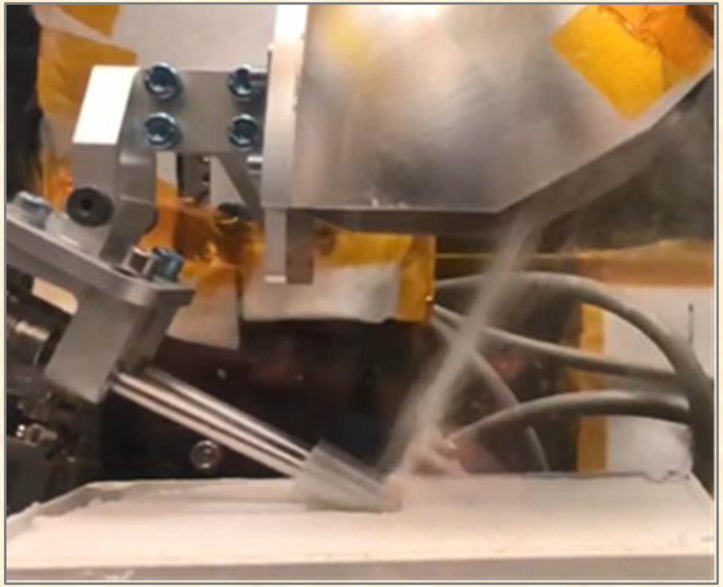

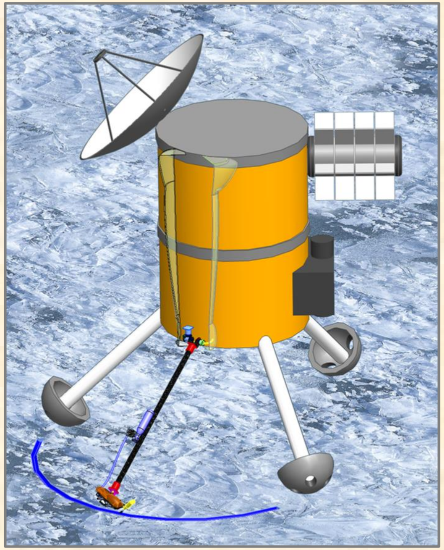

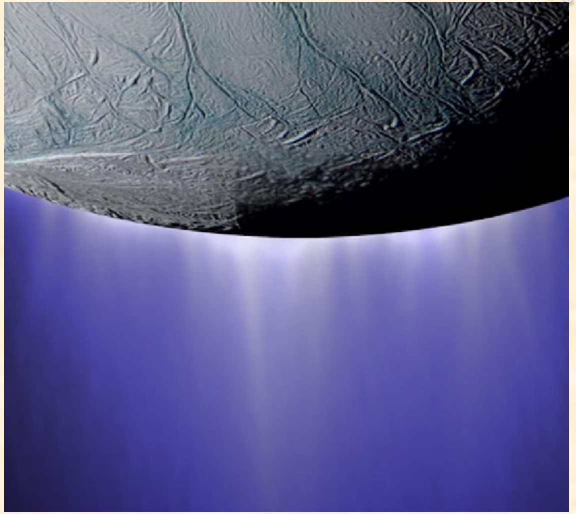

Virtual Research Presentation Conference 2020

Enceladus Surface Sample Acquisition for In Situ Measurements

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Program: R&TD Strategic Initiative

