

**Mechanical Characterization of  
Lunar Regolith Through Resonant  
Column Procedures**



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style

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**Friday February 19, 2010**  
**Next-Generation Suborbital**

# Outline

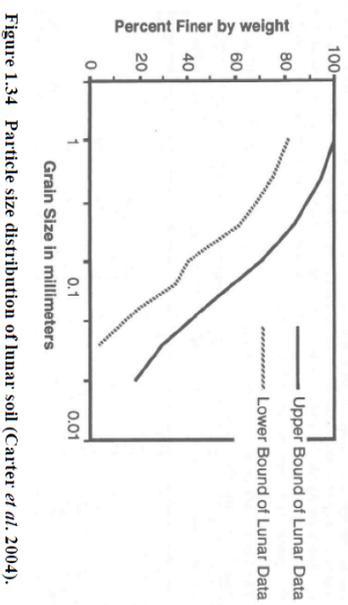
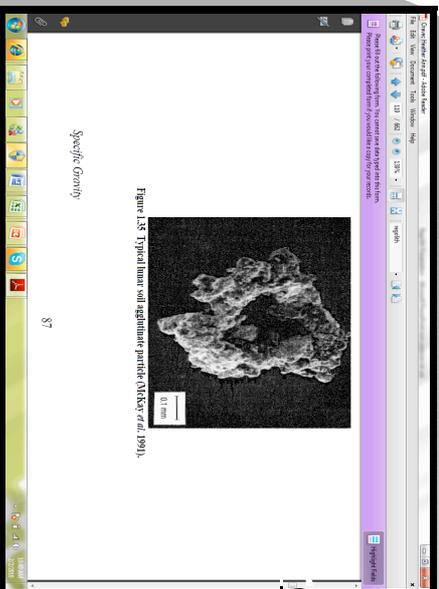
- Motivation for research.
- JSC-1A and JSC-1F lunar regolith simulants:
  - Literature Review
  - Properties
  - Comparison to lunar regolith
- Resonant column apparatus and procedures:
  - Damping Ratio ( $\xi$ )
  - Shear Modulus ( $G$ )
- Particle size analysis and effects on mechanical properties-glass beads.
- Resonant column experiments on lunar regolith.
- Current state of research and future endeavors

# Motivation

- Understanding dynamic responses through the **shear modulus (G)**, density ( $\rho$ ), and **damping ratio ( $\xi$ )**.
- Using common geotechnical testing procedures to estimate a system's behavior on macro-scale levels.
- Obtaining meso-scopic properties of regolith through simulants to predict behaviors.
- Other extraplanetary applications--simulants are the only accessible material.

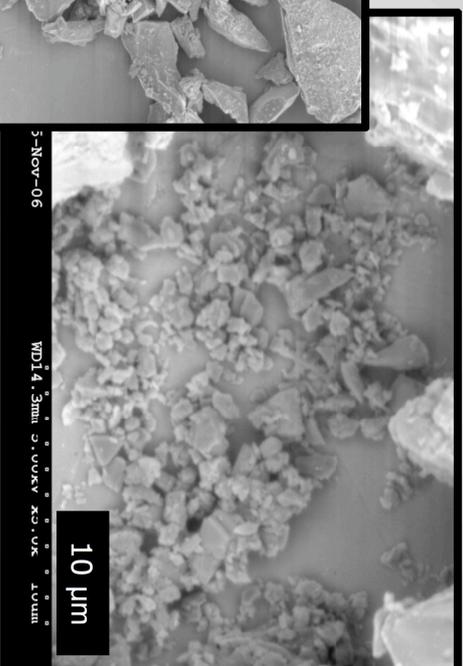
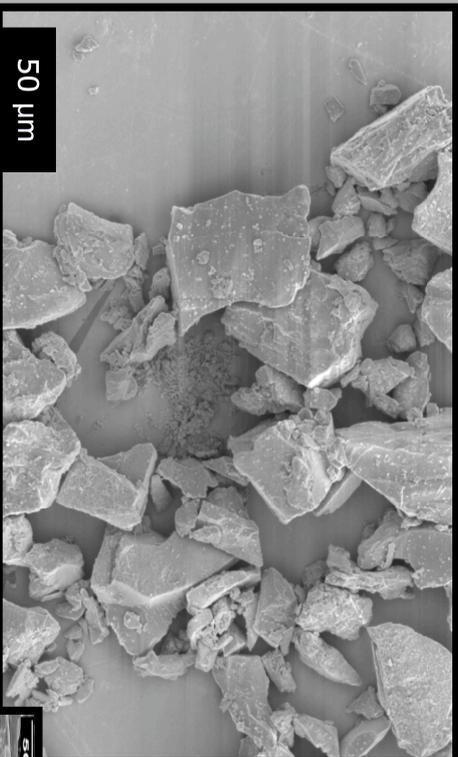
# Literature Review

