Electrodynamic Regolith Conveyor Sub-Orbital Flight Experiment

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Outline

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- Payload & Experiment Requirements
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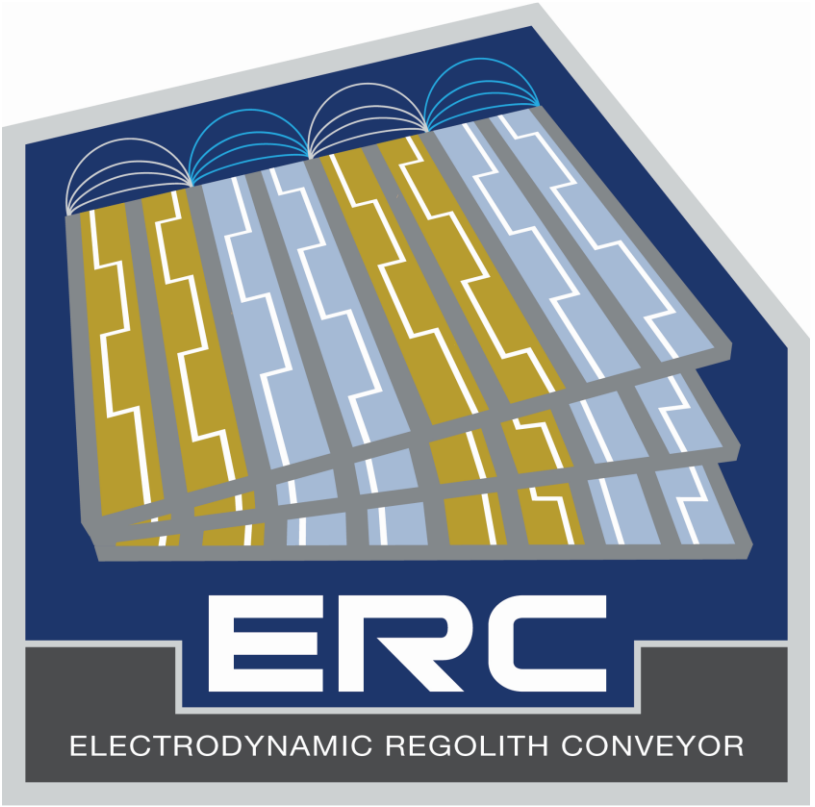


Introduction – Electrodynamic Regolith Conveyor

- **NASA KSC is developing the Electrodynamic Regolith Conveyor (ERC) technology as a solution for conveying, directional dust mitigation, soil sampling, and beneficiation**
  - Low power, no mechanical actuation, dust tolerant regolith transport

- **Extension of the Electrodynamic Dust Shield (EDS)**
  - Developed for lenses, solar panels, radiators, seals, fabric, and foldable mats

- **The objective of the ERC sub-orbital flight experiment is to perform testing to advance the TRL of the ERC technology by:**
  - Measuring regolith transport flow rate, power consumption and range of particle trajectories at four different inclinations in a simulated lunar gravity and vacuum environment.
  - Anchoring discrete element modeling efforts with test data

Electrodynamic Dust Shield

3-Phase +/-1 kV Square Wave on Spiral Pattern

Electrodynamic Dust Shield

Active Dust Mitigation Lunar Demonstration

Date: 2024

Lander: Firefly Aerospace Blue Ghost

Landing Site: Mare Crisium

Objectives: Evaluate EDS on the Moon

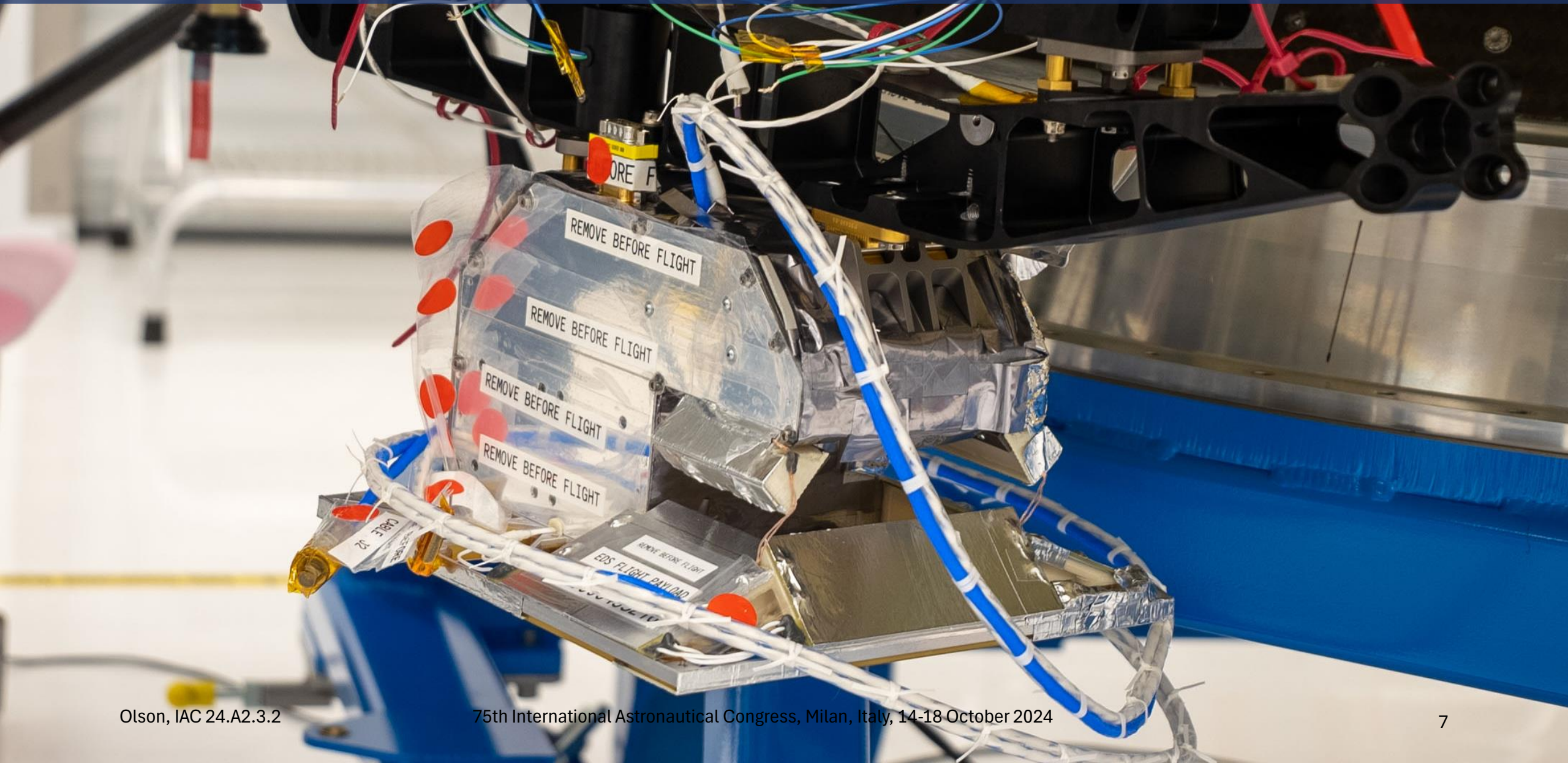
- Optical surfaces (solar panels, lenses)
- Thermal radiator surfaces
- Day and night operation (time permitting)

