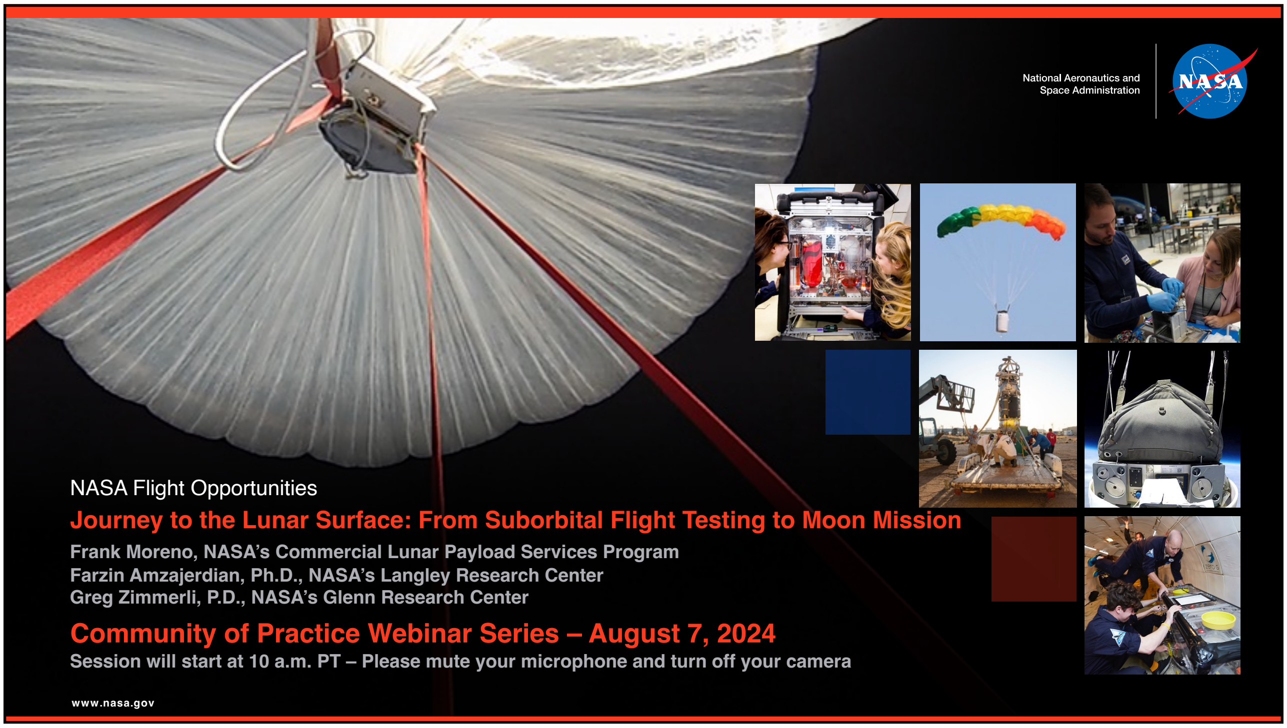

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Welcome to the Community of Practice Webinar Series!

First, a bit of housekeeping…

- Please mute your microphone and turn off your camera
- Today's session will be recorded
- Recordings for this and all future sessions will be posted on the Flight Opportunities website
- Please engage!
  - Use the chat throughout the session to ask questions

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NASA FLIGHT OPPORTUNITIES

National Aeronautics and Space Administration

Welcome to the Community of Practice Webinar Series!

Flight Opportunities hopes these webinars will enable researchers, program staff, and flight providers to connect informally and share information

- Designed to distill and share the most important lessons learned to:
  - Increase the impact of suborbital flight tests
  - Transfer best practices
  - Optimize the experience of current and prospective program participants
- Part of a broad effort to capture, organize, and communicate lessons learned by suborbital researchers
- An opportunity to hear from subject matter experts on best practices for preparing for suborbital flight tests

3

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Future webinars

- Webinars are held 1st Wednesday of each month at 10 a.m. PT
- Topics will be announced in the Flight Opportunities newsletter and website
- Session recordings will be posted on the Flight Opportunities website
- Let us know session topics you would like to see covered

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4

NASA FLIGHT OPPORTUNITIES

National Aeronautics and Space Administration

Today's Speakers

Frank Moreno
Commercial Lunar Payload Services (CLPS) Integration Manager
NASA's CLPS Program

Farzin Amzajerdian, Ph.D.
Senior Scientist
NASA's Langley Research Center
Navigation Doppler Lidar (NDL)

Greg Zimmerli, Ph.D.
Research Aerospace Engineer
NASA's Glenn Research Center
Radio Frequency Mass Gauge (RFMG)

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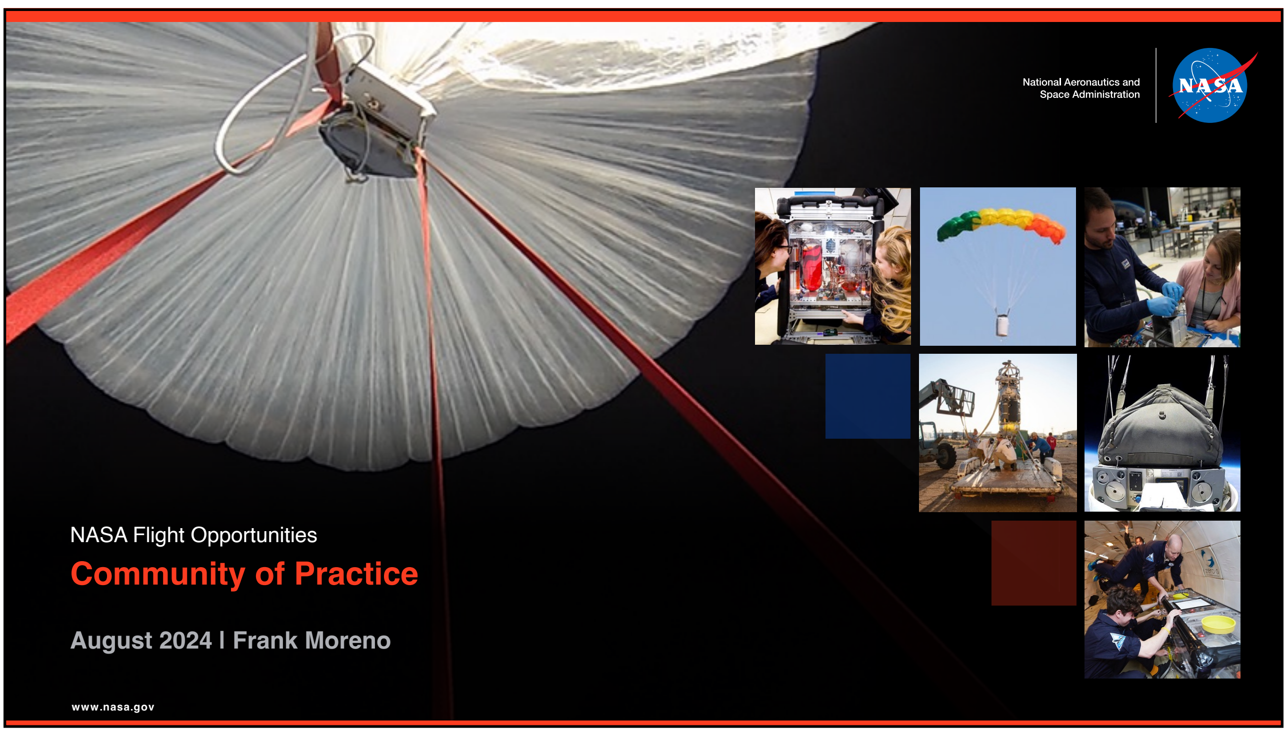

