Analysis of Navigation Doppler Lidar Performance for Moon and Mars landing

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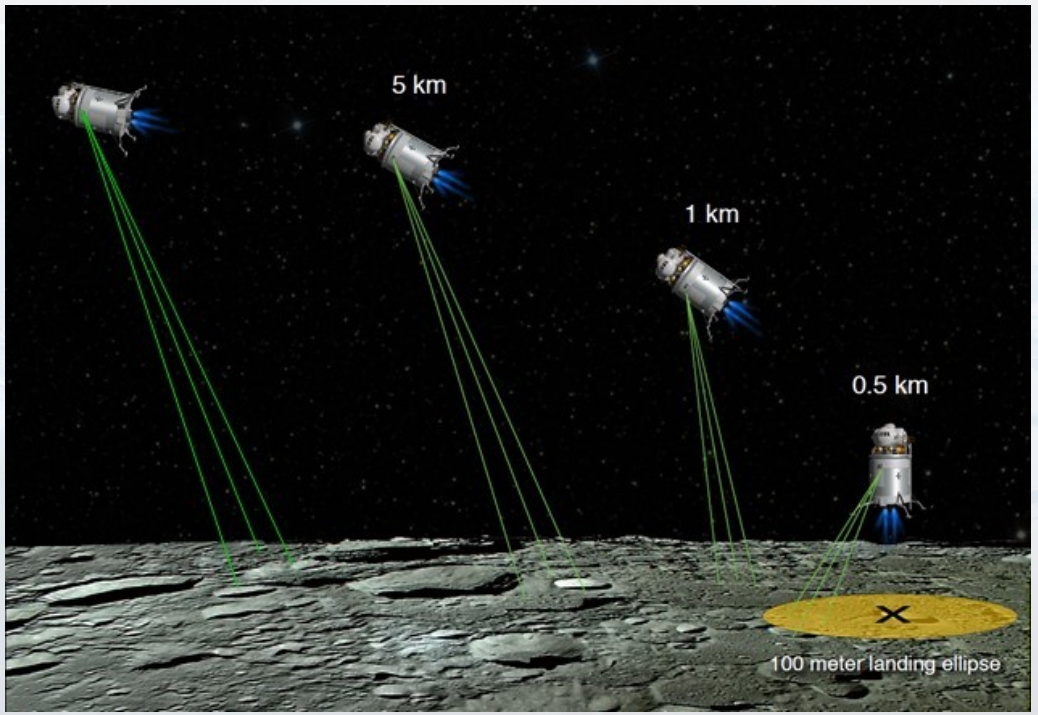
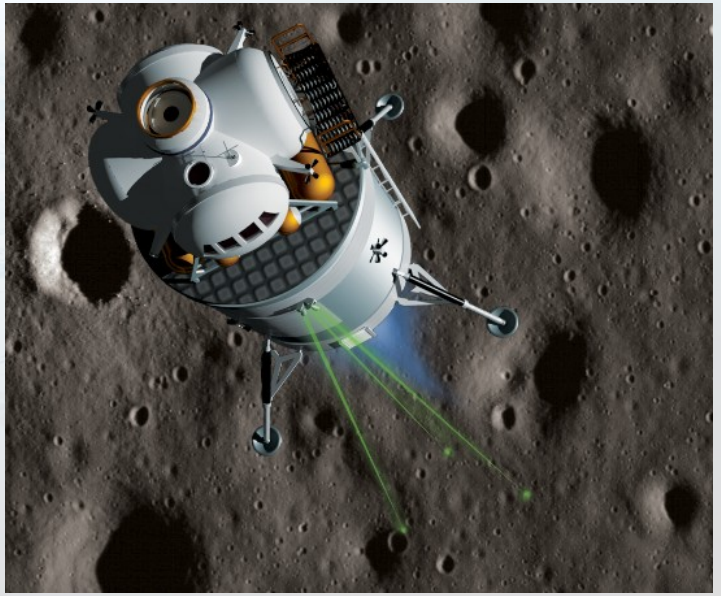
Navigation Doppler Lidar (NDL)

- **NDL is a laser sensor capable of providing precision vector velocity and altitude data**
- **Viable replacement for radars with an order 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

