Development and Testing of a Sample Handling System for In-Situ Lunar Geochronology with KArLE

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***Abstract*—Honeybee Robotics has developed an end-to-end sample handling system for the Moon utilizing PlanetVac to acquire material, a novel sample triaging station, and a high-heritage carousel to deliver samples to the KArLE instrument for in-situ geochronology. The carousel has been leak tested to meet instrument requirements and thermal-vacuum qualified to TRL6. The end-to-end system was demonstrated in vacuum.**

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1. INTRODUCTION

Only Earth-based laboratories are currently capable of the precise radiometric dating of lunar rocks required to establish an age-map of the Moon. This map is critical to understanding the Moon's formation and history, and by extension the history of the solar system. The Potassium-Argon Laser Experiment (KArLE), developed at NASA's Goddard Space Flight Center (GSFC), aims to solve this problem by combining several high-heritage instruments to perform in-situ radiometric dating to +/-100M years [1]. KArLE is scalable and lowers the cost barrier to age-dating rocks with various mission profiles in mind.

Honeybee Robotics (HBR) developed KArLE's sample handling system (SHS) to select rocks from the lunar surface, triage them for scientific value, cache and index individual rocks in a rotating carousel, and hermetically seal individual samples inside an analysis chamber. The instrument fires a laser at the rock to ablate a small amount of sample; laser-induced breakdown spectroscopy (LIBS) measures the potassium content, and mass spectrometry measures the liberated argon. The potassium and argon levels determine the age of the rock in a process analogous to carbon dating.

2. ARCHITECTURE OVERVIEW

The SHS nominally uses PlanetVac [2] to acquire lunar surface material (regolith) with a puff of high-pressure gas that transports sample along a transfer tube to the triage station (Figure 1 and Figure 2). The triage station interfaces between the SHS and the sample acquisition tool; it cleans, isolates, inspects, and handles rocks before entering the SHS.

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Figure 1. PlanetVac subsystem

Figure 2. SHS subsystems (from left to right): elevator (blue), carousel (yellow), and triage station

The triage station initially captures regolith in a mesh sieve that leaves only rocks of the desired size (5-20mm). Single rocks are isolated in a bin by a rotating brush. Additional rocks simply are swept over the single rock and return to the bulk collection area. The isolated rock is then "triaged" (e.g. a photograph transmitted for ground-in-the-loop evaluation), and a puff of gas either accepts or rejects the rock through a cylindrical diverting valve.

Accepted rocks are delivered to the SHS carousel, which is based on HBR's Sample Manipulation System (SMS) on Curiosity [3]. The carousel is an actuated, hubless ring holding 20x sample cups, each of which can hold a single sample. The carousel can rotate a sample cup to the elevator. The elevator, also based on SMS heritage, seals the sample cups to the analysis chamber by preloading the copper gasket on each cup against the titanium knife edge on the chamber with up to 3200N (verified from -40C to +70C). The KArLE instruments then analyze the rock.

3. Design

A. Triage Station

The triage station is a novel robotic system that enables more selective delivery of samples prior to detailed analysis. Operationally, this consists of: (1) accepting sample, (2) purging fines and keeping pebbles of Ø0.5-2cm, (3) separating individual rocks, (4) presenting those rocks to the "triage" assessment tool, (5) delivering desired rocks to SHS and rejecting undesired rocks outside of system, (6) resetting to accept a new sample.

HBR has previously developed systems that perform several of these functions, but new to the KArLE triage station design is the ability to isolate individual rocks (operation #3) before delivery or rejection (operation #5). An architecture trade study yielded robustness to irregular rock geometries as a deciding metric, as the triage station is a single-point failure. Eight different concepts were prototyped and assessed with AirCrete rocks up to Ø2cm (Figure 3 and Figure 4).

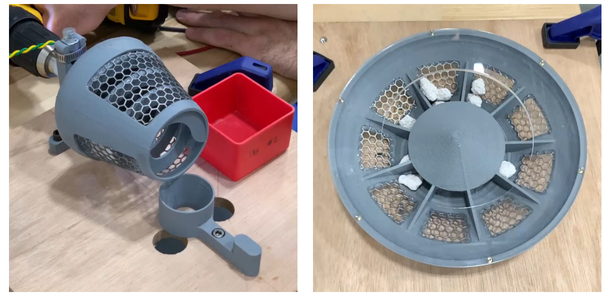

Figure 3. Cement-mixer (left) and roulette wheel (right) sorting system prototypes

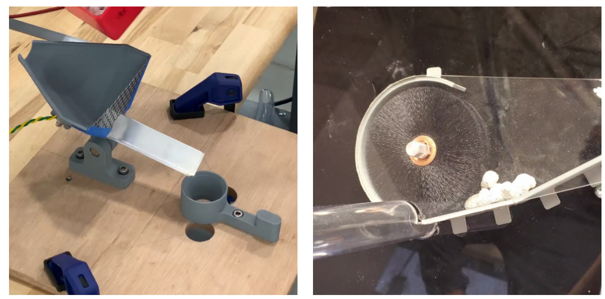

Figure 4. Vibrating funnel (left) and rotating shoe brush (right) sorting system prototypes

The roulette wheel and shoe brush sorters were the most robust to failure so were developed further to incorporate the rest of the triage station's required functions (Figure 5).

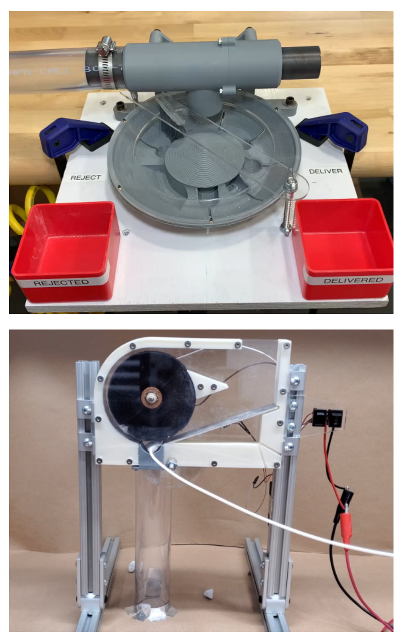

Figure 5. Prototype roulette wheel triage station (top) and shoe brush triage station (bottom)

The shoe brush architecture was ultimately selected due to its more predictable behavior, compared to the chaotic nature of the centrifugal sorter. The shoe brush is relatively compact, requires minimal ground-in-the-loop (GITL) operation, uses slow actuation, and handles over-filling of sample. HBR then matured the triage system design to TRL5 (Figure 6).

