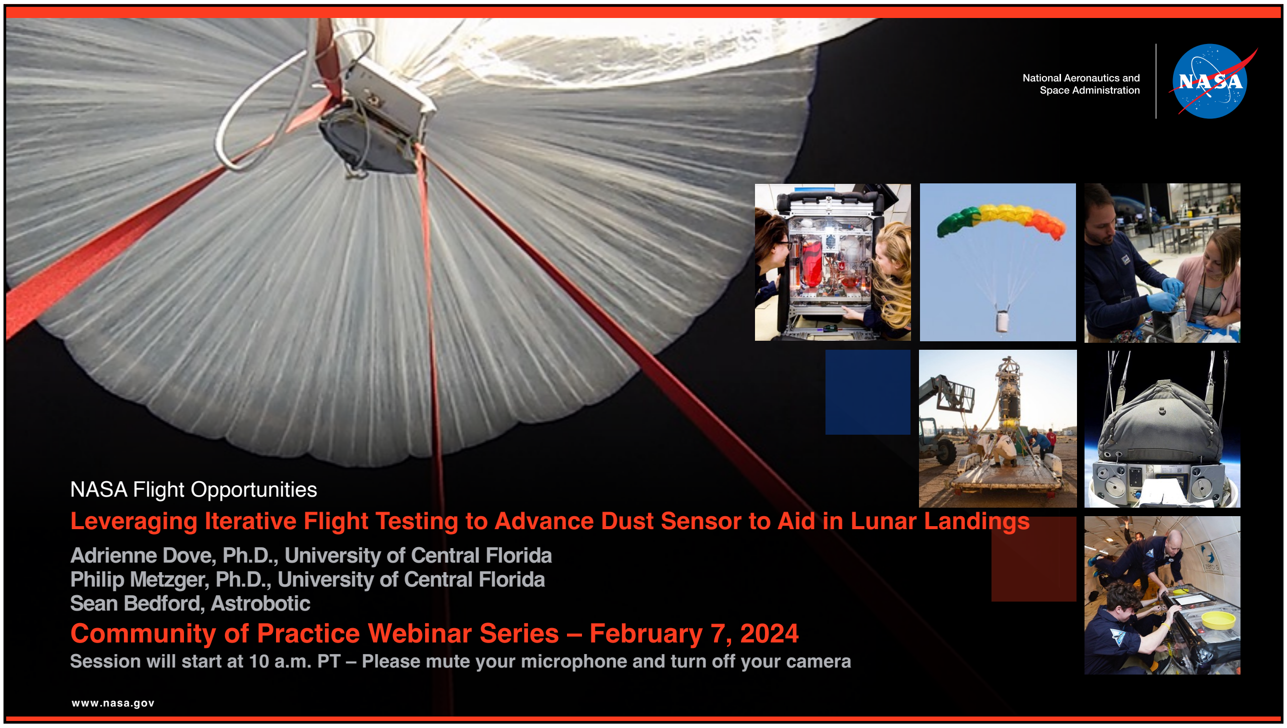

1

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National Aeronautics and Space Administration

Welcome to the Community of Practice Webinar Series!

First, a bit of housekeeping…

- Please mute your microphone and turn off your camera
- Today's session will be recorded
- Recordings for this and all future sessions will be posted on the Flight Opportunities website
- Please engage!
  - Use the chat throughout the session to ask questions

2

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NASA FLIGHT OPPORTUNITIES

National Aeronautics and Space Administration

Welcome to the Community of Practice Webinar Series!

Flight Opportunities hopes these webinars will enable researchers, program staff, and flight providers to connect informally and share information

- Designed to distill and share the most important lessons learned to:
  - Increase the impact of suborbital flight tests
  - Transfer best practices
  - Optimize the experience of current and prospective program participants
- Part of a broad effort to capture, organize, and communicate lessons learned by suborbital researchers
- An opportunity to hear from subject matter experts on best practices for preparing for suborbital flight tests

3

3

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Future webinars

- Webinars are held 1st Wednesday of each month at 10 a.m. PT
- Topics will be announced in the Flight Opportunities newsletter and website
- Session recordings will be posted on the Flight Opportunities website
- Let us know session topics you would like to see covered

