



Space Technology Mission Directorate Game Changing Development Program

Andrew Horchler | FY23 Astrobotic TRN Annual Program Review Presentation | 09.20.23
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Standalone Sensor for High Precision Planetary Landing

Technology Goals & Project Objectives



Technology Goals

Goal #1	Develop a TRN sensor (and supporting systems) and raise it to TRL 9. TRL 9 is interpreted as “flight-proven” through a successful demonstration of the OPAL Sensor in a flight to the Moon.
Goal #2	Provide the capability to estimate and log absolute spacecraft pose from the initiation of powered descent to the initiation of terminal descent in order to enhance the absolute position knowledge of the spacecraft. The goal is a final touchdown accuracy of 100 m during future closed-loop lunar landings for realistic lunar trajectories (sufficiently lit surface, pointed at surface, spacecraft capable of divert maneuvers, etc.).

Project Objectives

Objective #1	Integration – The OPAL Sensor shall be integrated with the Peregrine lander (referred to as the spacecraft herein) no later than three months prior to launch.
Objective #2	Functionality – The OPAL Sensor shall estimate and log absolute spacecraft pose from the initiation of powered descent to the initiation of terminal descent.
Objective #3	Performance – The OPAL Sensor shall enhance the spacecraft absolute position knowledge.

Astrobotic TRN – Project Overview

➤ Technology Product Capability

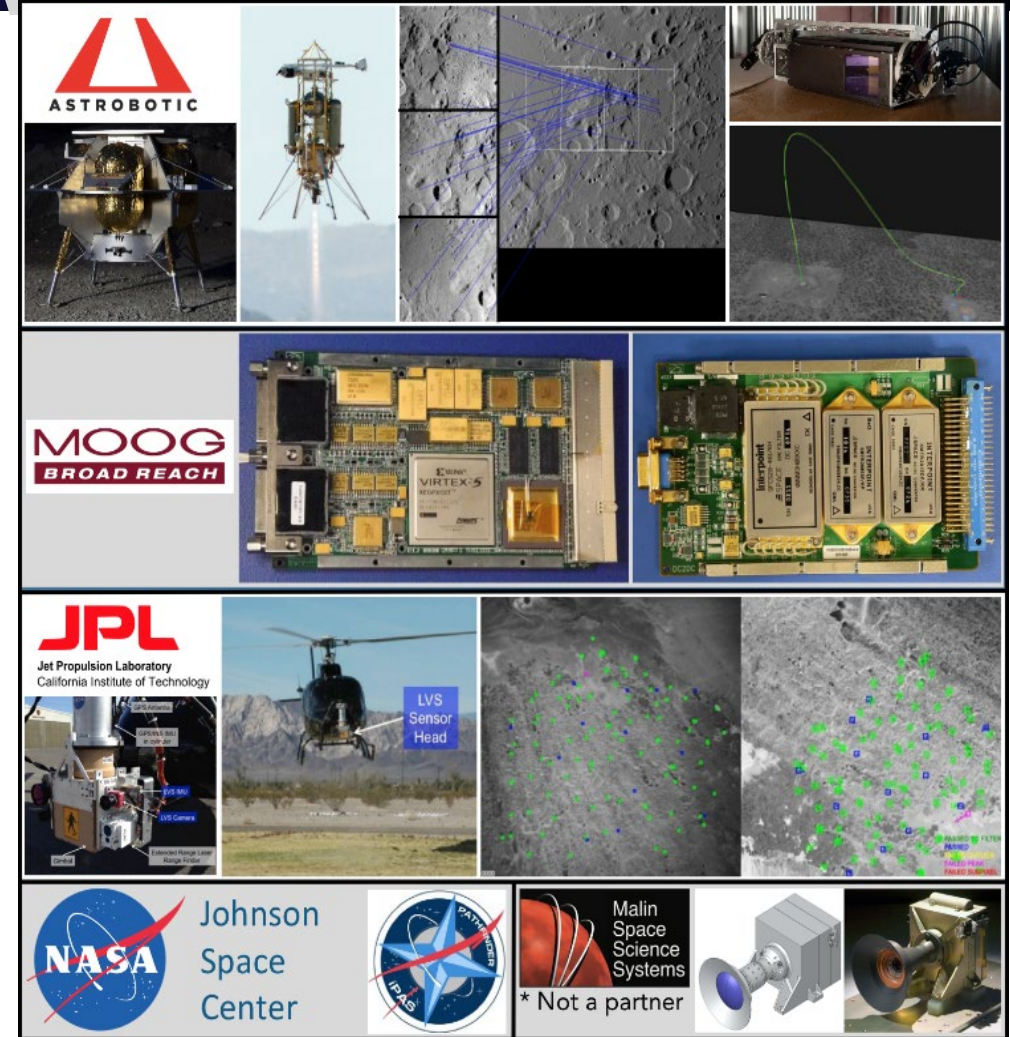
- Commercial bolt-on Terrain Relative Navigation (TRN) sensor system to enable 100-m precision planetary landing by estimating spacecraft pose relative to an onboard map
- Builds on Astrobotic's and JPL's prior TRN systems