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National Aeronautics and Space Administration
EXPLORE SCIENCE
Commercial Lunar Payload Services (CLPS)
Francisco Moreno
CLPS Integration Manager
NASA Johnson Space Center
August 7, 2024
7

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Agenda
1. NASA Agency Priorities
2. CLPS Overview
3. CLPS Vendor Pool
4. CLPS Organization
5. CLPS Focal Points-of Contact
6. CLPS Lunar Delivery Timeline
7. CLPS Active Task Order Landing Sites
8

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NASA Agency Priorities
To achieve a sustainable presence on the moon through innovative public-private partnerships with U.S. commercial companies and international partners.
9

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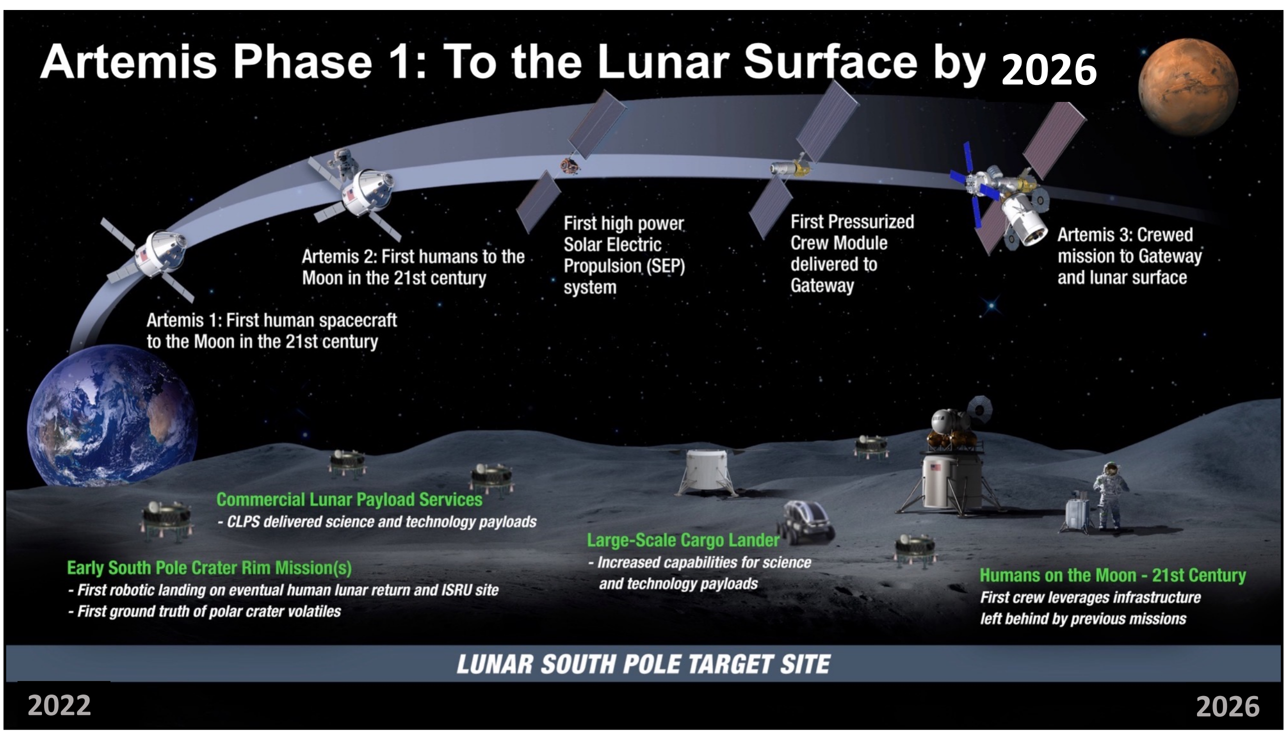
Artemis Phase 1: To the Lunar Surface by 2026
Artemis 1: First human spacecraft to the Moon in the 21st century
Artemis 2: First humans to the Moon in the 21st century
First high power Solar Electric Propulsion (SEP) system
First Pressurized Crew Module delivered to Gateway
Artemis 3: Crewed mission to Gateway and lunar surface
Commercial Lunar Payload Services
- CLPS delivered science and technology payloads
Early South Pole Crater Rim Mission(s)
- First robotic landing on eventual human lunar return and ISRU site
- First ground truth of polar crater volatiles
Large-Scale Cargo Lander
- Increased capabilities for science and technology payloads
Humans on the Moon - 21st Century
First crew leverages infrastructure left behind by previous missions
LUNAR SOUTH POLE TARGET SITE
2022
2026

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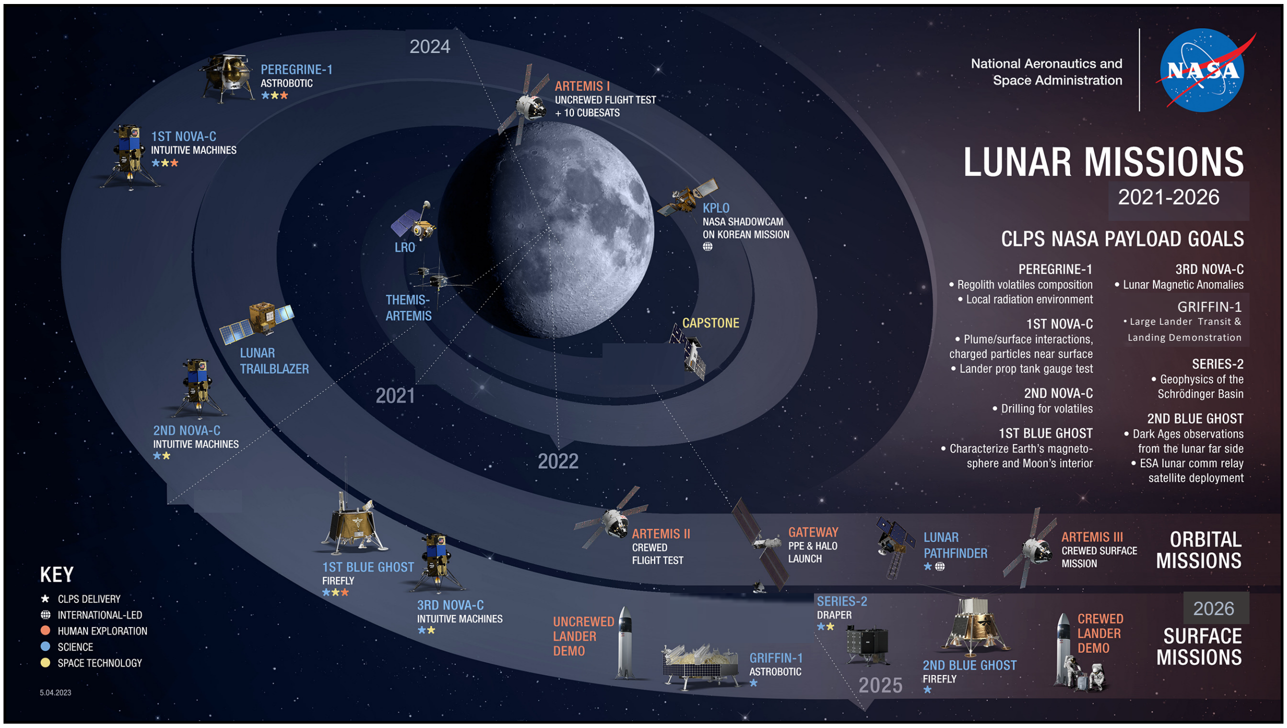

