Advanced Space Exploration

LEO Propellant Depot: Servicing Impact on Space Missions

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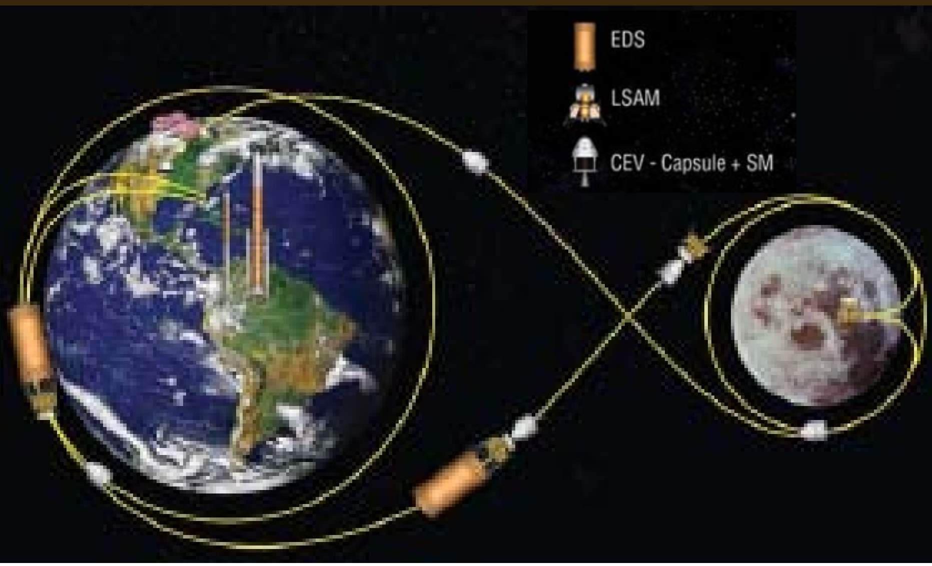
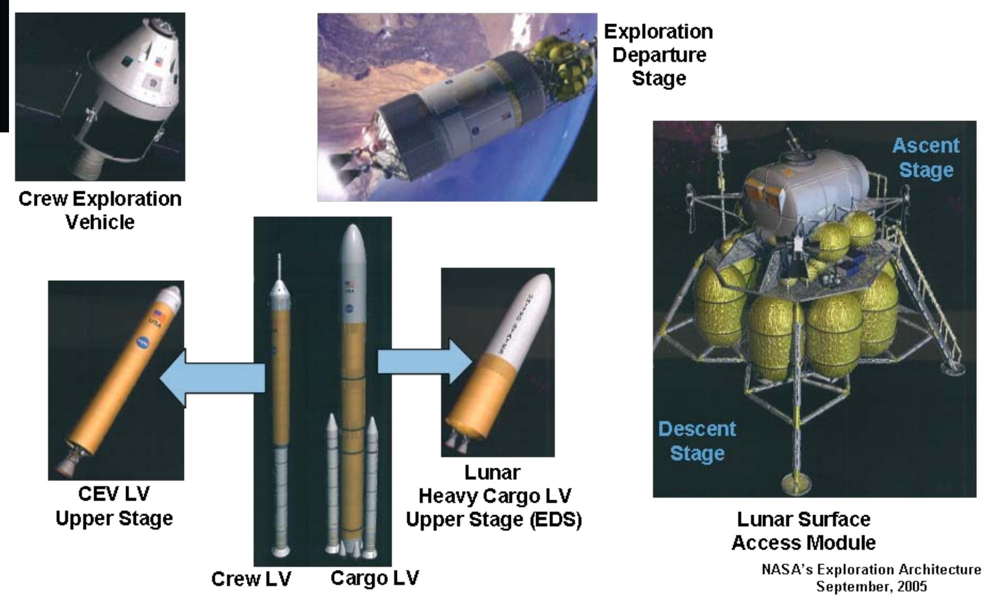
First, There was the Vision. . .

Then, the ESAS Final Report. . .



