Stereo Cameras for Lunar Plume-Surface Studies (SCALPSS)
CLPS CS-6 Payload Workshop

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24-25 February 2025

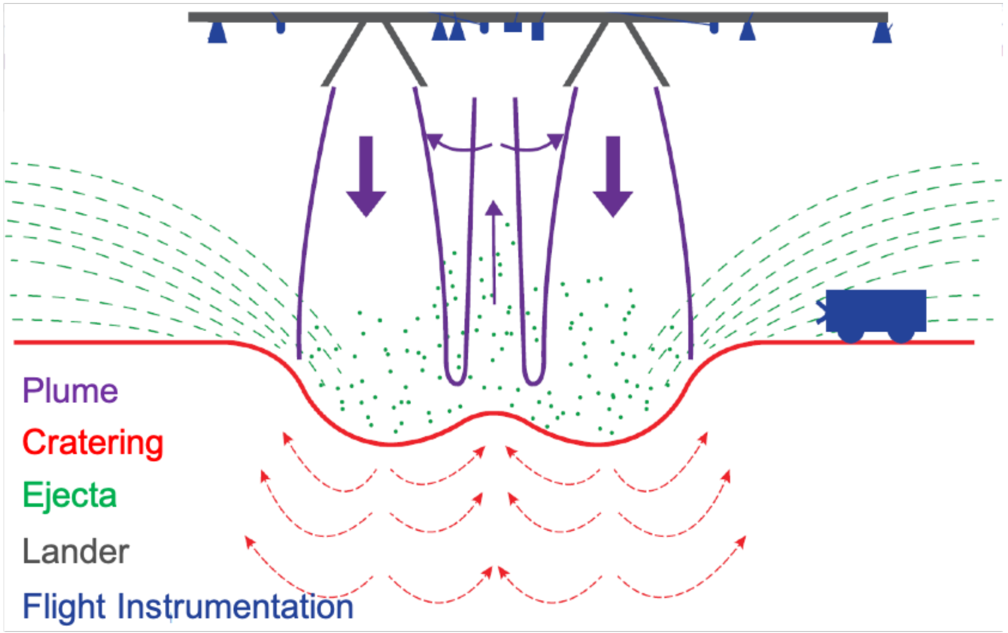
SCALPSS Payload Team

- NASA Langley Research Center:
  - project management
  - systems design and engineering
  - hardware development
    - ❑ electronics (MSE-lite)
    - ❑ SCALPSS cameras
    - ❑ illumination system (active and passive)
  - assembly, integration and testing
  - payload delivery
- NASA Marshal Research Center:
  - principle investigator
  - camera / lens selection and performance
  - PSI CFD modeling
- NASA Glenn Research Center:
  - particle impact sensor
- NASA Johnson Research Center:
  - camera calibration (post lander integration)
  - MLI

- Payload POCs:
  - Project Manager: Rob Maddock (robert.w.maddock@nasa.gov)
  - Principle Investigator: Wesley Chambers (wesley.chambers@nasa.gov)
  - Technical Lead: Chi Nguyen (dung-chi.p.nguyen@nasa.gov)
  - Electronics: Ray Lueg (raymond.t.lueg@nasa.gov)
  - Imaging; camera and illumination system configuration: Olivia Tyrrell (olivia.tyrrell@nasa.gov)
  - Particle Impact Sensor: Michael Anderson (michael.d.anderson-1@nasa.gov)
  - Flight Software: Cornell Wilson (cornell.j.wilson@nasa.gov)
  - Thermal: Kim Martin (kimberly.martin@nasa.gov)
  - Mechanical: Nick Vitullo (nicholas.a.vitullo@nasa.gov)
  - Structural Analyses: TBD
  - Assembly, Integration and Test Lead: Josh Beverly (joshua.s.beverly@nasa.gov)

Understanding Plume-Surface Interaction

- Rocket plume-surface interaction (PSI) is a complex, multi-phase discipline that describes the lander environment due to the impingement of hot rocket exhaust on the regolith of planetary bodies.
- Understanding PSI means understanding the effects of, and being able to correctly model the:
    - surface regolith
    - rocket plume
    - erosion of the surface
    - characteristics of the ejecta (what and where)
    - induced environments underneath the lander
- Facilities and/or capabilities for ground testing (e.g., full scale engines in a vacuum into lunar regolith) do not currently exist.
    - Current (and planned) ground test data still requires significant extrapolations for estimating CLPS (and HLS) scale effects.
- There is currently a lack of lunar flight data from PSI effects during descent and landing which is necessary to anchor computational and engineering models to be used to enable safe and low risk design of future landers, surface elements and surface operations.