4

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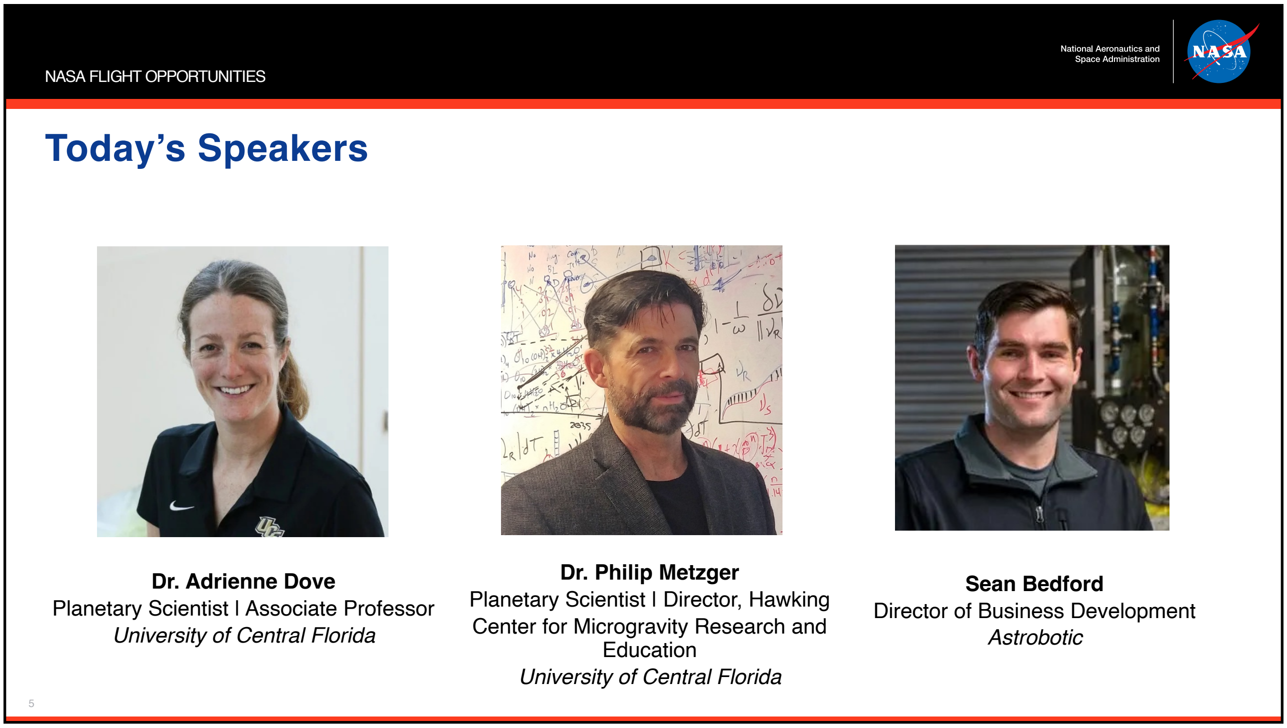
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National Aeronautics and Space Administration
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Today's Speakers
Dr. Adrienne Dove
Planetary Scientist I Associate Professor
University of Central Florida
Dr. Philip Metzger
Planetary Scientist I Director, Hawking Center for Microgravity Research and Education
University of Central Florida
Sean Bedford
Director of Business Development
Astrobotic
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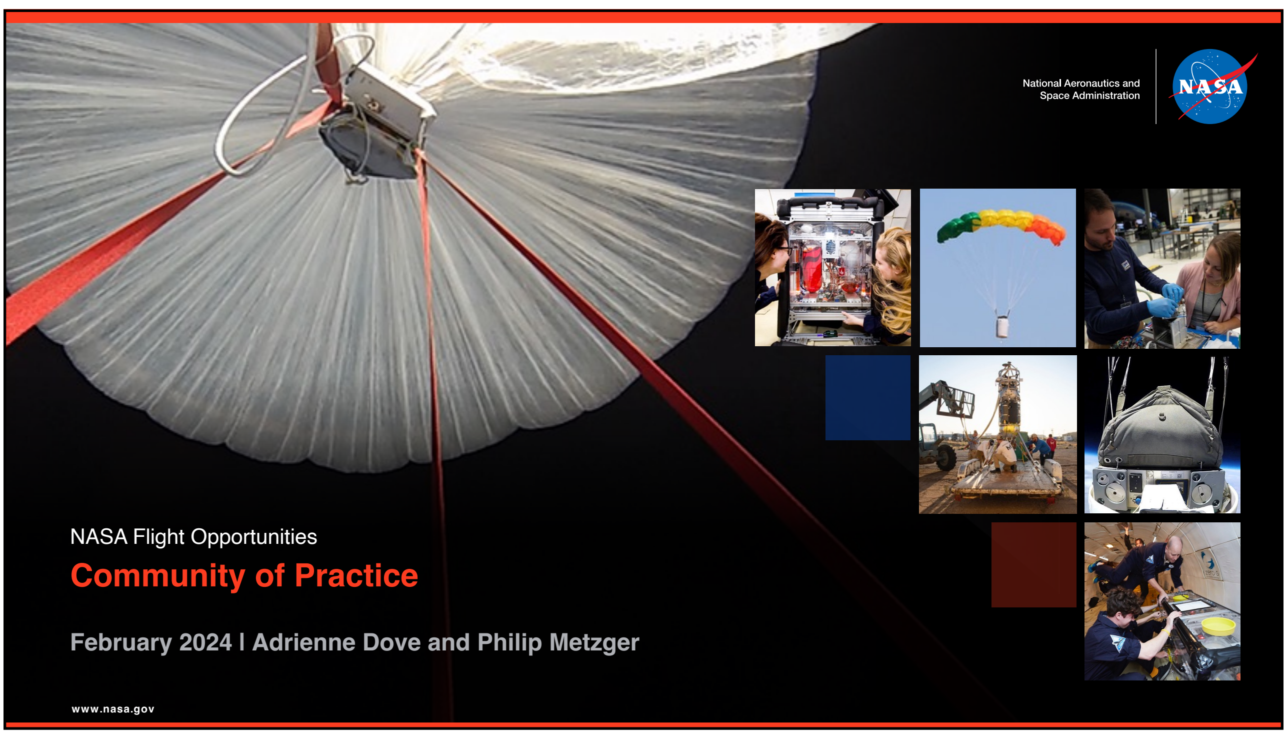
National Aeronautics and Space Administration
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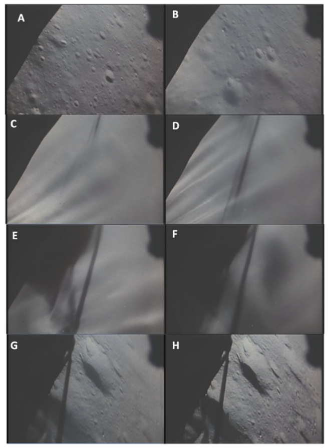
NASA Flight Opportunities
Community of Practice
February 2024 I Adrienne Dove and Philip Metzger
www.nasa.gov