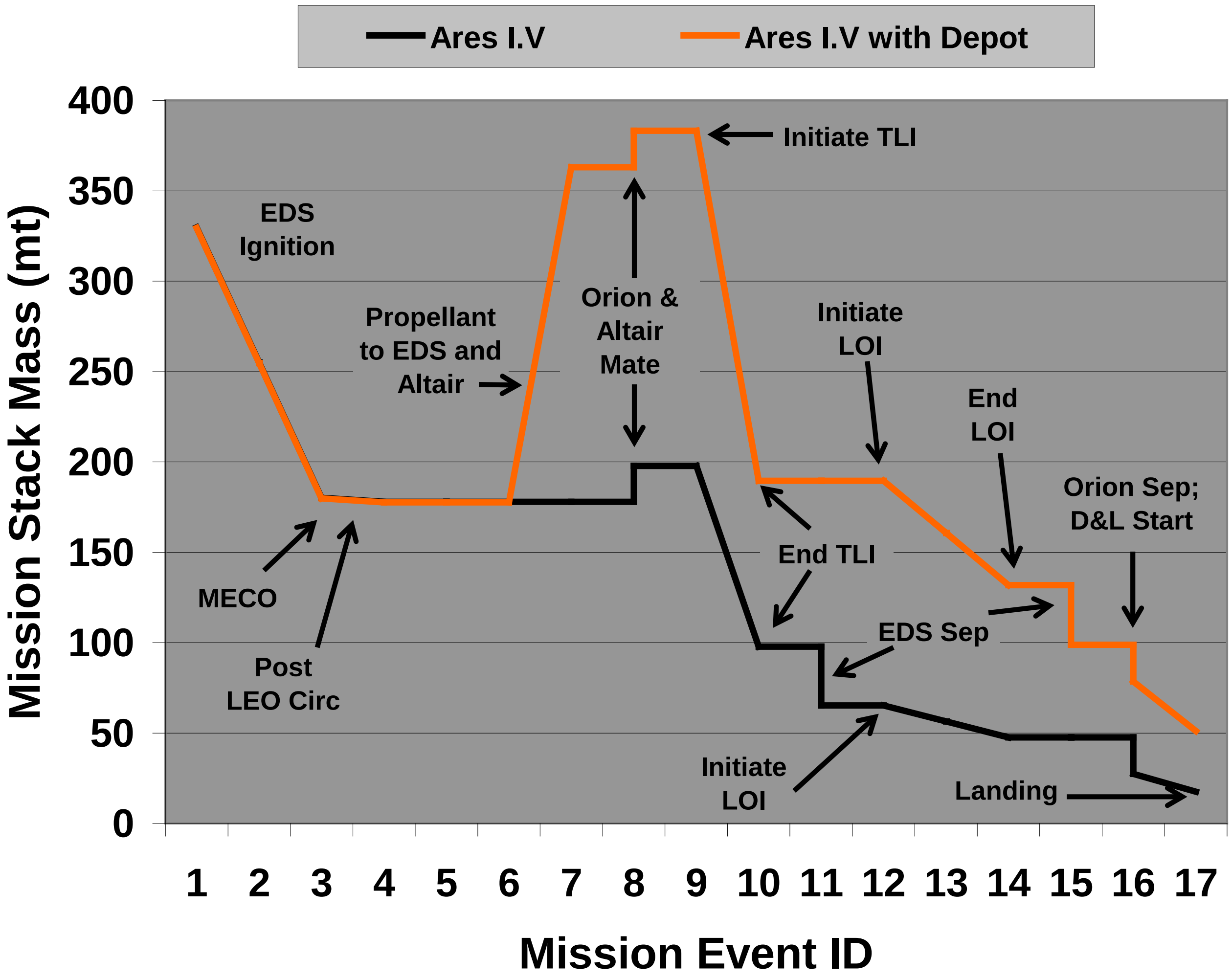
- **1.5 Launch architecture: Ares I & V**
- **Earth orbit rendezvous: CEV to LSAM/EDS**
- **EDS performs Earth orbit insertion & circularization and TLI burns**

If a depot NASA would use it;
propellant worth $10K/kg – Griffin, Nov. 2005



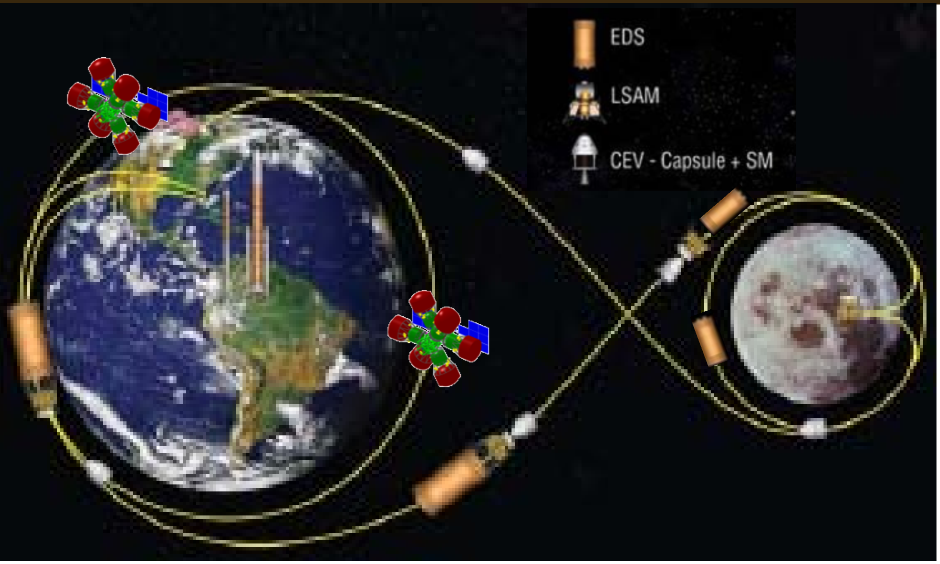
- **LSAM DS performs LOI with CEV and lunar descent and landing**
- **Lunar orbit rendezvous: LSAM AS to CEV**
- **LOx/LH in EDS and LSAM DS**
- **Lox/Methane in LSAM AS and CEV**

