Enceladus Surface Sample Acquisition for In Situ Measurements

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Program: FY21 R&TD Strategic Initiative   **Strategic Focus Area: Enceladus Surface Sample Acquisition for In Situ Measurements**

Objectives

The overall objective was to develop a TRL 5 sampling system that can acquire and transfer samples to in-situ instruments on an Enceladus lander which would analyze plume material that accumulated on the surface. To accomplish the overall objective, there were four detailed objectives: 1) Constrain Enceladus surface mechanical porosity, strength, and microstructure properties; 2) Generate simulants representative of the top 1cm of the Enceladus surface that accumulated from plume material which fell to the surface (water ice 40-95% porosity, strength 1MPa to 15 MPa cone penetration test (CPT)); 3) Develop a sampling system that can operate in Enceladus surface conditions (1%g, ~75K, vacuum) to acquire and transfer samples of volume 1cc to 5cc with 5mm maximum particle dimension to in-situ instruments; 4) Validate sampling system to TRL 5 across potential range of Enceladus simulants and operational conditions.

Background

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, where the presence of hydrothermal activity has been strongly suggested by the Cassini mission, is available on its surface after being ejected by plumes and then settling on the surface. In addition, the low radiation environment of Enceladus would not significantly alter the chemical make-up of samples recently deposited on the surface. The task developed a sampling system concept that could be used in an Enceladus lander mission. This sampling system fills a gap in NASA sampling technology needed for surface sampling in the low gravity (1% Earth-g) environment of Enceladus. The surface environment of Enceladus represents a new challenge for surface sampling that is not met by sampling systems developed for microgravity (e.g. comets and asteroids) or higher gravity (e.g. Europa 13%g, Moon 16%g, or Mars 38%g) environments. It is desired to acquire shallow surface plume material to ensure acquisition of the least processed material.

Significance/Benefits to JPL and NASA

Successful testing of the Dual-Rasp sampling system in a thermal-vac chamber at representative Enceladus surface conditions with sintered ice simulants provides NASA with a validated sampling system for a future Enceladus lander mission. The system has only three actuators and requires only a two degree-of-freedom (DoF) deployment arm to enable robust sampling. The two DoF arm allows for sampling across an arc in front of the lander to ensure the ability to sample the full required volume of material from a wide range of surface roughness conditions. The rasp cutting heads robustly sample material from unconsolidated to strong consolidated material with low reacted forces to the lander as is needed in low gravity environments such as the Enceladus surface. Samples can be acquired to individual science chambers or accumulated for large sample volumes.

Publications

1. Mircea Badescu, Tyler Okamoto, Paul Backes, Scott Moreland, Dario Riccobono, Matthias Kugel, Alex Brinkman, Mathieu Choukroun, Jamie Molaro, Timothy Newbold, Andrew B. Heness , "The Dual-Rasp Sampling System Design with Closed Pneumatic Sample Transfer," IEEE Aerospace Conference, March 2021.

2. Mathieu Choukroun, Paul Backes, Morgan L. Cable, Edith Fayolle, Robert Hodyss, Andrii Murdza, Erland M. Schulson, Mircea Badescu, Michael J. Malaska, Eloise Marteau, Jamie L. Molaro, Scott J. Moreland, Aaron C. Noell, Tom A. Nordheim, Tyler Okamoto, Dario Riccobono, Kris Zacny. "Sampling Plume Deposits on Enceladus' Surface to Explore Ocean Materials and Search for Traces of Life or Biosignatures," The Planetary Science Journal, 2:100 (7pp), 2021 June

Approach and Results

The Dual-Rasp tool is deployed to the surface using a two DoF manipulator arm. Two counter rotating rasp-type heads cut through consolidated or loose material and throw cuttings up between them and into an ellipsoidal guide that causes the cuttings to flow into a sample collection cup, exploiting the guide's foci locations. Grids in the sample collection cup ensure sample retention in low gravity environments. After sample collection, the tool's guide reconfigures to create a closed cavity with the sample cup, and compressed gas transfers the sample from the cup through tubing along the arm and to a science sample chamber in the lander.