6

Ejecta STORM – the Need

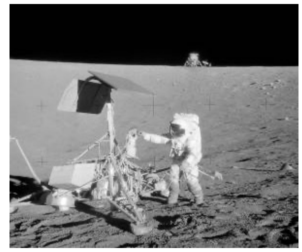
Technology Need

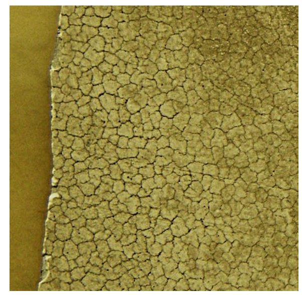
- Lunar landers plumes produce ejecta and cratering effects that can be deleterious to the lander and any surrounding structures.
- The physics of soil erosion in these extreme conditions is too difficult to solve
- Modeling must be based on high-quality measurements during actual lunar landings (TA 7.6.1, 7.6.1.22)
- Goal: mature an instrument that will make the right measurements to make modeling truly predictive, enabling realistic mitigation plans.



Technology End Users

CLPS Payload Providers, NASA Planetary Science Division, Science Directorate; NASA Human Exploration and Operations Mission Directorate; Private companies with interest in exploration, in situ resource utilization on the lunar surface.





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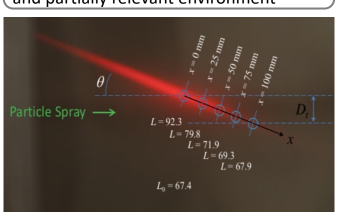
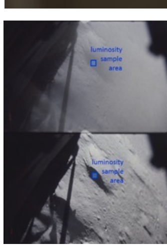
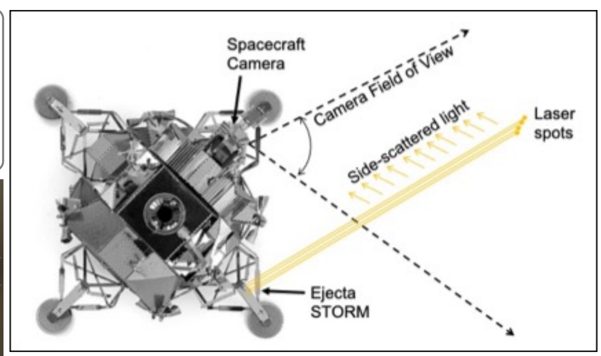
Ejecta STORM Instrument Concept

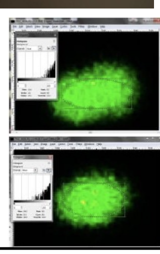
Technology Concept

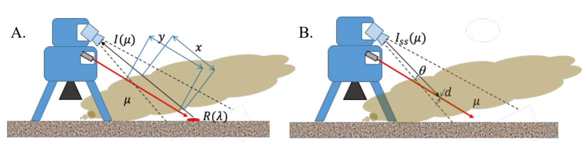
Ejecta STORM is a laser instrument that measures density and particle sizing of lunar lander plume ejecta. Currently at TRL 4/5 –a breadboard prototype that has been validated in a lab environment and partially relevant environment











$$I(\mu) = I_0 R(\lambda) e^{-\mu(x+y)} + I_{\text{Sun}}$$

$$I_{SS}(\mu) = I_0 e^{-\mu s}\left(1 - e^{-\mu d \csc\theta}\right) + I_{\text{Sun}}$$

