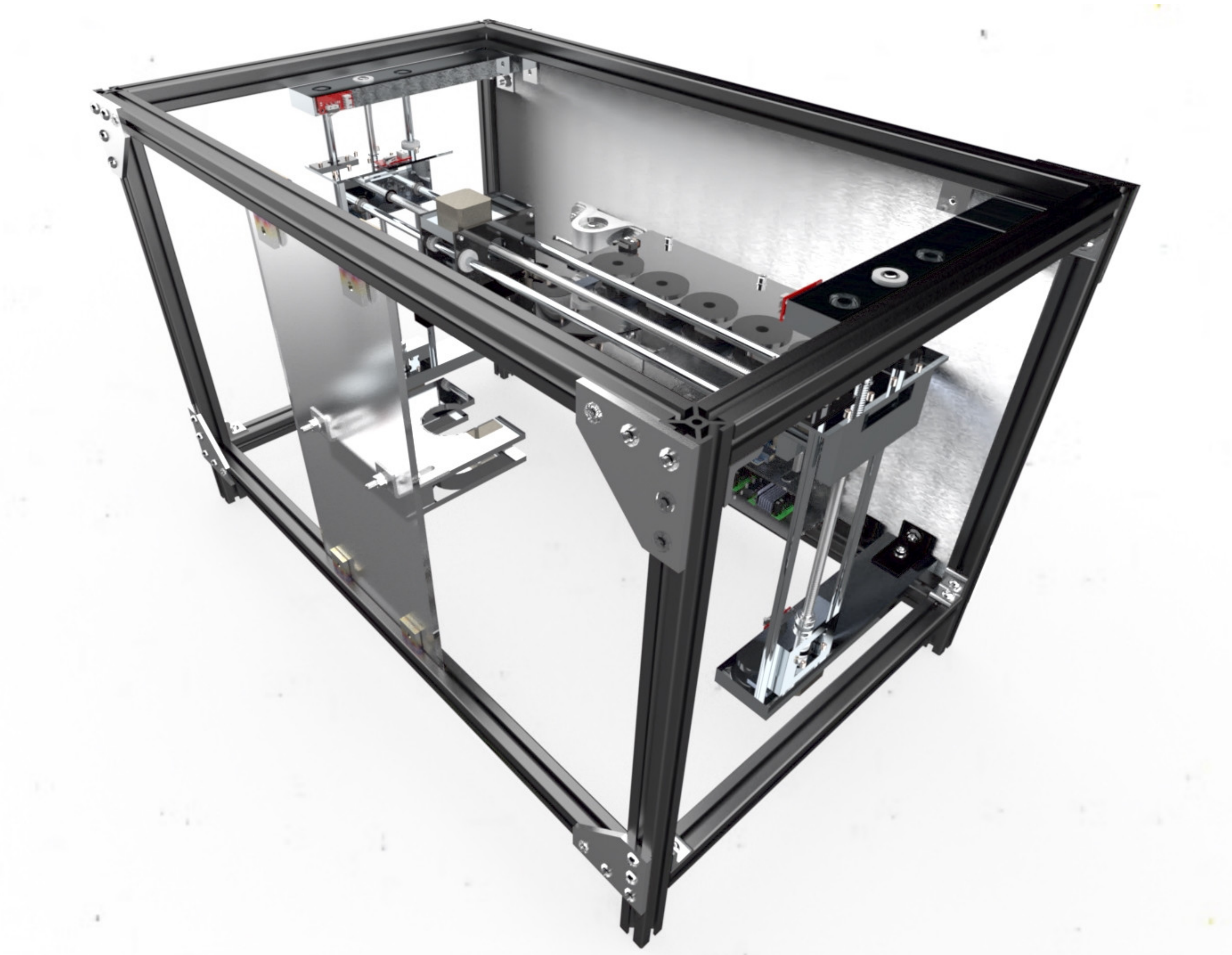
CU Boulder Team 22 | JPL | Design Center Colorado

ICY WORLDS SAMPLING

A sample measurement and handling mechanism to aid the search for life beyond Earth



