Exploration Requirements for Earth to Orbit

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Sustainable Planetary Surfaces

Go anywhere, anytime

Stepping Stones

Accessible Planetary Surface

Earth’s Neighborhood

Earth and LEO
Core Capabilities & Technologies

Potential Destinations from Science Objectives

Common Capabilities

Technology Building Blocks

- Efficient In-Space Aeroaassist
- Low-cost Engines
- Cryo Fluid
- Robust/Efficient Lightweight
- Radiation Research
- Zero/Low-g Research
- Regenerable Life Support
- Advanced Lightweight EVA
- Innovative Mission Concepts
- Breakthrough Technologies (Examples)
- Wireless Power Transmission
- Regenerative Aerobraking
- Revolutionary ETO Rockets
- Lightweight structures, systems, sensors, micro/nano electronics
- Radiation Research
- Zero/Low-g Research
- Regenerable Life Support
- Advanced Lightweight EVA
- Innovative Mission Concepts

Mission Analyses
The Value of Technology Investments
Mars Mission Example

Cumulative Mass Savings (Per Cent)

Today’s Technology

- All Propulsive, Chemical
- Aerocapture (50%)
- Advanced Propulsion (EP or Nuclear) (46%)
- Closed Loop Life Support (19%)
- Advanced Materials (14%)
- Maintenance & Spares (21%)
- Advanced Avionics (11%)
Libration Points and New Ideas

• Libration Points are relatively stable locations in space oriented to orbiting planetary bodies
• Access to all locations on moon and Mars is equivalent
• Very low energy transfers between libration points are possible
Gateway Architecture

“Earth’s Neighborhood”

Crew departs from and returns to ISS

Crew Transfer Vehicle
- Transports crew between ISS and Gateway
- Nominal aerocapture to ISS, or direct Earth return contingency capability

L_1 Gateway
- “Gateway” to the Lunar surface
- Outpost for staging missions to Moon, Mars and telescope construction
- Crew safe haven

Lunar Lander
- Transports crew between Gateway and Lunar Surface
- 9 day mission (3 days on Lunar surface)

Lunar Habitat
- 30-day surface habitat placed at Lunar South Pole
- Enables extended-duration surface exploration and ops studies

GPS Constellation

Lunar Habitat

Lunar Lander

L_1 Gateway

Crew Transfer Vehicle

Earth's Neighborhood
Lunar $L_1$ “Gateway”

**Key Attributes**

- Earth-Sun Telescope assembly and servicing
- Gateway serves as “stepping stone” - opportunity to test technology and operational concepts
- Architecture can be bought “by the yard” - increasing capabilities and operational experience
- Employs existing and modest augmentation of existing launch vehicles
- Common architecture elements for all Earth’s Neighborhood missions
- Potential for repairing outbound planetary spacecraft

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**“Transhab” - class inflatable pressure shell (1/2 length)**

**TM-50 Hall Effect Thruster (6x50kWe each)**

**NGST sunshield inflatable deployment concept**
Earth’s Neighborhood

Evolution in Vehicle Designs

Crew Transfer Vehicle

Gateway

(Evolution in Vehicle Designs)

- Advanced Avionics (7%)
- Maintenance & Spares (18%)
- Advanced Materials (17%)
- Aerobraking (42%)
- Closed Life Support (34%)
- Advanced Propulsion (EP) (45%)

- Today

- Gateway (Including Deployment)
Mission Architecture Summary

LUNAR SURFACE

1) GATEWAY WITH SOLAR ELECTRIC PROPULSION STAGE TO L₁
2) SOLAR ELECTRIC PROPULSION STAGE TO LEO
3) L₁ LUNAR LANDER TO LEO, AUTO RNDZ & DOCK
4) L₁ LUNAR LANDER TO GATEWAY
5) LUNAR TRANSFER VEHICLE (LTV) TO ISS
6) LOGI-PACK AND CREW TO ISS
7) KICK STAGE TO ISS VICINITY
8) LTV, LOGI-PACK AND KICK STAGE, AND CREW TO GATEWAY
9) CREW AND L₁ Lunar Lander TO LUNAR SURFACE
10) CREW AND L₁ Lunar Lander TO L₁
11) CREW AND LTV AEROBRAKE TO ISS
12) CREW AND LOGI-PACK TO EARTH VIA SHUTTLE
13) SOLAR ELECTRIC PROPULSION STAGE TO LEO
14) LUNAR HABITAT LANDER TO LEO, AUTO RNDZ & DOCK
15) TO LUNAR SURFACE

