Michel LOUGE
Sibley School of Mechanical and Aerospace Engineering
192 Rhodes Hall, Cornell University, Ithaca, NY 14853
e-mail MYL3@cornell.edu
Telephone: (607) 255 4193

SMD Division: Planetary/Lunar Science

Title: Gas-Particle Interactions in a Microgravity Flow Cell

Two projects:

name	status	app. tot. cost	orbit time (hr)	power (W / V)
micro-SiGMA	ready-to-go	$700k	10	500 / 28
SiGMA	post-2010	$1.75m	100	500 / 28

NASA Relevance: ISRU, geophysics, solids processing, dust storms, rocket blast.

Granular materials are ubiquitous on the Moon and Mars. Their processing depends crucially on environmental conditions and particle properties, which are not known with sufficient certainty to guarantee successful equipment design without trial and error. The safe return of astronauts and their protection demands a deeper understanding of the fine-grained material covering the Martian and lunar landscapes. Shelter construction, spaceport maintenance, and In-Situ Resource Utilization (ISRU) all require reliable processing of massive amounts of granular materials with or without gases. The safe landing of large astronaut-bearing spacecrafts on the Moon and Mars is only feasible if rocket blast, which involves interacting gases and solids, can be mitigated to prevent destruction of craft and nearby equipment (Donahue, Metzger and Immer, 2006).

The human exploration of space also brings a convergence of interests between Engineering and Geophysics. An understanding of Martian landslides requires better insight on dynamics of granular materials found at future settlements, such as constitutive relations. Much Martian sedimentary rock is believed to be of volcanic Aeolian origin. Although erosion and dust-lifting mechanisms elicit research on Earth, see for example Ancey, et al. (2006), not enough is known to predict Martian conditions with certainty.

A common challenge in the geophysics and engineering of granular materials is to understand how finely divided solids interact among themselves and with gases. Sand storms, pneumatic transport lines, solid-processing ISRU equipment, mining, excavation, etc, all require such knowledge. Recent progress has been made in simulating small gas-solid systems using Lattice-Boltzmann (Verberg and Koch, 2006; Louge and Xu, 2004). However, these simulations and theories have not yet been validated with experiments.

To do so, until recently, NASA sponsored the SiGMA flight project ("Solids interacting with a Gas in a Microgravity Apparatus"), which was to employ long-term microgravity platforms to elucidate the detailed interactions between a gas and dispersed particles. Conscious of the merits of this work, leading oil, food, chemical, pharmaceutical and mining companies also lend their support through the International Fine Particle Research

Institute. Unfortunately, NASA could not commit resources to complete this and other projects, which NASA-GRC had regrouped in the ISS Granular Flow Module.

From our Science Requirements Document and Test Matrix, NASA-GRC developed a unique axisymmetric Couette cell producing shear flows of gas and agitated solids in microgravity (Fig. 1), to recreate gas-particle interactions at conditions relevant to planetary, industrial and ISRU processes. We demonstrated feasibility of the apparatus by testing prototypes on the KC-135, and with breadboards on the ground.

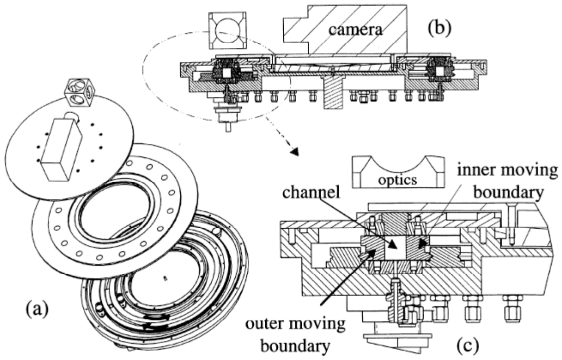

Fig. 1. Sketch of the SiGMA flight shear cell. (a) Exploded view showing counter-rotation of inner and outer boundaries; (b) Cut with channel, camera, optics, pressure and gas distributors; (c) enlarged view.

