
# Lunar Logistics, Mobility, and Cargo

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# Architecture White Papers


Lunar Surface Cargo

Lunar Mobility Drivers and Needs

Introduction

NASA's new campaign of lunar exploration will see astronauts visiting sites of scientific or strategic interest across the lunar surface, with a particular focus on the lunar South Pole region.[1] After landing crew and cargo at these destinations, local mobility around landing sites will be key to movement of cargo, logistics, science payloads, and more to maximize exploration returns.

NASA's Moon to Mars Architecture Defin tion Document (ADD)[2] articulates the work needed to achieve the agency's human lunar exploration objectives by decomposing needs into use cases and functions. Ongoing analysis of lunar exploration needs reveals demands that will drive future concepts and elements.

Recent analysis of integrated surface operations has shown that the transportation of cargo on the surface from points of delivery to points of use will be particularly important. Exploration systems will often need to support deployment of cargo in close proximity to other surface infrastructure. This cargo can range from the crew logistics and consumables described in the 2023 "Lunar Logistics Drivers and Needs" white paper,[3] to science and technology demonstrations, to large-scale infrastructure that requires precision relocation.e

Mobility Needs

2024 Moon to Mars Architecture Concept Review

**NASA's Moon to Mars Architecture defines the capabilities and elements needed for long-term, human-led scientific discovery in deep space.**

- Through detailed architectural assessments of lunar surface needs, capability gaps have been identified in:
  - **Logistics Systems** - elements that play a role in the containment and transportation of Logistics Items or Cargo, and
  - Uncrewed Mobility Systems – elements capable of delivering items to their point of use
- Given the scope and scale of forward demand, NASA published multiple white papers to grow awareness across industry and the NASA stakeholder community, including
  - Lunar Logistics Drivers and Needs *(2023 White Paper)*
  - Lunar Surface Cargo *(2024 White Paper)*
  - Lunar Mobility Drivers and Needs *(2024 White Paper)*

# Lunar Surface Cargo Background

- The architecture includes several surface cargo delivery or support functions, with some — but not all — needs current fulfilled by the Human Landing System (HLS), Human-class Delivery Lander (HDL), and Commercial Lunar Payload Services (CLPS)
- Analysis leading to and supporting the small cargo lander mission concept review (MCR) also revealed implications across the architecture strategy (e.g., available/contracted cargo capacity today versus aggregated future cargo demand)
- NASA allocated 17 functions to lunar surface cargo delivery in ADD Rev-A:
  - Nine identified as key; Eight identified as potential. (Potential reflects optional services that may be needed on some but not all landers.)
  - **The ability to deliver cargo to the lunar surface is critical to the architecture**

| Key | Potential | Lunar Surface Cargo Delivery Functions | |
|---|---|---|---|
| X | | FN-018-L | Transport cargo from Earth to the lunar surface |
| X | | FN-088-L | Provide precision landing for cargo transport to the lunar surface |
| X | | FN-122-L | Decommission surface delivery system(s) and/or surface asset(s) |
| X | | FN-126-L | Reduce blast ejecta |
| X | | FN-141-L | Deliver cargo(s) to distributed sites on the lunar surface |
| X | | FN-256-L | Provide physical and electronic safeguards for automated asset(s) operating near crew |
| X | | FN-257-L | Detect and avoid hazards during landing in darkness, high contrast, and long-shadowed lighting conditions in the presence of lunar dust and debris |
| X | | FN-277-L | Unload large utilization assets on the lunar surface |
| X | | FN-280-L | Deliver cargo(s) to south polar region sites on the lunar surface |
| | X | FN-066-L | Transport cargo from Earth to the far side of the lunar surface |
| | X | FN-123-L | Provide propellant/fluid transfer through common interface(s) between assets on the lunar surface (demonstration) |
| | X | FN-129-L | Transfer of propellant/fluids between assets on the lunar surface (demonstration) |
| | X | FN-139-L | Deploy (including setup, activation, and operation) science and/or monitoring utilization payload(s) on the lunar surface |
| | X | FN-144-L | Transport large exploration asset(s) from Earth to the lunar surface |
| | X | FN-148-L | Perform robotic manipulation of payloads, logistics, and/or equipment at multiple scales |
| | X | FN-254-L | Provide safety features, including shutoff, on robotic and/or autonomous system(s) |
| | X | FN-255-L | Robotic system(s) interaction with logistics carriers on the lunar surface |

