National Aeronautics and Space Administration

Long-Distance Altimetry and Terrain Relative Navigation Capabilities of a Multi-Functional Imaging Lidar

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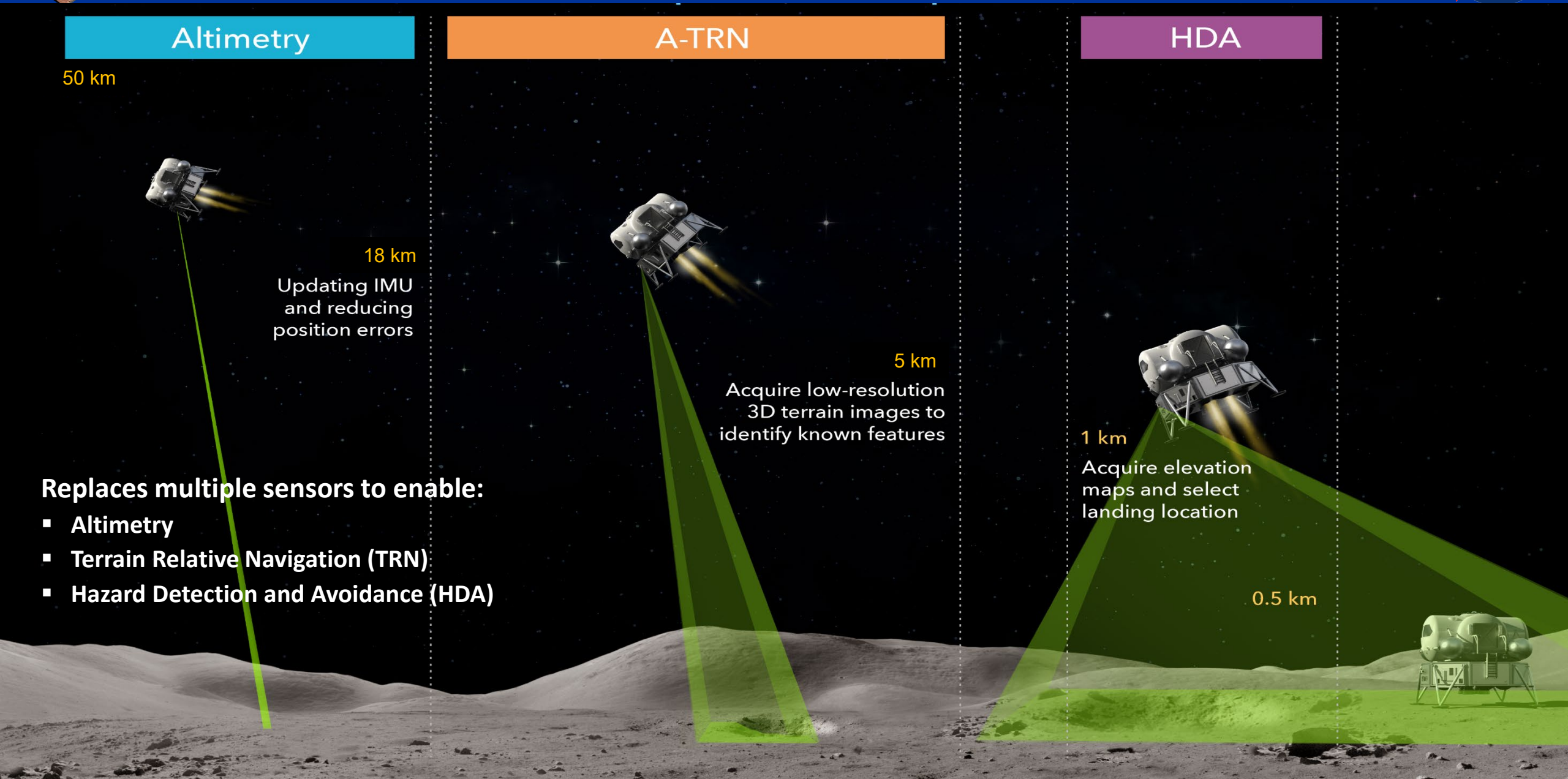
Coherent Applications

