National Aeronautics and Space Administration

NDL

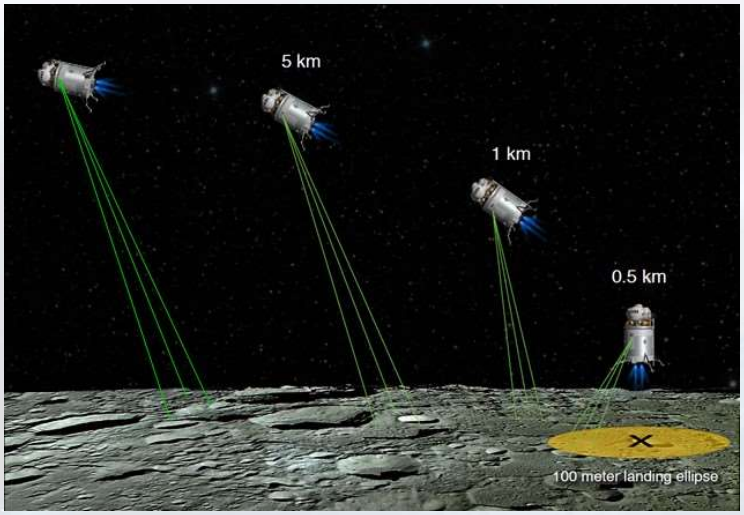
NAVIGATION DOPPLER LIDAR

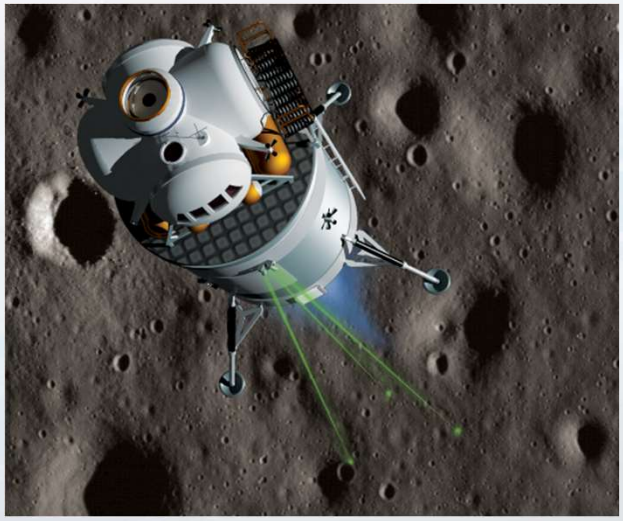
Flight Opportunities Community of Practice Webinar

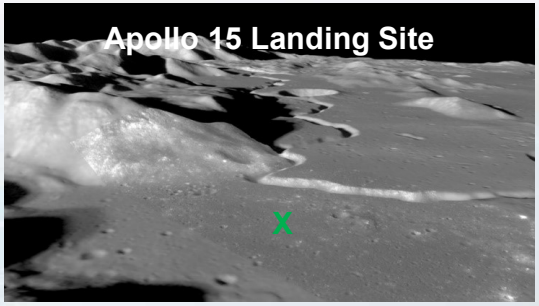
August 7, 2024

Navigation Doppler Lidar (NDL)

- **NDL provides vehicle precision vector velocity and altitude data**
- **Viable replacement for radars with over two orders of magnitude higher precision and much better data quality**
  - Enables "***precision navigation***" to the designated landing location
  - Enables "***well-controlled***" descent, landing, and ascent maneuvers to within a few cm/sec







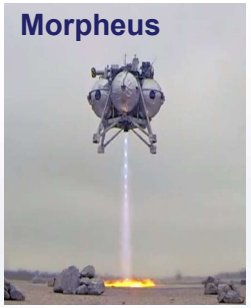
FOP played a key role in overcoming the valley of death

- **Masten flight verified TRL 5 and paved the path for the development of the ETU and CLPS missions**