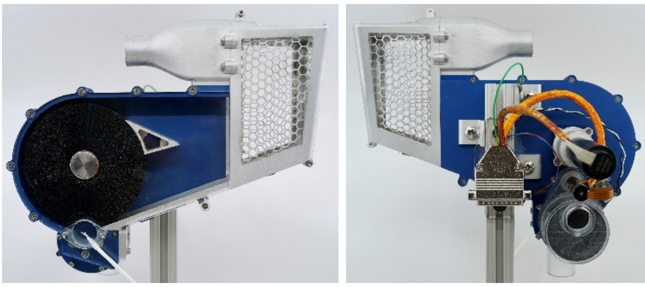

Figure 6. Two views of the TRL5 triage station

Initial sieving is performed by the mesh catch; additional fines are collected in the bin by vibrating the chute and rotating the wheel counterclockwise to prevent target size rocks entering. A puff of gas ejects these fines.

To triage, the brush wheel is rotated for 30s in the clockwise direction then 60s in the counterclockwise direction, to allow a single rock to enter the triage bin and additional rocks to pass over. This approach was a robust method of separating a single rock from the rest with occasional empty bins occurring due to the target rock protruding too far out of the bin and removed during counterclockwise rotation. If an empty bin occurred, the operation could be repeated. This method never resulted in overfilled or jammed bins. Occasional jamming was observed between the front and rear plates on either side of the vibrating chute above the brush, always with a rock just larger than 2cm in one dimension. This could be mitigated with more aggressive vibration or different chute geometry.

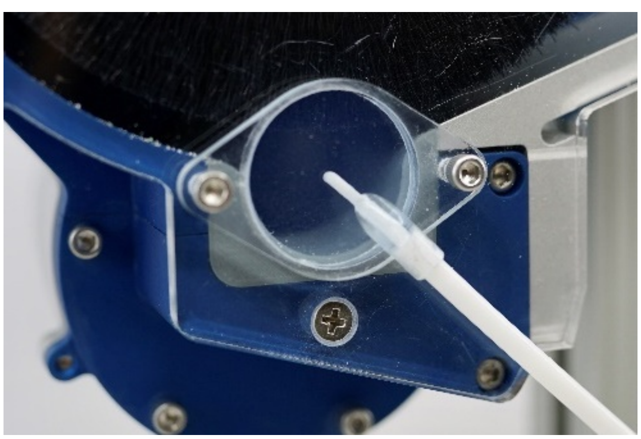

Figure 7. Closeup view of the triage bin and window

Once a single rock is in the triage bin, a picture (or other low-resource analysis) is used to evaluate scientific value with GITL. A three-position cylindrical diverter valve located on the opposite side of the bin rotates from a closed position to its “deliver” or “reject” position. Then the rock is propelled with a burst of gas from the nozzle built into the triage window (Figure 7). In vacuum, this burst of gas creates a shockwave that kicks the rock through the valve.

B. Sample Cups

A sample delivered by the triage station lands in a sample cup on the SHS carousel. The sample cups are sized to hold a single rock of up to Ø2cm. The sample cup holds the rock still as it travels around the carousel to the elevator, which interfaces to the sample cup via the bottom flange. The copper gasket brazed to the outside shoulder of the cup can then be preloaded against a titanium knife edge (~Ø2.5cm) on the bottom of the analysis chamber to create a seal.

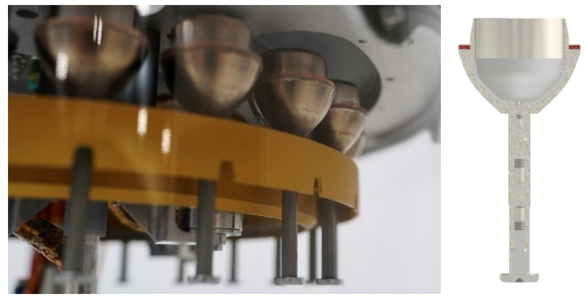

Figure 8. KArLE's sample cups in the carousel (left) and section diagram (right)

The sample cup draws on design heritage from both SMS and DrACO [3] [4]. It deviates from heritage with a larger cup diameter (to accommodate larger sample sizes), a shorter stem (due to reduced travel needed to seal/unseal to the analysis chamber), and the cup’s internal modular internal geometry (to hold calibration targets).

The cup, stem, and bottom flange are Grade 5 Titanium, and the cup is tapered at the top to self-align with the sample analysis chamber. The copper (C101) gasket is hermetically brazed to a shoulder on the cup. The bottom flange has two holes for a spanner wrench and a conical bore for centering on the elevator carriage. The sample cups have been iteratively designed using finite element analysis to guarantee positive margin on yield under the highest sealing forces.

The stem has a diameter step down to go from a close fit to a loose fit with the cup retainer. The stem also has a groove to interface to spring-loaded fingers on the cup retainer. The stem exteriors are coated with General Magnaplate Canadize to resist galling and seizing at the interface with the retainers.

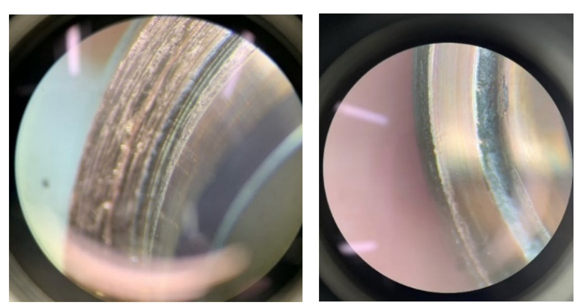

Figure 9. Rough turned gasket with deep tool marks (left), refinished gasket with smooth finish (right)

Initially, the sealing surface of the copper gaskets was faced to Ra 125µin. This yielded low quality seals to the analysis chamber with high leak rates, caused by small gaps where the surface finish amplitude exceeded the depth of knife edge deformation. Once the gaskets were resurfaced to ~Ra 32µin, gas-tight seals were achieved.

C. Carousel

The carousel is an actuated, hubless ring that holds 20x sample cups and precisely moves them from the triage interface to the elevator. The carousel includes a dedicated retainer for each cup and is driven by a pinion gear that interfaces to a large ring gear on the carousel.

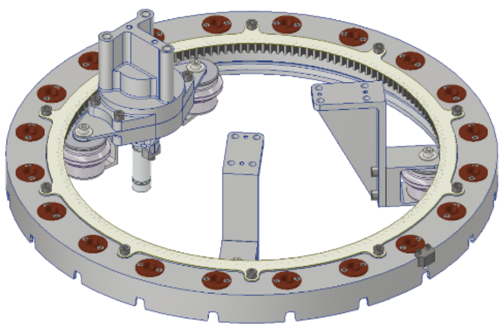

Figure 10. Carousel diagram

The carousel's hubless design is compact and scalable, maintaining high heritage design features from SMS [3]. The use of rollers rather than a single large bearing enables easy adjustments to the number and size of the cups. The architecture also enables an optimized load path for the elevator and the bulkhead interface can be readily adapted for additional stations such as an imager.

