In June 1999 the NASA Administrator chartered an internal NASA task force, termed the Decadal Planning Team, to create new integrated vision and strategy for space exploration. The efforts of the Decadal Planning Team evolved into the Agency-wide team known as the NASA Exploration Team (NEXT). This team was also instructed to identify technology roadmaps to enable the science-driven exploration vision, established a cross-Enterprise, cross-Center systems engineering team with emphasis focused on revolutionary not evolutionary approaches. The strategy of the DPT and NEXT teams was to “Go Anywhere, Anytime” by conquering key exploration hurdles of space transportation, crew health and safety, human/robotic partnerships, affordable abundant power, and advanced space systems performance. Early emphasis was placed on revolutionary exploration concepts such as rail gun and electromagnetic launchers, propellant depots, retrograde trajectories, nano structures, and gas core nuclear rockets to name a few. Many of these revolutionary concepts turned out to be either not feasible for human exploration missions or well beyond expected technology readiness for near-term implementation. During the DPT and NEXT study cycles, several architectures were analyzed including missions to the Earth-Sun Libration Point (L2), the Earth-Moon Gateway and L1, the lunar surface, Mars (both short and long stays), one-year round trip Mars, and near-Earth asteroids. Common emphasis of these studies included utilization of the Earth-Moon Libration Point (L1) as a staging point for exploration activities, current (Shuttle) and near-term launch capabilities (EELV), advanced propulsion, and robust space power. Although there was much emphasis placed on utilization of existing launch capabilities, the team concluded that missions in near-Earth space are only marginally feasible and human missions to Mars were not feasible without a heavy lift launch capability. In addition, the team concluded that missions in Earth’s neighborhood, such as to the Moon, can serve as stepping-stones toward further deep-space missions in terms of proving systems, technologies, and operational concepts.

The material contained in this presentation was compiled to capture the work performed by the Mars Sub-Team of the DPT NEXT efforts in the late 1999-2001 timeframe.
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## CONTENTS

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DPT Mars Short-Stay Mission

Architecture Status

Mid-Term (2018) Nuclear Thermal Propulsion System Option

Bret G. Drake
NASA/Johnson Space Center

July 11, 2000
Outline

• Ground Rules and Assumptions
• Trajectory Options
• Mission Case Studies
• Systems Overview
  – Transit Habitat
  – Descent / Ascent Vehicle
  – Interplanetary Transportation
• Technology Needs
• Architecture Summary
Guiding Principles

• Go Anywhere - Go Anytime

• Avoid political obstacles - No HLLV

• Limit the total mission duration (goal of one-year)

• Push advanced technologies
  – Advanced space transportation - NTR
  – Advanced materials (factor of 9)
Mars Short-Stay Ground Rules and Assumptions

- Detailed GR&A provided in the “Mars ‘Short-Mission’ Scenario/Architecture GR&A” document dated 4-10-2000

- Primary DPT GR&A which drive this architecture include:
  - “Go Anywhere – Go Anytime” Philosophy
  - Short stay on Mars
  - Short total mission duration – goal of one year round-trip
  - First cargo mission 2016, First human mission 2018
  - Four crew
  - Zero-g transits
  - Technology freeze to TRL 6 by 2011
  - Factor of nine improvement for primary and secondary structures
  - Transportation Assumptions
    - EELV-H for cargo delivery to Earth orbit
    - Bi-Modal Nuclear Thermal Propulsion for interplanetary transits
    - Long-term cryogenic fluids storage
Purpose of Architecture Analysis

• Development of architectures serve as an “Existence Proof” of the various technology options and mission approaches under consideration
  – Feasibility check
  – Plausibility

• Architecture analysis includes detailed end-to-end analysis of
  – Mission goals and objectives
  – Mission sequence
  – Approaches to minimizing risks and maximizing crew safety
  – Vehicles and systems
  – Technology applicability and benefits
  – System drivers
  – Operations concepts
  – Schedules

From Earth – to the destination – back to Earth
Study Process

**Initial Payload Definition** (JSC)
- Transit Habitat
- Descent/Ascent Vehicle

**Transportation Studies** (MSFC)
- Abundant Chemical, Tethers, EP, NTR, VASIMR, Pulsed Detonation, M2P2, Beamed MPD, etc.

**Payload / Mission Refinement** (JSC)
- Trajectory Options
- Advanced Materials
- Trip-time sensitivities
- Vehicle configurations

**Results and Issues** (Architecture Team)

**NTR Case Study Analysis** (GRC)
- Feasibility
- Initial Mass in LEO
- Number of Launches

**NTR Concept Initialized** (Architecture Team)
- Initialization Package
- Case Studies Defined
- System Concepts Refined

**Architecture Refinement**
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.
Total Mission $\Delta V$ vs Earth Departure Date

Short-Stay Mars Missions

**Assumptions**
- All propulsive mission
- Earth parking orbit = 407 km
- Mars parking orbit = 500 km
- 40 day Mars stay
- Figure of merit = Total $\Delta V$ (all legs)

---

**Mission $\Delta V$ (m/s)**

**Earth Departure Date**
- 01-Jan-15
- 31-Dec-16
- 31-Dec-18
- 30-Dec-20
- 30-Dec-22
- 29-Dec-24
- 29-Dec-26
- 28-Dec-28
- 28-Dec-30
- 27-Dec-32

**Local Min $\Delta V$**
- Venus Swby

**Local Min $\Delta V$ (Return Leg)**
- No Inbound Venus Swingby
- Inbound Venus Swingby

**365 Day Mission**
- No Venus Swby

**One Way Cargo**
- 275 day
- 205 day
- 206 day
- 347 day
- 332 day
- 312 day
- 300 day
Minimum Solar Distance vs. Mission Opportunity
Short-Stay Mars Missions

Radiation doses during solar fly-by can increase 2-8 times

- Assumptions:
  - All propulsive mission
  - Earth parking orbit = 407 km
  - Mars parking orbit = 500 km
  - 40 day Mars stay
  - Figure of merit = Total $\Delta V$ (all legs)
  - All minimum solar distances are due to inbound leg(s) unless accompanied by an "O" indicating minimum solar distance due to the outbound leg.

- Earth Departure Date:
  - 1-Jan-15 to 27-Dec-32

- Missions:
  - 365 Day Mission No Venus Swby (unless indicated)
  - Local Min $\Delta V$ No Venus Swby
  - Local Min $\Delta V$ Venus Swby (Return Leg Only)
  - Long-Stay Mission with Fast Transits to/from Mars

G. Condon/JSC/EG
Mars Short-Stay Initial Case Studies

- Prior to performing detailed architectural analysis a series of focused case studies were conducted.

- Primary case study variables included:
  - WORST versus BEST mission opportunity
  - HIGH versus LOW Mars parking orbit
  - Pre-deploy LANDER versus pre-deploy LANDER & RETURN VEHICLE

- The results were used to determine the relative benefits and technology needs for the various mission approaches under consideration.
## Mars Short-Stay Initial Case Studies

<table>
<thead>
<tr>
<th>Opportunity</th>
<th>Energy Level</th>
<th>Trip Time</th>
<th>Mars Orbit</th>
<th>Pre-Deploy</th>
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<td>6.1</td>
<td>Worst (2026)</td>
<td>Minimize $\Delta V$</td>
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<td>250 x 33,793 km</td>
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<td>Minimize $DV$</td>
<td>&lt; 650 days</td>
<td>250 x 33,793 km</td>
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</table>
**Mars Mission Overview**
*(NTR Option)*

**Cargo Vehicles Delivered to Low-Earth Orbit via EELV-H Launch Vehicles**
- Descent-Ascent Lander
- Descent-Ascent Lander NTR
- Earth Return NTR
- Earth Return Propellant
- TMI/MOI Propellant

**Ascent/Descent Vehicle**
- Aerocaptures and remains in Mars orbit for the crew

**Earth return vehicle**
- Propulsively captures into Mars orbit and remains

**Crew travels to Mars. Propulsively captures into Mars orbit**

**Crew rendezvous with Descent/Ascent Vehicle and Earth Return Vehicle**

**Crew ascends and rendezvous with waiting Earth Return Vehicle**

**Crew returns to Earth with Direct entry at Earth**

**30 day Science mission**

**Earth Orbit**

**Mars Surface**
Short-Stay Mission Sequence

Mission 1
1 Cargo

Mission 2
2 Crew

Mission 3
3 Cargo

Mission 4
4 Crew

Mission 5
5 Cargo

Mission 6
6 Crew

Mission 7
7 Cargo

Mission 8
8 Crew

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<td>8 Crew</td>
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</tbody>
</table>

- Return Vehicle
- Descent/Ascent
- Crew Transits
- Surface Mission
- Cargo Outbound
- Unoccupied Wait
Mars Short-Stay Mission
Initial NTR Case Study Results