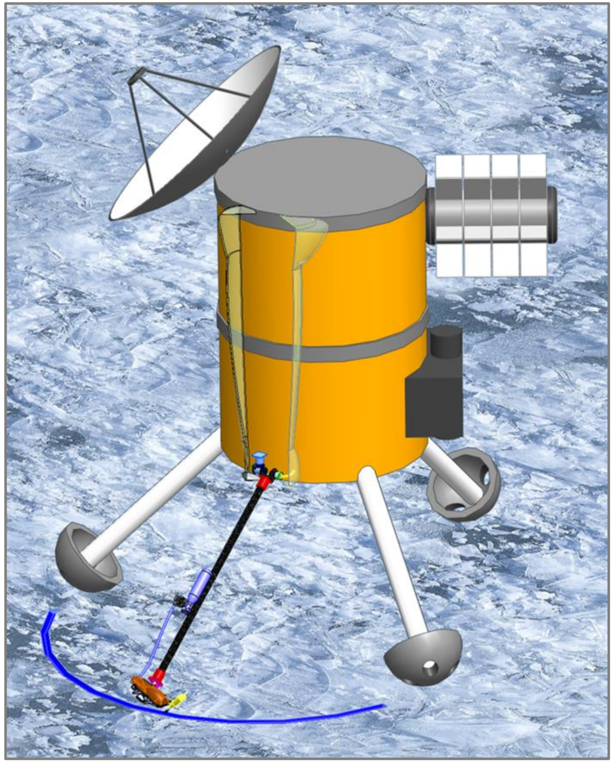
Presentation # RPC-259

Jet Propulsion Laboratory
California Institute of Technology

Tutorial Introduction

Abstract

The Dual-Rasp sampling system is being developed to acquire and transfer samples to science instruments on a potential Enceladus lander. The potential range of mechanical properties of the Enceladus surface are being determined by performing ice sintering experiments and developing a model of the ice sintering process. The Enceladus surface environment provides unique challenges for a sampling system including 1% of earth's gravity, vacuum, cryogenic temperatures, and a potentially large range of surface mechanical properties. A two degree-of-freedom robotic arm would deploy the sampler to enable sampling across an arc in front of the lander. Counter-rotating rasps are used for sample acquisition and pneumatic sample transfer is used to transfer the sample to the inlet port of science instruments.

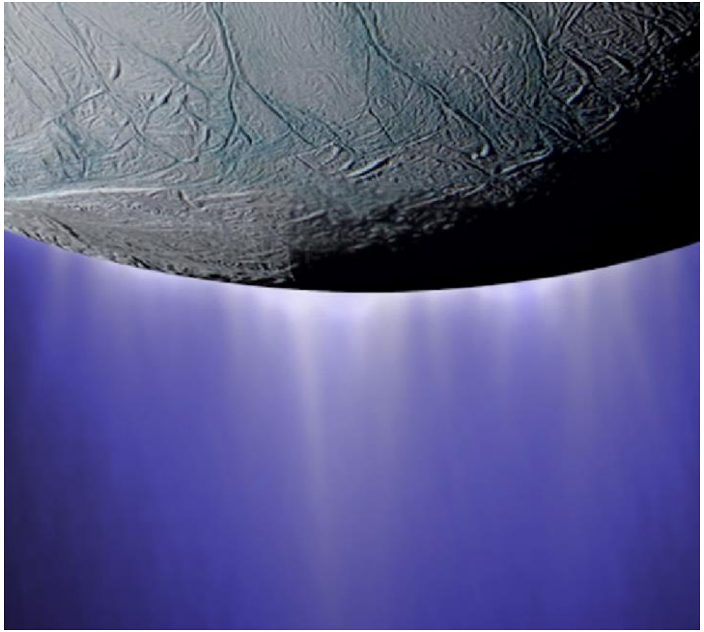


Concept Drawing

Problem Description

Motivation:

An in-situ mission to the surface of Enceladus could be the lowest cost mission to determine if life exists beyond Earth since material from the subsurface ocean is being ejected by plumes and then falls to the surface where it accumulates. Findings from the Cassini mission indicate that Enceladus has the three ingredients necessary for life: liquid water, chemicals, and energy from hydrothermal activity.



Problem Description

State-of-the-art sampling systems:

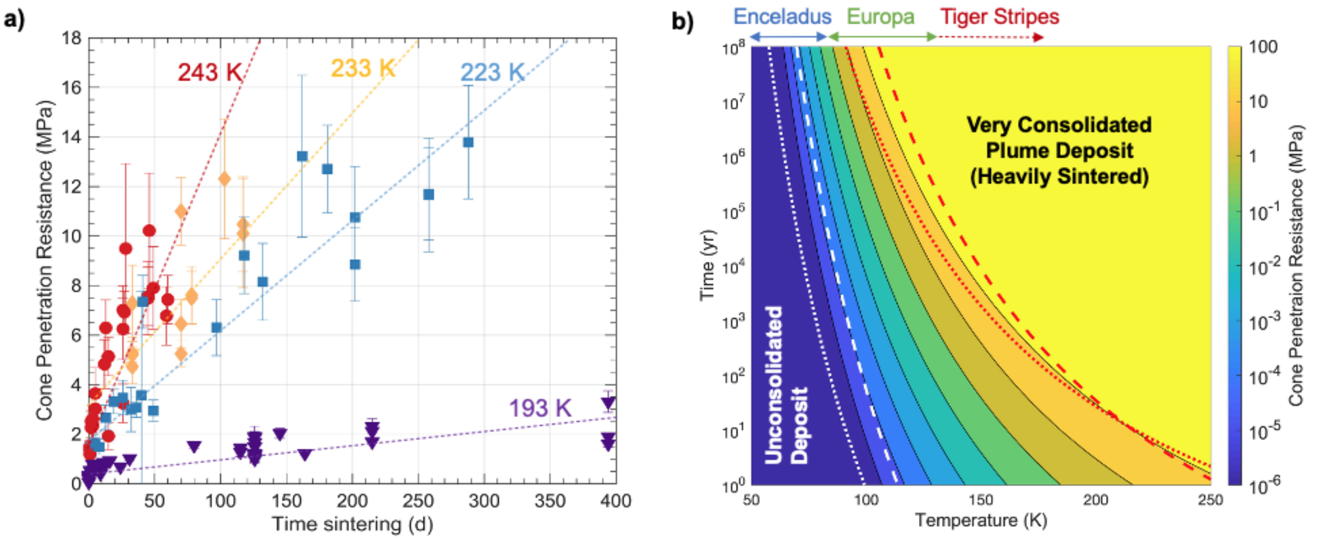
Existing sampling systems do not meet the unique requirements of an Enceladus lander mission.