Depot Impact on Constellation Lunar Mission Events and Mass



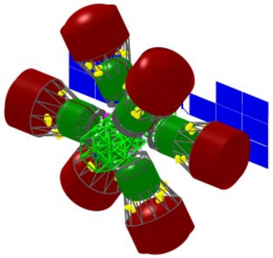
- One additional mating with propellant transfer
- 180 t additional mass at TLI
- EDS does TLI and LOI burn
- EDS released in LLO
- Altair tanks full in LLO
- 51 vs 18 t landed

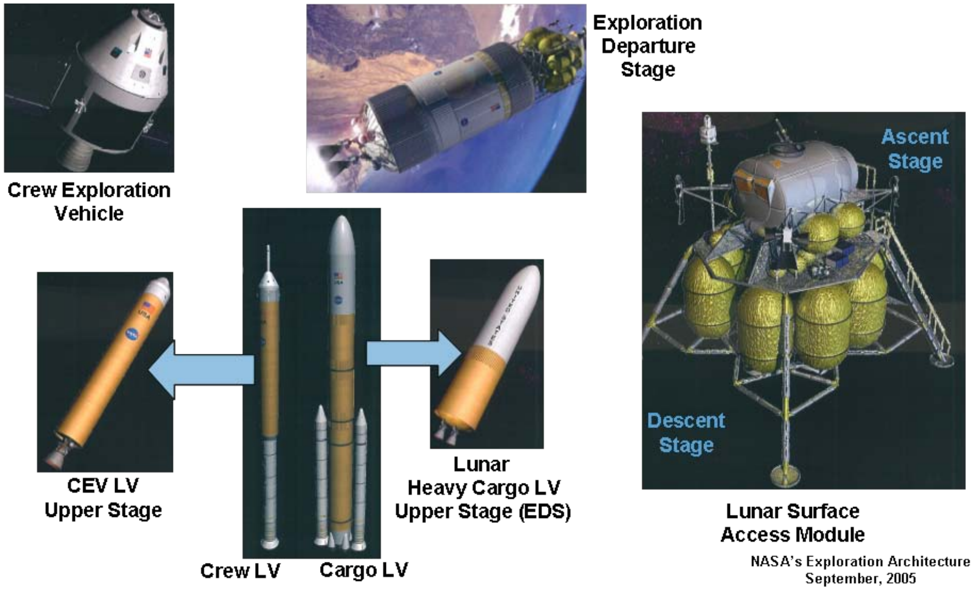
The Exploration Architecture with a LEO Propellant Depot



- 1.5 Launch or Single Launch architecture: Ares I & V or Ares V
- EDS & LSAM receive propellant in LEO
- Enables two sorties per lunar mission
- Earth orbit rendezvous: CEV to LSAM/EDS
- EDS performs Earth orbit insertion & circularization, TLI, and LOI burns

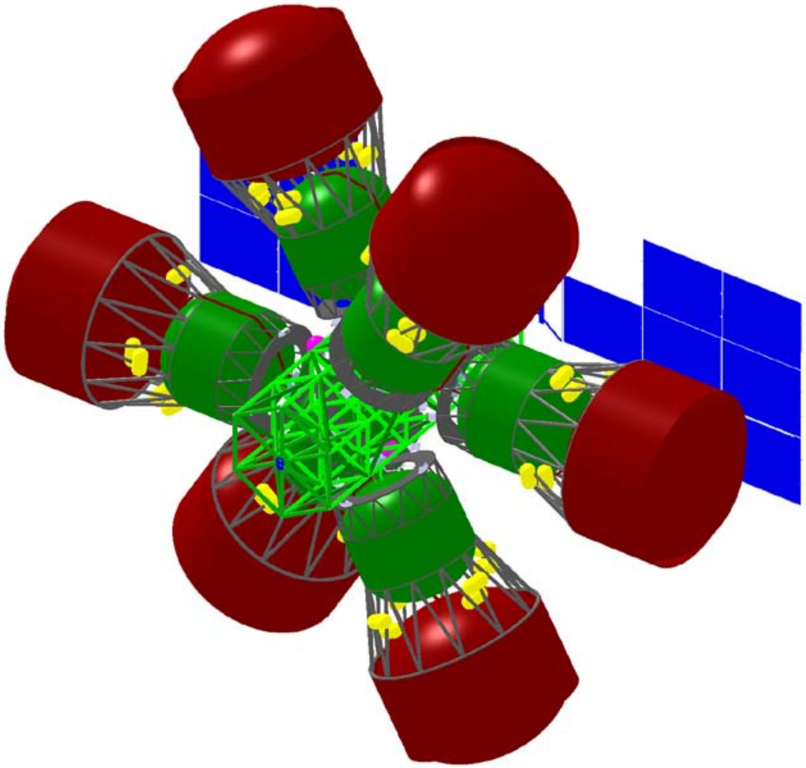
- LSAM DS performs only lunar descent and landing
- Lunar orbit rendezvous: LSAM AS to CEV
- LOx/LH in EDS and LSAM DS
- Lox/Methane in LSAM AS and CEV