Worst Opportunity
(2026 No Swing-by)

Best Opportunity (2018)

Initial Mass in LEO (mt)

Descent / Ascent Vehicle
Piloted Round-Trip
Piloted Earth-Return
Piloted Outbound

ISS at Assembly Complete
(470 t)

Long Stay Mission

Ref. Glenn Research Center
EELV-H Launch/Assembly Scenario

LANDER AND RETURN PROPELLANT

4 Vehicle
3 Propellant Tanks

9 Vehicle
7 Propellant Tanks

Cargo Launches
Lander Ascent,
Descent Aerobrake assembled in LEO

STS
Crew involvement TBD

Cargo Launches
NTR cargo vehicle & crew return vehicle launched & assembled

STS
Crew involvement TBD

PILOTED VEHICLE

4 Vehicle
2 Propellant Tanks

STS
Transit Habitat, Earth Return Capsule

Cargo Launches
NTR piloted vehicle launched & assembled

STS
Crew involvement TBD

STS
Crew Delivery

Placeholder for NTR Graphic
## Mars Short-Stay Launch Strategy
### EELV-H Option (Best Opportunity Example)

*Best Opportunity (2018) Pre-Deploy Lander and Return Vehicle*

### Assumptions:
- Evolved commercial EELV, heavy lift option, with exploration unique upper stage
- Large shroud assumed (8 x 30 m)
- 35 mt lift capacity due east (assumed performance - no data yet)
- Only mission hardware considered (need for on-orbit infrastructure not yet determined)
- Crew support for on-orbit assembly, outfitting, and checkout not yet addressed
- Launch rate shown does not support continuous exploration (cargo launches must be supported in the 2018 launch opportunity)
- Detailed analysis not yet complete

<table>
<thead>
<tr>
<th>Launch #</th>
<th>Descent / Ascent Vehicle</th>
<th>Vehicle Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ascent Stage</td>
<td>Delta IV-H</td>
</tr>
<tr>
<td>2</td>
<td>Aerobrake / Deorbit Descent Stage</td>
<td>Delta IV-H</td>
</tr>
<tr>
<td>3</td>
<td>Propellants</td>
<td>Delta IV-H</td>
</tr>
<tr>
<td>4</td>
<td>NTR Core Stage</td>
<td>Delta IV-H</td>
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<tr>
<td>5</td>
<td>NTR Structure Assembly</td>
<td>Delta IV-H</td>
</tr>
<tr>
<td>6</td>
<td>NTR Propellant Tank</td>
<td>Delta IV-H</td>
</tr>
<tr>
<td>7</td>
<td>NTR Propellant Tank</td>
<td>Delta IV-H</td>
</tr>
</tbody>
</table>

### Earth Return Vehicle

| 8        | NTR Core Stage           | Delta IV-H   |
| 9        | NTR Structure Assembly   | Delta IV-H   |
| 10       | NTR Propellant Tank      | Delta IV-H   |
| 11       | NTR Propellant Tank      | Delta IV-H   |
| 12       | NTR Propellant Tank      | Delta IV-H   |
| 13       | NTR Propellant Tank      | Delta IV-M   |
| 14       | NTR Propellant Tank      | Delta IV-H   |
| 15       | NTR Propellant Tank      | Delta IV-H   |
| 16       | NTR Propellant Tank      | Delta IV-M   |

### Transit Habitat

| 17       | Transit Habitat          | Delta IV-H   |
| 18       | Habitat Consumables / ERC / Shadow Shield | Shuttle |
| 19       | NTR Core Stage            | Delta IV-H   |
| 20       | NTR Structure Assembly    | Delta IV-H   |
| 21       | NTR Tank Set 2            | Delta IV-H   |
| 22       | NTR Tank Set 3            | Delta IV-H   |
| 23       | Checkout Crew             | Shuttle      |
| 24       | Flight Crew               | Shuttle      |

Cargo launches for next mission
"Shuttle Compatible" Launch/Assembly Scenario

LANDER AND RETURN PROPELLANT

2

- Cargo Launches Descent/Ascent Vehicle
- STS No Crew involvement

4 Propellant Tanks

- Cargo Launches NTR cargo vehicle & crew return vehicle launched & assembled
- STS Crew involvement TBD

PILOTED VEHICLE

1

- STS Transit Habitat, Earth Return Capsule
- Cargo Launches NTR piloted vehicle launched
- STS Crew Delivery

1 Vehicle
**EELV-H Launch/Assembly Scenario**

**Worst Case (2026) Mission Opportunity**

**LANDER AND RETURN PROPELLANT**

5

- **Cargo Launches**
  - Assembly platform
  - Lander, Aerobrake assembled in LEO

23

- **STS**
  - Crew involvement TBD
- **Cargo Launches**
  - NTR cargo vehicle & crew return vehicle launched & assembled

**PILOTED VEHICLE**

26

- **STS**
  - Transit Habitat, Earth Return Capsule
- **Cargo Launches**
  - NTR piloted vehicle launched & assembled
- **STS**
  - Crew Delivery

**Placeholders for NTR Graphic**
“Shuttle Compatible” Launch/Assembly Scenario
Worst Case (2026) Mission Opportunity

LANDER AND RETURN PROPELLANT

1 Cargo Launches
Descent/Ascent Vehicle

STS No Crew involvement

CARGO LAUNCHES

3 Vehicle
7 Propellant Tanks

CARGO LAUNCHES
NTR cargo vehicle &
crew return vehicle
launched & assembled

STS Crew involvement
TBD

PILOTED VEHICLE

11 Vehicle
9 Propellant Tanks

STS Transit Habitat, Earth
Return Capsule

CARGO LAUNCHES
NTR piloted vehicle
launched & assembled

STS Crew involvement
TBD

STS Crew Delivery
Initial Mars Short-Stay NTR Case Study Findings
Non-Venus Swing-by Option

- It is the consensus of the architecture team that the only way to perform the short-stay, non-Venus swing-by missions in the harder opportunities is to pre-deploy both the lander and return propellant
  - Lowers mission mass by approximately 36% (return propellant pre-deployed on minimum energy transfers)
  - Increases risk: rendezvous in Mars orbit must be performed for crew survival (return)
  - Increases operating time of crew systems by 114% (as compared to non pre-deploy missions)

- Number of launches required poses a significant challenge
  - # of EELV-H launches = 54 (1 launch every 2 weeks)
  - # of 80 mt Shuttle Compatible launches = 22 (1 launch every 4 weeks)
  - Neither of these launch rates can be sustained
    - No margin for launch failure
    - No margin for launch delay
    - Current production/launch rate for Delta-IV is 14 per year (x 4 current capacity)
  - Probability of mission success significantly decreases with increased launch rate

<table>
<thead>
<tr>
<th>&quot;Go Anywhere / Go Anytime&quot; + Small Launch Vehicle</th>
<th>Launch Vehicle Size / Number of Launches</th>
<th>Launch Vehicle Reliability</th>
<th>Probability of Successful Launches</th>
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<tr>
<td>EELV-H / 54</td>
<td>94%</td>
<td>4%</td>
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<tr>
<td>EELV-H / 54</td>
<td>99%</td>
<td>58%</td>
<td></td>
</tr>
<tr>
<td>&quot;Shuttle Comp.&quot; / 22</td>
<td>94%</td>
<td>26%</td>
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<tr>
<td>&quot;Shuttle Comp.&quot; / 22</td>
<td>99%</td>
<td>80%</td>
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</table>

Current Industry Launch Success Rate 94%
Utility of Venus Swing-by Trajectories

- Venus swing-by trajectories can significantly decrease mission mass
- Characterized by one short leg combined with a long Venus swing-by leg
- Swing-by occurs on either outbound or inbound leg
- Desired to constrain the swing-by to the inbound leg
  - Short outbound leg maximizes crew health at Mars
  - Crew will have Earth support at end of mission
  - Can save up to 39% delta-V
- Allowing the Venus swing-by on either leg
  - Outbound legs can be up to 310 days long
  - Can save up to 42% delta-V
- Issues of solar distance during swing-by need to be addressed
  - Radiation dose to the crew
  - Thermal environment
## Trajectory Characteristics Comparison

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1-Year</th>
<th>Opposition</th>
<th>Conjunction</th>
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<tbody>
<tr>
<td>Interplanetary Delta-V (m/s)</td>
<td>21,700-31,200</td>
<td>14,800-25,800</td>
<td>5,600-6,700</td>
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<td>Normalized Mass Ratio (for NTR)</td>
<td>5.9 – 16.8</td>
<td>2.7 – 9.3</td>
<td>1.0 – 1.1</td>
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<tr>
<td>Mission Duration (months)</td>
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<tr>
<td>Surface Stay</td>
<td>12</td>
<td>15-22</td>
<td>30-32</td>
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<td>One-Way Transits</td>
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<td>Total Transit Time</td>
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<td>14-21</td>
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<td>Health Concerns</td>
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<td>% Time in Zero-g Space</td>
<td>92%</td>
<td>93-96%</td>
<td>38-44%</td>
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<tr>
<td>% Time on Mars Surface</td>
<td>8%</td>
<td>7-4%</td>
<td>56-62%</td>
</tr>
</tbody>
</table>