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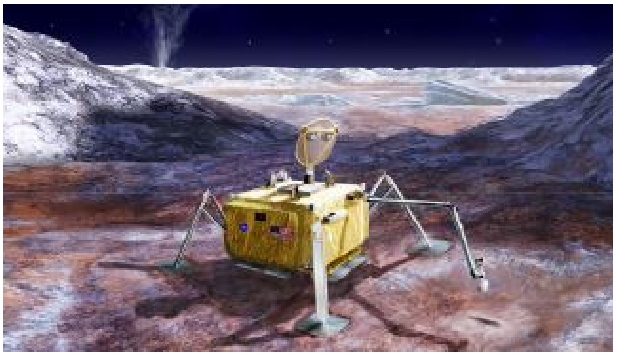
01 INTRODUCTION

Background



As the search for life beyond Earth continues, future missions to explore icy worlds are regarded by many as the best chance to find other signs of life. These icy worlds include Saturn's moon Titan and Jupiter's moon Europa.

The Icy Worlds project is in its conceptual phase. Technologies and methodologies need to be developed for an official mission to be proposed. Our prototype was designed for a proposed Icy Worlds Lander. This project bridges the gap between sample excavation and sample testing in what will be in the mobile laboratory of the Icy Worlds Lander. Its purpose is to receive a bulk sample of cryogenic ice outside of the lander, divide it into three different discrete volumes and distribute it to three instruments inside of the lander.

Mission Statement

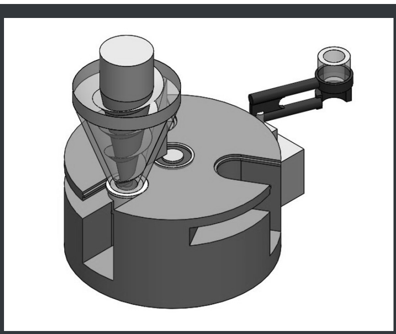
To create an adaptable sample measurement and handling mechanism to interface between the sample drop-off and the instrumentation suite on the Icy Worlds Lander.

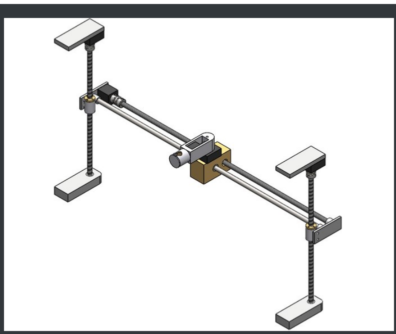
Design Considerations

- Reliability
- Maturability
- Iterative Ideation
- Size
- Power Consumption
- Gravity
- Run Time
- Sample Integrity

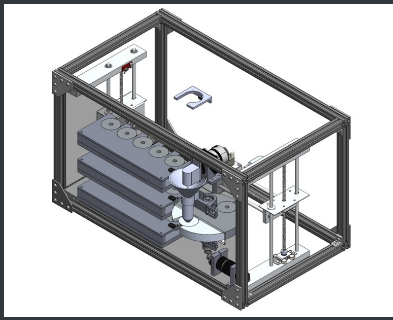
By emphasizing ideation and adaptable designs, rather than adherence to strict environmental and spaceflight requirements, we opened up the design space to novel and creative proof-of-concept solutions that can be matured into flight-ready configurations.

