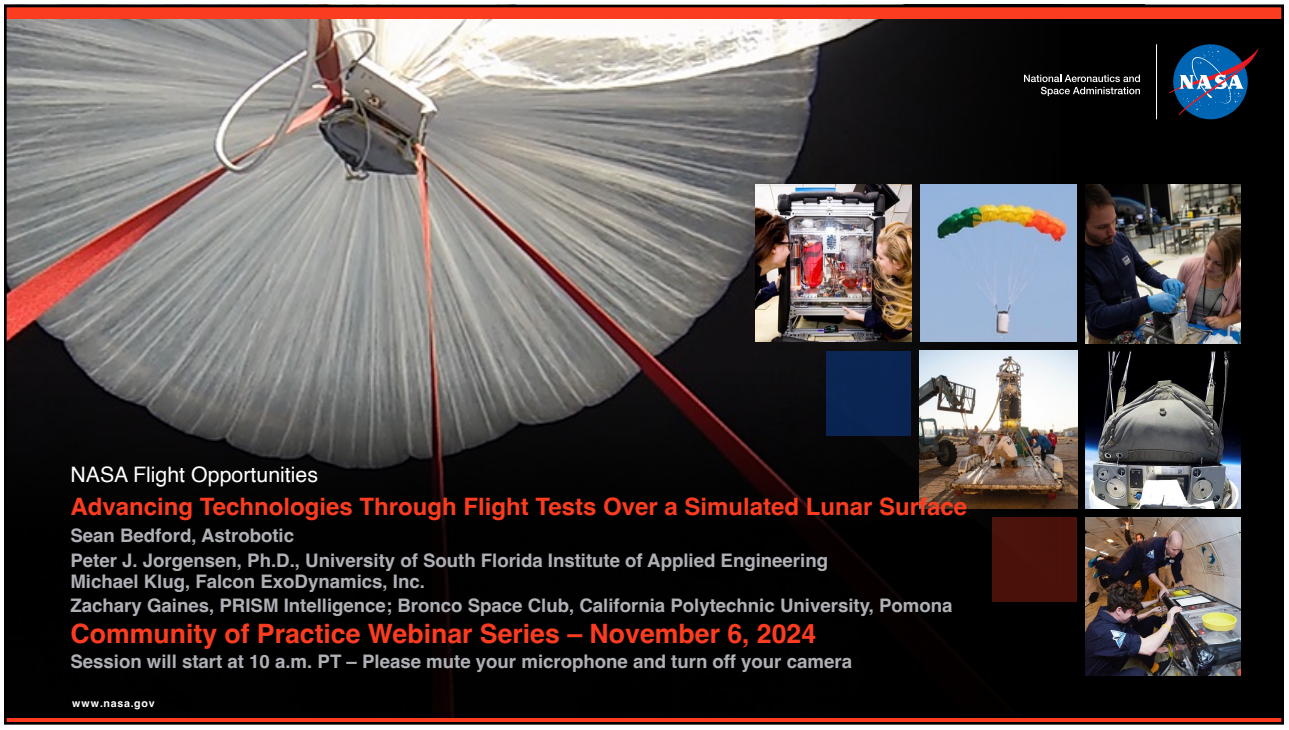
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NASA Flight Opportunities
Advancing Technologies Through Flight Tests Over a Simulated Lunar Surface
Sean Bedford, Astrobotic
Peter J. Jorgensen, Ph.D., University of South Florida Institute of Applied Engineering
Michael Klug, Falcon ExoDynamics, Inc.
Zachary Gaines, PRISM Intelligence; Bronco Space Club, California Polytechnic University, Pomona
Community of Practice Webinar Series – November 6, 2024
Session will start at 10 a.m. PT – Please mute your microphone and turn off your camera
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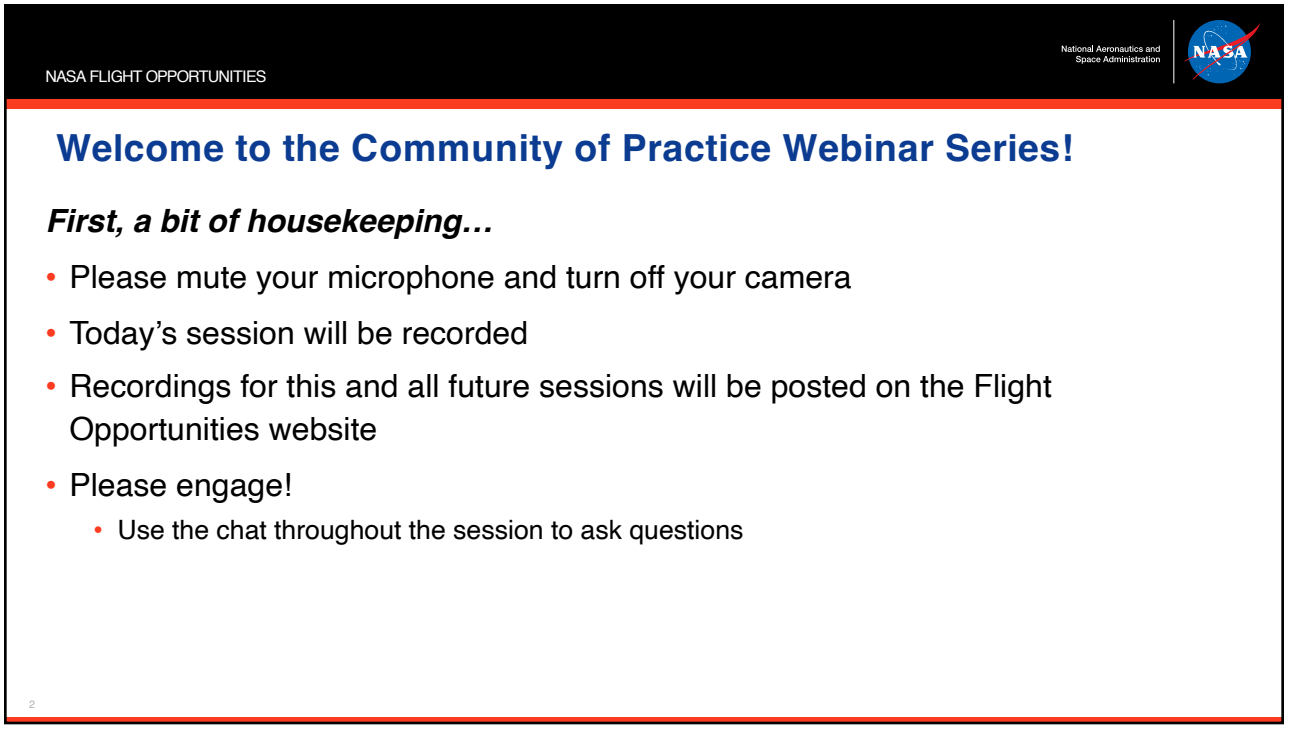
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Welcome to the Community of Practice Webinar Series!
First, a bit of housekeeping…
• Please mute your microphone and turn off your camera
• Today's session will be recorded
• Recordings for this and all future sessions will be posted on the Flight Opportunities website
• Please engage!
• Use the chat throughout the session to ask questions
2