Electrodynamic Dust Shield

Lunar Payload Prior to MLI & Lander Integration

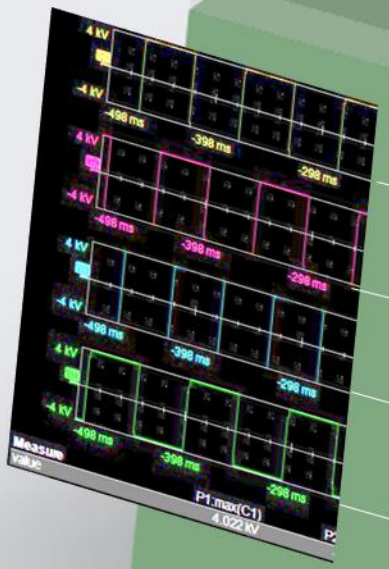
Electrodynamic Dust Shield

Blue Ghost Lander Integration in 2024



EDS Discrete Element Modeling

EDS modeling with various lunar simulant & operating parameters



$$m_i\ddot{\boldsymbol{x}}_i = \boldsymbol{F}_{coulomb_i} + \boldsymbol{F}_{DEP_i} + \boldsymbol{F}_{image_i} + \boldsymbol{F}_{drag_i} + \boldsymbol{F}_{friction_i} + \boldsymbol{F}_{adhesion_i} + m_i\boldsymbol{g}$$

$$\boldsymbol{F}_{coulomb} = \boldsymbol{E}q$$

$$\boldsymbol{F}_{DEP} = \frac{4\pi\varepsilon_0(\varepsilon-1)R^3\boldsymbol{E}_0\nabla\boldsymbol{E}_0}{\varepsilon+2}$$

$$\boldsymbol{F}_{image} = \frac{1}{4\pi\varepsilon_0}\sum_{n=1}^{N}\left(\frac{q_i q_n}{2d}\right)^2\left(\frac{\boldsymbol{d}}{|\boldsymbol{d}|}\right)$$

$$\boldsymbol{F}_{drag} = -6\pi\eta R\dot{\boldsymbol{x}}$$

$$\boldsymbol{F}_{friction} = -\mu\boldsymbol{F}_{\boldsymbol{n}}\boldsymbol{n}$$

Programs/Codes

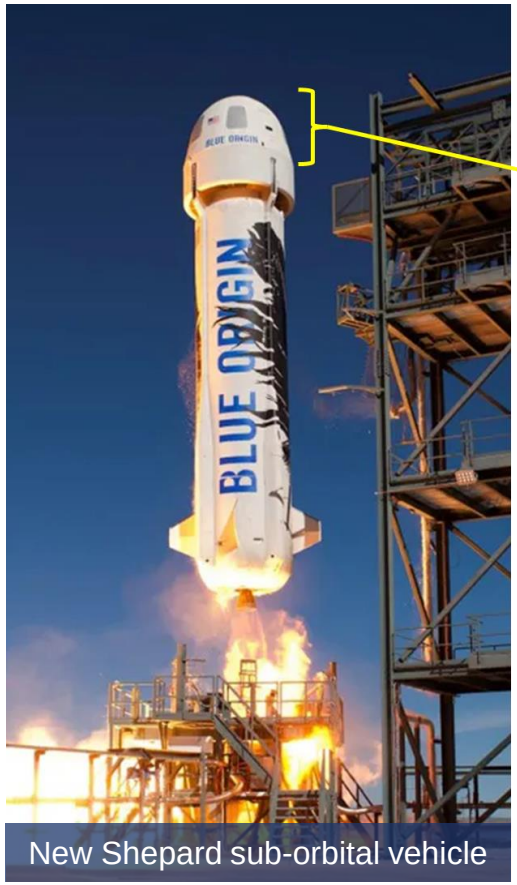
- LIGGGHTS
- Aspherix/CFDEM

Payload Requirements

- The ERC payload designed for a Blue Origin New Shepard capsule single size payload locker
- Launch loads, EMI/EMC, Interfaces, etc…

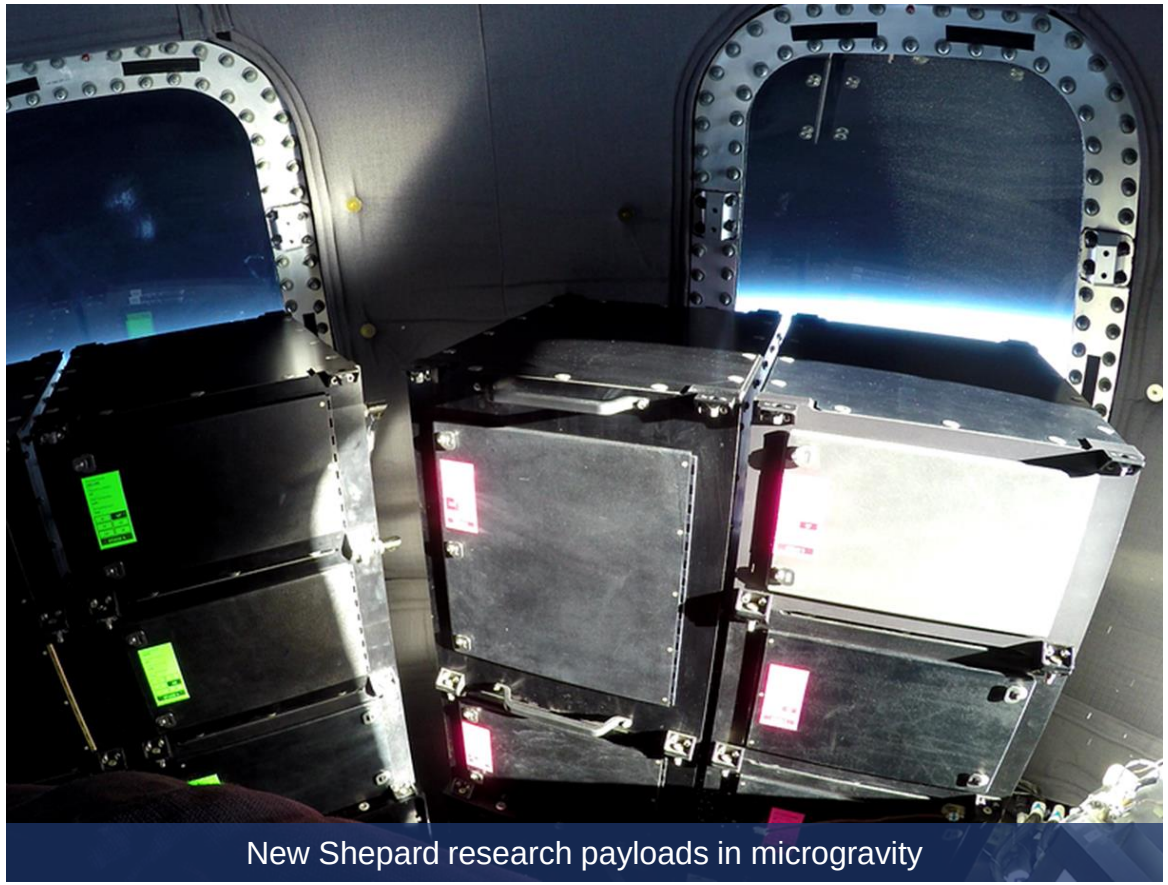
Table 1. Blue Origin New Shepard Single Locker

Payload locker type	Single
Internal dimensions	52.3 x 41.4 x 24.1 cm
Payload mass	11.34 +0/-0.045 kg
Payload power	18 V, 8 A max



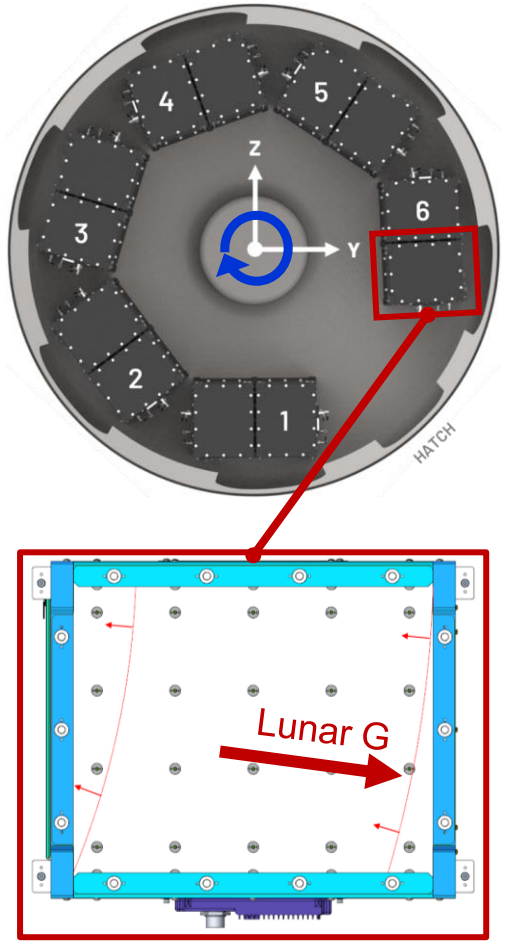
New Shepard sub-orbital vehicle


New Shepard Capsule landing


New Shepard research payloads in microgravity

Experiment Requirements

Capsule simulating 1/6 gravity by spinning during freefall (Blue Origin Payload User's Guide)