2008

2010

2012

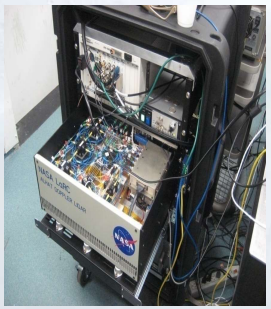


2014

2017

Proof-of-Concept → Breadboard → GEN 2 Breadboard → Prototype

~ 200 kg



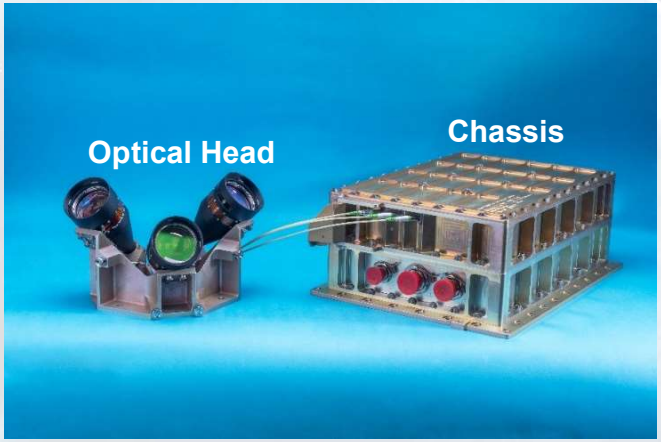
~ 60 kg

17 kg

10 kg

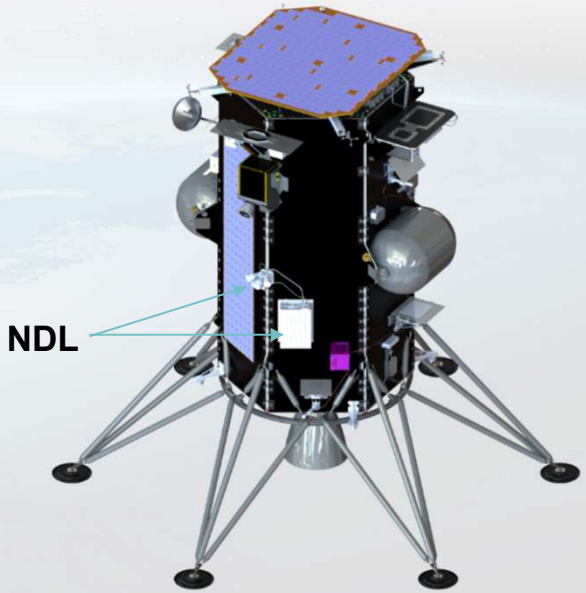
NDL CLPS Missions

- ***Astrobotic***: **NDL was the primary navigation sensor**
  - **Not a CLPS payload**
- ***Intuitive Machines***: **NDL was planned to be used as a secondary sensor for velocity**
  - **CLPS contract did not allow the use of NDL as a critical sensor**