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Commercial Lunar Payload Services (CLPS) Overview

- CLPS is an innovative, service-based, competitive acquisition approach that enables rapid, affordable, and frequent access to the Lunar surface via a growing market of American commercial providers
- The CLPS contract was awarded to 14 domestic teams who are all eligible to bid for Task Orders
- Lunar Delivery Service Task Orders are firm fixed price (FFP) for the full scope of delivery: from payload hand-over to delivery (and often operation) on the lunar surface
- NASA wants to be one of many customers for CLPS services
- CLPS deliveries are CLPS Provider missions (not NASA missions) and approved/licensed by the Federal Aviation Administration (FAA) and other agencies
- CLPS Project Office is managed at JSC and includes:
  - Development of payload, science, and mission operation requirements
  - Procurement of payload delivery services, monitoring integration, performing risk assessments
  - Encouraging growth of the CLPS community

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CLPS IDIQ Contract and Portfolio

- 14 domestic companies eligible to compete for Lunar surface delivery task orders
- 9 awarded lunar surface deliveries actively in work with initial deliveries as soon as mid 2023.
- NASA expects to continue cadence of ~2 flights per year
- CLPS contractors are encouraged to sell lunar delivery services outside of the CLPS IDIQ to non-NASA and non-USG customers.

Initial CLPS companies (Nov 2018):

- *Astrobotic*
- *Deep Space Systems*
- *Draper*
- *Firefly Aerospace*
- *Intuitive Machines*
- *Lockheed Martin Space*
- *Masten Space Systems*
- *Moon Express*
- *Orbit Beyond*

First On-Ramp (Nov 2019):

- *Blue Origin*
- *Ceres Robotics*
- *Sierra Nevada Corporation*
- *SpaceX*
- *Tyvak Nano-Satellite Systems, Inc.*

Awarded Deliveries:

2024	2024	2024	2024	2024	2024	2025	2026
TO #2	*TO #2/#20C*	*TO #PRIME-1*	*TO #19D*	*TO #CP-11*	*TO #20A*	*TO #CP-12*	*TO #CS3*
Astrobotic	*Intuitive Machines*	*Intuitive Machines*	*Firefly Aerospace*	*Intuitive Machines*	*Astrobotic*	*Draper*	*Firefly Aerospace*
Peregrine	*NOVA-C*	*NOVA-C*	*Blue Ghost*	*NOVA-C*	*Griffin*	*Series-2*	*Blue Ghost*

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ESSIO

Commercial Lunar Payload Services (CLPS)

- Competition for CLPS Task Orders is open to U.S. commercial Contractors of space transportation services, consistent with National Space Transportation Policy and Commercial Space Act
  - CLPS releases a Request for Task Plan (RFTP) to solicit CLPS Contractor proposals to provide lunar delivery services for NASA-sponsored payloads
- Structured so that NASA is one of many customers of commercial lunar delivery service
- CLPS Contractors are responsible for:
  - Accommodation of payload interface, operation, and environments requirements
  - Safe integration, delivery, deployment and/or operation of payloads including command and telemetry communication
  - Launch vehicles, lunar lander spacecraft, lunar surface systems, earth re-entry vehicles, and associated resources as needed to fulfill each Task Order

CLPS Do No Harm Philosophy

The Contractor shall ensure that the Lander and other co-manifested payloads cannot interfere with, or harm, the NASA-sponsored payloads (e.g., physical , Wi-Fi, EMI/EMC, off gassing, or other operational interferences).

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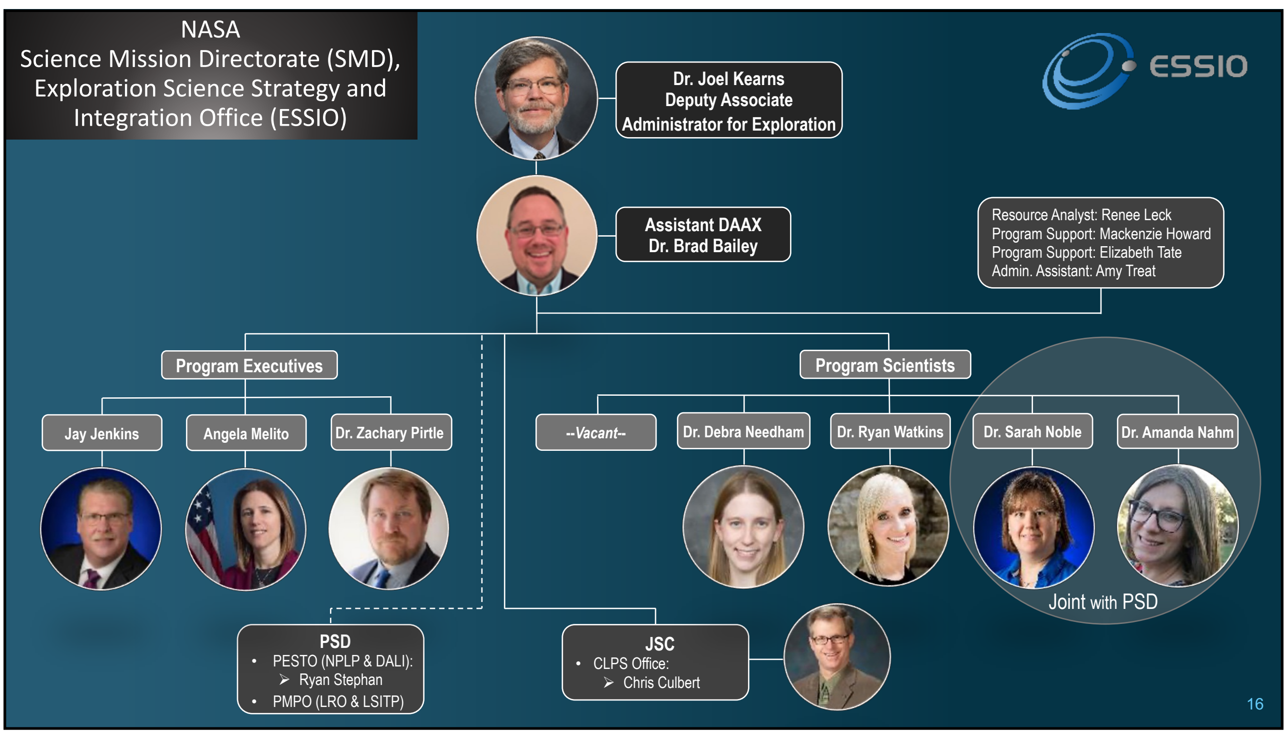