- The potentially strong surface material precludes sampling tools that only work for weak material such as the OSIRIS-REx mission TAGSAM sampler or the CAESAR comet sample return sampling system.
- The low reaction force to maintain lander stability in 1%g precludes high reaction load sampling tools such as the Mars Science Laboratory powder drill.
- The BiBlade developed for comet surface sampling and Brush Wheel Sampler developed for asteroid surface sampling were designed for high reaction loads available in a touch-and-go mission architecture where spacecraft mass reacts sampling forces up to 1000s of N.
- The Rosetta mission Philae lander SD2 drill could only acquire weak material, and along with the Phobos Grunt mission CHOMIK percussive drive tube sampler, are poorly suited for collecting shallow surface material.

Methodology

1-bar isothermal sintering experiments

- Fine grained porous ice samples prepared in amounts up to 2.2 kg by atomization into liquid nitrogen.
- Samples evolved for several months at 4 temperatures, cone penetration resistance routinely measured.
- Arrhenius analysis allowed to model effect of temperature.

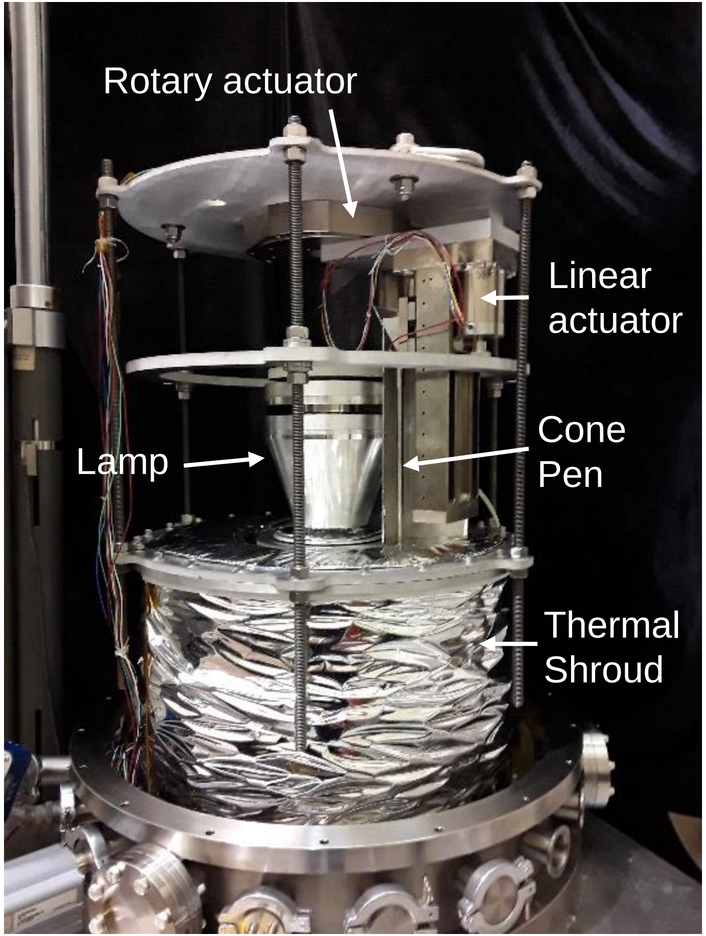


a) Evolution with time of the cone penetration resistance of ice plume deposit analogs at several temperatures. *b)* Predicted cone penetration resistance of icy plume deposits as a function of temperature and sintering time. Black contours are for the best-fit activation energy value. Dashed and dotted contours illustrate the effect of the uncertainty on activation energy. For legibility, these contours are only shown for the 10^{-5} (white) and 100 MPa (red) cone penetration resistance levels. After Choukroun et al., *GRL* **47**, p.e2020GL088953, 2020.