### Transit Times (months)

- **Outbound**
- **Surface**
- **Return**

### One-Year Round-Trip

- **Outbound**: 7 months
- **Surface**: 1 month
- **Return**: 4 months

### Typical Opposition Class

- **Outbound**: 6 months
- **Surface**: 1 month
- **Return**: 12 months

### Typical Conjunction Class

- **Outbound**: 6 months
- **Surface**: 18 months
- **Return**: 6 months
Total Mission $\Delta V$ vs Earth Departure Date
Short-Stay Mars Missions

Assumptions
- All propulsive mission
- Earth parking orbit = 407 km
- Mars parking orbit = 500 km
- 40 day Mars stay
- Figure of merit = Total $\Delta V$ (all legs)

- 365 Day Mission
- No Venus Swingby
- Local Min $\Delta V$ No Venus
- Local Min $\Delta V$ Venus Swby (Return Leg)

Local Min $\Delta V$
Venus Swingby Where Appropriate

One Way Cargo

Earth Departure Date
01-Jan-15 31-Dec-16 31-Dec-18 30-Dec-20 29-Dec-22 29-Dec-24 29-Dec-26 28-Dec-28 28-Dec-30 27-Dec-32
Comparison of Mission Trajectories
Initial Mass and NTR Vehicle Complexity

<table>
<thead>
<tr>
<th>Mission Type</th>
<th>Total Mission Mass (t)</th>
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<td>No Venus Swing-by</td>
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<td>Pre-Deployed Mars Lander and Return Vehicle</td>
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<td>Pre-Deploy Mars Lander and Return Vehicle</td>
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<td>Pre-Deployed Crew Return Vehicle</td>
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<td>610</td>
<td>Represented Venus Swing-by</td>
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<td>Pre-Deploy Lander and Return Vehicle</td>
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<td>2026 (Worst Case)</td>
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<tr>
<td></td>
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<td>460 Days (180-40-240)</td>
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<td>Pre-Deploy Lander and Return Vehicle</td>
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<td></td>
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<td>2016 Launch Opportunity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>479 Days (179-40-250)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pre-Deploy Lander and Return Vehicle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2018 (only)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>365 Days (109-40-216)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pre-Deploy Lander and Return Vehicle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4+STS)</td>
</tr>
<tr>
<td></td>
<td>158</td>
<td>(5)</td>
</tr>
<tr>
<td></td>
<td>298</td>
<td>(5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(7+STS)</td>
</tr>
<tr>
<td>One-Year Round-Trip</td>
<td>138</td>
<td>Pre-Deployed Mars Lander and Return Vehicle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2018 (only)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>365 Days (109-40-216)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pre-Deploy Lander and Return Vehicle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4+STS)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(5)</td>
</tr>
</tbody>
</table>

Note: Vehicles are 50-75% propellant (H₂)

Ref. Glenn Research Center
Technology Driven Capabilities

Advanced Habitation
- Radiation Protection
- Closed-loop Life Support
- Large Volume
- Advanced Health Care

Electric Propulsion

Nuclear Thermal Propulsion

Near Earth Transportation
- Radiation Protection
- Closed-loop Life Support
- Large Volume
- Advanced Health Care
**Mars Short-Stay Transit Habitat**

- Supports mission crew of four for up to 365-650-days round-trip missions to and from Mars
- Crew consumables and support systems tailored for mission duration
- Zero-g configuration with integrated deep-space radiation protection
- Power generation provided by the bi-modal NTR vehicle
- Closed-loop (air and water) life support system
- Advanced health care systems
- Advanced materials for primary and secondary structures
- Advanced MEMS / wireless avionics for increased reliability and redundancy
- Earth return vehicle for crew return

### Transit Mass (4 Crew, 650 total days)

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass (kg)</th>
<th>Stowed Vol. (M3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 Power System</td>
<td>2362.6</td>
<td>0.000</td>
</tr>
<tr>
<td>2.0 Avionics</td>
<td>287.0</td>
<td>0.140</td>
</tr>
<tr>
<td>3.0 Environmental Control &amp; Life Support</td>
<td>3948.9</td>
<td>19.133</td>
</tr>
<tr>
<td>4.0 Thermal Management System</td>
<td>1257.3</td>
<td>5.260</td>
</tr>
<tr>
<td>5.0 Crew Accommodations</td>
<td>3396.1</td>
<td>21.235</td>
</tr>
<tr>
<td>6.0 EVA Systems</td>
<td>879.9</td>
<td>3.653</td>
</tr>
<tr>
<td>7.0 Structure</td>
<td>817.3</td>
<td>0.000</td>
</tr>
<tr>
<td>7.1 Margin (20%)</td>
<td>2426.4</td>
<td>9.884</td>
</tr>
<tr>
<td>Crew</td>
<td>372.0</td>
<td>- - - - -</td>
</tr>
<tr>
<td>Food (Return Trip)</td>
<td>2600.0</td>
<td>9.043</td>
</tr>
<tr>
<td>Food (Outbound Trip)</td>
<td>2600.0</td>
<td>9.043</td>
</tr>
<tr>
<td>Food (Contingency)</td>
<td>0.0</td>
<td>0.000</td>
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<tr>
<td><strong>Total Transit Habitat Mass</strong></td>
<td>20947.5</td>
<td>77.392</td>
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</table>

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth Return Vehicle</td>
<td>4270.6</td>
</tr>
<tr>
<td><strong>Total Mass</strong></td>
<td>25218.1</td>
</tr>
</tbody>
</table>

Ref. Johnson Space Center
Mars Descent / Ascent Vehicle

- Small shroud of the EELV-H has significant impact on the Descent / Ascent Vehicle
- Vertical lander configuration is not viable for small launch shrouds
  - Packaging and volume problems
  - High center of gravity increases landing stability problems
  - Assembled vehicles have larger c.g. uncertainty – increases aerocapture and aeroentry precision
  - Ingress / Egress difficulties
  - Launch vehicle shroud cannot be used as the Mars aerobrake or aeroentry shield
  - Parachute deployment speeds: Parachutes cannot be used due to high deployment speeds (M=4.5) due to high ballistic coefficient
  - Aerobrake on-orbit assembly and checkout required or other concepts which utilize deployed systems are needed
- Large 8 x 30 m shroud assumed for vehicle elements

6 m Delta-IV H
(Not Standard)

8 m Diameter Shroud

Parachute deployment speeds

<table>
<thead>
<tr>
<th>Mach No. at 10 Km Altitude - ND</th>
<th>Current Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Mach number parachute deployment limits</td>
<td>1.50</td>
</tr>
<tr>
<td>Aeroshell Length to Diameter Ratio - ND</td>
<td>2.00</td>
</tr>
</tbody>
</table>

BGD/Short Stay Architecture 7/11/2000 6
## Short-Stay Mars Descent / Ascent Vehicle

- Transports four crew from Mars orbit to the surface and return to Mars orbit
- Vehicle supports crew for 30-days
- Two-stage design for high Mars orbit staging
- Regenerative air, open water life support system
- Advanced EVA and mobility
- Crew health and maintenance, including exercise equipment, for adaptation to martian gravity

### DESCENT/ASCENT LANDER

<table>
<thead>
<tr>
<th>High Mars Orbit Option</th>
<th>Mass (kg)</th>
<th>Stowed Vol. (M³)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Payloads and Systems</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0 Power System</td>
<td>4226.0</td>
<td>0.000</td>
</tr>
<tr>
<td>2.0 Avionics</td>
<td>153.0</td>
<td>0.279</td>
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<tr>
<td>3.0 Environmental Control &amp; Life Support</td>
<td>1037.6</td>
<td>3.983</td>
</tr>
<tr>
<td>4.0 Thermal Management System</td>
<td>527.4</td>
<td>2.350</td>
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<tr>
<td>5.0 Crew Accommodations</td>
<td>727.7</td>
<td>5.776</td>
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<tr>
<td>6.0 EVA Systems</td>
<td>1073.9</td>
<td>7.539</td>
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<tr>
<td>7.0 In-Situ Resource Utilization</td>
<td>0.0</td>
<td>0.000</td>
</tr>
<tr>
<td>8.0 Mobility</td>
<td>1350.4</td>
<td>8.171</td>
</tr>
<tr>
<td>9.0 Science</td>
<td>301.2</td>
<td>1.600</td>
</tr>
<tr>
<td>10.0 Structure</td>
<td>1339.8</td>
<td>0.000</td>
</tr>
<tr>
<td>Margin (20%)</td>
<td>1807.4</td>
<td>5.689</td>
</tr>
<tr>
<td>Food</td>
<td>360.0</td>
<td>1.252</td>
</tr>
<tr>
<td>Crew</td>
<td>372.0</td>
<td></td>
</tr>
</tbody>
</table>

| Total Mass             | 72140.4  |                 |

### Ascent Stage (Two Stage)

<table>
<thead>
<tr>
<th><strong>Ascent Stage (Two Stage)</strong></th>
<th>Mass (kg)</th>
<th>Stowed Vol. (M³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crew Module</td>
<td>1617.5</td>
<td>1.000</td>
</tr>
<tr>
<td>Stage</td>
<td>161.3</td>
<td>0.000</td>
</tr>
<tr>
<td>Propulsion</td>
<td>4675.6</td>
<td>0.000</td>
</tr>
<tr>
<td>Propellants</td>
<td>24988.2</td>
<td>0.000</td>
</tr>
</tbody>
</table>