LEO

DELTA IV HEAVYS
SHUTTLE
DELTA IV HEAVY
SHUTTLE
DELTA IV HEAVYS
**Simplifying Exploration Infrastructure**

- **Space Super Highways** are corridors through the Solar System that balance the gravitational forces of the Sun and the Planets.
- Vehicles require minimal thrust and mass to move from one Libration point to another.
- Earth System to Mars System transfers have the potential to transfer cargo at significant cost reduction over previous trajectory designs.
Potential “Earth’s Neighborhood” Destinations

Interplanetary Destinations

Earth-Moon Gateway

Earth-Sun
L_1

L_2

Earth-Sun

Lunar Science

• Establish Impact History in Inner Solar System
• Determine Composition of Lunar Mantle
• Insight into Past and Current Solar Activity
• Poles - History of Volatiles in Solar System

Lunar Science

Construct and Deploy, and Service Advanced Astronomical Instruments

• Determine Physical Characteristics of Planetary Systems of other Stars
• Search for Worlds that Could or Do Harbor Life

Construct and Deploy Solar Sentinels

• Understand Origins of Solar Variability
• Understand Effects on Solar Atmosphere and Heliosphere
• Understand Space Environment of Earth and Other Planets
• Improve Space Weather Forecasting
**Trajectory Options Under Consideration**

- **One-Year Mission**
  - Missions with short Mars surface stays with total mission duration of one year or less

- **Opposition Class Mission**
  - Variations of missions with short Mars surface stays and may include Venus swing-by

- **Conjunction Class Mission**
  - Variations of missions with long Mars surface stays.

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Outbound

Surface Stay

Inbound

Ref. Johnson Space Center
Round-Trip Mars Mission Energy (Delta-V) Variations

**Short-Stay Missions (Opposition Class)**
Minimum delta-v for a 40-day stay

**Long-Stay Missions (Conjunction Class)**
Minimum delta-v

Earth Departure Date

Minimum Total Propulsive DV (Km/sec)

- 30
- 20
- 10
- 0
**Mars Architecture Mass Comparison**

<table>
<thead>
<tr>
<th></th>
<th>Initial Mass in Low Earth Orbit (Metric Tonnes)</th>
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<tbody>
<tr>
<td>1</td>
<td>Short Stay, Chem/Aerocapture</td>
</tr>
<tr>
<td>2</td>
<td>Short Stay, Chem/Aerocapture</td>
</tr>
<tr>
<td>3</td>
<td>Short-Stay, Nuclear Thermal Rocket (NTR)</td>
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<tr>
<td>4</td>
<td>Short Stay, NTR</td>
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<tr>
<td>5</td>
<td>Long Stay, NTR, ISRU, Dual-Hab</td>
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<tr>
<td>6</td>
<td>Long Stay, NTR, ISRU, Single-Hab</td>
</tr>
<tr>
<td>7</td>
<td>Long Stay, DRM 4 Refinement (NTR or SEP)</td>
</tr>
<tr>
<td>8</td>
<td>Long Stay, Dual Landers, Solar Electric (SEP)</td>
</tr>
<tr>
<td>9</td>
<td>Short Stay (Best Opp.) (NTR or SEP)</td>
</tr>
</tbody>
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ISS @ Assembly Complete (470 tons)
Solar Electric Propulsion Concept

- Array sized to provide 1700 kWₑ throughout first mission
- 14700 m² CuInS₂ array area
- 171 m span (wingtip-wingtip)
- 17 x 100 kWₑ Hall Thruster Propulsion
- Articulated boom thruster

ISS Mass ≈ 470 MT
SEP-TV dry mass ≈ 36 MT
### Mars Mission Vehicle Concepts

#### Mars Transit Vehicle
- Supports mission crew of six for up to 200-day transits to and from Mars
- Return propulsion stage integrated with transit system
- Provides return-to Earth abort capability for up to 30 hours post-TMI
- Total Vehicle Mass in High-Earth Orbit = 188 mt

#### Mars Surface Habitat
- Vehicle supports mission crew of six for up to 18 months on the surface of Mars
- Provides robust exploration and science capabilities
- Descent vehicle capable of landing 36,000 kg
- Total Vehicle Mass in High-Earth Orbit = 99 mt

#### Descent/Ascent Vehicle
- Transports six crew from Mars orbit to the surface and back to orbit
- Provides contingency abort-to-orbit capability
- Supports six crew for 30-days
- Vehicle capable of utilizing locally produced propellants
- Total Vehicle Mass in High-Earth Orbit = 103 mt
Lander Dimensions

Habitat Lander

Descent / Ascent Vehicle

Inflatable Habitat

Crew Module
Habitat Lander and Ascent/Descent Vehicles delivered to Low Earth Orbit with Magnum. Solar Electric Propulsion stage spirals cargo to High Earth Orbit. Chemical injection used at perigee. SEP spirals back to LEO for reuse.