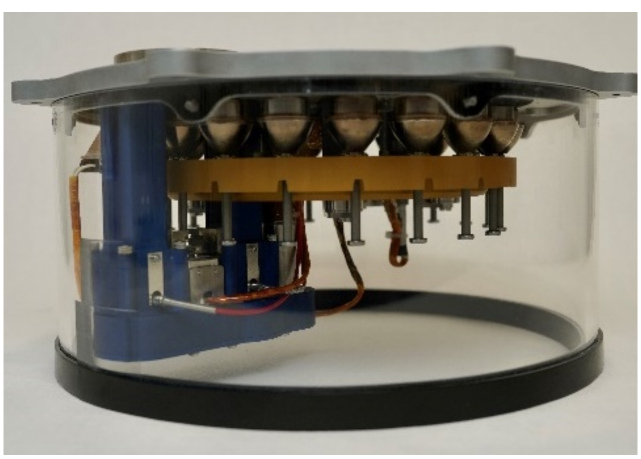

Figure 11. Side view of assembled carousel with sample cups installed

Asymmetric roller positions resulted in small deflections of the carousel as the cup retainer mated/demated with the cup stem. This was not an issue when lifting the cups from the carousel but had to be compensated for when lowering the cups to seat them properly in the cup retainers. Moving the two rollers by the elevator closer together and reducing the effective beam length would reduce this deflection.

A custom Ø8mm brushless DC actuator from Maxon with Braycote 610EF lubricant and PTFE insulated conductors drives the carousel. The motor mounts to the housing with threads on its gearbox and a secondary radial clamp to reduce vibration. An anti-backlash gear was selected as the pinion to reduce play in the system and increase positional precision, ensuring the meshed teeth are contacted on both sides.

The carousel drive motor uses Halls sensors and a 1024-count optical quadrature encoder for redundant positional control. A known home position for the carousel is established with a limit switch mounted to the outer elevator tower that interfaces with a boss on the carousel. Notches on the carousel are compatible with SMS optical encoder, which was not used during this phase of the project.

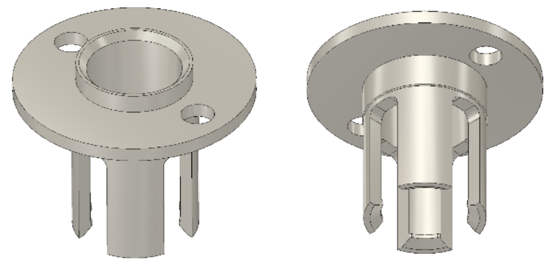

Figure 12. Two views of the titanium cup retainer

The cup retainers pull heritage from SMS and Dragonfly's sampling system DrACO [3] [5]. The retainer, shown in Figure 12, is a flexure mechanism with a tight tolerance bore at the top to radially align the cup's major axis and four sprung fingers at the bottom to engage with a circumferential notch in the sample cup's stem for retention in the carousel. These flexures underwent detailed analysis to ensure the cups would be retained during launch vibrations (GEVS).

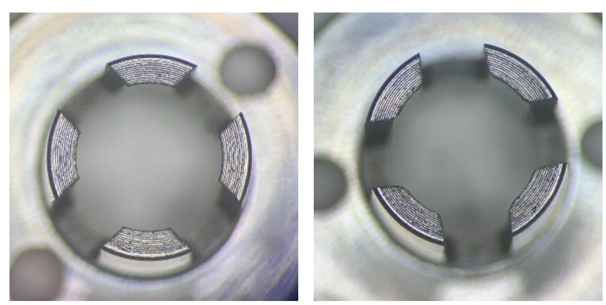

Figure 13. Retainer fingers before (left) and after post-processing (right)

The carousel's cup retainers were turned on a lathe before the fingers were cut using wire-EDM. This prevented the finger warping observed on the SMS retainers (the fingers were milled), but resulted in sharp corners that required post-processing to reduce wear to the stems (Figure 13).

D. Elevator

The elevator, shown in Figure 14, leverages designs from SMS and DrACO Phase A [3] [5]. The elevator lifts and lowers sample cups into the analysis station with an actuated dual leadscrew mechanism. The primary function of the elevator is to apply preload (up to 3200N) to the sample cups to create a hermetic seal between the sample cup and the analysis station.

The dual-leadscrew architecture has several advantages: increased force capacity while maintaining compact packaging, no cantilevered load paths, non-backdrivable operation, and minimal lubrication requirements.

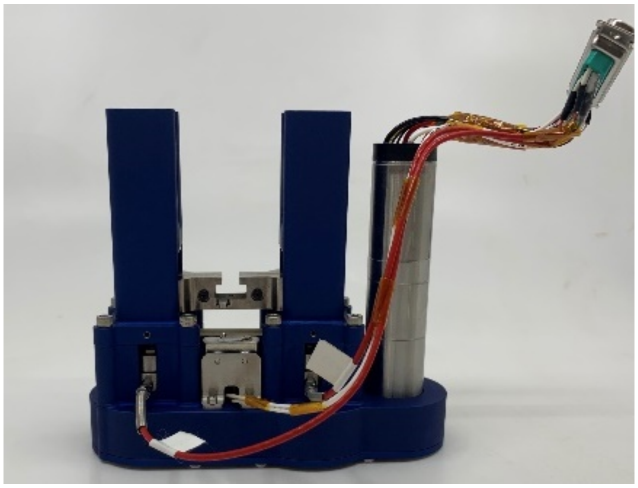

Figure 14. Final assembly of the elevator

Bushings radially support the leadscrews. Anti-galling material combinations (Nitronic 60 and Stainless Steel 416) are used at sliding interfaces (e.g. between the nuts and the leadscrews). A thrust bearing with a spherical joint provides the interface between leadscrews and a Futek 500lbf through-hole load cell located below each leadscrew, providing force feedback for the elevator (Figure 16).

Leadscrews are driven by a gearbox machined from Vascomax C250, selected for margin on contact and bending stresses during the peak sealing conditions. The actuator is a custom Ø22mm brushless DC motor from Maxon with Braycote 601EF lubricant and PTFE insulated conductors. Braycote 601EF grease also lubricates the elevator gearbox, leadscrews, leadscrew nuts, and bushings.

The elevator carriage (Figure 17) is the interface between the lead screws and sample cups updates a heritage design from SMS and DrACO [3] [5]. A rotary hard stop between the inner lead screw nut and the leadscrew limits the motion of the carriage and prevents the carriage from crashing into the gearbox. These features were match-machined to collide before the bottom of nuts wedged against the leadscrews to ensure the elevator can back off from its hard stop.

