NASA Exploration Team (NExT)
In-Space Transportation Overview

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Enabling the Strategy

The Hurdles

• Space Transportation
  – Safe, fast, and efficient

• Affordable, Abundant Power
  – Solar and nuclear

• Crew Health and Safety
  – Countermeasures and medical autonomy

• Optimized Robotic and Human Operations
  – Dramatically higher productivity; on-site intelligence

• Space Systems Performance
  – Advanced materials, low-mass, self-healing, self-assembly, self-sufficiency...

The Criteria

• Compelling science objectives and benefits

• Knowledge about destinations

• Reliable and affordable mission concepts

• Acceptable technology readiness achieved

• Validation of capabilities for deep space missions

• Identified opportunities for partnership/leadership

• Inspiring and engaging to students and the public
Exploration of Earth’s Neighborhood

Human Mars Exploration
- Technology Development
- Deep-Space Operational Experience
- Mission Staging

Earth’s Neighborhood” Capabilities

Construct, Deploy, and Service Advanced Astronomical Instruments
- Detect Biological Activity on Extra-Solar Planets
- Image Surfaces of Extra-Solar Planets
- Search for Location and Mechanism of Solar Flares
- Increase Lead Time and Accuracy for Geospace Forecasts

Commercialization Opportunities
- Lunar Oxygen or Water Production
- Regolith Materials Processing
- Fuel Depot

Lunar Science
- Impact History in Near-Earth Space
- Composition of Lunar Mantle
- Past and Current Solar Activity
- Poles - History of Volatiles in Solar System
Earth's Neighborhood Architecture & Elements

Crew departs from LEO and returns to Earth

Lunar Transfer Vehicle
- Transports crew between LEO and Lunar $L_1$ (4-6 day trip)
- Nominal aerocapture-entry with contingency direct Earth return

High-Energy Propulsion Stage
- High-efficiency stage used to deliver cargo from LEO to a final destination.

Earth-Moon $L_1$ Outpost
- "Gateway" to the Lunar surface
- Outpost for staging missions to Moon, Mars and telescope construction

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

Lunar Habitat
- 30-day surface habitat placed at Lunar South Pole

Low-Energy Transfer
"Interplanetary Superhighway"

Earth $L_2$

Moon

Mars
Earth’s Neighborhood Transportation Elements

In-Space Transportation
- Deep-space propulsion for capture, orbital maintenance, and element return to Earth
- Key Technologies & Options:
  - Advanced Chemical (CH₄/O₂)
  - Long-term Cyro Storage

High-Energy Injection
- Injects mission payloads from low-Earth orbit (LEO) toward their intended destination
- Key Technologies & Options:
  - Advanced Chemical (H₂/O₂)
  - Solar Electric Propulsion
  - Long-term Cyro Storage

Earth-to-Orbit (ETO)
- Transports cargo elements and crew from Earth to LEO
- Options:
  - Shuttle-derived
  - Evolved EELV

Descent / Ascent
- Deep-space propulsion for descent to and ascent from the lunar surface
- Key Technologies & Options:
  - Advanced Chemical (CH₄/O₂)
  - Long-term Cyro Storage

Earth Return
- High-energy aeroassist for orbital capture and entry of Earth’s atmosphere
- Key Technologies & Options:
  - Advanced Ablators
Mars Mission Trajectory Options

Short-Stay Missions (Opposition Class)
Variations of missions with short Mars surface stays and may include Venus swing-by.

Long-Stay Missions (Conjunction Class)
Variations of missions with long Mars surface stays.
Delta-V Variations

Short-Stay Missions (Opposition Class)

Long-Stay Missions (Conjunction Class)

Earl Launch Date

Earth Departure Date

Minimum Total Propulsive DV (Km/Sec)
Mars Long-Stay Mission Overview Option
(Solar Electric Propulsion Option)

Habitat Lander and Descent/Ascent Vehicles delivered to Low Earth Orbit. Solar Electric Propulsion stages spirals cargo to High Earth Orbit. Chemical injection used at perigee. (Option: SEPs spiral back to LEO for reuse).

Crew travels to Mars in “fast transit” 180-206 day transfer. Aerocaptures into Mars orbit

Transit Habitat vehicle delivered to LEO. SEP spirals Transit Habitat to High Earth Orbit. Crew delivered to vehicle via crew taxi. (Option: SEP spirals back to LEO for reuse).

Surface Habitat and exploration gear aerocaptures into Mars orbit

Descent/Ascent Vehicle aerocaptures and remains in Mars orbit for the crew

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

Crew lands on surface. 30 days provided to satisfy “long-stay” criteria.

In-depth regional exploration (500-600 days). Crew ascends and rendezvous with waiting Transit Habitat

Crew returns to Earth on “fast transit” 180-206 day transfer.