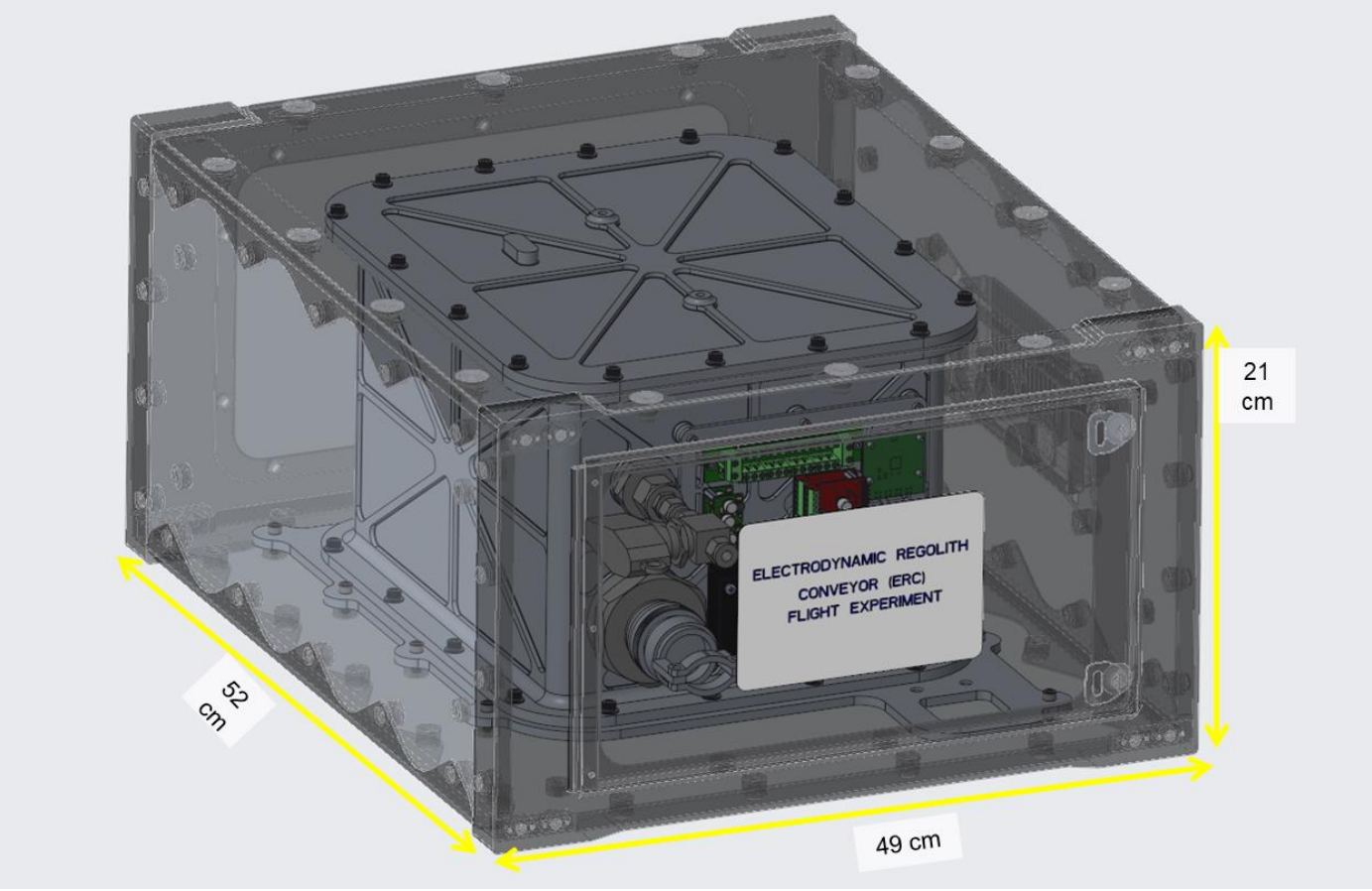
Payload locker arrangement inside capsule and the associated centripetal acceleration during the spin phase of flight

Table 2. High level ERC experimental requirements

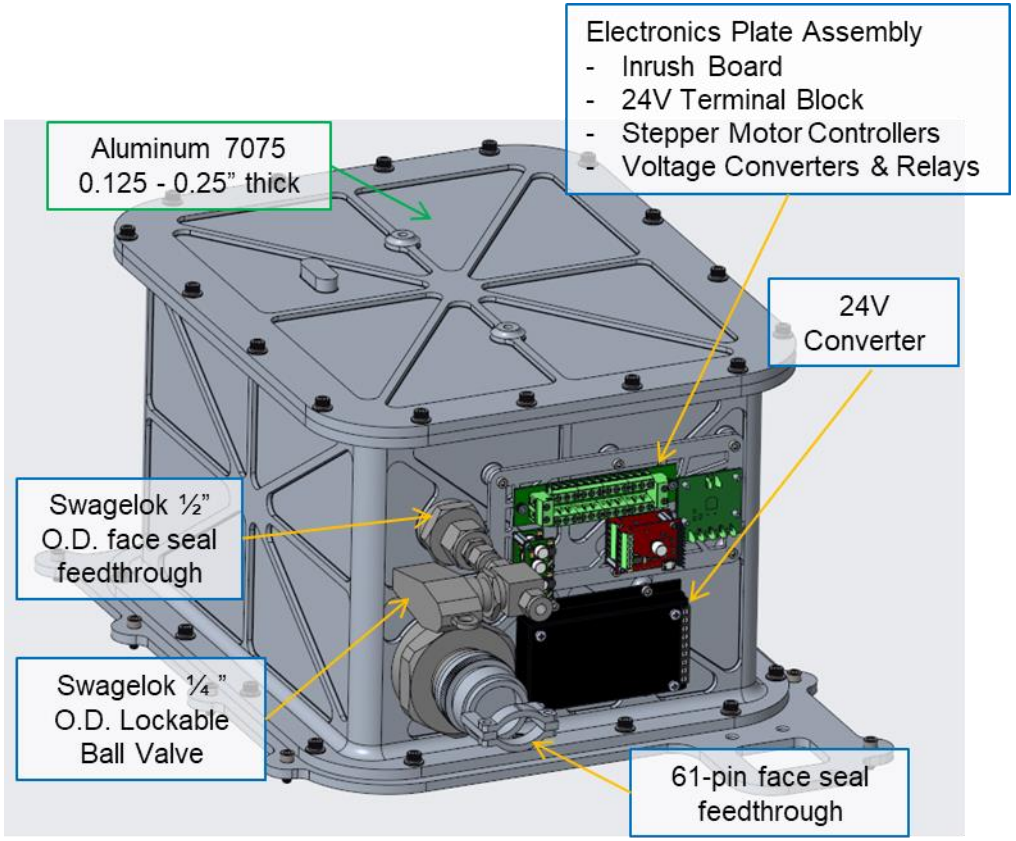
#	High level requirements
	Environmental
1	<500 mTorr experiment pressure during operation
	Regolith Flow
2	Storage of 200 or more g of < 200-micron regolith simulant
3	Feed up to 1.2 g/s of regolith simulant onto and uniformly across the conveyor surface
	Conveyor Operation
4	+/- 4 kV 10 Hz 4-phase square waveform
5	Rotating conveyor plane >10 degrees from horizontal
6	Side and top view of regolith motion
	Instrumentation
7	240 fps video recording, profile and top views
8	Lighting for general observation and particle flow tracking
9	Regolith and experiment temperature measurement
10	Pressure measurement
11	Regolith flow rate measurement
12	Power measurement (voltage and current)

System Design

- The ERC payload's primary structure, mounted to its payload locker, is an aluminum vacuum chamber
- ERC consists of three primary internal subsystems: Feeder, Conveyor, Instrumentation



