POLITECNICO DI TORINO

Department of Mechanical and Aerospace Engineering

Development of a sample chain for Enceladus surface sample acquisition

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JVSRP – JPL Visiting Student Research Program

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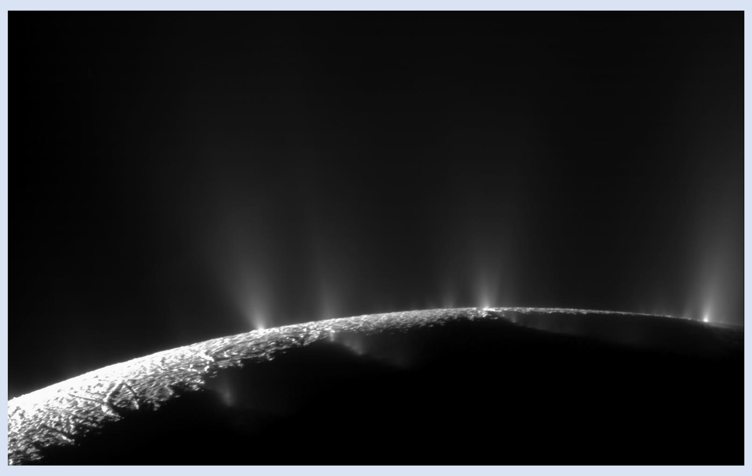
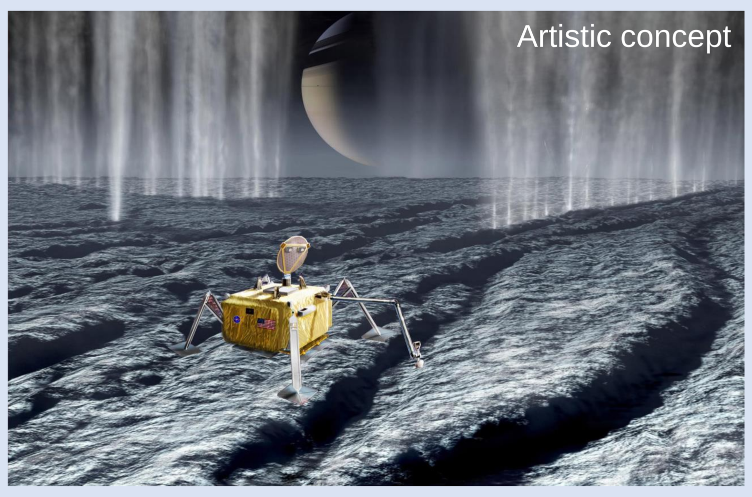
1. Background

A mission to the surface of Saturn's moon Enceladus could determine if life exists beyond Earth since ejected plume material from the subsurface ocean has fallen onto the benign surface.

- Saturn's moon Enceladus is one of the most promising places in the Solar System that might potentially host the life beyond Earth.
- The Cassini mission observed material from the subsurface ocean being ejected by plumes and then settling on the surface.
- A potential future mission landing on the surface of Enceladus would have the goal of collecting surface samples for in-situ analysis.
- The low radiation environment would help preserving the chemical composition of samples deposited on the surface.
- The low surface gravity of Enceladus (1% of Earth's gravity) represents a unique challenge for sample collection and handling.



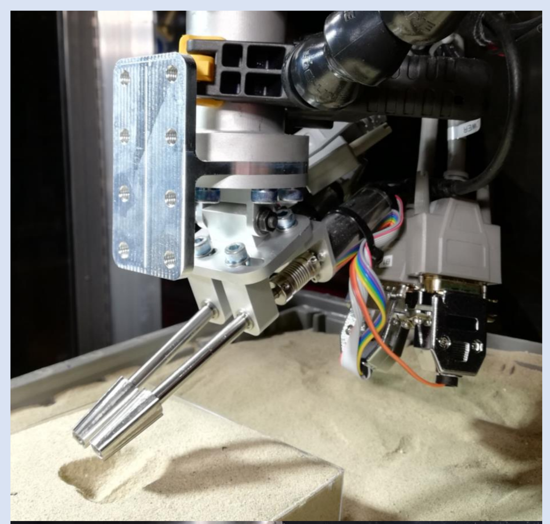


Artistic concept

2. Problem definition

Develop a sampling system generating low reaction forces and capable of dealing with a wide range of surface properties. Investigate tool-soil interaction and resulting material flow to support the sampling system design.