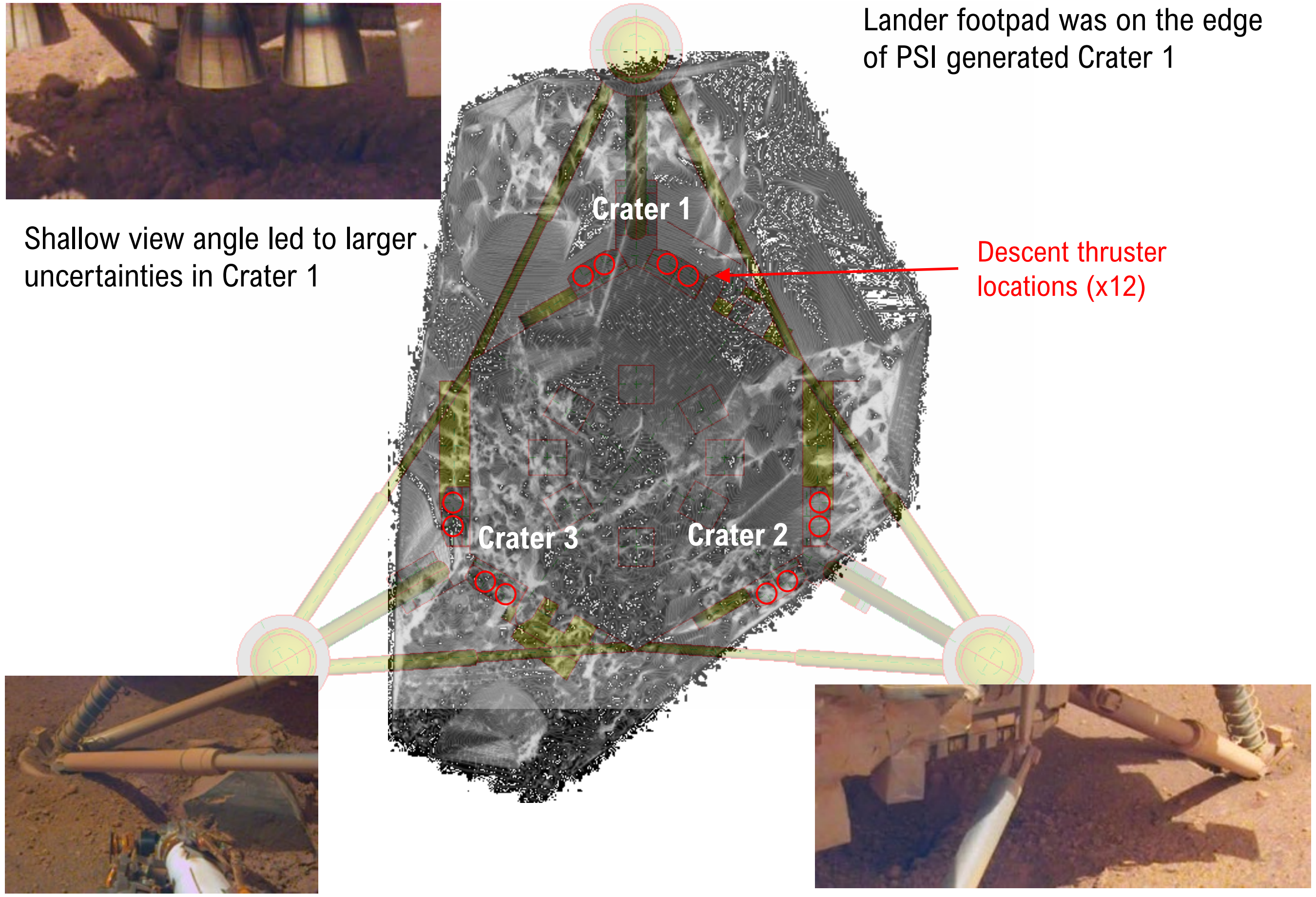
plume-surface interaction

spacecraft rocket exhaust interacting with unimproved planetary surfaces

fluid granular physics

SCALPSS Science - Erosion

- SCALPSS is the first ever payload specifically designed to directly collect PSI measurements during lunar landing.
- Stereo Photogrammetry can be used to determine the morphology of a surface in 3D space through the process of comparing two or more images of that surface taken from **known** relative locations.
  - requires detailed characterization and calibration of the imaging system to reduce measurement uncertainties
- Not only can the onset of PSI erosion be determined, but by comparing surface morphology from before, during and after PSI, an accurate estimate of total erosion that occurs can be made.