Transit Habitat vehicle delivered to LEO with Magnum. SEP spirals Transit Habitat to High Earth Orbit. Crew delivered to vehicle via crew taxi. SEP spirals back to LEO for reuse.

Surface Habitat and exploration gear aerocaptures into Mars orbit. Ascent/Descent Vehicle aerocaptures and remains in Mars orbit for the crew.

Crew travels to Mars in "fast transit" 180-day transfer. Aerobrakes into Mars orbit.

Crew rendezvous with Descent/Ascent Vehicle in Mars Orbit then lands in vicinity of Habitat Lander.

Crew ascends and rendezvous with waiting Transit Habitat.

Crew returns to Earth on "fast transit" 180-day transfer. Direct entry at Earth.

30 days provided to satisfy "long-stay" criteria.

Initial outpost established.

Crew lands and performs initial setup and checkout - Initial outpost established.

Mars Surface
**Mars Mid-term Case Study Set 2 Results**

![Chart showing initial mass in LEO for different cases and mission durations.](chart.png)


Ref. Johnson Space Center
Mission Sequence
High Earth Orbit Boost Phase

UNPILOTED VEHICLES

“Shuttle Class” 2 SEP launched to low Earth orbit
“Shuttle Class” 3 Descent/Ascent vehicle, aerobrake, and TMI stage launched LEO
“Shuttle Class” 4 Surface Habitat Lander, aerobrake, and TMI stage launched LEO
SEP vehicles boost Descent/Ascent and Surface Habitat landers to High Earth Orbit
STS 4 / Taxi Servicing mission in High Earth Orbit

PILOTED VEHICLES

“Shuttle Class” 1 Transit Habitat launched to low Earth orbit
STS 1 & 2 Transit Habitat outfitting missions
“Shuttle Class” 5 Transit Habitat SEP vehicle launched to low Earth orbit
“Shuttle Class” 6 Transit Habitat propulsion stages launched to low Earth orbit
SEP vehicle boosts Transit Habitat to High Earth Orbit
STS 3 / Taxi Transit Habitat servicing mission in High Earth Orbit
TOTAL LAUNCH MASS
- 450 Metric Tonnes

Launch Reliability = 99.7%
(STS Reliability)

97% (EELV Reliability Req.)

94% (World-wide Reliability)

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Effects of “Launch Package” Size

- Range of individual launch package masses have been assessed for exploration missions
- Package sizes in the range of current launch capabilities show significant disadvantages
  - Mass efficiency losses due to non-optimal packaging - ISS experience is ~70% utilization
  - Design inefficiencies for large volumes (prop tanks, habitat module)
    - Increase in interfaces
    - Excessive mass for bulkheads, docking mechanisms, plumbing
  - Increased reliance on on-orbit construction of flight-critical structures
    - Heat shields, aerobrakes
  - Reliability of launch vehicle would need to be extremely high for successful launch of all components
- Payloads consistent with STS-level GLOW launch vehicle could orbit 80-100 metric tons
  - Could relieve these concerns
  - Could have small impact to current launch infrastructure
Exploration Requirements

- Payload Mass- 80 to 100 metric tons (100 preferred)
- Delivery to 28.5 degree inclination, 407 km altitude
- Rendezvous with pre-deployed assets in Earth orbit
- Volume- 8m dia. X 30m length
- Reliability- 99.7% or better (Shuttle Equivalent)
- Goal- $1000 per pound
- Cargo launch Shroud= Mars entry heat shield
Summary

• NASA has conducted human Mars mission studies for more than 12 years
  – Variety of mission goals
  – Variety of mission durations
  – Variety of assumptions in technology employed
• Total initial mission mass in low earth orbit has varied from 400 to 1400 metric tons to send a crew to Mars
• Current estimated mass~ 450 metric tons
• Launch package sizes on the order of 80 to 100 metric tons allow for simplest interfaces between vehicle components