ERC payload design (inside transparent payload locker)



ERC vacuum chamber and its external components

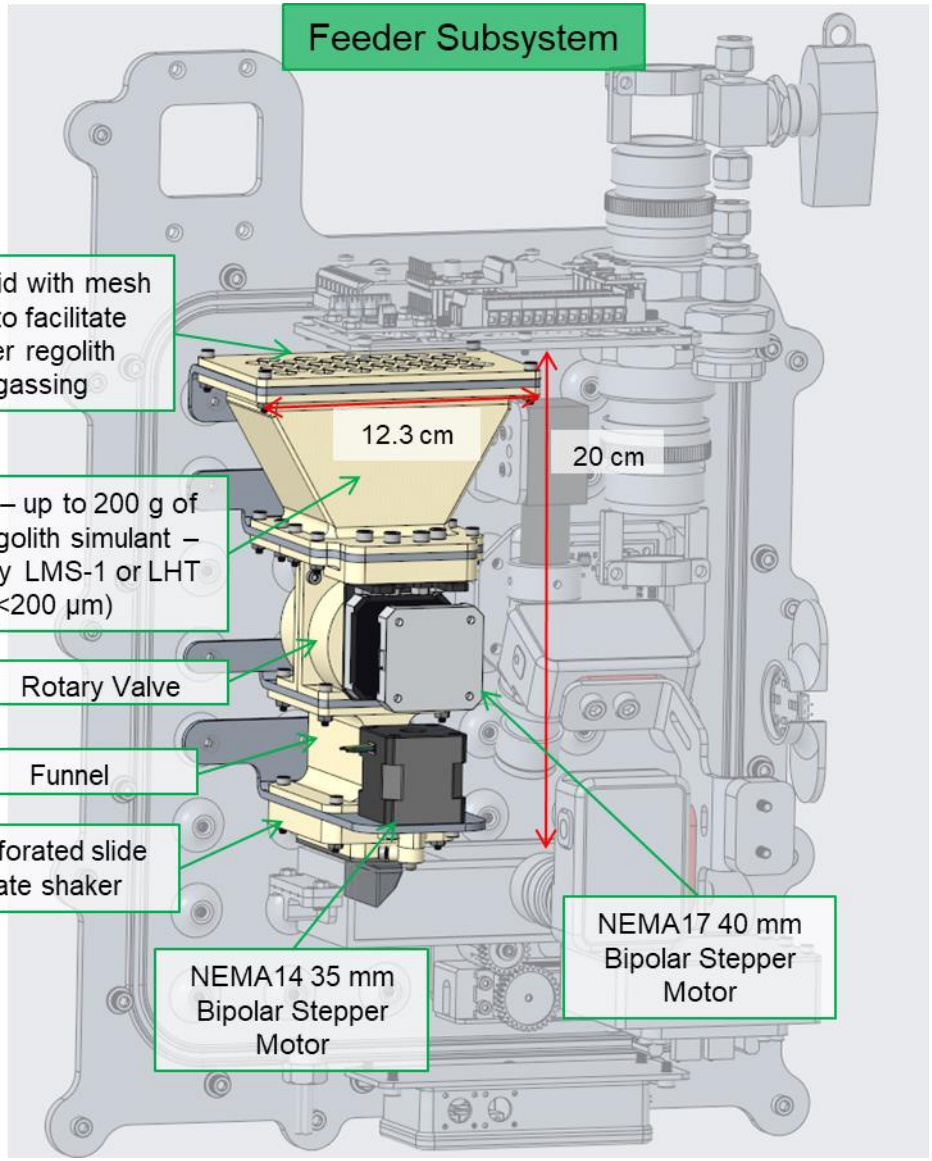
Subsystem Design

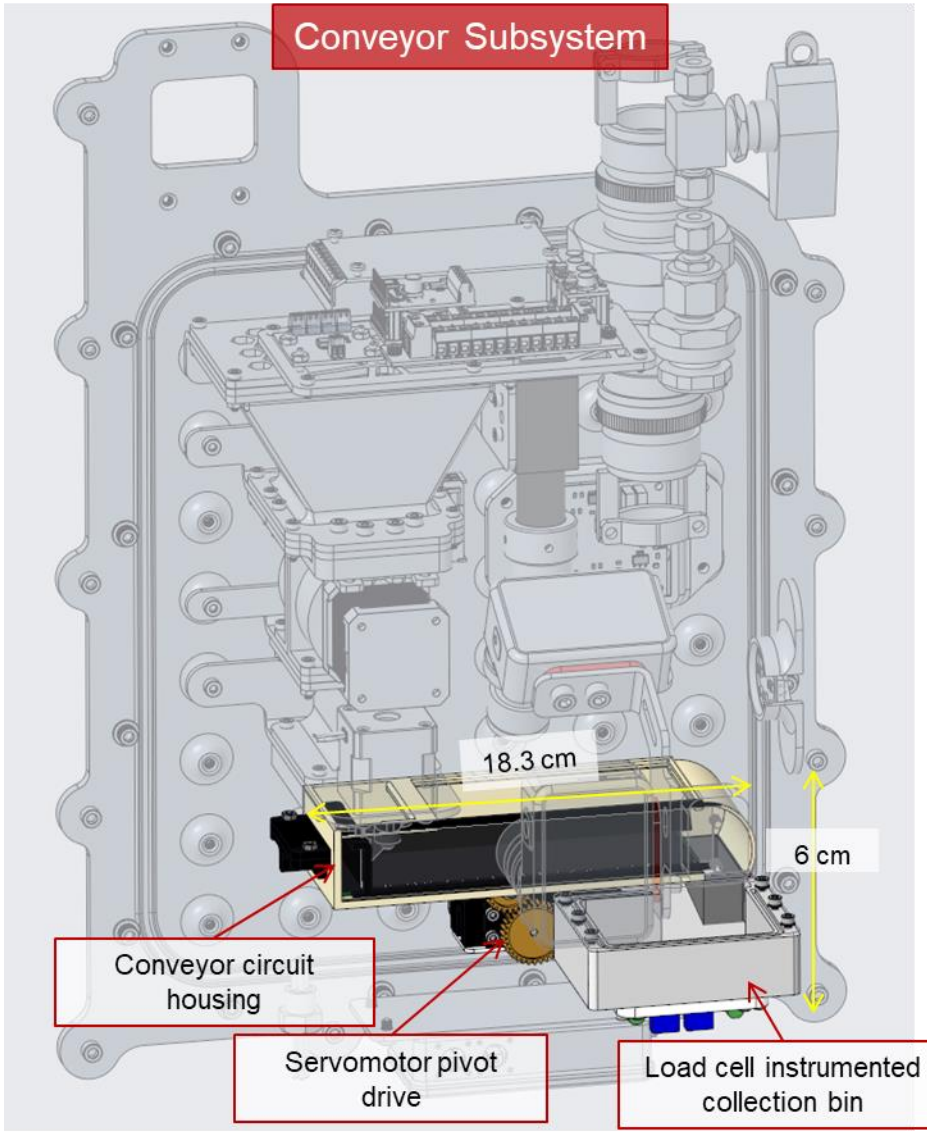
Feeder

- Stores up to 250 g of regolith
- Feeds regolith at a controllable rate onto the conveyor surface

Conveyor

- 4-phase EDS
- Transparent windows
- Pivots up to 15°
- Load cell instrumented collection bin