Shallow view angle led to larger uncertainties in Crater 1

Lander footpad was on the edge of PSI generated Crater 1

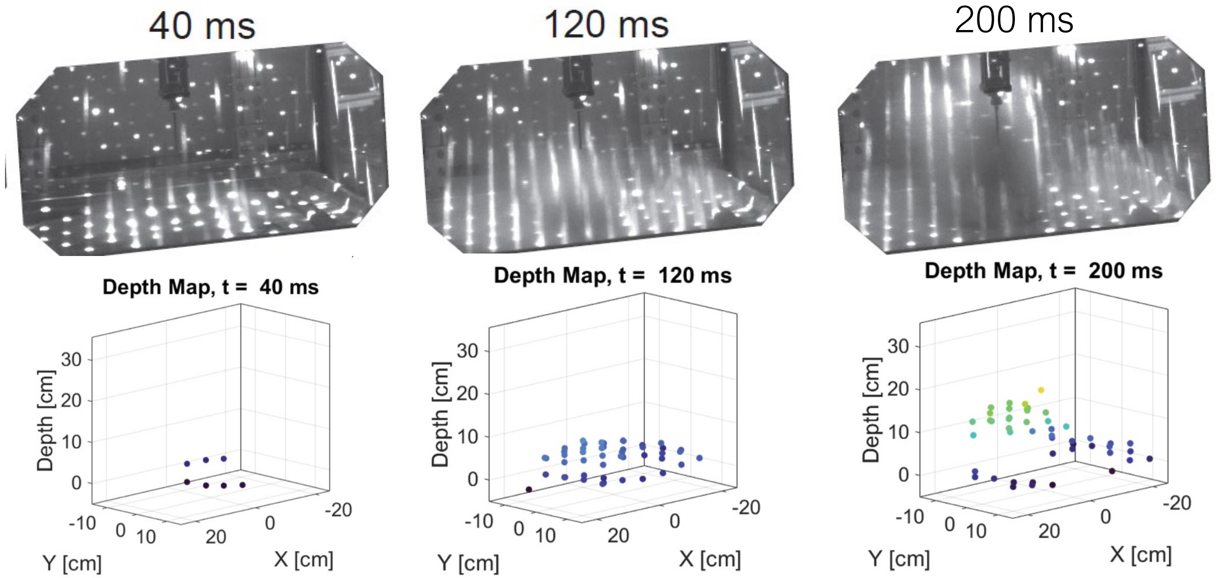
Descent thruster locations (x12)

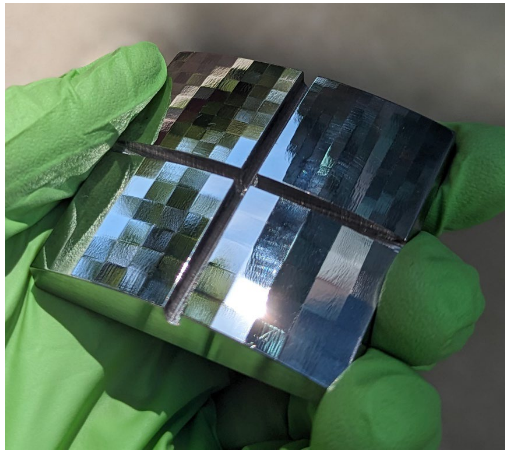
Example of using "pseudo" photogrammetry to measure erosion from the Mars Insight Lander

SCALPSS Science – Ejecta Sheet Measurement

- Structured illumination in the form of a grid of points is provided from a compact laser source with a Diffractive Optical Element (DOE) or a passive reflector.
- These grid points are projected onto the surface plane (regolith) where they illuminate the surface as discrete points that are captured by the stereo cameras to reconstruct the 3D shape.
- During PSI, the grid points project into the path of the ejecta and the light is scattered by the moving particles. The scattered light at the surface of the ejecta sheet is captured by the stereo cameras and a 3D ejecta sheet shape can be measured.