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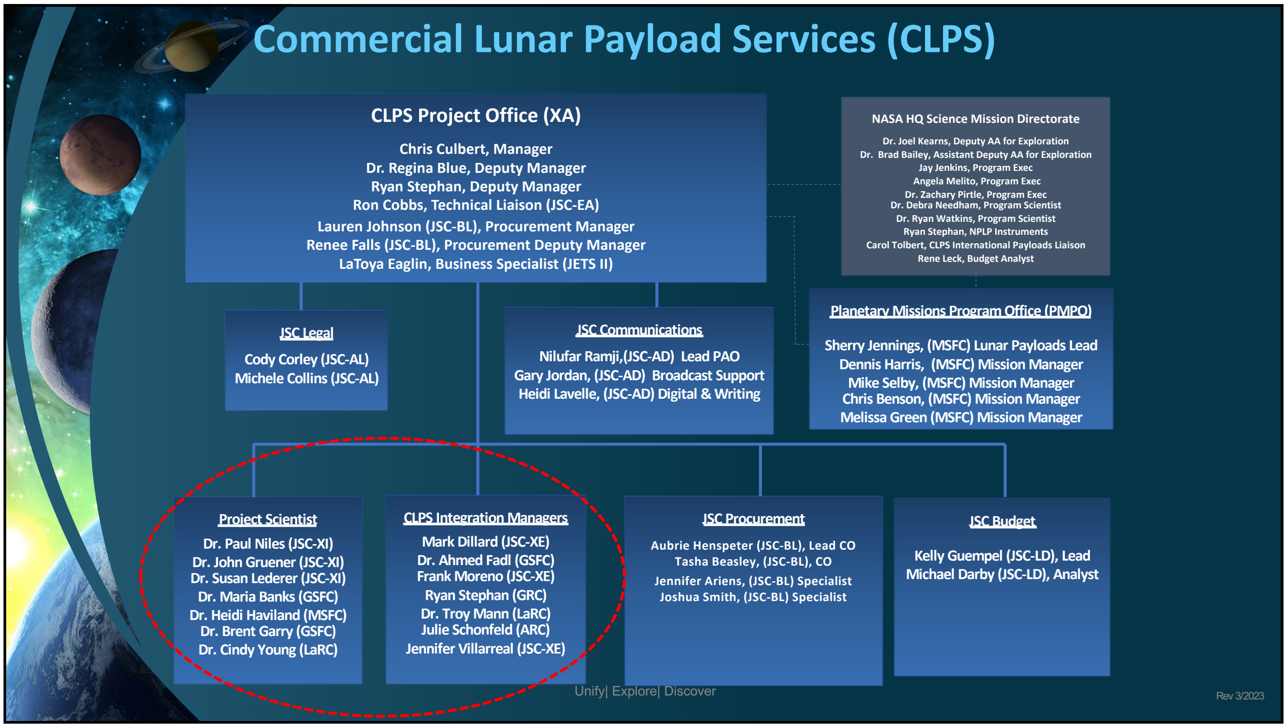

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CLPS Integration Manager Role

- Works closely with CLPS NASA-Sponsored Payload (NSP) Project Teams to define accommodation requirements for the RFTP Appendix A
- Primary interface between CLPS payloads and CLPS Provider
- Tracks lander development and CLPS integration schedule
- Assists CLPS Contracting Officer to brokers agreements for documents, data, and system deliverables to and from the CLPS Contractor
- Adjudicates mission resources for CLPS NSPs as necessary
- Provides technical evaluation for any CLPS NSP or CLPS Contractor driven contract changes
- Verifies RFTP and ICD requirements are met
- Works with CLPS NSP Project Team to coordinate deliverables with CLPS Contractor and execute NSP integration Testing
- Support NSP Real-Time Operations

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CLPS Project Scientist Role

- Works closely with CLPS NASA Program Scientist and NSP Teams to define landing site requirements
- CLPS Science Ops Lead; ensures coordination of CLPS NSP science ops
- Develops CLPS Task Order specific Science ConOps Document
- Provides science impact evaluation for any CLPS NSP or CLPS Contractor driven contract changes
- Facilitates CLPS NSP real-time ops changes with CLPS NSP's and CLPS Contractor
- During real-time ops works with CLPS Integration Manager and CLPS Contractor to adjudicate mission resources for CLPS payloads as necessary

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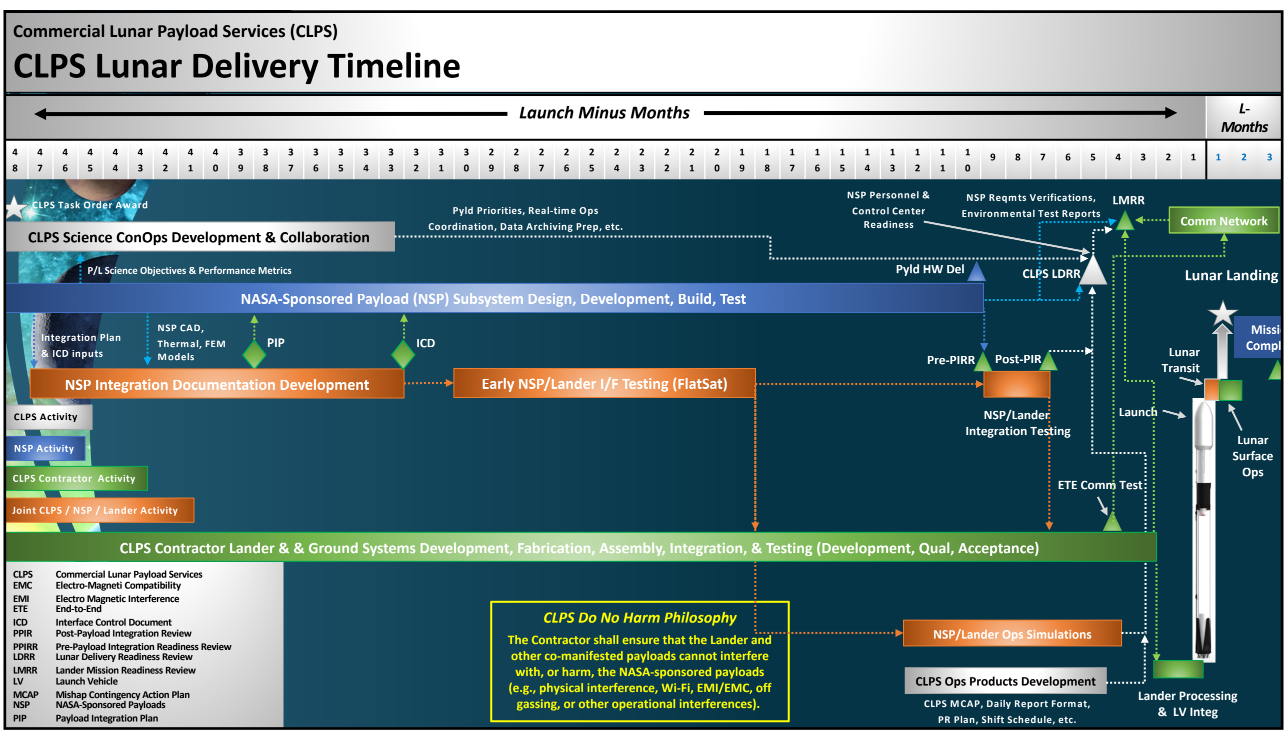

