SLS Dual Use Upper Stage (DUUS) Opportunities

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Objective

- **Provide an overview of SLS DUUS type capability requirements to provide context for possible International Partner collaboration**

- **DUUS Overview Approach**
  - DUUS Capability
  - DUUS Generic Requirements
  - DUUS Development Timeframe
  - Typical SLS/DUUS Design Reference Mission
  - DUUS Description Overview
  - Primary Structure, Exploded View
  - Cryogenic Fluid Management
  - Main Propulsion System
  - Electrical Power System
  - Thermal Control System

DUUS Significantly Enhances Exploration Capability

- **Current SLS Block 1 configuration delivers ~90t to LEO and ~25t to Trans Lunar Injection (TLI)**

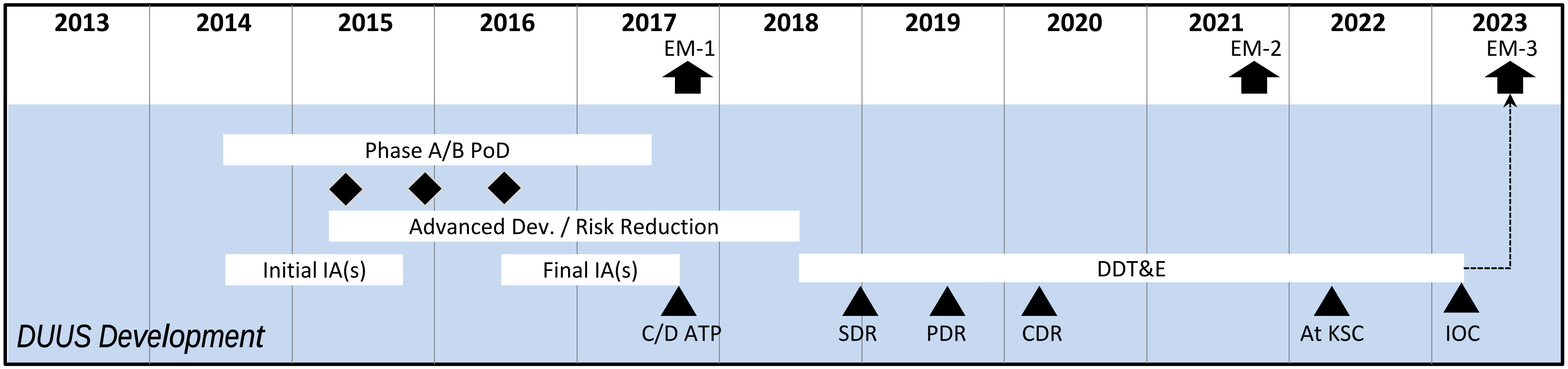
- **Addition of a DUUS would greatly increase exploration mission capture and performance margin for cis-Lunar and Near Earth System exploration campaigns**

- **Exploration Mission Capability Provided by a DUUS**
  - Low Earth Orbit Mission Class
    - **LEO delivery capability, 105 – 130t delivery**
    - Stage life/duration, 10 min – 5 hours
  - Destination Injection Mission Class
    - **Trans-Lunar, 40 – 50t delivery**
    - **Trans-Mars, 25 – 35t delivery**
    - Stage life/duration, 5 hours
  - Cis-Lunar Mission Class
    - **EM-L2 or Low Lunar Orbit, 30 – 35t delivery**
    - Stage life/duration, 5 days