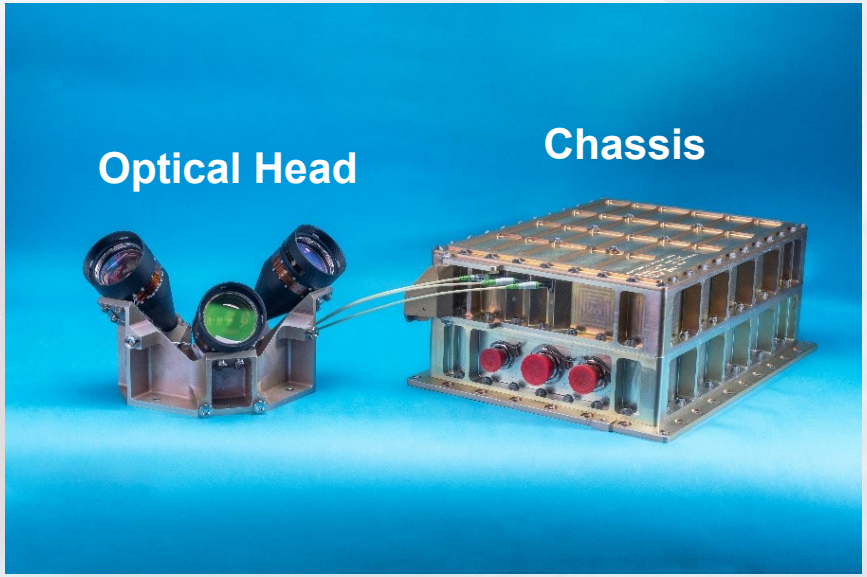




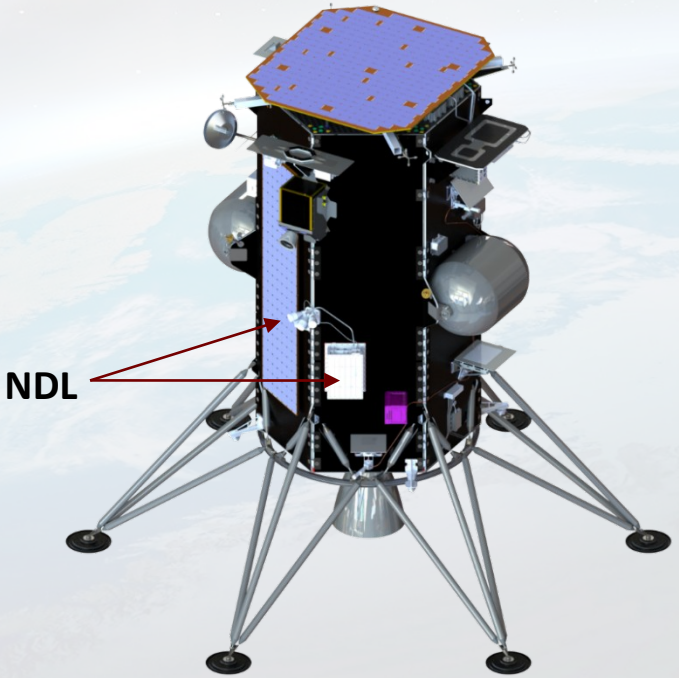
Spaceflight Engineering Test Units (ETUs)

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 (2021)
- # 3 – Lunar Landing Demonstration onboard Intuitive Machines lander (2022)
- # 4 – Lunar Landing Demonstration onboard Astrobotic lander (2022)