Subsystem Design

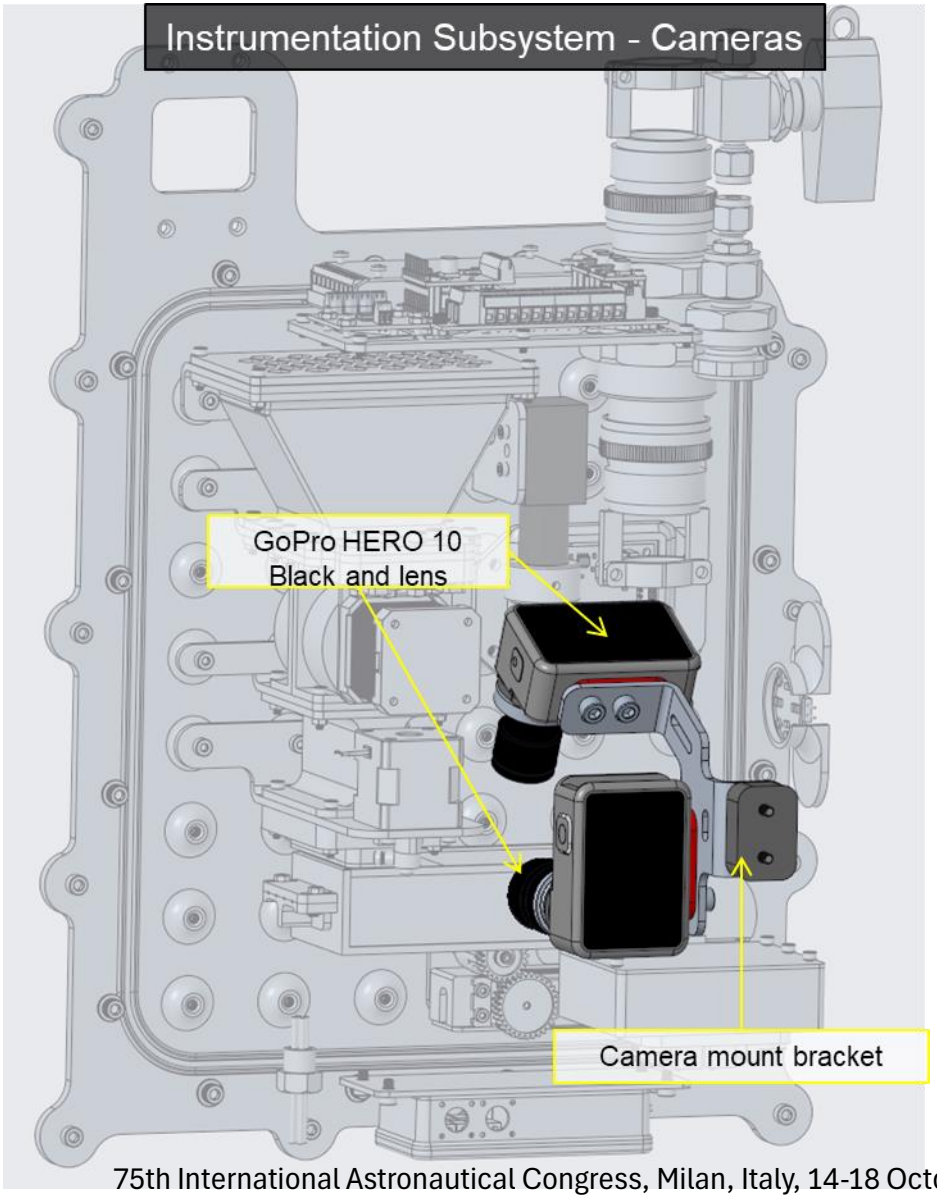
Cameras
- 4K GoPro HERO 10
- Overhead view with LED light
- Profile view – used with laser

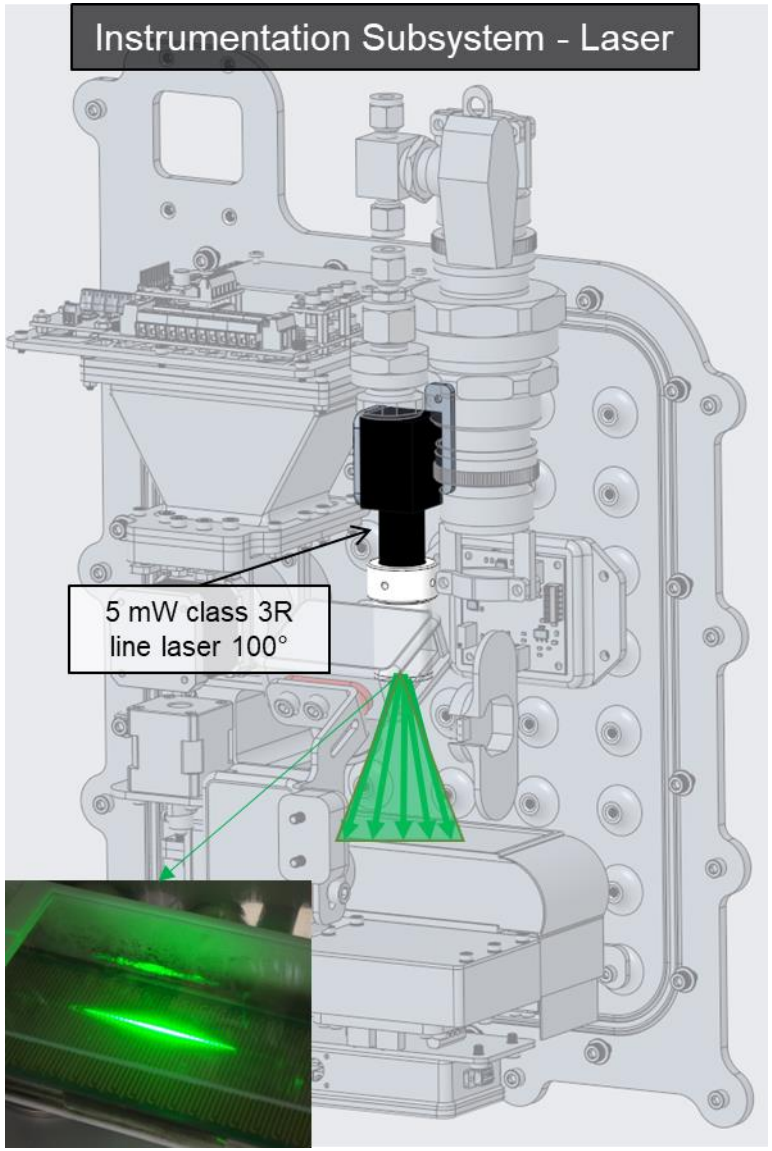
Laser
- 5 mW 532 nm line laser
- Cylindrical lens

Pressure Sensor
- In-vacuum Pirani

Temperature Sensors
- RTDs on chamber, largest motor

Controller Measurements
- Voltage, current
- Load cell data
- Control status
- RTDs
- Pressure

