“I need more power, Scotty!”

The Potential Impact of High Power Propulsion on the Human Exploration of Space

John H. Scott
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Evolvable Mars Campaign
(ca. 2015)

First Crewed Mission to Mars Surface

Mars Surface Prodeploy (5 landers)

Lunar Gravity Assist (LGA), Solar Electric Propulsion (SEP), Chemical Propulsion (CP)

Crew on board (●●●), HPS 1 (○), HPS 2 (●), HPS 3 (●●), HPS 4 (●●●), HPS 5 (●●●), HPS 6 (●●●)

Evolvable Mars Campaign

SEP/Chemical “Hybrid” Stage

- 318 kW_e to EP thrusters @ 2-3000 sec I_sp
- MMH/N_2O_4 chemical thrusters @ 890 N

Design Reference Architecture 5.0
(ca. 2009)

Crewed Mission to Mars Surface

~500 Days at Mars

High Mars Orbit
(250 x 33,813 km)

Aerocapture/EDL

EDL/Descent Maneuvers

Ascent Maneuvers

Trans-Earth Injection

Earth Slow-Down Maneuver
(as required)

Direct Earth Entry

Note: Earth days

TBD SLS Launches
Ref. Assembly Orbit

TBD SLS Launches
(TBD days between launches)

SLS-Cargo

SLS-Cargo

SLS-Crew

Pre-Deploy Cargo

Crew to Mars

TBD SLS Launches
1 SLS-80 Crew Launch
(TBD days between launches)

SLS-Cargo

SLS-Cargo

SLS-Crew

Ref. Assembly
(Crew)

SLS-Cargo

SLS-Cargo

SLS-Crew

Note: Earth days

NASA/SP–2009-566

AIAA Power & Energy Conference
Salt Lake City UT
25-7 July 2016

8 July 2016
# Design Reference Architecture 5.0

In-Space Power/Propulsion Options

<table>
<thead>
<tr>
<th>Design</th>
<th>Cargo Missions</th>
<th>Crew Mission</th>
</tr>
</thead>
<tbody>
<tr>
<td>2037 Conjunction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class &quot;long stay&quot;</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>mission</td>
<td>Chemical</td>
<td>Nuclear</td>
</tr>
<tr>
<td>Electric Power</td>
<td>N/A</td>
<td>Thermal</td>
</tr>
<tr>
<td>level</td>
<td>2.5 MW crew/</td>
<td>Nuclear</td>
</tr>
<tr>
<td></td>
<td>1 MW cargo</td>
<td>Electric</td>
</tr>
<tr>
<td>Total Mass</td>
<td>~1250 t</td>
<td>~770 t</td>
</tr>
<tr>
<td># Heavy Lift</td>
<td>~12</td>
<td>~7</td>
</tr>
<tr>
<td>(SLS) Launches</td>
<td>9 (7)</td>
<td></td>
</tr>
<tr>
<td>SLS Delivery to LEO</td>
<td>105 and 130</td>
<td>105 and 130</td>
</tr>
<tr>
<td>LEO (t)</td>
<td>105 (130)</td>
<td>105 and 130</td>
</tr>
<tr>
<td>SLS Shroud Dia.</td>
<td>10 / 22</td>
<td>10 / 25</td>
</tr>
<tr>
<td>or Barrel Length</td>
<td>10 / 25</td>
<td>10 / 15</td>
</tr>
<tr>
<td>Trip Duration</td>
<td>180 / 500 / 200</td>
<td>309 / 400 / 224</td>
</tr>
<tr>
<td>(days to Mars,</td>
<td>174 / 539 / 201</td>
<td>439 / 300 / 224</td>
</tr>
<tr>
<td>on Mars, back</td>
<td>914 days total trip</td>
<td>1065 days total trip</td>
</tr>
<tr>
<td>home)</td>
<td>980 days total trip</td>
<td>1-2 ATV launches required to provide consumables to E-M L2</td>
</tr>
<tr>
<td>Comments</td>
<td>Requires propellant depot</td>
<td>Number of launches reduced to 7 with 130 mt SLS</td>
</tr>
</tbody>
</table>

NASA/SP–2009-566-ADD2
Integrated Manned Interplanetary Spacecraft Concept Definition (ca. 1968)