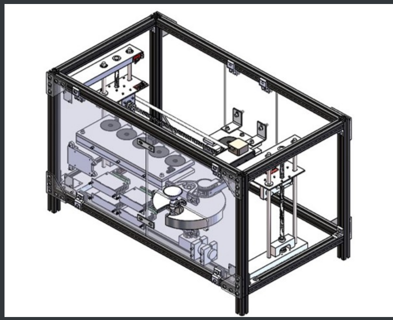
02 DESIGN PROCESS





Ideation



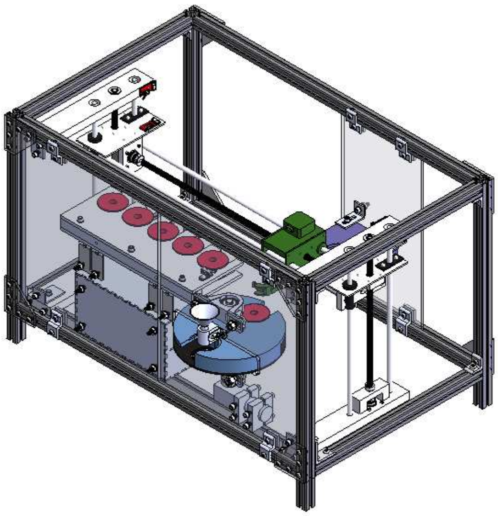


Design Development

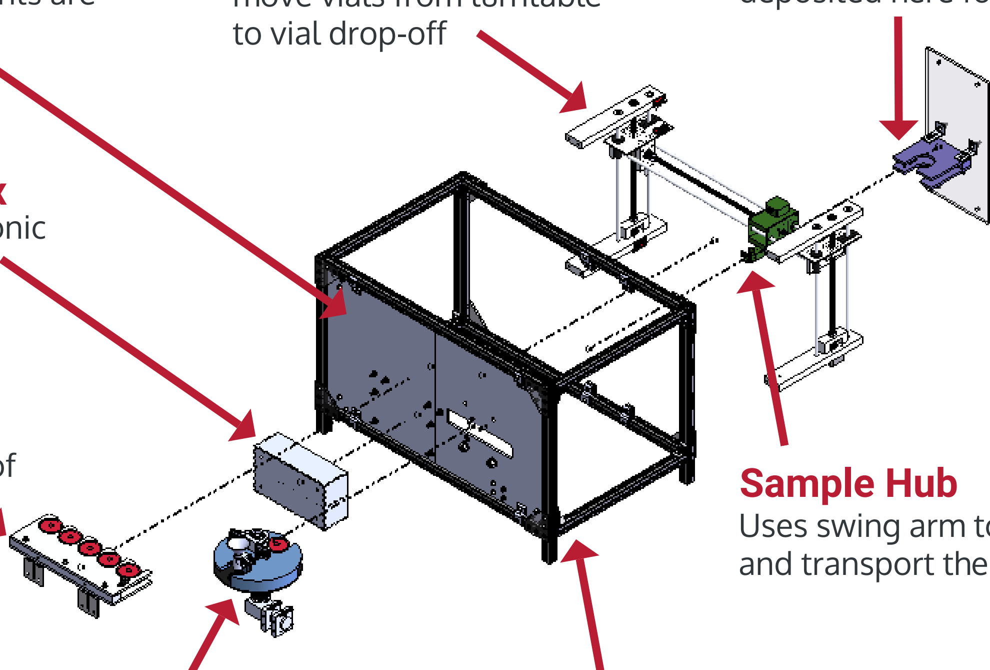
Final Deliverable

Design was a large focus of this project given the Icy Worlds mission is in its early stage of development. The system requires two separate functions: measurement and transportation. We designed three concepts for each function. These designs ranged from a measurement system that uses centripetal force to fill containers to a transportation system that spools cables to deliver the sample. We conducted a trade study which ranked each design over a set of attributes critical to system success. The attributes considered in the trade study—including controllability, manufacturability, reliability and accuracy—aided us in choosing the designs to develop further. The images above show the progression of the chosen design over the span of five months from notional concepts to a fully integrated system.

03 SYSTEM OVERVIEW



The final system design is shown above. The exploded version below highlights each subassembly and its purpose. Critical components are highlighted in color for clarity.



Front Plate
Aluminum front plate to which all components are mounted

2-Axis Gantry
Transportation system to move vials from turntable to vial drop-off

Instrument Drop-Off
Vial full of sample deposited here for testing

Electronics Box
Housing for electronic components

Vial Cache
Stores extra vials of varying sizes

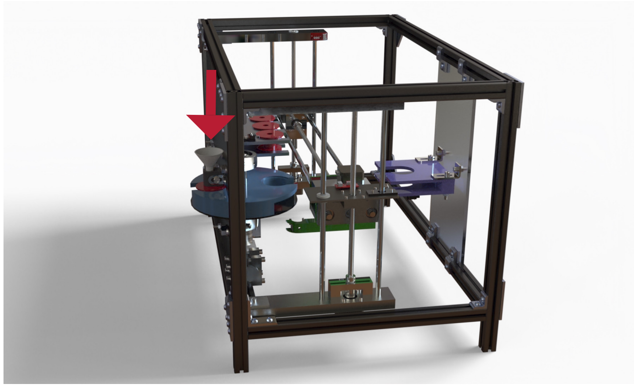
Sample Hub
Uses swing arm to pick up and transport the sample

Turntable
Measurement design that shears the sample by rotating vials from outside the system to inside