### Descent Stage (Payload Down)

<table>
<thead>
<tr>
<th><strong>Descent Stage</strong></th>
<th>Mass (kg)</th>
<th>Stowed Vol. (M³)</th>
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</thead>
<tbody>
<tr>
<td>Crew Module</td>
<td>1242.3</td>
<td>0.000</td>
</tr>
<tr>
<td>Stage</td>
<td>4658.9</td>
<td>0.000</td>
</tr>
<tr>
<td>Propellants</td>
<td>11336.0</td>
<td>0.000</td>
</tr>
</tbody>
</table>

### Aerobrake

<table>
<thead>
<tr>
<th><strong>Aerobrake</strong></th>
<th>Mass (kg)</th>
<th>Stowed Vol. (M³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LO₂/CH₄ Ascent Engines (2)</td>
<td>10184.1</td>
<td>0.000</td>
</tr>
</tbody>
</table>

**Ref.** Johnson Space Center
“Bimodal” NTR Transfer Vehicles for Mars Cargo and Piloted Missions


Cargo Mission 1
Descent / Ascent Lander
IMLEO = 123 - 157 mt

Cargo Mission 2
Crew Return Vehicle
IMLEO = 250 - 612 mt

Piloted Mission
Crew Transfer Vehicle
IMLEO = 104 - 896 mt

Ref. Glenn Research Center
• **Human Support**  
  – Advanced health care systems for long periods away from Earth (22 months)

• **Advanced Space Transportation**  
  – Advanced interplanetary propulsion: Options include:
    • Bi-Modal Nuclear Thermal Propulsion (925 sec Isp, 15 kWe)
    • High Power Nuclear Electric (Ion, MPD, or VASIMIR at multi-MW power levels) ?  
  – Large volume / large mass Earth-to-Orbit transportation  
  – Very high rate payload and launch vehicle processing land launch capability  
  – Advanced LEO automated rendezvous, assembly, checkout, and verification facilities and techniques  
  – Long-term storage of hydrogen in space

• **Advanced Space Power**  
  – Nuclear power reactor 15-30 kWe for high-latitude scientific investigations

• **Miscellaneous**  
  – Integrated vehicle health maintenance for vehicles unattended for long periods (21-22 months)  
  – Advanced reliability for long vehicle operations (up to 44 months excluding LEO assembly ops)
## Architecture Comparison Criteria

### Short-Stay Mars Mission

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architecture Evolution Potential</td>
<td>Focus on short stay limits evolution</td>
</tr>
<tr>
<td>Architecture Commonality</td>
<td>Very little propulsion system commonality</td>
</tr>
<tr>
<td>Initial Mass in Low-Earth Orbit</td>
<td>522-1665 mt</td>
</tr>
<tr>
<td>Mass to Mars Surface</td>
<td>13 mt</td>
</tr>
<tr>
<td>Number of Crew</td>
<td>4</td>
</tr>
<tr>
<td>Number of Cargo Launches</td>
<td>17-55</td>
</tr>
<tr>
<td>On-orbit Assembly Required?</td>
<td>Yes</td>
</tr>
<tr>
<td>Number of Crew Launches</td>
<td>tbd</td>
</tr>
<tr>
<td>Architecture Redundancy</td>
<td>No overlapping of resources</td>
</tr>
<tr>
<td>Architecture Complexity</td>
<td>Very complex LEO mission</td>
</tr>
<tr>
<td>Architecture Sensitivity</td>
<td>High</td>
</tr>
<tr>
<td>Crew Hazards</td>
<td>Mars orbit rendezvous, 365-650-day long mission</td>
</tr>
<tr>
<td>Time in Interplanetary Space</td>
<td>620 total days</td>
</tr>
<tr>
<td>Time on Surface</td>
<td>30 total days</td>
</tr>
</tbody>
</table>
Mars-Short Stay Mission
Architecture Summary

**Strengths**

- One-year mission is possible in some opportunities
- Shorter total mission reduces reliability requirements
- Accomplish mission events quicker allowing crew return phase to begin sooner
- Shorter mission reduces crew time spent beyond Earth orbit (365-650 total days)
- Minimizes surface infrastructure

**Weaknesses**

- Large initial mass in LEO
- Large variation in mass; large sensitivity to mass, level of redundancy, and technology changes
- Science return is local “focus” oriented (10 km)
- No overlap of mission/vehicle resources
- Launch facilities and launch rate impacts as well as on-orbit assembly and checkout issues
- Majority of mission is spent in zero-g radiation environment (95%)
- Close sun passage increases radiation dose to the crew (0.35-0.7 AU)
- Short surface stay allows less time for contingencies and re-planning (30 days)
Architecture Issues and Follow-on Work

• Results are due to the short-stay mission constraints and are not due to the NTR system performance. The trends of these results will be similar for all advanced propulsion options.

• Small launch vehicle constraints force large levels of on-orbit assembly and checkout in low-Earth orbit which significantly increases mission complexity, mission risk, and cost.

• Separating crew from their return vehicle increases risk to the crew (survival)

• Requirements of the short stay mission poses a significant mission, design, assembly, and risk challenge for minimal return

• Additional analysis is required to determine feasibility
  – Finalize trajectory options
  – Update vehicle concepts
  – Launch/assembly impacts
  – Operations concepts
  – Risk analysis
  – Crew health and performance
  – Parking orbit analysis
  – Power strategy
Mars Short-Stay Architecture Analysis
Remaining Work

• **Finalize Mars Short-Stay Mission Trajectory Options**
  – Variation and sensitivity across the entire synodic cycle
  – Vehicle and crew impacts of heliocentric passage
  – Parking orbit arrival/departure constraints for short Mars vicinity stay

• **Launch Vehicle / Assembly Assessments**
  – Launch vehicle impacts
  – On-orbit assembly / checkout concepts
  – Vehicle support concepts (fuel depot?)

• **Probabilistic Risk Assessments for leading architecture concepts**

• **Operations Concepts**
  – Launch operations, vehicle, and payload processing
  – Flight and surface mission
  – Abort concepts

• **Crew Health and Performance Assessments**
  – Radiation and zero-g for various total mission durations
  – Crew health and countermeasures for long-outbound transits

• **Power System Strategy**
  – Strategy to meet high latitude, mobility, and science requirements

• **Update Vehicle Concepts**
  – Mars Descent / Ascent Vehicle
  – NTR Piloted Vehicles
Backup
Short-Stay Mars Mission Implications

• **Large energy requirements increases mission vehicle size dictates need for advanced propulsion technology**

• **Significant variation of propulsion requirements for the Short-Stay mission across synodic cycle (100%)**
  – Significant impacts to vehicle design and certification due to wide variation of vehicle size

• **Short stay in the vicinity of Mars compromises mission return and crew safety**
  – Limited time for gravity-acclimation
  – Limited time for contingencies or dust storms
  – Majority of time spent in deep space (zero-gravity & deep space radiation)

• **Total mission duration for the Short-Stay Mission on the order of 12-22 months**
  – System reliability still critical to crew survival
  – Life support system reliability
  – Short (one-year) missions are possible, but limited to single opportunities over the 15-year synodic cycle (2018)

• **Venus swing-by’s can reduce propulsive requirement (and thus mission mass)**
  – Pass within 0.35-0.72 AU of the sun (increases radiation and thermal load)
  – Longer total mission duration in interplanetary space environment
**Normalized Mass Ratio**