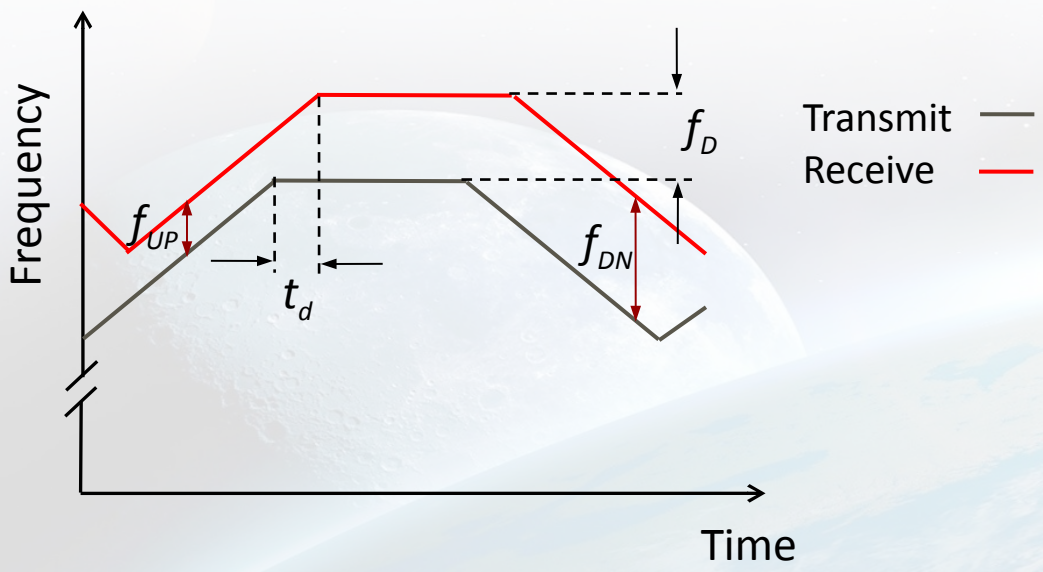
Intuitive Machines
Nova-C Vehicle

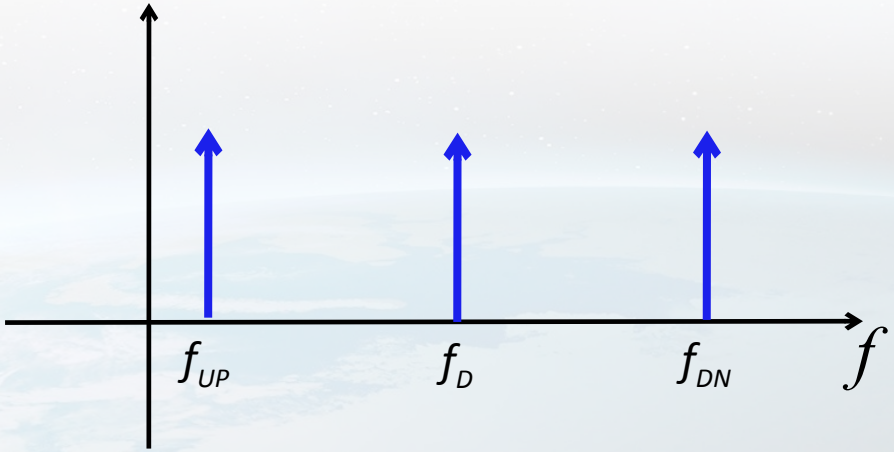


Astrobotic
Peregrine Vehicle

NDL Principal of Operation

- ***NDL utilizes Frequency Modulated, Continuous Wave (FMCW) Technique***
  - *3 segmented frequency waveform*
- **Velocity and range are extracted from signal frequencies associated with each segment of the waveform**





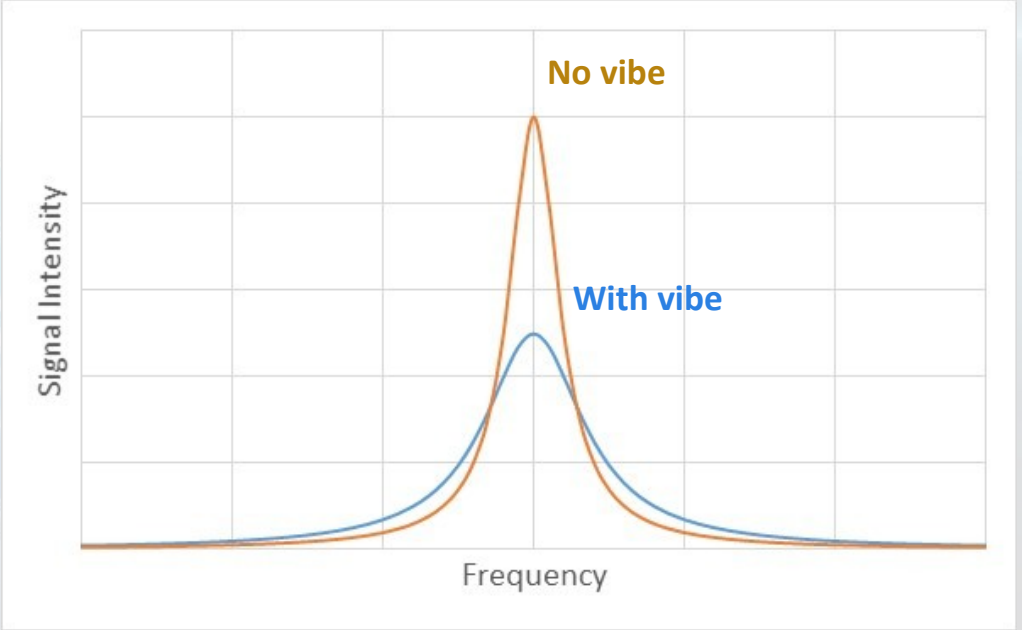
$$V = \left(\frac{\lambda}{2}\right) f_D$$

