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A SUSTAINABLE LOGISTICS ARCHITECTURE FOR EXPLORATION OF THE MOON, ASTEROIDS, AND MARS

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Introduction

Which one do you use to ship your groceries & furniture? Which one do you take on vacation?

Aerojet has identified a sustainable logistics architecture for human exploration of the Moon, Earth-Moon Lagrange points, asteroids, and Mars.

Sustainable architectures must have:
- flexibility to support multiple destinations beyond LEO
- maximum use of common elements
- separate crew and cargo missions to optimize vehicle mass & requirements
- modular, fuel efficient transportation systems
- pre-placement & verification of non-time critical elements and successive capabilities demonstrations

Optimized Space Architecture are Critical for Sustainable Beyond LEO Operations
In-Space Architecture Design

- Space architecture design drives LV requirements & architecture affordability
- Space architecture design establishes: destinations, mission phases, ΔV requirements, propulsion technology trade space, & and payload elements
- The majority of destinations do not have an opportunity to implement aerocapture
- Crew and cargo are separated to identify a minimum launch “bit”
  - Enables smaller commercial launch providers to participate
  - Enables partners to participate in developments (NASA/DoD/Commercial)
  - Maximizes launch opportunities through multi-manifesting
- Two approaches for the Earth insertion and Earth Descent phases:
  - LEO Return (Orion), Direct Return (Commercial Crew)

**Optimized Space Architectures Maximize Participatory Exploration**
Space Architecture Analysis

- Objectives: Identify affordable, repeatable, multi-destination solutions
- Analysis was conducted in reverse of the conduct of the mission
  - Start at the final state using the delivered mass requirements
  - Work backward to the initial state in LEO
- Approach identified
  - Optimal CONOPS
  - minimum IMLEO requirements
  - minimum payload bit sizes
  - propulsive elements
  - Common vehicle sizes

Optimized Space Architectures Start with the Payload and Work Back to the Pad
Crewed mission consists only of the crew habitat, consumables for the journey, and the propulsion stage for Earth departure and Mars arrival maneuvers.


SEP freighter cargo approach enables a LEO return
- Enables commercial crew options
- with 14% reduction over baseline direct return approach

Optimized Space Architectures Enable Mission Flexibility
Partial CONOPS for Mars Mission

- Mars Surface
  - 3. SEP Loiter
- Mars 500km Circular
  - 11. Tank & LH2 Transfer
  - 12. Rendezvous with SEP
  - 13. Attach Return Stages
  - 14. SEP Return to Earth
- Earth Sphere of Influence
  - 2. SEP Transfer (Low Thrust)
  - 10. Insertion Burn
- LEO (407km circ)
  - 8. LEO Departure Burn
  - 6. LEO Staging & loiter in LEO
- LEO Launch (~100t)
  - 1. Cargo Launch (~100t)
  - 4. Crew Launch 1 (~100t)
  - 5. Crew Launch 2 (~25t)
- 7. Orion separation & loiter in LEO
- 9. Jettison Earth Departure Tank
- 19. Departure Burn
- 18. Ascent Stage Separation
- 15. Rendezvous with Descent/Ascent Vehicle*
- 16. Exploration
- 17. Rendezvous with Return Vehicle
- 12. Orion Rendezvous*
  - *Pre-deployed cargo
- 13. Orion Braking Burn
- 14. Orion Departure Tank
- 15. Orion Braking Burn
- 16. Orion Re-Entry
- 17. Orion Landing & Crew Recovery
## Architecture Element Summary

### Optimized Space Architectures Maximize Use of Common, Modular Vehicles

<table>
<thead>
<tr>
<th>Element Concept</th>
<th>Element Name</th>
<th>Dry Mass, mT</th>
<th>Maximum Wet Mass, mT</th>
<th>L2/Moon</th>
<th>NEO</th>
<th>Photos</th>
<th>Mars Surface</th>
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Focus on SEP Freighters

SEP Freighters can be Developed using Demonstrated Technologies

**300kW Freighter**
- First flight: 2017
- Dimensions (stowed): 5m dia., 8m overall length (OAL)
- Mass: 36t wet, 6t dry
- Propellants: Xenon or Krypton (30t)
- Propulsion: 3 x 150kW modules @ 3000s
  - Leverages NASA 457M development
  - Carries one spare 150kW module
- Utility: High ΔV maneuvers on long duration cargo missions with 35t class payloads
- Technology: Implements high efficiency radiation hardened solar arrays, 150kW Hall thruster propulsion systems, light weight inert gas propellant tanks

**600kW Freighter**
- First flight: 2020
- Dimensions (stowed): 5m dia., 10m OAL
- Mass: 76t wet (via 70t ORU), 8t dry
- Propellants: Xenon or Krypton (65t)
- Propulsion: 5 x 150kW modules @ 3000s
  - Leverages 300kW Freighter propulsion
  - Carries one spare 150kW module
- Utility: High ΔV maneuvers on long duration cargo missions with 70t class payloads
- Technology: Implements high efficiency radiation hardened solar arrays, 150kW Hall thruster propulsion systems, light weight inert gas propellant tanks

**ISS**
- Power ~300kW
- Area ~600kW
  With Current Cells
Exploration Launch Campaign

Optimized Architectures Implement Successive Capabilities Demonstrations
Waypoint Exploration with Flight Proven Technologies is Possible Today
Comparison of SEP Freighter vs. Chemical for EML2 Missions

Small SEP Freighters Enable Maximum Payload Delivery for Waypoints
Comparison of SEP Freighter vs. Chemical for EML2 Missions

Small SEP Freighters Enable Minimized LV Requirements for Waypoints
Conclusions

- An sustainable logistics architecture for human exploration of the Moon, NEOs, Phobos and the Martian surface has been identified.
- SEP Freighters enable Commercial crew services options for launch and in-space transportation for human exploration beyond LEO
- 30kW SEP freighters can be built with already flight proven systems enable waypoint missions
- TRL 5 technologies enable development of 300kW and 600kW freighters for human exploration missions including Lunar, NEOs, and Mars