A LEO Propellant Depot Concept

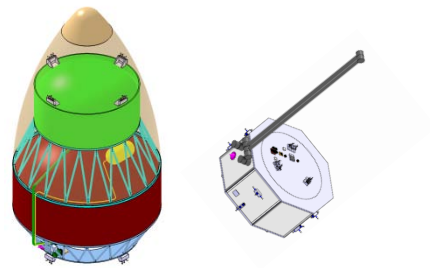
- **180 t capacity**
- **28.5 x 400 km orbital location**
- **Structural spine with subsystems and interfaces**
- **Multiple tanks to minimize failure impact**
- **Micrometeorite and orbital debris protection**
- **Thermal and fluid management**



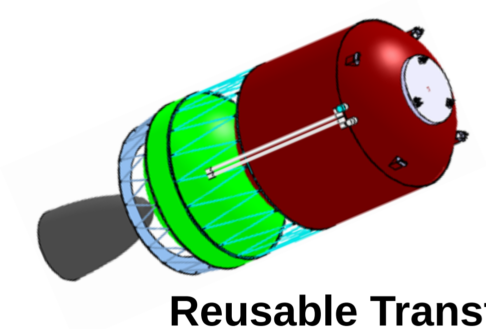
A Modular LEO Propellant Depot

A LEO Propellant Depot Architecture with Reusable Propellant Carrier and Depot Tug

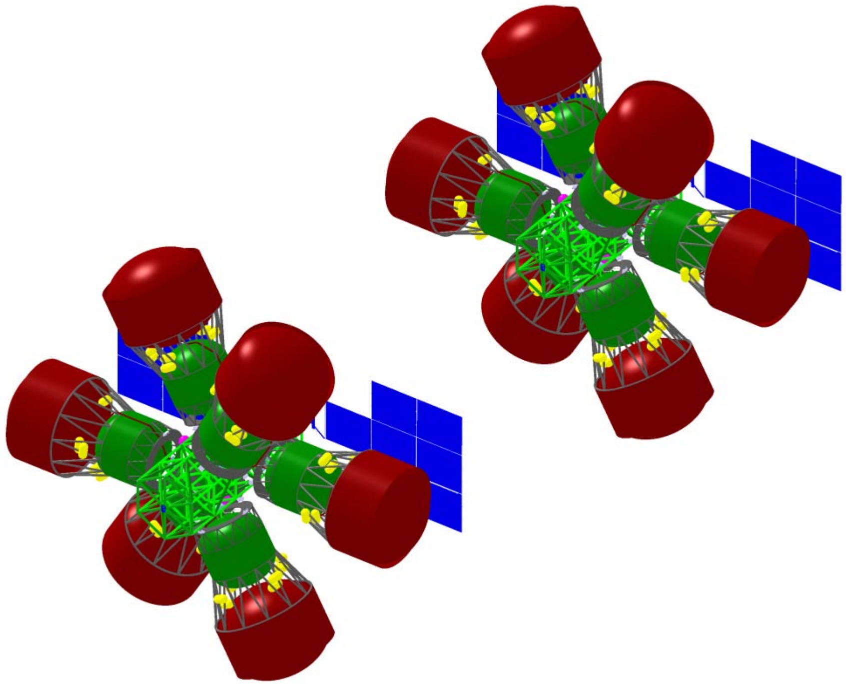
Low-cost launch provider
Space X Falcon 9-3.6 shown



