Methane Propulsion Elements for Mars
Tom Percy, Tara Polsgrove, Dan Thomas: NASA Marshall Space Flight Center

April 4, 2017
Introduction

- Human exploration beyond LEO relies on a suite of propulsive elements to:
  - Launch elements into space
  - Transport crew and cargo to and from various destinations
  - Provide access to the surface of Mars
  - Launch crew from the surface of Mars

- Oxygen/Methane propulsion systems meet the unique requirements of Mars surface access

- A common Oxygen/Methane propulsion system is being considered to reduce development costs and support a wide range of primary & alternative applications
METHANE APPS
- Commercial Earth-to-Orbit
- Orbital Maneuvering @ Earth
- Orbital Maneuvering @ Moon
- Lunar Surface Access
- Interplanetary Transport of Humans
- Orbital Maneuvering @ Mars
- Mars Descent and Landing
- Mars Ascent
Methane Propulsion System Definition

**Integrated Reaction Control System (iRCS)**

- **Benefits:**
  - Packaging: Limited real estate for MAV systems
  - Specific Impulse: Reduction in total RCS propellant load
  - Thermal: Centralized propellant storage
- **RCS Requirements & Assumptions**
  - Support steady-state and pulsed mode operations
    - Attitude control, AR&D, small steady-state burns
    - For In-Space Transportation, on average the RCS propellant budget is ~30% of the total stage prop budget (can be as high as 55%)
  - Provide attitude control for Mars descent & ascent
  - Need both 100 lbf-class and 1000 lbf-class thrusters

**Cryogenic Fluid Management (CFM)**

- **Benefits:**
  - Propellant Enabler: Enables use of Lox/LCH$_4$ propulsion systems
- **CFM Requirements & Assumptions**
  - Eliminate boil-off under steady-state conditions
  - Support ISRU liquid oxygen production on Martian surface (including liquefaction)
  - 90 K, 100 W cryo-cooler (~10 W/W)

**Main Propulsion System (MPS)**

- **Benefits:**
  - ISRU: Production of LOX from Martian atmosphere reduces MAV landed mass by 25t
  - Density-$I_{sp}$: Balance of performance, packaging & storage
- **MPS Requirements & Assumptions**
  - Engine Thrust ~ 22,500 klbf
  - Engine $I_{sp}$ ~ 360 s
  - Throttle Range ~ 5:1
  - In-space / Martian Surface Dormancy periods > 5 years
  - Minimal propellant loss (~0.15 kg/day)
Methane Commonality: Driving Requirements to Family of Elements

- **Precursor & Spin-Off Applications**
  - Mars Transportation & Support Elements
  - Mars Surface Access

- **Mars Surface Access Drives Methane Propulsion Requirements**
  - MAV packaging constraints lead to iRCS
  - Methane propellant selection leverages ISRU to reduce landed mass of MAV
  - Main Engine Thrust & $I_{sp}$ set for MAV performance
  - Main Engine throttling required for MDM

- **Common Propulsion Leads to Inheritance of Performance & Design**
  - In-space elements add engine restart requirement
  - Different performance benefits ID'd & leveraged

- **Spin-Off Applications Leverage Investment**
  - Early application can provide demo opportunities
  - Alternative applications not in Mars critical path but available before and during Mars campaign

- **Delivery of First In-Space Transportation Element Drives Development Schedule**
  - Precursor & spin-off availability tied to, but do not drive, development schedule
  - Precursor applications provide system demo opportunity

<table>
<thead>
<tr>
<th>Phase 1 &amp; 2</th>
<th>Phase 3 &amp; 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>2021</td>
<td>2029</td>
</tr>
<tr>
<td>2022</td>
<td>2030</td>
</tr>
<tr>
<td>2023</td>
<td>2031</td>
</tr>
<tr>
<td>2024</td>
<td>2032</td>
</tr>
<tr>
<td>2025</td>
<td>2033</td>
</tr>
<tr>
<td>2026</td>
<td>2034</td>
</tr>
<tr>
<td>2027</td>
<td>2035</td>
</tr>
<tr>
<td>2028</td>
<td></td>
</tr>
</tbody>
</table>
• This Mars Ascent Vehicle (MAV) carries 4 crew members and science cargo off the surface of Mars to rendezvous with an Earth Return Vehicle waiting in a 1 Sol Mars orbit.