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

4

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Today's Guest Speakers



Sean Bedford
Director of Business Development
Astrobotic



Peter J. Jorgensen, Ph.D.
Director of Engineering
University of South Florida Institute of Applied Engineering



Michael Klug
President and CEO
Falcon ExoDynamics, Inc.



Zachary Gaines
Co-Founder
PRISM Intelligence
Director of Operations
Bronco Space Club, California State Polytechnic University, Pomona

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NASA FLIGHT OPPORTUNITIES

National Aeronautics and Space Administration

NASA TechLeap Prize

- Rapidly identify and develop space technologies that address specific technology shortfalls for NASA and the nation
  - Cash prize and opportunity for a flight test
  - Open to qualified businesses, universities, entrepreneurs, and other innovators
- **Upcoming Challenge:** NASA intends to open a new TechLeap challenge in December 2024
  - Subscribe to the Flight Opportunities newsletter to receive alerts

NASA TechLeap PRIZE

6

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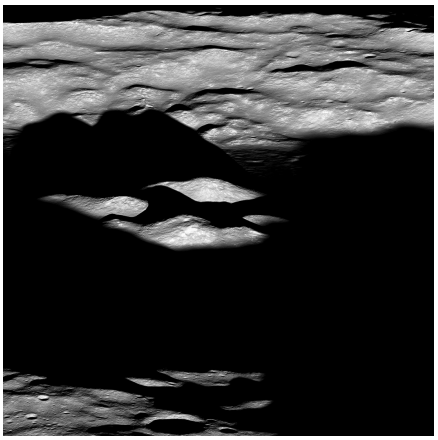
NASA FLIGHT OPPORTUNITIES

National Aeronautics and Space Administration

The Nighttime Precision Landing Challenge

- Advance the affordability and reduce the size and mass of precision landing systems
- Deliver spacecraft to safe landing locations
  - Hazardous terrain
  - Challenging lighting conditions
- Flight test at night over lunar surface proving ground
- Technical goals:
  - Less expensive, smaller, and lower mass systems
  - Detect hazards from 250+ meters high
  - Gather surface terrain data suitable for facilitating safe landings in the dark



This image of the Moon's Bhabha crater illustrates the dark and rocky terrain of the lunar surface. Credits: NASA/Arizona State University

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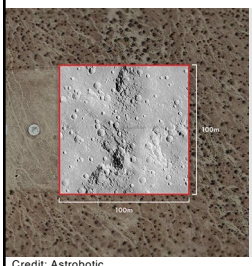
NASA TECHLEAP PRIZE – NIGHTTIME PRECISION LANDING CHALLENGE

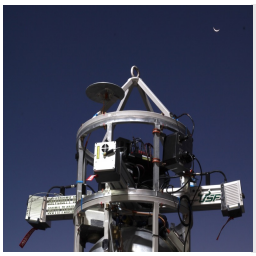


Credit: Astrobotic

Astrobotic's Lunar Surface Proving Ground

Flight Opportunities supported the development of a test field that serves as a spectral analog of the lunar surface.

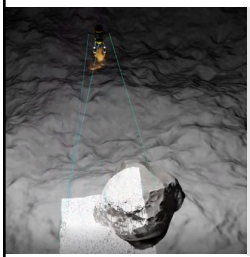
Flight tests at night using Xodiac vehicle Aug-Oct 2024



Credit: University of South Florida/Peter Jorgensen

A-LiST: Univ. of South Florida Institute of Applied Engineering

Combines multiple commercially available lidar sensor heads to collect point data across multiple perspectives simultaneously



Credit: Bronco Space

MoonFALL: Bronco Space, Cal Poly Pomona

Utilizes artificial intelligence and edge computing to create real-time maps to improve traditional terrain mapping; leverages structured light superimposed over potential landing area in combination with advanced image processing and lidar



Credit: NASA/Mathew Kuhns

LITTLE OWL: Falcon ExoDynamics

Performs multi-view monocular photogrammetry using the motion of an observing platform to achieve very long baseline stereoscopic imagery in lit and unlit conditions