**Figure 1:** Typical lunar soil agglutinate particle (Mckay *et al.* 1991).

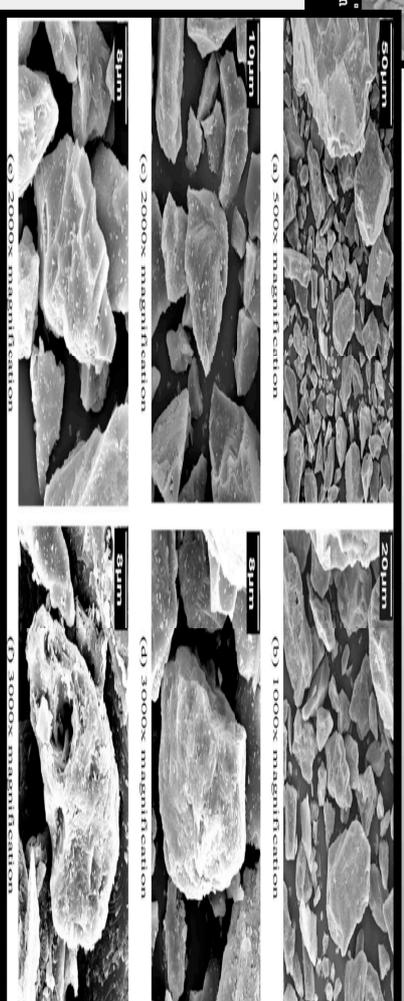


**Figure 2:** Particle size distribution of lunar soil (Carter *et al.* 2004).

# Literature Review



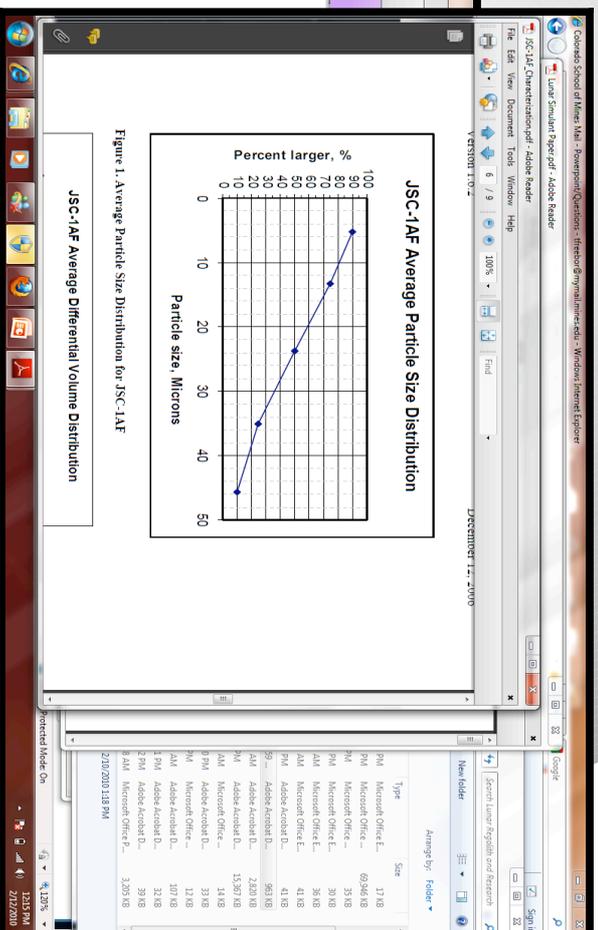
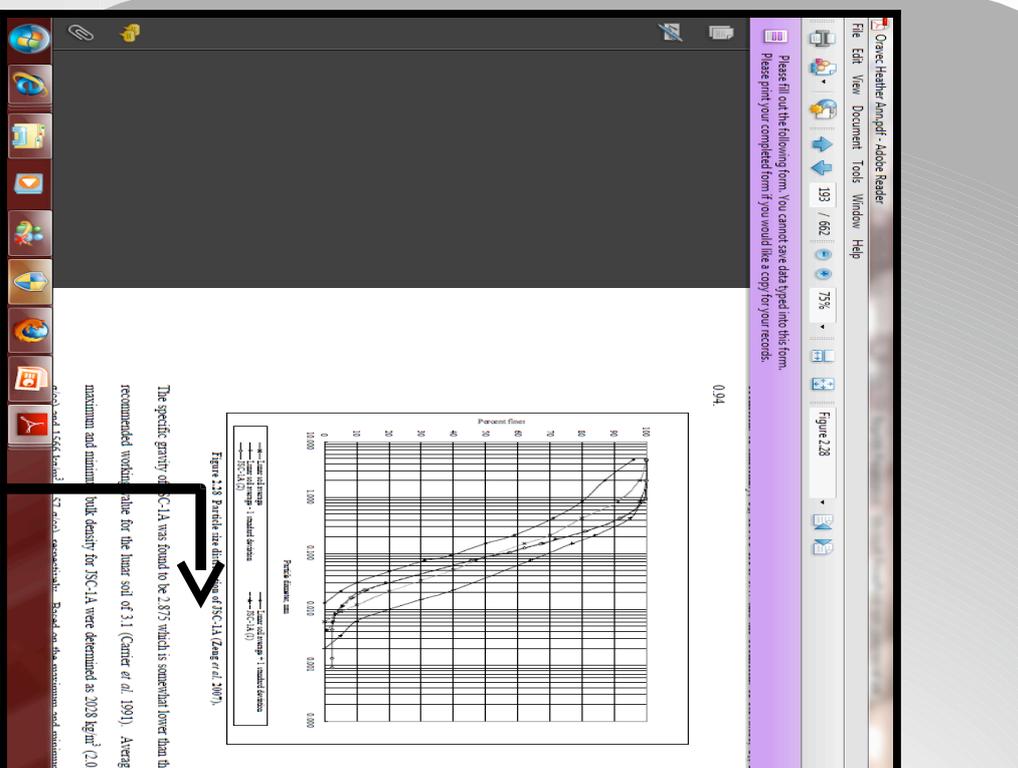
## JSC-1A



**Figures 3 and 4:** High resolution photographs of typical lunar simulant particles.

Pictures courtesy of Oravec, 2006 and Alshibli, 2009.