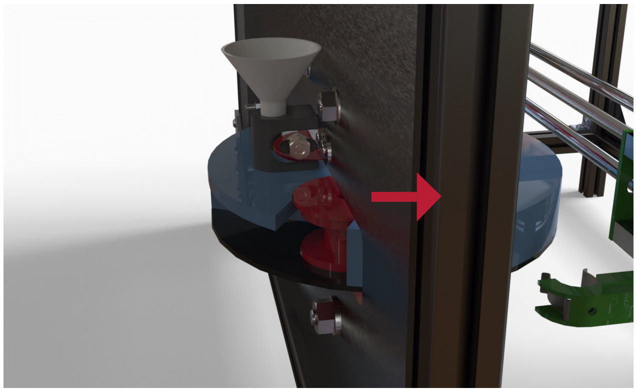
Structure
System housing composed of 80/20 framing

04 FUNCTIONALITY

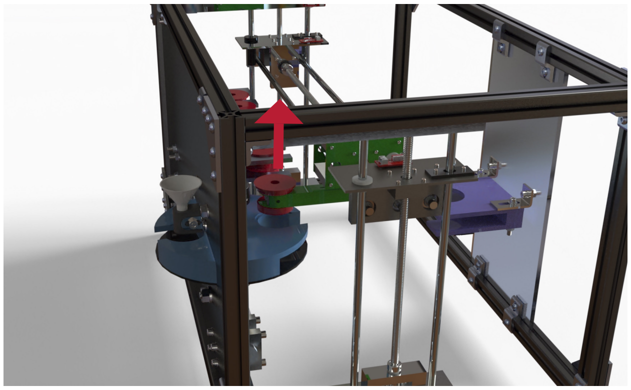
The following sequence demonstrates the functionality of the design by following the path of a sample through the system. The red arrows indicate the motion of the sample in each step.



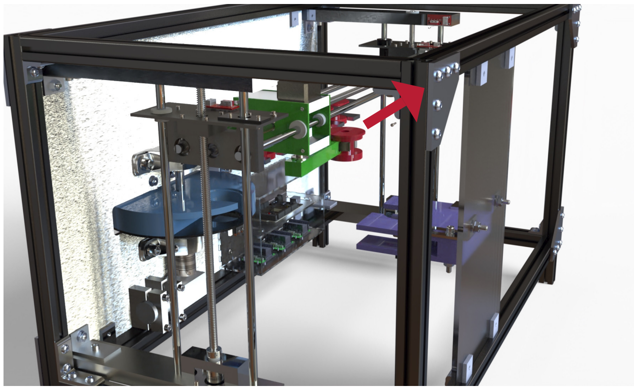
Receive sample in funnel and fill vial in turntable below



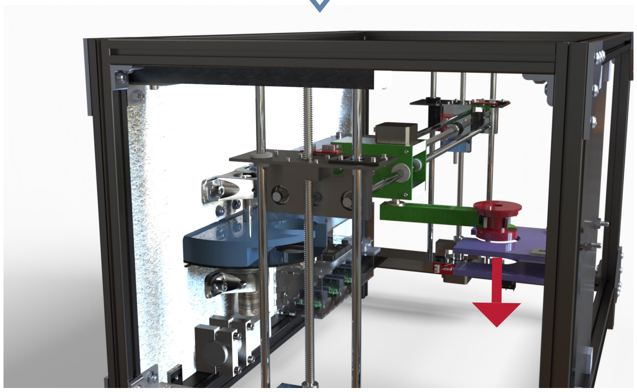
Rotate turntable to shear off excess sample and bring vial inside the lander



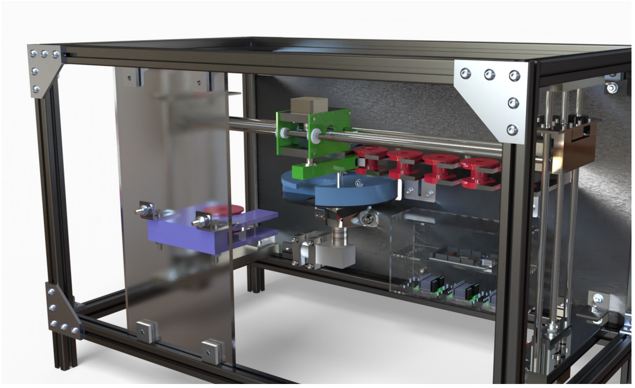
Pick up sample using 2-axis gantry and swing arm