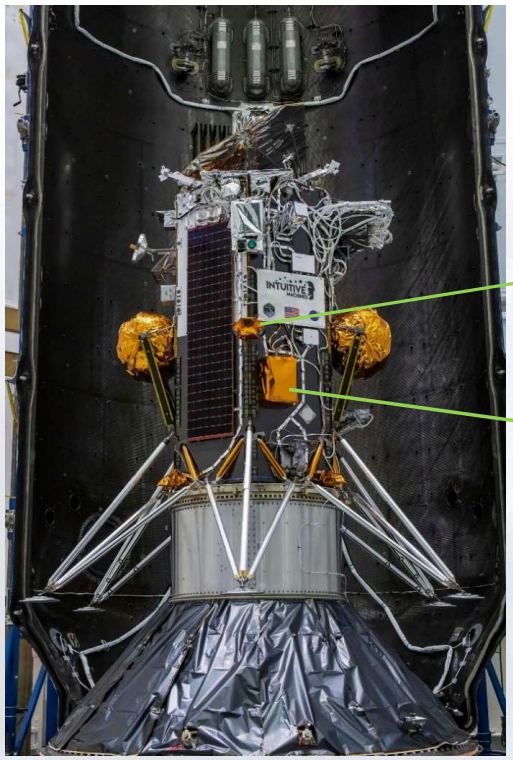
Astrobotic Peregrine Vehicle

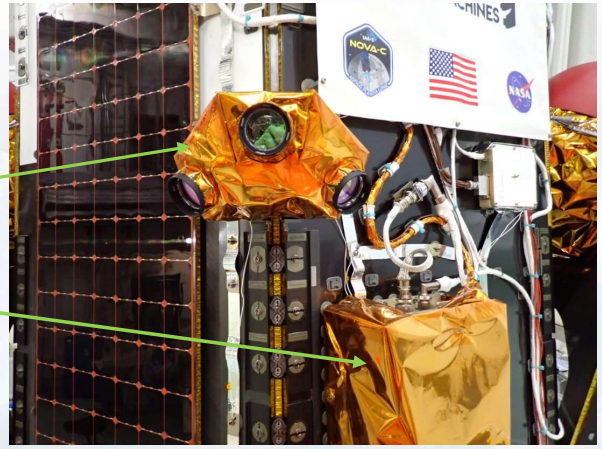
Intuitive Machines Nova-C Vehicle



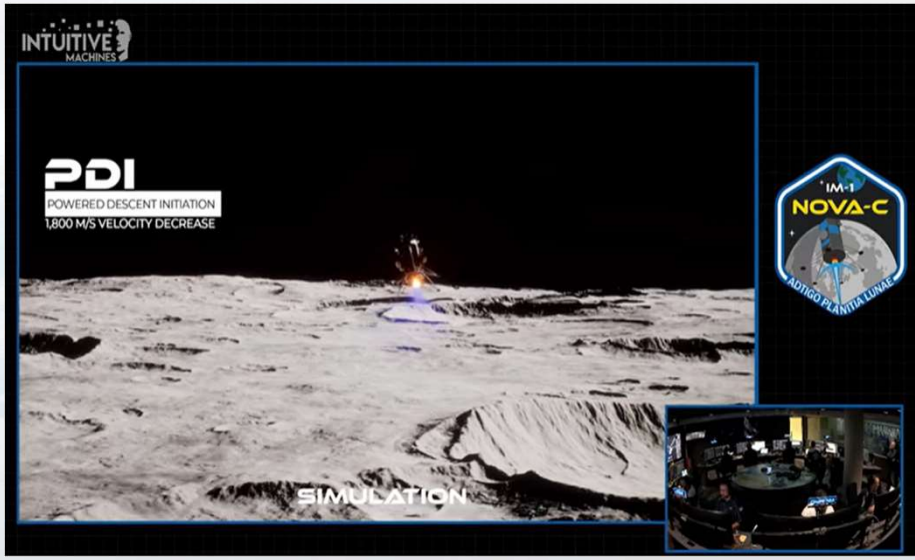
NDL on Intuitive Machines Odysseus Lander

NDL on Odysseus Lander



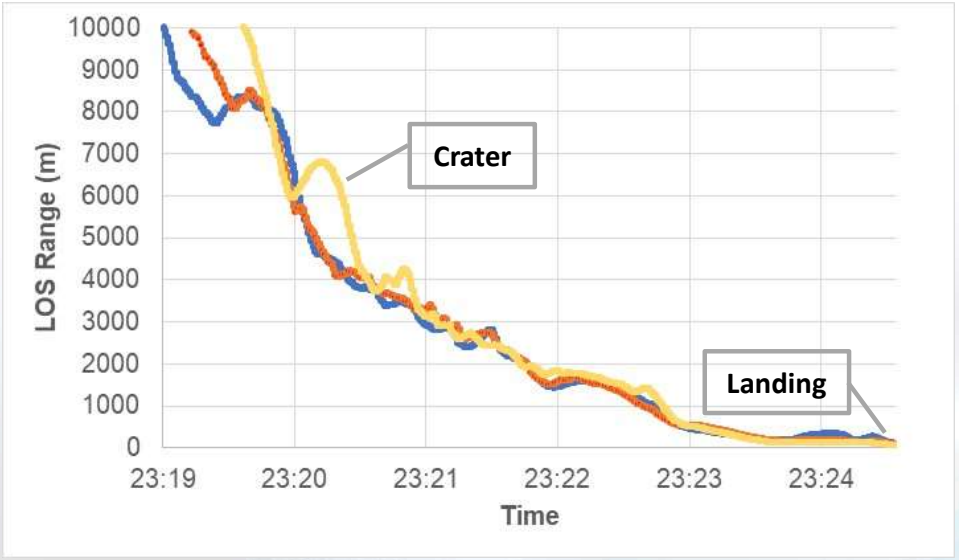


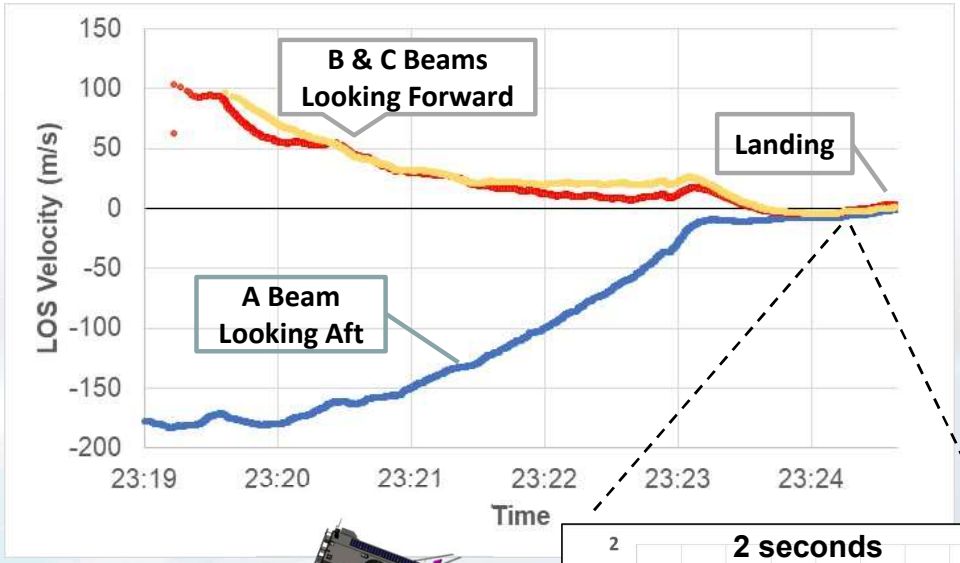
NDL was planned to be used as a secondary sensor for velocity data during descent from about 5 km altitude to ground

