Panelists:
- Badri Younes, Deputy Associate Administrator for Space Communications and Navigation (SCaN), NASA
- Philip Baldwin, SCaN Network Operations Manager, NASA
- Dr. Jason Mitchell, Director, Advanced Communications and Navigation Technology, NASA
- Greg Heckler, Director, Commercial Communications Services Division, NASA
Artemis Overview

Badri Younes
Deputy Associate Administrator for
Space Communications and Navigation (SCaN), NASA
“We are SCaN” Video
ARTEMIS Notional Space Communications and Navigation Mission Segments

- Pre-Launch and Launch Boosters and Launch Abort System Separation
- Core Stage Separation
- Perigee Raise Maneuver
- Trans Lunar Injection (TLI) Burn
- Orion Perigee Raise Burn
- Earth Orbit
- Orion and ESPRIT docks with Gateway, ESPRIT Activated.
- Orion Perigee Raise Burn
- Trans Lunar Injection
- Journey to the Moon
- Trans Lunar Injection Burn
- Orion Insertion burn for Gateway Orbit
- Orion and ESPRIT docks with Gateway, ESPRIT Activated.
- Orion Perigee Raise Burn
- Trans Lunar Injection
- Journey to the Moon
- Trans Lunar Injection Burn
- Orion Insertion burn for Gateway Orbit
- Orion and ESPRIT docks with Gateway, ESPRIT Activated.
- Human Landing System (HLS) Trajectory to Lunar Orbit
- HLS Enters Low Lunar Orbit
- HLS Descent to Touchdown
- HLS Takeoff to Lunar Orbit
- HLS Trajectory to Gateway Orbit and Docking Procedure
- Orion Undocks Gateway and Returns to Powered Flight
- Lunar Departure
- Orion Return Transit
- Return Trajectory Burn
- Crew Module Separation
- Re-Entry Interface
- Splashdown and Recovery

Notional Lunar Landing Details

1. Outbound Trajectory
2. Journey to the Moon
3. Lunar Orbit Insertion
4. Orion and ESPRIT docks with Gateway, ESPRIT Activated.
5. Orion Perigee Raise Burn
6. Trans Lunar Injection
7. Journey to the Moon
8. Trans Lunar Injection Burn
9. Orion Insertion burn for Gateway Orbit
10. Orion and ESPRIT docks with Gateway, ESPRIT Activated.
11. HLS Enters Low Lunar Orbit
12. HLS Descent to Touchdown
13. HLS Takeoff to Lunar Orbit
14. HLS Trajectory to Gateway Orbit and Docking Procedure
15. Orion Undocks Gateway and Returns to Powered Flight
16. Lunar Departure
17. Orion Return Transit
18. Return Trajectory Burn
19. Crew Module Separation
20. Re-Entry Interface
21. Splashdown and Recovery

Near Space Network (NSN)
- NSN DTE
- NSN TDRS

Deep Space Network (DSN)
- DSN/TDRS
- DSN/DTE
Enabling Requirements for Artemis

NASA SCaN continues to collect lunar requirements for the initial Artemis architecture.

Example needs include:
- 4k video
- Telemedicine
- Remote operations
- Tracking of the health and safety of astronauts
SCaN Network Operations
Perspective and Plans

Philip Baldwin
SCaN Network Operations Manager, NASA
Artemis Plan Communications Approach

Deep Space Network (DSN) 34-Meter Antenna Upgrades

Lunar Exploration Ground Sites (LEGS) – 18-meter Class Antenna Subnet

Lunar Relay and Interoperable Lunar Network
Deep Space Network Upgrades

- Upgrades to DSN’s 34-m subnet represent a low-risk option to help meet Artemis program and Lunar science needs.

- Modifications will be made to two antennas at each DSN complex – total of six antennas.

**Simultaneous Operations**

- S+Ka-band or X+Ka-band
- Simultaneous Ka-band

**LOW Latency**

- Data processing >150Mbps

**HIGHER DATA RATES**

- Ka-band
  - >100Mbps
  - >20Mbps

- X-band
  - >2Mbps
  - >5Mbps
**Lunar Exploration Ground Sites Overview**

- Lunar Exploration Ground Sites (LEGS) will provide Direct to Earth (DTE) RF comms to users ranging from Earth GEO orbit cis-Lunar space and to Sun-Earth-Lagrange orbits.
- Minimum of three sites located around the Earth to provide continuous coverage.
- Ability to add further assets as demand grows.