Milestone (1), Validation of Dual-Rasp sampling across range of simulants in vacuum: The Dual-Rasp tool was used to successfully sample ambient simulants from unconsolidated to 15MPa strength in a portable vacuum chamber both in a JPL laboratory and aircraft zero-g flight.

Milestone (2), Production of range of bulk sintered ice representing Enceladus surface material: Atomized water was sprayed into a LN2 bath and the LN2 boiled off to create Enceladus representative surface plume deposit ice material that was then sintered under controlled conditions to produce simulants across a range of strengths and provided for the thermal-vac tests.

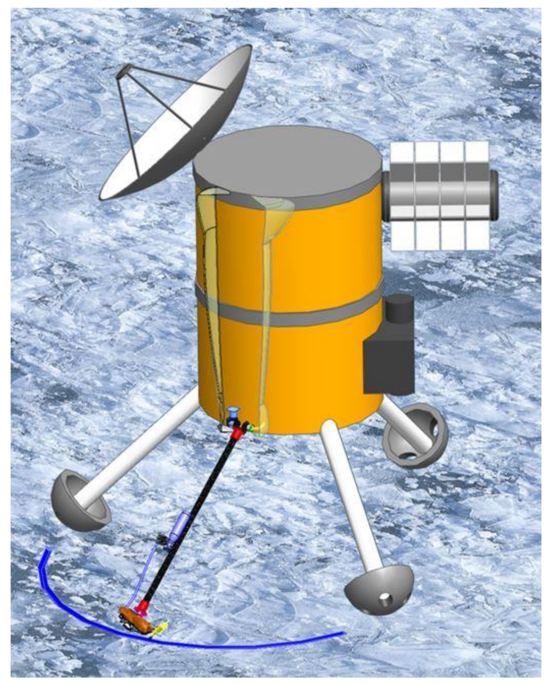
Milestone (3), Validation of Dual-Rasp sampling with closed pneumatic sample transfer in thermal-vac chamber: The sampling system was integrated into the CITADEL thermal-vac chamber and sampling with closed pneumatic sample transfer tests were successfully completed with unconsolidated and stronger 4.7MPa CPT and 11MPa CPT sintered ice simulants in Enceladus surface representative conditions. The requirement of acquiring 1-5cc sample volumes was accomplished by filling a 5cc volume sample chamber. Accumulation of sample in a larger volume sample chamber from multiple sampling activities was also demonstrated.

Milestone (4), Design, build, and validate Dual-Rasp sampling with open pneumatic sample transfer: A Dual-Rasp with open pneumatic sample transfer system was built and tested in a vacuum chamber with ambient simulants. The open pneumatics sample transfer version of the sampling system was built and tested at Honeybee Robotics.