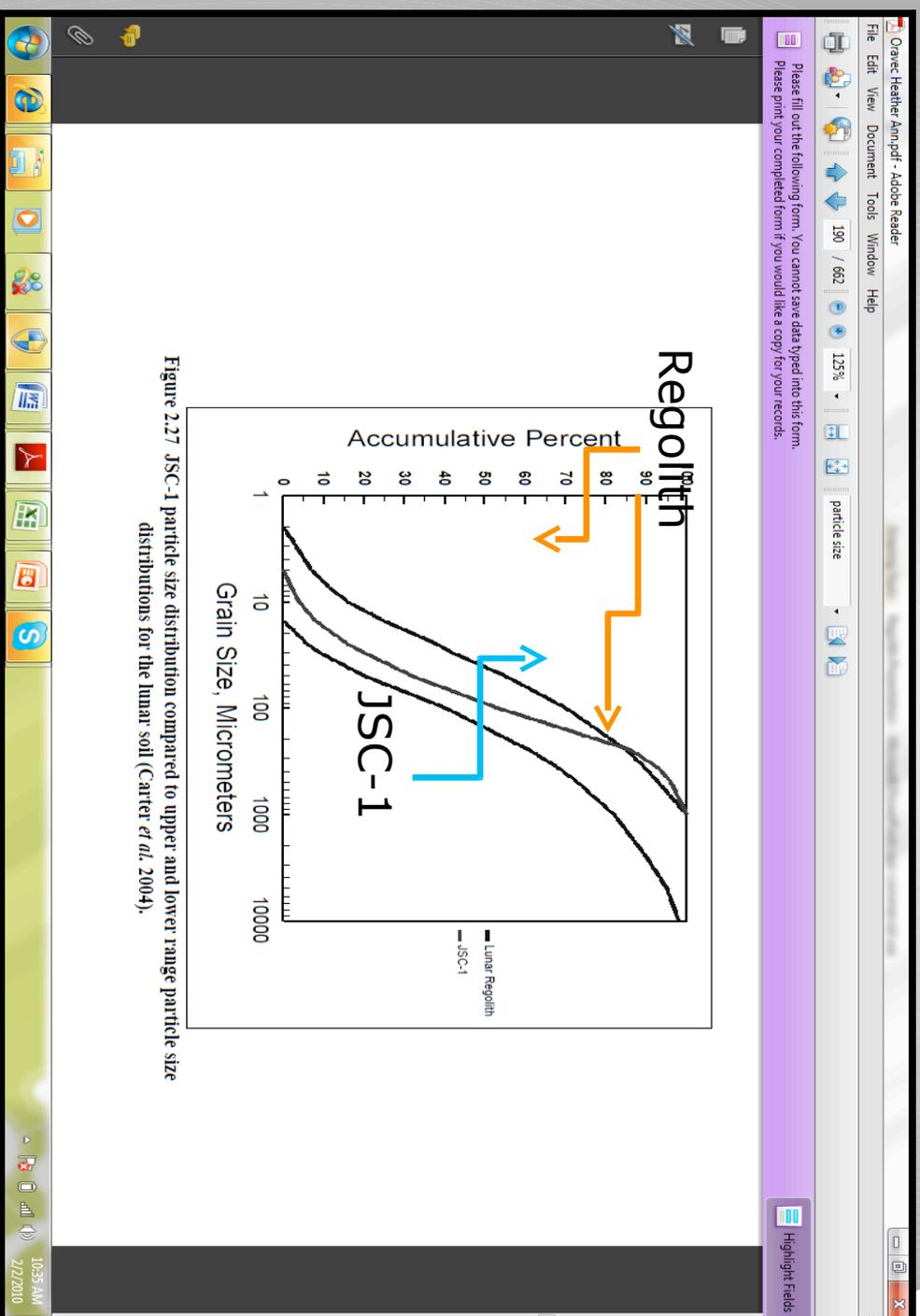
# Literature Review



**Figure 5:** Particle size distribution for JSC-1AF (Oravec *et al.*, 2006).

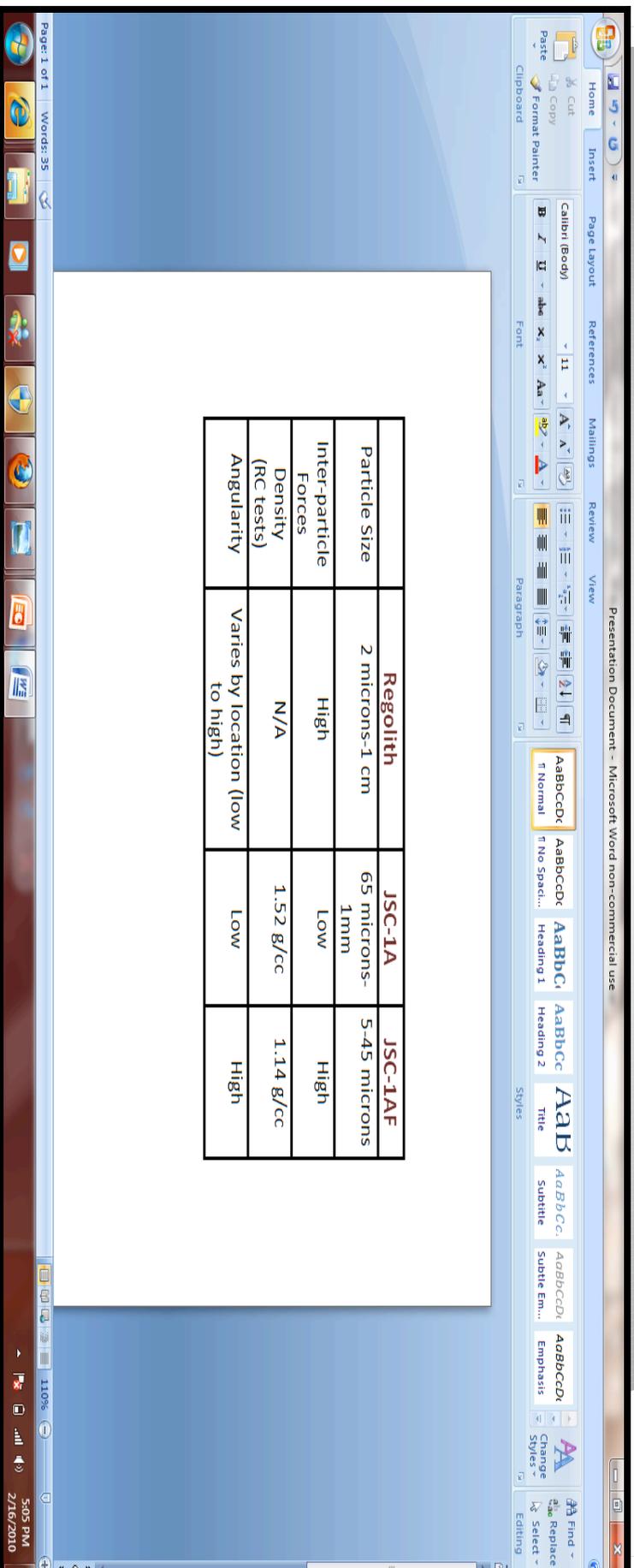
**Figure 6:** Particle size distribution for JSC-1A (Zeng *et al.*, 2007).

# Literature Review



**Figure 7:** JSC-1 particle size distribution compared to upper and lower range particle size distributions for the lunar soil (Carter *et al.* 2004).

# Lunar Regolith and Simulants



The image shows a screenshot of a Microsoft Word 2010 document. The document title is "Presentation Document - Microsoft Word non-commercial