Depot Tug with
Propellant Carrier
9400 kg PC mass
LOx/LH

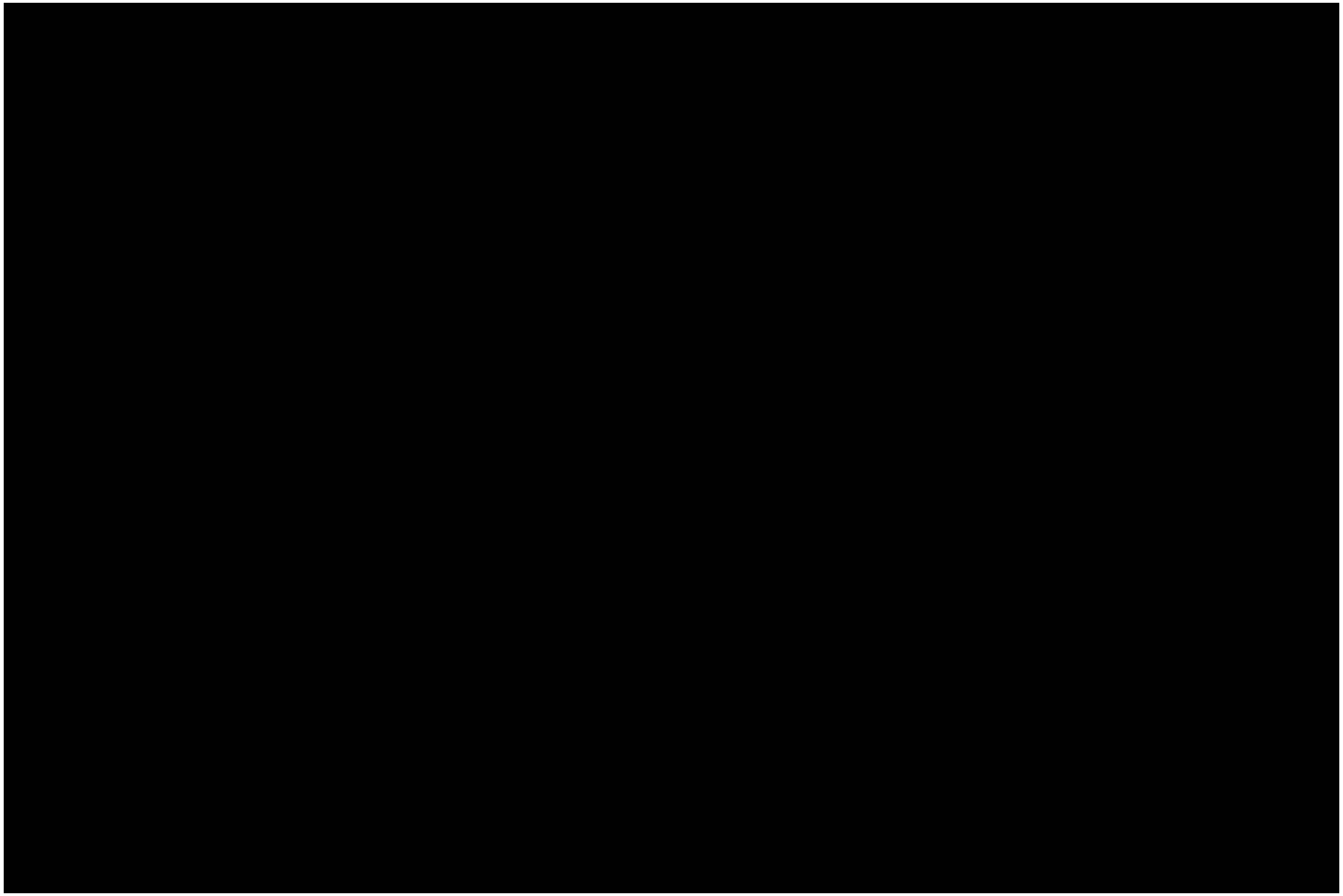


Reusable Transfer Stage
GTO and/or GEO delivery
LOx/LH

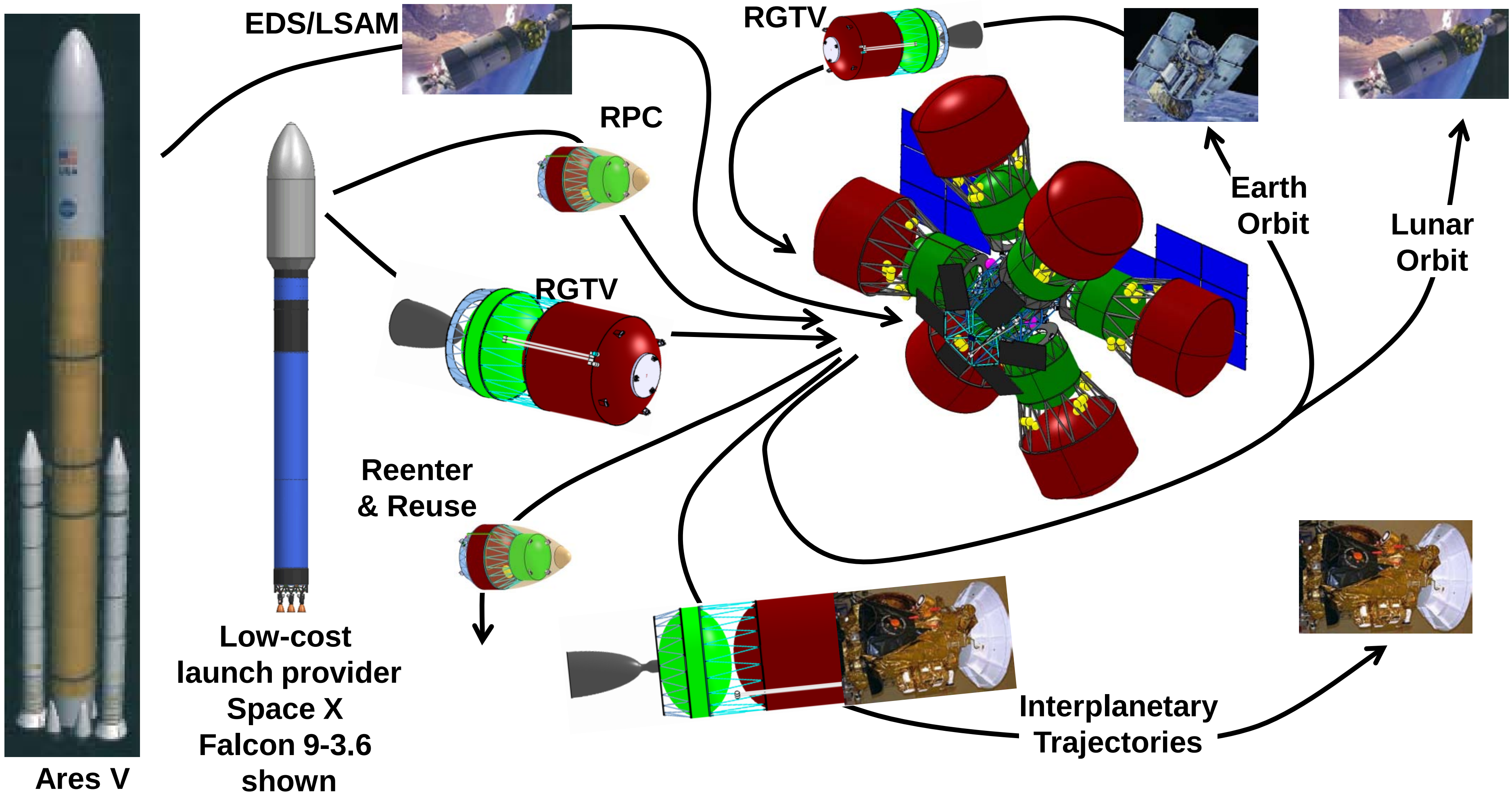