- Provides a top-level comparison of the relative initial mass in LEO
- Derived from the rocket equation

\[
\frac{M_f}{M_i} = \frac{\Delta V}{g \cdot Isp}
\]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(M_f)</td>
<td>Final Mass (kg)</td>
</tr>
<tr>
<td>(M_i)</td>
<td>Initial Mass (kg)</td>
</tr>
<tr>
<td>(\Delta V)</td>
<td>Velocity Change (m/s)</td>
</tr>
<tr>
<td>(g)</td>
<td>Gravitational Acceleration (m/s²)</td>
</tr>
<tr>
<td>(Isp)</td>
<td>Specific Impulse (s)</td>
</tr>
</tbody>
</table>

![Graph showing Normalized Mass Ratio vs Delta-V (m/s)](image-url)
Short-Stay Operational Considerations

• Need to maintain abort gap closure for all interplanetary propulsion options considered
• A separate Earth Return Vehicle (ERV) remains an important safety and mission success asset, and should be retained in this architecture
• Mars orbital operations (capture, rendezvous, phasing for departure, etc.) needs further assessment
• Short-stay surface adaptation story is mixed:
  – Short-stay allows for simpler surface spacecraft, but
  – will generate pressure to get on with the exploration phase early (adaptation issues)
  – Initial operations (g-transition, vehicle safing, appendage deployments) must occur without crew exertion
• Entry, Descent, and Landing (EDL) precision for this mission is primarily for mission success (along with rendezvous with pre-deployed robotic systems)
• 10 km radius has been established as a reasonable traverse radius about the landing zone (walkback). Unpressurized rover(s) is assumed to be used during this mission due to the short-stay
• Surface mission likely similar to an extended and very complex ISS assembly mission
• Shorter exposure window to radiation and dust storm events on the surface, but due to visibility restrictions, the crew may get to Mars and be NO GO to land due to dust storms in the landing zone.
• Initial timeline assessment: 21 EVAs of 6.5 hour duration are supported:
  • 5 local area (acclimation, area science, rover assembly)
  • 5 rover-assisted traverses
  • 11 Core drills at three different sites (Core A is assumed to take only 3 EVAs, the others require 4 each)
• This timeline is considered optimistic
Variation in Daylight Hours During a Martian Year for Mid to High (+/- 40, 50, & 60 deg) Latitudes

Mission Date and Landing Site Location Significantly Influence Length of Operational “Day” Science Landing Requirements

5° S to 65° N

Daylight Hours

Days From Mars’ Northern Vernal Equinox (0 - 688)

Highest Probability of Global Dust Storms
**Variation of Daylight Hours**

**Low Latitude Landing Sites**

Variation in Daylight Hours During a Martian Year for Low (+/- 10, 20, & 30 deg) Latitudes

Days From Mars' Northern Vernal Equinox (0 - 688)

- **Arrival (7/18/20)**
- **Departure (8/27/20)**
- **Arrival (9/28/18)** (7/17/22)
- **Departure (11/17/18)** (8/26/22)
- **Arrival (7/27/24)**
- **Departure (9/5/24)**
- **Arrival (9/13/26)**
- **Departure (10/23/26)**
- **Arrival (8/01/29)**
- **Departure (9/10/29)**

Highest Probability of Global Dust Storms
**Mars Transit Habitat**

- **LEVEL 4**
  - Pressurized Tunnel

- **LEVEL 3**
  - Crew Health Care Area

- **LEVEL 2**
  - Crew Quarters & Mech Rm

- **LEVEL 1:**
  - Galley / Wardroom Area
    - 20" WINDOW (2)

- HATCH DOORS
- INFLATABLE SHELL
- SOFT STOWAGE ARRAY
- CENTRAL STRUCTURAL CORE
- INFLATABLE OUTFITTING
- COMPRESSION RING
- INTEGRATED WATER TANK / STORM SHELTER
- TREADMILL
- ERGOMETER

Ref. Johnson Space Center
**Modular “Bimodal” NTR Transfer Vehicle Designs Developed for Mars Cargo and Piloted Missions**

**Bimodal NTR:** High thrust, high Isp propulsion system utilizing U\(^{235}\) produces thermal energy for propellant heating and electric power generation enhancing vehicle capability.

**Vehicle Characteristics**
- Versatile design
- “Bimodal” stage produces 50 kW\(_e\)
- Power supports active refrigeration of LH\(_2\)
- New “saddle” truss design allows easy jettisoning of “in-line” LH\(_2\) tank & contingency consumables
- Propulsive Mars capture and departure on piloted mission
- Fewest mission elements, simple space operations & reduced crew risk

**Engine Characteristics**
- Three 15 klbf tricarbide engines
- Each bimodal NTR produces 25 kW\(_e\)
- Utilizes proven Brayton technology
- Variable thrust & Isp optional with “LOX-afterburner” nozzle (LANTR)

**TransHab**

**Crew Transfer Vehicle**

Ref. Glenn Research Center
DPT Mars Long-Stay Mission

Architecture Status

Mid-Term (2018) Nuclear Thermal Propulsion and Solar Electric Propulsion System Options

Bret G. Drake
NASA/Johnson Space Center

July 11, 2000
Outline

• Architecture Overview
• Ground Rules and Assumptions
• Detailed Mission by Phase
• Capability Evolution
• Systems
  – Transit Habitat
  – Surface Habitat
  – Descent / Ascent Vehicle
  – Interplanetary Transportation
  – Launch Vehicle
• Architecture Features
• Technology Needs
• Architecture Summary
Evolution of the Long-Stay Mission Philosophy

1988: Case Studies
- Short Surface Stay
- Chemical / Aerobrake
- Split Sprint Missions

1989: Case Studies
- Short Surface Stay
- Chemical / Aerobrake
- All-up Mission Profile

1990: 90-day Study
- Short Surface Stay
- Split Sprint Missions
- Various propulsion options

1991: Synthesis Group
- Short Surface Stay
- Nuclear Thermal Propulsion
- Heavy lift launch vehicle

1997: DRM 1.0
- Long Surface Stay
- Nuclear Thermal Propulsion
- Heavy lift launch vehicle

1999: Dual Landers
- Long Surface Stay
- NTR or SEP
- Enabled Global Access

- Short-stay missions are energy intensive
- On-orbit assembly increases mission complexity
- Large masses/volumes require large launch vehicle

- “Free-Return trajectories not beneficial
- Crew acclimation for short stay missions needs further investigation
- Large masses/volumes require large launch vehicle

- NTR propulsion, Aerobraking and ISRU are promising technologies to pursue
- Large masses/volumes require large launch vehicle

- “Key” Technologies identified
- Large masses/volumes require large launch vehicle

- Crew exposure to interplanetary space limited
- Large masses/volumes require large launch vehicle
- Functional redundancy maximized

- Lowest mass approach
- Crew exposure limited
- Science return maximized
- “Shuttle Compatible” launch vehicle
Mars Long-Stay Mission Significant Features

- Balances technical, programmatic, mission, and safety risks
- Lowest number of launches per human mission
- Simple LEO operations – automated rendezvous and docking of two elements
- High scientific return (500+ days on Mars) with continuous collaboration with colleagues on Earth
- Minimizes exposure of crew to interplanetary environment (zero-g and deep-space radiation)
- Maximizes reuse of mission elements: SEP and surface habitat (if desired)
- Vehicle design independent of mission opportunity (Small variation (10%) in vehicle size for every Mars opportunity)
- Enables global surface access if desired
High Earth Orbit Staging Mission Scenarios

- Elliptical Parking Orbit (EPO)
- Earth Space Station Orbit (LEO)
- Mars Aerocapture
- Near Earth Asteroids
- Libration Points
- Chemical Injection Burn
- EP Transfer
- Crew Transfer via Crew Taxi
- Rendezvous
Mars Mission Overview
(SEP Option)

Habitat Lander and Ascent/Descent Vehicles delivered to Low Earth Orbit with “Shuttle Class” launcher. Solar Electric Propulsion stage spirals cargo to High Earth Orbit. Chemical injection used at perigee. SEP spirals back to LEO for reuse.

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

Transit Habitat vehicle delivered to LEO with “Shuttle Class” launcher. 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 rendezvous with Descent/Ascent Vehicle in Mars Orbit then lands in vicinity of Habitat Lander.

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

Habitat remains in Mars orbit.

30 days provided to satisfy “long-stay” criteria.

Crew ascends and rendezvous with waiting Transit Habitat.

Surface Habitat lands and performs initial setup and checkout - Initial outpost established.