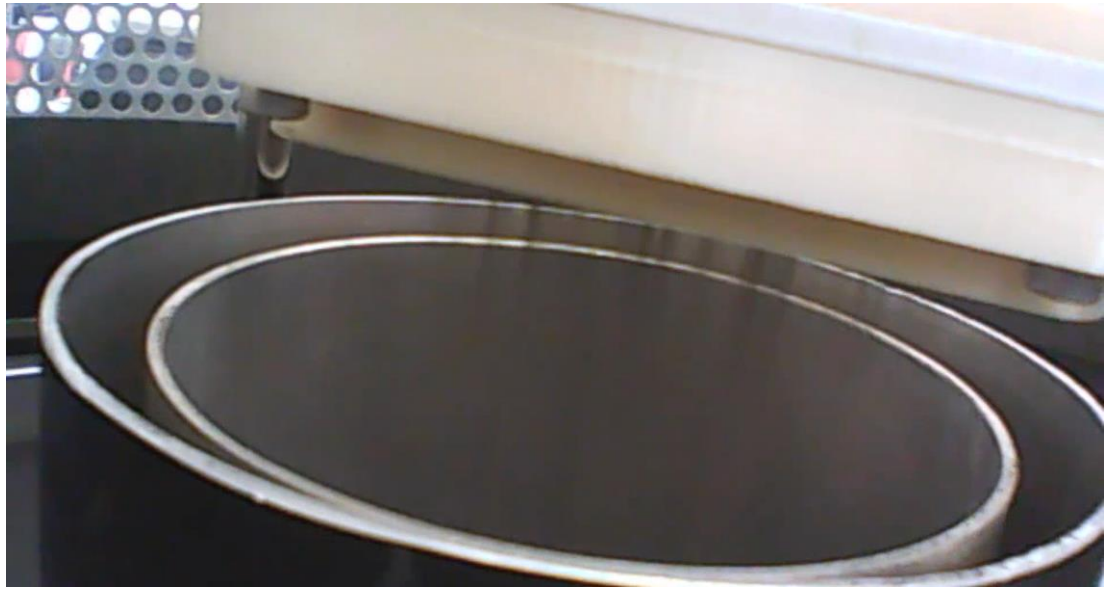




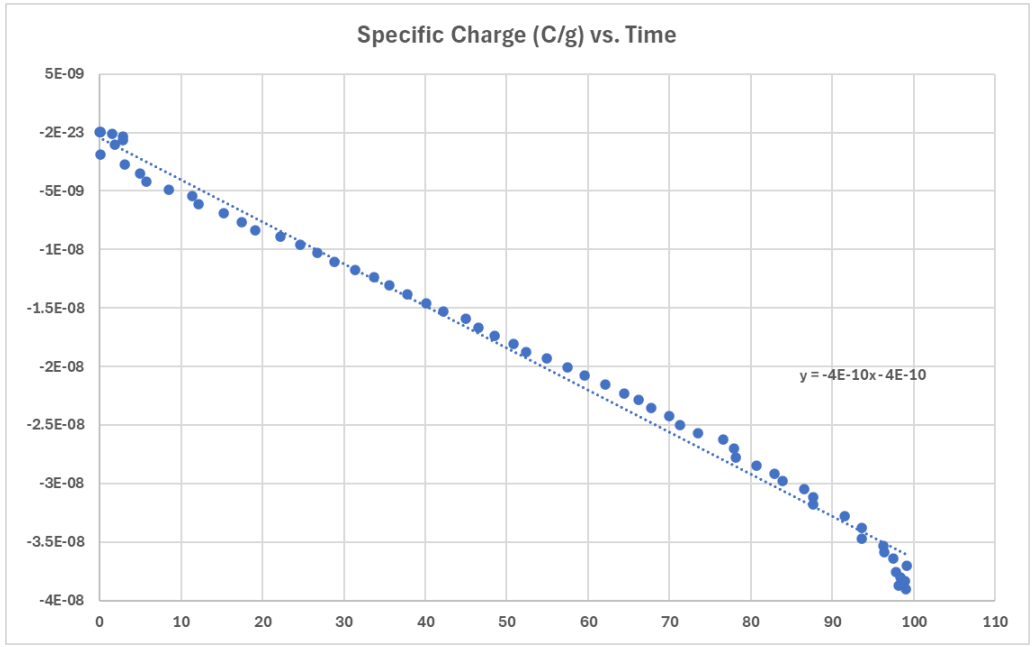
Subsystem Testing

Regolith Storage & Flow

- >200 g hopper regolith storage, and >1.2 g/s flow rate demonstrated
- Charge/mass ratio recorded for post analysis (proportional to coulomb force on particles)



JSC-1A 100-200 micron regolith simulant flowing through the ERC feeder and into an electrometer instrumented faraday cup at ~ 1E-05 Torr

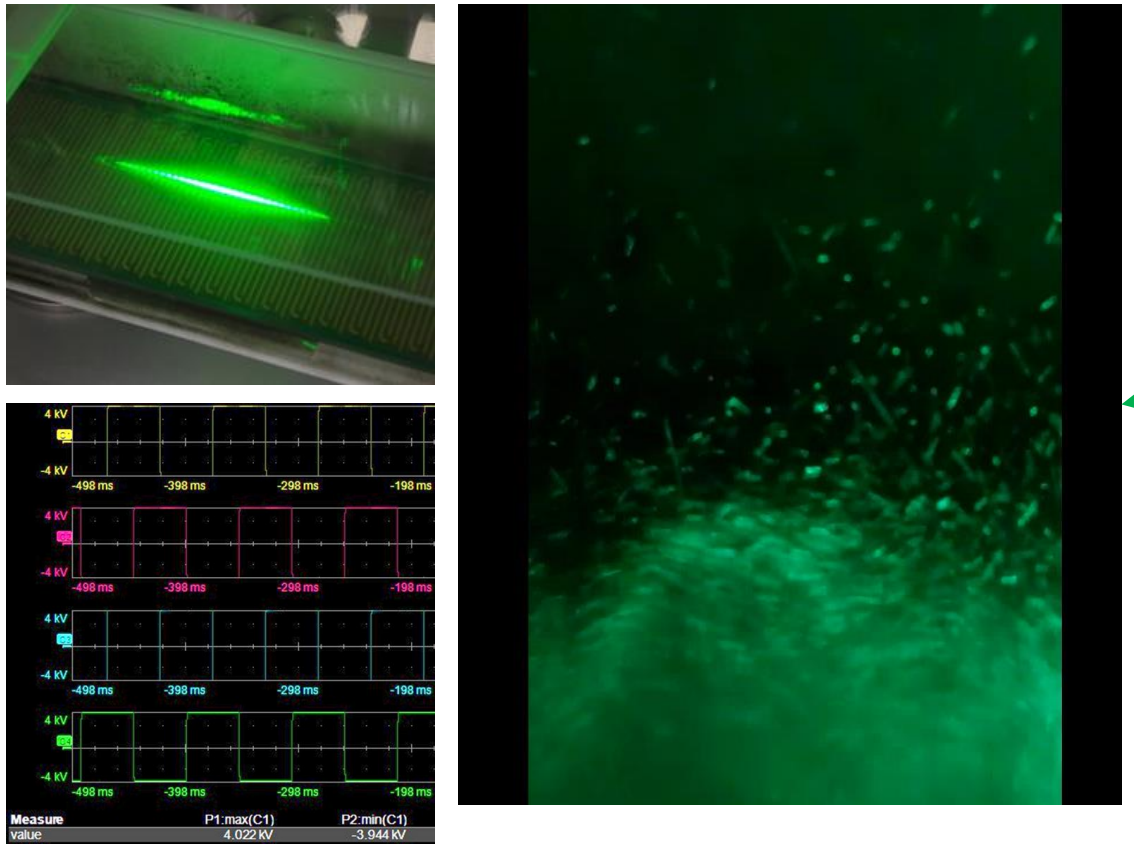


Mass normalized charge vs. time for JSC-1A 100-200 micron regolith simulant from the ERC feeder subsystem