**LEGS support from 36K to 2M km**

- **RF Links** – S-, X-, and Ka-band

**Data Interface**

- Near Space Network (Scheduling, Forward/Return Data Transfer, Status/Performance)
Critical Need For Lunar Relay and An Interoperable Lunar Network – LunaNet

“LunaNet” is a scalable, extensible, and reusable network architecture framework
• Initial focus on lunar vicinity comms
• Framework is extensible to Mars and beyond

Lunar Relay services needed as early as 2024 to support key missions and spacecraft
• Solves mission communications for scenarios with limited Missions DTE visibility
• Missions without line-of-sight visibility issues also benefit from relay
Other Core Capabilities

Delay/Disruption Tolerant Networking:
- DTN protocol enables efficient data transmissions
- More DTN nodes = more data pathways
- Reusable interoperable solutions

Multiple Spacecraft Per Aperture:
- MPSA antenna receives data simultaneously from multiple spacecraft \(\rightarrow\) more efficient use of each DSN asset

Simultaneous Frequency Communications:
- DSN dichroic mirrors / mirror configuration updated for simultaneous comm. in multiple bands
Timeline and Evolution

Now to 2024

**Deep Space Network Upgrades**
First upgrades in 2022 completed in 2024

**LEGS 1**
First Lunar Exploration Ground Site 2024

**Lunar Relay**
One or more Relays Developed by 2024
- *LunaNet Compatibility*

2024 to 2028

**LEGS 2 & 3**
Expansion of Lunar Exploration Ground Sites by 2026

2028 and Beyond

**Lunar Relay**
Comprehensive relay network

• Evolution Infrastructure
• Infusion of New Technology
• Surface Comm & Nav Assets
• Full LunaNet Services
Technology Enabling C&N Capability at the Moon and Beyond

Dr. Jason Mitchell
Director, Advanced
Communications and Navigation
Technology, SCaN Program, NASA
Autonomy Drives Technology Needs

The new era of lunar exploration is a departure from Apollo
• Volume of missions and assets – complexity of ops
• Greater precision for science and ops
• Greater autonomy required to perform, and prep for Mars
• High-rate data aggregation to reduce user burden

Elements of our Technology Portfolio:
• Lunar Global Navigation Satellite System (GNSS) capability
• Deep Space Atomic Clocks
• Autonomous Navigation
• Optical trunk links supporting LunaNet
GNSS at the Moon and High-Rate Data Aggregation

Global Navigation Satellite System (GNSS) reception in cislunar environment dramatically reduces network burden and enables autonomous operations.

Build on experience with successful high-altitude GPS application: Magnetospheric Multi-Scale Mission (MMS) demonstrated success at 29.3 Earth radii (50% of lunar distance).

NavCube3-mini (NC3m) multi-GNSS receiver
- <2U, 2 kg, ~12 W
- Onboard navigation filter
- TRL6 targeting mid-2022

Space Service Volume (SSV) (3,000 to 36,000 km)

Near-Earth GNSS Sidelobe Signals

Cislunar GNSS Sidelobe Signals

Crosslinks

Lunar relay services address far-side access
DSAC is a mercury ion (Hg+) atomic clock demonstration that recently set the record for long-term stability in space.

Provides more than 50x better long-term stability over current atomic frequency standards.

1-day STABILITY = 3e-15
DRIFT = 3e-16/day

Enhances autonomous navigation performance.

DSAC2 is smaller and requires less power—will fly on VERITAS.
Autonomous Navigation

Fusion of a diverse set of measurements will enable spacecraft autonomy.

INTERFACES:
- Position, Velocity, Time, Attitude
- Maneuver, Epoch, Vector and Duration, Commands, Telemetry, Power

FLIGHT SOFTWARE
- Flight Computer
- Optimal Sensor
- Radio Sensor
- Clock
- Data Storage

Target Body
- Centroid or Landmarks
- Optical Beacon: Earth-based or In-Situ

Cruise: Target body, asteroids, and stars

Approach

Optical Triangulation

Image-based Example Approach: Combine Celestial and Terrain-Relative Navigation

Radio Sensor

FLIGHT SOFTWARE

Filtering (GEONS)

Actualise

Guidance

Core FLIGHT SYSTEM

COORDINATION LAYER

ALGORITHMS

Sense

Determine

Actuate
SCaN Commercialization Opportunities

Greg Heckler, Director,
Commercial Communications
and Services Division, SCaN
Program, NASA
What Could Commercial Service at the Moon Look Like?

- Bringing near-Earth commercial capability to the lunar environment
- Lunar surface use cases are analogous to terrestrial use cases that are supported by 4G/LTE standards
- First steps... NASA awarded a Lunar Surface Innovation Initiative Technology Demonstration to Nokia, partnering with Intuitive Machines to demonstrate a 4G/LTE base station and user radio on the moon
Commercialization Underway

NASA is already working to commercialize our near-Earth services... extend to lunar domain.
How We Get There

Can space missions be a 5G NTN user in Near Earth?

And...then can we extend these same capabilities and standards to the moon?
Outreach and Engagement

NASA is actively encouraging the commercial industry to participate in lunar efforts for communication and navigation on LEGS and Relay services. Outreach beginning in the summer of 2020 has led to a recent Source Sought Notice (September 2021). Planned Requests for Proposals (RFPs) in 2022 will span services:

- DTE for near-earth
- Lunar DTE communications
- Lunar relay communications and navigation