$$R = \left(\frac{TC}{2B}\right)\left(\frac{f_{DN} - f_{UP}}{2}\right)$$

ETU performance is dominated by vehicle vibration

- **Vibration broadens laser linewidth which in turn broadens the signal frequency spectra and lowers its peak intensity**
  - Reduces maximum operational range
  - Increases measurement noise
- **Signal frequency broadening is proportional to vibration load and increases with range**

Signal spectra broadening with vibration

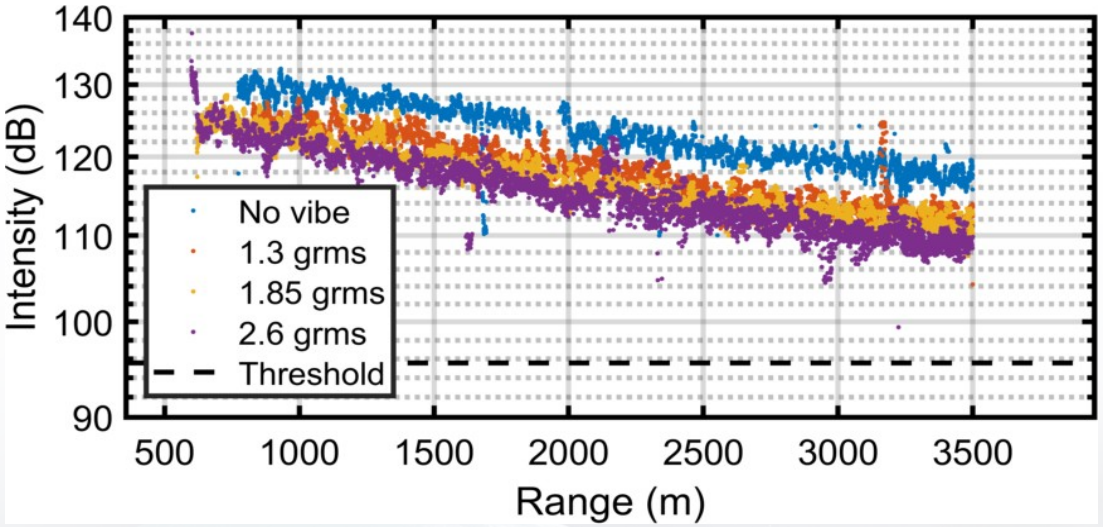


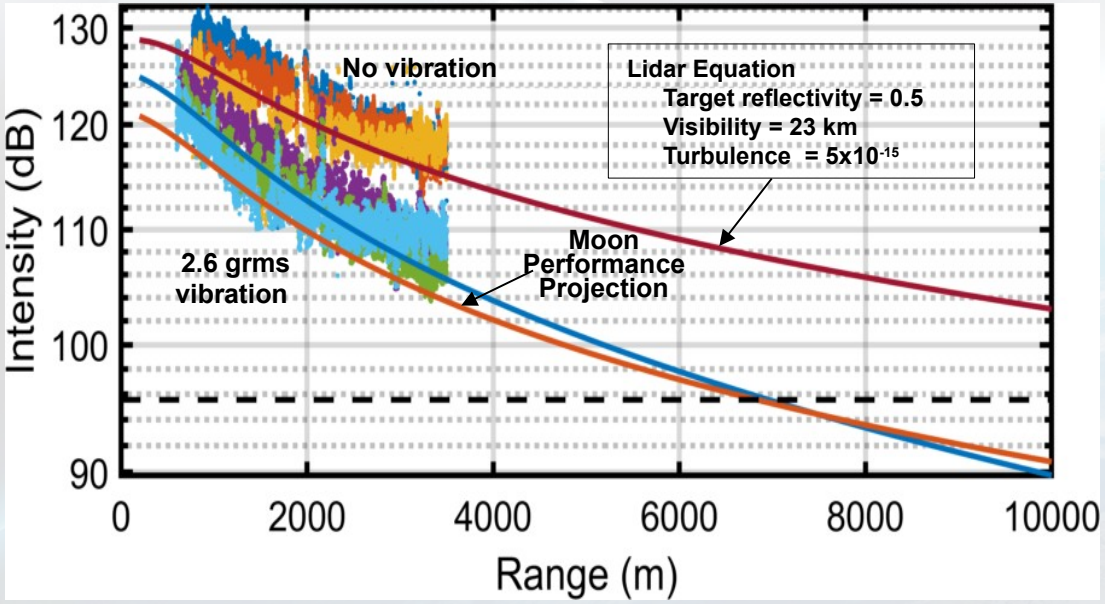
Comprehensive Functional Test

- **Measured signal strength and spectral broadening at different vibration loads versus range**

Truck test at Joint Base Langley-Eustis

Maximum Operational Range





- **Maximum operational range in Moon environment is extrapolated from measured data**
  - Remove atmospheric effects