Methodology

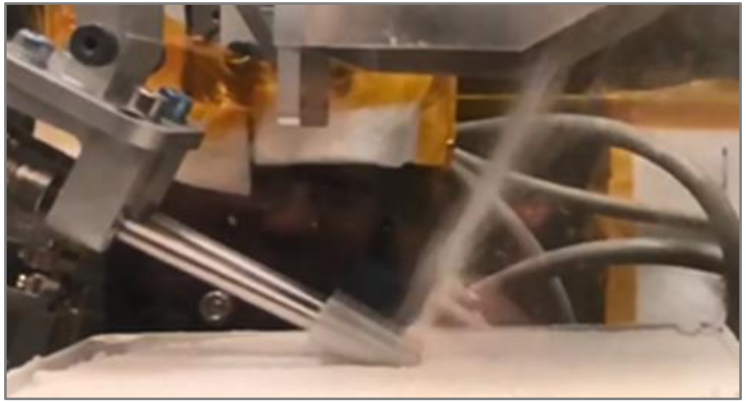
Icy Bodies Simulator (IBoS) Development

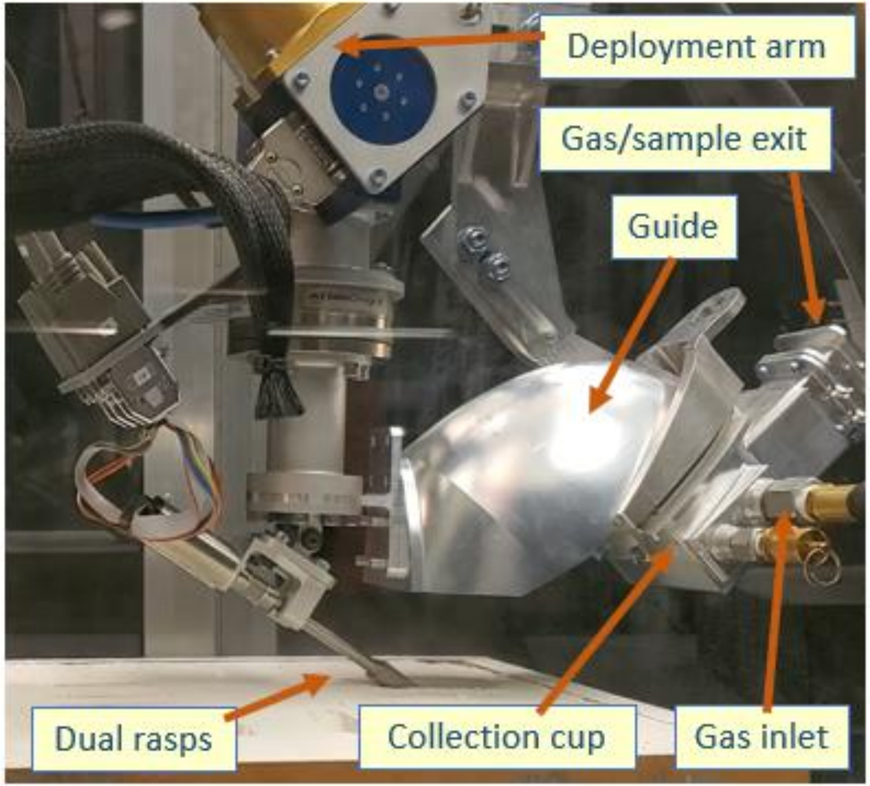
- IBoS module within high-vacuum cryogenic chamber will be used for ice sintering experiments under Enceladus surface conditions.
- IBoS module was built and installed in vacuum chamber, and FY20 was spent working on interfaces.
- Developed lamp calibration procedure and purchased sensors and stages for testing.
- Developed all plumbing for lamp cooling, sample preparation, liquid nitrogen.
- Developing electrical and thermal interfaces for testing in FY21.



Methodology

- Counter-rotating rasps break apart surface material and throw it up between them for capture in a collection cup.
- Rasps are able to acquire a wide range of weak to strong materials with a low sampling preload.