➤ Technical Capabilities

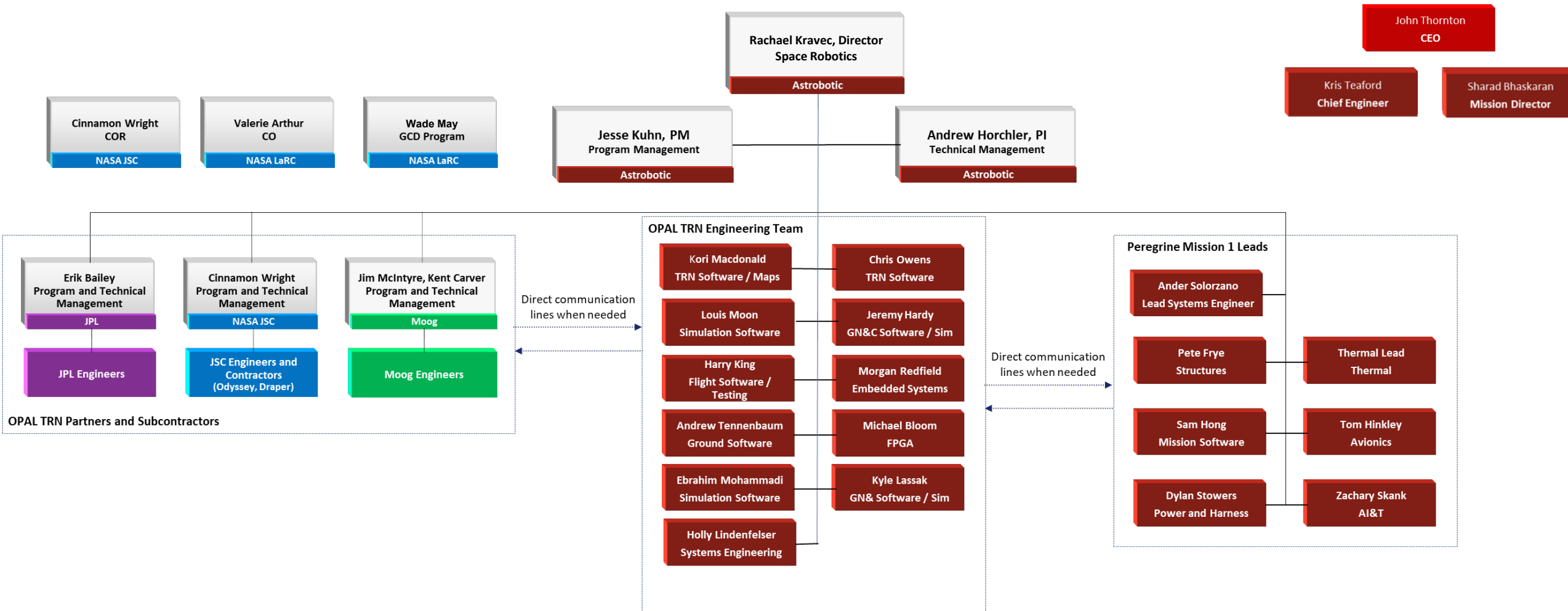
- Enables robust 100-m precision planetary landings
- Unique signature-based algorithms facilitate lander integration
- System includes:
 - High-performance standalone TRN sensor
 - Hardware-accelerated TRN algorithms that work on Moon, Mars, Earth and beyond
 - Accurate lunar map generator and tools for TRN analysis
 - Fast, high-fidelity lunar simulator for hardware-in-the-loop testing

➤ Exploration & Science Applicability

- Vision-based precision planetary landing technology
- Algorithms demonstrated to work at Moon and Mars
- Enabling capability for science and business objectives
- First Astrobotic TRN sensor will fly on Astrobotic's Peregrine lunar lander launching in 2023