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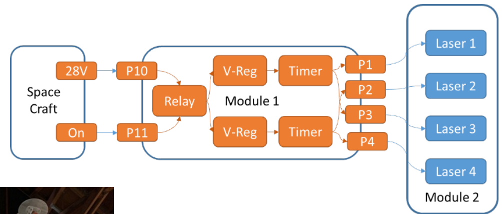
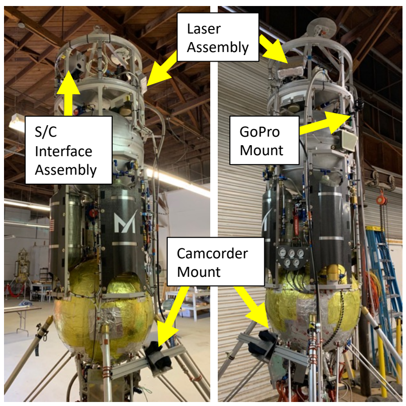
Ejecta STORM Prototype for Masten Space Systems / Astrobotic Xodiac

Technology Development Team
PI Dr. Philip Metzger, UCF
Co-I Dr. Adrienne Dove, UCF
Astrobotic





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Ejecta STORM Requirements and FOP Test Objectives

Science Focus	Science Goals	Science Objectives	Direct or Enabling	Scientific Measurement Requirements		Instrument Functional Requirements		Instrument Performance	Mission Rqrmnt
				Physical Parameters	Observables	Item	Value		
Atmosphere and dust environment	SCEM Goal 8	8b. Properties of electrostatically transported dust	Direct	Particle size of electrostatically lofted dust particles	**Post-landing 1**: particle size is constrained by Mie scattering amplitude as a function of wavelength	Number of lasers & wavelengths	Four: 419-641(950) nm, spaced ≥ 60 nm	±5% (update in this study)	Measure for 10 minutes each during at least three solar insolation angles
				Spatial distribution of ejected dust	**Post-landing 2**: Amplitude of scattered light at different heights in the laser beam	Laser power, camera sensitivity	200 mW, TBD in this study	±20 mW (update in this study)	
		8a. Global density, composition, and time variability of lunar atmosphere	Enabling (crucial)	Quantity of rocket exhaust gas captured in the environment in various ways (locally, regionally, and globally) and re-released during the mission.	**During descent 1**: Amplitude of scattered and reflected light	Laser power, camera sensitivity	200 mW, TBD in this study	±20 mW (update in this study)	Measure during last 40 m of descent to 5 min post shutoff
					During descent 2: Regolith optical maturity	Number of lasers & wavelengths	Two: 419 & 641 or 740 & 950 nm	±5% (update in this study)	
					During descent 3: Mie scattering at multiple wavelengths constrains particle sizes	Number of lasers & wavelengths	Four: 419-641(950) nm, spaced ≥ 60 nm	±5% (update in this study)	
		8d. Transport of water	Enabling (crucial)		During descent 1-3 (see above)	Same as descent 1-3	Same as descent 1-3	Same as descent 1-3	
Regolith processes, weathering	SCEM Goal 7	7b. Properties of regolith at diverse locations	Enabling (crucial)	Quantity (depth and distance) or regolith disturbance	During descent 1-3 (see above)	Same as descent 1-3	Same as descent 1-3	Same as descent 1-3	Measure during last 40 m of descent to 5 min post shutoff
		7c. Regolith modification, weathering and volatiles	Enabling (crucial)		During descent 1-3 (see above)	Same as descent 1-3	Same as descent 1-3	Same as descent 1-3	
Volatile flux of solar system history	SCEM Goal 4	4a. Composition and distribution 4b. Sources 4c. Transport 4d. Polar regolith properties 4e. Ancient solar enviro.	Enabling (crucial)	Quantity of rocket exhaust gas captured in the environment in various ways (locally, regionally, and globally) and re-released during the mission.	During descent 1-3 (see above)	Same as descent 1-3	Same as descent 1-3	Same as descent 1-3	Measure during last 40 m of descent to 5 min post shutoff
Exploration Goals									
Engine blast ejecta	SKG III-D-4	Quantify the ejecta	Direct	Details of emission model and particle-scale plume transport	During descent 1-3 (see above)	Same as descent 1-3	Same as descent 1-3	Same as descent 1-3	Measure during last 40 m of descent to 5 min post shutoff
Nonpolar volatiles	SKG I-C-2	Measure solar wind gases in undisturbed soil at meter and decameter scales (laterally) and 0-2m depth.	Enabling (crucial)	Plume volatiles injected into the subsurface as a function of depth and location	During descent 1-3 (see above)	Same as descent 1-3	Same as descent 1-3	Same as descent 1-3	

Flight Requirements/Objectives

- Flights on the MSS Xodiac will simulate lunar landing profiles
- Landing surfaces will be constructed to best reproduce lunar landing conditions, i.e. with a consolidated surface underneath a regolith with specific particle size distributions
- Determine Camera Settings, Lighting, Plume Conditions, Look-Angles, Generic Vehicle Integration