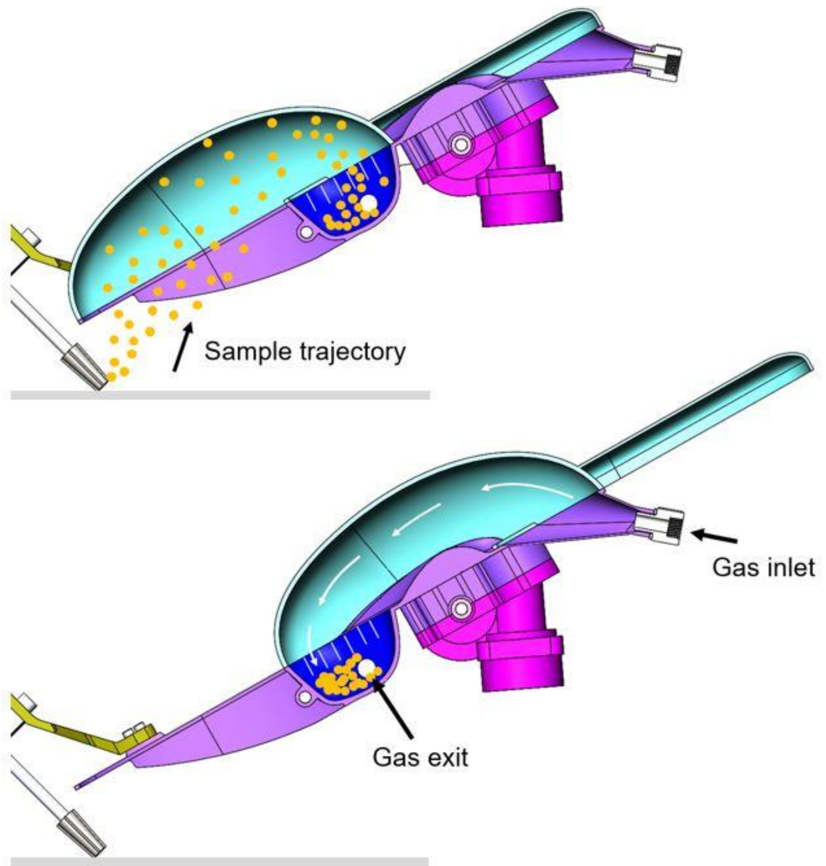
Milestone (5), System level validation of Dual-Rasp sampling system: A two degree-of-freedom robotic arm was built and mechanized and pneumatic tubes were made to carry gas from the arm-mounted Dual-Rasp, up the arm, and to sample chambers at a location representative of a lander location. Passive joints were fabricated to carry the gas across the two arm actuators. System level validation will be performed in first quarter FY'22.

Milestone (6), Icy Bodies Simulator (IBoS) chamber assembly and initial experiments: The chamber was assembled and component testing was accomplished. Longer-term sintering experiments are planned to be performed in the coming year. The IBoS chamber will enable production and characterization of Enceladus equivalent bulk simulants in a highly controlled environment.

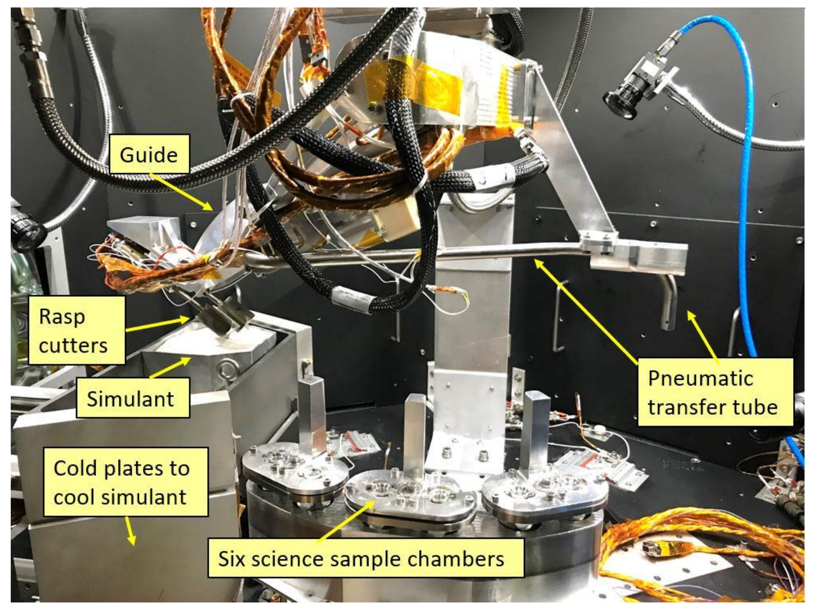
The high level objective of TRL 5 validation was accomplished primarily through the successful integrated sampling and sample transfer tests performed in the CITADEL thermal-vac chamber. The atomized and sintered ice simulants were representative of the range of potential Enceladus surface materials and the thermal-vac chamber provided cryogenic and vacuum conditions representative of the Enceladus surface environment.