Team Members / Project Org Slide

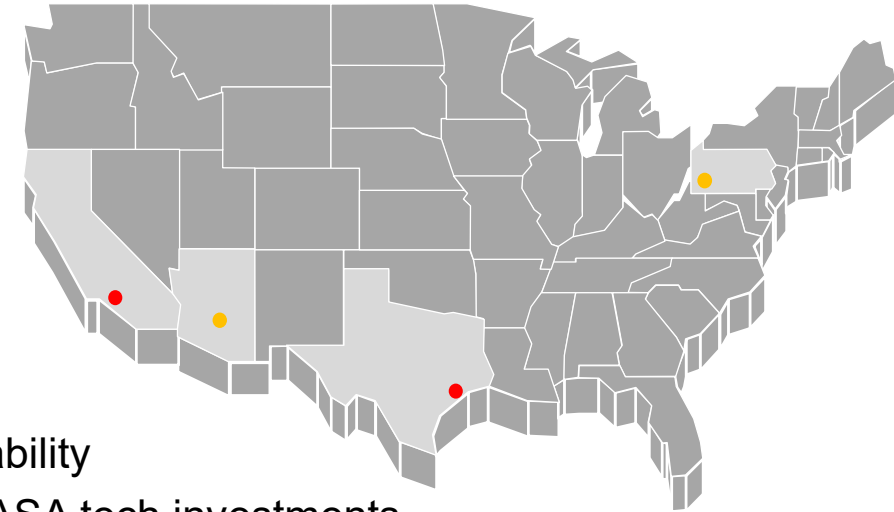


Collaboration & Partnerships



➤ Contributing Partners and/or Stakeholders

- Astrobotic Technology, Inc.
- Moog, Inc.
- Jet Propulsion Laboratory
- NASA Johnson Space Center