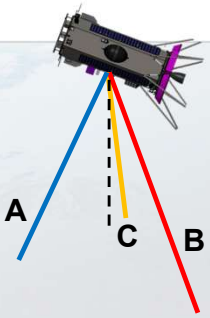


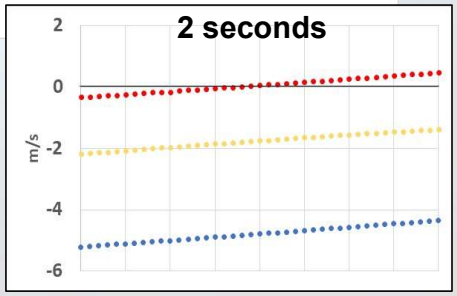
NDL Data from IM Lunar Mission

NDL provided 100% valid measurements from 10 km to surface

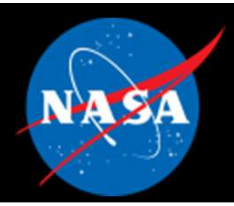








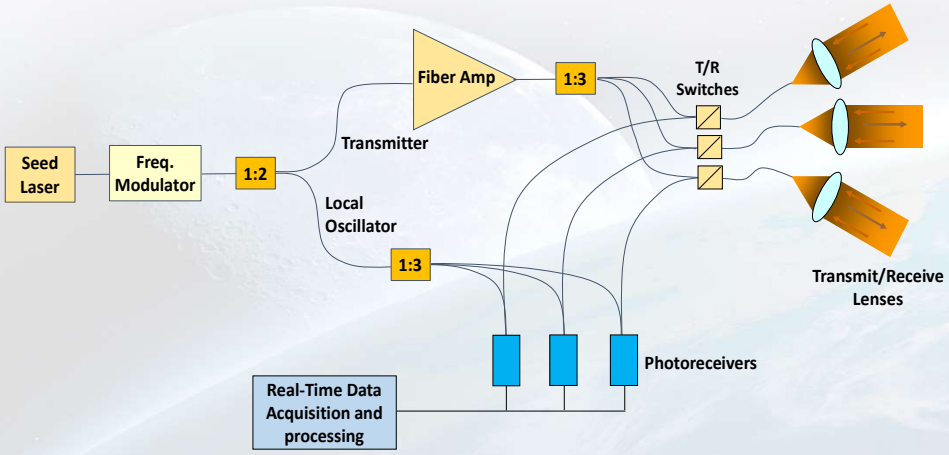
- **Measurements precision is over 2 orders of magnitude better than Mars Lander Radar (1 cm/s velocity, 80 cm range)**

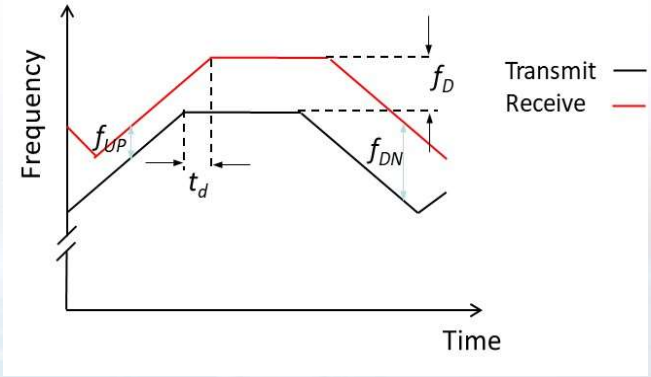


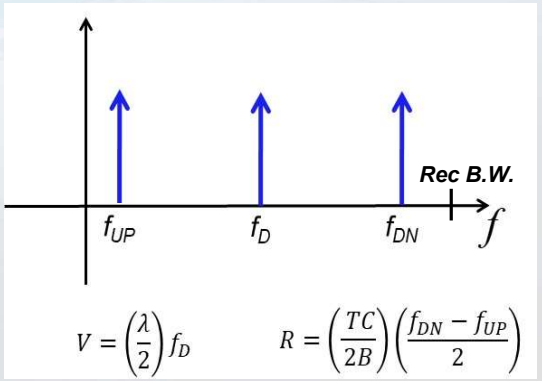
Backup

Navigation Doppler Lidar (NDL)