Technology Advancement

- The proposed flight program will demonstrate
  1. Integration with a lander
  2. Operation in flight conditions with simulated lunar plume effects
- Instrument will be TRL 6 post-flight

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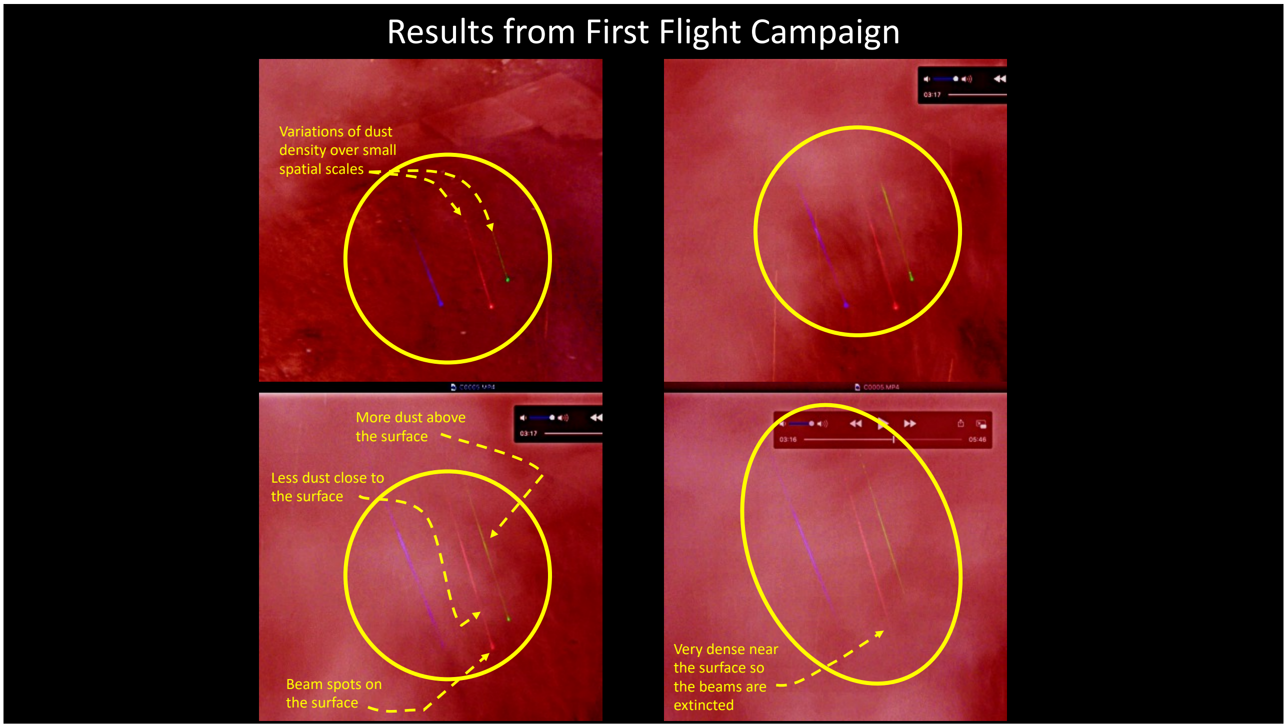
Results from First Flight Campaign
Variations of dust density over small spatial scales
More dust above the surface
Less dust close to the surface
Beam spots on the surface
Very dense near the surface so the beams are extincted

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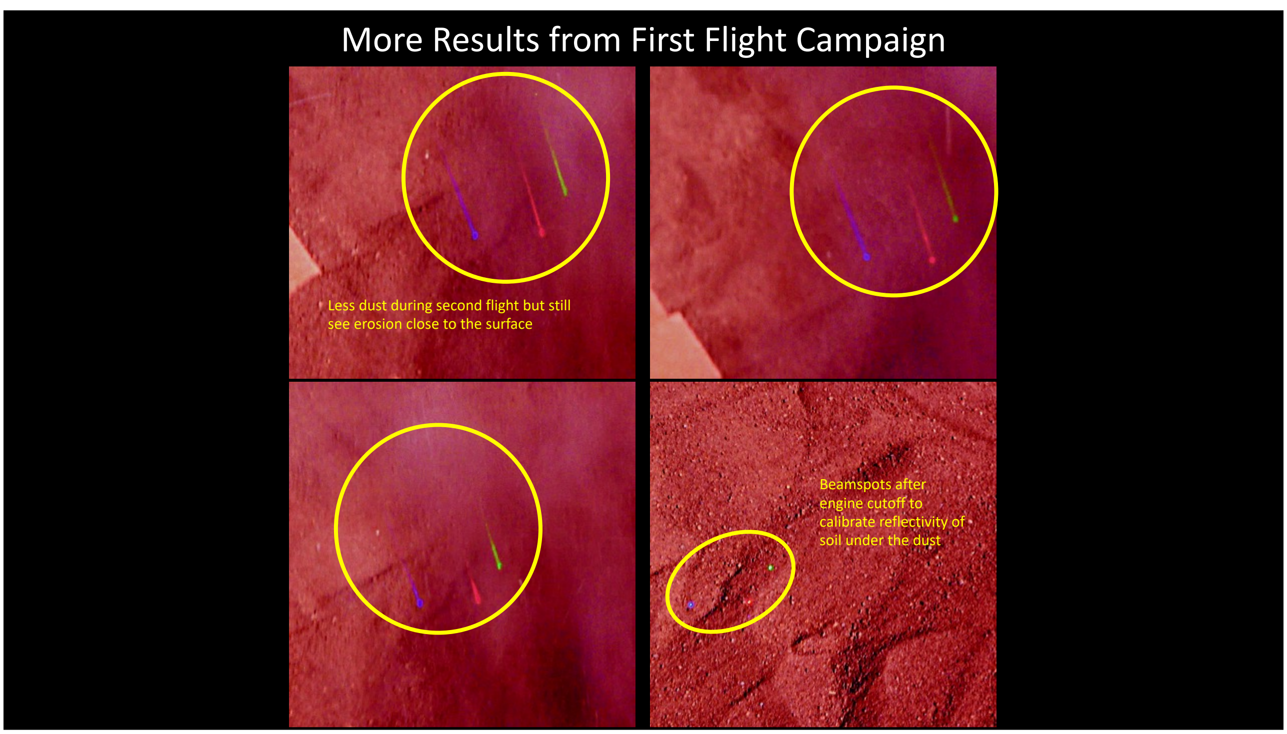
More Results from First Flight Campaign
Less dust during second flight but still see erosion close to the surface
Beamspots after engine cutoff to calibrate reflectivity of soil under the dust