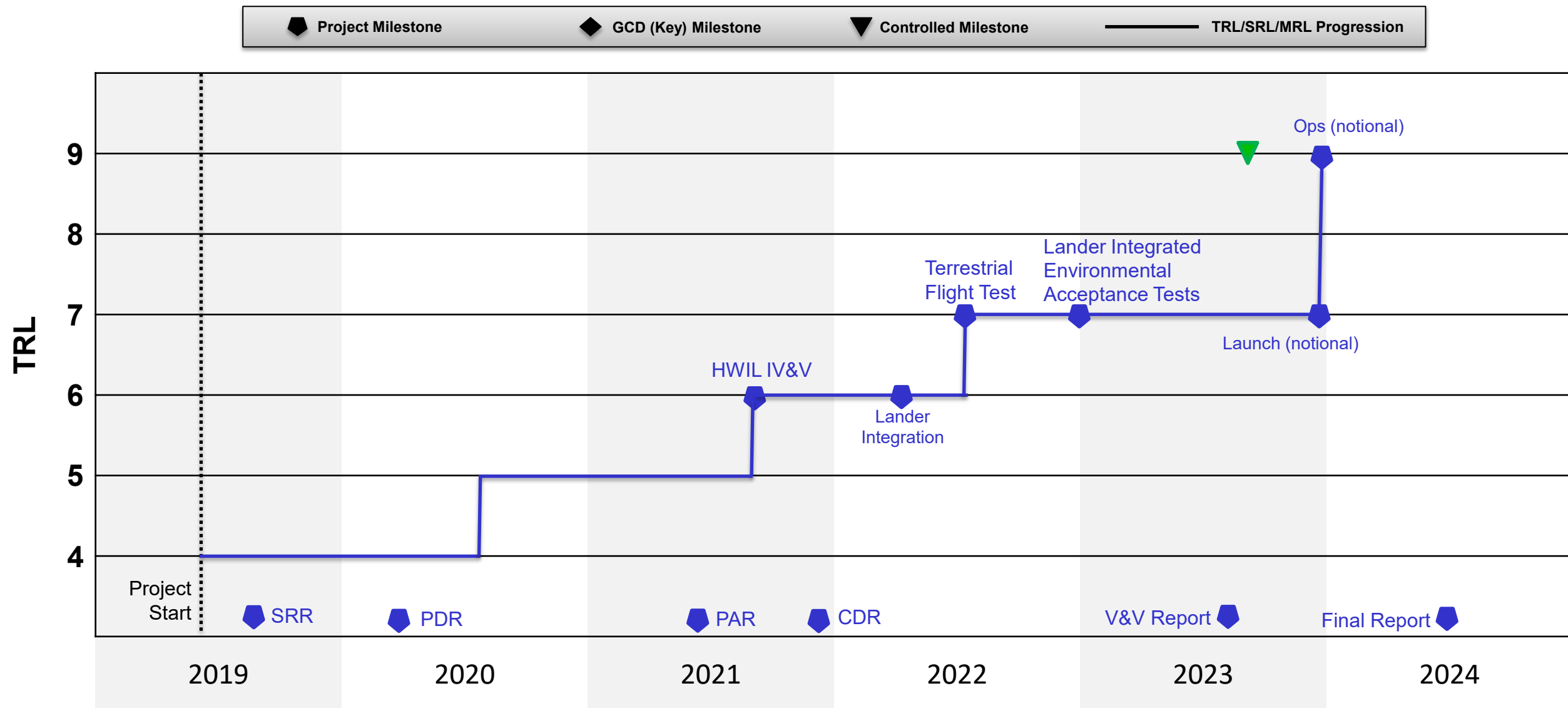


➤ Infusion/Transition Plan

- Goal: Develop a product and a complete toolchain, not just an internal capability
- Leveraging Public-Private Partnerships via Tipping Point to capture prior NASA tech investments
- Transfer Mars 2020 LVS + Feature Descriptor IP Implementation to Industry
- JPL Consulting on software approaches based on Mars 2020 LVS expertise
- Flying TRN Sensor on Astrobotic Peregrine Mission 1, the Griffin-VIPER mission to the South Pole, and on future commercial missions
- OPAL Sensor's high reliability design suitable for missions beyond the Moon
- Partnering with other companies to provide TRN capabilities
- Pitching to DoD agencies and primes to adapt technology for defense applications
- Internal R&D program supported by Phase II SBIR (GSFC) to port Astrobotic's TRN software to lower SWaP-C hardware

Astrobotic TRN Sensor (OPAL)

TRL Progression



Accomplishments (1 of 7)



- Final Peregrine lunar lander integration and mission ops testing...

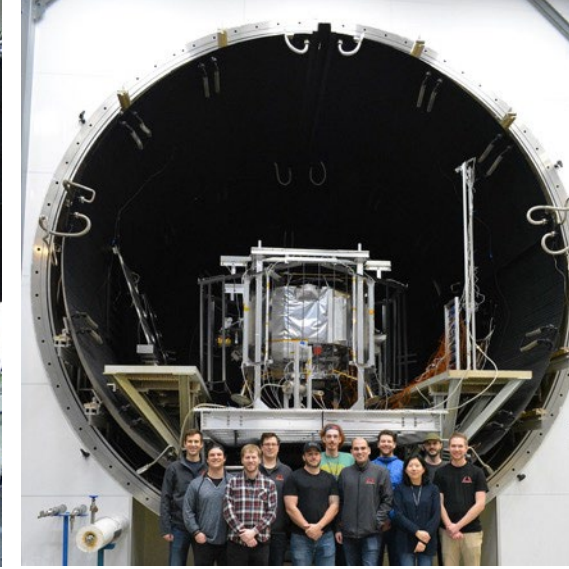
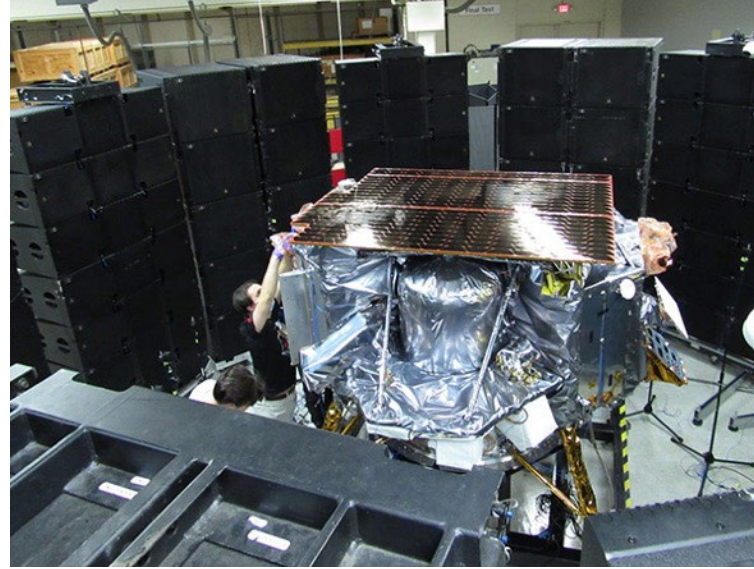
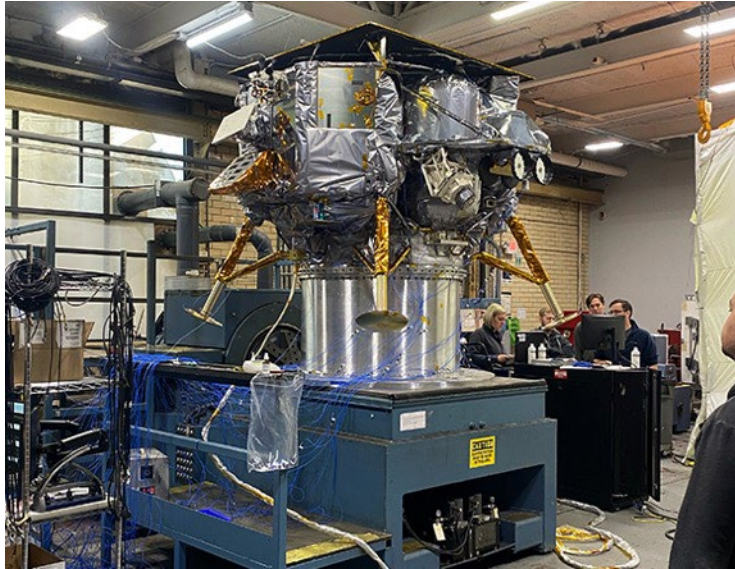


