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22-2022 SFO-0002

Acoustofluidics-based Multifunctional Manipulation of Micro- and Nanoparticles under Reduced Gravity

The University of Mississippi

Director/PI: Dr. Nathan Murray

Tiny particles suspended in a liquid, colloids occur in many different forms (e.g., milk, muddy water, shampoo, and medicine) in our daily lives. Recently, colloids have shown great potential for additive manufacturing, drug delivery, and constructing colloidal superstructures. Scientists of the NASA Science Mission Directorate conducted years of research on colloids in microgravity. However, few studies investigated the effects of acoustic waves on colloids under reduced gravity. Few platforms can actively control the concentration, pattern, assembly, and alignment of tiny particles in liquids under reduced gravity.

On the other hand, engineers at NASA Marshall Space Flight Center are very interested in developing in-space manufacturing technologies for long space voyages. To fabricate polymer matrix composites reinforced/functionalized with tiny particles, such as carbon nanotubes (CNTs) and silicon carbide (SiC) whiskers, techniques that can arrange particles suspended in polymer resins are critical. However, no 3D printing platforms have been demonstrated to arrange tiny particles in resins and print polymer matrix composites containing patterned/aligned particles under reduced gravity.

The overall objective of this research is to develop and demonstrate novel acoustofluidic platforms that enable two unique capabilities: (i) multifunctional control (e.g., concentration, patterning, and alignment) of micro/nanoparticles, and (ii) printing polymer matrix composites containing patterned micro/nanoparticles under reduced gravity. To achieve this objective, we will accomplish five Tasks. Task 1 is to upgrade and optimize our previously developed acoustofluidic platforms for manipulating particles under reduced gravity. Task 2 is to develop theoretical models for predicting acoustofluidics-based particle manipulation under reduced gravity. Task 3 is to perform particle manipulation tests using our acoustofluidic platforms during the ZERO-G parabolic flight. Task 4 is to perform reduced-gravity 3D printing tests, by using our acoustics-assisted

3D printing platform that integrates an acoustic array for arranging micro/nanoparticles in polymer resins and a light projection unit for photocuring. Task 5 is to analyze and compare the data collected under different gravity conditions, in order to understand the mechanisms of acoustically manipulating particles in liquids under reduced gravity.

We expect this research will lead to both critical scientific contributions and new technologies. (i) This study will generate new knowledge about the acoustic effects on micro/nanoparticles in liquids under reduced gravity. (ii) This study will lead to novel acoustofluidic technologies and fully functional platforms for actively manipulating (i.e., concentrating, patterning, and aligning) micro/nanoparticles in liquids under reduced gravity. (iii) This study will lead to an acoustics-assisted 3D printing platform, which can print multifunctional composite structures in reduced gravity environments. Particularly, the printed composite structures will contain lattice-like patterns of particles, and we expect these patterned internal particles can tailor the mechanical and electrical properties of printed composites.

This project aligns with the Physical Science Program of the NASA Science Mission Directorate by contributing to the research on colloids in microgravity. Moreover, this project aligns well with the Advanced Manufacturing Program of the NASA Space Technology Mission Directorate. Specifically, the acoustics-assisted 3D printing platform to be developed in this project will greatly contribute to space and surface manufacturing toward sustainable exploration activities, as mentioned in the letter of support provided by Dr. Protz: create controlled polymer matrix composites by 3D printing in low g environments has the potential to reduce up mass and effectively use available resources on Mars for example.

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Experimental Measurement of Granular Flow Free Cooling in Microgravity

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Director/PI: Dr. Leonard Miller

Granular and particulate flows are ubiquitous in our world, from river sediment transport to the formation of planetesimals in a solar system. However, a predictive granular theory and associated model are still out of reach. Because collisions between solid particles are inelastic, a granular system is essentially dissipative and far-from equilibrium, which results in the clustering of particles. There is no consensus about the decay rate of particle kinetic energy in a free cooling state after the occurrence of clustering. Existing theories make distinctive predictions. In the proposed research, these predictions will be examined experimentally. The results will validate and improve the theories. The proposed research will use a novel experimental technology known as magnetic particle tracking (MPT). Since a dense granular flow is usually opaque, advanced optical diagnostic techniques are useless. The magnetic tracking method, in contrast, relies on the magnetic field of a few labeled tracers, which can penetrate commonly used non-ferromagnetic materials. The magnetic tracking method is able to provide the Lagrangian trajectory and orientation of a magnetic particle. Hence, its velocity and kinetic energy can be calculated.