use". The ribbon is set to "Home" with the "Font" group selected. The font is Calibri (Body), size 11. The document contains a table with the following data:

	Regolith	JSC-1A	JSC-1A-F
Particle Size	2 microns-1 cm	65 microns-1mm	5-45 microns
Inter-particle Forces	High	Low	High
Density (RC tests)	N/A	1.52 g/cc	1.14 g/cc
Angularity	Varies by location (low to high)	Low	High

**Figure 8:** Comparison of properties of lunar regolith versus JSC-1 simulants.

(Data courtesy of H. Oravec, 2009. )

# Resonant Column Tests

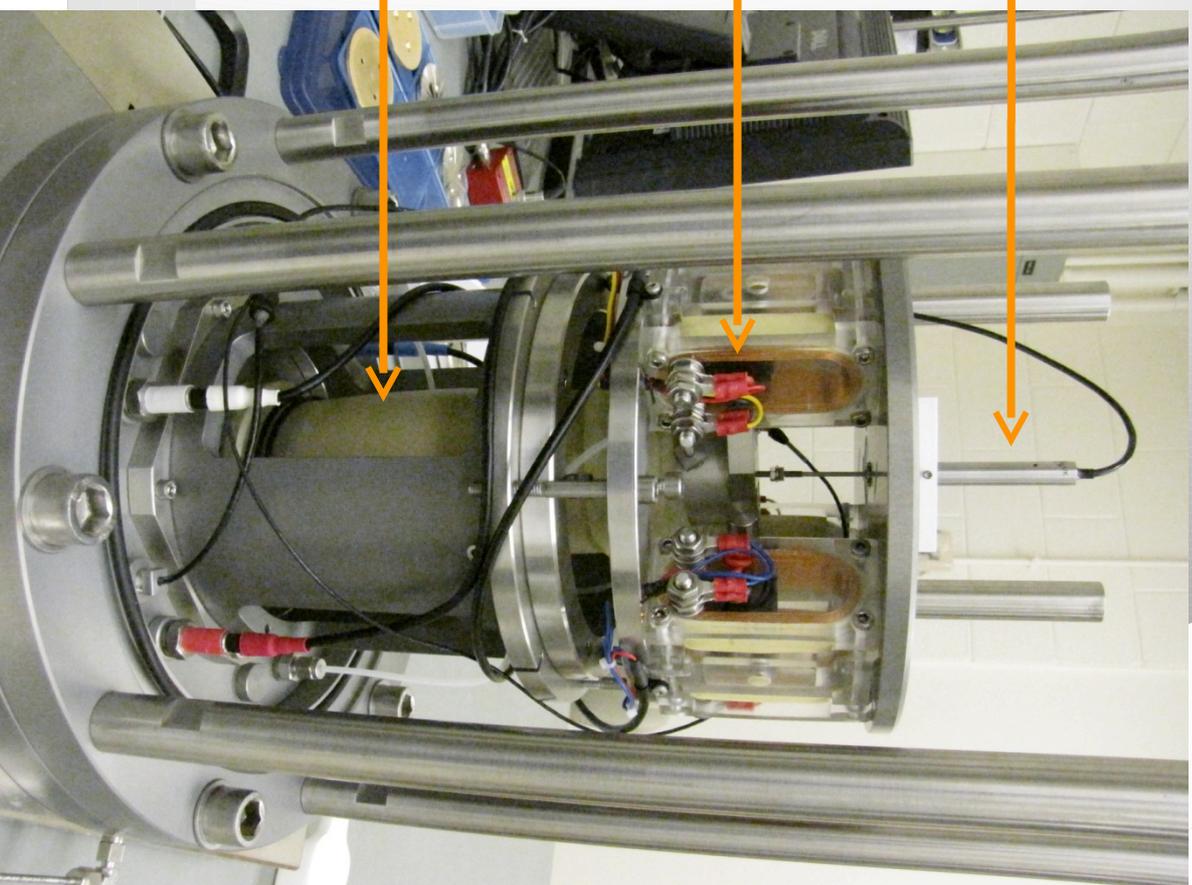
- Air Pressure Tube
- Cell Cover
- Confinement Cell