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Benefits/Outcome of Flight

- Validated that lasers can be seen (except violet)
  - In bright ambient sunlight
  - In a range of dust-blowing conditions as expected in lunar landings
- Validated camera settings (frame speed, shutter speed, zoom, etc.)
- Demonstrated that flight vibration does not disrupt the videography
- Validated camera and laser pointing

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Problems Found & Need for Reflight

- Laser alignment was inadequate – lasers are not parallel which makes data reduction more difficult
- Violet laser was not visible in the video in bright ambient sunlight (combination of camera sensitivity in that band and violet content of ambient light near noon)
  - Need higher power violet laser
  - Or need camera more sensitive in that band
- The first four flights perfected the arrangement of regolith on and near the launch pad to make the effects lunar-like despite the terrestrial atmosphere, but now we need to take better data with the perfected setup
  - It was impossible to predict before the flight campaign how to arrange the regolith due to lack of understanding of the same physics that this sensor is designed to measure
  - Therefore, we had to use trial-and-error to perfect the method
- Desire to use more variation in cameras to match the CLPS cameras including the SCALPSS camera to provide direct support of that payload
- Due to pre-flight hardware failure we were unable to test the on/off circuitry in Ejecta STORM. Had to rely on a hardwired switch at the last minute. Need to retest with improved control circuitry active.

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Results of Reflight Campaign

- Successfully flew four flights. Sensor operated well each flight.
- Still had problems with remote on/off circuitry due to brightness of sunlight in Mojave washing out the IR sensor. Not sure why it works in Florida but not in Mojave.
- Violet laser with higher power had to be adjusted further after delivery to Mojave to account for the bright sky. Successfully had visible violet laser in the Mojave as-installed conditions. Results of using violet laser still being assessed. Will affect design of flight system for lunar landings.
- Laser alignment mechanism was improved. Demonstrated adjustment of lasers after delivery to Mojave to obtain nearly parallel beams.
- Regolith arrangement methods were improved based upon first flight campaign. Plume flow was smoother across the regolith and dust was blown in a smooth sheet as desired.
- Ongoing image analysis post-flight. Using more advanced methods to extract laser brightness data along each segment of the beam.

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Regolith Preparation for Reflights

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Rocket Blowing Regolith

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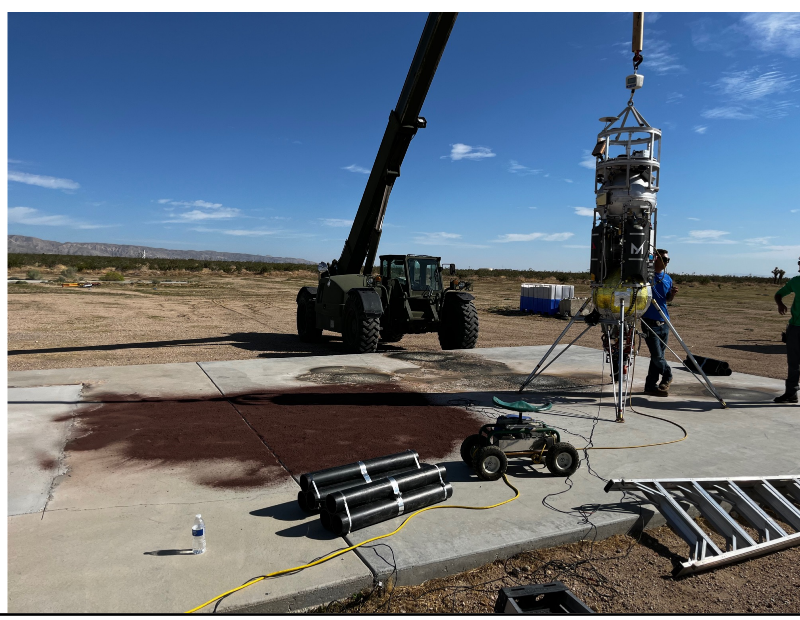
Regolith Before First Reflight