Unlike Earth-bound flows where the gas velocity must be large enough to defeat particle weight, long-term microgravity makes it possible to create suspensions in which particle agitation and gas flow are controlled independently by adjusting the gas pressure gradient along the flow, the relative motion of the boundaries, and the absolute pressure.

We plan two series of tests. The first, called “Viscous Dissipation Experiments,” characterize the dissipation of particle velocity fluctuations by the gas, without a relative velocity between gas and solids. They are ideal to test theories predicting processes, like fluidized beds, that contacts gases and solids. To that end, NASA-GRC built a flight-certified apparatus (Fig. 2), called “micro-SiGMA”, complete with avionics and controls, for the Microgravity Science Glovebox (MSG). Its mass of 16.6 kg (plus approximately 5 kg of camera system and avionics) and dimensions 0.36 x 0.32 x 0.67 m are well within the bounds of this RFI. It requires no astronaut involvement and is ready-to-go.

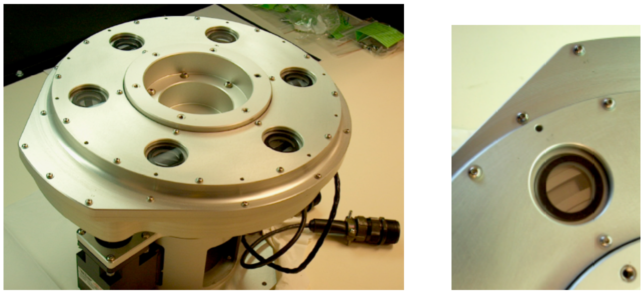

Fig. 2. micro-SiGMA hardware. Right: Detail showing the channel visible through a circular window.

In a second series of tests, called "Viscous Drag Experiments," a gas pressure gradient induces a relative velocity between gas and solids, while the shearing sets the solids agitation independently (Fig. 3). This lets us record how drag depends on solid volume fraction and particle agitation. Partial evacuation also reveals how the particle Reynolds number affects drag. The Viscous Drag experiments inform systems with relative velocity between gas and solids, such as rocket blast, dust storms, and particle separation.

The current status of this project is as follows:

1. We passed the Science Concept Review in May 2000.
2. The micro-SiGMA flight hardware of Fig. 2 is available at Cornell.
3. We have archived NASA-GRC's design of the SiGMA hardware.
4. Our theory predicts behavior of the experiment, and produced the test matrix.
5. We have successfully tested prototypes on the microgravity aircraft and demonstrated feasibility of all computer-vision tracking and instruments.

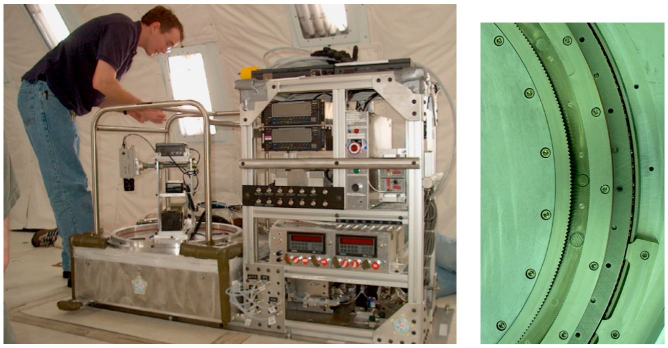

Fig. 3. SiGMA prototype. Left: tests on the KC-135 of motor controls, pressure measurement, capacitance probes, gas manifold, high-speed camera, and computer vision. Right: detail of the channel.

In summary, the SiGMA project includes two potential payloads for deployment on the ISS or elsewhere. They do not require astronaut involvement. The first has existing flight hardware and avionics (micro-SiGMA) and is ready-to-go. The second has already undergone a thorough design; its feasibility has been demonstrated; instruments and computer-vision software exist; complete science requirements and test matrix are available. Its deployment requires a final design of flight-certified hardware, a task that we estimate will take a year. The project will produce unique data to test theories and numerical simulations of broad relevance to human exploration of space, ISRU systems, industrial processes on Earth, and planetary phenomena involving gases and solids.

References

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