(Left and center) OPAL camera (red lens cover) shown fully integrated on Peregrine lunar lander prior to environmental acceptance test campaign.
(Right) OPAL Systems Engineer Holly Lindenfelser participating in Peregrine lander mission simulations.

Accomplishments (2 of 7)



- Peregrine lunar lander ... and OPAL ... successfully complete integrated environmental acceptance testing (mass props, vibe, acoustic, EMI/EMC, TVAC)...

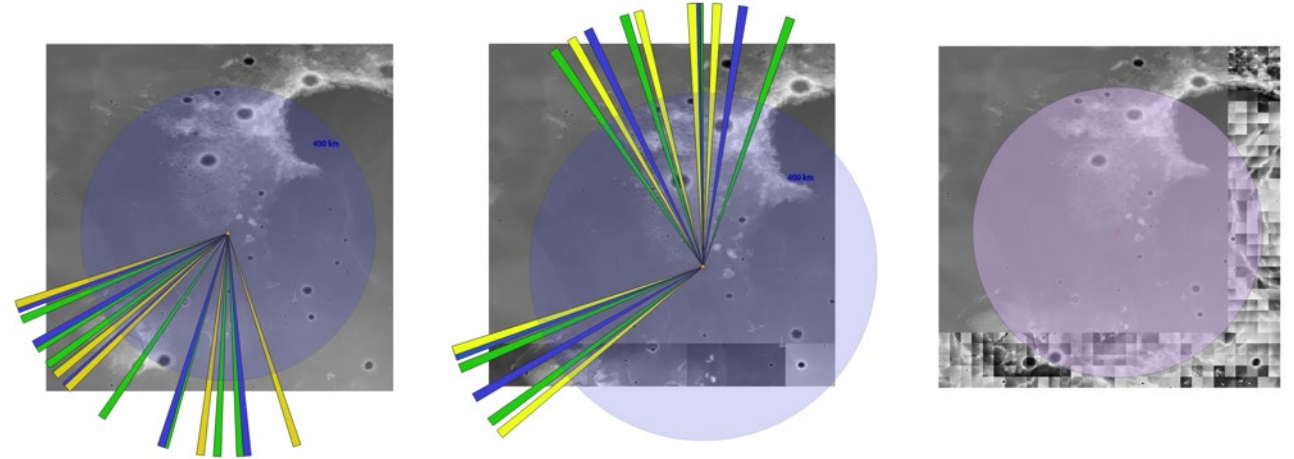


(From left to right) Peregrine mass properties test, vibration test, acoustic test, and TVAC testing (the latter at MSFC).

Accomplishments (3 of 7)



➤ NASA Requests Peregrine Mission 1 landing site to be changed...