National Aeronautics and Space Administration

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Astrobotic

Company Overview

ASTROBOTIC



- Founded in 2007 in Pittsburgh
- 270 Employees
- Over $600M in Active & Completed Contracts
- Primary Technology Areas:
  - Lunar Landers
  - Suborbital Launch Services
  - Robotics & Surface Systems
- Two Primary Facilities:
  - Pittsburgh, PA (Headquarters, Mission Control)
  - Mojave, CA (Propulsion & Test, Rocket Flight Range)

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VTVL Rocket

Flight Heritage



- **625+ successful VTVL flights since 2009**
  - 170+ successful flights by Xodiac rocket lander
- **Historic Innovation**
  - Winner of 2009 Lunar Lander X-Challenge
  - First ever VTVL in-air engine shutoff + relight
  - First TRN-in-the-loop landing of rocket vehicle
  - 5 flights in 1 day, 12 flights in 5 days
- **5 XA-Class Rocket Vehicles Designed, Built, and Flown**



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Xodiac

VTVL Rocket Lander

- VTVL rocket lander for testing lunar / planetary landing technology
- 170+ successful flights
- NASA Flight Opportunities qualified vehicle
- Demonstrated track record of technology maturation
- Past and present customers include:

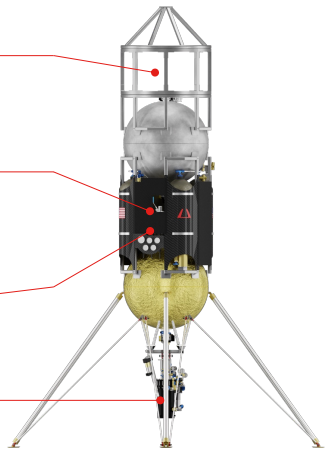
NASA · ASTROBOTIC · JPL · Truventic · DRAPER · PSIONIC

PAYLOAD BOTTLE
38 kg standard capacity
(50 kg max)

PRECISION LANDING
Proven autonomous navigation system enables <3cm precision

CLOSED-LOOP TESTING
Sensei™ Hypervisor system allows safe closed-loop testing

SCIMITAR ENGINE
Throttleable 1,200-lbf LOX/IPA engine enables control, hovering



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Xodiac VTVL Rocket Lander

Max. Flight Speed: 27 m/s

Standard Range: 300 m

Standard Altitude: 500 m

Flight Duration: <180 sec

Max. Off-Vertical: 20°

Roll Control Tolerance: ±3°

Landing Precision: <3 cm

Test Range: Mojave Air & Space Port Test Site 5

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Xodiac Trajectories

Max. Flight Speed: 27 m/s

Standard Range: 300 m

Standard Altitude: 500 m

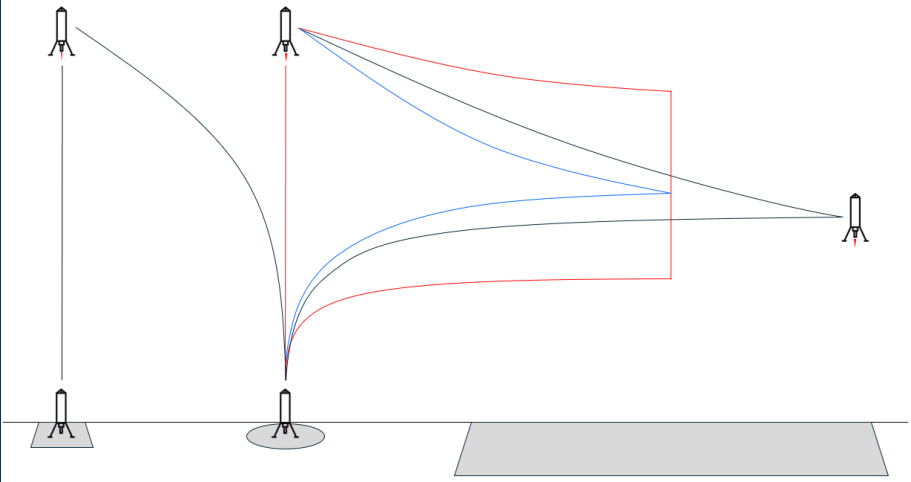
Flight Duration: <180 sec

Max. Off-Vertical: 20°

Roll Control Tolerance: ±3°

Landing Precision: <3 cm

Test Range: Mojave Air & Space Port Test Site 5



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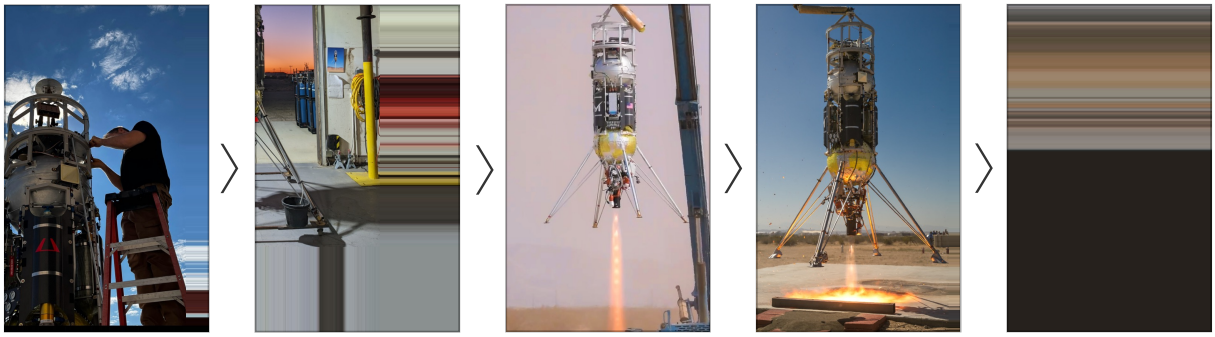
Xodiac

Flight Campaign Progression



INTEGRATION | CHECKOUT | TETHERED TEST | TETHERED TEST | FREE FLIGHT

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Xodiac

Payload Integration

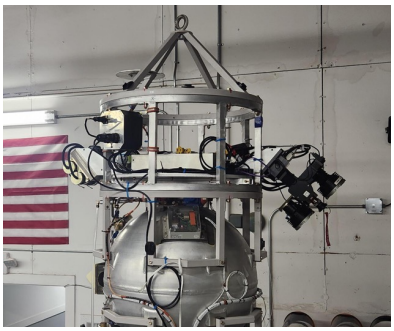
Custom Integration Solutions: Astrobotic works with payload teams to develop mounting and integration solutions that meet vehicle and payload requirements and optimize technical value to the payload.