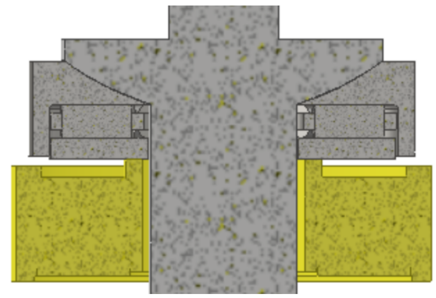

Figure 16. Snapshot of load cell (yellow) interface to leadscrew (gray)

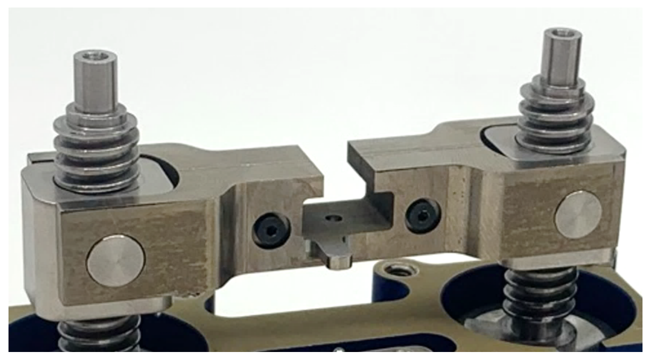

Figure 17. Elevator carriage

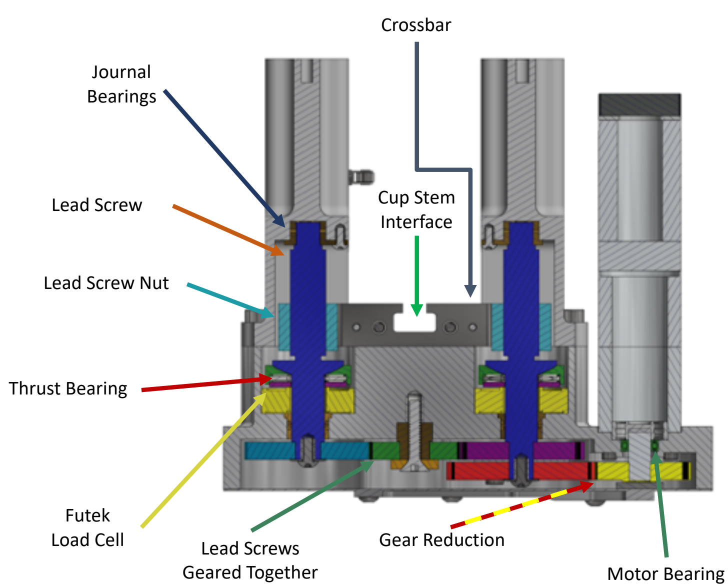

Figure 15. Elevator cross-section

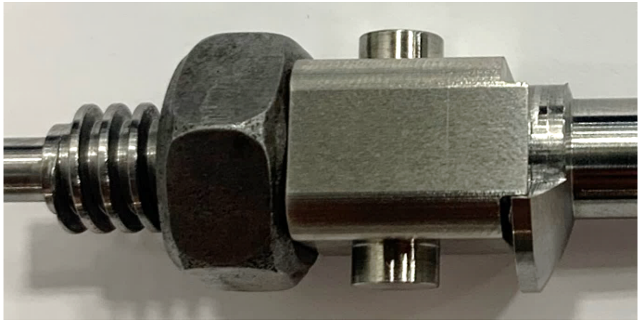

Figure 18. Leadscrew hard stop after match machining: the bottom (right) of the leadscrew nut contacts the radial hard stop while maintaining axial clearance

A calibrated reference load cell verified the elevator's force feedback to ensure valid telemetry (Figure 19).

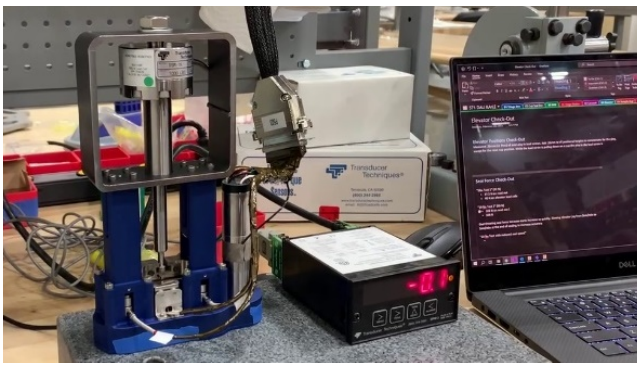

Figure 19. Preload verification testing prior to integrating elevator into the SHS

The KArLE elevator is homed with a shimmed mechanical limit switch for repeatability. The rotary hard stop provides a redundant homing approach.

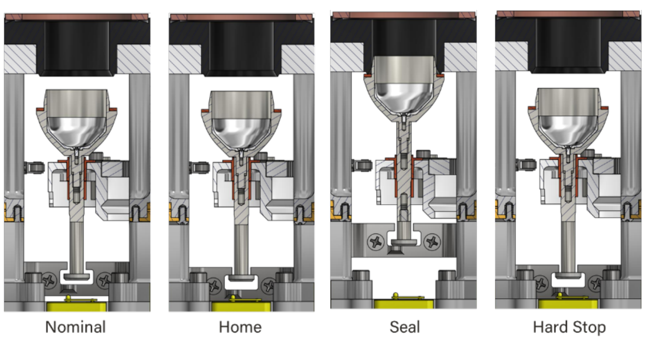

Figure 20. Elevator positions: nominal (allows cups to pass through), home (limit switch engaged), seal (load cells measuring preload on cup), and hard stop (rotary hard stop engaged)

E. Analysis Chamber Interface

A well-honed knife edge was required to produce high quality seals; the turned surface required finishing with #12000 grit paper (Figure 22). A Magnagold coating was applied to the honed knife edge for improved durability (Figure 21).

Figure 21. Knife edge coated with Magnagold

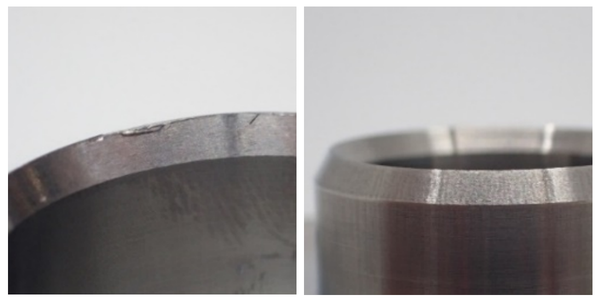

Figure 22. Knife-edge defect (left), after grinding (right)

F. EGSE

The SHS EGSE included: power, motor control (Copley ACJ-series), data acquisition (LabJack T7-Pro), signal amplification (Futek IAA100), and user communication.

Figure 23. KArLE SHS control box

The SHS has four harnesses: two inside the chamber and two outside the chamber. All harnesses use Accuglass D-sub connectors for high-vacuum compatibility.

G. Software

Honeycomb, HBR's internal testing framework, is used to control the SHS. A screenshot of the user interface is shown in Figure 24.