Transport sample across working volume via 2-axis gantry and swing arm



Drop off sample at instrumentation suite by lowering the vial into place



Pick up an empty vial from the cache and place it in the turntable

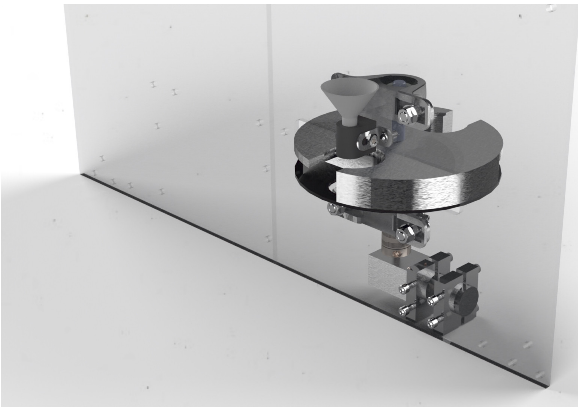
05 DESIGNING INTERACTIVE SUBSYSTEMS

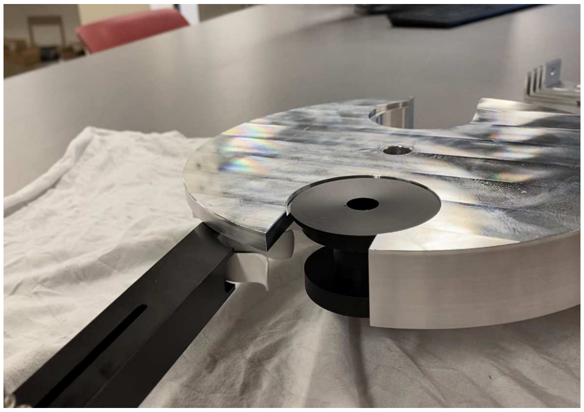
The Dual Functionality of the Turntable

The measurement subsystem takes the bulk sample and divides it into discrete volumes between 1cc and 5cc. The transportation subsystem delivers the measured sample to instruments inside the vault. The turntable acts as both the measurement subsystem and the first stage of the transportation subsystem when it rotates to bring the sample inside the lander and passes it off for further transport.

Measurement to Turntable

The vials are designed to hold varying sample volumes. The turntable aligns the vials with the exit of the funnel. When the turntable rotates, it shears excess material off the top of the vial. As the turntable rotates, it brings the filled vial inside the vault, and an empty vial rotates outside of the vault to receive the next sample.





Turntable to Transportation

Once inside the lander, the samples are delivered to various instruments using the 2-axis gantry. The cut-out path underneath the turntable allows the gantry to drive the swing arm laterally, passively engage the vial, and lift it out of the turntable. Similarly, the swing arm retrieves and deposits vials in the vial cache and instrument suite. The swing arm and the gantry span the entire working volume by combining two degrees of linear motion with a rotary motion.

Challenges of Designing for Interactive Subsystems

We made the following considerations when designing to ensure that parts would fit together:

- Thermal expansion and contraction due to wide temperature range in space
- Internal stress caused by moving mechanisms and weight of system
- Machining tolerances

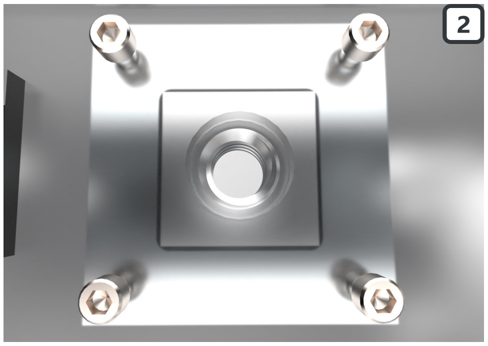
06

DESIGN HIGHLIGHT - LINEAR MOTION

A gantry system acts as our sample transportation mechanism. Cartesian coordinate mapping suits our wide working volume, and it's adaptable to varying instrument locations. Though the motion could be accomplished by a robotic arm, the gantry's simplicity is an asset. Linear motion mechanisms do, however, come with many challenges. Some of the unique design choices we made to overcome these obstacles are discussed below.