Generic Mission/Stage/Engine Requirements

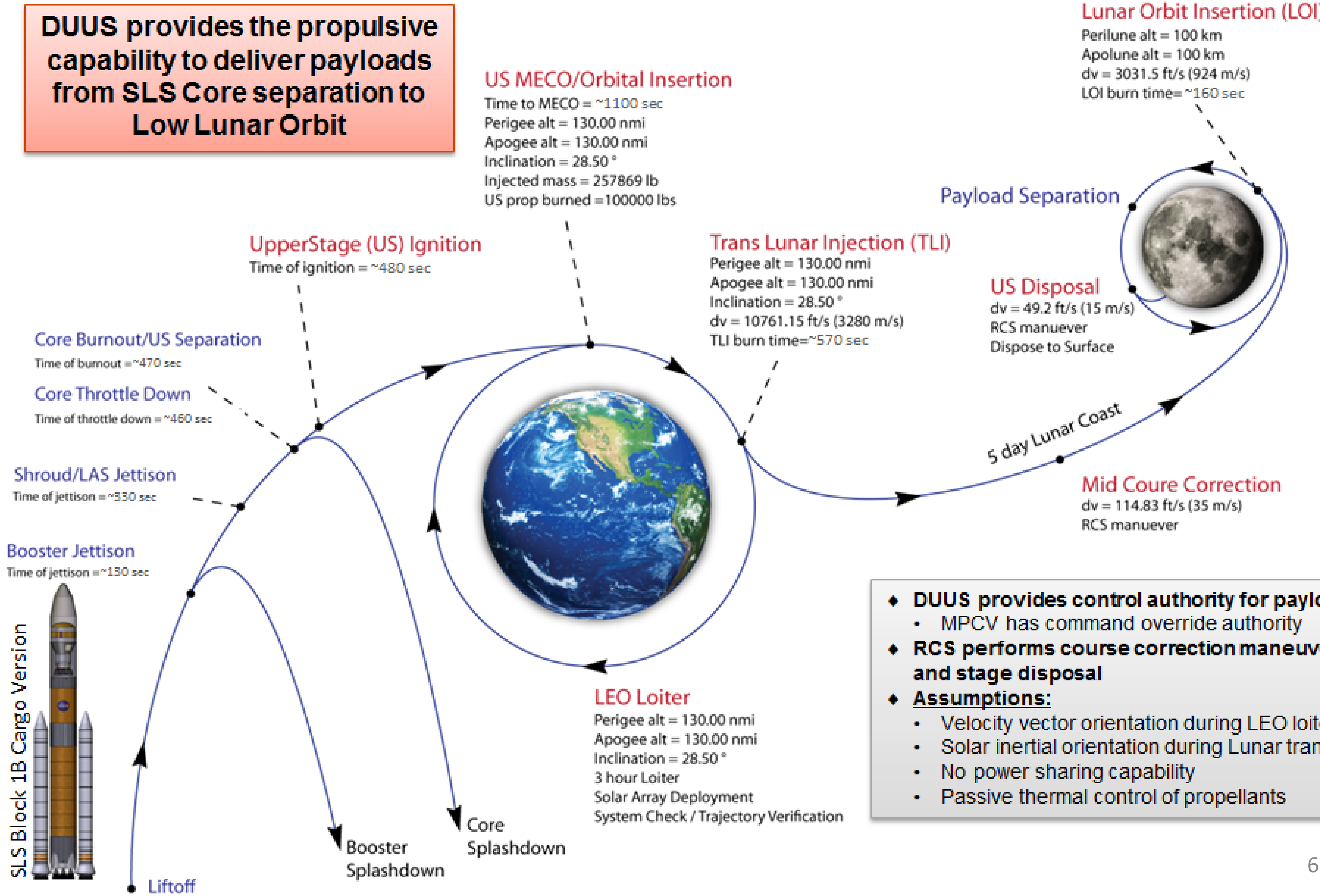
- **Stage provides multiple propulsion functionality**
  - Ascent burn (to range of LEO)
  - Trans-Destination Injection Burn (from LEO to Destination)
  - Insertion (Braking) Burn at Destination
- **Stage design considerations (Usable Propellant Mass Fraction is a Priority)**
  - Minimal Dry Mass
  - Minimal and Efficient Functionality
  - Maximum Usable Propellant
- **Stage description guidelines**
  - 130t Propellant Load (Oxygen / Hydrogen)
  - 100-120K lb Total Thrust Class
  - 8.4m maximum diameter
  - 8.4m H_2 Tank / 5m O_2 Tank (5.5m and 6.4m O_2 Tank Options)
  - 18.3m maximum height
- **Engine description guidelines**
  - 500-700s maximum single engine burn
  - 1100-1300s total mission burn time for single engine
  - 2-3 mission starts
  - 30 to 60K lb thrust per engine; 462 - 465 sec I_{sp}
  - Throttle TBD
  - Extendable Nozzle Option