Picture courtesy of A. Ham, 2008.

# Resonant Column Tests

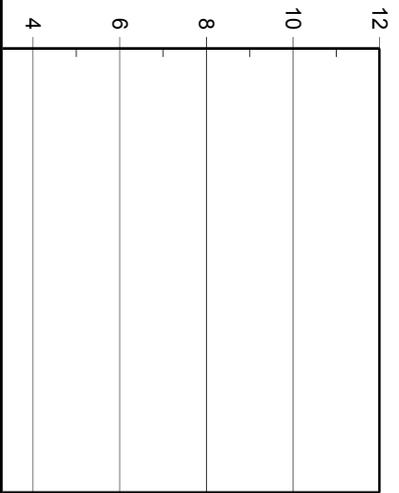
- LVDT (measures displacement)
- Magnetic Coils/Magnets (motor device)
- Sample (140x70mm)



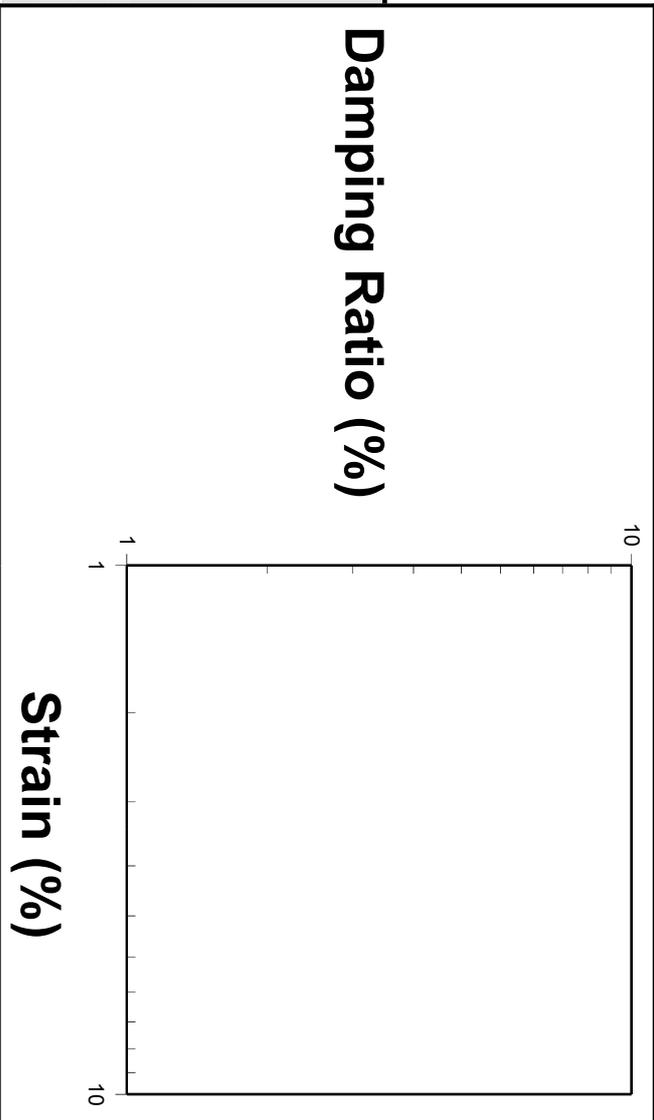
Picture courtesy of A. Ham, 2008.

# Resonant Column Tests

Typical Data-Sand



Strain Dependent Properties



Courtesy of A. Ham,  
2008.