Laboratory Demonstration Using Active (Laser) Illumination

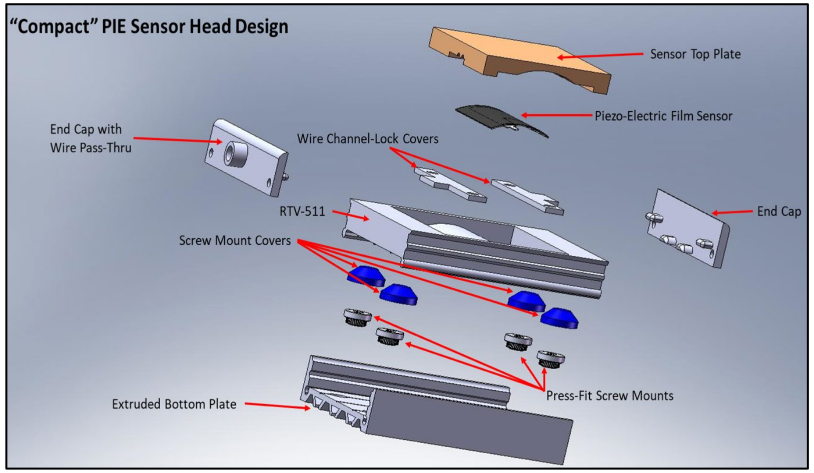




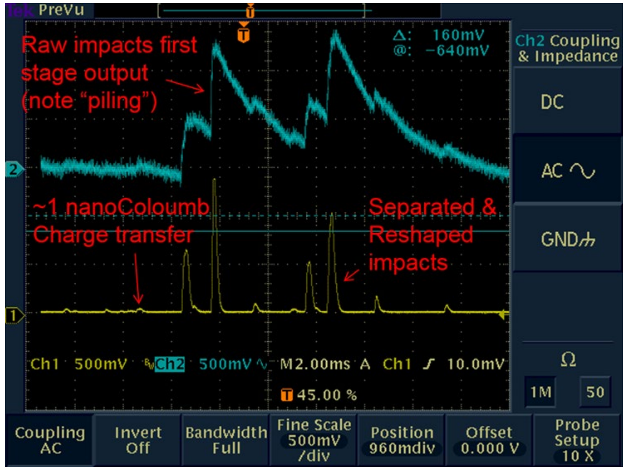
Prototype of Passive Illumination Reflector

SCALPSS Science – Ejecta Particle Impact Energy

- During lunar descent, the particle impact detector captures both the relative time between particle impact events and the event magnitudes to determine the energy and flux of the plume ejecta (at ~100 kHz).
- Data can be used to validate computational particle transport models on the moon (with a specific emphasis on the effects caused by PSI).
- The sensor utilizes a single piezoelectric sensor that is enabled with logarithmic data processing for a range of particle energies (multiple velocities and sizes).
    - Similar sensor / technology developed for saltation sensor applications at Mars.
    - Each particle impact with the piezo sensor generates a charge which “piles” with the charges from subsequent impacts.
    - A gaussian shaper circuit separates the signals from multiple impacts into easily identifiable gaussian pulses whose amplitude is representative of the impact energy.
    - The sensor and electronics can be tailored to accommodate the high flux rates and high energy levels during a PSI experiment.



Early sensor prototype conceptual design



Impact sensor scope trace of sand impacts from 1 cm height

SCALPSS Payload Evolution

	SCALPSS 1.0 **CLPS TO#2 / IM-1: Q1 CY2024**	**SCALPSS 1.1** **CLPS 19D / Firefly BG-1: Q1 CY2025**	**SCALPSS 1.x** **CLPS CT-3 / Blue Origin Mk-101: Q3 CY2025**	**SCALPSS 2.0** **CLPS CS-6: Q3 CY2028 target**

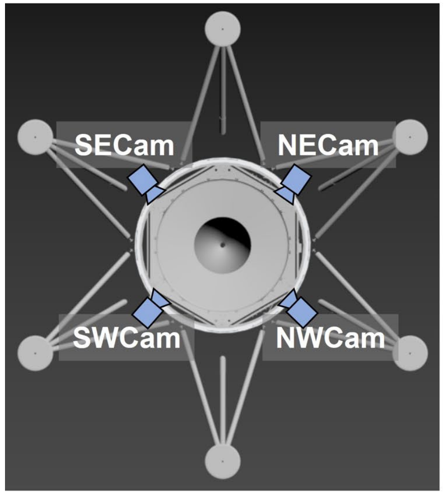
Measurement Objectives	• Capture post-landing 3D site alteration morphology
	  - Measure crater depth/size and erosion volume
	• *Capture pre-PSI (2D) landing topography*
	• *Detect PSI onset*
	• *Record transient site alteration morphology*
	• *Measure ground obscuration (onset and extent)*
	• *Measure dust settling density as a function of time*
	Primary objective
	Secondary objective
		• Capture post-landing 3D site alteration morphology
		  - Measure crater depth/size and erosion volume
		• **Capture pre-PSI 3D landing site morphology**
		• **Detect PSI onset**
		• **Record transient site alteration morphology**
		• *Measure ground obscuration (onset and extent)*
		• *Measure dust settling density as a function of time*
		New primary objective
		New secondary objective
			• Capture post-landing 3D site alteration morphology
			  - Measure crater depth/size and erosion volume
			• *Capture pre-PSI (2D) landing topography*
			• *Detect PSI onset*
			• *Record transient site alteration morphology*
			• *Measure ground obscuration (onset and extent)*
			• *Measure dust settling density as a function of time*
				• Capture post-landing 3D site alteration morphology
				  - Measure crater depth/size and erosion volume
				  - **improved coverage and/or resolution**
				• Capture pre-PSI 3D landing site morphology
				  - **improved coverage and/or resolution**
				• Detect PSI onset
				• Record transient site alteration morphology
				  - **improved coverage and/or resolution**
				• **Measure ground obscuration (onset and extent)**
				• **Measure ejecta sheet structure**
				  - **Ejecta angles, sheet morphology, etc.**
				• ***Measure ejecta particle velocities***
				• ***Measure ejecta particle sizes***
				• *Measure dust settling density as a function of time*