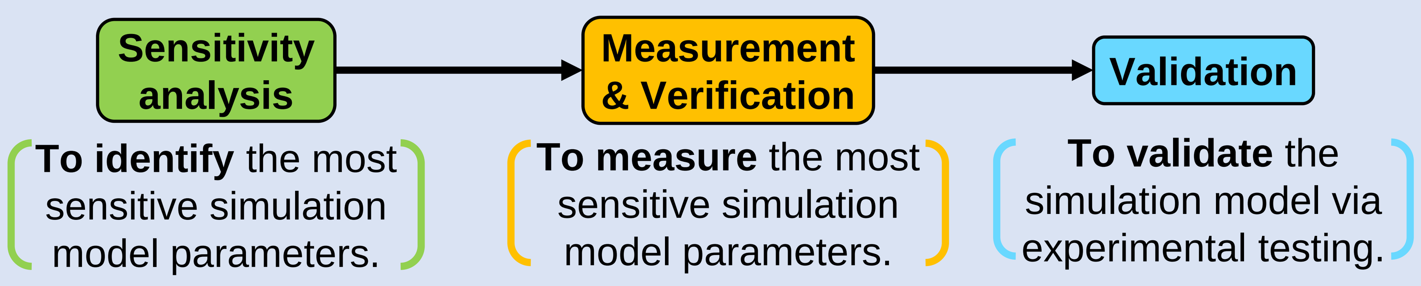
- The Dual Rasp sampling tool is being considered to acquire surface samples.
- The sampling tool exploits the combination of two high-speed, counter-rotating cutters to enable rapid sampling and collection of surface material into receptacles via momentum transfer.
- The sampling tool shall collect ten 1cc to 5cc samples from top 1cm with 40-95% porosity and 400 kPa to 12 MPa unconfined compressive strength.
- Investigate the tool-soil interaction and the resulting granular material flow. Develop strategies to guarantee successful sample collection.