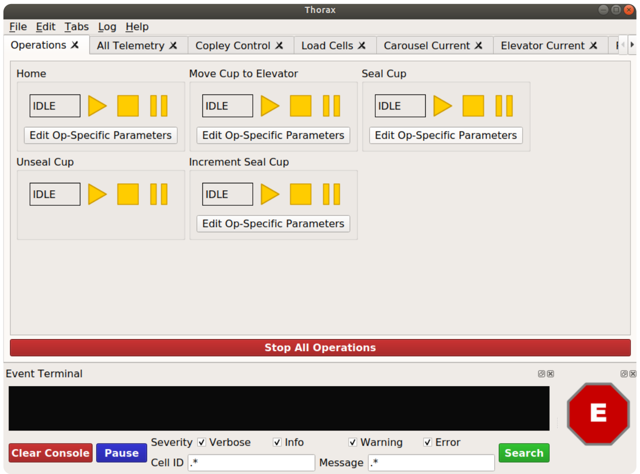

Figure 24: Honeycomb's user interface for the SHS

Homing—To account for backlash, a custom homing sequence was implemented:

1. Jog towards the limit switch
2. Overtravel a fixed distance after the limit switch is pressed
3. Slow jog in the reverse until switch released

Seal Force Control Loop—The elevator seals by quickly jogging up until the sample cup gasket is approximately 2mm from the knife edge and then it enters sealing mode where it slowly travels up at a fixed speed until the load cells indicate the specified load was reached.

Figure 26 shows typical relaxation of the sealed system as the motor is unloaded, where the mechanism maintains the seal rather than continuous torque output of the elevator motor.

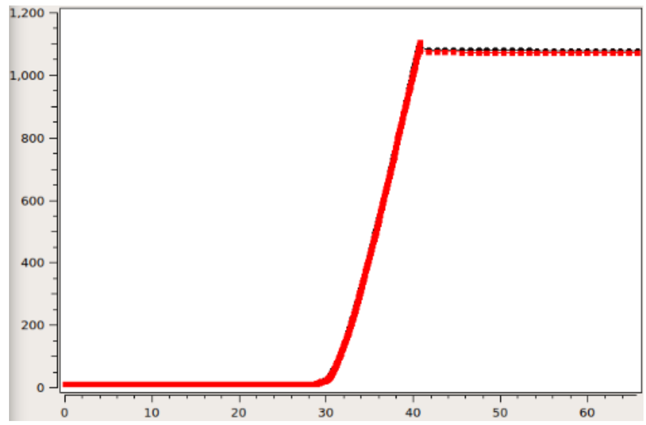

Figure 26. Typical plot of load cell feedback. X-axis is time in seconds, Y-axis is preload in Newtons

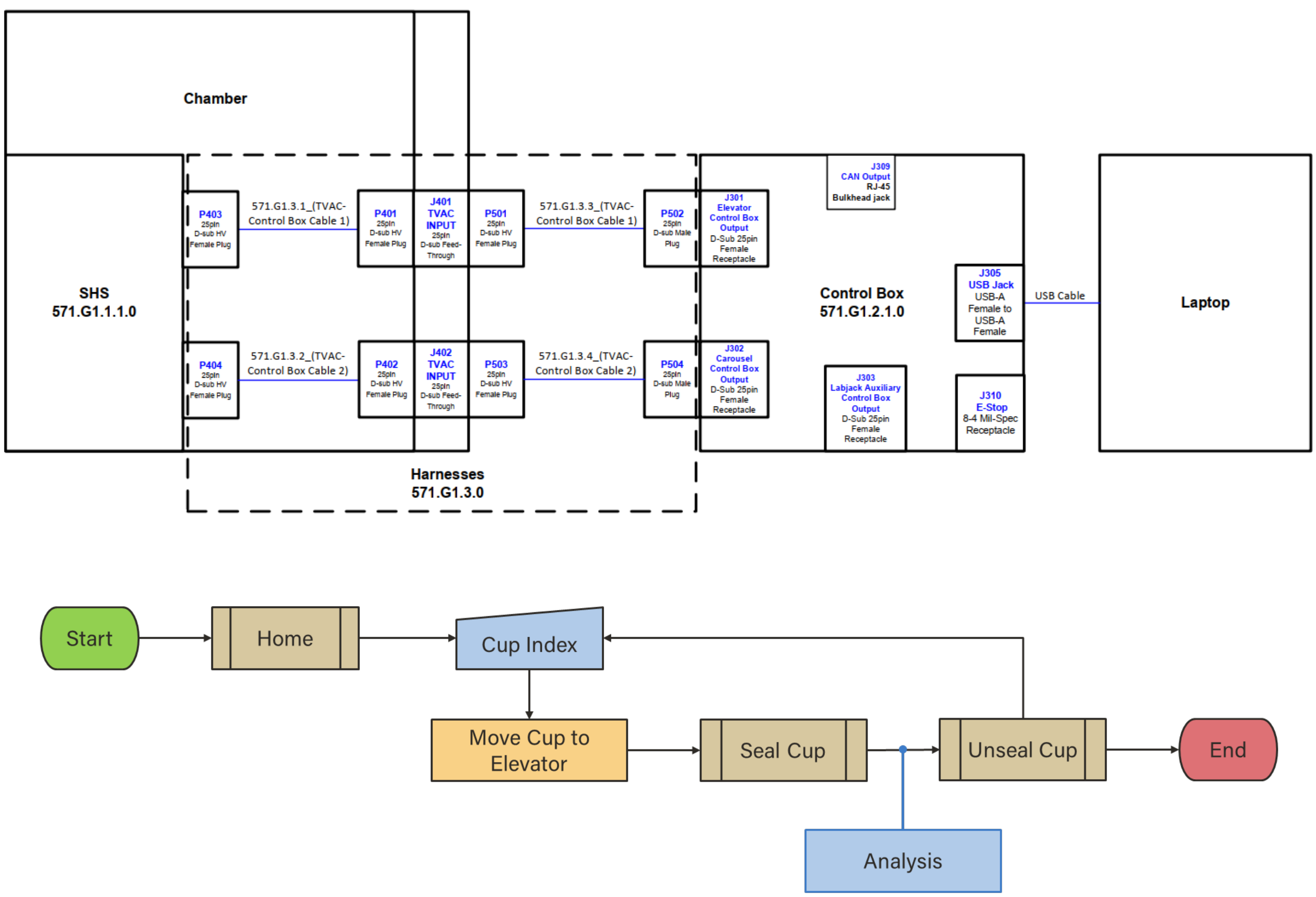

Figure 25. EGSE block diagram (top), software flow chart (bottom)

4. Testing

The SHS underwent three test campaigns: leak rate characterization, thermal-vacuum (TVAC) qualification, and end-to-end sampling testing were conducted for the SHS.