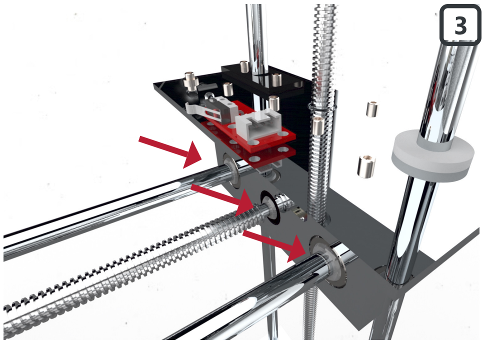
Two Guide Rods 1

Our gantry's linear motion is achieved via lead screws. To counteract the moment imposed by the screw, guide rods are used to drive linear motion. Only one rod is necessary for this function, however. The choice for two was made to remove lateral loads on the lead screw, allowing the motor to drive the same motion with less torque.



Square Nut 2

To eliminate overconstraint between the lead screw and guide rods, a small amount of flexibility is introduced into the system. This is achieved through the use of a square nut inside a housing with a slightly larger area. As a result, any misalignment between these three rods during assembly is accounted for, eliminating unwanted stresses.



Spherical Bearings 3

Spherical bearings are implemented to overcome another aspect of overconstraint. They accommodate both angular and axial misalignment of the vertical assemblies.

Custom Bushing - Slot Combination 4

The carriages make contact with the guide rods through a slot and bushing. The slot combined with the square nut eliminates all overcontraint between the rods and lead screw. On the vertical carriages, a longer, custom bushing is implemented because binding occurred when using a shorter, off-the-shelf bushing. The length addition eliminated the heel-toeing effect intrinsic to the shorter bushing which originally caused these issues.

07 SENIOR DESIGN JOURNEY

Here are some of the highlights of our Senior Design journey:

2 Months of Ideation and Trade Studies

2 Months of Design Refinement

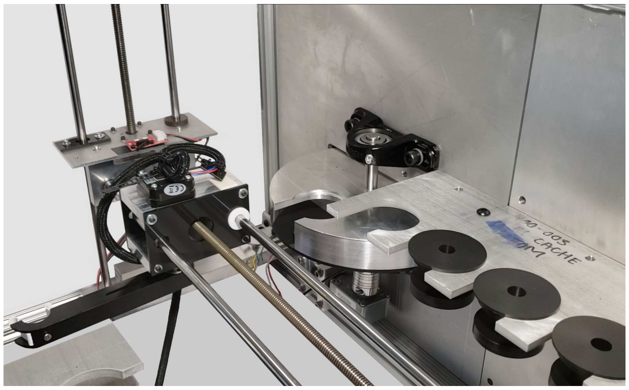
> 250 Hours Machining Custom Parts

Assembly of >300 Parts

Controls and Testing of 4 Integrated Subsystems

Future Work Development

Our journey in Senior Design provided us with the opportunity to experience challenges and develop skills from the conceptual stages to the final creation. After an entire semester of designing, it was rewarding to see our prototype come to life after more than 250 hours of machining over 50 custom parts. Despite many unforeseen obstacles, we are proud to present a functional prototype, shown in the image to the right.



The original specifications of the prototype that we accomplished were for the mechanism to:

- mount to the front plate
- operate within 48 V and consume >200 W
- operate under Earth's gravity
- deliver each sample in less than 10 minutes to anywhere within a 20 cm by 50 cm space on the instrument plane

This project presented many technical challenges. Designing a mechanism that does not rely on gravity was non-trivial. Creating subsystems that interface mechanically, electrically, and structurally required comprehensive design iteration, testing, programming, and integration. Due to the overall complexity of our assemblies, we learned how to design for manufacturability.

The final prototype has over 300 parts. Given this complexity, we learned how to communicate well with one another, take ownership, and break a huge project into smaller, bite-size pieces. Ultimately, it was critical for us to learn how to use our resources, ask for help, and know our boundaries. We will apply these lessons, in addition to the technical skills we learned, to our future careers.

08 FUTURE WORK

The design presented was developed with spaceflight in mind and emphasis was placed on developing creative proof-of-concept solutions rather than a flight-ready product. Future work involves maturing the prototype into a flight-ready configuration.

Environmental Considerations

To endure the cryogenic temperatures and vacuum on the surface of icy worlds like Europa, the following considerations are a subject of future work on this project:

- Low outgassing materials that can handle extensive radiation
- Lubrication-free nut and lead screw material selection tested at cryogenic temperatures
- Method to protect the lead screws from particulate — bellows, for example

Due to intense radiation, a driving factor for many solutions will be the short mission length ranging from 7 to 30 days.