Mars Surface

Earth
**Mars Mission Overview**  
**(NTR Option)**

- **Cargo Vehicles Delivered to Low-Earth Orbit** via “Shuttle Compatible” Launch Vehicle  
  - Surface Habitat/Lander  
  - Surface Habitat NTR  
  - Descent-Ascent Lander  
  - Descent-Ascent Lander NTR

- **Crew Vehicles Delivered to Low-Earth Orbit** via “Shuttle Compatible” Launch Vehicle  
  - Transit Habitat/Lander  
  - Transit Habitat NTR  
  - Crew delivered to Mars Vehicle via Shuttle

- **Surface Habitat and exploration gear aerocaptures into Mars orbit**  
- **Ascent/Descent 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 travels to Mars in “fast transit” 180-206 day transfer. Propulsively captures into Mars orbit**

- **Crew returns to Earth on “fast transit” 180-206 day transfer. Direct entry at Earth**

- **Surface Habitat lands and performs initial setup and checkout - Initial outpost established**

- **30 days provided to satisfy “long-stay” criteria.**

- **Crew ascends and rendezvous with waiting Transit Habitat**

- **Habitat remains in Mars orbit**
Long-Stay Mission Sequence

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</tbody>
</table>
**Surface Architecture**

**Outpost Missions (Bite Size Chunks)**
- Full Mission and augmented systems
  - Rovers
  - Power (nuke)
  - Science (drills)
  - etc.

**Basic Survivability (30 Days)**
- Short-stay capability (30 days)
  - Ascent vehicle and propellant (abort-to-orbit)
  - Contingency science
  - Common lander design

**Full Mission Capability (18 Months)**
- Full surface mission support systems
  - Power
  - Life Support
  - Maintenance
  - Thermal
  - Crew accommodations
  - Science
  - Common lander design
Mars Long-Stay Ground Rules and Assumptions

• Detailed GR&A provided in the “Mars Long-Mission GR&A” document dated 4-20-2000

• Primary DPT GR&A which drive this architecture include:
  – First cargo mission 2016, First human mission 2018
  – Short transits to/from Mars (180-206 days) with long surface stay
  – Six crew
  – Zero-g transits
  – Technology freeze to TRL 6 by 2011
  – Factor of nine improvement for primary and secondary structures
  – Advanced mobility and scientific laboratory capability for enhanced science

Transportation Assumptions
• “Shuttle Compatible” launch vehicle for cargo (80 mt)
• Both SEP and NTR investigated
• Aerobraking at Mars
• Long-term cryogenic fluids storage
Mission Sequence
High Earth Orbit Boost Phase

UNPILOTED VEHICLES

- Cargo Launch 2
  SEP launched to low Earth orbit

- Cargo Launch 3
  Descent/Ascent vehicle, aerobrake, and TMI stage launched LEO

- Cargo Launch 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 (contingency)

PILOTED VEHICLES

- Cargo Launch 1
  Transit Habitat launched to low Earth orbit

- STS 1 & 2
  Transit Habitat outfitting missions

- Cargo Launch 5
  Transit Habitat SEP vehicle launched to low Earth orbit

- Cargo Launch 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 (contingency)
Mission Sequence
Trans-Mars Injection / Mars Arrival Phase

- Surface Habitat Lander
  - Unpiloted Vehicles injected toward Mars on near minimum energy transfers
- Descent/Ascent Vehicle
  - Unpiloted vehicles aerocapture into Mars orbit prior to the crew
- Transit Habitat
  - Transit habitat aerocaptures into Mars orbit
  - Transit Habitat Habitat Trans-Mars Injection (180-206 day transfers)
- Surface Habitat
  - Surface Habitat performs deorbit, entry, descent, and precision landing on Mars
- STS 5 / Taxi Flight Crew Delivery to Transit Habitat
- Crew transfers to Descent/Ascent Vehicle

Transit Habitat performs rendezvous with Descent/Ascent vehicle in Low Mars Orbit.
**Mission Sequence**

**Surface Mission / Mars Ascent / Return Phases**

- **Surface Exploration**: Concentrates on the search for life, drilling, geology, and microbiology investigations (up to 18 months long).

- **Initial Habitat Operations**: Safe vehicle, habitat inflation, power system deployment, habitat outfitting and systems checkout.

- **Initial Operations**: 30 days for systems checkout and crew acclimation. Contingency abort-to-orbit capability.

- **Low-Mars Orbit Wait**: Transit Habitat remains in low-Mars Orbit during surface mission (unmanned).

- **Ascent & Rendezvous**: Ascent from Mars surface and rendezvous with Transit Habitat in low-Mars orbit.

- **Earth Return**: Direct Earth entry at end of mission.

- **Crew performs deorbit, entry, descent, and precision landing on Mars in Descent / Ascent Vehicle**.
**Solar Electric Vehicle Transportation Concept**

**2016**

- **Cargo Boost**
  SEP-1 vehicle boosts cargo vehicles to high Earth departure orbit

**2018**

- **Piloted/Cargo Boost**
  Both cargo and piloted vehicles are boosted to high Earth departure orbit

**2020**

- **Return**
  SEP-2 vehicle returns to LEO for new propulsion module and mission payload

**Return**
SEP-1 vehicle returns to LEO for new propulsion module and mission payload
Technology Driven Capabilities

Advanced Habitation
- Radiation Protection
- Closed-loop Life Support
- Large Volume
- Advanced Health Care

Electric Propulsion

Nuclear Thermal Propulsion

Near Earth Transportation
- Radiation Protection
- Closed-loop Life Support
- Large Volume
- Advanced Health Care

Exploration Office
Mars Transit Habitat Configuration

- Docking/Crew Transfer Tunnel/EVA Airlock
- Communications Antenna - Earth Return/Aborts
- Crew Earth Return Vehicle
- Communications Antenna - Mars Transit
- Ellipsled
- TEI Stage
- Inflatable TransHab
- Double-Sided Radiator (30.5 m²)
- TMI Stage
- Mars Circularization Stage
- Solar Array (200 m²)
- Body-Mounted Radiator (70 m²)
• Supports mission crew of six for up to 200-day transits to and from Mars
• Provides zero-g countermeasures and deep-space radiation protection
• Return propulsion stage integrated with transit system
• Provides return-to Earth abort capability for up to 30 hours post-TMI
Mars Habitat Lander

- 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

<table>
<thead>
<tr>
<th>HABITAT LANDER</th>
<th>Mass (kg)</th>
<th>Stowed Vol. (M³)</th>
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<tbody>
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| Crew Module | 110.0 | 0.000 |
| Stage | 133.1 | 0.000 |
| Propulsion | 0.0 | 0.000 |
| Propellants | 0.0 | 0.000 |

| Descent Stage | 12636.3 | 0.000 |
| (Payload Down) | 30586.3 | 0.000 |
| Stage | 1002.1 | 0.000 |
| Propulsion | 3436.0 | 0.000 |
| Propellants | 8198.2 | 0.000 |

| Aerobrake | 4656.2 | 0.000 |

| Circ/Deorbit Stage | 9494.0 | 0.000 |
| Stage | 365.0 | 0.000 |
| Propulsion | 1339.5 | 0.000 |
| Propellants | 7789.5 | 0.000 |

| TMI Stage | 24357.3 | 0.000 |
| (TMI Payload) | 57354.8 | 0.000 |
| Stage | 686.4 | 0.000 |
| Propulsion | 2045.9 | 0.000 |
| Propellants | 21625.1 | 0.000 |

INITIAL MASS IN HIGH EARTH ORBIT 81712.1

Ref. Johnson Space Center
Mars Descent / Ascent Vehicle

- Transports six crew from Mars orbit to the surface and return to Mars orbit
- Provides contingency abort-to-orbit capability
- Vehicle supports crew for 30-days
- Vehicle capable of utilizing locally produced propellants

### Payloads and Systems

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<th>Mass (kg)</th>
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#### Ascent Stage

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#### Aerobrake

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#### Circ/Deorbit Stage

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#### TMI Stage

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</table>

**INITIAL MASS IN HIGH EARTH ORBIT** 82630.4

Ref. Johnson Space Center
SETV Baseline 3.3B Rev 1

SETV Deployed with Mars Payload Element

- Photovoltaic Array Blanket
- Inflatable Ribs
- Kapton Webbing
- Mars Payload
- Articulated Thruster Boom
- SETV Bus Module
- SEP Transfer Vehicle
- SEP Power Module
  - Central Bus
  - Power System
  - Manipulator Arm
- SEP Propulsion Module
  - Propulsion Platform
  - Propellant Feed System
- Maximum Propellant Load

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<th>SEP Transfer Vehicle</th>
<th>Total Mass (kg)</th>
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<td>Reusable SEP Power Module</td>
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<td>Manipulator Arm</td>
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<tr>
<td>Maximum Propellant Load</td>
<td>64,335</td>
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</table>

Ref. Glenn Research Center
“Bimodal” NTR Transfer Vehicles for Mars Cargo and Piloted Missions

(6 Shuttle Compatible Launch Vehicles plus Shuttle for Crew and TransHab Delivery)

2016 Cargo Mission 1
Habitat Lander
IMLeo = 131.5 mt

2016 Cargo Mission 2
Cargo Lander
IMLeo = 132.5 mt

2016 Piloted Mission
Crew Transfer Vehicle
IMLeo = 168.5 mt

Optional “In-Line” LH₂ Tank (if needed)
Launch Vehicle

- Cost effective delivery of large mass and large payload
- Maximizes the cost effective use of common Shuttle boosters and launch facilities
- Shuttle compatible
  - Core equal to the diameter of the External Tank (27.6 mt)
  - Common Pad Hold Down System
  - Common Use of ET Handling & Manufacturing Hardware
  - Same mobile launch platform (modified flame trenches)
- Common Boosters
- Similar GLOW: Use of Shuttle Crawlers & MLPs
“Shuttle Compatible” Launch Vehicle
RFS Configuration

- 220 NMI/28.5 Degrees
- P/L: 80 mt
- P/L: 25 ft Dia X 92 ft

Payload Fairing
92 ft cyl x 25 ft I.D.