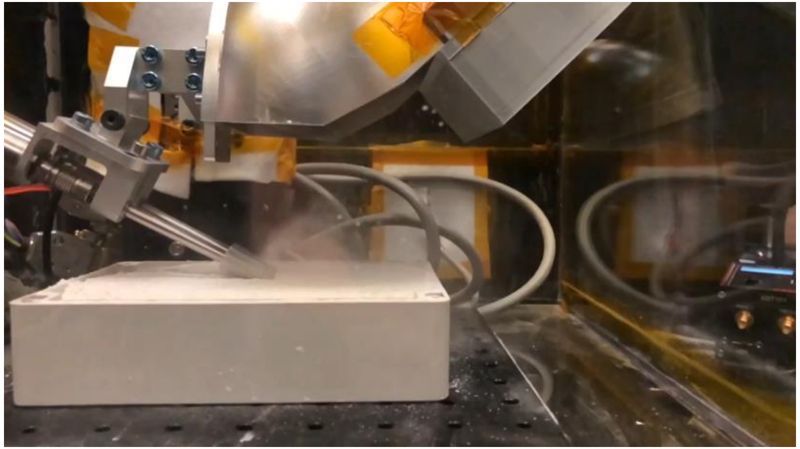


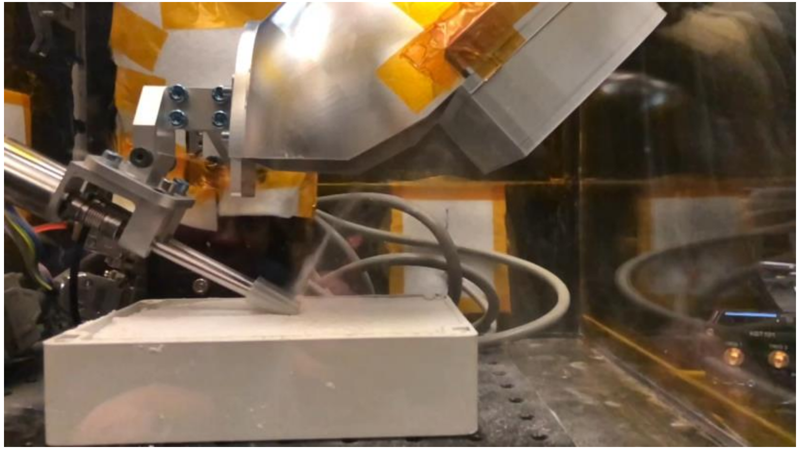
Prototype built in FY'20

Methodology

- The effects of vacuum conditions were tested by sampling in 1.0 atm (Earth ambient) and 0.05 atm (near vacuum) conditions. At Earth ambient pressure the 10µm particles dispersed in the air. In vacuum conditions particles flowed directly to the guide and into the sample cup.