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Regolith After First Reflight

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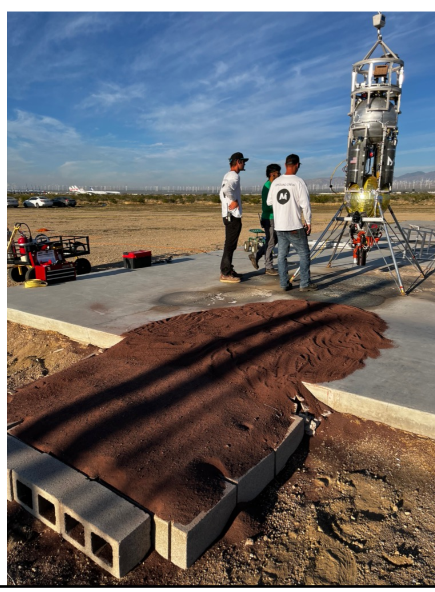
Before & After Final Reflight



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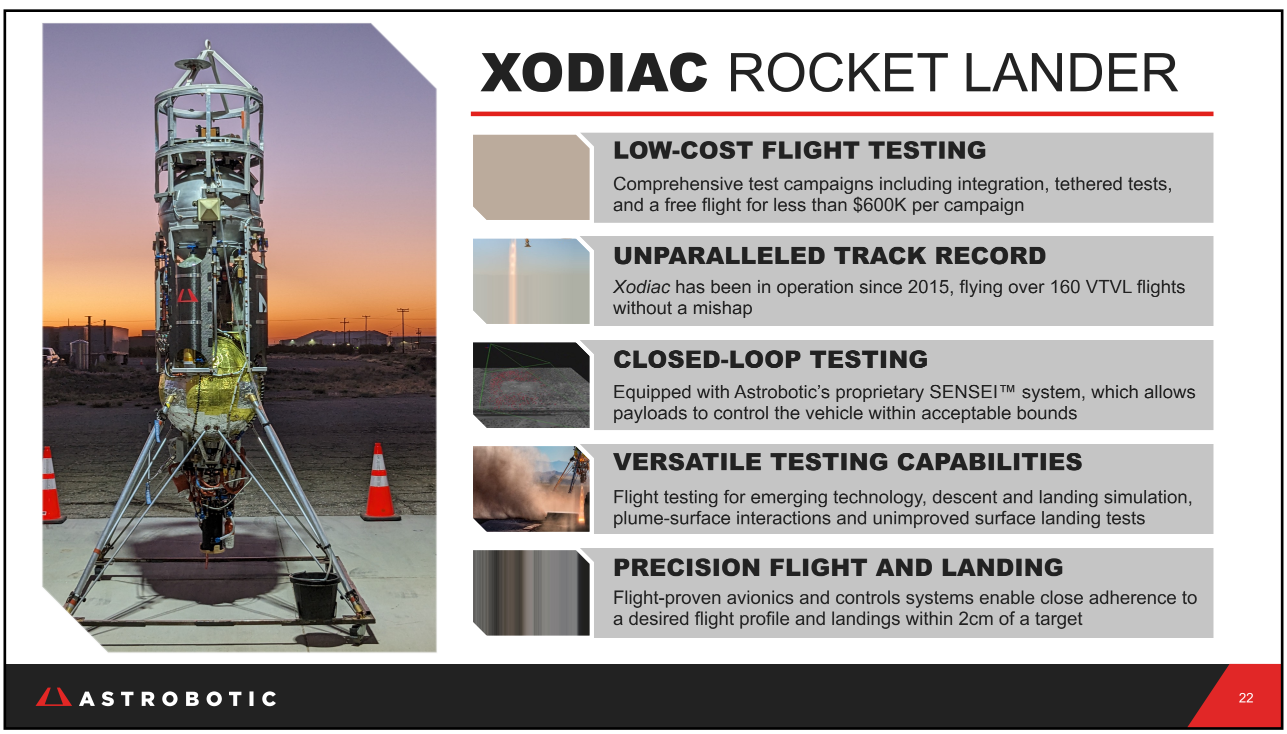
XODIAC ROCKET LANDER
LOW-COST FLIGHT TESTING
Comprehensive test campaigns including integration, tethered tests, and a free flight for less than $600K per campaign
UNPARALLELED TRACK RECORD
Xodiac has been in operation since 2015, flying over 160 VTVL flights without a mishap
CLOSED-LOOP TESTING
Equipped with Astrobotic's proprietary SENSEI™ system, which allows payloads to control the vehicle within acceptable bounds
VERSATILE TESTING CAPABILITIES
Flight testing for emerging technology, descent and landing simulation, plume-surface interactions and unimproved surface landing tests
PRECISION FLIGHT AND LANDING
Flight-proven avionics and controls systems enable close adherence to a desired flight profile and landings within 2cm of a target
ASTROBOTIC
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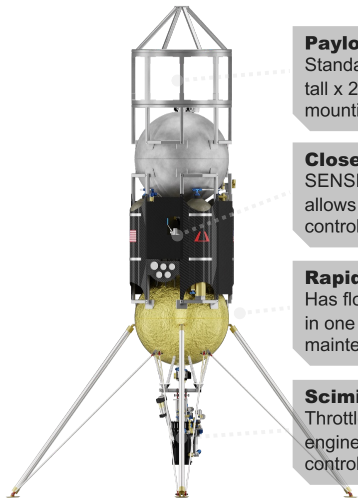
XODIAC ROCKET LANDER