- **Utilizes FMCW technique to measure velocity and range along three laser beams**
- **Simultaneous line-of-sight measurements are used to estimate:**
  - **Vector Velocity (V)**
  - **Altitude relative to local ground (No external data required)**







Spaceflight Engineering Test Units (ETUs)

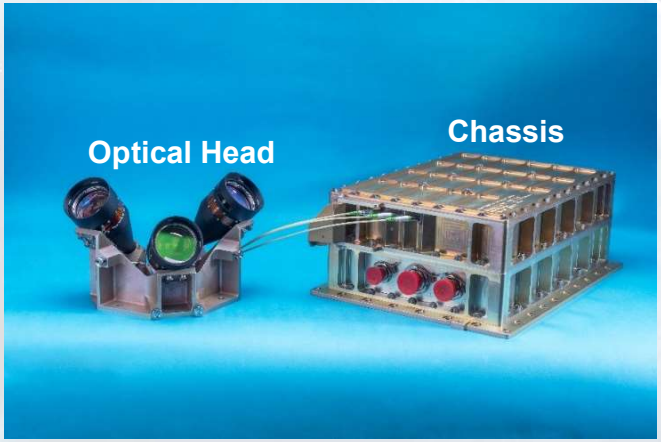
4 ETUs have been built and tested

 # 1 – Aircraft flight tests and integrated tests with other avionics

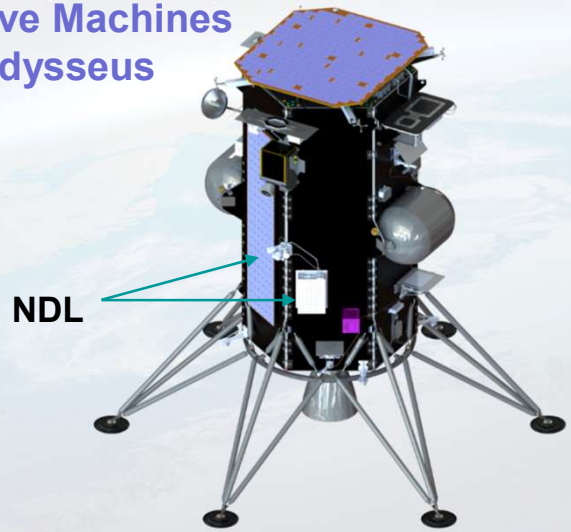
 # 2 – Suborbital flight test on Blue Origin New Shepard vehicle (2020 and 2021)