Circularization Stage
LO2 Tank

Liquid Flyback Booster (2)
LH2 Tank

Fwd Booster Attach
Aft Booster Attach
Thrust Structure
RS 68 Engines (2)

Ref. Marshall Space Flight Center
Baseline Processing Option

MARS PROCESSING FLOW

LFBB PROCESSING FACILITY

MAGNUM CORE DELIVERY

MAGNUM CORE VEHICLE

MARS ENCAPSULATED PAYLOAD

VAB

O&C

TMI STAGE TO LOW BAY

KICKSTAGE DELIVERY

LC-39A OR B (MODIFIED)

Ref. Kennedy Space Center
Baseline Payload Processing Option

MARS PAYLOAD PROCESSING

- TEI STAGE
- MARS CARGO DESCENT
- MARS TRANSHAB DESCENT
- NPP
- PHSF
- MARS TRANSHAB DESCENT
- NPP
- TEI STAGE
- SSPF
- MARS ASCENT STAGE
- CARGO VEHICLE
- RETURN HAB
- LOGISTICS ITEMS
- ECRV
- TRANS HAB
- ISPP
- INFLATABLE HAB
- MPPF
- INFLATABLE HAB
- MARS ENCAPSULATED PAYLOADS
- VAB

Ref. Kennedy Space Center
KSC Facility Modifications

- The KSC Operations Assessment team has developed a processing concept that requires an additional Mobile Launcher Platform but does not require construction of new facilities
  - Minor modifications to existing infrastructure can adequately accommodate the processing of the maximum inventory of flight hardware to support the launch campaign

Mobile Launch Platform
- Two Mobile Launcher Platforms (MLPs) will be required to support the “Shuttle Compatible” and not interfere with the Space Shuttle Program
- New MLP
- Modify existing MLP 1

Pad Modifications
- One pad will require modifications for both Shuttle and “Shuttle-Compatible” Launches
- New crawlerway

Operations and Checkout Building
- No modifications required

Vehicle Assembly Building
- Only platform modifications are required

Ref. Kennedy Space Center
Low-Earth Orbit Rendezvous and Docking

- Utilizing a large volume, large mass launch vehicle requires only automated rendezvous and docking

- Both Earth surface and LEO based navigation and control infrastructure utilized to enable LEO operations

- Dual launch sequence:
  - Mars payload launched first to LEO
  - Injection stage launched second
  - Mars payload acts as primary control vehicle during rendezvous and docking maneuver

- Vehicles remotely checked out in LEO prior to initiating Trans-Mars Injection maneuver
The Forward Deployment Strategy

Cargo Missions

Outbound
Prior to Crew Arrival
Crew Arrival

Crew Mission

Depart Earth
Arrive Mars
Depart Mars
Arrive Earth

Primary Use

Forward Deployment Provides the Crew Dual Abort Paths

Cargo Missions

Architectural/Functional Backup

Architectural Backup for Crew #1
Example Power System Redundancy

First Human Mission Elements

- Primary Power
  - Nuclear
  - Spare Engine
  - Spare Radiator

- Emergency Backup
  - Solar/Regenerative Fuel Cell

- Emergency Backup
  - ISRU Fuel Cell Reactants

- Emergency Backup
  - Surface Mobile Power Systems

Abort to Orbit

Second Human Mission Elements

- Primary Power
  - Nuclear
  - Spare Engine
  - Spare Radiator

- Emergency Backup
  - Solar/Regenerative Fuel Cell

- Emergency Backup
  - Surface Mobile Power Systems
**Example Life Support System Redundancy**

**First Human Mission Elements**

- **Life Support System**
  - Bioregenerative

- **Emergency Backup**
  - Physical/Chemical

- **Long-Term Backup**
  - ISRU Water/ O₂ Cache

**Abort to Orbit**

**Second Human Mission Elements**

- **Life Support System**
  - Bioregenerative

- **Emergency Backup**
  - Physical/Chemical

- **Long-Term Backup**
  - ISRU Water/ O₂ Cache
**Earth Vicinity Abort Scenarios**
*(SEP Architecture)*

**Post-Trans-Mars Injection Aborts:** Trans-Earth Injection stage can be used to return the crew from an off-nominal TMI burn

**Post-Trans-Mars Injection Abort Options**

1. **Long Return Option (within 8 hrs of TMI)**
   - Crew lives in Transit Habitat after abort declaration
   - Crew returned to Earth in the Earth Return Vehicle up to 30 days later

2. **Quick Return Option (within 30 hrs of TMI)**
   - Crew returned in the Earth Return Vehicle
   - Return transit time 1-2 days

3. **Heliocentric Aborts (1-2 months after TMI)**
   - Return transit times range from 360-570 days
   - Crew lives in the Transit Habitat during return - direct Earth entry via Earth Return Vehicle
   - Can perform this abort only for some (3 of 7) opportunities (2014, 2016, 2018) with the current TEI size (33% increase to cover all opportunities)
**Mars Vicinity Abort Options**

- **System Pre-Deployment**
  - Surface habitat pre-deployed prior to crew landing.
  - Initial habitat safing, checkout, and verification
  - Risk to crew is reduced since crew does not commit to the landing phase until all habitat systems are operational.

- **Initial Operations (30 days)**
  - Crew lands in separate vehicle
  - 30-day initial operations for crew acclimation, initial science
  - Once acclimated, crew performs habitat system initialization, checkout and verification.
  - Contingency abort-to-orbit capability provided

- **Full Surface Mission (600 days)**
  - Crew transition to surface habitat complete
  - Long-stay criteria met
  - Ascent Vehicle placed in stand-by mode
  - Contingency abort-to-orbit in Ascent Vehicle if required. Must wait in Mars orbit until Trans-Earth Injection window opens.

**Habitat Pre-Deployment**

**First 30 Days**

**600-Day Surface Mission**
Assumptions:

- Cargo launch concept based on Shuttle compatible systems
- 80 mt lift capacity due east
- Shroud 8 x 30 m
- Rendezvous and docking of two exploration elements
- Launch rate shown does not support continuous exploration (cargo launches must be supported in the 2018 launch opportunity)
- Detailed analysis of payload processing, payload and vehicle flows, facility impacts and modifications, schedule impacts, and cost assessments complete.

<table>
<thead>
<tr>
<th>Launch #</th>
<th>Descent / Ascent Vehicle</th>
<th>Vehicle Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Wet Descent / Ascent Vehicle</td>
<td>Shuttle Compatible</td>
</tr>
<tr>
<td>2</td>
<td>Wet NTR Stage</td>
<td>Shuttle Compatible</td>
</tr>
<tr>
<td>3</td>
<td>Wet Habitat Lander</td>
<td>Shuttle Compatible</td>
</tr>
<tr>
<td>4</td>
<td>Wet NTR Stage</td>
<td>Shuttle Compatible</td>
</tr>
<tr>
<td>5</td>
<td>Transit Habitat</td>
<td>Shuttle</td>
</tr>
<tr>
<td>6</td>
<td>Habitat Consumables / NTR Core</td>
<td>Shuttle Compatible</td>
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<tr>
<td>7</td>
<td>NTR Tank Set</td>
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<td>8</td>
<td>Checkout Crew</td>
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<tr>
<td>9</td>
<td>Flight Crew</td>
<td>Shuttle</td>
</tr>
</tbody>
</table>

Cargo launches for next mission
# Mars-Long Stay Launch Strategy
## EELV-H Option

## Assumptions:
- Evolved commercial EELV
- Heavy lift option with exploration unique upper stage
- 35 mt lift capacity due east (assumed performance - no data yet)
- Non-standard large shroud (8 x 30 m)
- Only hardware and volume launch considered thus far
- Crew support for on-orbit assembly, outfitting, and checkout not yet taken into account.
- Launch rate shown does not support continuous exploration (cargo launches must be supported in the 2018 launch opportunity)
- Detailed analysis not yet complete

