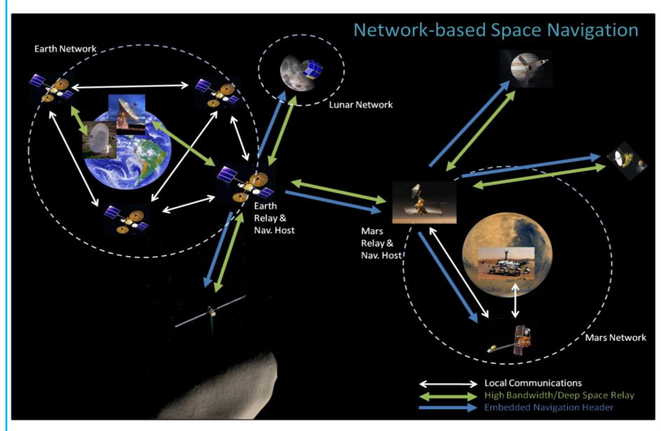
Lunar Node 1: Flight Experience and Next Steps

Evan Anzalone (PI), MSFC/EV42, evan.j.anzalone@nasa.gov
Tamara Statham (Co-I), Anthony Guillory (PM), Garrick Merrill (LSE),
Jacob Jensen, Thomas Brooks, Jarret Bone, Patrick Campbell, Sarah Watkins, Brandyn Rowling, Geoff Lochmaier

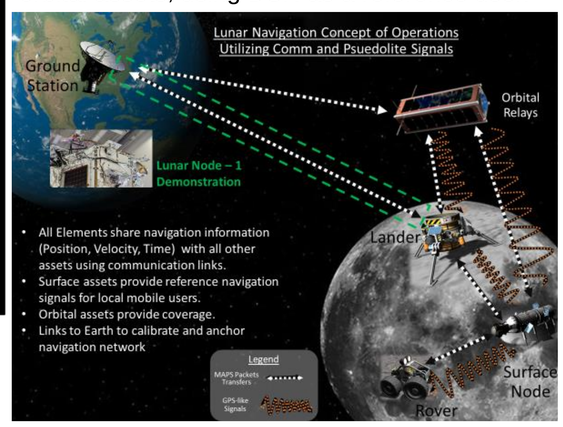
Overview of Lunar Node – 1 Payload

LN-1 is a navigation beacon demonstration payload proving out concepts for comm-based navigation using time-transfer mechanisms to measure packet time of flight between vehicles, included with a broadcast of vehicle position and velocity. LN-1 was delivered to IM in April 2021.

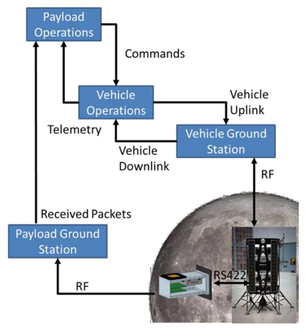


Multi-spacecraft Autonomous Positioning System: network of assets broadcasting position, velocity, time and uncertainty; enabling navigation through time-of-flight measurements.

LN-1: Focuses on near-time Lunar use cases, focusing on navigation between surface and orbital assets, using DSN as a reference user.