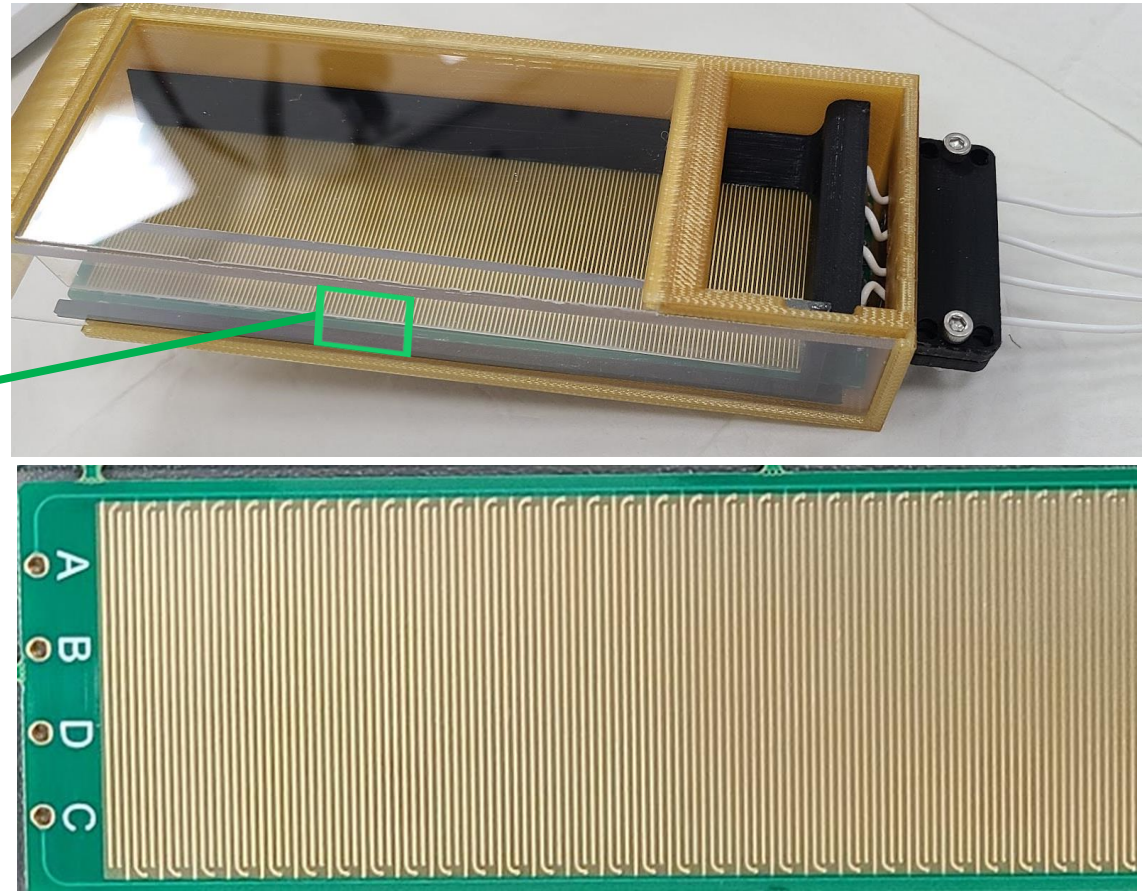
Subsystem Testing

Conveyor Operation & Laser/Camera Testing

- Regolith directional conveying (power supply + circuit) and laser-based flow tracking demonstrated

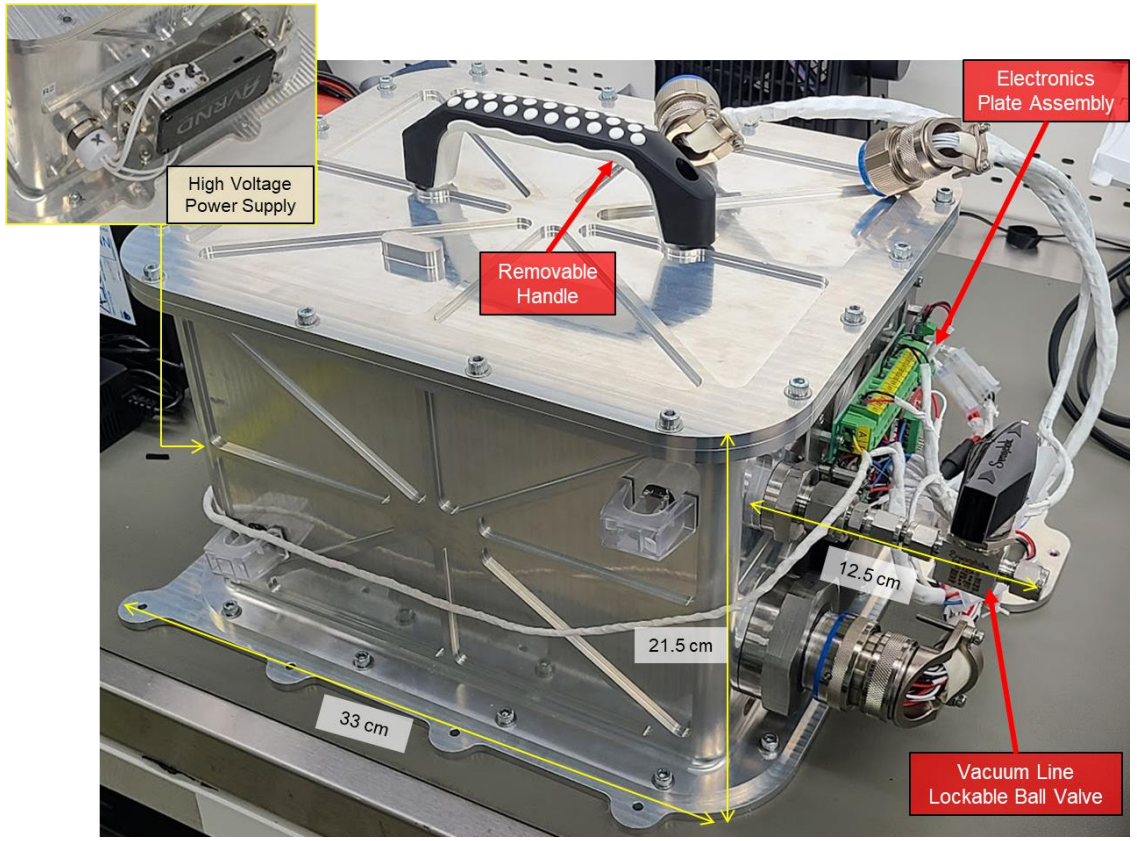


Line laser impinging on conveyor circuit surface through top window (top left), high voltage power supply +/- 4 kV four phase output (bottom left) and regolith flow (right)

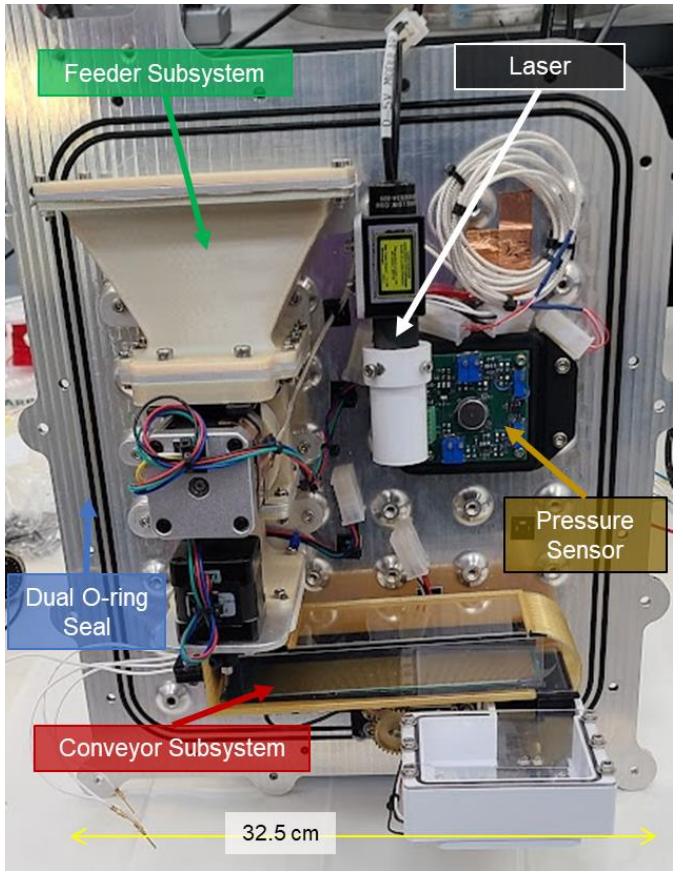


ERC conveyor enclosure (top) and 0.3 mm trace width x 0.3 mm gap width 4-phase circuit (bottom)