# Particle Size Trends

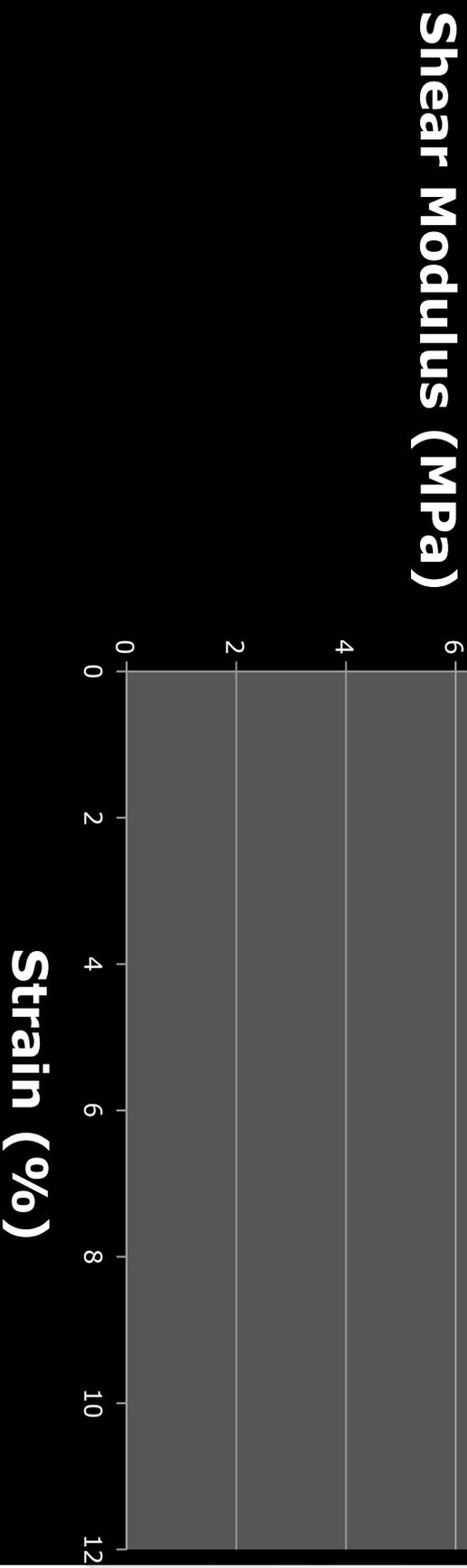
## Glass bead analysis

- Isolate particle size trends in order to understand meso-scale behavior by looking at parts of the whole.
- Observe meso-scale behavior so that eventually angularity and sphericity may be taken into account.