2026 MSS Active E-O Systems Conference

Terrain Sensing Lidar (TSL)

- TSL has been developed for future landing missions
  - Provides relative position knowledge after deorbit and during descent
  - Detects terrain hazards and identifies safe landing location
- TSL is based on linear-mode *flash lidar* technology utilizing *real-time image enhancement and processing algorithms*

Concept of Operations



Replaces multiple sensors to enable:

- **Altimetry**
- **Terrain Relative Navigation (TRN)**
- **Hazard Detection and Avoidance (HDA)**

Terrain Sensing Lidar (TSL)

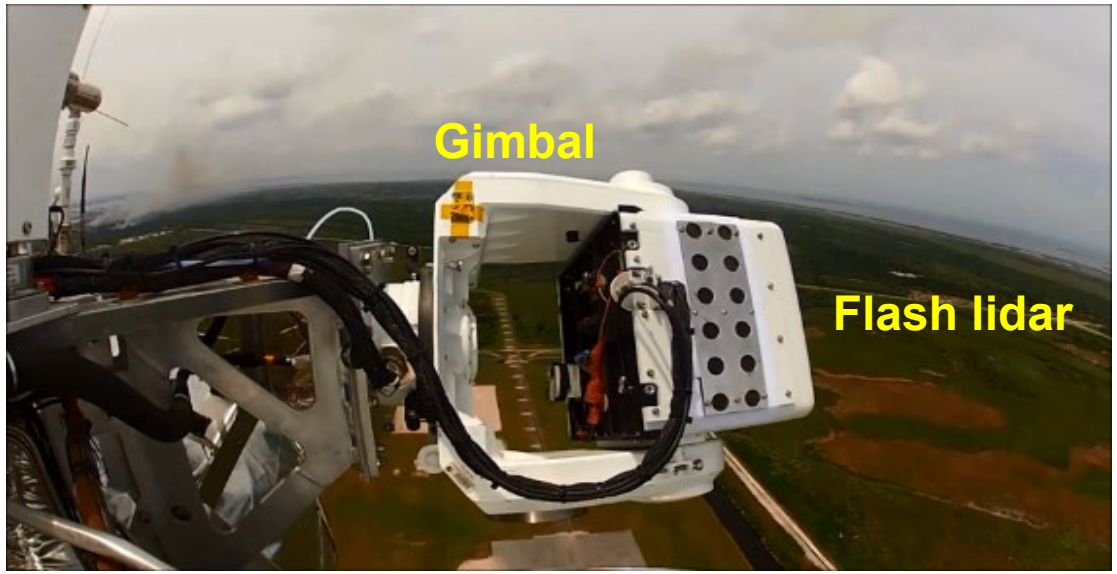
- HDA has been demonstrated through a helicopter flight test and a drone flight test
  - Tested up to 250 m range
  - Additional flight tests are needed for demonstration over full operational range
- Preparing for high-altitude flight tests for demonstration of long-distance altimetry and TRN