2 Modular Propellant Depots
180 t capacity
LOx/LH

LEO Propellant Depot Assembly and Operations



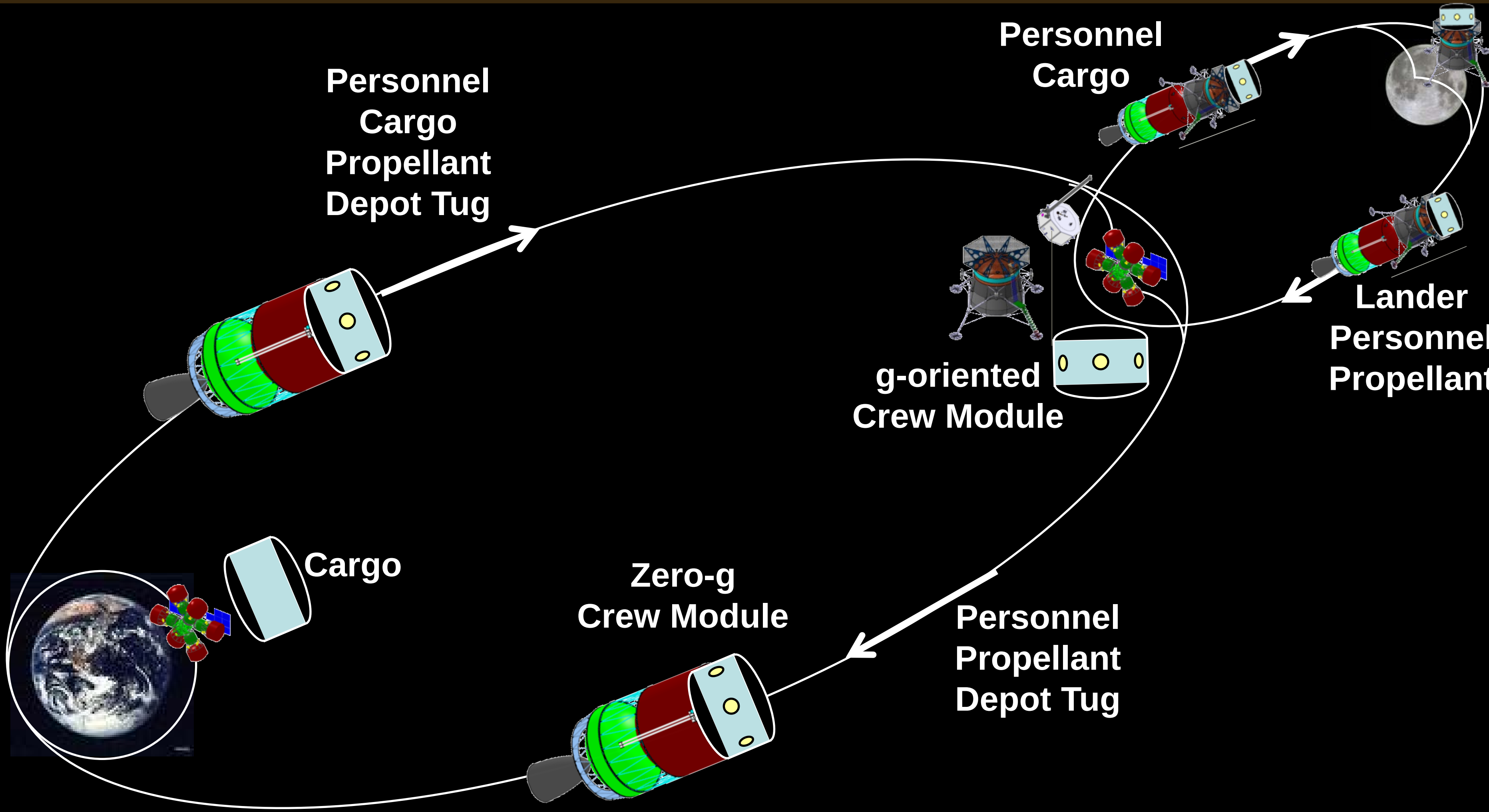
A LEO Propellant Depot Operational Concept: A Hub for Exploration and HEO Missions