Total mission duration: 892-945 days
Time on Mars surface: 500-600 days

Ref. Johnson Space Center
Mars Architecture

Key Attributes

- Crew of 4-6
- Short (30-day) initial visits for focused local science evolving to long (500-day) stays for extensive regional exploration
- Total mission durations range from 365 to 950 days.
- Capability to go to Mars any opportunity
- Maximum use of capabilities developed for Earth’s Neighborhood
- Ability to introduce new technologies as they are developed
- Advanced transportation and enhanced launch capacity required to reduce risk and architecture cost
Mars Exploration Transportation Elements

**In-Space Transportation**
- Deep-space propulsion for element delivery and return to Earth
- Key Technologies & Options:
  - Nuclear Electric Propulsion
  - Solar Electric Propulsion
  - Advanced Chemical

**Aeroassist**
- Utilization of Mars atmosphere for capture, entry, and descent
- Key Technologies & Options:
  - Advanced Ablators
  - Integrated Launch Shroud / Aeroshell

**Descent / Ascent**
- Deep-space propulsion for descent to, and ascent from, the martian surface
- Key Technologies & Options:
  - Advanced Chemical (CH₄/O₂)
  - Long-term Cyro Storage

**Earth-to-Orbit (ETO)**
- Transports cargo elements and crew from Earth to LEO
- Options:
  - Shuttle-derived
  - Clean-sheet approach

**Earth Return**
- High-energy aeroassist for orbital capture and entry of Earth’s atmosphere
- Key Technologies & Options:
  - Advanced Ablators
Mars Architecture Mass History

1 1988 Mars Expedition (Chem A/B)
2 1989 Mars Evolution (Chem A/B)
3 1990 90-Day Study (NTR)
4 1991 Synthesis Group (NTR)
5 1995 DRM 1 Long Stay (NTR)
6 1997 DRM 3 Refinement (NTR)
7 1998 DRM 4 Refinement (NTR or SEP)
8 1999 Dual Landers (SEP)
9 2000 Short Stay (NTR or SEP)

ISS @ Assembly Complete (470 tons)
Mars Mission Launches Required and Associated Reliability

**Launch Reliability = 99.7%**
(STS Reliability)

**97% (EELV Reliability Req.)**

**94% (World-wide Reliability)**

- Integral Aerobrakes Lost
- Integral Injection Stages Lost
- Packaging Inefficiencies Increase
- Onorbit Integration Complexity Increases

**Total Launch Mass**
- 450 mt

**Payload per Launch (Metric Tonnes)**

**Number of Launches Required**

**Cumulative Launch Reliability**

**Loss of Commonality with STS Infrastructure**
Nuclear Electric Propulsion Advantages

- **High propulsive performance**
  - Captures energetically challenging Mars missions in all opportunities (for ~ same prop mass)

- **High power availability**
  - Robust power for crew, spacecraft systems (<1% of propulsion requirements)

- **Potential technology convergence with advanced robotic exploration and NSI**
  - Reactor, power conversion, thrusters
  - Human exploration nuclear power requirements ready to submit to Nuclear Space Initiative

- **Potential convergence with technology development of surface nuclear power**
  - Moon -> 14 days (non-polar) at fixed location
  - Mars – “long” stay

- **Allows Sustainable, Evolvable Exploration Capability**
  - High reactor energy content and low prop mass fraction allows high degree of vehicle reusability for Mars missions
  - Evolution of power/propulsion possible to even more ambitious missions
Artificial Gravity (AG) Option

- Alternative to long-duration μ-g crew countermeasures
  - 1-g @ 4 rpm
- May simplify qualification of some spacecraft systems
  - Ameliorates extensive μ-g qualification
- Impacts currently under study
  - Vehicle design
  - Mass penalty
  - Mission capabilities
  - Operational considerations
  - No show-stoppers so far
- Good synergism between AG requirements and NEP vehicle characteristics
  - Booms/masts for rad exposure amelioration and AG moment arm
  - “Power module” as counterweight
- May greatly enhance short-stay missions
  - Crew readaptation time avoided
**Key In-Space Transportation Technology Options & Needs**

**Earth-to-Orbit Launch**

**Application:** Affordable delivery of cargo elements and crew from Earth to LEO.

**Needs:** 80-100 mt with payload volumes up to 10 m x 30 m.

**Key Options:** Shuttle derived or clean sheet approaches

**Advanced Chemical Propulsion**

**Application:** High energy injection stages for transportation of elements in near-Earth space. Advanced chemical engines for descent and ascent at planetary destinations.

**Needs:** 5-6 klbf throttleable engines which are compatible with utilization of local resources.

**Key Options:** O2/Methane, O2/Hydrogen

**Electric Propulsion**

**Application:** High-efficiency propulsion for delivery of cargo and crew elements from Earth vicinity to planetary destinations & return.

**Key Options:** 6-20 MWe nuclear electric.

1-3 MWe solar electric (combined with chemical injection stages and aeroassist at Mars).
**Key In-Space Transportation Technology Options & Needs**

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**Aeroassist**

**Application:** Utilization of planetary atmospheres (Mars and Earth return) for orbital capture, entry, descent, and landing.

**Needs:** Arrival speeds of 7.4 km/s (Mars) and 11.0 – 13.5 km/s (Earth return).

**Key Options:** Advanced ablators. Integrated aeroshell/payload shroud concepts.

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**Cryogenic Fluid Management**

**Application:** Long-term storage of cryogenic fluids in space and on planetary surfaces.

**Needs:** Storage of cryogenic fluids (H₂, O₂, CH₄) for up to 1200 days.

**Key Options:** Combination of passive and active systems.