TSL Prototype
6.8 kg and 48 W
including processor

Hazard Detection and Avoidance Requirements

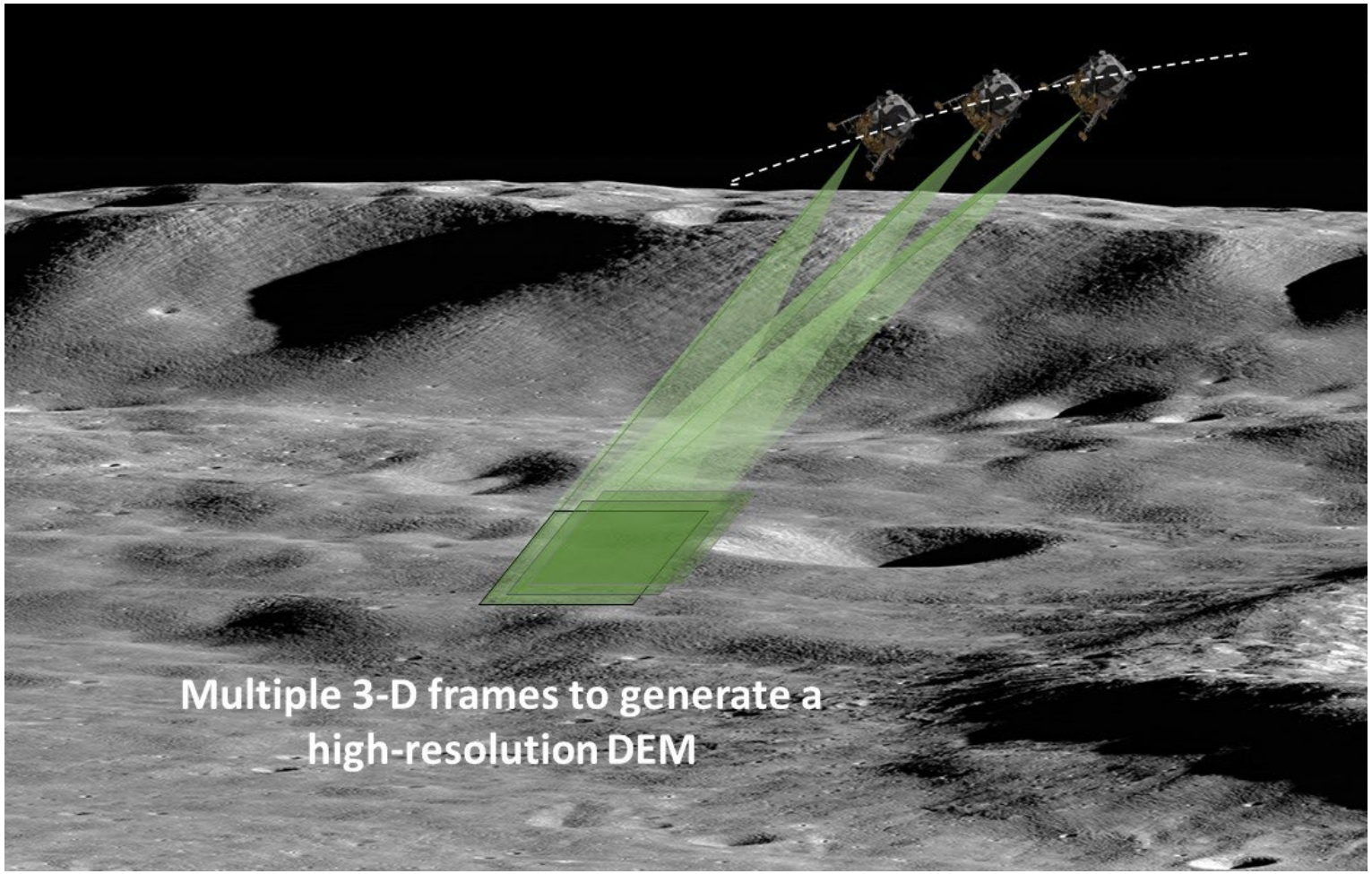
- Survey 100 m x 100 m area from > 1km range and detect 30 cm radius hazards
  - Require < 15 cm Ground Sample Distance (GSD), i.e., > $(100/0.15)^2$ = 0.44M pixels
- Commercial linear-mode flash lidar camera has 128 x 128 = 16.4k pixels
- Past demonstration used a mechanical gimbal to generate a mosaic of image frames

Flash lidar closed-loop demonstration onboard rocket-powered Morpheus vehicle (2014)