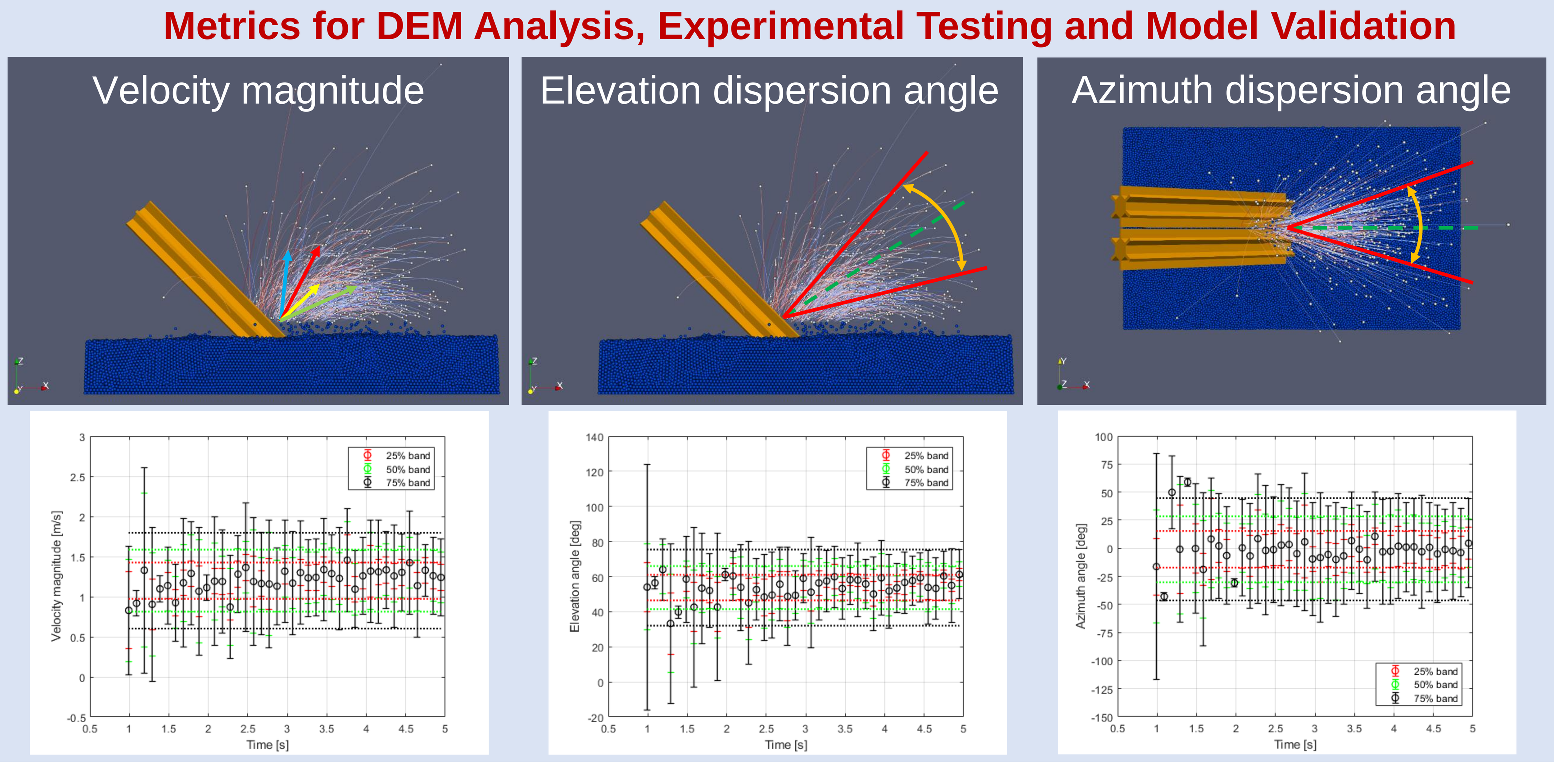
3. Approach

A numerical model based on the Discrete Element Method (DEM) was developed to investigate the tool-soil interaction and the resulting material flow. A set of metrics was developed to characterize both the simulated and the experimental material flow for apples-to-apples comparison.

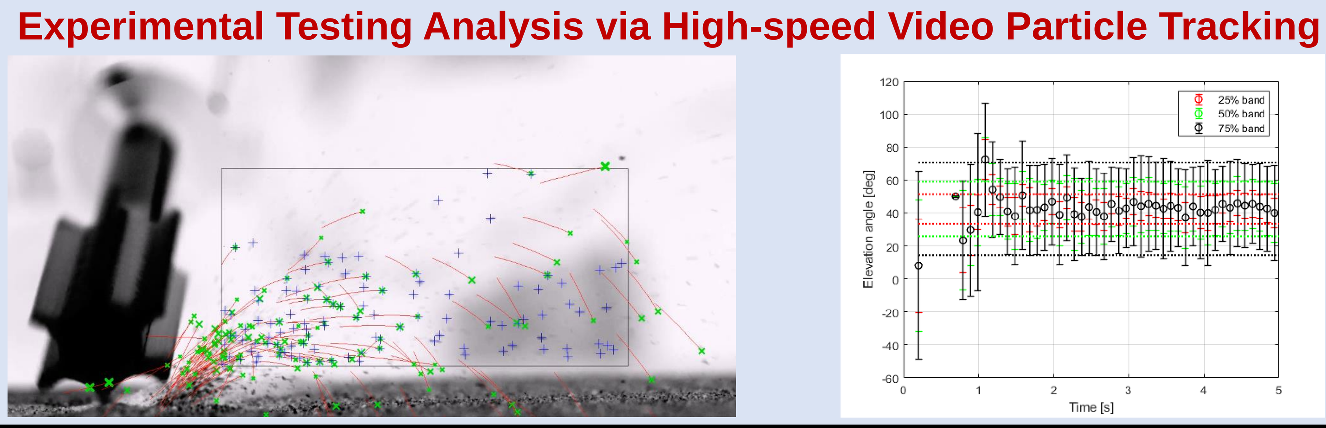
DEM Model Validation Process



Metrics for DEM Analysis, Experimental Testing and Model Validation



Experimental Testing Analysis via High-speed Video Particle Tracking



4. Results

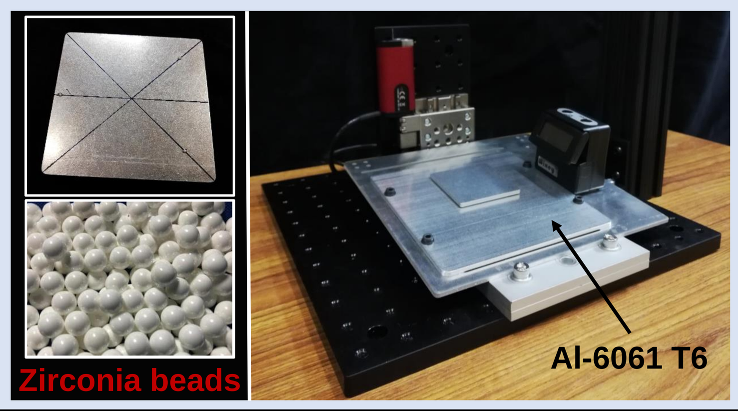
The most sensitive DEM model parameters influencing the granular flow were determined and directly measured via independent tests performed by using custom designed apparatus.