Payload Bottle
Standard payload bottle is 14" tall x 24" diameter; custom mounting options also available

Closed-Loop Testing
SENSEI™ Hypervisor system allows payloads to effectively control the vehicle in flight

Rapidly Reusable
Has flown as many as five flights in one day with no-touch maintenance between flights

Scimitar Engine
Throttleable 1,200-lbf LOX-IPA engine enables carefully controlled descent and hovering

Height	3.4 m
Fuselage Diameter	0.7 m
Payload Mass	50 kg
Std. Payload Volume	100 L
Max. Speed	25 m/s
Max. Altitude	500 m
Max. Range	800 m
Max. Flight Duration	120 s
Landing Precision	2 cm
Successful Flights	160+

ASTROBOTIC 23

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ASTROBOTIC

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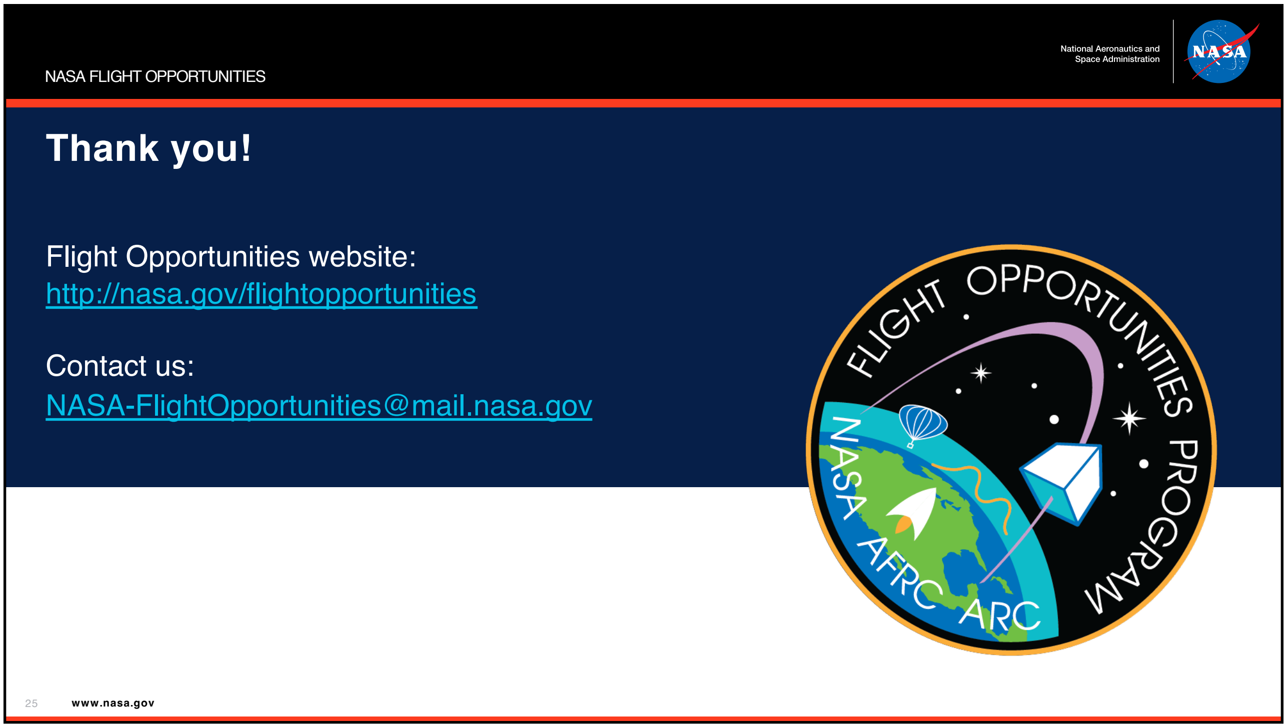
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