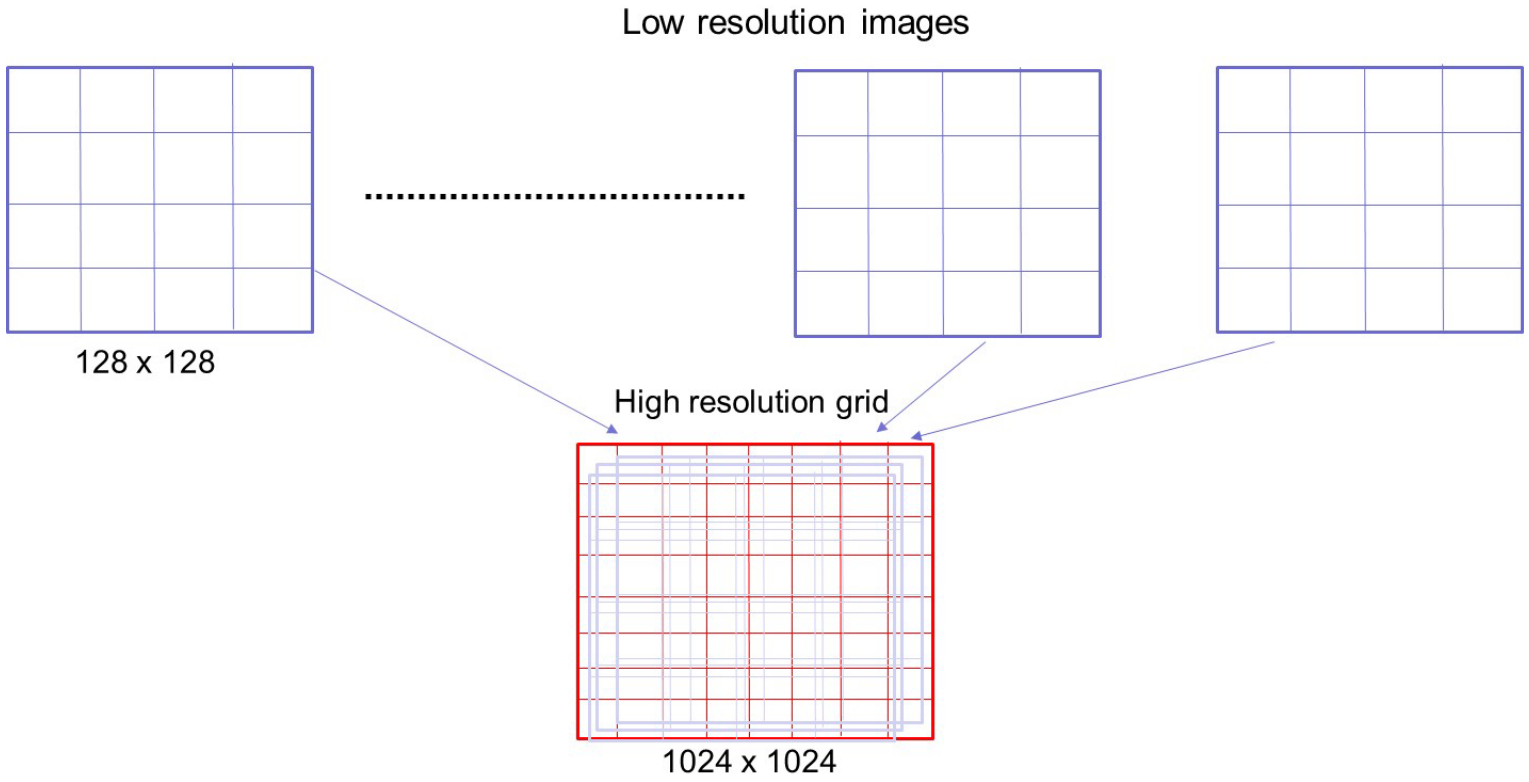
3-D Super-Resolution Algorithm

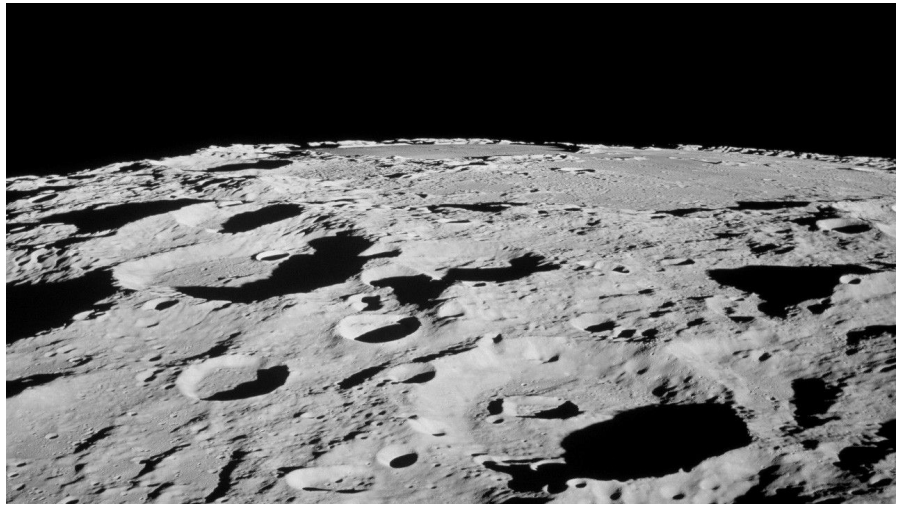
- Super-Resolution (SR) technique uses a set of consecutive frames, from slightly different positions and angles (resulting from platform motion), to generate a high-resolution DEM
- Generates high-res DEMs at 1 Hz rate using 20 frames