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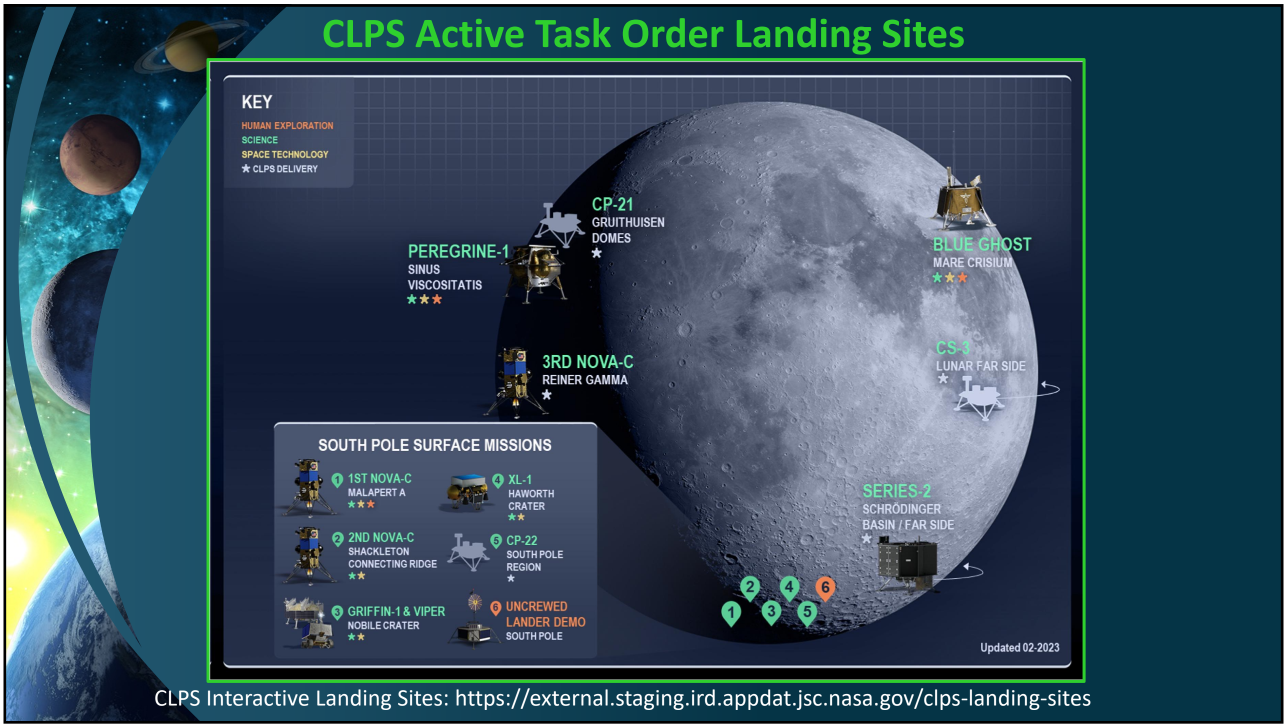
CLPS Active Task Order Landing Sites
KEY
HUMAN EXPLORATION
SCIENCE
SPACE TECHNOLOGY
★ CLPS DELIVERY
CP-21
GRUITHUISEN DOMES
PEREGRINE-1
SINUS VISCOSITATIS
BLUE GHOST
MARE CRISIUM
3RD NOVA-C
REINER GAMMA
CS-3
LUNAR FAR SIDE
SOUTH POLE SURFACE MISSIONS
1 1ST NOVA-C MALAPERT A
4 XL-1 HAWORTH CRATER
2 2ND NOVA-C SHACKLETON CONNECTING RIDGE
5 CP-22 SOUTH POLE REGION
3 GRIFFIN-1 & VIPER NOBILE CRATER
6 UNCREWED LANDER DEMO SOUTH POLE
SERIES-2
SCHRÖDINGER BASIN / FAR SIDE
Updated 02-2023
CLPS Interactive Landing Sites: https://external.staging.ird.appdat.jsc.nasa.gov/clps-landing-sites

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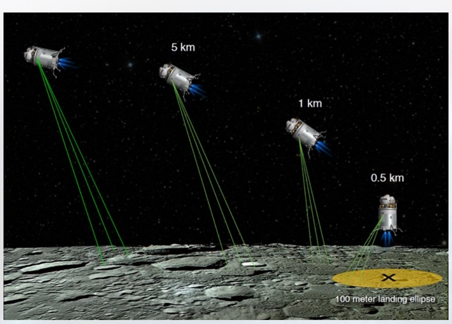
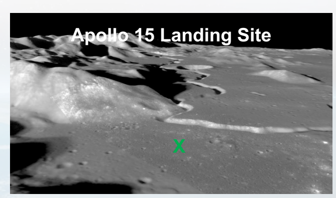
Navigation Doppler Lidar (NDL)

- NDL provides vehicle precision vector velocity and altitude data
  - Enables "*precision navigation*" to the designated landing location
  - Enables "*well-controlled*" descent, landing, and ascent maneuvers to within a few cm/sec





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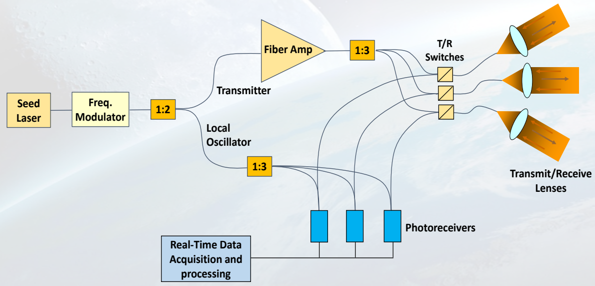
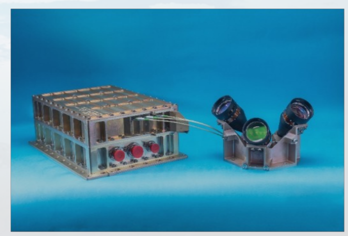
NDL Principle of Operation

- Range and velocity data are measured simultaneously but independent of each other
  - Range is measured based laser beam time of arrival thus affected by terrain features
  - Velocity is measured based on Doppler effect not affected by terrain features
- Simultaneous line-of-sight measurements along 3 beams are used to estimate:
  - Vector Velocity (V)
  - Altitude relative to local ground (No external data required)

Frequency Modulated Continuous Wave (FMCW) Technique





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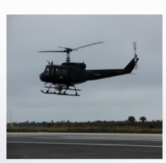
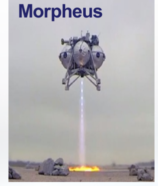
FOP played a key role in navigating valley of death

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


2008


2010


2012

Morpheus

2014

FOP - Masten Flight Test

2017

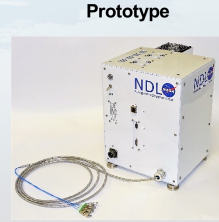
Proof-of-Concept — Breadboard — Brassboard — Prototype