System Integration



Fully integrated ERC payload



ERC components mounted to the vacuum chamber baseplate

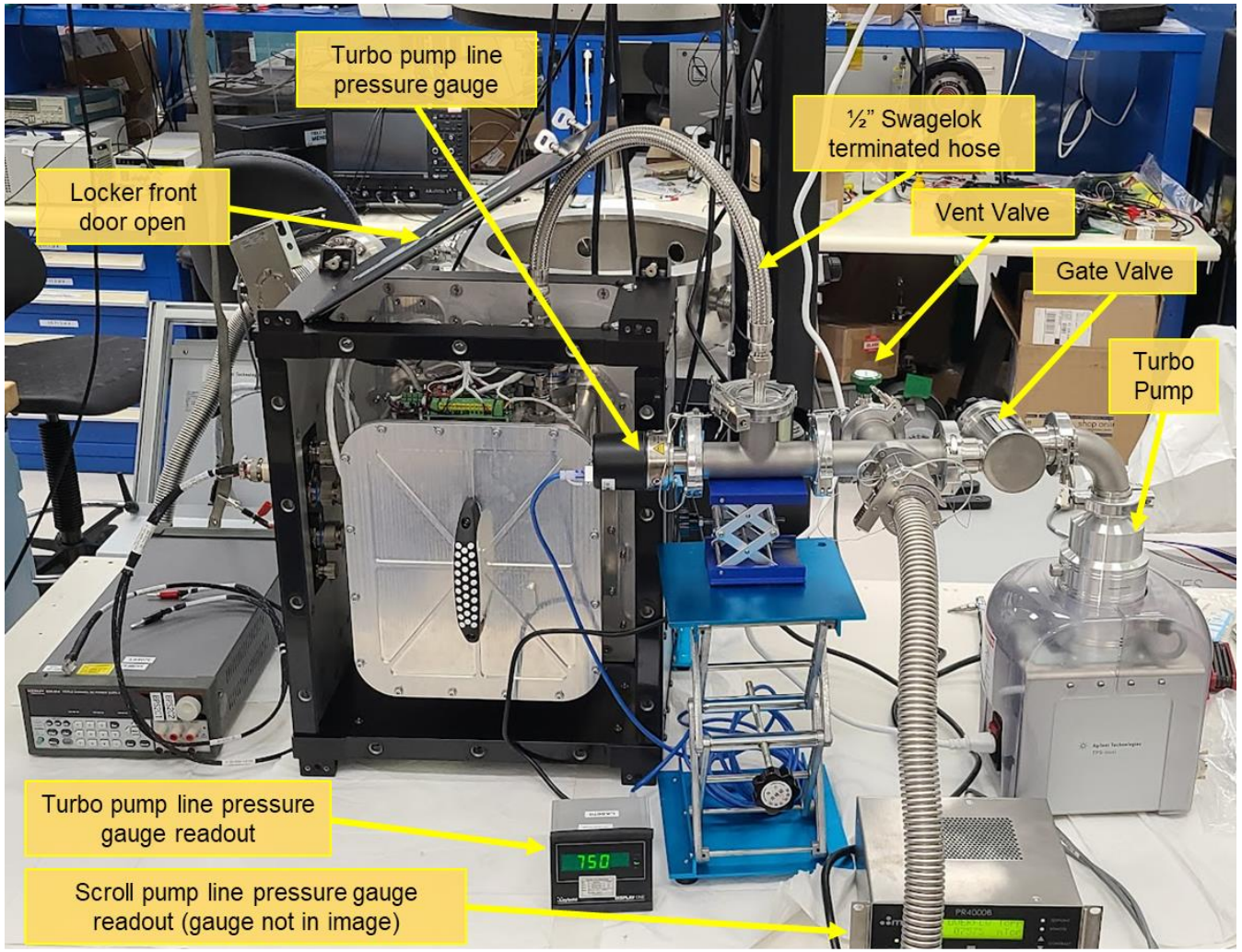
ERC cameras and lenses on the vacuum chamber top plate

System Testing

Payload Interface Requirements Met
- Power, Mass, CG
- Environments

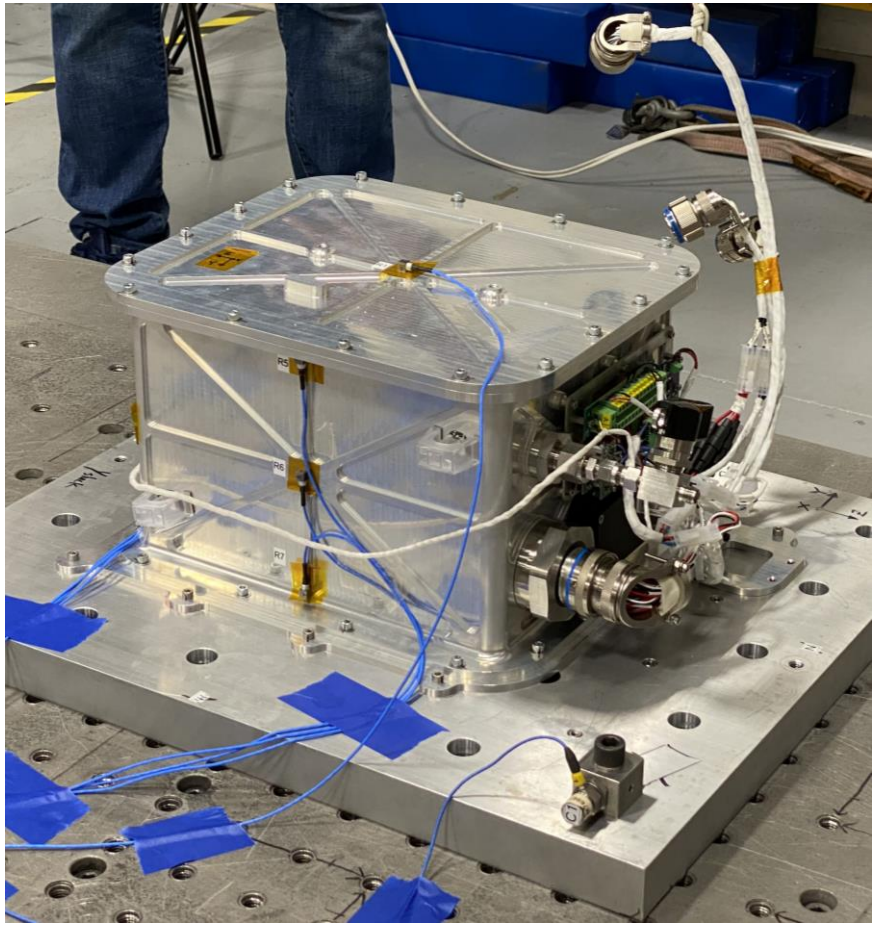
Vacuum Chamber Pressure at Flight Time
- <400 mTorr chamber pressure after 10 hr wait

ERC Experiment Requirements Met
- Regolith Storage & Flow
- 4-Phase Conveyor
- Instrumentation

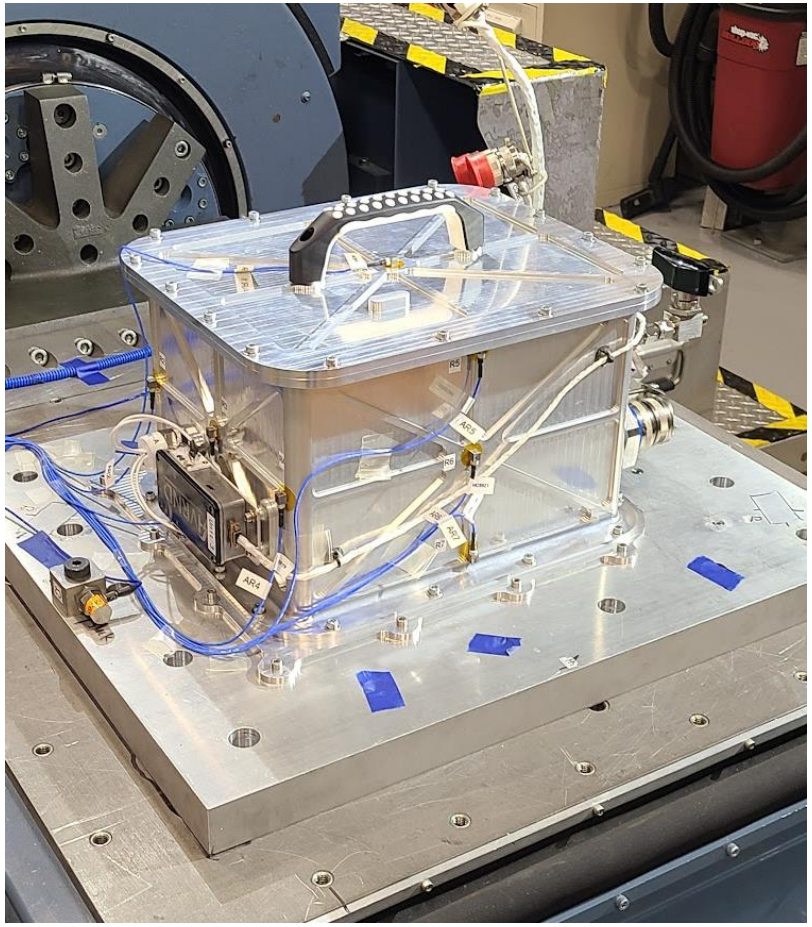


Fully integrated ERC payload after a run for record test at vacuum

Environmental Testing



Random vibration testing



Shock (half-sine pulse) testing

EMI/EMC testing

Future Work

- Launch Date Pending
- Post Flight Analysis
- Discrete Element Modeling
- Potential Applications

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