DUUS Development Timeframe



Typical Lunar Surface DRM Profile

DUUS provides the propulsive capability to deliver payloads from SLS Core separation to Low Lunar Orbit



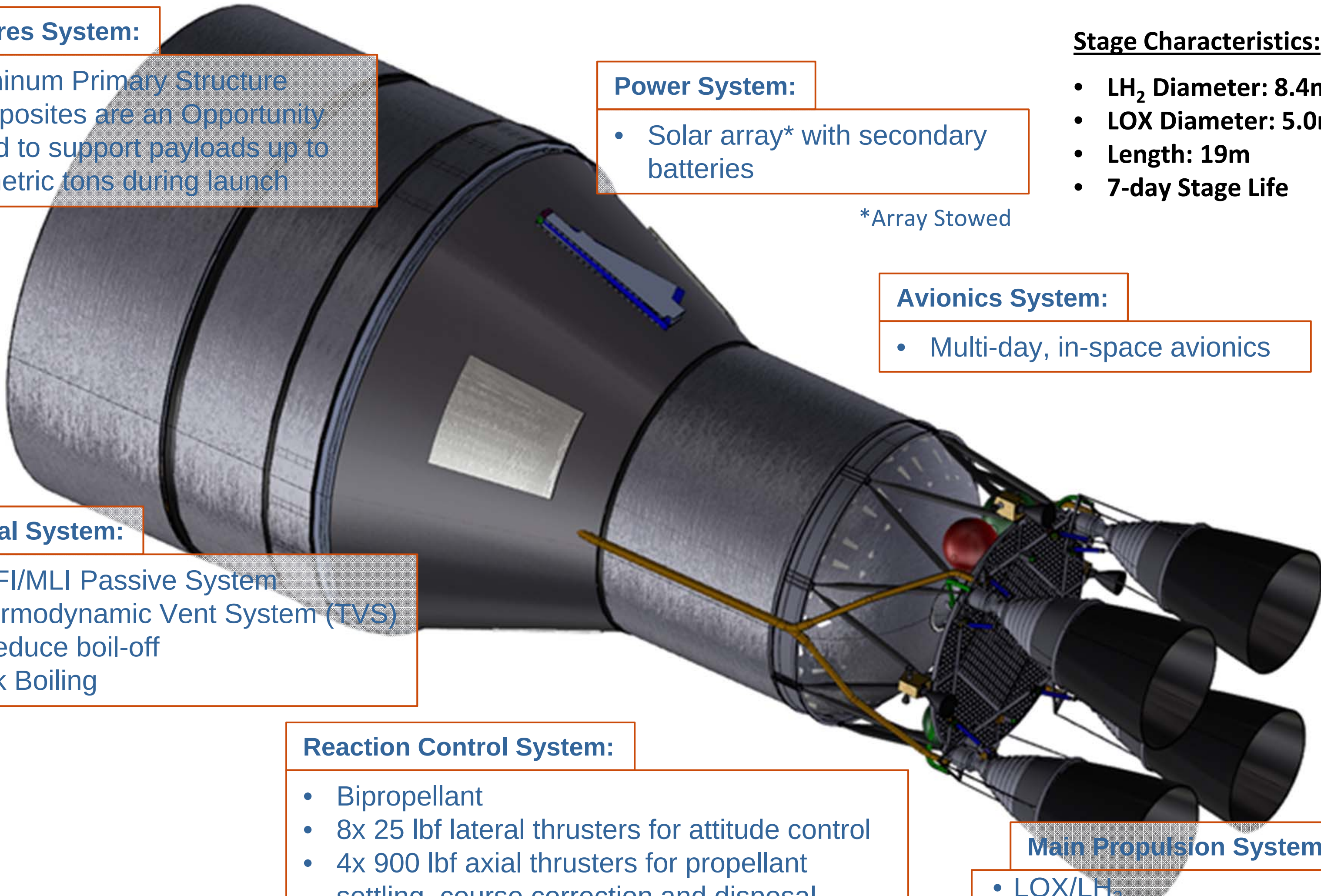
- **DUUS provides control authority for payload**
  - MPCV has command override authority
- **RCS performs course correction maneuvers and stage disposal**
- **<u>Assumptions:</u>**
  - Velocity vector orientation during LEO loiter
  - Solar inertial orientation during Lunar transit
  - No power sharing capability
  - Passive thermal control of propellants