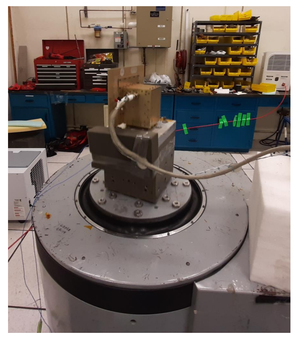


Ground Testing and Installation

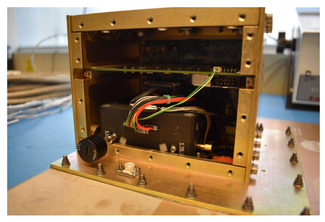


Vehicle Con-ops

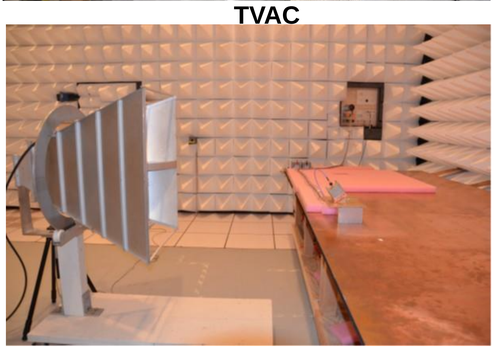
TVAC



Vibration



Interior of Payload



EMI

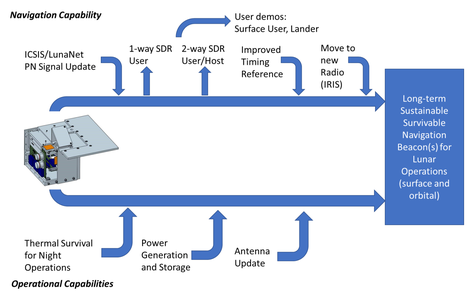
Installed on NOVA-C

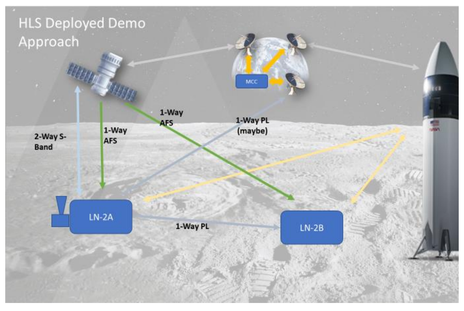
Next Steps

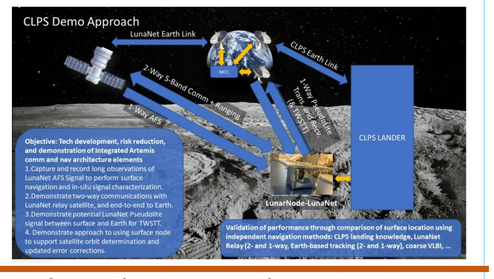
LN-1 is a first step towards deploying surface navigation aids to support a variety of users and functions: providing landers with a precise well-known reference to aid in precision navigation, providing a capability to monitor and observe other in-situ navigation signals, provide a radiometric signal that can be used to “direction find” to a known location, and providing a psuedolite signal to increase coverage of robustness of signals generated by orbital assets.

Multiple follow-on efforts are underway to continue to develop and mature the Lunar Node concept towards its next flight opportunity:

- Ongoing characterization with a flight spare and flight-like LN-1 radio to assess long-term stability as a function of temperature and clock reference (TCXO, OXCO, etc)
- Work within ES to develop a software-defined transmitter and receiver of the proposed LunaNet Augmented Forward Signal, which will be the basis of Lunar in-situ PNT being deployed by NASA, ESA, and JAXA
- Procurement of a flight EDU with an AFS receiver implementation to form the basis of a LCRNS monitor station to provide an early demo and verification of LCRNS PNT capability from the lunar surface
- Procurement of additional hardware (such as power management system, additional control board components, high stability oscillators) to provide ground demonstrations and characterizations of a future Lunar Node element
- Demonstration and usage of LN-1 beacon capability (one- and two-way in field demonstrations, using Lunar Harpoons with SDR implementation)







CONCLUSION

LN-1 collected limited observations of the payload from the lunar surface. The team continues to assess and process the flight data and perform orbit determination to compare between IM-1 solutions and the LN-1 solution. Due to the limited data, the team will rely on further ground testing to capture long-term stability of the payload using a ground receiver. Continued development is focused on upgrades of LN-1 to be a LunaNet-compatible navigation beacon via further hardware, software, and systems analysis.

