Evolution of MPCV Service Module
Propulsion and GN&C Interface Requirements

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Summary

• Introduction
• Mission Description
• ESM Propulsion Subsystem Design
• SM Propulsion and GNC Interfaces
  – Main Engine and TVC
  – Auxiliary Engines
  – RCS Engines
• Conclusions
Introduction

- Service Module provides propulsion, regulates heat for the spacecraft, generates electrical power, and stores commodities for life support for the Orion spacecraft

- Propulsion subsystem characteristics
  - Propellant: NTO/MMH
  - Usable Propellant Load: 18964 lbm (8600 kg)
  - Single main engine with TVC, eight auxiliary engines, suite of RCS engines

- In 2012 NASA and ESA entered into a partnership for the delivery of the ESM
  - Prime contractor for ESM is Airbus Defense and Space
  - Prime contractor and integrator of MPCV is Lockheed Martin

- MPCV currently has two primary missions: EM-1 and EM-2

- Propulsion interface requirements with GNC have been updated between CxP SM and ESM due to desired use of heritage hardware and updates in the exploration architecture
**EM-1: 25-26 Day DRO**

1. **Launch**
2. **Perigee Raise Maneuver (PRM)**
   - ICPS - 100x975 nmi (185x1806 km)
3. **Trans-Lunar Injection (TLI)**
   - ICPS
4. **Trans-Lunar Injection (TLI)**
   - ICPS
5. **Outbound Power Flyby (OPF)**
6. **Distant Retrograde orbit Insertion (DRI)**
7. **Distant Retrograde Orbit (DRO)**
   - 37,797 nmi (70,000 km)
8. **High Lunar Orbit (HLO)**
   - 54x5400 nmi (100x10,000 km)
9. **Return Trajectory Correction (RTC)** burns
   - Orion
10. **Return Trajectory Correction (RTC)** burns
    - Orion
11. **CM/SM Sep**
    - EI-20 min
12. **Entry & Landing**

**Total Mission Duration: 25-26 days**

**Return: 12 days**

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**EM-2: 10-14 Day HLO**

1. **Launch**
2. **Perigee Raise Maneuver (PRM)**
   - ICPS - 100x975 nmi (185x1806 km)
3. **Outbound Trajectory Correction (OTC)** burns
   - Orion
4. **Outbound Trajectory Adjust (OTA)**
   - Orion
5. **Lunar Orbit Insertion (LOI)**
   - Orion
6. **Trans-Earth Injection (TEI)**
   - Orion
7. **Return Trajectory Correction (RTC)** burns
   - Orion
8. **CM/SM Sep**
   - EI-20 min
9. **Entry & Landing**

**Total Mission Duration: 10-14 days**

**Return: 3-6 days**
<table>
<thead>
<tr>
<th>Table 1. CxP and EM-2 HLO Comparison.</th>
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<tr>
<td><strong>Constellation</strong></td>
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<tr>
<td>Mission Type</td>
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<tr>
<td>Lunar Lander</td>
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<tr>
<td>Launches</td>
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<tr>
<td>Mission Duration</td>
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<tr>
<td>Rendezvous</td>
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<td>Upper Stage Separation</td>
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<td>Outbound Trajectory Correction Burns</td>
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<tr>
<td>Free Return Trajectory</td>
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<tr>
<td>OTA</td>
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<tr>
<td>LOI</td>
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<tr>
<td>Time in Lunar Orbit</td>
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<tr>
<td>Orbit Maintenance</td>
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<tr>
<td>TEI</td>
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<td>Landing</td>
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ESM Propulsion Subsystem

- **Pressurization**
  - 5800 psi (40 Mpa) helium
  - Single COPV per commodity, ATV/EPS heritage
  - Electronic Pressure Regulation (bang-bang), BDRV

- **Propellant Storage and Distribution**
  - Four tanks, two per commodity, OST-23 heritage
  - Serial tank configuration, PMD in downstream tank

- **Main Engine**
  - Space Shuttle OMS-E with TVC (6000 lbf)
  - Isolated by mainline isolation valve

- **Auxiliary Engines**
  - Eight R-4D-11 (110 lbf)
  - Isolated into one string by Aux Engine Isolation Valve

- **Reaction Control System**
  - Twenty-four 50 lbf engines, ATV heritage
  - Isolated into two strings of twelve
  - Each string isolated into three groups of four engines
Main Engine and TVC Prop/GNC Requirements

- **CxP Main Engine: Orion Main Engine (OME)**
  - Derived key characteristics from Shuttle OMS-E
    - Increased chamber pressure, area ratio, and mixture ratio achieves higher thrust and specific impulse
  - Thrust and Isp driven by abort coverage, North Atlantic and higher delta V performance
    - RTAL/TAL overlap coverage with Ares ISS trajectories
    - 170 ft/s additional delta V performance
  - Vacuum starts driven by CxP nominal plus contingency starts
  - TVC range and slew rate driven by angular control authority for CxP missions and aborts