Bronco Space Club at Cal Poly Pomona
MoonFALL



University of South Florida Institute of Applied Engineering
A-LiST



Falcon ExoDynamics, Inc.
LITTLE OWL

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LSPG Lunar Surface Proving Ground



- **~2.5-acre simulated lunar field (98m x 98m)**
- **Test field shaped into lunar topography and covered with a mix of concrete and unfinished stucco**
  - No regolith simulant (outdoors in windy environment)
  - Mimics contrast and reflective properties of lunar surface
- **Features craters, ridges, mounds, and other terrain representative of the Lunar South Pole**
  - Designed with support from Astrobotic's LunaRay software
  - Based on candidate landing site for *Griffin Mission 1*
- **Can be used to study lighting conditions at LSP**
  - New Moon and pre-Moonrise conditions can be used to set up custom lighting configurations to mimic shadows and glare

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A-LiST
Automated LiDAR Scanning Topography
2022 NASA TechLeap
Nighttime Precision Landing Challenge
NASA Flight Opportunities Webinar
6 November 2024
AUTOMATED LIDAR SCANNING TOPOGRAPHY
NASA TECHLEAP NIGHTTIME PRECISION LANDING CHALLENGE
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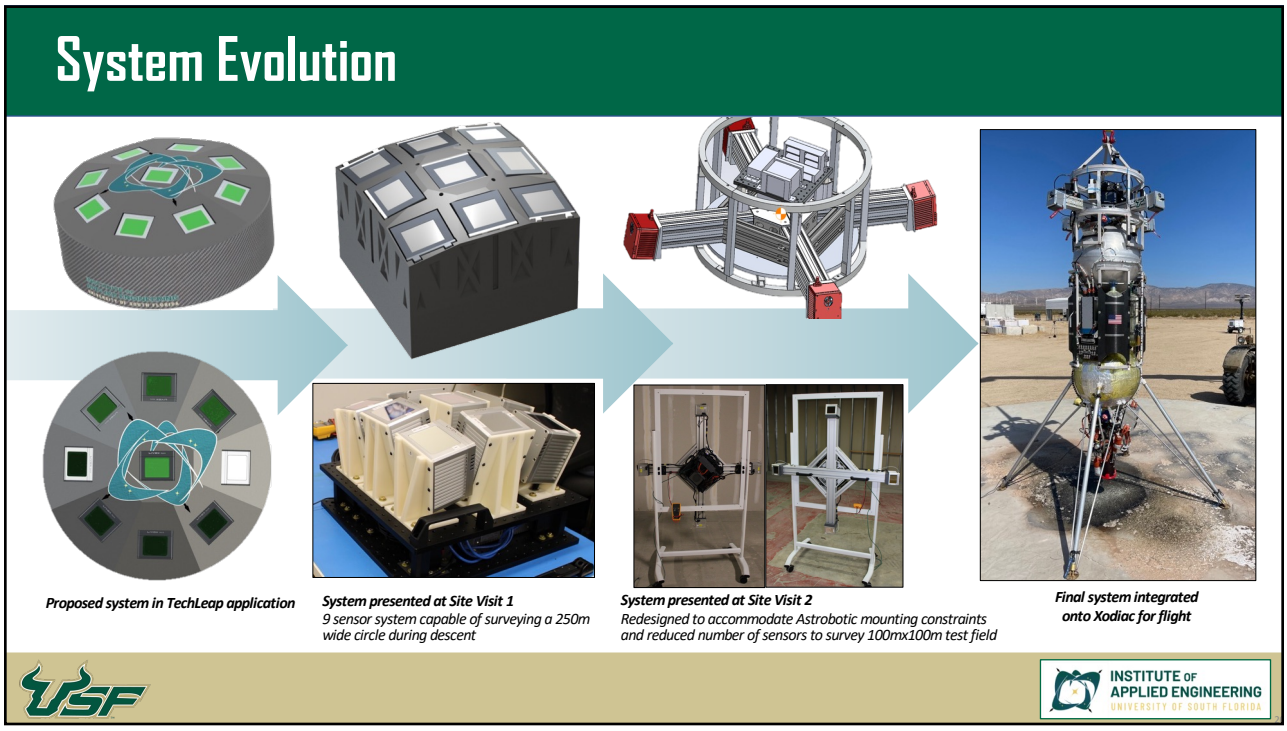
System Evolution
Proposed system in TechLeap application
System presented at Site Visit 1
9 sensor system capable of surveying a 250m wide circle during descent
System presented at Site Visit 2
Redesigned to accommodate Astrobotic mounting constraints and reduced number of sensors to survey 100mx100m test field
Final system integrated onto Xodiac for flight
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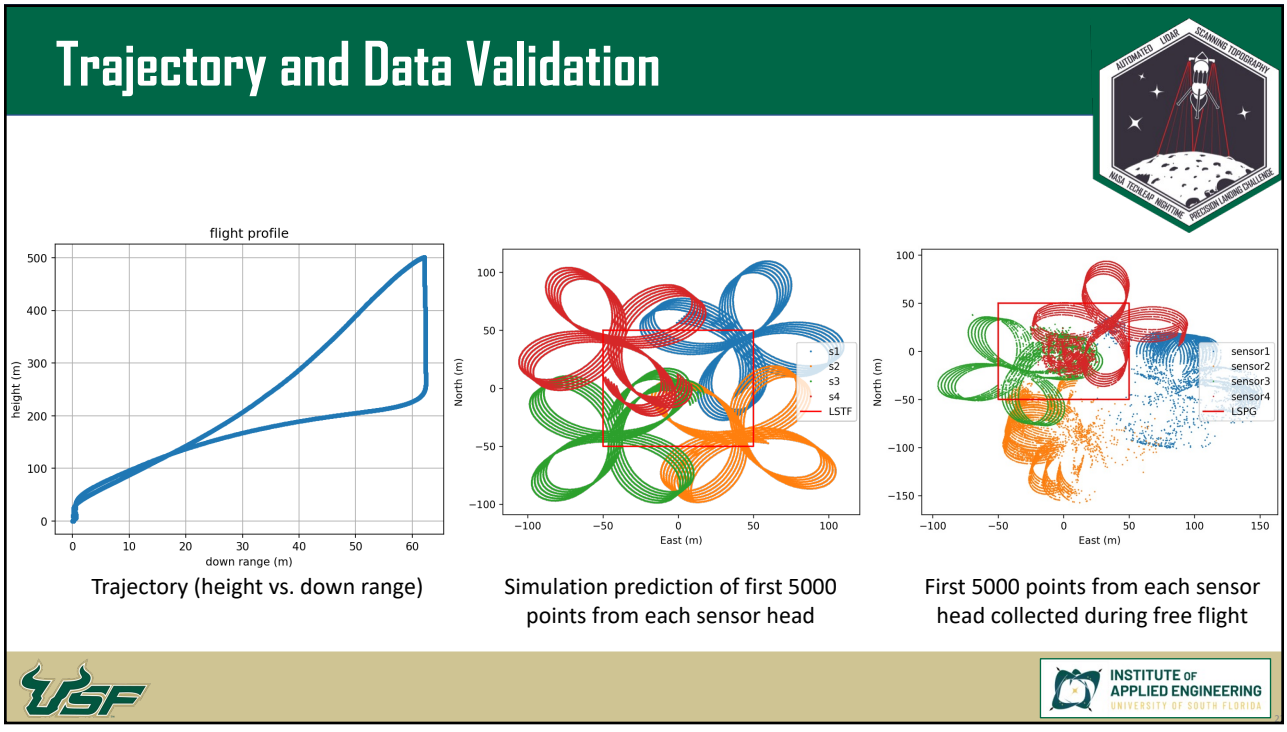

