Advanced Development

Mars Architecture Mass Comparison

ISS @ Assembly Complete (470 tons)

<table>
<thead>
<tr>
<th>Year</th>
<th>Study Description</th>
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<tbody>
<tr>
<td>1988</td>
<td>1988 Mars Expedition (Chem A/B)</td>
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<td>1989</td>
<td>1989 Mars Evolution (Chem A/B)</td>
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<td>1990</td>
<td>1990 90-Day Study (NTR)</td>
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<td>1991</td>
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<td>1995 DRM 1 Long Stay (NTR)</td>
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<td>1997</td>
<td>1997 DRM 3 Refinement (NTR)</td>
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<td>1998</td>
<td>1998 DRM 4 Refinement (NTR or SEP)</td>
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<td>1999</td>
<td>1999 Latest Results (SEP)</td>
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**High Earth Orbit Staging Mission Scenarios**

- **Elliptical Parking Orbit (EPO)**
- **Earth Space Station Orbit (LEO)**
- **Mars Aerocapture**
- **Chemical Injection Burn**
- **Crew Transfer via Crew Taxi**
- **EP Transfer**
- **Chem Transfer**
- **Rendezvous**

**Near Earth Asteroids**

**Libration Points**

**Moon**

**Mars**
Human Exploration Common Capabilities

Earth to Orbit Transportation
- Moon (follow on)
- Asteroids
- Mars

Interplanetary Habitation
- Moon
- Sun-Earth Libration
- Asteroids
- Mars

Crew Taxi / Return
- Moon
- Sun-Earth Libration
- Asteroids
- Mars

EVA & Surface Mobility
- Moon
- Mars
- Asteroids

Advanced Space Transportation Options
- Advanced Chemical
  - "Small"
    - Moon (follow on)
    - Sun-Earth Libration
    - Asteroids
    - Mars
  - "Large"
    - Asteroids
    - Mars
- Electric Propulsion
  - <500 kWe
    - Moon
    - Sun-Earth Libration
    - Mars Outpost
  - >1 MWe
    - Asteroids
    - Mars
- Nuclear Thermal
  - Asteroids
  - Mars
  - Moon (follow-on)

In-Situ Resource Utilization
- Moon
- Mars

Com/Nav Infrastructure
- Moon
- Mars
Architecture Evolution

- Common Technologies
  - Solar Electric Propulsion
  - Habitation Systems
  - Crew Transportation
  - Advanced EVA

- Unique Orbital Dynamics
  - Human Activities at Earth-Moon L1
  - Remote Delivery, Retrieval of Science Instruments
The Value of Technology Investments
Mars Mission Example

NOTES:
• Results are cumulative and thus trends will be different for different technology combinations/sequences
• The change between points shows the relative mass savings for that particular technology
• 2018 One-Year Round-Trip Mission, Crew of 4, Lander pre-deployed

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

- Orbital Dynamics in Earth-Moon System Leads to Unique Capabilities
  - Low-Energy Transfer from Earth-Moon L1 to Solar Libration Points and Return
  - Potential Staging Point for Human Mars Missions
- Allows for Earth-Moon L1 Deployment and Servicing of Science Assets
**Human Mars Exploration**
- Technology Development
- Deep-Space Operational Experience
- Mission Staging (Hybrid Prop Module Fuel Depot)

**“Earth’s Neighborhood” Capabilities**

**Construct, Deploy, and Service**

**Advanced Astronomical Instruments**
- Detect Biological Activity on Extra-Solar Planets
- Image Surfaces of Extra-Solar Planets

**Construct and Deploy Solar Sentinels**
- Search for Location and Mechanism of Solar Flares
- Increase Lead Time and Accuracy for Geospace Forecasts

**Lunar Science**
- Impact History in Near-Earth Space
- Composition of Lunar Mantle
- Past and Current Solar Activity
- Poles - History of Volatiles in Solar System
Evolutionary Elements

<table>
<thead>
<tr>
<th>Earth-to-Orbit</th>
<th>Earth’s Neighborhood</th>
<th>Asteroids</th>
<th>Mars</th>
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</thead>
<tbody>
<tr>
<td>Existing/Planned</td>
<td>Lx</td>
<td>Moon</td>
<td>Solar Electric</td>
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<td>New</td>
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Advanced Development

Earth’s Neighborhood

Lx

Moon

Asteroids

Mars

Habitation

Crew Taxi

Space Power

Transportation

Solar Electric

Nuclear Electric

In-Situ Resources

EVA

Advanced Development
### Exploration Common Capabilities

#### Potential Destinations

- **Medium Earth Orbit**
  - High Earth Orbit
  - Geosynchronous Orbit
  - Earth-Moon L₁
  - Lunar Vicinity
  - Earth-Sun L₂

