# Lunar regolith simulant requirements: Mechanical properties considerations.

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# Outline

- Projects & needs
- Properties of interest
- Approach
- Quantity/cost considerations
- Suggestions

# ESRT Extramural: Project Titles

- Modular Regolith "Characterization" Instrument Suite for Construction and In-Situ Resource Utilization Surveys
  - Lead Agency: CRREL – Dr. Jerome Johnson
  - Duration: 4 years
  - Partners: Jet Propulsion Lab, Honeybee Robotics, Los Alamos National Lab, Univ. of Arizona, Kennedy Space Center & ERDC-GSL
- Lunar Regolith Handling "Construction" Equipment.
  - Lead Agency: Caterpillar – Paul Corcoran
  - Duration: 2 years
  - Other Partners: CRREL, Kennedy Space Center, Johnson Space Center & Honeybee Robotics

# Properties of interest

- Quasistatic mechanical properties
  - Modulus
  - Cohesive strength (short term/higher rates related to cutting)
  - Short-term compressive & shear strength
  - Long-term compressive creep/consolidation
  - Internal friction, angle of repose
  - Friction and adhesion with metal (re: drilling/excavation)
- Dynamic mechanical properties
  - P & S Wave speed and attenuation
  - Granular flow
- Grain-scale physical properties
  - Grain size distribution
  - Specific gravity
  - Angularity/surface roughness characteristics

# Characterization of simulant

- Laboratory-scale testing
- Mechanical properties as a function of:
  - Bulk/relative density
  - Grain size distribution*
  - Stress state
  - Loading rate
  - Ice content
    - Distribution
    - Temperature

*Suggest that gradation be treated as a variable.

# Rationale for physically based approach

- Some applications in the ESRT program will require predictions of engineering properties of the regolith based on rudimentary characterizations supplied by precursor missions.
- Physical and therefore mechanical properties of the regolith will vary with location.
- Terrestrial work on simulants should recognize this and treat the simulant properties as variables.
- This suggests that we should - to the extent possible - adopt a mechanistic (vs. empirical) approach to our characterization of simulants to account for material variability.

# Additional considerations

- Particle bonding issues
  - Type of bonding (water ice, $CO_2$)
    - Need to quantify effects of low ice concentrations (most previous work examined only saturated case)
  - Influence on strength and friction
- Analytical approach will influence characterization methods
  - Grain-scale micro-mechanics to support DEM modeling
  - Bulk behavior to support continuum mechanics approach

# Quantity/cost considerations

- Characterization project
  - If the simulant is relatively inexpensive: 40-50 $m^3$
  - If it is expensive: up to 5 $m^3$

  These quantities will support individual instrument testing by the developers and work in the planned CRREL test bed (to -40C) and at the KSC regolith chamber.
- Construction project
  - Tons

# Suggestions
## Selection and characterization of the simulant

- Must have the proper mechanical properties
  - Chemical, thermal and optical properties are secondary considerations
- Relatively inexpensive
- Consider a consolidated testing effort to:
  - Economize
  - Provide a consistent set of properties to interested parties
- Details of the testing effort should be developed jointly among experimentalists, modelers and engineering application specialists.
- Develop an interim simulant source to accommodate immediate project needs