Trajectory (height vs. down range)

Simulation prediction of first 5000 points from each sensor head

First 5000 points from each sensor head collected during free flight

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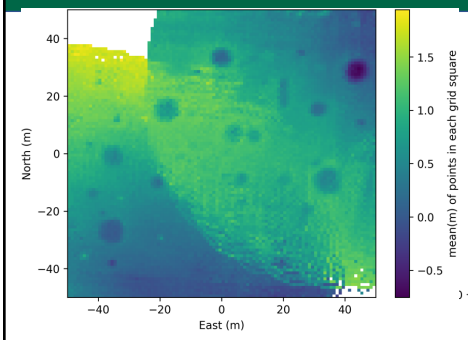
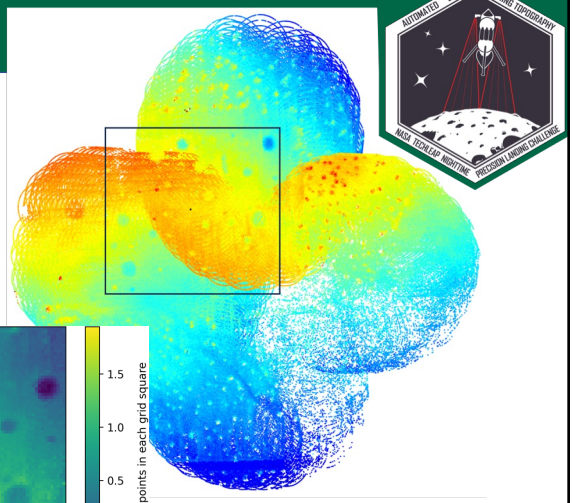
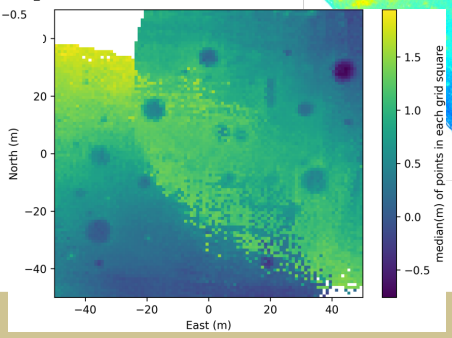
Digital Elevation Map Results







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Flight Success Evaluation

System **successfully** triggered initiation and termination of data capture of vehicle data.

System **successfully** collected LiDAR sensor data with 4/4 of all sensors on our system that can be used for constructing a digital elevation model.

Successful processing of captured sensor data and vehicle telemetry, utilizing onboard computer, to generate a digital elevation model.

Successful operation of system on vehicle when operated over the trajectory taking it over the lunar surface proving ground (LSPG) under low lighting conditions (nighttime).