> 200 kg


~ 60 kg


17 kg


4 kg



10 kg

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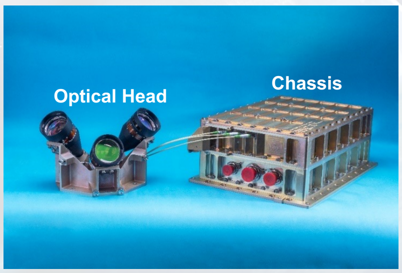
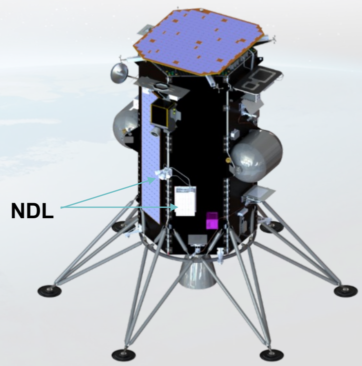
NDL CLPS Missions

- ***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



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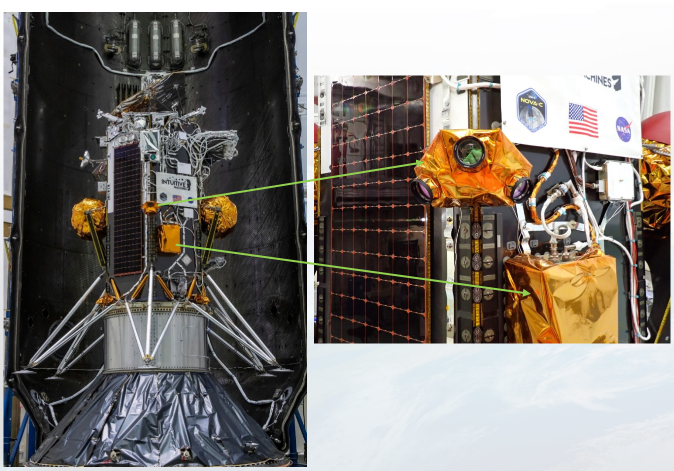
NDL on Intuitive Machines Odysseus Lander

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

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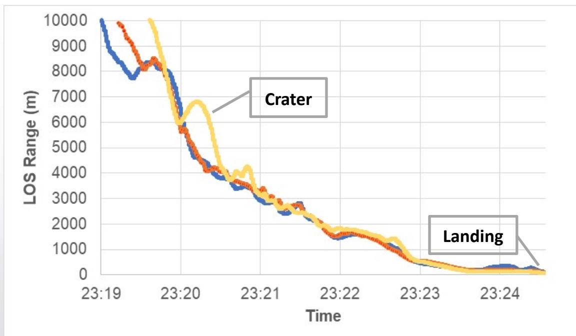
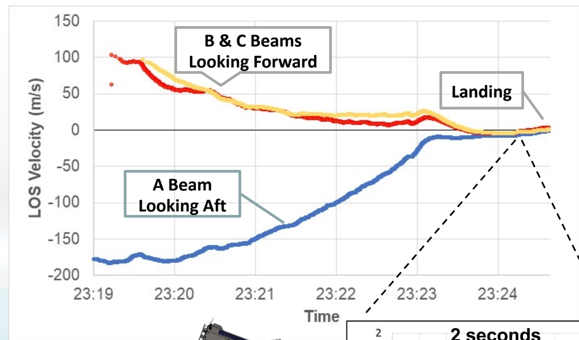
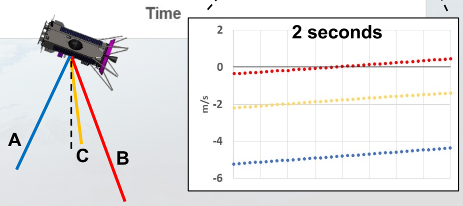
NDL Data from IM Lunar Mission

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 at 10 km)

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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

- Lunar lander provided an almost perfect test environment for analyzing the lidar data
  - No atmosphere
  - No water and vegetations
  - Low albedo variability
- Odysseus lunar landing was an excellent demonstration of the NDL for future landing missions

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NDL Team
NDL
NASA

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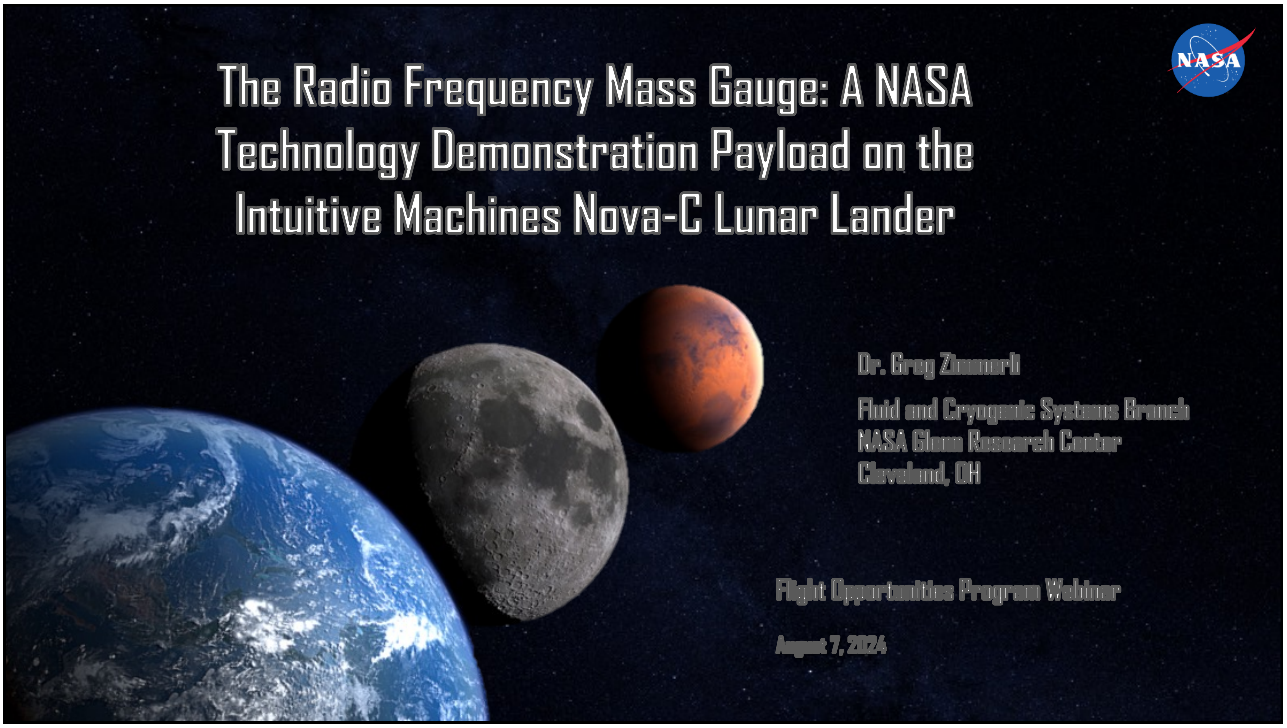

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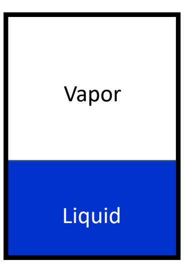
IN-SPACE PROPELLANT GAUGING

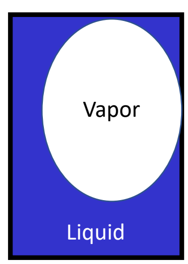
Challenge: How to measure propellant quantity in spacecraft tanks

State of the art methods:



Settled

Level sensors:
- Capacitance probe
- Wet-dry sensors
- Delta-P (pressure head)
- Ultrasonic liquid-level sensor
- Settling the liquid requires vehicle thrust, which consumes propellant