Crewed Mission to Mars Surface

Figure 4-14
Crewed Missions to Mars Surface

Conjunction “Long Stay” Class
Synthesis Group “America at the Threshold” 1991

Opposition “Short Stay” Class
“90-Day Study on the Human Exploration of the Moon and Mars” 1989

Not including surface stay time
Total crewed duration: ~900 days

Including 25 day surface stay time

“SOA” Nuclear Electric Propulsion (NEP)


Solid Core Fission Reactor
Brayton conversion
\[ I_{\text{sp}} \approx 5000 \text{ sec} \]
\[ T_{\text{top}} = 1500 \text{ K} \]
\[ T_{\text{rad}} = 500 \text{ K avg.} \]
\[ \alpha_{\text{pwr}} = \approx 11 \text{ kg/kW}_e \]
\[ \alpha_{\text{prop}} = \approx 2 \text{ kg/kW}_e \]
Parametric Mars Architecture Studies
(ca. 1989)

Crewed Missions to Mars Surface with “SOA” NEP ($\alpha = \sim 13 \text{ kg/kW}_e$)

Conjunction “Long Stay”
Synthesis Group “America at the Threshold”

Opposition “Short Stay” Class
“90-Day Study on the Human Exploration of the Moon and Mars” 1989

- Total IMLEO = ~500 mT
- Piloted In-space time = 360 days

- Total IMLEO = ~480 mT
- Piloted time = 510 days
“Advanced” Nuclear Electric Propulsion (NEP)

5 MW\textsubscript{e} to EP

2.5 MW\textsubscript{e} to EP

Crewed Missions to Mars Surface with “Advanced” NEP ($\alpha \approx 5 \text{ kg/kW}_e$)

- **Conjunction “Long Stay” Class**
  - Synthesis Group “America at the Threshold” 1991
  - Opposition “Short Stay” Class
  - “90-Day Study on the Human Exploration of the Moon and Mars” 1989

- Not including surface stay time
- Total crewed duration: ~900 days
- Total IMLEO = ~400 mT
- Piloted in-space time = 260 days

- Including 25 day surface stay time
- Total IMLEO = ~360 mT
- Piloted time = 400 days

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**Parametric Mars Architecture Studies (ca. 1989)**


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[Diagram showing various mission scenarios and technologies]
Aneutronic Fusion Power NEP

**Fusion Fuel Pairs (Product Energy)**

D + T = n⁰ (14.07 MeV) + ⁴He (3.52 MeV)

D + D = n⁰ (2.45 MeV) + ³He (0.82 MeV) (50%)
D + D = p (3.02 MeV) + T (1.01 MeV) (50%)

D + ³He = p (14.68 MeV) + ⁴He (3.67 MeV)

p + ¹¹B = ³He (8.7 MeV)

**Fusion Reaction Cross-Sections**

Figure 5 — Typical Fusion Reaction Cross Sections

- P⁺¹¹B Fusion Reactor
- Direct conversion to power
- Advanced PMAD
- Advanced Plasma Thruster
  - \( I_{sp} \approx 10000 \) sec
  - \( \alpha_{pwr} = \sim 2 \text{ kg/kW}_e \)
  - \( \alpha_{prop} = \sim 1 \text{ kg/kW}_e \)
Crewed Missions to Mars Surface with Aneutronic Fusion ($\alpha = \sim 3 \text{ kg/kW}_e$)

- Total IMLEO = $\sim 400 \text{ mT}$
- Piloted In-space time = 220 days

- Total IMLEO = $\sim 350 \text{ mT}$
- Piloted time = 350 days

Conjunction “Long Stay” Class
Synthesis Group “America at the Threshold” 1991

Opposition “Short Stay” Class
Human Exploration of the Moon and Mars” 1989
150 kW_e max power.
- 1600 mT launched to assembly orbit
- 220 mT to Mars surface
- ~300 day surface stay
- ~1000 day mission duration
- Evolutionary PV technology

15 MW_e max power.
- 360 mT launched to assembly orbit
- 125 mT to Mars surface
- ~25 day surface stay
- ~350 day mission duration
- Advanced fusion technology