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Thank you!
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Community of Practice
November 2024 | Michael Klug
www.nasa.gov

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LITTLE OWL Flight Results and Lessons

6 November 2024

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LITTLE OWL System Overview

- Integrated high resolution camera and high output floodlights mounted on a gimbal
- 3D reconstruction using Structure from Motion algorithms onboard with graphics processor system
- Payload components with space qualified equivalents or identified path to flight qualification



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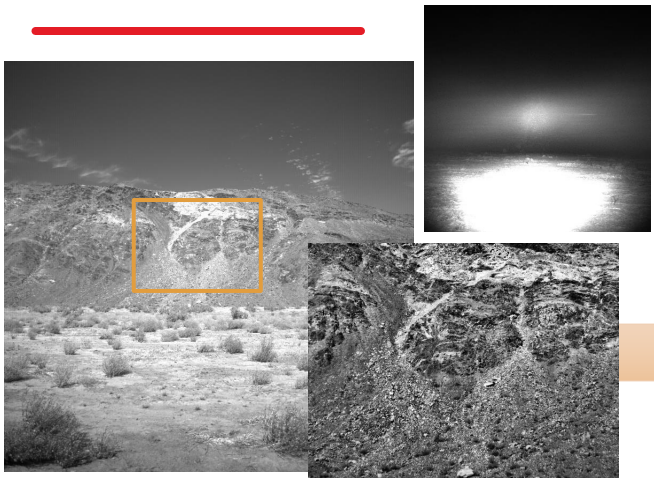
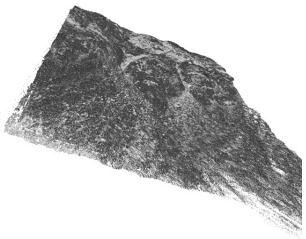
Outdoor Testing



485 meters from aimpoint
Cropped region is ~130m tall and 221m wide

- Outdoor testing performed in the desert collecting daytime and nighttime imagery
  - Flight-equivalent trajectory (just horizontally)
- Daytime collects resulted in excellent reconstruction, but nighttime suffered from "volumetric clutter" (i.e., wind and dust)



Outdoor testing helped us gain confidence in the design and uncover possible issues

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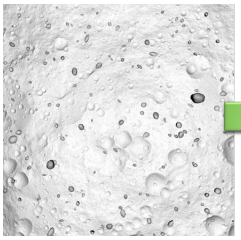
Flight Simulation

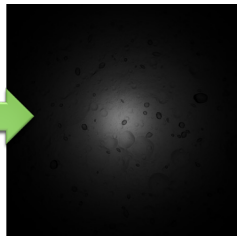
- Performed a variety of simulation runs with our terrain simulator and processed images within the 200-500m altitude window
- Included lighting results from our outdoor testing and motion blur
- Always a trade off balancing further simulation with more fidelity vs. gathering information from the flight test

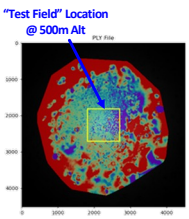
Simulation helped use refine image processing parameters and understand preferred flight trajectories

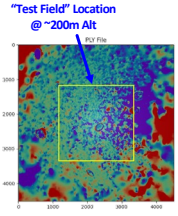
Full "Simulated" Lunar Terrain



Adjusted for Lighting and Noise (*based on outdoor testing data*)







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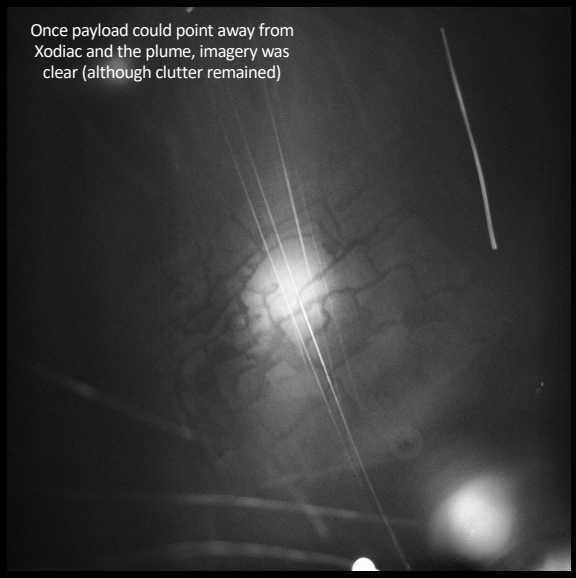
Sample of Flight Images



"Volumetric clutter", plume, and reflections from Xodiac were significant.

Once payload could point away from Xodiac and the plume, imagery was clear (although clutter remained)



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A Few Lessons-Learned

- That plume and stray light – ouch!
  - Trajectory that allows the payload to point further out and away from the lander
  - Better understanding of plume characteristics and behavior
  - Different mechanical mounting options
- "Volumetric Clutter"
  - Performing tests in atmosphere, near the ground, in dusty area, and on a windy night requires additional design that may not be needed for lunar landings (in vacuum)
- Relative results – not absolute measurements
  - Need better understanding and measurement of payload location on vehicle and associated vehicle metrology (mechanical and in-flight)

First flight test results were mixed but showed promise in the approach – we are taking lessons-learned to improve the design as we move forward