- No external sensor data is required
- Provides 6-DOF relative state vector and velocity at 20 Hz

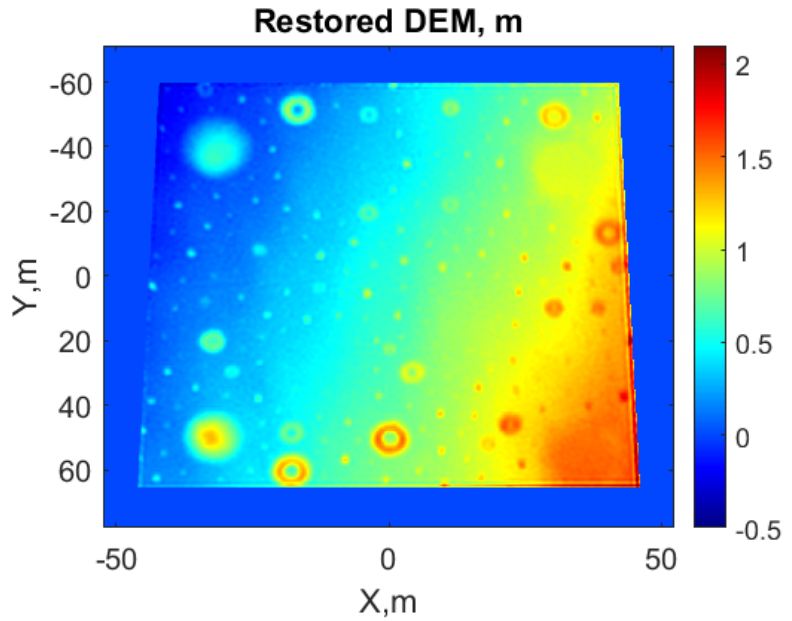


3-D Super-Resolution Algorithm

- Determines the platform 6-DOF state vector (position and pointing angles) from images
- Performs back projection
- Blends image frames to generate high resolution Digital Elevation Maps