 # 3 – Lunar Landing Demonstration onboard Intuitive Machines lander (2024)

 # 4 – Lunar Landing Demonstration onboard Astrobotic lander (2024)

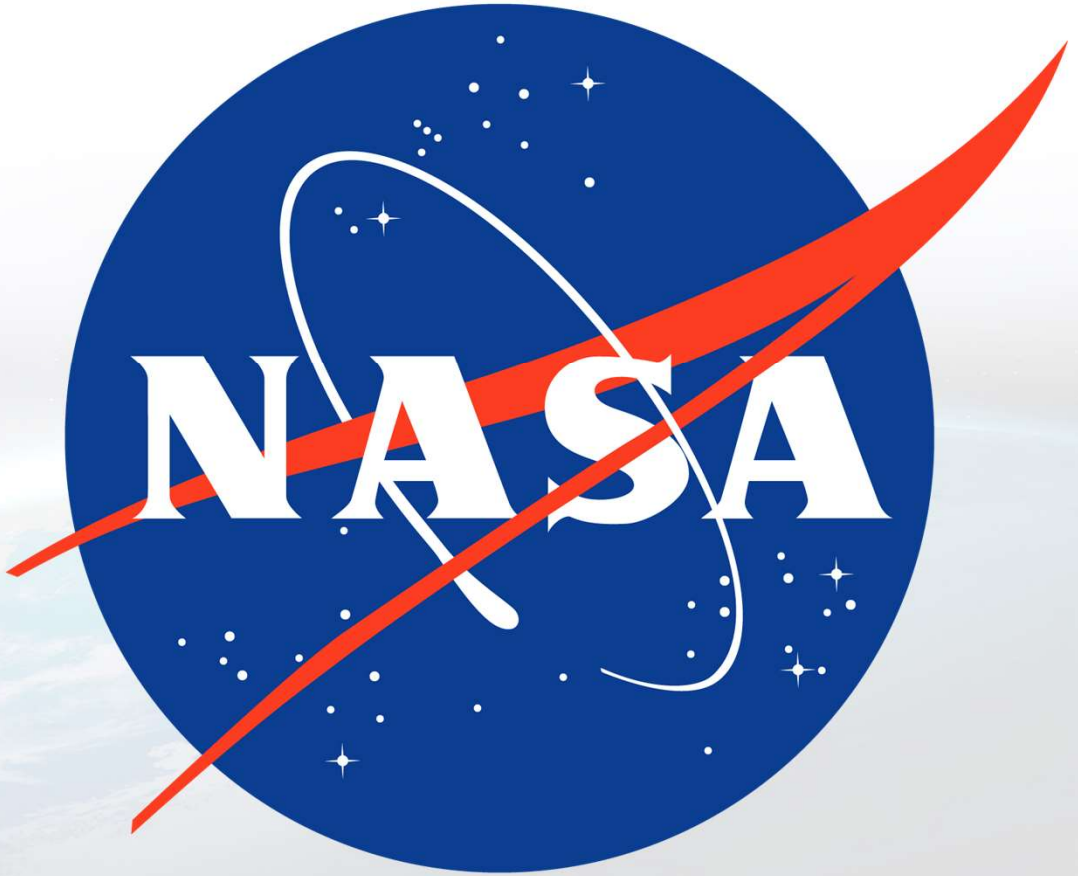


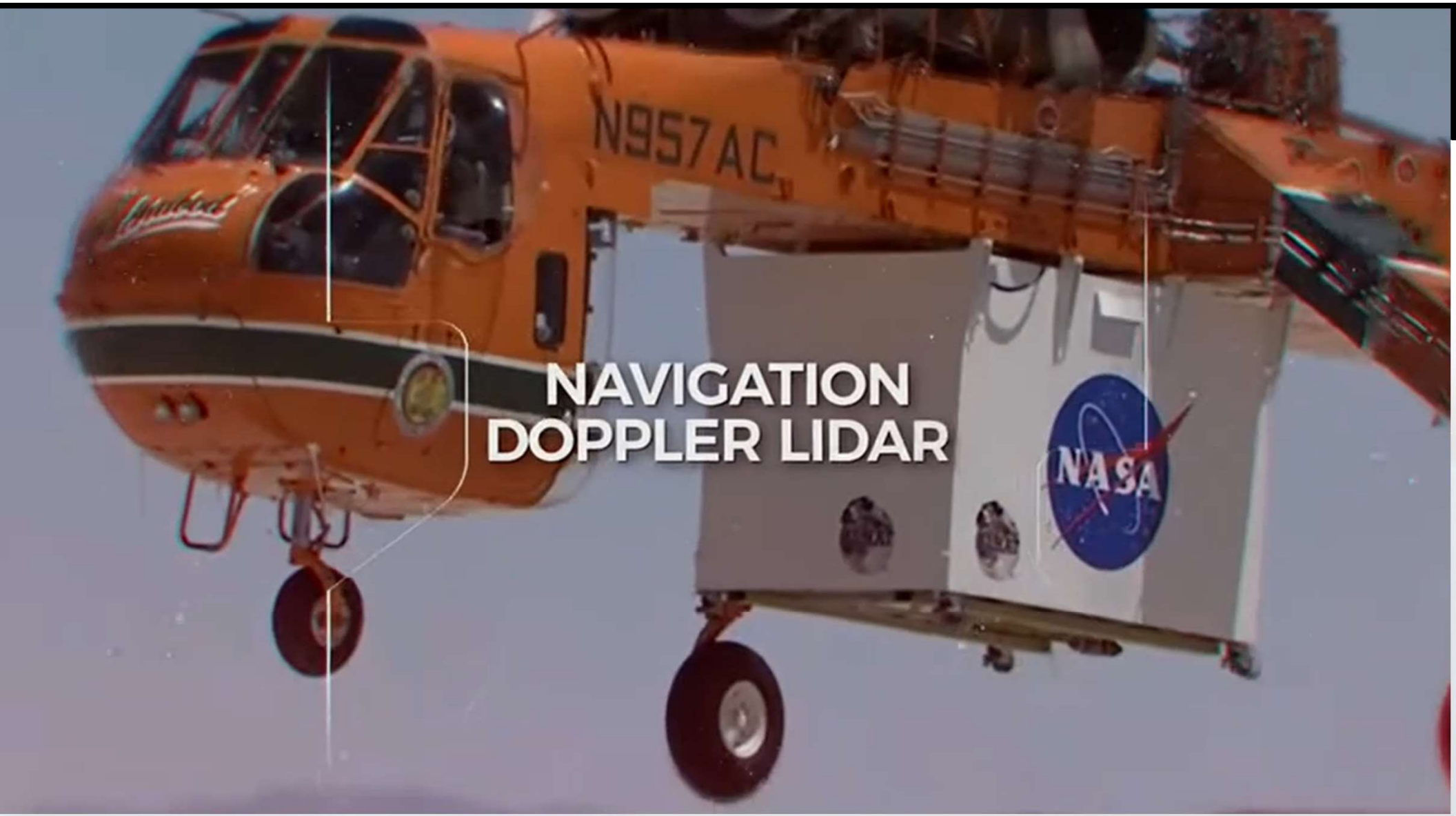
Intuitive Machines
Odysseus



Astrobotic
Peregrine

Test Campaign Video




N957AC
NAVIGATION
DOPPLER LIDAR
NASA


0
25
50
75
100
125
150
175
200
225
250

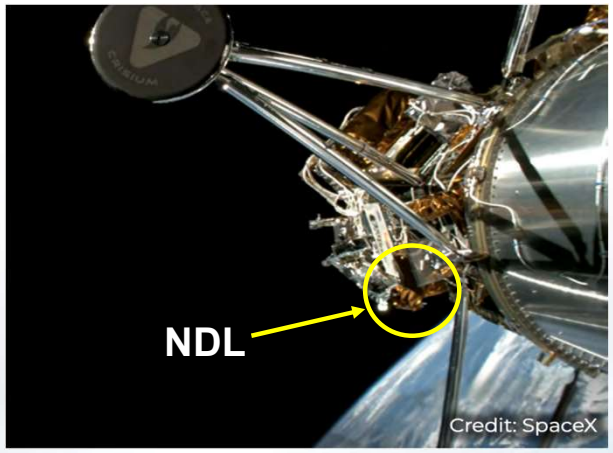
Astrobotic Mission

- Launched on Vulcan rocket on January 8, 2024
- Experienced an anomaly with propulsion system about 7 hours after launch and could not complete its mission
- Spacecraft operated 10 days and 13 hours in space before returning to Earth
- NDL operated nominally for 6.5 hours

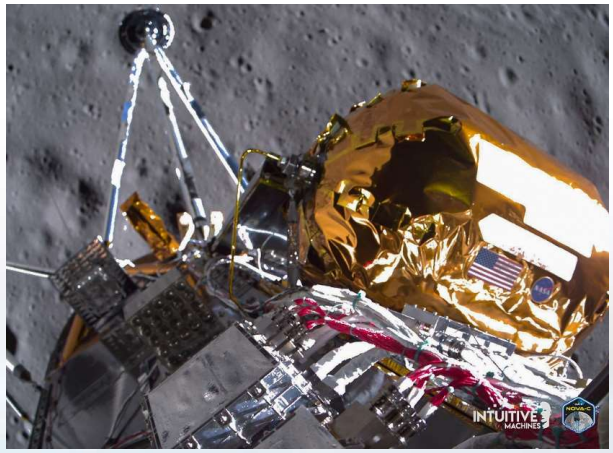
Intuitive Machines (IM) Mission

- **NDL operated flawlessly for 1.6 hour during checkout and 1.5 hour during deorbit/descent/landing**
- **Remained in operational mode on the ground for another ~ 4 hours**

Transit Checkout on Feb 19



Landing on Feb 22



IM Attempted Use of NDL During Lunar Descent

- **NDL was planned as a secondary sensor for velocity data during descent**
- **IM found out hours before landing that their laser range finders couldn't be turned on due to a manual safety switch**
- **IM asked NASA and the project for permission to use NDL as their primary sensor for range data**
- **IM performed an extra orbit to buy 1.5 hours to prepare and upload a software update to ingest NDL range measurements**

9:26 p.m. ET, February 22, 2024

This is the NASA instrument that saved Odysseus' mission

From CNN's Jackie Wattles

NASA's Navigation Doppler Lidar.