Typical Mission Campaign Requirements

Design Reference Mission Description and Phasing	Payload Mass (t)	DUUS Mission Duration	Primary Propulsion System Burns	Delta V (m/s)
Tactical / Lunar Vicinity	25 t	5 hr	2	2900 - 3100
Strategic Class Exploration	20 - 30 t	5 hr / 5 days	2 / 3	3300 - 4500
Architectural Class Exploration	25 - 32+ t	5 hr / 5 days / 50+ days	2 / 3	3300 - 4700
Low Lunar Orbit Delivery	25 - 30 t	5 days	3	4300 - 4500

* All numerical values are representative approximations and not to be used for actual mission design.

DUUS Description Overview (Notional)



Structures System:

- Aluminum Primary Structure
- Composites are an Opportunity
- Sized to support payloads up to 35 metric tons during launch

Power System:

- Solar array* with secondary batteries

*Array Stowed

Stage Characteristics:

- **LH_2 Diameter: 8.4m**
- **LOX Diameter: 5.0m**
- **Length: 19m**
- **7-day Stage Life**

Avionics System:

- Multi-day, in-space avionics

Thermal System:

- SOFI/MLI Passive System
- Thermodynamic Vent System (TVS) to reduce boil-off
- Bulk Boiling

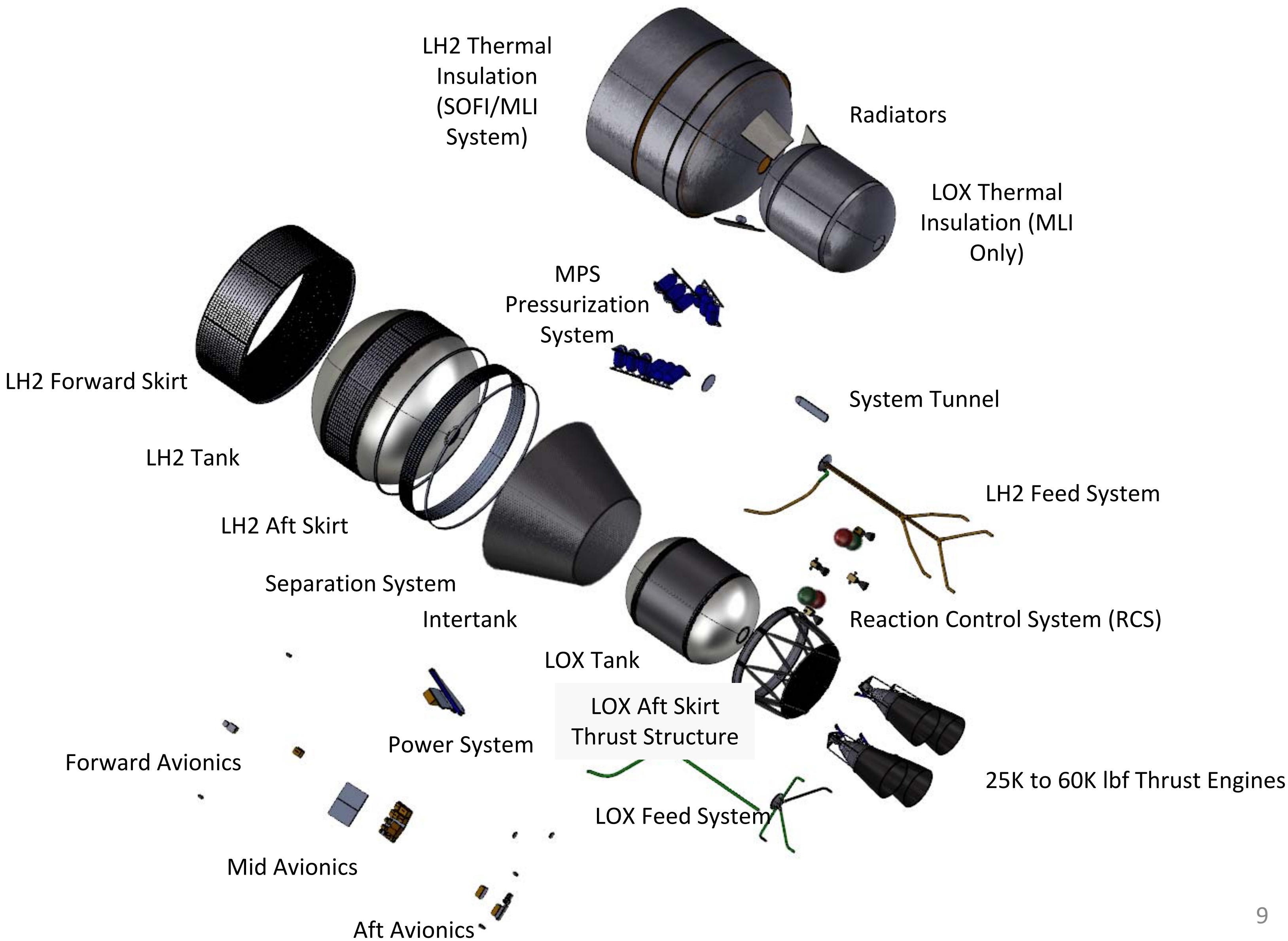
Reaction Control System:

- Bipropellant
- 8x 25 lbf lateral thrusters for attitude control
- 4x 900 lbf axial thrusters for propellant settling, course correction and disposal

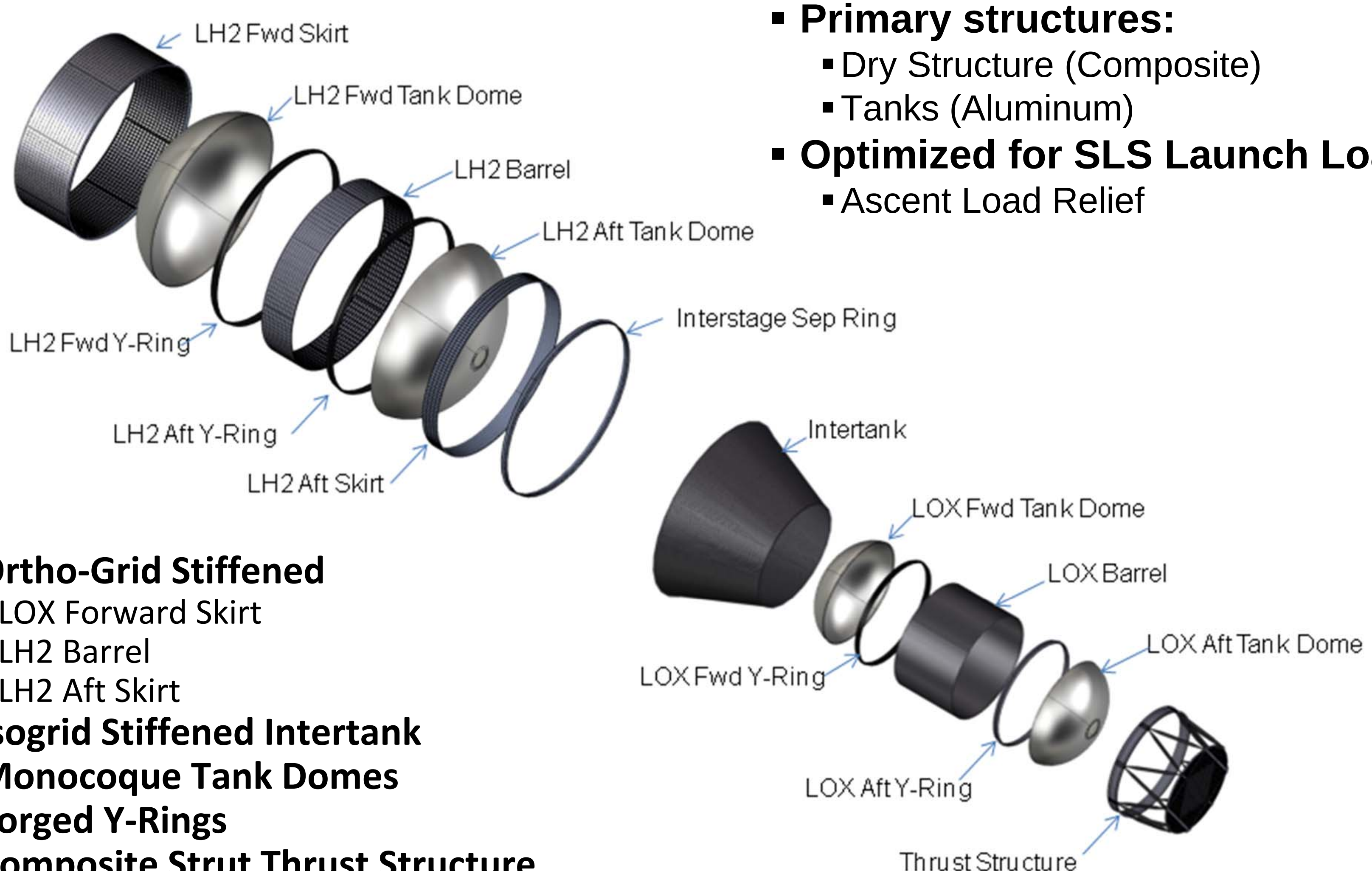
Main Propulsion System:

- LOX/LH_2
- 2 to 4 Engines
- 100K-120K lbf total Thrust Class
- 462 – 465 sec I_{sp}

DUUS Description (Exploded View)



DUUS Primary Structures

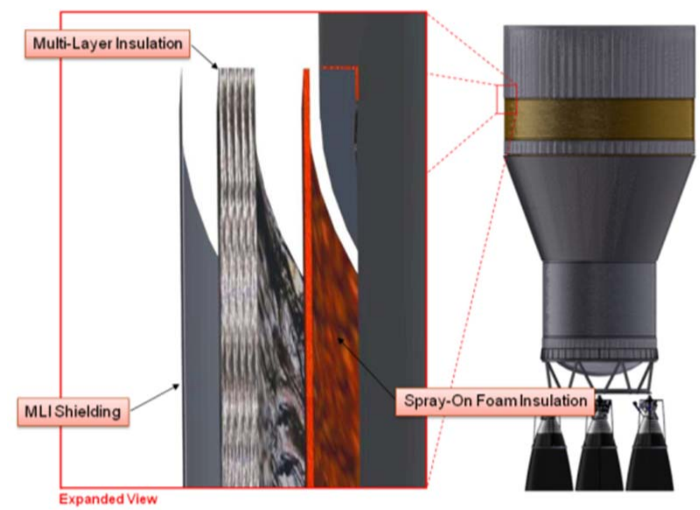


- **Primary structures:**
  - Dry Structure (Composite)
  - Tanks (Aluminum)
- **Optimized for SLS Launch Loads**
  - Ascent Load Relief

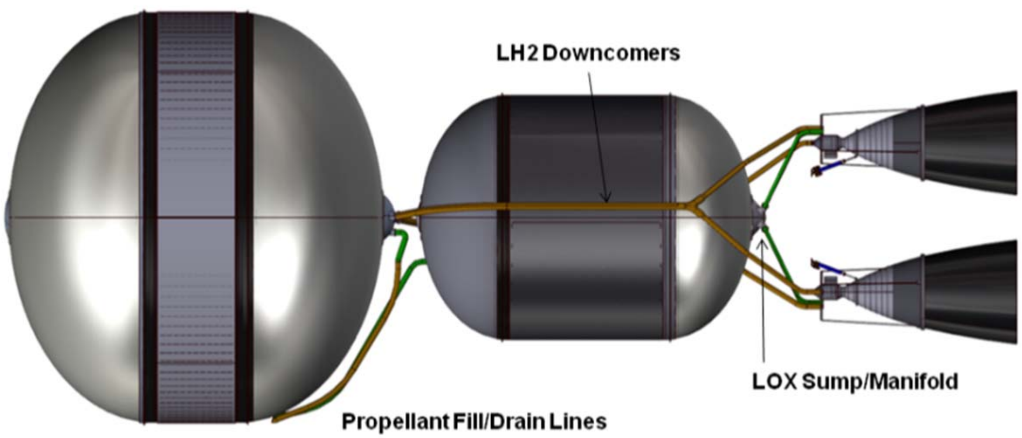
- **Ortho-Grid Stiffened**
  - LOX Forward Skirt
  - LH2 Barrel
  - LH2 Aft Skirt
- **Isogrid Stiffened Intertank**
- **Monocoque Tank Domes**
- **Forged Y-Rings**
- **Composite Strut Thrust Structure**
  - Primarily driven by thermal considerations (boil-off reduction)