<table>
<thead>
<tr>
<th>Launch #</th>
<th>Descent / Ascent Vehicle</th>
<th>Vehicle Type</th>
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<td>Aerobrake / Deorbit Descent Stage</td>
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Cargo launches for next mission
**Human Exploration of Mars**

**Evolution of Common Capabilities**

**L1/L2 Gateways**
- Long duration support of mission crew in interplanetary environment with limited resupply capabilities

**Mars Habitats**

**L1/L2 SEP**
- Transports mission payloads from low-Earth orbit to mission destination and return

**L1/L2 Transfer Vehicle**
- Transports mission crew from low-Earth orbit to mission destinations and high-Earth staging orbits

**Mars SEP Taxi**

**Lunar EVA**
- Enables routine access to the planetary surface and expands the range of access for exploration

**Mars EVA**
Architecture Unique Technology Needs
Long-Stay Mars Mission

• **Human Support**
  – Advanced surface mobility and EVA: suitable for robust surface exploration (dexterity, mobility, maintainability)
  – Advanced health care systems for long periods away from Earth (30 months)

• **Advanced Space Transportation**
  – Advanced interplanetary propulsion: Options include:
    • Solar Electric Propulsion (1.7 Mwe, 18 % efficiency thin film solar)
    • Bi-Modal Nuclear Thermal Propulsion (925 sec Isp, 25 kWe)
  – Large volume / large mass Earth-to-Orbit transportation
  – In-situ consumable production for EVA system breathing oxygen and ECLSS backup
  – Automated rendezvous and docking of exploration payloads (2) in Earth orbit

• **Advanced Space Power**
  – Nuclear power reactor 15-30 kWe for high latitude science investigations

• **Miscellaneous**
  – Integrated vehicle health maintenance for vehicles unattended for long periods (22-42 months)
  – Advanced reliability for long vehicle operations (up to 32-51 months)
## Architecture Comparison Criteria
### Long-Stay Mars Mission

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Value</th>
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<tr>
<td>Architecture Evolution Potential</td>
<td>Long-stay human expansion</td>
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<td>Architecture Commonality</td>
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<td>Initial Mass in Low-Earth Orbit</td>
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<td>Architecture Redundancy</td>
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<td>Architecture Sensitivity</td>
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<td>Crew Hazards</td>
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<td>Time in Interplanetary Space</td>
<td>360-380 total days</td>
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<tr>
<td>Time on Surface</td>
<td>540 total days</td>
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Mars-Long Stay Mission
Architecture Summary

**Strengths**

- Low initial mass in LEO (430 mt)
- Small variation in mass; less sensitive to mass, level of redundancy, and technology changes
- Science return is regional “discovery” oriented
- Crew time spent in free space zero-g/radiation environment is minimized (360 days total)
- Potential for reuse of surface mission assets
- Functional overlap of mission resources
- Paced architecture allows for contingencies and re-planning
- Rendezvous and docking of two elements in low-Earth orbit

**Weaknesses**

- Long mission requires high reliability (30 months)
- Long surface mission (18 months)
- Many unknowns and crew health issues of long surface mission and surface environment (radiation, dust, gravity, etc.)
- Long-range roving capabilities for regional science (1000 km desired)
- Development of new 80-mt launch vehicle
- Crew productivity and challenges during long mission
Backup
Mars Long-Stay Mission Objectives

- Balance technical, programmatic, mission, and safety risks
- Provide an operationally simple mission approach emphasizing the judicious use of common systems
- Provide a flexible implementation strategy
- Limit the length of time that the crew is continuously exposed to the interplanetary space environment
- Define a robust planetary surface exploration capacity capable of safely and productively supporting crews on the surface of Mars for 500-600 days each mission
- Enable the capability to live off of the land
- Design systems capable of performing in each launch opportunity
- Examine at least three human mission to Mars
Mars Transit Habitat

LEVEL 4
Pressurized Tunnel

LEVEL 3
Crew Health Care Area

LEVEL 2
Crew Quarters & Mech Rm

LEVEL 1:
Galley / Wardroom Area

20" WINDOW (2)

INFLATABLE SHELL

CENTRAL STRUCTURAL CORE

INFLATABLE OUTFITTING COMPRESSION RING

INTEGRATED WATER TANK / STORM SHELTER

HATCH DOORS

SOFT STOWAGE ARRAY

TREADMILL

ERGOMETER
• **“Requirements”**
  – Launch and recovery in Space Shuttle or Based at ISS
  – Utilizes space storable propellants
  – Crew of 6 with ∆V capability of >3100 m/s
  – Ten day upper limit for orbit phasing, rendezvous, and missed rendezvous
  – Aerocapture maneuvers at lunar return speeds to ISS orbit

• **Preliminary Concept**
  – Lifting body for crew g reduction
  – Integral LOX/CH₄ propulsion system
  – Lightweight docking system

Ref. Johnson Space Center
Dual Lander Configurations

Surface Habitat

- Ellipsled Aerobrake
- Hab Lander (Deflated)
- Circ. Stage
- TMI Stage

Descent / Ascent Vehicle

- Descent / Ascent Vehicle
- Circ. Stage
- TMI Stage

Ref. Johnson Space Center
SETV Resupply Proximity Operations

- Inflatable Ribs
- Folded Articulated Thruster Boom
- PV Array Sectors
- HET Thruster Platform
- SETV Bus Module
- Xenon Tank
- Electric Propulsion Module
- Payload Docking Interface
- EPM Docking Interface
- TMI Stage
- Mars Payload

Ref. Glenn Research Center
Emerging Solar Array Technology

- Current SEP concept assumes thin film arrays
- Loose pointing requirements
- Requires 14,700 m²

- In the near term, lab demonstrations of 300 W/m² for flexible concentrators
- Tight pointing requirements
- Area reduced to 6700 m²
**Modular “Bimodal” NTR Transfer Vehicle Designs Developed for Mars Cargo and Piloted Missions**

**Bimodal NTR:** High thrust, high Isp propulsion system utilizing U\(^{235}\) produces thermal energy for propellant heating and electric power generation enhancing vehicle capability

**Engine Characteristics**
- Three 15 klbf tricarbide engines
- Each bimodal NTR produces 25 kW\(_e\)
- Utilizes proven Brayton technology
- Variable thrust & Isp optional with “LOX-afterburner” nozzle (LANTR)

**Vehicle Characteristics**
- Versatile design
- “Bimodal” stage produces 50 kW\(_e\)
- Power supports active refrigeration of LH\(_2\)
- New “saddle” truss design allows easy jettisoning of “in-line” LH\(_2\) tank & contingency consumables
- Vehicle rotation (\(w \leq 4\) rpm) can provide Mars gravity to crew outbound and inbound (available option)
- Propulsive Mars capture and departure on piloted mission
- Fewest mission elements, simple space operations & reduced crew risk
- Bimodal NTR vehicles easily adapted to Moon & NEA missions
“Shuttle Compatible” Launch Vehicle Configurations

Large Payload Missions to LEO
(HMM w/ Expendable Shroud)

- Payload = 188 klb
  (to 220 nmi circ @ 28.5°)
- Payload = 197 klb
  (to 220 nmi circ @ 28.5°)

Space Based Laser (SBL) Delivery

HMM with Integrated Shroud/Aerobrake

- Payload = 139 klb
  (to 700 nmi circ @ 40°)

Ref. Marshall Space Flight Center
Payload/Vehicle Processing

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• **Reliability and survivability of critical systems will be a major challenge for all Mars missions**
  
  – Long-duration missions
  – No capability for resupply
  – Limited abort capabilities

• **Risk reduction achieved by several techniques**
  
  – Architectural redundancies through mission design
  – Functional redundancy by dis-similar means to accomplish same end result
  – Early development and implementation of systems (time on systems)
  – Proper systems designs

• **Selection of proper technique(s) requires cost/benefit analysis**
Hierarchy Process

① Mission Design
   - Forward deployment (overlapping of mission resources)
   - Verification and checkout prior to crew departure
   - Mission mission approaches

② Resource Sharing and Technologies
   - Advanced technologies (unique products and robust capabilities) provides cross-strapping of resources between systems

③ Operational Concepts
   - Conservation of resources (power, consumables, etc.)
   - Modularity of systems
   - In-flight maintenance and sparing
   - “Hanger Queen”
   - Procedures and concepts

④ Systems Designs
   - Flexibility of designs (unanticipated uses)
   - Experience of previous and current programs
   - Reliability
   - Robustness of mission elements and capabilities
   - Dual paths, isolation, interlinking, crossfeeding, etc.
Resource Sharing
Example: Power and Consumables

- In-Situ Resource Utilization
- Rovers
- Main Power
- Advanced Life Support
- Extra Vehicular Activity

- H₂O, O₂ (Makeup & Backup)
- PV/RFC (Backup)
- CO₂ Removal (Backup)

- O₂ Generation
- Recharge (Backup)