Camera System	• (4) FLIR Chameleon 3 USB (Monochrome)
	  - 3.2 MP, 3.45 µm/pixel
	  - 3.37 mm focal length lens (14 fps descent; NDR post-landing)
	  - Configuration / coverage optimized for post-landing surface imagery
		• (**6**) FLIR Chameleon 3 USB (Monochrome)
		  - 3.2 MP, 3.45 µm/pixel
		  - **(2) 50 mm focal length lenses (10 fps pre-onset and early descent)**
		  - **(2) 5.4 mm focal length lenses (8 fps descent; HDR post-landing)**
		  - (2) 3.37 mm focal length lenses (15 fps descent; HDR post-landing)
		  - Configuration / coverage optimized for **both pre-onset and** post-landing surface imagery
			• (4) FLIR Chameleon 3 USB (Monochrome)
			  - 3.2 MP, 3.45 µm/pixel
			  - 3.37 mm focal length lens (8 fps descent; NDR post-landing)
			  - Configuration / coverage optimized for post-landing surface imagery
				• (6) FLIR **Blackfly S GigE** (Monochrome)
				  - **12.3 MP**, 3.45 µm/pixel
				  - 3.37 – 25 mm focal length lenses (10-14 fps pre-onset and descent; HDR post-landing)
				• **Laser grid projection / active illumination**
				• **Additional PSI sensor (e.g., particle impact)**

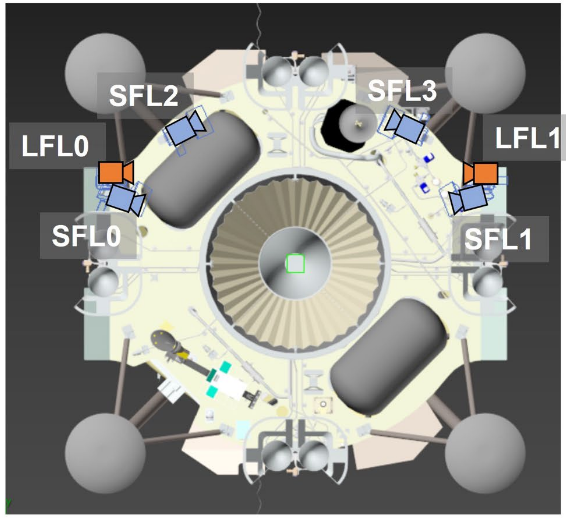
Electronics	• Mars 2020 EDLCam Data Storage Unit (DSU) "build-to-print"
	  - (1) USB 3.0 data port to USB Hub to (4) cameras
	  - RS-422 data interface to lander (limited to 3 Mbps)
		• Mars 2020 EDLCam Data Storage Unit (DSU) "build-to-print"
		  - (1) USB 3.0 data port to USB Hub to (4) cameras
		  - **(2) USB 2.0 data ports to (2) cameras**
		  - RS-422 data interface to lander (limited to 3 Mbps)
		• **Utilized full data handling capabilities**
		  - **Limited to 450 MBps write speed to memory**
		New to design
		Design limit
			• Mars 2020 EDLCam Data Storage Unit (DSU) "build-to-print"
			  - (1) USB 3.0 data port to USB Hub to (**2**) cameras
			  - (2) USB 2.0 data ports to (2) cameras
			  - RS-422 data interface to lander (limited to 3 Mbps)
				• **Mini-Suite Electronics (MSE-lite)**
				  - **(6) 1 Gbps ethernet ports to up to (6) cameras**
				  - **Improved data interface(s) to lander (100+ Mbps capability), including serial, USB, and LAN**
				  - **Improved data interface(s) to sensors, including serial, USB, and LAN**
				• **Improved data handling capabilities**
				  - **Capable up to 2 GBps write speed to memory**