A. Leak Rate Characterization

Achieving the target geochronological precision of +/-100M years required no more than 10% of the expected 40-Ar gas that is released from the rock during laser ablation to escape during analysis. On the Moon, where the ambient pressure is ~1E-12Torr, this corresponds to a leak rate requirement of 1.69E-1 atm*cc/sec He STD – which is readily achievable. Once the ambient pressure increases beyond the analysis chamber pressure (for example, in a vacuum chamber in the lab) the concern becomes ingress of ambient argon.

HBR used leak rate data from SMS and DrACO seal testing to develop a model of the knife edge leak rate. Based on this model, a performance requirement of <2.2E-6 atm*cc/sec He STD was established – a leak rate that would satisfy the science requirement in a sub-millitorr vacuum chamber such as the one that would be used to TRL6 qualify KArLE.

Test Objectives—A helium leak detector (HeLD) was used to verify the seal at cold (-40°C), nominal (23°C), and hot (70°C) operating temperatures.

Test Setup—The seal was tested via the storage-under-pressure approach, where the environment is pressurized with helium and ingress into the device-under-test is measured. Cold plates controlled by a Julabo Process System were mounted to the SHS bulkhead and used to regulate temperature. A flexible thermal strap was designed and fabricated to ensure the sample cup and knife edge reached the same operating temperature prior to forming the seal.

Test Procedure Overview—Several iterations were required to develop a robust test procedure, largely driven by the need to avoid saturating the HeLD.

The following is a high-level overview of the procedure:

4. Inspect the knife edge and gasket for FOD and damage
5. Pump the vacuum chamber to <1 Torr, then fill to ~300 Torr with dry N_2 gas
6. Pump the vacuum chamber to sub-millitorr range
7. Bring SHS to required temperature using the Julabo
8. Create an initial seal at 1300N preload using the elevator
9. Engage the HeLD roughing pump and begin incrementing the seal 10N at a time until the HeLD turbo-molecular pump engages
10. Add short (2-3s) bursts of dry He_2 gas to the chamber up to ~10 Torr until a baseline leak rate is established
11. Increment seal force until HeLD reads <1E-11 atm*cc/sec He, and then add helium to 700 Torr and record leak rates

Results—The leak rates achieved were near the HeLD's lower limit (where the valve to the HeLD was closed and only residual helium in the system was measured). Results from the leak rate verification are presented in Table 1. Figure 27 shows the relationship of leak rate with respect to force applied to the knife edge. As expected, after an initial seal is made, the leak rate gradually decreases with force as deformation of the gasket eliminates leak paths. After a threshold seal force, there are no more leak paths to be closed and the leak rate plummets. The lowest leak rate recorded for each test corresponds to ~700 Torr of helium in the chamber; the test chamber does not support pressures above ambient.

Table 1: Leak Rate Results.

Temperature	Leak Rate Achieved	Final Seal Force
[°C]	[atm*cc/sec He STD]	[N]
-40°	2.5E-10	2740
+23°	2.9E-09	2593
+70°	2.5E-09	2611

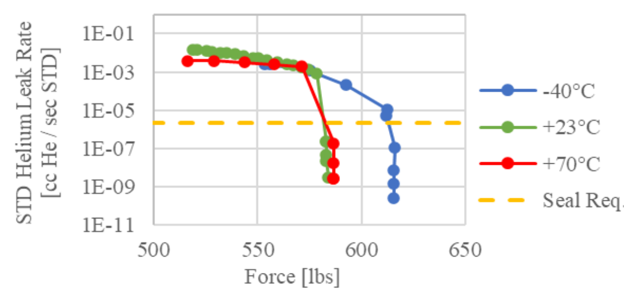

Figure 27. Plot of leak rate data when at least 1 Torr of helium is in the chamber

The SHS was demonstrated to satisfy both the TRL6 requirement (<2.2E-6 atm*cc/sec He STD), and was well below the flight requirement (<1.7E-1 atm*cc/sec He STD) at all operational temperatures.

B. TVAC Qualification

TVAC qualification verified functional performance of the SHS at the relevant environmental conditions.

Test Setup—The SHS was placed in the TVAC chamber and instrumented with thermocouples (Figure 28) and cold plates connected to a Julabo Process System.