0g - Unsettled

Unsettled methods:
- Bookkeeping (Burn Time Integration)
- Pressure-Volume-Temperature (PVT, requires helium; not used in-flight for cryos)
- Thermal pulse (storable {non-cryo} propellants)

For cryogenic propellants, settled measurements or bookkeeping is SOA

CRYOGENIC FLUID MANAGEMENT PORTFOLIO (CFMP) PROJECT 38

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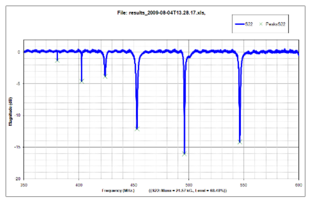
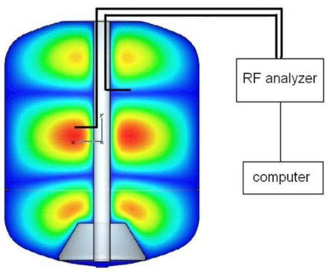
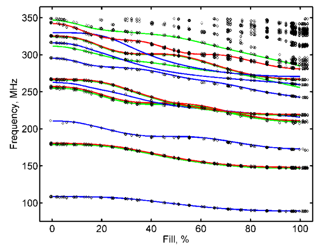
RADIO FREQUENCY MASS GAUGE (RFMG) OVERVIEW

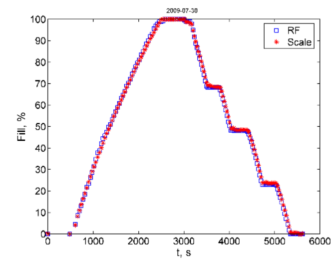
- Antenna sensors located inside the tank broadcast and receive the reflected RF signal
- Measure tank RF spectrum; the spectrum changes with fill level since the dielectric fluid slows the speed of light



- The basis of the RFMG is that these changes can be accurately predicted via RF/fluid simulations
- RFMG analysis software compares the measured tank spectra to a database of simulated spectra and returns the best match %fill-level information







RFMG TECHNOLOGY READINESS LEVEL (TRL) ADVANCEMENT

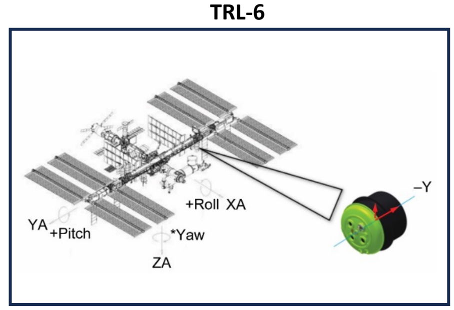
TRL-4

- First cryo test was liquid oxygen in 2005
- Ground testing using cryogenic liquids (N_2, O_2, H_2, CH_4)

TRL-5

- NASA Flight Opportunities Program sponsored low-g aircraft testing
- 30 gal. tank, Fluorinert FC-77 fluid
- Three flight campaigns 2010-2011

TRL-6



- Demonstration on GSFC Robotic Refueling Mission 3 payload on ISS
- 50L dewar with liquid methane
- Dec. 2018 – Apr. 2019

INTUITIVE MACHINES FLIGHT DEMO OF THE RFMG (2020-2024)

- Feb. 2019 – Notified that RFMG proposal to NASA Provided Lunar Payload (NPLP) Development Program was not selected for funding ("The selections were based primarily on the peer review evaluation, but in some cases programmatic considerations were considered in choosing the final NPLP portfolio.")
- Sep. 2019 – Initial discussions with IM regarding possible flight demo of RFMG on the IM-1 Nova-C lander
- January 2020 – Re-propose RFMG payload to NASA Science Mission Directorate, Commercial Lunar Payload Services (CLPS) program, and NASA Space Technology Mission Directorate (STMD) CFM program
- July 2020 – CLPS Task Order 20C issued; A contract with IM to integrate RFMG onto the lander and to provide NASA performance data from the flight cryogenic propulsion system.

Build RFMG hardware/software, test, delivery phase:

- July – Nov. 2020: Deliver EDU antennas, flight antennas, EDU avionics
- July 2021: Deliver flight RFMG avionics
- 2022: Tank & antenna design change. New antenna drawings, testing, delivery & installation
- Dec. 2022: LN2 cryo testing of flight tanks
- May 2023: Start RF/fluid flight simulations for RFMG database
- July 2023: Flight vehicle Hot-Fire test
- Feb. 2024: IM-1 flight, landing on the moon

INTUITIVE MACHINES NOVA-C LUNAR LANDER

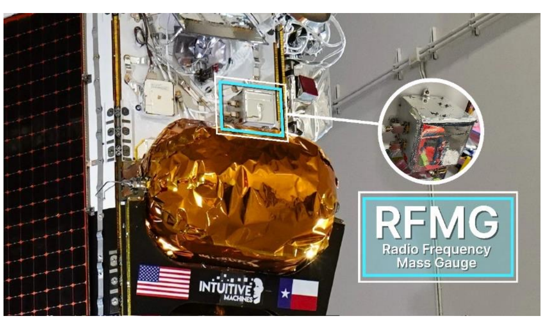


Image credit: Intuitive Machines, NASA

- **RFMG was one of six NASA payloads on the IM lander**
- **Liquid oxygen – liquid methane; composite propellant tanks**
- **One RFMG antenna sensor in each tank**
- **Similar RFMG hardware & software as used on GSFC RRM3 mission (ISS payload)**

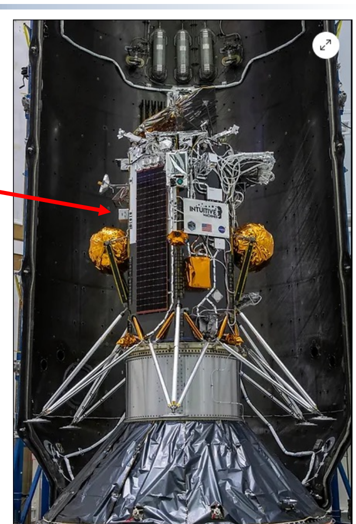
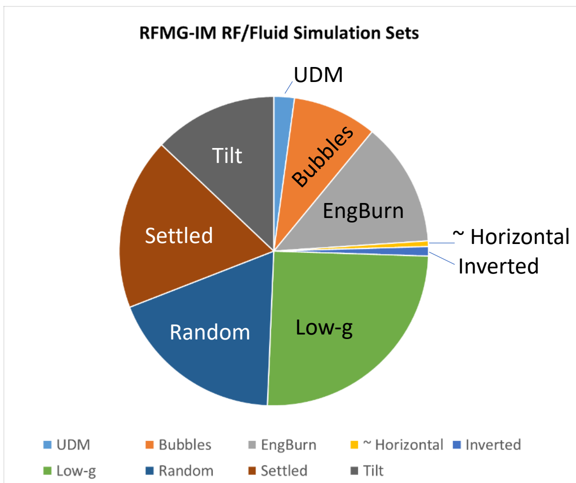