DUUS Subsystem: Cryogenic Fluid Management

- **Propellant Management and Conditioning**
  - – Boil-off reduction
- **Thermal Insulation System**
  - – Spray-On Foam Insulation (SOFI)
    - Ground Environments
  - – Multi-Layer Insulation (MLI)
    - In-space Environments
- **Thermodynamic Vent System (TVS)**
  - – Mixing device
  - – Heat exchanger
  - – Allows venting in micro-gravity
- **Bulk Boiling Fluid Control Option**



DUUS Subsystem: Main Propulsion System



- **MPS provides up to 99K lbf of mainstage thrust required for the LOR-Lunar Mission**
  - Four notional engines with the extendable nozzle operating at a 5.88 MR
    - Thrust per engine: 25K to 60K lbf class
    - Engine I_{sp}: 462 to 465 seconds

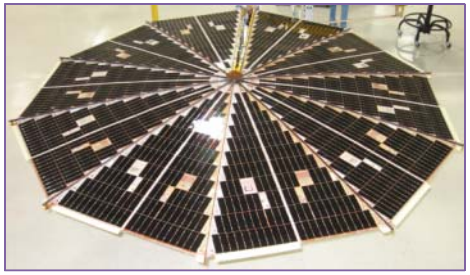
- **MPS supplies liquid propellant to the four notional engines at the flowrates, temperatures and pressures required for nominal engine operation.**
  - Two 5.0 inch runducts are connected to the fuel tank via a sump.
  - Each runduct supplies LH_2 to a manifold which connects two 3.5 inch propellant feedlines.
  - Four 2.5 inch propellant feedlines are connected to the LOX tank via a sump.
  - The feedlines carry propellant from the manifold and sump to the engine LH2 and LOX interfaces, respectively.

- **MPS supplies regulated gaseous helium for MPS and RCS pneumatics, and pressurant gases for the propellant tanks.**
  - Ten COPVs carry ~ 240 lbm gaseous helium.
  - Helium is regulated through a helium regulator package containing two parallel legs for redundancy.
  - Each parallel leg contains an electronically actuated isolation valve in the event a regulator fails open.

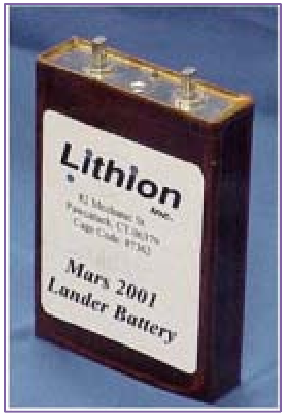
- **MPS supplies the LH2 tank with GH_2 pressurant gas during engine mainstage.**
  - Hot GH_2 is bled off the engines and used for autogenous pressurization.

DUUS Subsystem: Electrical Power System

- **Power Generation**
  - Capability similar to one 6.5m diameter UltraFlex solar array with two-axis tracking
  - Provides up to 7.7kW at EOL



- **Energy Storage**
  - Two lithium ion batteries
  - Single fault tolerant
  - Each battery provides up to 6.9kW-hr to loads



- **Power Management and Distribution**
  - Single fault tolerant electronics

DUUS Subsystem: Thermal Control System

- Provide thermal conditioning for avionics components
- Active TCS is required for long, in-space duration
- Maintain RCS propellant & MPS pressurant within acceptable temperature range
- Minimize heat leak into propellant tanks
- RCS & Helium Tanks Thermal Conditioning Subsystem
- Inputs to Cryogenic Fluid Management (Orbital Environments)