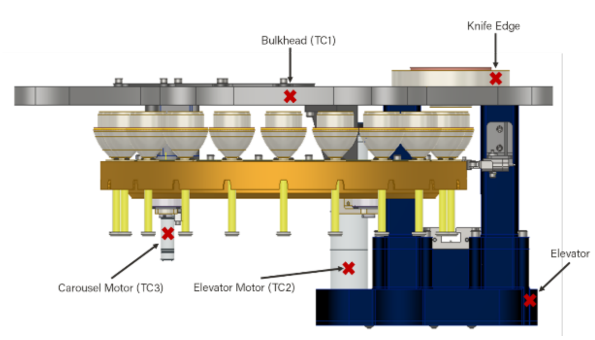

Figure 28. Thermocouple locations during qualification

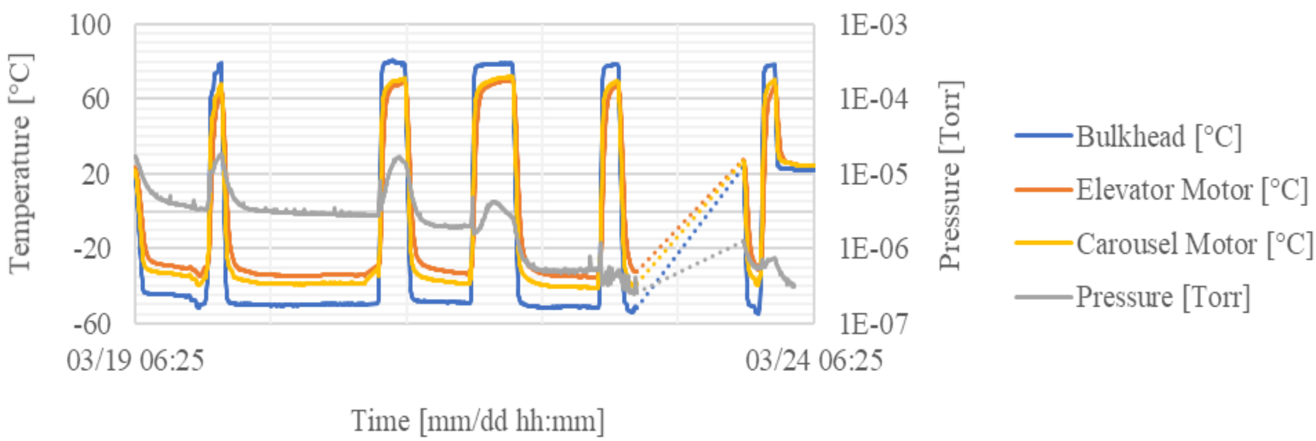

Figure 30. TVAC qualification environment

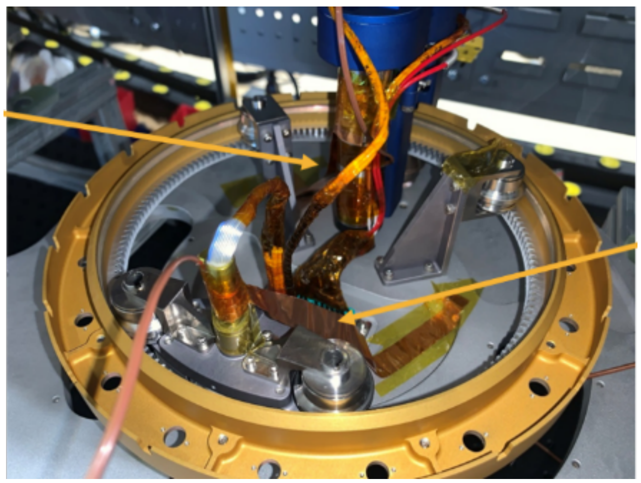

Figure 29. SHS with thermal straps on actuators

Mylar shrouding, G10 standoffs, and thermal straps were used to improve thermal control and stability (Figure 29).

Test Operation—The SHS was thermally cycled for five days from -40°C to 70°C (<2E-5 Torr) and a total of 19x functional test were conducted consisting of the following operations: Home, Seal Cup (to 2750 N), Unseal Cup, Home.

Faults and Root Causes—Three faults of note occurred during qualification testing. Each fault was addressed via software tweaks in real time without breaking the chamber seal to complete the entire qualification test campaign.

1. Carousel overcurrent fault. This was caused by an over-crimped D-Sub pin that caused one of the Halls conductors to break during thermal cycling. The carousel motor was reconfigured to use the redundant encoder for rotor resolving to complete testing.
2. Honeycomb failed to launch, requiring library relinking.
3. Elevator “following” error. Occurred in two functional tests when the motor position did not track with the commanded position due to the slow sealing speeds while the elevator was under load. Remedied by increasing speed at which seal force was incremented.

Results—The SHS was demonstrated to function over 5x thermal cycles in vacuum of ~2E-5 Torr to <3E-7 Torr.

C. End-to-End Demonstration

HBR performed an end-to-end demonstration of the integrated sampling system from sample acquisition to instrument delivery. Two vacuum chambers were used to separate "dirty" and "clean" areas for maximum visibility (**Error! Reference source not found.**).

While the purpose of this campaign was demonstration, it revealed valuable information about the triage station’s function in vacuum and adaptation of PlanetVac for new sample handling systems. For example, the triage station’s fines-purging operation was added after it was observed that the mesh sieve did not remove as many fines in vacuum as it did in ambient. Vibrating the chute and running the brush counterclockwise allowed for fines to flow into the triage bin to then be purged out the reject valve. This secondary process is extremely effective at retaining relevant samples and removing fines from the retained rocks.

D. Integrated Testing

The SHS was delivered to GSFC in June 2021, to be integrated into the rest of the KArLE instrument. KArLE will then be operated on a system level to demonstrate the ability to age-date lunar rocks and bring the system to TRL6.

5. Conclusion

The SHS successfully operated and met leak rate requirements in a relevant TVAC environments. End-to-end sample acquisition, sample triage, sample delivery, and sealing operation were also demonstrated.

Development of a flight version of KArLE will continue. The architecture is largely driven by the leak rate requirement between the sample cup and the analysis chamber; depending on the operational environment and seal requirements, complexity could be reduced by replacing the elevator with a passive sealing mechanism. Additional inspection systems could be integrated with the SHS carousel with minimal

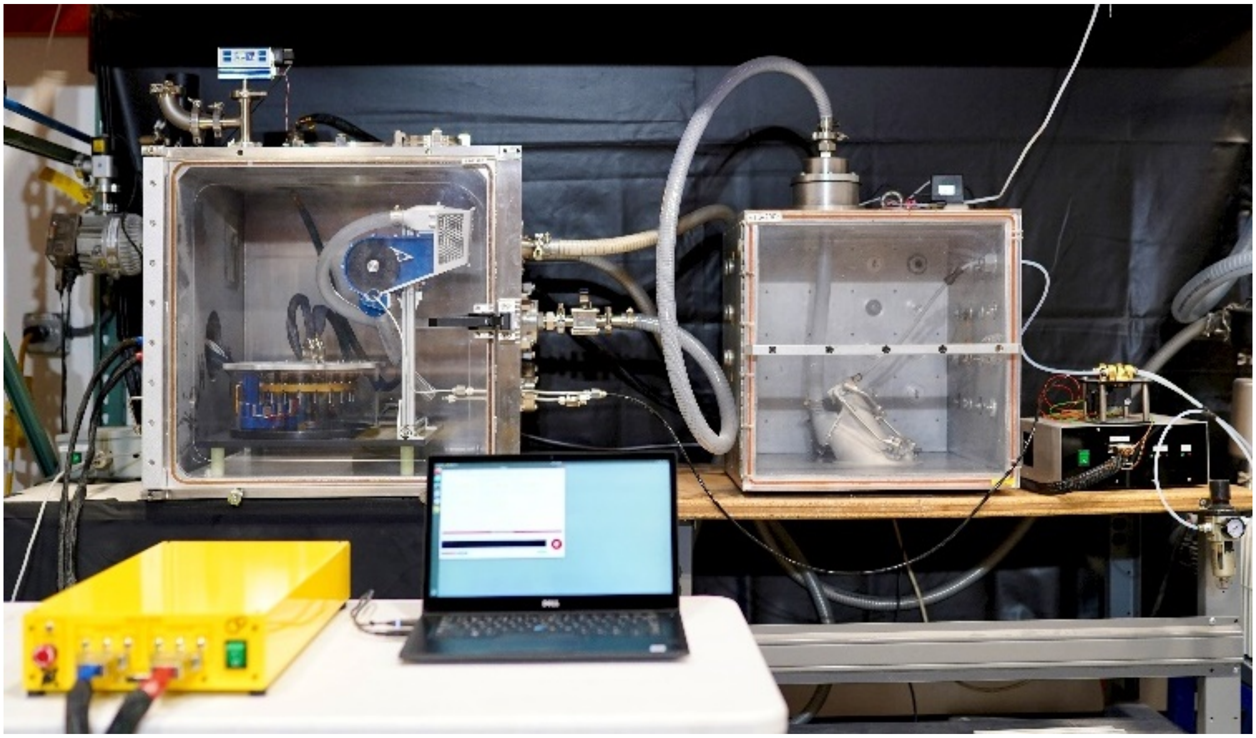

Figure 31. End-to-end KArLE sampling system set up for testing in linked clean (left) and dirty (right) chambers

architecture changes. The SHS design allows for scalability of both the number of sample cups and the sample cup sizes for various rock sizes.