NDL Operation During Lunar Descent

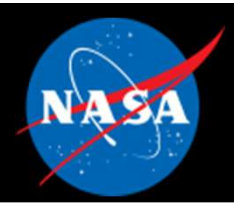
- **IM realized that the NDL data was not used after analyzing the GNC telemetry data**
- **There were errors in the last-minute SW update**
  - **GNC was still getting status flags from laser rangefinders**
  - **Neither range nor velocity data were used**
- **Intuitive Machines landed using data from their IMU and cameras, however they did not land upright and were short of their original target by ~ 2.5 km**

STEVE ALTEMUS, IM CEO, comments on NDL:

As it turns out though, as we worked all day to write that software, to solve the problem with the NASA Doppler LiDAR, as we went into power descent, **we did not receive those NDL measurements**. And so we landed without the laser altimeters in the end. But we had done some work, you know, to get us there. **And we looked at NASA's Doppler LiDAR telemetry, and boy, did it track perfectly so it would have really put us down softly if we could have read those measurements.**

https://mastersofscale.com/landing-on-the-moon/

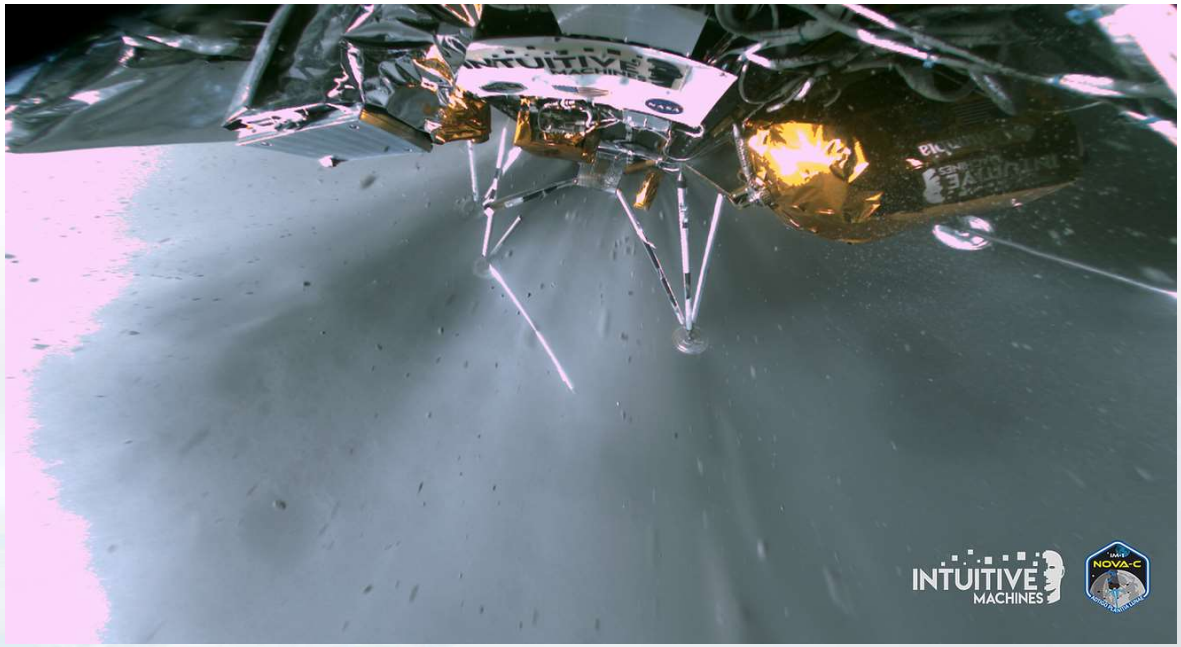
Projected Performance vs. Actual



Parameter	Projected Performance	Flight Results
Maximum LOS Range	6.0 km	10.0 km
Maximum LOS Velocity	+/- 218 m/s	+/- 218 m/s
LOS Velocity Noise @ 3 km	8.3 cm/sec	0.4 cm/s
LOS Range Noise @ 3 km	8.2 m	0.4 m
Data Rate	20 Hz	20 Hz

- **Odysseus lunar landing was an excellent demonstration of the NDL for future landing missions**

Odysseus Landing



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~ 200 kg

Proof-of-Concept

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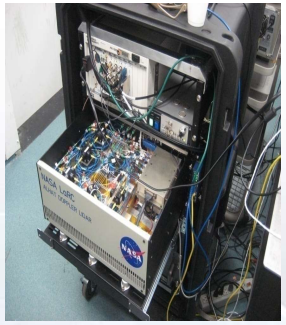

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Breadboard

2010

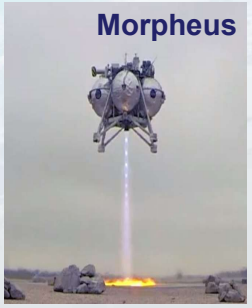
17 kg

GEN 2 Breadboard

2012

2014

Morpheus



Prototype

10 kg

FOP - Masten Flight Test
2017