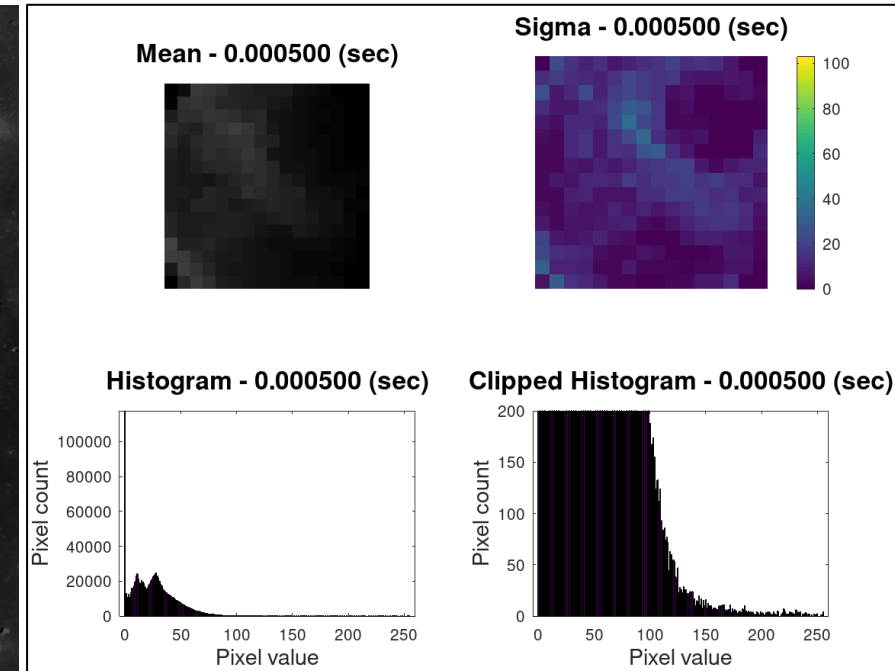
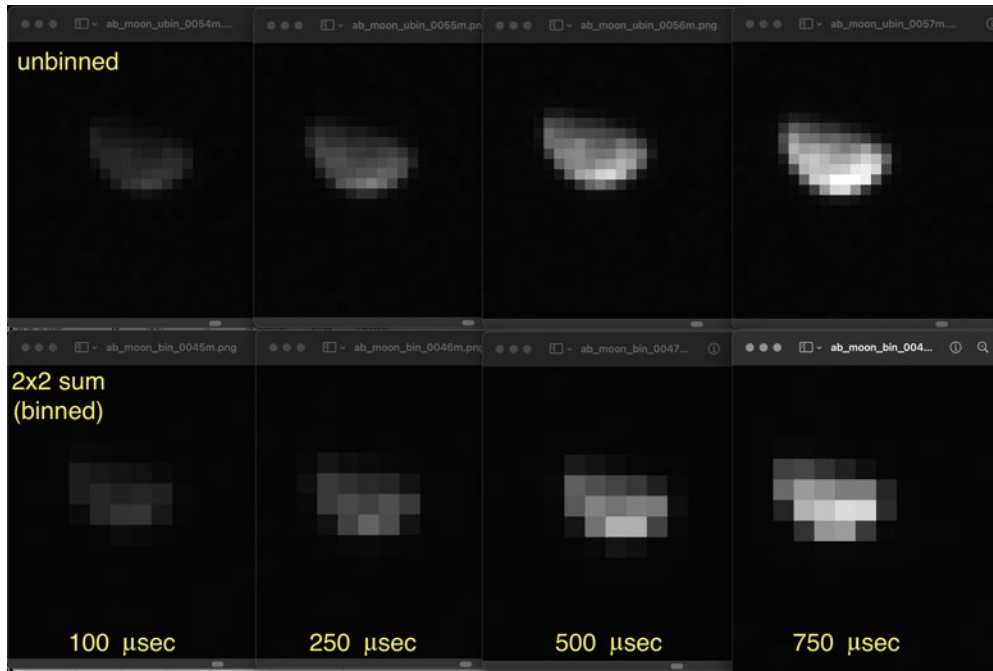


NASA requested that PM1 change its landing site from Lacus Mortis to the Gruithuisen Domes region. The new landing region was assessed for orbital data availability, terrain hazards, illumination conditions, line of sight comms, and TRN suitability using tools developed under this Tipping Point. New high fidelity terrain models and TRN map products were developed and validated. The mission timeline necessitated the rapid development of new tools to partially automate the TRN map generation and validation process.

Accomplishments (4 of 7)



- Star alignment and lunar exposure checkout ops software developed and tested...



The star alignment checkout during transit will capture star field images over a range of exposures, detect stars positions, and extract thumbnails around each star. This data along with spacecraft GNC data will be relayed to the ground for analysis on boresight relative to pre-launch metrology.

The lunar exposure checkout during lunar orbit will capture images of the lit Moon's surface over a range of exposures, calculate histograms, and generate low resolution thumbnails. This data with spacecraft GNC data will be relayed to the ground for analysis on final OPAL camera exposure for TRN operations. Astrobotic's exposure analysis has been validated through physical simulation and terrestrial images of the Moon captured by the OPAL camera (left). This analysis and on mission procedures have been reviewed by JPL to capture lessons learned from Mars 2020 TRN.