  - Correct for lunar surface albedo

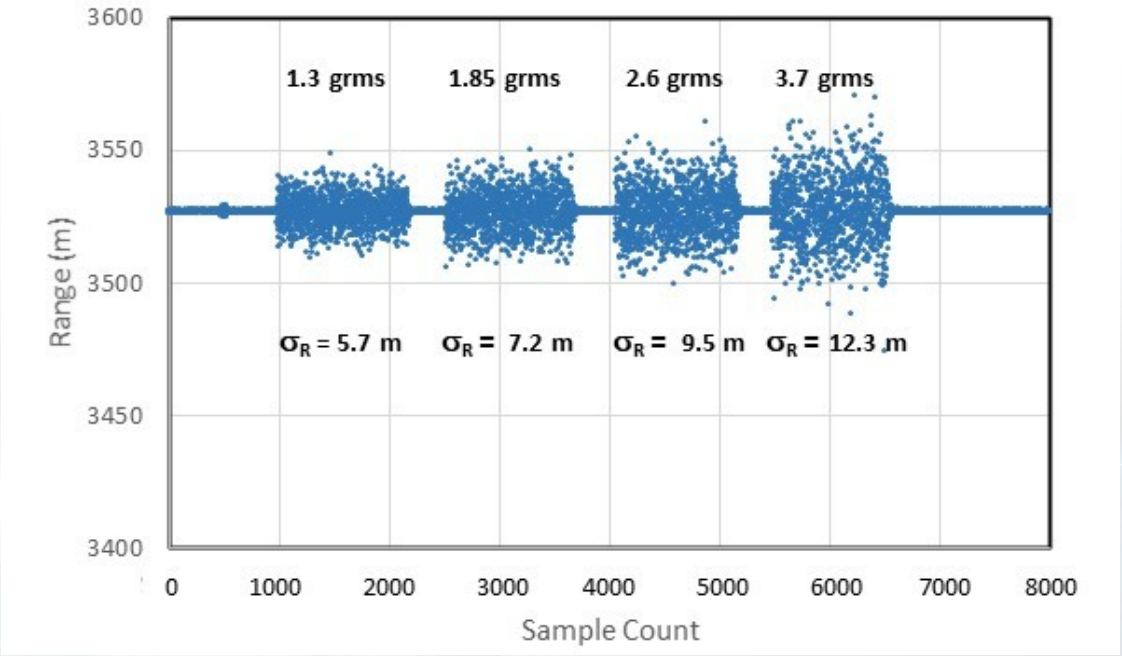
Measurements Precision

- **Estimated ETU range and velocity precision in 2.6 grms vibration environment:**

m

m/s

LOS Range	Velocity Noise	Range Noise
1000 m	3.86 cm/s	3.80 m
5000 m	12.82 cm/s	12.64 m



Concluding Remarks

- **NDL can provide critical vehicle velocity and altitude data for precision soft landing on the Moon, Mars, and other destinations**
- **Completed 4 ETUs of NDL for lunar landing demonstration and other tests**
- **Conducted a series of tests and analyses to estimate the NDL performance for Moon and Mars landing**
- **Performance of NDL ETU is dominated by the vehicle vibration**
  - Vehicle vibration impacts maximum operational range and measurements precision
  - Velocity and range errors may increase from 2 mm/s and 13 cm by more than an order of magnitude