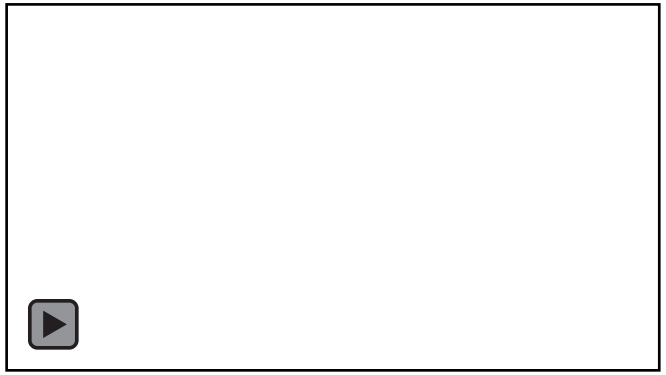




TSL Modes of Operation

Function	Operational Range (km)	Beam Div. (deg.)	No. of Pixels	GSD
HDA	1.3	5.0	128 x 128	0.9 m
TRN	10	0.7	18 x 18	6.8 m
TRN	18	0.35	9 x 9	13.6 m
Altimetry	50	0.13	3 x 3	40.9 m

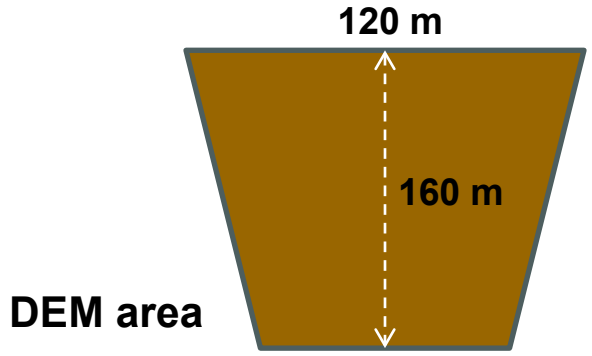
Transmitter Beam Divergence Wheel



$$\frac{R_2}{R_1} \propto \frac{\theta_1}{\theta_2} \propto \left[\frac{(\#of\ pixels)_1}{(\#of\ pixels)_2}\right]^2$$

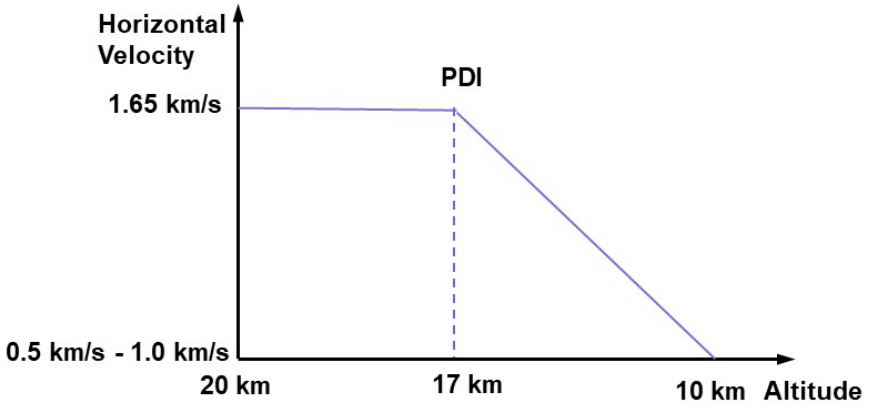
Projected Performance Specifications HDA