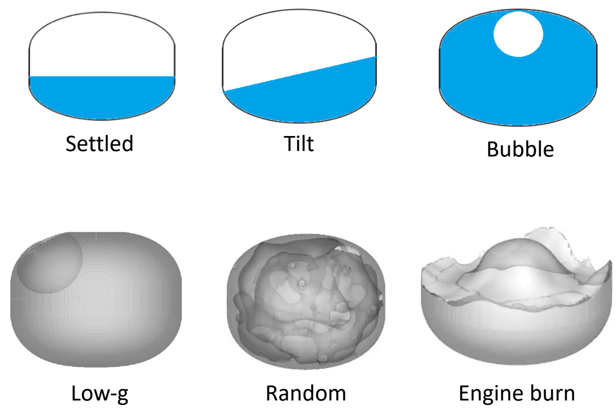
Image Credit: SpaceX

SpaceX F9 Payload Processing Facility

RF/FLUID SIMULATION SUMMARY



- Completed over 10,000 RF/fluid simulations for each tank (O2 and CH4)



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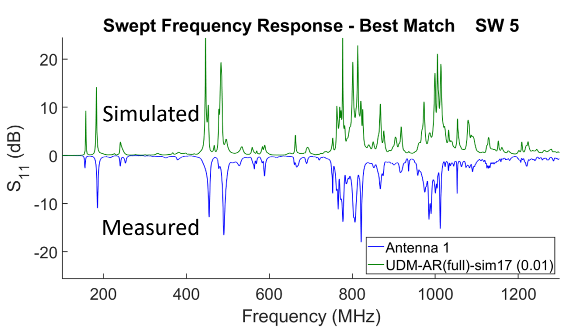
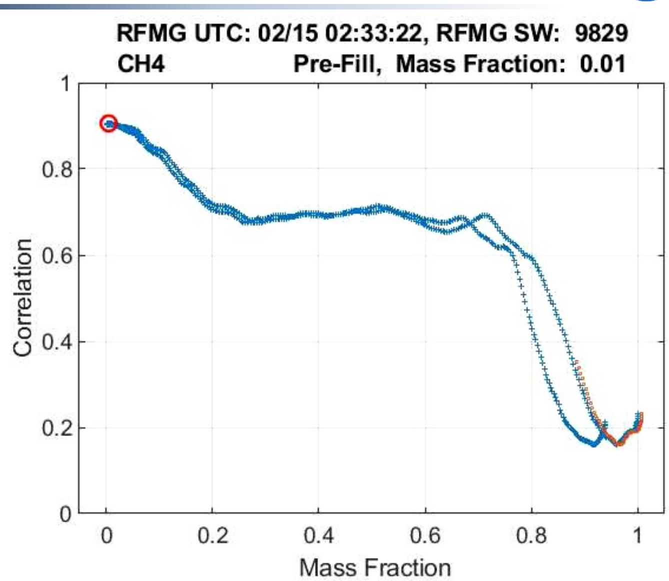
CH4 SPECTRA CORRELATIONS: ENTIRE MISSION

Correlation between measured tank RF spectra and the database of RF simulated spectra.





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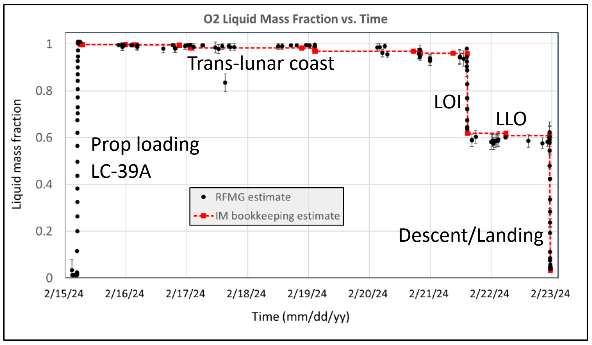
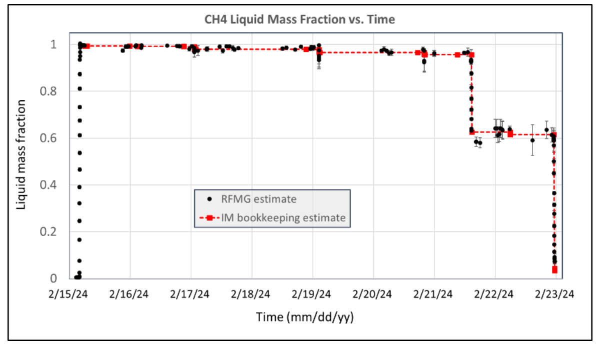
RFMG RESULTS FROM IM-1 MISSION





- Acquired RFMG data throughout all phases of the mission, from pre-launch tank loading to post-landing on the moon
- RFMG data shown above is as we reported to IM during the mission
- RFMG results are generally within a few percent of IM's post-mission bookkeeping estimate

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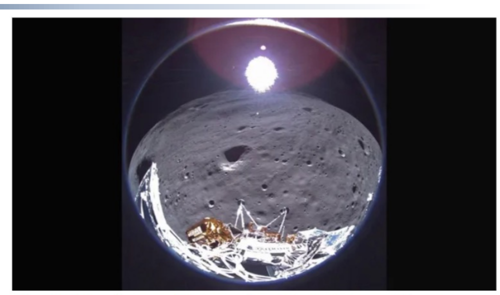
ON-GOING AND FUTURE WORK

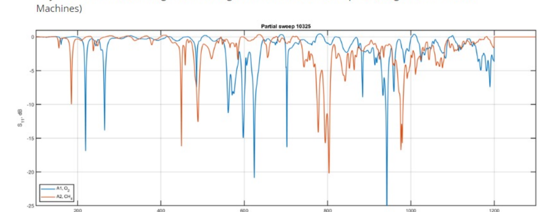
- Development of next-generation RFMG controller based on a space-grade Software Defined Radio
- Implement real-time onboard gauging
- Explore and test other gauging algorithms (e.g., based on machine learning)
- Rigorous investigation of sources of error/uncertainty
- Technology transfer/licensing to interested industry partners

Our goal is to make the RFMG competitive with other level-sensing technologies and improve the low-g gauging accuracy as much as possible.

TRL-7



Odysseus' final farewell image of its landing site on the moon's south pole. (Image credit: Intuitive Machines)



Post-landing tank spectra; Blue – O2 tank; Red - CH4 tank

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ACKNOWLEDGEMENTS

This flight demonstration was made possible by a team of people, this is partial list of significant contributors:

- Erin Pisciotta & Hans Hansen (NASA): RFMG Project Management
- Marius Asipauskas (USRA): RF-fluid simulations, Matlab guru
- Dr. Carol Kory (USRA): RF modeling of the IM propellant tanks
- Dr. David Fischer (NASA): RFMG Analysis Software & gauging algorithms
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- Ray Wade (NASA): RFMG Avionics
- Andy O'Connor (HX5): RFMG Flight Software
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- Jesse Hawk (HX5): Design, Drawings
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- Kate McGinnis (NASA): Materials
- Sean Beckman, Doug Edsey, Brian Morris, Brian Loucks: Quality Assurance
- Alan Sikon (MTS): Scheduler; Toni Rusnak (NASA): Configuration Management
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- Mike Meyer: NESC Cryogenics Technical Discipline Lead
- Cryogenic Fluid Management Program & Commercial Lunar Payload Services personnel

RFMG-IM mission op's team

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NASA FLIGHT OPPORTUNITIES

National Aeronautics and Space Administration

Thank you!

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