LEO Propellant Depot Provides Existing Systems 2-3x Performance Capability

	Current	With Depot
Constellation Lunar Missions		
• Landed mass	18 t	51 t
• Lunar surface payload:	2 t	35 t
• Sorties (with ESAS landed mass)	1	2
GTO mission (167 km x 35,788 km x 27):		
• Delta IV H:	13 t	35 t
• Atlas V 551:	9 t	23 t
GEO mission		
• Delta IV H:	6 t	18 t
• Atlas V 551:	4 t	10 t
Interplanetary injection (C3 = 0)		
• Delta IV H:	10 t	20 t
• Atlas V 551:	7 t	15 t
Flexible Path injection (C3 = 0)		
• EDS	~70 t	~200 t

A Depot-Enabled Reusable Cislunar Architecture



Potential In-Space Propellants / Fluids Requiring Transfer and Storage

Propellant	Driving Mission or System
Argon; Xenon	Electric propulsion systems
Carbon Dioxide	Mars atmosphere as departure propellant source
Carbon Monoxide	Mars ascent propellant
Hydrazine	Existing satellite propellant
Hydrogen	Existing upper stages; Constellation EDS and Altair Descent Stage; Moon and Mars ISRU products; VASIMR and Nuclear Thermal stages
Methane	Orion Service Module and Altair Ascent Stage; Mars departure propellant
Nitrogen	Inert atmospheric gas make-up
Nitrogen Tetroxide	Existing upper stages and satellites
Oxygen	Constellation EDS and Altair; Moon and Mars ISRU product
Water	Human exploration life support Moon and Mars ISRU product

Cryo In-Space Transfer and Depot Technologies

Transfer interfaces/umbilicals	TRL 3
Cryo fluid management	
• Acquisition	3
• Gauging	3
• Transfer flow measurement	3
Cryocoolers (active; zero boil-off)	4
Multi-layer insulation for long term storage	5
Low heat leak integrated structure/insulation	5
Thermal Vent Systems	5
MMOD shielding	9
Autonomous rendezvous & prox ops	9

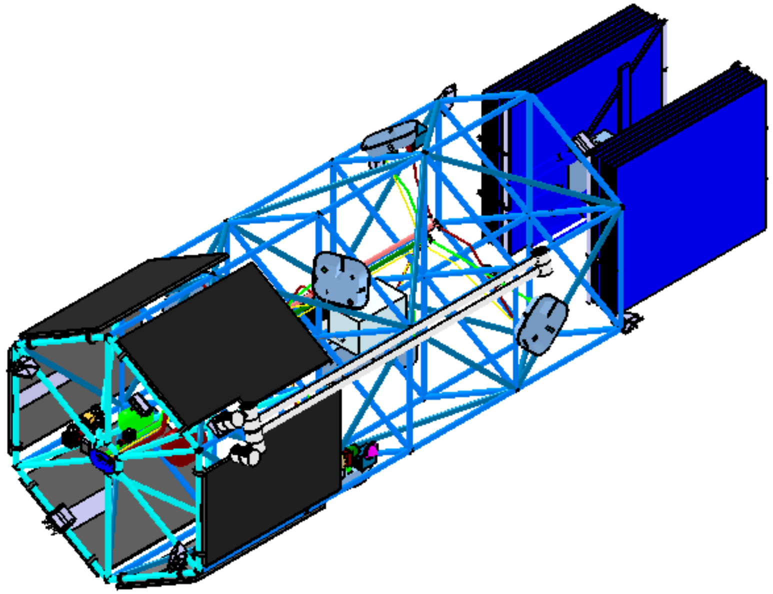
Propellant Transfer and Depots are Key to Robust Reusable In-Space Transportation

- **Decouple mission capability from launch limitations**
- **Provide 2-3x capability increase for current systems**
- **Enable reusable in-space transportation architectures**
- **Provide large continuous demand for commodity launch**
- **Depots may need to handle multiple propellants/fluids**