SCALPSS Payload Configuration Considerations

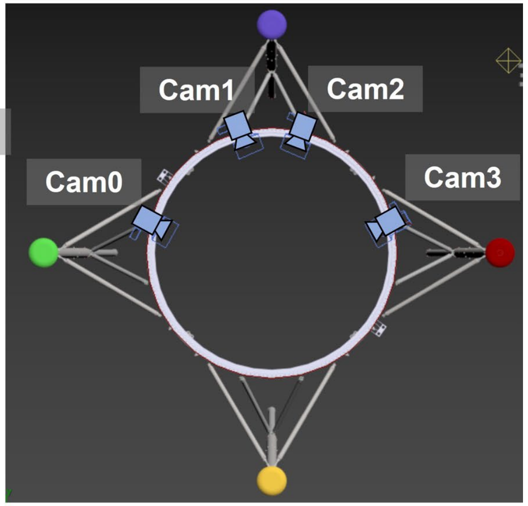
- Utilization of a new MSE-lite electronics removes the need for a separate USB Hub.
- A change from USB to LAN cameras removes any constraint on harness run length between the electronics and cameras.
- The configuration of the cameras (location and pointing) and the active illumination system (grid size, spacing, projection, etc.) is ***very*** lander dependent.
  - camera pairs, with large separation between the cameras with each pair, provide best photogrammetry resolution, however, co-location of some cameras (not of the same pair) may be possible
  - cameras and the active illumination system require a clear FOV of the ground below the descent engine(s) (i.e., mounting on base of the lander); requires a "custom" mount design for each lander



SCALPSS 1.0: Intuitive Machines Nova-C



SCALPSS 1.1: Firefly Aerospace Blue Ghost



SCALPSS 1.X: Blue Origin MK1

- Particle impact sensors need to be located within the ejecta sheet which is expected to expand at a low angle (< ~5 deg) from the surface.
  - requires mounting on the lander leg(s) as close to the footpads as practical

Key Accommodation Requirements

- The Contractor shall provide up to 60 Watts of power, exclusive of payload heaters, to the SCALPSS payload during any payload operation.
  - Maximum power draw is likely to occur during descent, just prior to landing, when all cameras are imaging, the particle impact sensors are collecting data, and returned sensor data is being written to payload memory.
- The Contractor shall accommodate up to eleven (11) mechanical interface locations for the MSE-lite and PSI devices with brackets provided by SCALPSS.
  - A trade can be made between the number of cameras, the number particle impact sensors, the number and type of illumination systems, etc. to optimize the available mass allocation for the payload.
- The Contractor shall provide wired communication to the SCALPSS payload.
  - The type of interface (LAN and/or RS-422) and number of channels can be optimized based on the descent data volume and desired time to transfer all descent data to the lander.
- The Contractor shall provide temperature monitoring and heater control during the entire duration of the mission.
  - Power for temperature monitoring and heater control will not be counted towards the payload total power allocation.
  - Heaters will be sized based on integrated thermal analysis.

SCALPSS Payload Components

- Sensor mount/bracket design uncertainty (driven by sensor location) could have largest impact to payload mass uncertainty.
  - Sensor types/numbers can be scaled as necessary if mass becomes a concern.
- All harnessing between payload components is provided by the payload.
  - Contractor is responsible for harnessing between the lander and the MSE-lite.
- All temperature sensors and heaters (with wiring pigtails) will be provided by and installed by the payload.
  - Contractor is responsible for integration of these harnesses to the lander.
- MLI will be designed and provided as necessary by the payload.

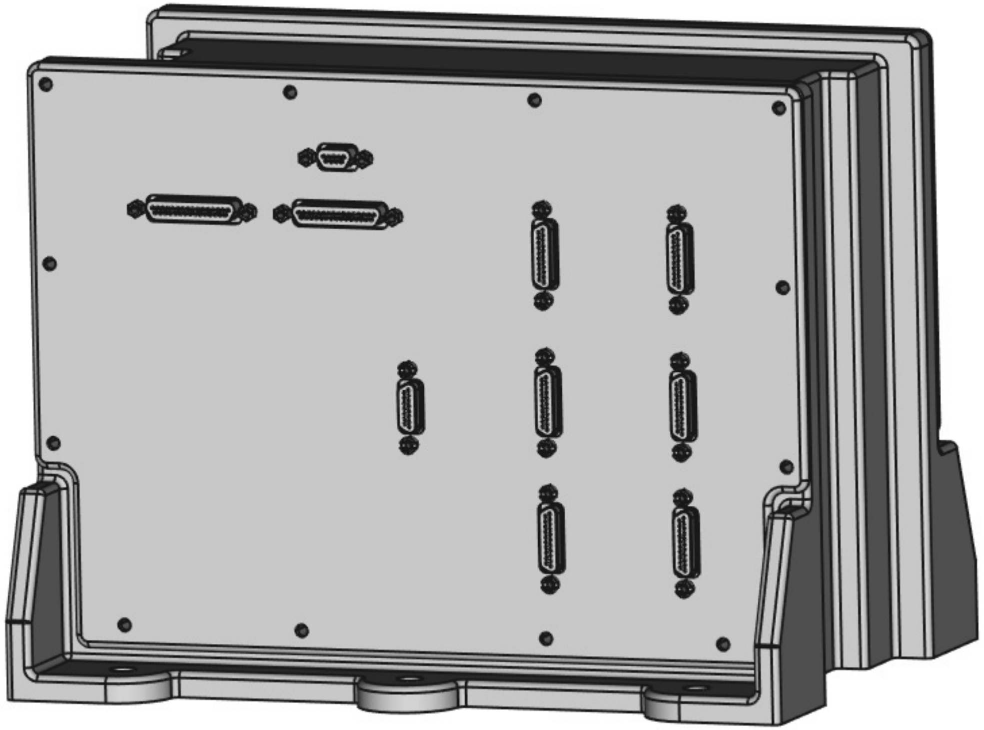
SCALPSS Payload Components (all values are current best estimate)