The proposed research constructs a payload with automated MPT measurements of a large ensemble of particles distributed in 3D suitable for flight on a reduced gravity aircraft. This aircraft will expose the payload to short periods of microgravity (~20 s) by flying a parabolic path. The proposed effort collects at least 100 such observations, between which the experiment is reset. The MPT technique will allow for 10 trajectories of particles in each experiment to be reconstructed, allowing computation of the free cooling rate for comparison to theory. Observation and measurement of such a visually obscured particle distribution in microgravity has never been done before. Previous experiments have focused on a small number of particles, 2D distributions, or were constrained by the technical difficulties of gravity so that free cooling rates could not be observed. The first results of this experiment would be data supporting the standing model of free cooling in the absence of clustering under these conditions (3D, large ensemble, microgravity), which are data not known to exist in the literature. After clustering begins, the data collected can help to determine which of the theories explaining the free cooling rate are correct, increasing our understanding of this phenomenon. This explanation would not be possible without microgravity. In addition to making an immediate impact supporting existing scientific understanding, the proposed project reduces the risk of future long-term MPT experiments in microgravity which could better investigate more complicated phenomena.

22-2022 SFO-0005

Activation of Self-folding Origami in Microgravity Environment (AoSOME)

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The goal of the proposed research is to understand the self-folding dynamics of shape memory polymer (SMP) sheets in microgravity. Shape memory polymers can be used as lightweight mechanical actuators to deploy solar arrays or open/close antennas. They offer significant weight savings over motors and are not likely to be affected by lunar dust. Lightweight mechanisms are obtained by pre-straining the polymer so that it shrinks when heated above the glass transition temperature. Specific actuation/folding patterns may be obtained by controlling local energy absorption properties of the material, e.g. via coating. Local heating due to infrared (IR) light absorption by ink patterns produces a gradient of temperature and shrinking through the thickness of the sheet, which induces self-folding. This approach has been demonstrated in ground-based experiments, and the effects of parameters such as ink pattern geometry, darkness, and light intensity have been investigated. Unfortunately, we do not know how SMP actuators adapt to space environments. As these actuators are driven by the release of stored energy, understanding the building blocks of self-folding science will inform the design and development of SMP deployment mechanisms. The effects of space environments, e.g. radiation and vacuum, on polymers have been evaluated through combinations of ground and on-orbit based testing. However, microgravity effects on self-folding can only be approximated in ground-based experiments for the simplest of fold patterns. As a step toward resolving unknown self-folding SMP behaviors, we propose to investigate self-folding of single fold and intersecting fold (e.g. Miura-Ori) patterns in a microgravity environment and to compare the results to ground-based experiments. A suborbital, parabolic flight profile produces microgravity conditions for self-folding that cannot be obtained in a ground-based setting, and characterization of self-folding in microgravity is necessary to advance the TRL for future applications in deployable structures. The objectives of the proposed research follow.

Objective 1: Adapt ground-based apparatus for testing in microgravity flight

The current experimental apparatus consists of four 250 W IR heat lamps and a heated surface. We will adapt this fixture for microgravity testing by securing all components to a test frame, incorporating a preheating chamber, and implementing a system for automating sample placement, self-folding, and recovery.

Objective 2: Design of Experiments Study to Determine Major Drivers for Microgravity Behavior

Parameters to be considered include pattern geometry, ink darkness, sample orientation, light intensity, and initial temperature. This study will enable the test parameters to be finalized in advance of the suborbital flight. Ground-based testing of the selected parameters will be used to validate the modified test apparatus before flight.

Objective 3: Analyze Self-Folding Dynamics in Microgravity
We will perform self-folding experiments in reduced gravity and compare the results to ground based tests. Single fold and coordinated fold patterns will be considered. These tests will enable us to evaluate the effects

of parameters identified in Objective 2 on self-folding dynamics in conjunction with microgravity. The results can be used to calculate the torque available during self-folding, which is relevant to the size limits of a large SMP structure or the mass limit of components that could be deployed by SMP.

The expected impacts of this study are that we will foster the creation of new lightweight actuation mechanisms for the deployment and assembly of emergent space structures. The research will contribute to the Artemis mission in the following ways. SMP actuation mechanisms may be infused into lightweight roll-out structures (TX12.1.1, TX12.1.3, and TX12.2.1) for lunar geophysical in-situ observations, radio and communication devices, and power generation.