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
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 Isp ~ 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

Phase 1 & 2
2021 2022 2023 2024 2025 2026 2027 2028

Phase 3 & 4
2029 2030 2031 2032 2033 2034 2035
Methane Element: Mars Ascent Vehicle

• 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 1st Stage, 1 on 2nd stage)

• General Design Notes
  – 2 Stage to Orbit
  – Nested propellant tanks
  – ISRU Oxygen Production
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
- ΔV capacity ~ 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