Flight Experience – IM-1

Several challenges occurred during the mission surrounding initial attitude sensor operation, operation of liquid LOX/CH4 engine beyond LEO with multiple restarts, orbit determination, and landing sensors. Despite these challenges, the IM-1 team was able to direct the vehicle to the moon and land on the South Pole. LN-1 operations were limited during cruise by to challenges with vehicle pointing, and from the surface by uncertain vehicle power levels due to the as-landed orientation. Regardless, LN-1 was able to execute all functional modes, albeit over shorter durations (mins vs days). LN-1 also provided IM with an interface (both for data and scheduling) to DSN ground networks and enabled rapid turn-on of additional navigation and communication capability to enable precision navigation of the IM-1 vehicle.

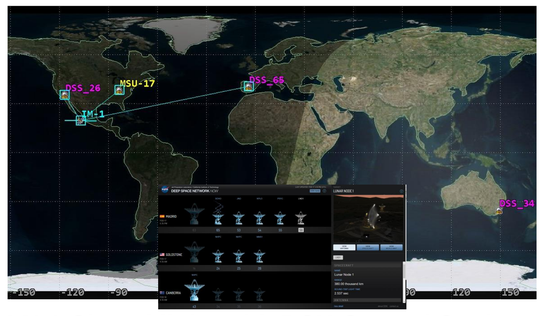
Data Summary:

- > 200 MB of Tracking Data (one-way Doppler of IM-1 and LN-1, two-way Doppler of IM-1, 2 passes with three-way Doppler Tracking) across entire mission (cruise/surface)
- ~4.5 hours of MAPS packets transmission from LN-1 to DSN across 4 cruise passes (>40K one-way MAPS packets)
- 15 minutes of MAPS packet transmission from Lunar Surface
- 15 minutes of one-way PN Ranging from Lunar Surface
- Multiple raw RF recordings of LN-1 transmissions by DSN to assess multipath and data processing

Views from IM-1 During the Mission

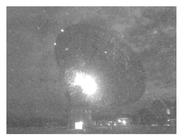
IM-1 Near Earth (L), Leaving Earth (M), in Lunar Orbit (R)

Ground Station Support



LN-1 Closed links with DSN Ground Stations in Goldstone, Canberra, and Madrid, with Morehead State University also recording raw data/ Goonhilly and Parkes additionally supported downlink from surface.

Goonhilly Satellite Earth Station

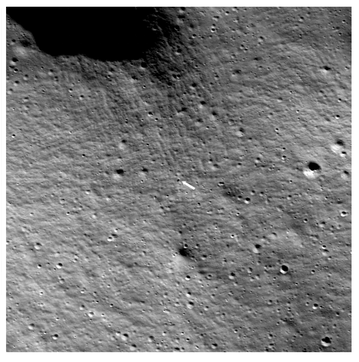


Parkes Observatory

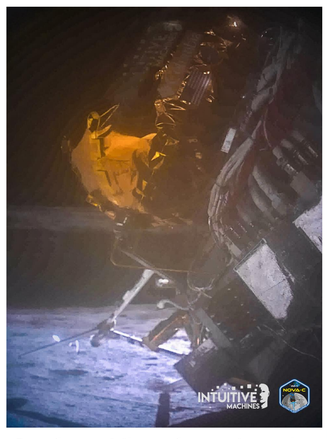
LN-1 Team After First Ground Pass with DSN During Cruise

Landing Site Insights

Simulated View of Planned Landing Site



Landing Site LROCNAC frame M1463440322L
NASA/Goddard/Arizona State University



Surface View from Lander
(Intuitive Machines)

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- Integration with Intuitive Machines led by the CLPS Project Scientist Office by Susan Lederer, Frank Moreno, and John Gruener.
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- Operations conducted out of the HOSC in the LUCA lab with primary support from Sarah Watkins, Brandyn Rolling, and Geoff Lochmaier. Our appreciation is due to all of the staff who keep the HOSC and operational flight networks running.
- LN-1 was designed, built, assembled, and tested by NASA/MSFC. The flight would not have been possible without the incredible support of the electrical, mechanical, and assembly shops as well as the on-site testing capabilities (EMI, Vibe, TVAC).=
- The team is grateful to all of those who have supported LN-1 and previous SNS and MAPS efforts that laid the groundwork for this mission, including management and prior partners and collaborators.