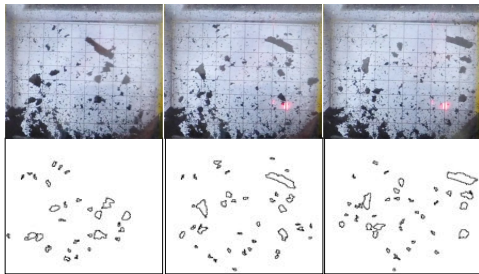


Figure 4: Using ImageJ tracking software we analyzed short continuous clips of data during the weightless portion of the parabolic flight shown here. The frames were analyzed to isolate the clusters of particles that formed in the low-gravity environment as shown by the lower series of B&W images.

For the various experiment boxes the data shows a clear favoring to aggregation in the smallest particle size boxes. The olivine at the smallest size fraction has relatively sparse number density but readily formed clusters. Determining the shapes and volumes of the aggregate in the future will lead to calculations of their densities and bulk porosities. The uptick in 0.5 – 2.0 mm aggregate sizes may be simply due to larger particles and not clusters, more analysis is needed.

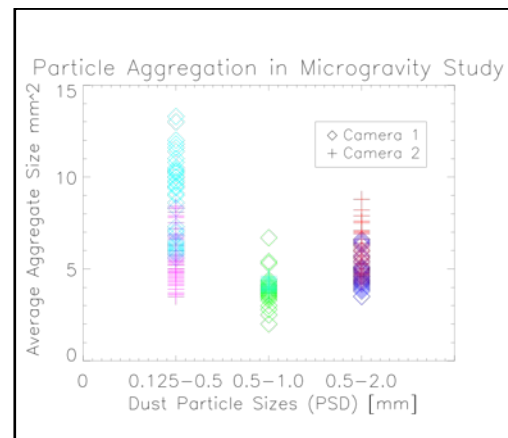


Figure 5: The aggregate sizes obtained from the tracked clip image sequences and plotted in bins according to their respective particle size distributions.

Discussion and Future Work: During our first flight we saw the formation of clusters in nearly every single experiment and found the composition of the dust was not as important to aggregate formation as the particle size distribution and the number density in the cloud. This was not assumed but we were pleased to observe such behavior in all boxes, indicating the ease to which small dust grains adhere in a reduced-gravity environment such as the solar nebula or asteroid surface. This perhaps indicates a very low bouncing regime threshold for aggregates such as these, which could possibly enhance the planet formation process, but more work is needed here. Future analysis of this data will include dependencies on number density and composition. We will attempt to describe the size and number distributions of the aggregate sizes with respect to the independent variables.

Due to meticulous planning by our team we were able to accomplish all of the Flight #1 objectives, and have isolated efforts and changes that will need to be made for future flights, such as a handle to make catching the box after free-float easier. Our next flights (2) are in November 2019 and we plan to fly our enstatite dust samples, crushed meteorites (carbonaceous CM and ordinary LL), and mixtures of olivine pyroxenes for a much wider array of materials and number densities.

References: [1] Blum and Wurm 2008; [2] Love et al 2014; [3] Metzger et al. 2018, LPSC # 2926; [4] Poppe and Schräpler 2005.

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