1.0 atm

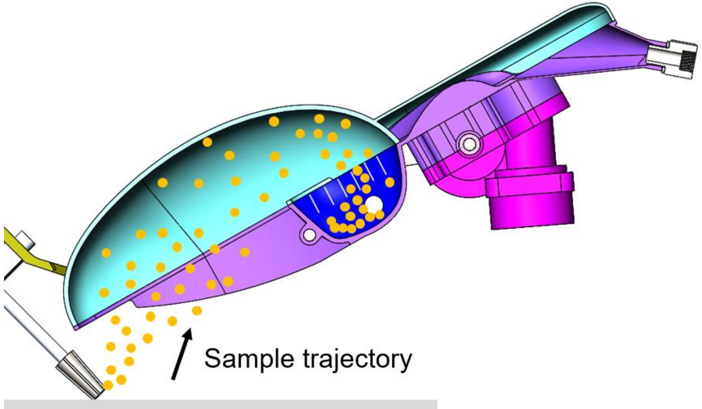




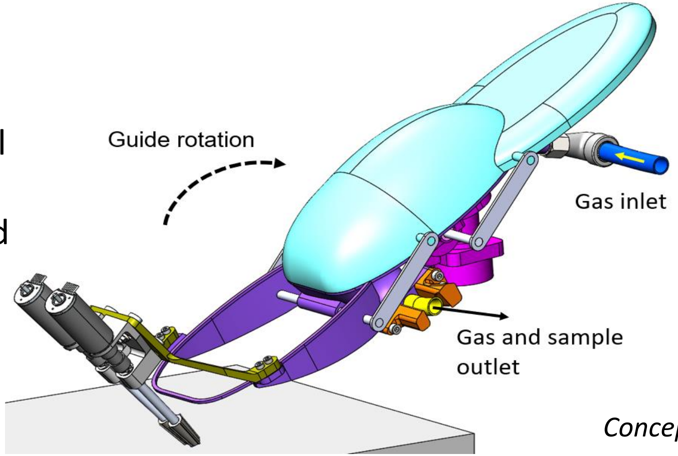
0.05 atm

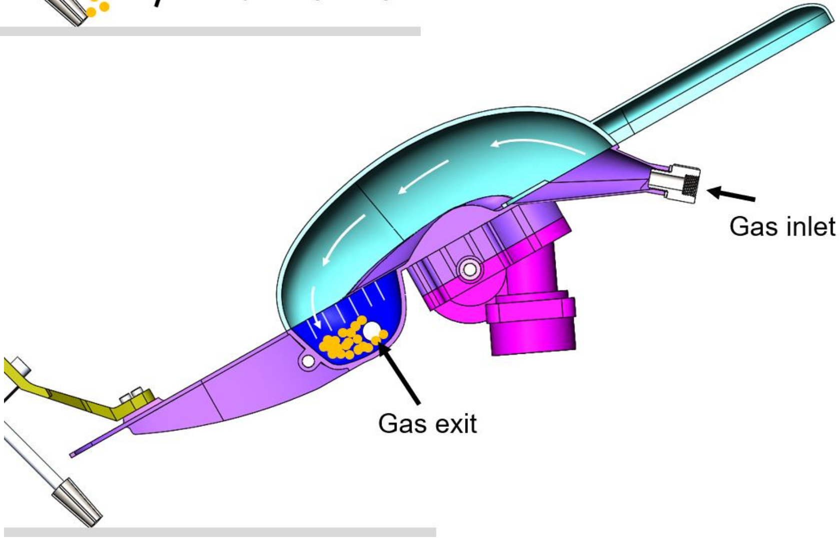
Methodology

- After sampling, the guide rotates to close the sample cup to create a closed pneumatic system.
- Compressed gas from a tank on the deployment arm transfers the sample from the cup, through a rigid tube up the arm, through passive pneumatic joints at the arm base, and to science instruments.