- **Lunar Vicinity**
  - Lunar Vicinity
  - Earth-Sun L₂

- **Near-Earth Asteroids**
  - Near-Earth Asteroids
  - Mars

#### Capabilities

- **MEO Sorties**
  - HEO Sorties
  - High-Speed Aerocapture

- **Low-Speed Aerocapture**
  - HEO Sorties
  - High-Speed Aerocapture

- **Extended-Duration Operations Beyond LEO**
  - Construction, Maintenance at Libration Points

- **Extended-Duration Operations in Deep Space**
  - Human Missions to Mars

#### Elements

- **Crew Transfer Vehicle**
  - EELV Heavy and Derivatives
  - High Energy Injection Stage

- **Deep-Space Habitation ("Gateways")**
  - Electric Propulsion
  - Advanced In-Space EVA

- **Advanced Electric Propulsion**
  - Planetary Surface Access

- **Construction, Maintenance at Libration Points**
  - Construction, Maintenance at Libration Points

- **Advanced Development**
  - Advanced Development

### Exploration Common Capabilities

- **Potential Destinations**
  - Medium Earth Orbit
  - Lunar Vicinity
  - Near-Earth Asteroids

- **Capabilities**
  - MEO Sorties
  - Low-Speed Aerocapture

- **Elements**
  - Crew Transfer Vehicle
  - Deep-Space Habitation ("Gateways")
POTENTIAL DESTINATIONS

- LOW EARTH ORBIT
- MEDIUM EARTH ORBIT
- HIGH EARTH ORBIT
- GEOSYNCHRONOUS ORBIT
- EARTH-MOON L₁
- LUNAR VICINITY
- EARTH-SUN L₂
- LUNAR SURFACE

CAPABILITIES

- EXTENDED-DURATION LOW EARTH ORBIT OPERATIONS
- MEO SORTIES
- LOW-SPEED AEROCAPTURE
- HEO SORTIES
- HIGH-SPEED AEROCAPTURE
- EXTENDED-DURATION OPERATIONS BEYOND LEO
- CONSTRUCTION, MAINTENANCE AT LIBRATION POINTS
- GLOBAL LUNAR SURFACE ACCESS

ELEMENTS

- SPACE SHUTTLE
- ISS
- CREW TRANSFER VEHICLE
- EELV HEAVY and DERIVATIVES
- HIGH ENERGY INJECTION STAGE
- DEEP-SPACE HABITATION ("GATEWAYS")
- ELECTRIC PROPULSION
- ADVANCED IN-SPACE EVA
- LUNAR LANDER
- SURFACE SUPPORT SYSTEMS
- ADVANCED SURFACE EVA

POTENTIAL DESTINATIONS

- LOW EARTH ORBIT
- MEDIUM EARTH ORBIT
- HIGH EARTH ORBIT
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- SURFACE SUPPORT SYSTEMS
- ADVANCED SURFACE EVA
Core Capabilities & Technologies

Common Technology Building Blocks
(Core Technologies)

Common System Building Blocks
(Core Capabilities)

Potential Destinations

Examples

Efficient In-Space Prop.
Aeroassist
Low-cost Engines
Cryo Fluid Management
Robust/Efficient Power
Lightweight structures
Radiation Research
Zero/Low-g Research
Regenerable Life Support
Advanced Lightweight EVA

“Breakthrough” Technologies

System Design

Mission Analyses

Examples of potential technologies and systems include:

- Efficient In-Space Prop.
- Aeroassist
- Low-cost Engines
- Cryo Fluid Management
- Robust/Efficient Power
- Lightweight structures systems, sensors, micro/nano electronics
- Radiation Research
- Zero/Low-g Research
- Regenerable Life Support
- Advanced Lightweight EVA

“Breakthrough” Technologies in various mission scenarios.
1) Ion Propulsion to Earth Transfer Trajectory

2) Heliocentric Ballistic Return Targeted to "Miss" Earth (by a lot)

3) Ion Propulsion Targets Capture into Very High Earth Orbit (HEO)

4) Ion Propulsion Performs Gradual Orbit Transfer from HEO to LEO

5) LEO Rendezvous & Acquisition by Shuttle

Solar Electric Propulsion Mars Sample Return Spacecraft

Sample Containment Vault

Shuttle Retrieval
Human/Robotic Mars Critical Technology Investments

**Higher Efficiency Aero-Entry**
- SOA is 70’s Viking shape
- Poor launch vehicle packaging efficiency, limited maneuvering capability
- Bi-Conic or “Ellipsled” shapes offer superior performance

**Precision Landing**
- Three-sigma footprint reduction from 200x100 km to less than 10x10 km predicted

**Solar Electric Propulsion**
- Mass reduction over chemical
- Opens new mission options (MSR to earth orbit)

**Hazard Avoidance**
- JSC participating with ARC, JPL, LaRC to develop autonomous system
- Apollo-LEM-based algorithms combined with LIDAR system show significant potential
The Value of Technology Investments
Mars Mission Example

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Advanced Materials (14%)
Maintenance & Spares (21%)
Advanced Avionics (11%)
Closed Loop Life Support (19%)
Advanced Propulsion (EP or Nuclear) (46%)
Aerocapture (50%)
All Propulsive Chemical