Sensitivity Analysis of DEM Model Parameters

Parameters	Metrics: Velocity magnitude	Metrics: Azimuth angle	Metrics: Elevation angle
Particle Young's Modulus	0.50	0.42	0.42
Particle Poisson's ratio	0.33	0.25	0.25
Particle density	0.33	0.25	0.25
Particle-particle coeff. static friction	0.50	0.42	0.42
Particle-particle coeff. restitution	0.50	0.42	0.42
Particle-particle coeff. rolling friction	0.33	0.25	0.25
Particle-tool coeff. static friction	**0.92**	**0.75**	**0.75**
Particle-tool coeff. restitution	**1.00**	**0.75**	**0.75**
Particle-tool coeff. rolling friction	0.42	0.42	0.42

Measurement of DEM Model Most Sensitive Parameters

- The particle-tool coefficient of static friction was measured by performing an inclined plane test. A value of 0.15 ± 0.01 was found.
- The particle-tool coefficient of restitution was measured by performing a particle drop test. A preliminary value of 0.65 ± 0.05 was found.

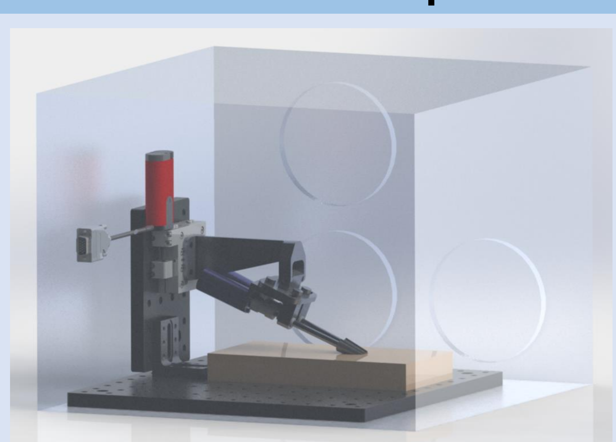


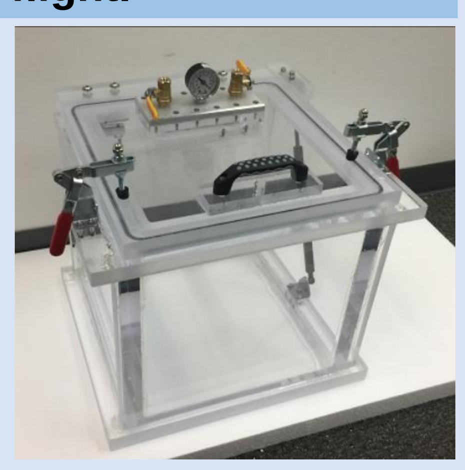
Preliminary DEM-driven design of sample collector

- DEM modeling is being used to drive the design of a sample collector.
- The first design iteration of the sample collector has been completed and a prototype has been built.
- Preliminary test results qualitatively agree with DEM simulation results.

5. Future work

DEM model 1g experimental validation is planned to be conducted by using a clear acrylic vacuum chamber. Future work aims to submit a proposal for conducting a low-g experimental validation on a parabolic flight.





6. Publications

- D. Riccobono, S. Moreland, P. Backes, G. Genta, *Discrete element modelling of low-gravity sample collection and transfer operations for Enceladus surface acquisition*, Engineering Mechanics Institute Conference, 2019.
- D. Riccobono, S. Moreland, P. Backes, G. Genta, *Modelling of pneumatic sample transport systems for Enceladus surface acquisition*, 11th IAA Symposium on the Future of Space Exploration, 2019.
- M. Badescu, P. Backes, S. Moreland, A. Brinkman, D. Riccobono, *Sampling tool concepts for Enceladus lander in-situ analysis*, IEEE Aerospace Conference, 2019.
- D. Riccobono, S. Moreland, P. Backes, G. Genta, *Granular flow characterization during sampling operation for Enceladus surface acquisition*, ASCE Earth & Space Conference, 2020 (abstract submitted).

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