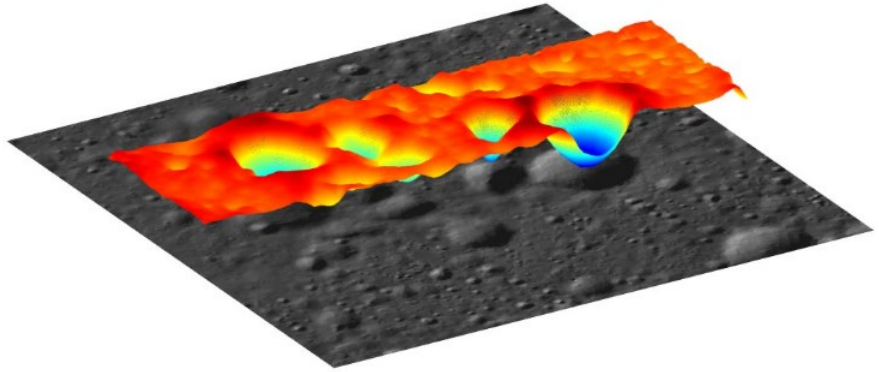
Digital Elevation Map (DEM) size	160 m x 110 m @ 1.3 km 45° slant range 125 m x 85 m @ 1.0 km 45° slant range
Number of DEM pixels	1.05M (1024 x 1024)
DEM and Hazard Map Update Rate	1 Hz with 35 msec latency
Minimum Detectable Hazard	25 cm radius
Elevation Noise	3 cm 1-σ

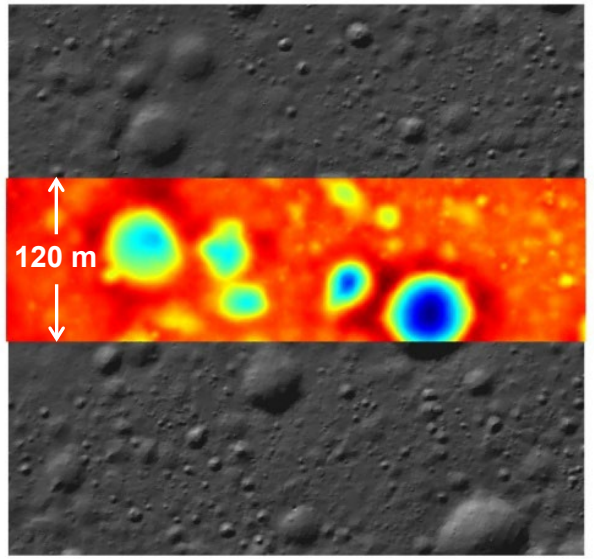


Projected Performance Specifications TRN

Operational Range	18 km – 5 km
Swath width	120 m (18 pixels) @ 10 km
Ground Sample Distance (GSD)	6.8 m @ 10 km
DEM update rate	1 Hz
Elevation Precision	20 cm @ 10 km
Position Resolution	Limited to Ref. Map GSD







Overlap of consecutive frames: 30% @ 20 km,
60% @ 10 km (assuming 1000 m/s horizontal velocity)

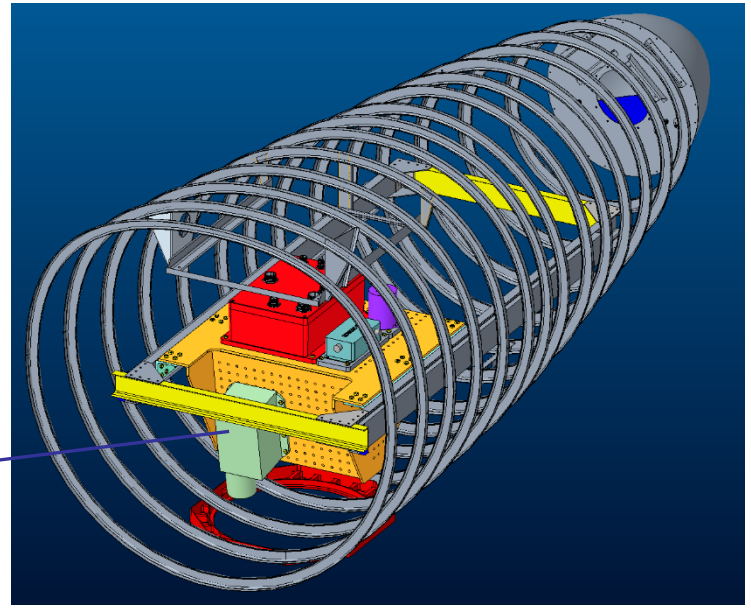
Projected Performance Specifications Altimetry