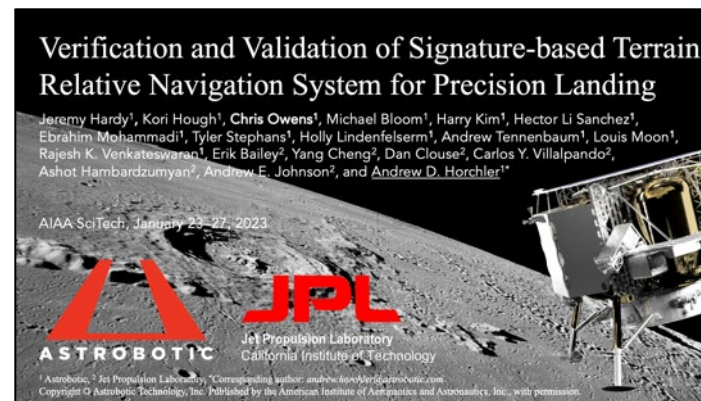
Accomplishments (5 of 7)



➤ Deliverables, publications, and presentations...



Flight Test Report and Requirements Verification Report delivered to NASA



AIAA Scitech paper on TRN V&V published and presented



Space Imaging Workshop presentation on LunaRay and DEMkit



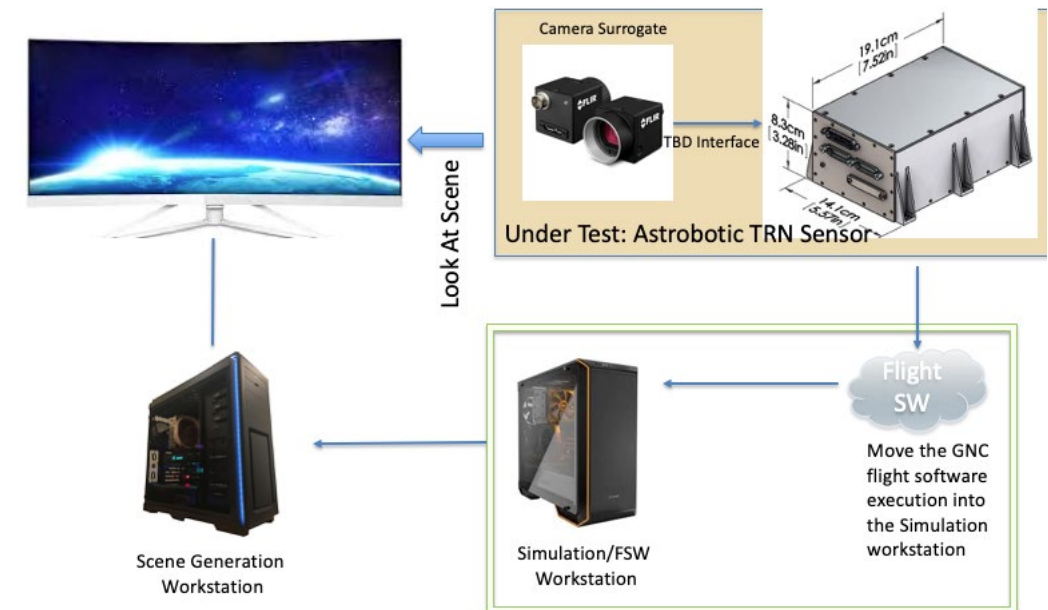
Presentation to NASA LunaMaps team on simulation and terrain modeling capabilities

Accomplishments (6 of 7)



➤ IV&V Testing at JSC...

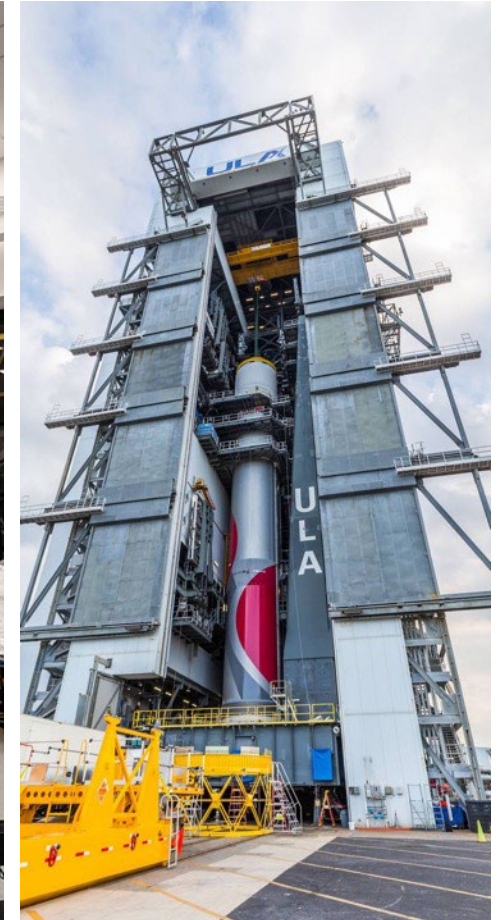
- Independent V&V of the Astrobotic TRN sensor
- Developed tools, simulation, and rendering capabilities independent of Astrobotic (both SITL and HITL implementation)
- Performed onsite HWIL Testing using independent AstroCat HWIL setup with 8K monitor and renderer
- Updating simulation to take into account Astrobotic landing site change
- Astrobotic delivered OPAL TRN software for testing along with representative flight maps
- Continuing effort on independent closed-loop performance assessment with OPAL TRN software integrated within JSC simulation utilizing independent lunar renderer for scene generation



Accomplishments (7 of 7)



➤ Ready for launch...