TRL 5 tool being fabricated

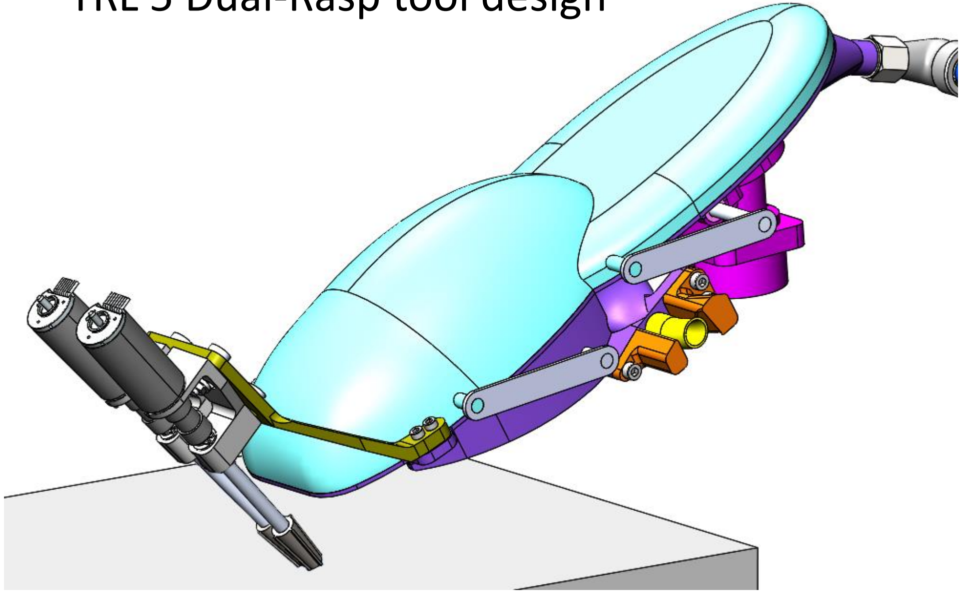




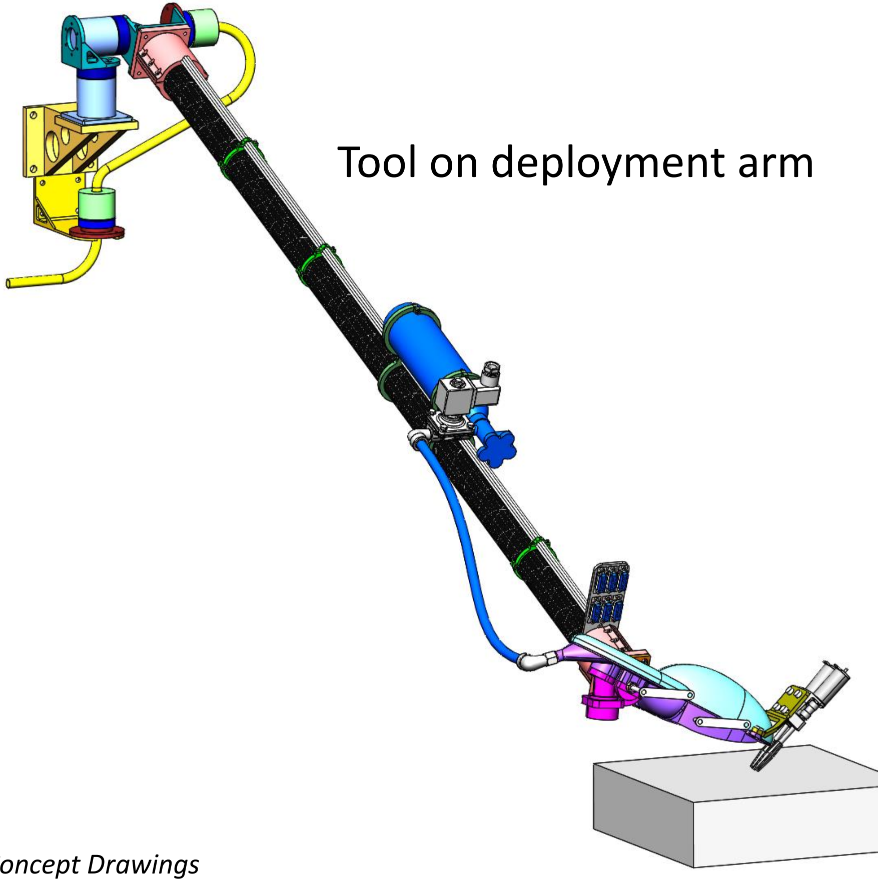
Concept Drawings

Methodology

TRL 5 Dual-Rasp tool design



Tool on deployment arm

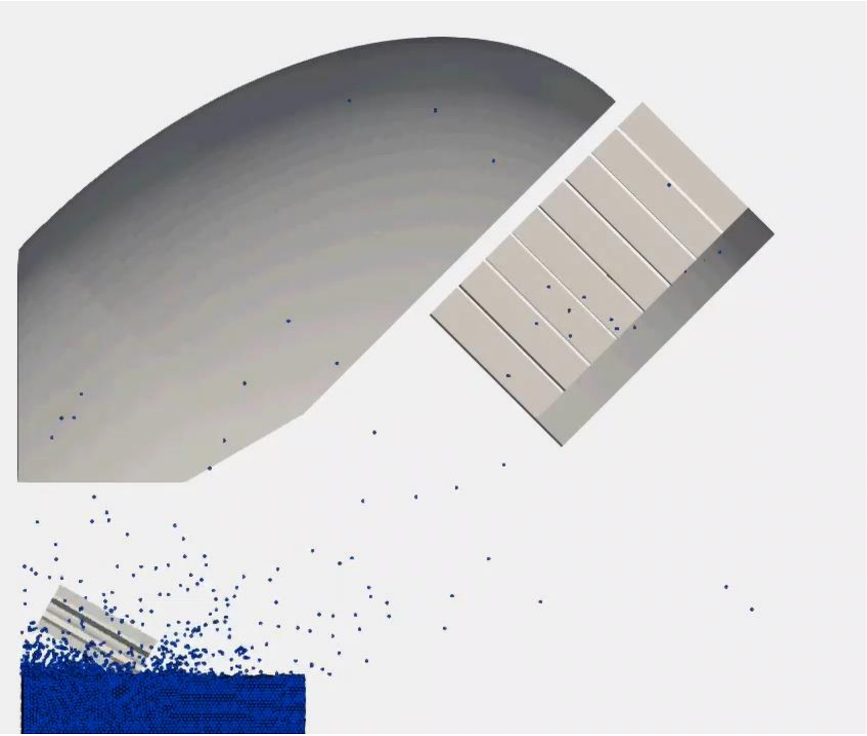


Concept Drawings

Methodology

Particle Transport Modeling

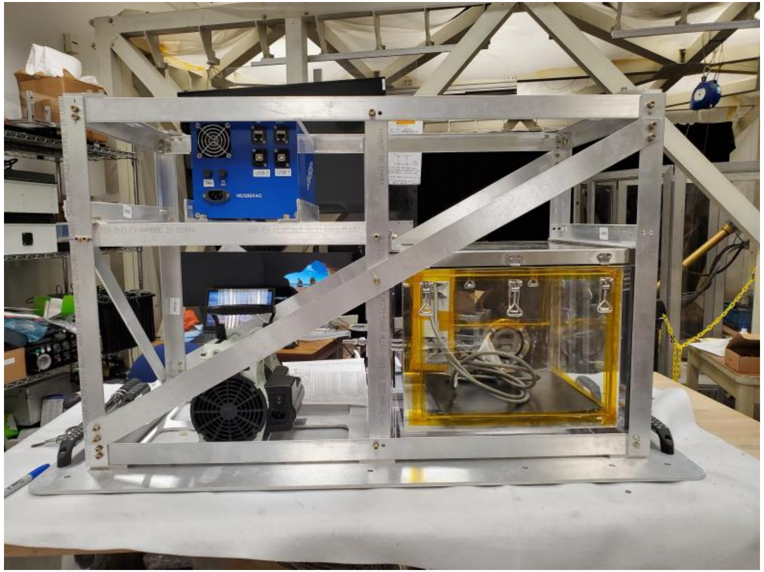
- Particle transport modeling is used to investigate the granular material flow generated by the sampling process in 1%g vacuum Enceladus surface environment.
- Particle transport modeling uses the Discrete Element Method (DEM).
- A set of analysis metrics was developed to characterize the granular material flow, and used both in numerical analysis and experimental testing for model validation.
- DEM model results are used to improve the sampling system design.