# Particle Size Trends

## Glass bead analysis

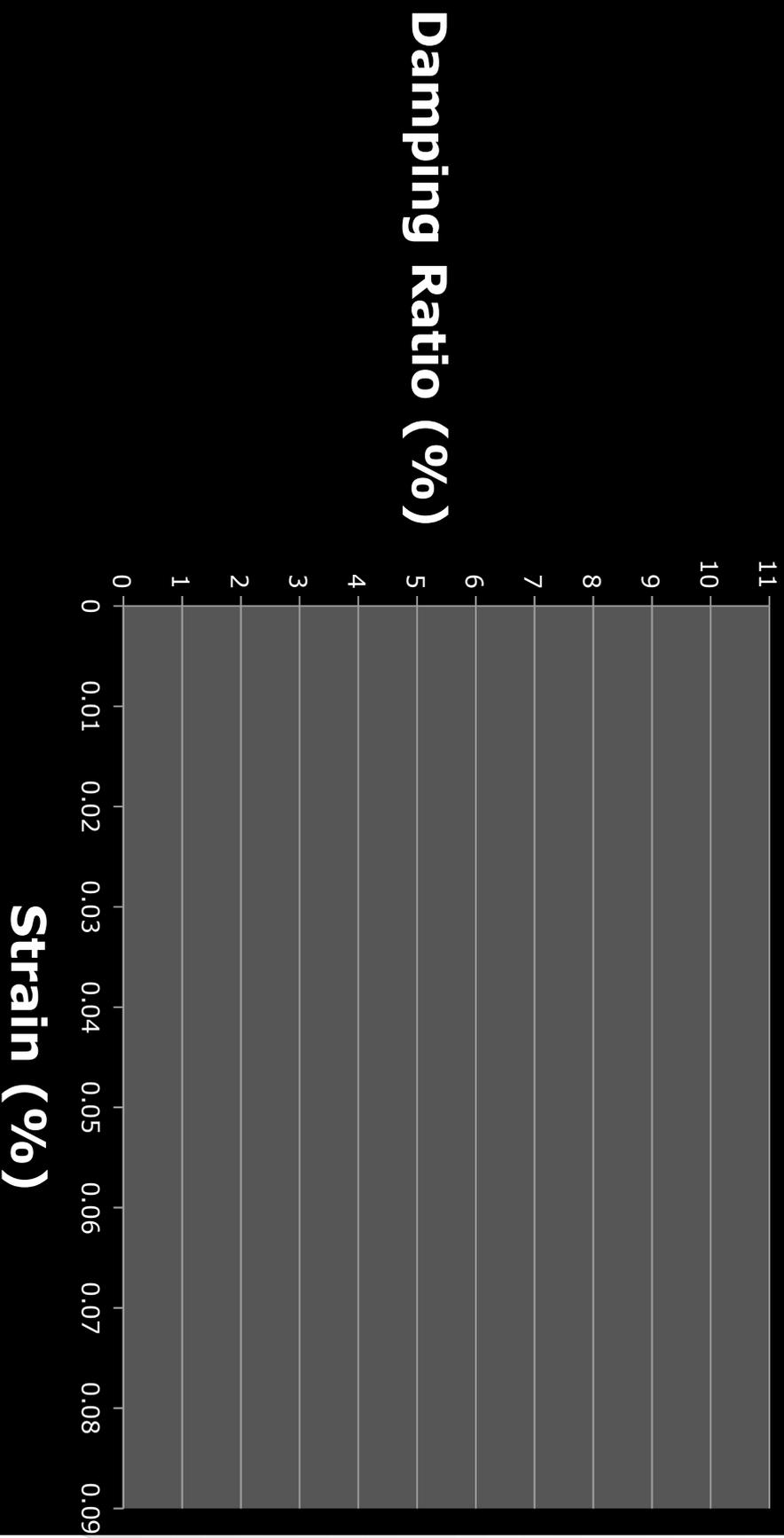
### Shear Modulus for Glass Beads



# Particle Size Trends

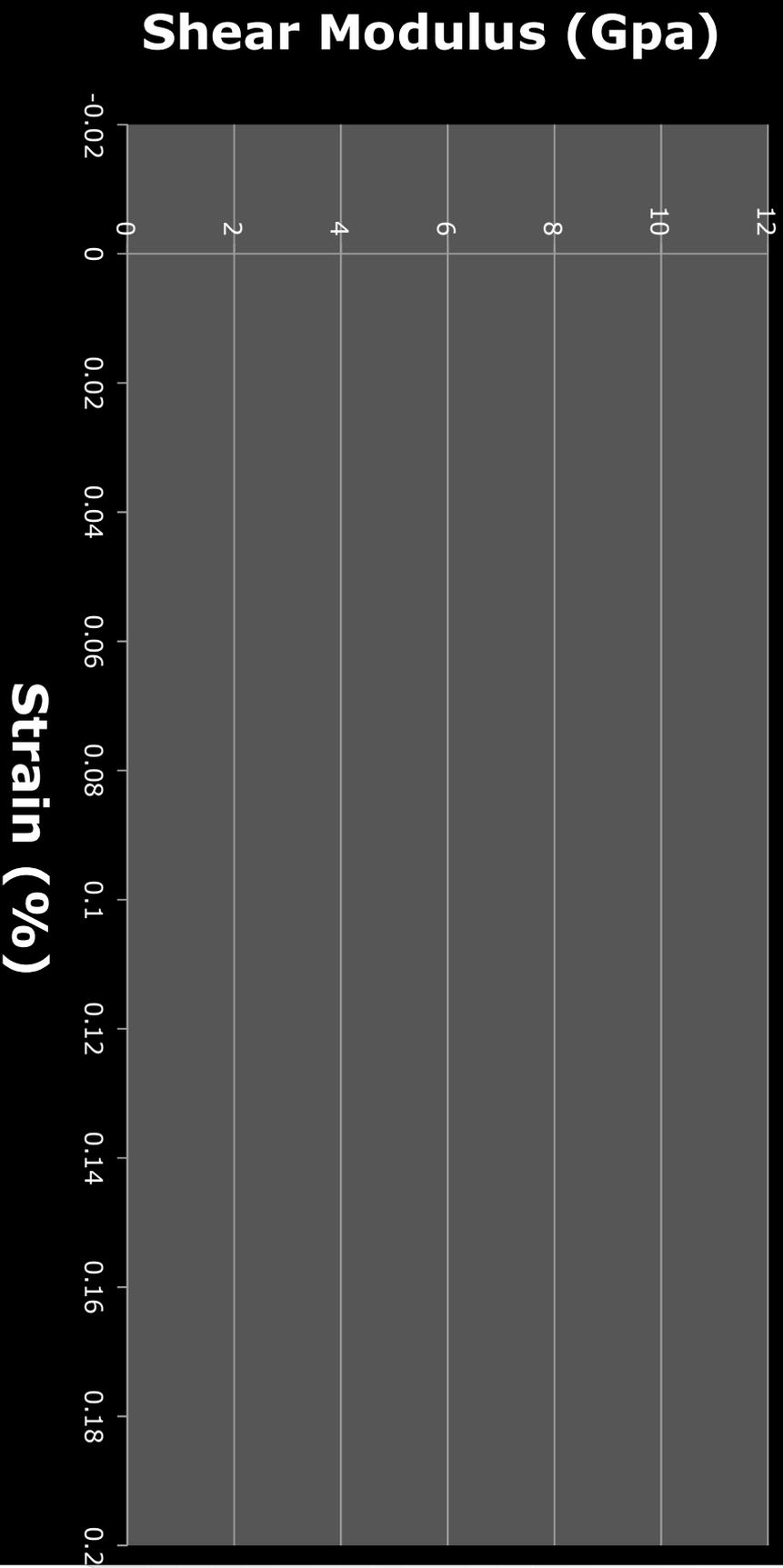
Glass bead analysis

## Damping for Glass Beads



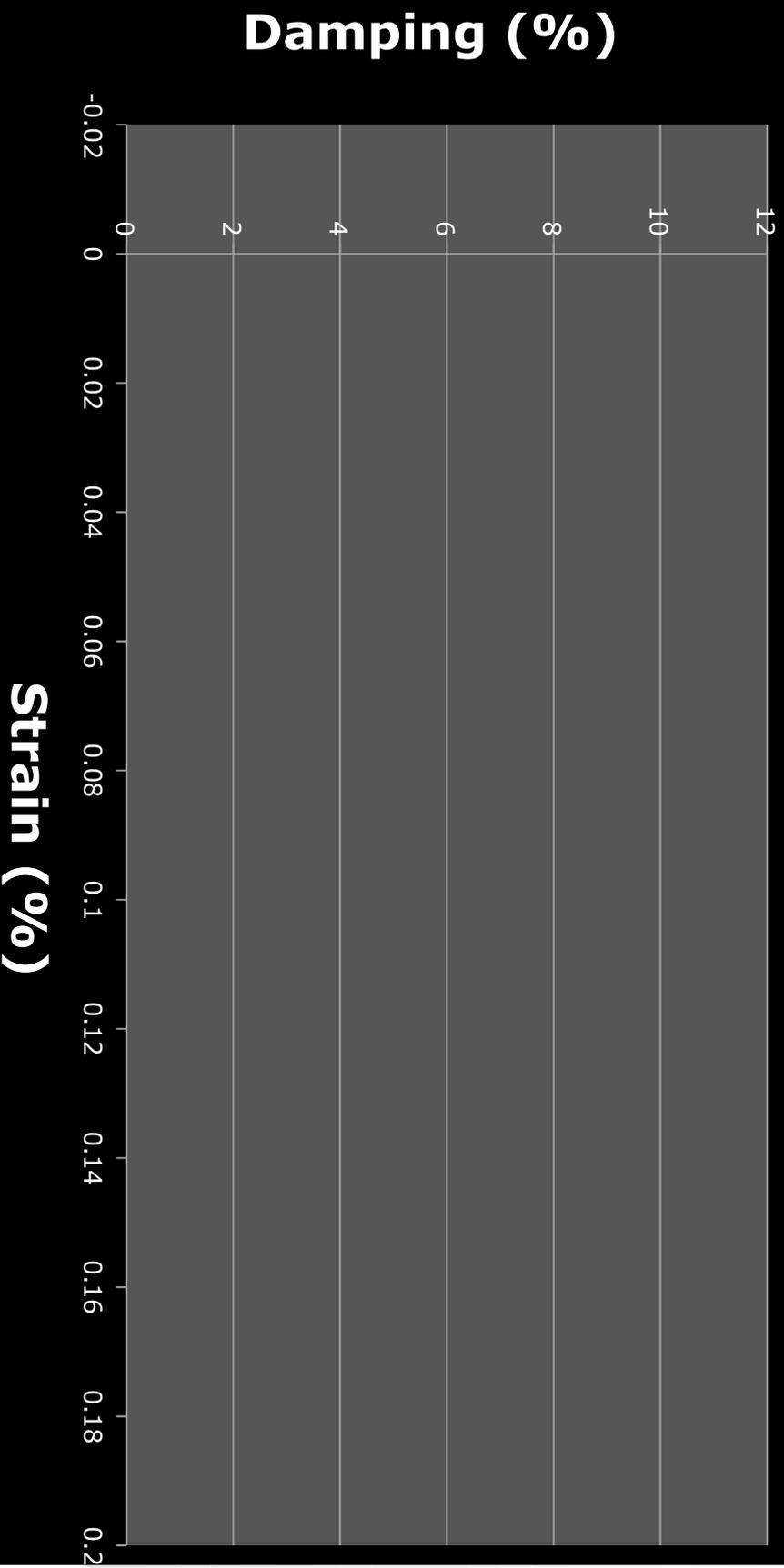
# Resonant Column Tests on Lunar Regolith Simulants

## Shear Modulus



# Resonant Column Tests on Lunar Regolith Simulants

## Damping Ratio



# Particle Size Trends

## Applying glass bead analysis to lunar regolith

	Resonance (Hz)	Damping (%)	G (Mpa)	Density (g/cm <sup>3</sup> )
JSC-1AF .005-0.045mm	45-59	0.48-4.78	14-23	1.14
JSC-1A .065-1mm	46-69	0.47-4.68	19-43	1.52
0.1 mm glass beads	76-95	0.47-3.01	51-78	1.49
2.5 mm glass beads	103-112	0.31-1.843	96-115	1.54
3.5 mm glass beads	109-117	0.20-1.837	109-124	1.55
6.35 mm glass beads	118-124	0.28-1.31	126-139	1.55

# Lower Gravity / Lunar Topography

- Studies on importance of particle size in low gravity environments.
- Inter-particle forces.
- Topography of the moon and differences in lunar soils.
- Other extraplanetary investigations.

# Current State of Research/ Future Work

- Trends are apparent but need to be fully understood through further study:
  - **Damping is inversely proportional and increases as particle size decreases.**
  - **Shear Modulus (stiffness) is proportional and increases as particle size increases.**
- Inter-particle forces most likely play a large role on regolith properties.
- Lunar regolith simulants must be studied to understand the complexities of lunar soils.

# Acknowledgements

- **Dr. Judith Wang**  
Colorado School of Mines
- **Dr. Masami Nakagawa**  
Colorado School of Mines
- **Dr. Heather A. Oravec**  
Nasa Glenn Research Center
- **Andrea Ham**  
Graduate Student, Colorado School of Mines