- **ESM Main Engine: Space Shuttle OMS-E**
  - Existing engine so performance parameters are fixed
    - Lower chamber pressure of OMS-E allows for lower system pressures
    - Lower thrust beneficial for on orbit loads on solar arrays
  - Thrust and Isp assessed to be adequate for aborts with SLS
    - 10 sec vs. 8 sec of abort overlap for MPCV vehicle configuration with SLS
  - Vacuum starts fixed, driven by OMS-E pneumatic pack, assessed to meet EM-1 and EM-2 missions
  - Space Shuttle TVC provides adequate abort and steering for EM-1 and EM-2
• **CxP Auxiliary Engines: Aerojet 164:1 R-4D-11**
  - Area ratio driven by accommodation, engines exterior to radiator panels
    - Lower AR Isp acceptable for CxP missions
    - Provides better duty cycle performance
  - Single burn duration driven by TEI backup
    - CxP had multi-burn TEI maneuver and longest burn is TEI-1
    - Calculated using 3 sigma low Isp and nominal thrust
  - Number of starts driven by cumulative operation at 1 Hz

• **ESM Auxiliary Engines: Aerojet 300:1 R-4D-11**
  - Area ratio driven by propellant utilization, engine interior to radiator panels
    - Higher AR can be accommodated due to smaller OMS-E
    - Provides improved delta V performance, 66 ft/s
    - Duty cycle performance still meets engine constraints
  - Single burn duration covers single burn TEI
    - Duration calculated assuming entire prop load consumed by auxiliary engine
  - Number of starts driven by cumulative operation at 1 Hz

### Table 3. Auxiliary Engine Driving Key Performance Parameters

<table>
<thead>
<tr>
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<th>CxP SSM</th>
<th>ESM</th>
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<tbody>
<tr>
<td>Nominal Specific Impulse</td>
<td>311 s</td>
<td>315 s</td>
</tr>
<tr>
<td>Single Burn Duration</td>
<td>4,500 s</td>
<td>7,200 s</td>
</tr>
<tr>
<td>Expected Duty Cycles</td>
<td>&gt; 50%</td>
<td>&gt; 50%</td>
</tr>
<tr>
<td>Number of Starts</td>
<td>10,000</td>
<td>7,200</td>
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RCS Prop/GNC IRD Requirements

• CxP RCS Engines: Aerojet R-1E
  – Thrust, min EPW, and configuration driven by needed authority, MIB, and plume impingement
  – Iterative approach between Prop/GNC/Vehicle Configuration converged on RCS thruster requirements
    • Sixteen engines arranged in a string/pair configuration
    • Engines in canted/skewed configuration with each engine providing pitch/yaw and roll
      – Optimizes redundancy with minimum number of thrusters
      – Provides capability for very small impulses

• ESM RCS Engines: 50 lbf engines from ATV
  – Thrust, min EPW, and configuration driven by needed authority and MIB and plume impingement
  – Authority and precision requirements defined to allow ESA and ADS to complete RCS design
    • Twenty-four engines arranged in a string/quad configuration
    • Engines in orthogonal configuration
      – Accommodates ESM solar array configuration
      – Increased thrust allows for additional control authority, small MIB meets precision requirements

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<tr>
<th></th>
<th>CxP SM</th>
<th>ESM</th>
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<tbody>
<tr>
<td><strong>Nominal Thrust</strong></td>
<td>25 lbf</td>
<td>50 lbf</td>
</tr>
<tr>
<td></td>
<td>(110 N)</td>
<td>(220 N)</td>
</tr>
<tr>
<td><strong>Minimum EPW</strong></td>
<td>40 ms</td>
<td>28 ms</td>
</tr>
<tr>
<td><strong>Number of Engines</strong></td>
<td>16</td>
<td>24</td>
</tr>
</tbody>
</table>
Summary

• Mission descriptions have evolved from CxP to MPCV
• The SM has maintained key functions through the implementation of MPCV and the partnership with ESA
  – Provides propulsion for the integrated Crew and Service Module
  – Generates electrical power
  – Regulates heat for the spacecraft
  – Stores commodities for life support
• Propulsion subsystem is a storable, pressure-fed bipropellant system feeding a main engine with TVC, eight auxiliary engines, and a suite of RCS engines
• Updates in the exploration architecture and the partnership with ESA have resulted in updates to the Propulsion interface requirements with GN&C
  – Main engine thrust, Isp, starts, and TVC performance
  – Auxiliary engine Isp, single burn duration, duty cycle performance, and starts
  – RCS engine thrust, min EPW, and configuration
• The ESM propulsion performance has been assessed to meet GNC requirements, supporting the use of hardware with heritage to the US and Europe