Component	Quantity	Dimensions (mm) (L x W x H)	Mass (kg) Each
MSE-lite	1	150 x 150 x 210	2.5
Camera Assembly (1 or 2 cameras)	4	30 x 75 x 120	1.0
Active Illumination System Laser	1 or 2	60 x 30 x 20	0.5
Active Illumination System Optics	1 or 2	200 x 50 x 50	0.5
Passive Illumination System	0 or 1	120 x 120 x 120	1.0
Ejecta Particle Impact Sensor	2	50 x 60 x 10	0.5
Harnessing and MLI	-	-	1.0
Fiducial Markings	16*	< 65 x 65 x 1	-

** The number of marks is dependent on camera placement / FOV; additional marks can be added for any desired lander measurements (e.g., leg movement / stroke during landing).*

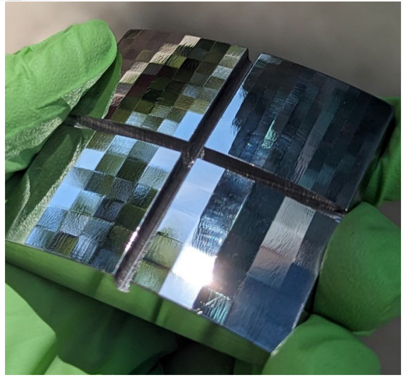
SCALPSS Payload Components: Mini-Suite Electronics ("lite")

- The MSE-lite is a modular, flexible, and expandable instrument control and data storage unit with the following capabilities:
  - 6x ethernet camera control
  - Configurable sensor port for power and data
    - ❑ 4x RS-422 channels
    - ❑ Up to 16x GPIO signals
  - Flexible host communications
    - ❑ 4x RS-422 channels
    - ❑ 1x LAN channel
- Enclosure mechanical specifications:
  - approx. 7.75" x 5.6" x 6.0"
  - < 2.5 kg
- The "full" MSE is being developed with an expanded capability to support a suite of several PSI sensors.



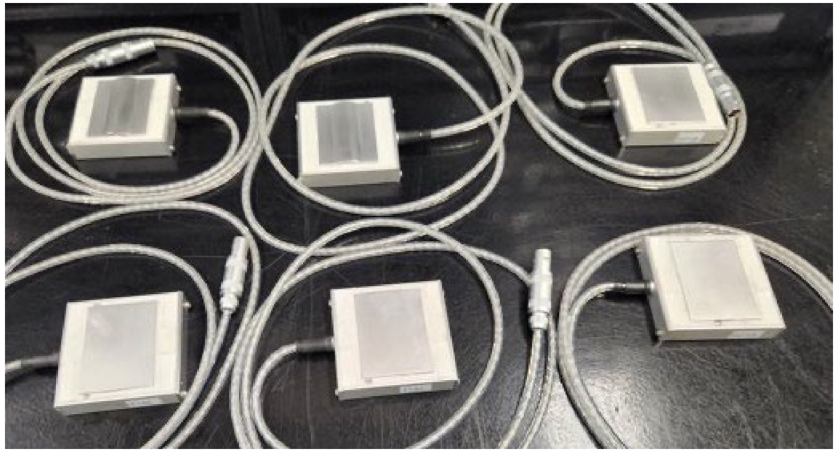
SCALPSS Payload Components: Imaging

- FLIR Blackfly S GigE Camera
  - 29 × 29 × 39 mm; 53 g mass
  - Variable sensor size allows for some customization of desired resolution and field-of-view
  - Variety of lenses available for the desired camera configuration (75 – 180 g mass range)
- Matchbox Laser (active illumination)
  - 50 × 30 × 18 mm; 120 g mass
  - Multi-mode fiber output enables beam steering and coupling into laser grid or laser sheet
  - Modulation/pulsing capability may enable particle velocity measurement
  - Optional fiber switch (~250 g) to enable alternation between lighting configurations and measurements (e.g., laser sheet and laser grid varying densities)
  - Each laser coupled into an optics assembly (50 × 50 × 200 mm; ~250 g mass)
- DISCOBaLL (passive illumination)
  - Directed Illumination of Sunlight Collimated and Observed Beneath a Lunar Lander
  - ~100 × 100 × 100 mm (TBR); ~750 g mass (TBR)
  - Passive reflector: requires no external power or thermal control, only ambient sunlight
  - Mass and volume can be tailored to meet mass constraints