Spaceflight Considerations

Given the rigor of spaceflight, development of the following items will improve reliability:

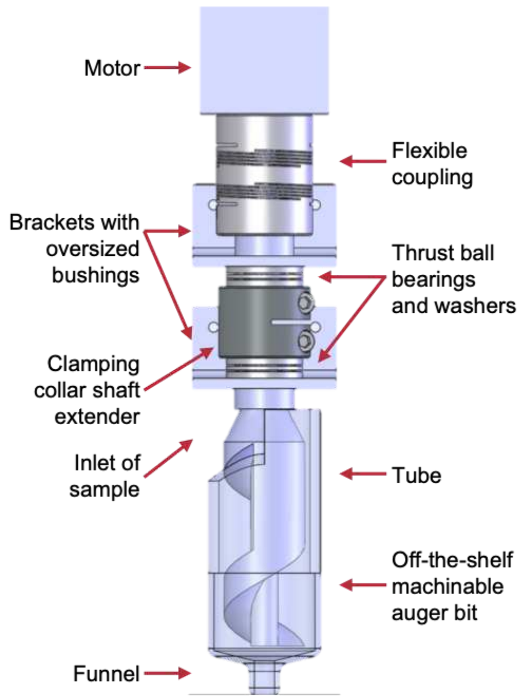
- Launch configuration to secure components
- Calibration routines to ensure the swing arm length can interface with five locations
- Redundancies and fault analysis to ensure mechanism functions without human input

Minimizing Contamination

To preserve sample integrity and minimize cross-contamination, our solution takes advantage of the short mission duration and uses individual vials for each sample. It is important that future work further reduce biological and non-biological contamination.

Gravity Independence

Gravity on Europa is 7.5 times less than that on Earth.[1] A method of packing vials while preserving sample integrity is necessary to remove gravity dependence. An initial solution is presented to the right. The auger bit acts as the screw conveyor to push the sample downward into a vial and control flow. The remaining challenges for this design are ensuring the auger is centered in the tube for the duration of the mission and minimizing cross-contamination of samples in the tube.



[1] Williams, Matt. "Jupiter's Moon Europa." Phys.org, Universe Today, 30 Sept. 2015, phys.org/news/2015-09-jupiter-moon-europa.html.

09 MEET THE TEAM

Left to right:

Dylan Ramaswamy | Test Engineer
Dylan focused heavily on design work and testing throughout the process. During the first semester he acted as design lead for the gantry subsystem, and for the second semester he formulated test procedures and assisted in the necessary controls for functionality.

Branden Adams | Logistics Manager / Controls Lead
Branden served as the primary point of contact between the team and our industry client representative. He conducted trade studies to support component selection during the project planning phase. Branden then pivoted to designing and integrating the system's electronics and control software architecture.

Brooke Shade | Systems Engineer
Brooke led the design of the turntable subsystem while also focusing on interfaces between all subsystems. Brooke spent the latter half of the project in the machine shop, writing controls for the turntable subsystem, and ensuring proper final integration.

Erid Pineda | CAD Engineer
As the CAD engineer, Erid's job was to provide the team with an easy to use CAD management solution. Through that process, he also created, developed and maintained designs as they matured.

Elise Niedringhaus | Project Manager
Elise developed individualized plans for each member to ensure team productivity. She checked in often to foster healthy team dynamics and assisted other team leads with design, machining and controls in both a technical and managerial capacity.

Valerie Sonnenberg | Manufacturing Engineer
Valerie designed part of the measurement subsystem and led the manufacturing process. She created and quality checked the manufacturing drawings, created a manufacturing schedule, and worked in the machine shop. She assisted with CAD design and prototype integration.

Alex Whitfield | Financial Manager
Alex kept track of the team's budget and selected items to be purchased. During the first semester he was the design lead for the rotary distributor and developed a purchase plan, and for the second semester he assisted in both the manufacturing and controls sections of the project.

Acknowledgments
The team would like to thank the following people for their invaluable support and assistance with our project: Mieszko Salamon, Dr. Derek Reamon, Dr. Julie Steinbrenner, Dr. Daria Kotys-Schwartz, Shirley Chessman, Greg Potts, Chase Logsdon, Victoria Lanaghan, and Mo Woods