Methodology

Particle Transport Modeling

- Performed sensitivity analysis of model parameters describing the soil and the tool-soil interaction.
- Performed measurement of most sensitive model parameters (i.e. tool-particle coeff. friction and coeff. restitution).
- Successfully tested the DEM-driven sample guide design.
- Successfully tested the DEM-driven sample collection cup provided with a sample retention system.
- Assembled and tested the vacuum chamber for DEM model validation in both 1g and low-g vacuum environment.



Results

Planned Subtask	Status
Sampling system updated requirements	Complete
Sampling system preliminary design, peer review	Complete
Sampling system final design, peer review	Complete
Sampling system fabrication	All parts done or in fab
Sampling system assembly and system check-out	Delayed to FY’21 Q1
1-bar sintered ice characterized vs. model	Complete
Submit ice sintering results to journal	Accepted to JGR Letters
IBoS chamber assembled and first tests	Delayed with COVID to FY’21 Q1

Results – Next Steps in FY'21

Milestones	Date
End-to-end test of sampling, closed pneumatic sample transfer, and science chamber collection	12/2020
On-going 1-bar simulant experiments completed – simulants reach plateau strength	12/2020
IBoS chamber initial bulk atomized ice simulants produced and mechanical properties measured	1/2021
Validated sampling across full range of surface mechanical properties (40-95% porosity, 1 MPa to 15MPa CPT strength, 1% earth g, vacuum) using simulant suite in vacuum chamber and modeling	3/2021
System-level validation of sample chain including passive pneumatic joints collecting ten 1-5cc samples of 5mm maximum dimension from top 1cm of surface delivered to science sample chamber	5/2021
Bulk sintered ice simulants produced and ready for use in sampling system chamber testing	7/2021
IBoS short-term (~ 1-2 weeks each) then long-term (~ months) sintering experiments completed	8/2021
Functional (4/2021) and validation of Dual-Rasp open pneumatic sample transfer system completed	8/2021
Thermal-vac chamber validation (vacuum, 75°K ice simulant) of Dual-Rasp with closed pneumatic sample transfer system completed; and with sample transfer to OWLS sample chamber	8/2021
IBoS and 1-bar evolved Enceladus analog simulants characterized with results in a journal article	9/2021
Sampling system design and results meeting the task objectives documented	9/2021

Publications

- Mathieu Choukroun, Eli Phelps, Jamie Molaro, Robert Hodyss, Karl Mitchell, "Sintering of Fine-Grained Porous Water Ice: Preliminary Investigation of Microstructure and Strength Evolution." American Geophysical Union poster, December 2018.
- M. Badescu, P. Backes, S. Moreland, A. Brinkman, D. Riccobono, M. Dotson, N. Csomay-Shanklin, S. Ubellacker, J. Molaro, M. Choukroun and G. Genta , "Sampling Tool Concepts for Enceladus Lander In-situ Analysis," IEEE Aerospace Conference, March 2019.
- P. Backes, S. Moreland, M. Badescu, D. Riccobono, A. Brinkman, M. Choukroun, J. Molaro, R. Aggerwal, T. Newbold, A. Ahmad and S. Ubellacker, "The Dual-Rasp Sampling System for an Enceladus Lander," in IEEE Aerospace Conference Proceedings, March 2020.
- Molaro, J.L., Choukroun, M., Phillips, C.B., Phelps, E.S., Hodyss, R., Mitchell, K.L., Lora, J.M., and Meirion-Griffith, G. (2019). "The Microstructural Evolution of Water Ice in the Solar System Through Sintering", Journal of Geophysical Research (Planets). 124, 243-277.
- Robert Hodyss, Mathieu Choukroun, Paul Backes, Mircea Badescu, Eloise Marteau, Jamie Molaro, Scott Moreland, Eli Phelps, Dario Riccobono, "A New Sampling System Tailored to Experimentally-derived Mechanical Properties of Icy Analogs for Evolved Enceladus Surface Plume Deposits." American Geophysical Union Fall Meeting, San Francisco, California, December 9-13, 2019.
- Choukroun, M., Molaro, J. L., Hodyss, R., Marteau, E., Backes, P., Carey, E. M., Dhaouadi, W., Moreland, S., Schulson, E. M. (2020). "Strength Evolution of Ice Plume Deposit Analogs of Enceladus and Europa". *Geophysical Research Letters*, 47, e2020GL088953. https://doi.org/10.1029/2020GL088953