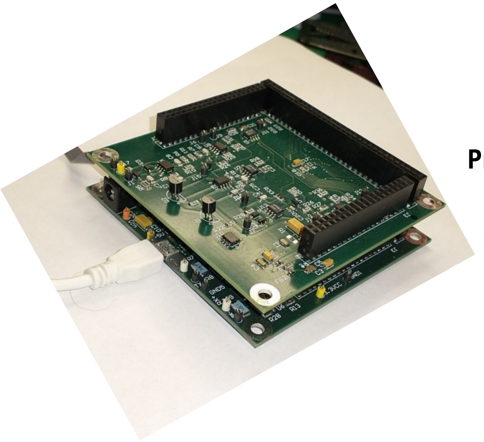


SCALPSS Payload Components: Particle Impact Sensor

- The MSE-lite is a modular, flexible, and expandable instrument control and data storage unit with the following capabilities:
- Sensor specifications:
  - prototype approx. 1.75” x 1.75” x 0.5”
    - flight sensor expected to be smaller
  - < 0.5 kg
  - ~3 W (per sensor)
  - RS-422/485 communication with MSE-lite
  - sample rate: ~100 kHz
- There are 3 variants of the current impact detection sensor design: flat sensor surface with flat piezo film mount, flat sensor surface with curved piezo mount and curved sensor surface with curved piezo mount.
  - Selection will be made based on sensitivity and accuracy required for each application.



Prototype sensors (2 curved front & back, 2 flat front, curved back, 2 flat front & back)



Prototype 1U form factor electronics

Payload Concept of Operations

- The SCALPSS payload CONOPS will be dependent on the lander descent profile and landing (and post-landing) operations.
- All payload checkout and science operations are completely autonomous and require no commanding from the ground.
  - Once powered on, the payload uses the lander mission phase and altitude provided in telemetry to execute automated scripts.
  - Payload settings can be changed in flight with upload of a new configuration file.
- Manual commanding of the SCALPSS payload in support of lander operations (e.g., engine burns, deployments, etc.) or other payload operations is also available.

Activity	Activity Start	Activity End	Data Volume Estimate	Notes
Long focal length imaging of target landing area	~50 m altitude	~5 m altitude	~1.0 GB	2 cameras @ 8-10 fps
Short focal length imaging of landing area; particle impact sensor operation	~30 m altitude	TD + ~10 sec	~2.5 GB	4 cameras @ 8-10 fps
Short focal length HDR imaging of landing area; descent data transfer to lander	TD + ~10 sec	TD + ~ 2-4 hrs *(depends on data transfer rate between lander and payload)*	~0.5 GB	4 cameras; HDR images consist of 4 frames from each camera and are captured at varying intervals (e.g., every 10 sec for first minute, then every minute for first 10 min, then every 10 min for first hour, then every hour…)
Surface HDR imaging	TD + ~1 hr	EOM	~20 MB (each)	4 cameras; HDR images are captured and immediately transferred to lander (requires ~5 min for each operation)

Data Volume and Management

- The SCALPSS payload is expected to acquire up to 5.0 GB of science data during the mission.
  - This does not include data acquired during payload checkouts (<40 MB total).
  - The total science data volume will depend highly on the lander descent profile, the final payload CONOPS, and the needed time to transfer/downlink the data.
  - The payload CONOPS / science data volume can be optimized based on the lander's data transfer and downlink capabilities.
- All science data collected by the payload is stored locally on the payload and will not be transferred to the lander until:
  - Partial data from each payload checkout (in the form of thumbnail images) are immediately transferred to the lander for downlink; additional data could be included or be manually commanded for transfer at a later time, if necessary.
  - Once the descent phase is complete (TD + ~10 sec; configurable), descent data *can* automatically begin transferring to the lander or await manual commanding to transfer.
    - ❑ Assuming the lander will downlink data using a FIFO approach, the payload data will be prioritized when being transferred to the lander so the most critical science data is first to be returned.
    - ❑ Automatic transfer can be turned off, however, transfer of data based on the specified priority may be complicated.
  - Surface HDR data captures *can* also immediately be transferred to the lander for downlink or await manual commanding to transfer.
    - ❑ Automatic transfer can be turned off, however, automated data collection would also need to be disabled.

Additional Questions?