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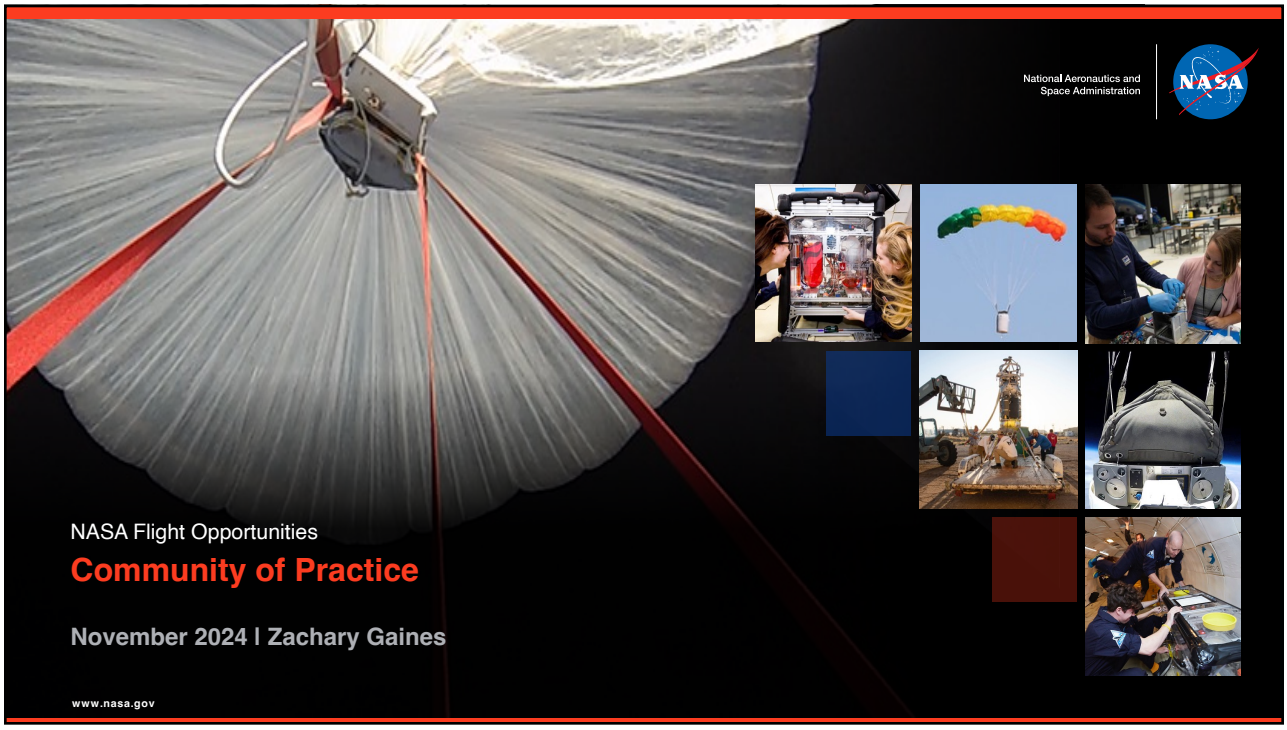
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BRONCO SPACE
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NASA Flight Opportunities
Community of Practice Webinar
11/6/24

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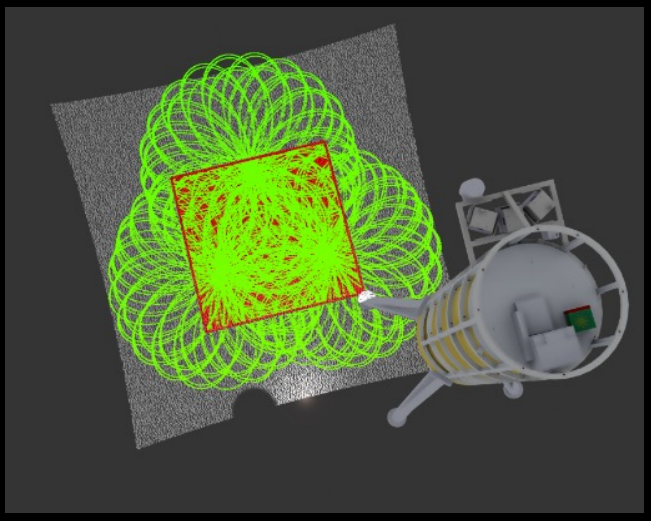
System Overview

- Combination of Structured Light and Lidar
- 3 Lidars, Camera, and High-Power Projector
- Structured Light Creates a relative depth map and then Lidar fills in detail



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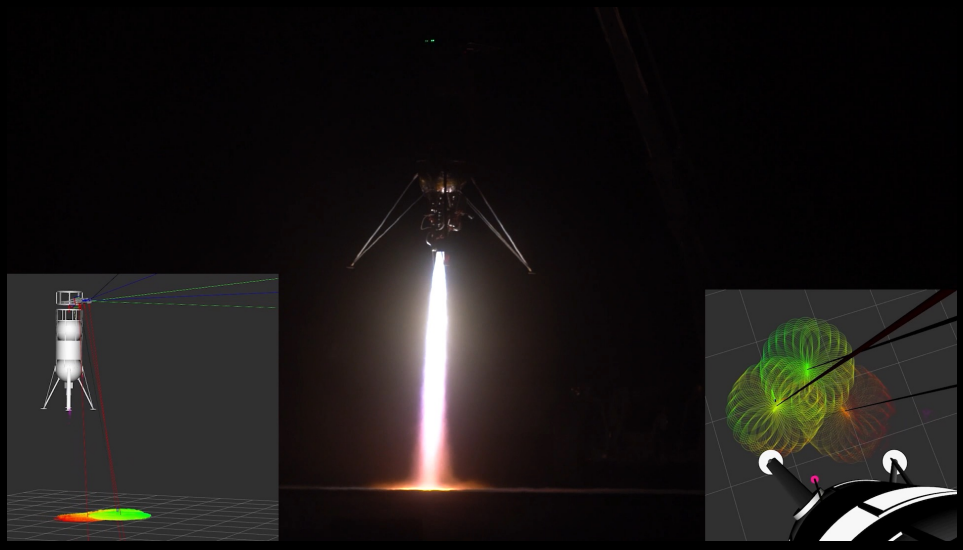
Flight Campaign- Tether Test



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Flight Campaign Lessons Learned

- Sensor Calibration is tricky
- Importance of Procedure Lists
- Visual Indications of functionality
- Translating performance on tether tests to free flight was rather challenging for our payload type