Challenges facing future SHS developments include verification of the science requirements, seal qualification, and integration of launch locks to survive vibration environments. The development detailed in this paper has provided critical insights to guide future designs.

This work was sponsored by the NASA DALI program.

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Biography

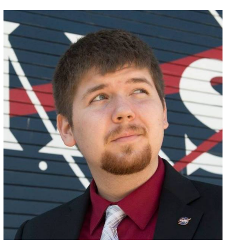
***J. Tighe Costa** is a robotics engineer, designer, and artist. He currently leads the Robotic Systems Group at Honeybee Robotics, where he specializes in the development and maturation of low-TRL robotic sampling systems for planetary exploration. Current projects range in scale from piezo-actuated micro sample transport to 10kW deployable solar arrays for lunar habitation. He holds a M.S.E. in Robotics ('16) from the GRASP Lab at the University of Pennsylvania and a B.S.E. Cum Laude ('16) in Mechanical Engineering, also from the University of Pennsylvania. His interests are antidisciplinary.*

***Caleb Lang** is a mechanical engineer in the Exploration Technology Group at Honeybee Robotics. Mr. Lang currently works on deep drilling project for the Europa environment. Mr. Lang received a B.S.E. in Mechanical Engineering from Northwestern University.*

Patrick Corrigan *is a mechanical engineer in the Exploration Technology Group at Honeybee Robotics. Mr. Corrigan received a B.S. in Biomedical Engineering from the University of Southern California.*

Jack Emery *is an electrical engineer in the Exploration Technology Group at Honeybee Robotics. He received a B.S. in Electrical Engineering and Microbiology from University of Washington. Alongside KArLE, he currently works on Lunar PlanetVac and LISTER which are planned for flight in 2023 Mare Cirsium as a part of the CLPS program, and MMX which is planned for flight to Phobos in 2023 in partnership with JAXA.*

Luke Thompson *received his B.S. in Computer Engineering from California Polytechnic State University-San Luis Obispo. He is the lead software engineer for the Lunar PlanetVac mission at Honeybee Robotics and has supported over a dozen additional projects destined for space. Before joining Honeybee Robotics he developed software and calibration methodologies for novel deep-sea sensors at Schilling Robotics.*



Nathan Jensen *is a mechanical engineer in the Exploration Technology Group at Honeybee Robotics. Mr. Jensen received his M.S. in Mechanical Engineering from the University of Nebraska.*

Hunter Rideout *is a mechanical engineer in the Exploration Technology Group and System Engineering Group at Honeybee Robotics. Mr. Rideout received a B.S.E. in Mechanical Engineering from Carenegie Mellon University.*

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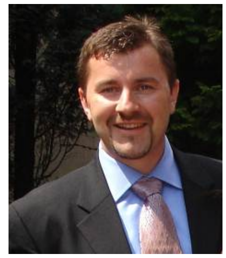
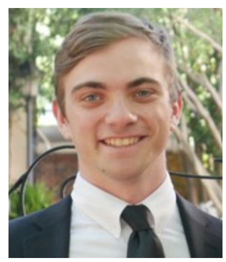
Bernice Yen *is a program manager in the Exploration Technology Group at Honeybee Robotics where she is feeding her interests in furthering space exploration through the mechanical design of systems capable of surviving off-world conditions. Ms. Yen received a M.S. in Mechanical Engineering from the University of California at Los Angeles.*



Dr. Kris Zacny *is Vice President of Exploration Technology Group at Honeybee Robotics. His interests include robotic exploration of planetary bodies. In his previous capacity as an engineer in South African mines, Dr. Zacny managed numerous mining projects and production divisions. Dr. Zacny received his PhD from UC Berkeley in Mars drilling and ME in Petroleum Engineering. He participated in several Arctic and the Antarctic drilling expeditions. Dr Zacny has over 300 publications, including an edited book titled "Drilling in Extreme Environments: Penetration and Sampling on Earth and Other Planets."*



Matthew Mullin *is a laser engineer at NASA Goddard Space Flight Center and is currently developing a space qualified UV laser for the Dragonfly Mission; leading the optical system design for the KARLE instrument; and is also assisting with several laser research and development efforts. He also participates in airborne LIDAR campaigns to collect data on forest and vegetation density levels which is used to validate spaceflight missions currently on the ISS such as GEDI (Global Ecosystem Dynamics Investigation). He graduated from The American University in 2018 with a BA in Environmental Studies and a Minor in Applied Physics.*

Dr. Fanny Cattani *works at NASA Goddard Space Flight Center as a CRESST Postdoc Associate at the Department of Physics at CUA through its Institute for Astrophysics and Computational Sciences (IACS). She has an undergraduate degree in Geology – Magmatic and volcanology specialization – and a Ph.D. in instrument and technique development dedicated to Mars. Her focus is on the in-situ K-Ar dating on the extra-terrestrial body.*

Erich Frese *Erich Frese is a Sr. Electrical Engineer for Space Systems and Applications Inc. (SSAI) as a government contractor for the National Aeronautics and Space Administration (NASA) at Goddard Space Flight Center. He works on center currently as a support for the parts analysis branch along with flight systems design and project development. He is also involved in laser engineering development and operations for several flight projects and is currently working on systems integration of a system KArLE. Some of his roles include but are not limited to; work order construction to develop and watch over hardware build and design, construct procedures, test modifications, and parameters for complex systems. In his down-time he enjoys hiking, biking, golfing and supporting his family and friends along with his lovely new wife.*

Paul Stysley *received his bachelor's degree in physics from St. Mary's College, St. Marys, MD, USA, in 1999, and the master's degree in physics from Catholic University, Washington, DC, USA, in 2002.*

He has more than 15 years of experience working as a Laser Engineer and an Associate Branch Head with the Lasers and Electro-Optics Branch, NASA Goddard Space Flight Center, Greenbelt, MD, USA. Most recently, he has been a Product Design Lead for laser systems on the ICESat-2, GEDI, and DraMS missions.

Dr. Barbara Cohen *is a planetary scientist at NASA Goddard Space Flight Center. Originally from upstate New York, Dr. Cohen earned her BS in Geology from the State University of New York at Stony Brook and her PhD in Planetary Science from the University of Arizona. Her main scientific interests are in geochronology and geochemistry of planetary samples from the Moon, Mars and asteroids. She is a Principal Investigator on multiple NASA research and space flight projects, including Lunar Flashlight, a lunar cubesat mission that will be launched in 2021 as an SLS secondary payload, and the PITMS, a mass spectrometer manifested aboard the Astrobotic Peregrine lander for a lunar surface mission in 2021. She has been a member of the science teams operating the Mars rovers Spirit, Opportunity, Curiosity, and Perseverance.*