**Architecture functions are intentionally decoupled from performance or demand to enable system analysis and trades.**

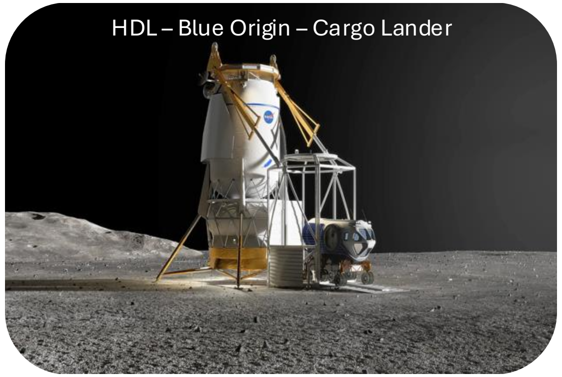
# Lunar Surface Cargo Capacity Estimates

National Aeronautics and Space Administration

| Lander Type | Mass Delivery Capability (t) | Provider |
|---|---|---|
| CLPS - Current Task Orders | 0.07 – 0.475 for existing task orders | U.S. |
| HDL Cargo Lander | 0 - 12 or 15 t | U.S. |
| ESA Argonaut Lander | Up to 2.1 t | International |
| JAXA Cargo Lander Capability | Under study | International |

**Current capabilities beyond HDL are not available from 500 kg to 12,000 kg, for which significant demand exists.**






# Lunar Mobility Drivers and Capacity

National Aeronautics and Space Administration