• General Design Specs
  – Operational Life = 2 days
  – Total Service Life ~ 3058 days
  – Crew Capacity = 4
  – 4 engines (3 on 1\textsuperscript{st} Stage, 1 on 2\textsuperscript{nd} stage)

• General Design Notes
  – 2 Stage to Orbit
  – Nested propellant tanks
  – ISRU Oxygen Production
Methane Element: Mars Descent Module

• The Mars Descent Module (MDM) is sized to carry all mission manifests to the Martian surface. Uses a combination of inflatable aerodynamic decelerator and super-sonic retro-propulsion to perform controlled entry, descent, & landing.

• General Design Specs
  – Total Service Life may be > 5 years
  – Cargo Capacity = 20t
  – 8 engines (throttle to 20%)

• General Design Notes
  – Use of HIAD (other decelerator approached being traded)
  – Supports aerocapture and EDL
  – Provides power & support to payloads during Earth-Mars transit
  – Supports MAV during Mars surface stay (structurally & thermally)
The Mars Cryo Propulsion Stage (MCPS) is one of several options currently being traded for Earth-Mars transportation.

**General Design Specs**
- Total Service Life may be > 5 years
- Total Prop Capacity ~43t
- 3 main engines
- 4 RCS pods with 1000 lbf rear-axial pointing thrusters for small translational maneuvers

**General Design Notes**
- Stages used for Earth return from Mars are pre-deployed and spend extended dormancy periods in orbit around Mars
- RCS maneuvers make up a significant portion of total propellant load
- Multiple main engine restarts required
Some Mars mission concepts under consideration have a functional requirement to transfer crew between different parking orbits at Mars. A vehicle based on the MAV 2nd stage is one concept being considered for use as the crew taxi.

**General Design Specs**
- Operational Life = 2 days w/ long periods of dormancy
- Crew Capacity = 4
- 1 main engine
- $\Delta V$ capacity $\sim 2$ km/s

**General Design Notes**
- Potentially common design with MAV
- Requires multiple restarts
- Extended dormancy period before and between operations
Methane Element: cis-Lunar Propulsion Module

• Methane propulsion could be applied to cis-Lunar propulsion functions for element maneuvering, aggregation, and repositioning. The concept shown here is designed to leverage propulsion systems required for Mars.

• General Design Specs
  – Long-duration active CFM for prop storage
  – Total Prop Capacity ~15t
  – 1 main engine

• General Design Notes
  – Designed to be co-manifested with large cargo elements on an SLS Cargo vehicle
  – Avionics and navigations system enable free-flyer operations
  – Potential to provide significant mass savings to Mars missions by performing “tug” functions during aggregation periods
• This is a conceptual vehicle design based on the cis-Lunar Propulsion Module which could provide Lunar surface access by leveraging the throttling capability of the Methane main engine.

• General Design Specs
  – Long-duration active CFM for prop storage
  – Total Prop Capacity ~15t
  – 1 main engine (throttleable to 20%)

• General Design Notes
  – Designed to be co-manifested with large cargo elements on an SLS Cargo vehicle
  – Avionics and navigations system enable free-flyer operations
  – Could be adapted for landing at other destinations.
Methane Element: Co-Manifested Prop Module

• This is a conceptual vehicle specifically designed to serve as a propulsion module for payload that are co-manifested on SLS Crew launches. It leverages the components of the iRCS for Mars.

• General Design Specs
  – Passive and active CFM variants have been designed
  – Total Prop Capacity ~2t
  – 4 x 1000 lbf RCS thrusters as main propulsion
  – 3-6t of payload delivered to LDRO

• General Design Notes
  – Designed to be co-manifested on SLS Crew vehicle with or without a payload element
  – Avionics and navigations system enable free-flyer operations
  – Variant shown on this chart supports a CFM Demonstration mission
Other Applications and Future Investigations

• Early applications of the Methane Propulsion System components can be designed to maximize mission flexibility
  – Key is to use only systems with direct ties to Mars elements (no new or unique developments)
  – Use of precursor elements builds flight time on crew-critical propulsion systems during the early phases of the program

• New elements and application still to be investigated
  – Some work has been completed looking at Lunar surface access with Mars lander elements
  – MSC will be looking at a variant of the Hybrid spacecraft with Methane propulsion

• Iterative design with technologist feedback is key
  – Preliminary designs assume levels of performance, reliability, and feasibility
  – Engagement with propulsion and CFM technologists will ensure that early lessons learned (including findings from relevant test programs) are incorporated into design refinements
Questions?

# JOURNEY TO MARS