- Number of pixels = 9 @ 50 km
- Measurement precision scales with range to ground

Operational Range	50 km – 2 m
Precision	1m @ 50 km 0.3 m @ 10 km
Update rate	20 Hz

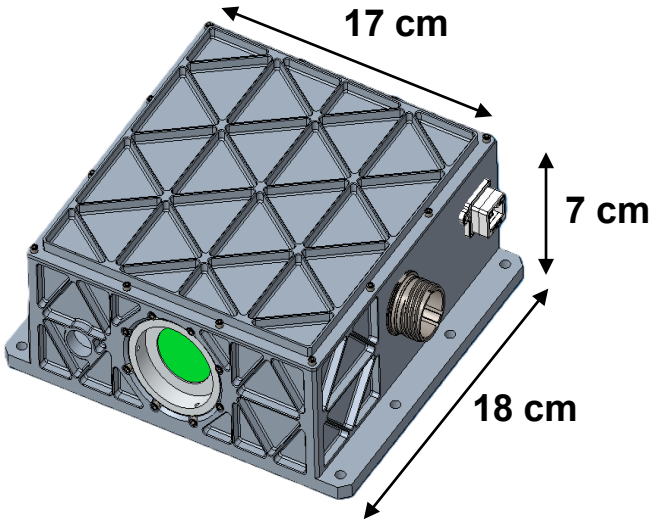
High-Altitude Aircraft Flight Test Planned for Summer 2026

- NASA AFRC's ER-2 aircraft
- Flight test is focused on altimetry and TRN performance characterization
- TSL will be powered on from ~ 700 m to ~21 km
  - Altimetry 700 m to 21 km
  - TRN 7 km to 18 km
  - HDA 700 m to 1200 m (limited operational characterization due to high horizontal speed)



Accurate Lunar Surveyor and Terrain-mapping Autonomous Rover (ALSTAR) Lidar

- **ALSTAR Lidar is a variant of TSL capable of providing**
  - **Obstacle identification and surface slope determination**
  - **Assistance with route planning**
  - **Relative velocity, position, and heading**
  - **Necessary data for mating with pressurized habitats**
  - **Situational awareness**
  - **Local area terrain maps for resource exploration and scientific purposes**



Summary

- Developed a linear-mode flash lidar utilizing real-time image enhancement algorithm for landing on planetary bodies
- Demonstrated HDA capabilities through drone and helicopter flight tests
- A compact prototype unit with multi-functional capability has been assembled for additional flight tests
- A high-altitude aircraft flight test is planned for demonstrating long-distance altimetry and TRN
- Pursuing opportunities for helicopter flight tests demonstrating HDA capability over its full operational range
- A variant of the TSL is being designed and analyzed for autonomous rovers

Backup

Major Attributes of Linear-Mode Flash Lidar

Attributes	Consequence
Pro: No mechanical scanner	• Increases reliability
Pro: Does not require vehicle motion correction	• Eliminates extensive processing power and time
Pro: Allows for multi-functional operation	• Extends operational range by reducing number of illuminated pixels
Pro: Generates organized 3-D pattern	• No need for oversampling of the landing site • Simplifies image processing algorithms and reduces processing time
Pro: Fast image acquisition time	• Can produce multiple elevation maps in a few seconds • Allows for video navigation
Con: Limited number of detector pixels	• Low resolution or small imaged area **Mitigation:** • Operate in hybrid configuration (scanning) • *Employ image enhancement algorithm*

TSL Generates Multiple High-Resolution DEMs

- DEMs and Hazard Maps are generated every 1 second with 30 msec latency
- Can cover up to 100 m x 400 m area and identify safe landing locations in 5 seconds