Project Assessment Summary



Project Name	Performance				Comments
	C	S	T	P	
Mid Year					Technical – Cost – All funds spent. Astrobotic expects an overrun (due to launch delays, landing site change, high hardware costs, and COVID). No work stoppage – other funds used to cover overrun. Astrobotic has discussed overrun with GCD, COR, and CO and is looking for future means to partially cover excess costs to this project, including data buys from the mission, licensing software tools, and providing additional analyses. Schedule – Programmatic –
Annual					Technical – Cost – All funds spent. Astrobotic expects an overrun (due to launch delays, landing site change, high hardware costs, and COVID). No work stoppage – other funds used to cover overrun. Astrobotic has discussed overrun with GCD, COR, and CO and is looking for future means to partially cover excess costs to this project, including data buys from the mission, licensing software tools, and providing additional analyses. Schedule – Programmatic –

* Rationale only required/provided for yellow and red color determinations.

Plans Forward and Transition / Infusion Plan



- Astrobotic's TRN system will be demonstrated aboard our Peregrine lunar lander in 2023 as part of this Tipping Point.
- The TRN system will be employed to safely and precisely land our Griffin lander and NASA's VIPER at the lunar South Pole in 2024. The system will undergo further flight testing before launch and is being developed along with a LiDAR hazard detection sensor.
- Astrobotic has sold our lunar TRN system (HW, SW, maps, simulation tools) to another space company. Partnering with others.
- Astrobotic is a member of Blue Origin's National Team for their Human and Cargo Landers (NextSTEP Appendix P: Human Landing System Sustaining Lunar Development).
- In conversations to provide GPS-denied navigation solutions for terrestrial applications.
- Under a Phase II NASA SBIR, Astrobotic is developing next generation vision-integrated compute HW to provide lower SWaP-C and higher performance TRN (and other advanced visual navigation applications). The system was tested at JSC's STAR Lab.
- LunaRay engine being used and marketed for landing site analysis as well as orbital simulation for RPOD/ISAM/SSA.

Education/Public Outreach

EPO Involvement

- Astrobotic [press release on TRN testing](#)
- [Inverse article](#) on TRN / lunar landing sensor technology.
- [Full paper on performance and testing of TRN system](#) presented at AIAA SciTech 2023
- Astrobotic's TRN and other tech presented at the [NASA Tech Showcase](#) (TRN and [LunaRay](#) abstracts)
- [Press release](#) and [Space News article](#) on on Peregrine lander passing TVAC acceptance testing.
- [Astrobotic](#) and [Blue Origin](#) press releases on NASA's selection of Blue Origin's National Team to develop human and cargo landers
- [Press release](#) on Astrobotic's new Lunar Surface Proving Ground 3D test field in Mojave, CA
- Presentation on TRN and space robotics for a Tech Briefs webinar on [Returning to the Moon with Robots](#)

EPO Calendar Outlook (High Priorities):

6 Month Look-Ahead

Astrobotic Peregrine Mission 1 Launch	TBD





Astrobotic TRN – Summary

- **Accomplishments for the Year-to-Date (Oct 2022–Sep 2023)**
 - Delivered OPAL TRN Terrestrial Flight Test Report to NASA
 - Completed OPAL hardware and software integration with Peregrine lunar lander
 - Completed integrated environmental acceptance testing campaign on lunar lander
 - Assessed new NASA-requested landing site for TRN suitability and developed new map products for flight
 - Validated and automated map generation process and validated lunar exposure analyses
 - Completed extensive lander flatsat testing of OPAL software functionality and FDIR
 - Finalized mission ops procedures for all checkouts and operations during descent and on the surface
 - Completed numerous mission ops simulations across all mission phases
 - Delivered Requirements Verification Report to NASA
- **Summary of TechMat Capability End State for the Scope of the Project**
 - Complete TRN solution demonstrated in lunar tech demo
 - Detailed performance analysis of precision landing capability
 - Sophisticated and mission-proven terrain modeling and simulation capability
- **Forward Work**
 - Finalization and upload of TRN flight maps; mission ops simulations
 - Lunar Tech Demo and post-mission analysis