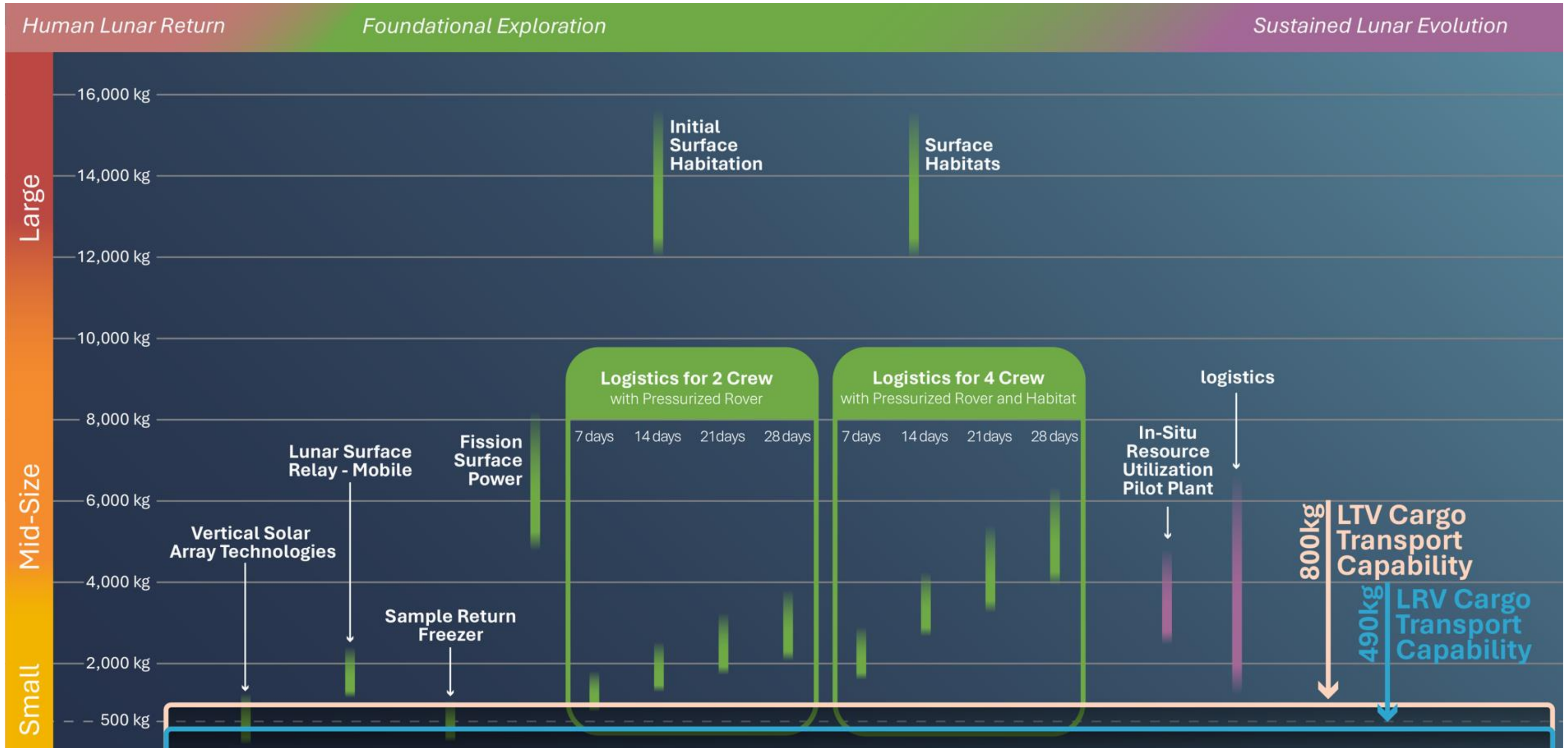
- Analysis leading to and supporting surface logistics, potential utility rover concepts, and initial surface habitation mission concept review (MCR) revealed implications across the architecture strategy:
  - Functional gaps and services not yet available for mobility of large uncrewed assets
  - Relocation and surface placement demand
  - Technological gaps in performance for mobility assets
  - Integrated architectural strategic considerations
- **Lunar surface mobility is allocated to 22 functions in M2M ADD Rev-B**
- Demand for mobility is driven by integrated architectural operations:
  - Relocation out of lander shadows or engine blast range
  - Deployment to optimal solar points
  - Aggregation of logistics to point of use
  - Infrastructure deployment