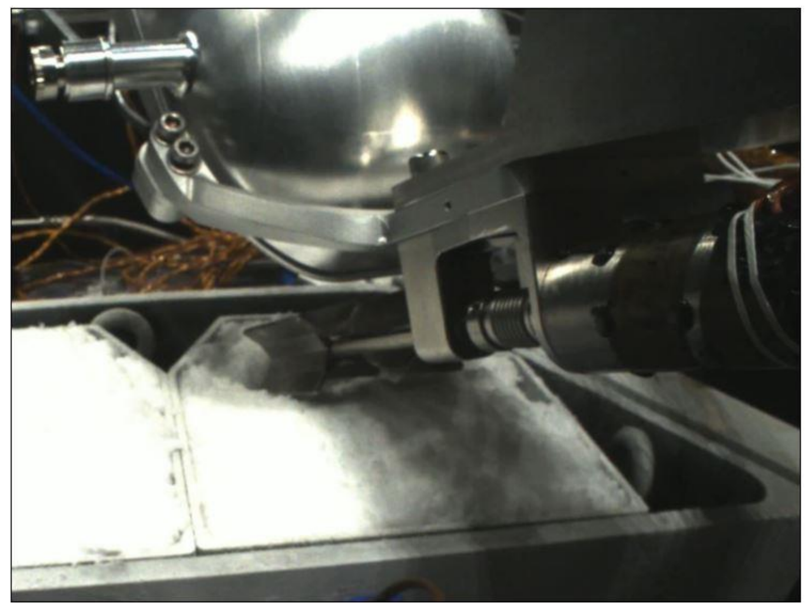
Dual-Rasp deployed by a two DoF arm enabling sampling across an arc in front of the lander



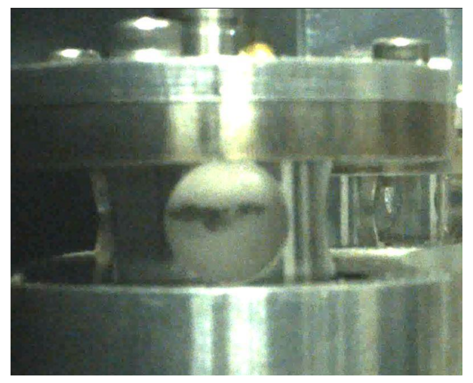
Dual-Rasp in sampling (top) and pneumatic sample transfer (bottom) configurations



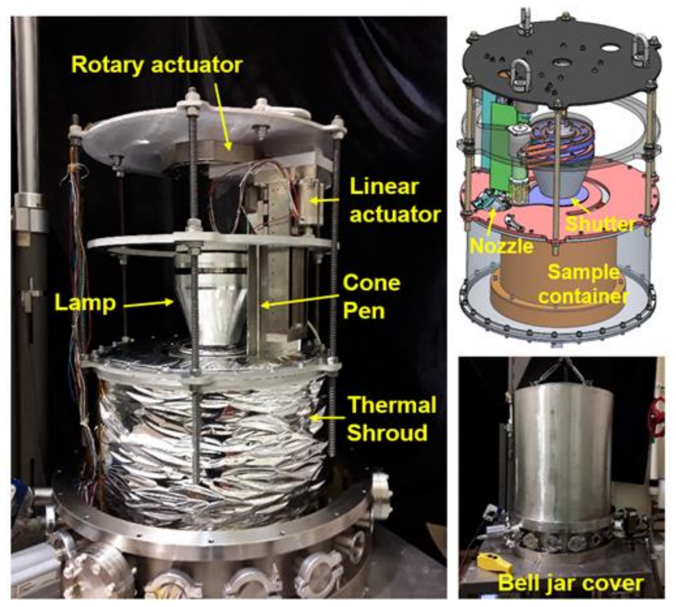
Dual-Rasp sampling system installed in CITADEL thermal-vac chamber



Dual-Rasp sampling sintered ice simulants in cryo-vacuum conditions



Resulting ice sample filling 5cc science sample chamber



Icy Bodies Simulator chamber

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