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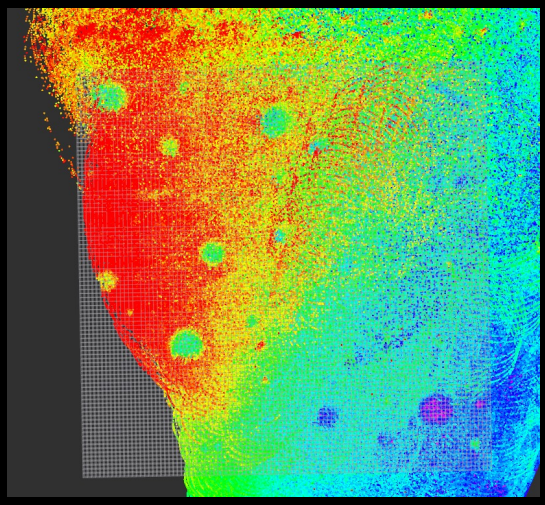
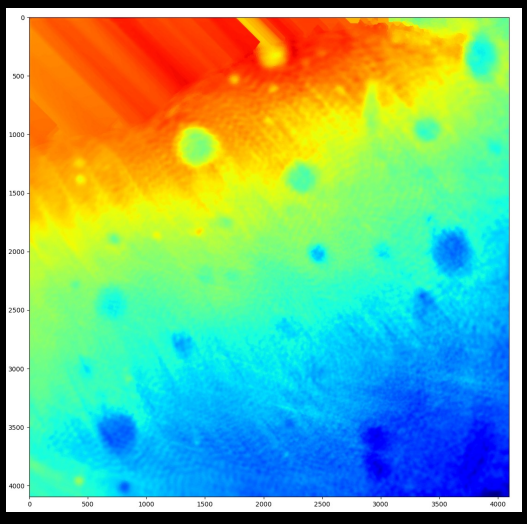
Preliminary Results





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Xodiac

How to Prepare for Testing

Best Practices for Payloads

- Overcommunicate
- Consistent participation from the whole payload team
  - More efficient technical interchange
  - Mitigates delays due to illness or unavailability
- Plan on 3 weeks in Mojave for the test campaign
  - First week can be done early as pre-integration
  - Flight testing and weather are inherently uncertain
- A good CAD model of the payload is helpful
- No USB-3 cables or ports (onboard GPS interference)

Contact Us

Sean Bedford
Director of Business Development
sean.bedford@astrobotic.com
(352) 226-5708



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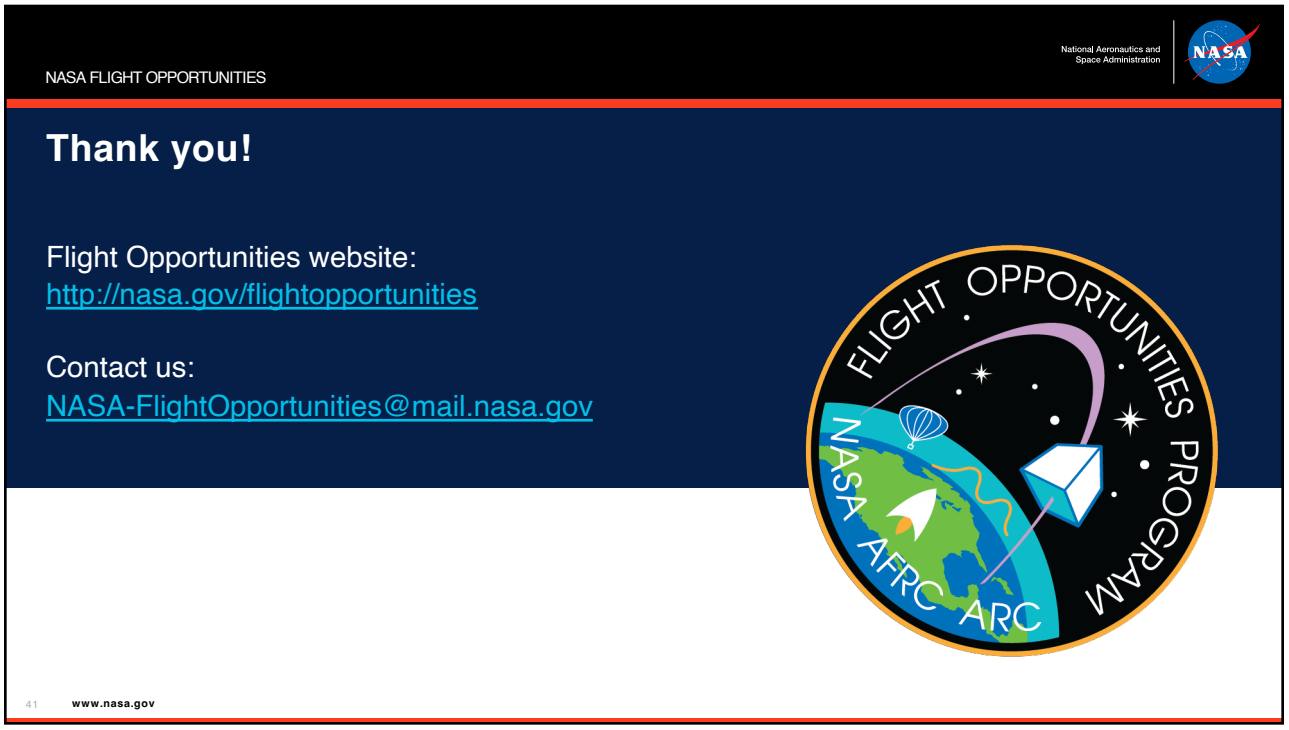
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