| Mobility Asset | Mass Transport Capability (kg) |
|---|---|
| Lunar Roving Vehicle (Apollo) | 490 kg |
| Lunar Terrain Vehicle (uncrewed capability) | 800 kg (full performance)<br>1600 kg (reduced performance) |
| JAXA Pressurized Rover | TBR |

**Mobility mass demand ranges are similar to those of landed cargo demand, but capabilities are not available for cargo or assets greater than 1,600 kg; No mobility assets exist that can relocate large elements (e.g., initial surface habitat)**

# Lunar Mobility Demand

National Aeronautics and Space Administration

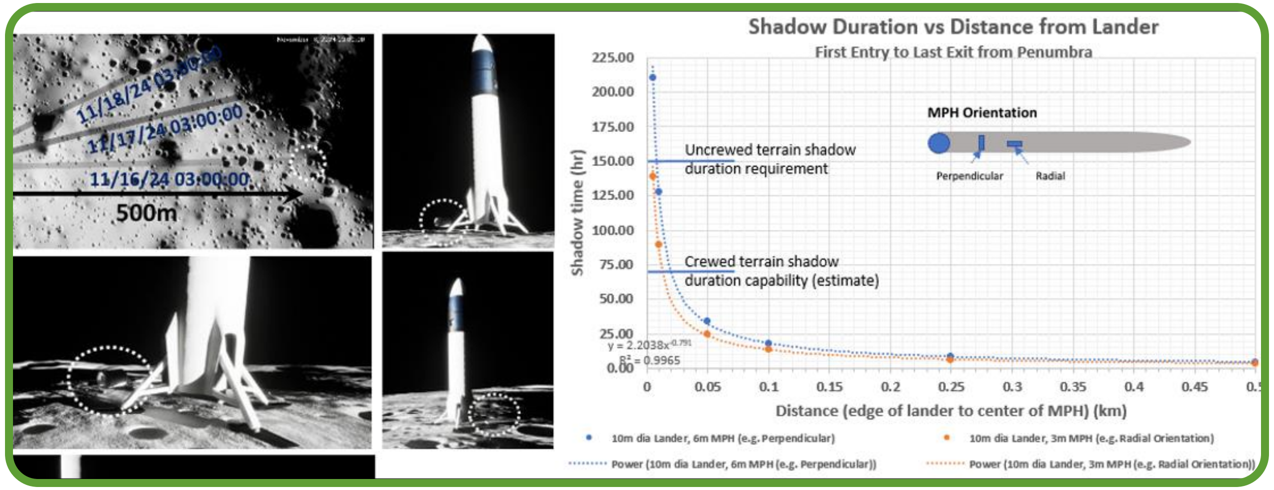


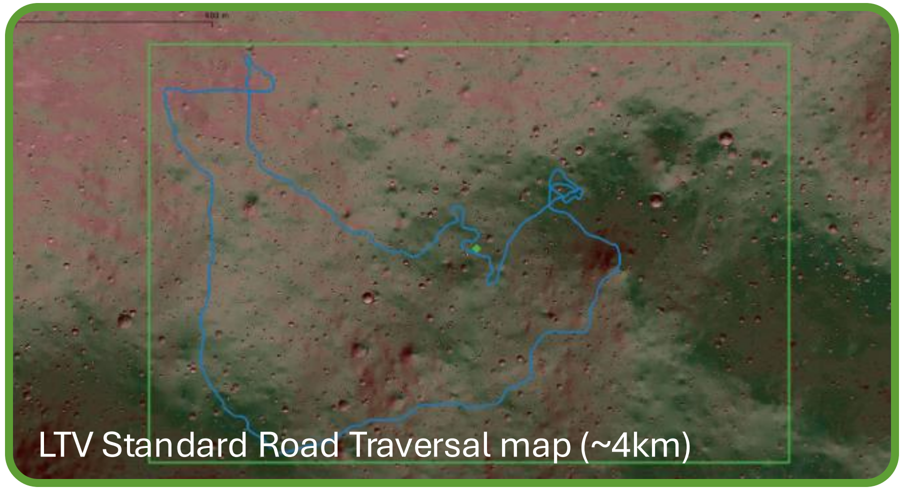

Foundational Exploration

**Mobility payload mass demand forecasts range from 500 kg to 15,000 kg per asset during the Foundational Exploration segment**

# Lunar Mobility Demand Range

- Assessment of range per asset deployed could be driven by multiple factors:
  - Min relocation distance to avoid lander shadows >50m
  - Min relocation distance to avoid lander blast ejecta >1,000m
  - Relocation from potential lander sites to optimal/aggregate surface locations up to 5,000m
- **Attempting multi-region mobility would require a capability of hundreds to thousands of kilometers**





LTV Standard Road Traversal map (~4km)

**Integrated architecture operations will necessitate non-trivial relocation and aggregation range demand for cargo and assets.**

# White Paper Key Takeaways

National Aeronautics and Space Administration

## Key Takeaways

- Foundational Exploration and Sustained Lunar Exploration segment goals require significant transportation of cargo to the lunar surface
- NASA anticipates an aggregate demand for lunar surface cargo on the order of 2,000 to 10,000 kg per year
- To mitigate this capability gap, strategic considerations include engaging multiple providers across both international partners and industry over time, offering dissimilar redundancy
- Communication of cargo demand to the exploration community helps enable industry and international engagement
- Lunar exploration objectives require significant mobility of cargo and assets across the lunar surface from landing site to point of use at ranges of 5 to 5,000 m
- Currently, the surface mobility capability expressed in the architecture is limited to 800 kg. However, future mobility demands include aggregated logistics and larger elements as massive as 12,000 kg or more
- Large-scale mobility is not simply scaled up small-scale mobility; energy and environmental considerations are crucial to the design process
- Interoperability and autonomous or semi-autonomous capabilities on mobility systems enable mission planning flexibility and increase available crew utilization time