Assembly Sequence Slides for Print Versions

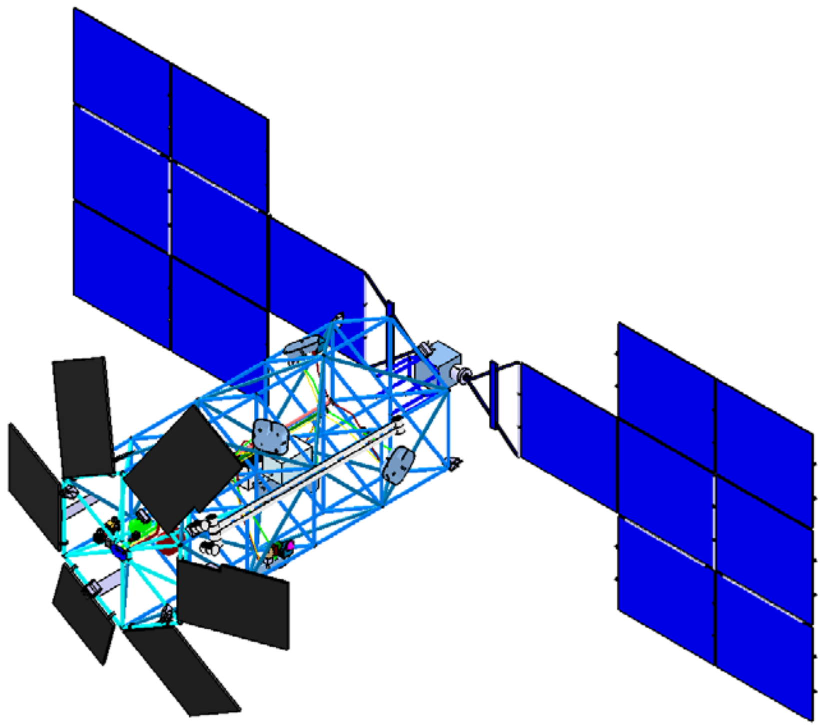
A LEO Propellant Depot Assembly Sequence – 1a

Low-cost launch Space X Falcon 9-5.2



Initial Launch
As Released

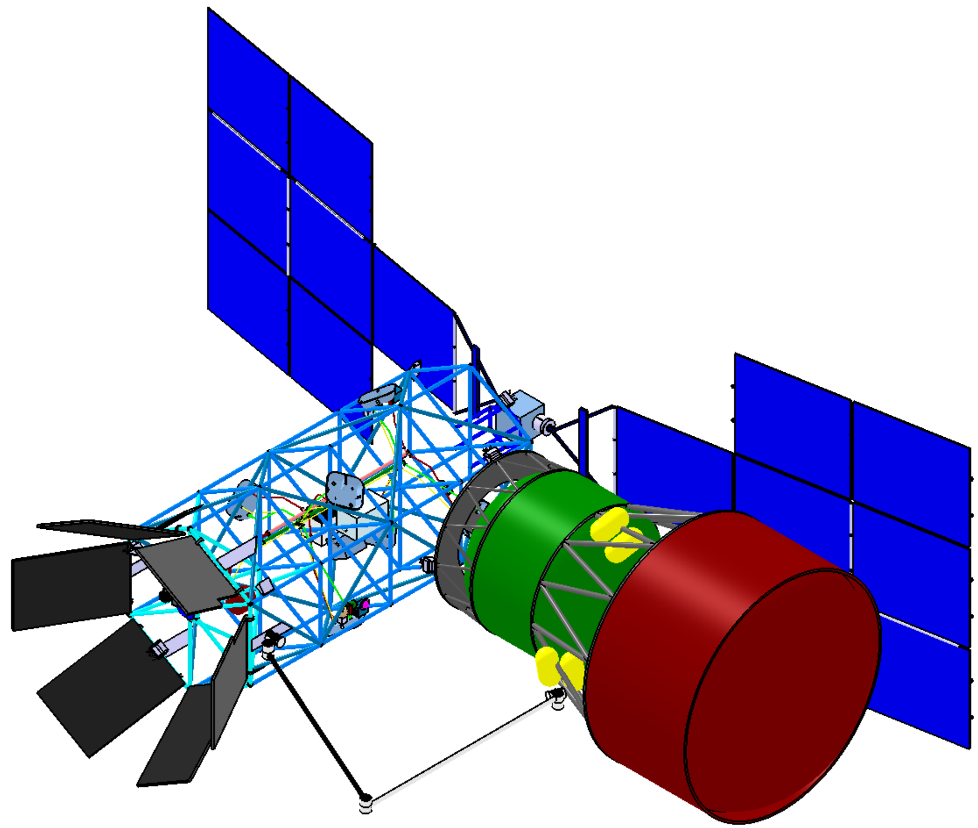
A LEO Propellant Depot Assembly Sequence - 1b



Initial Launch Deployed

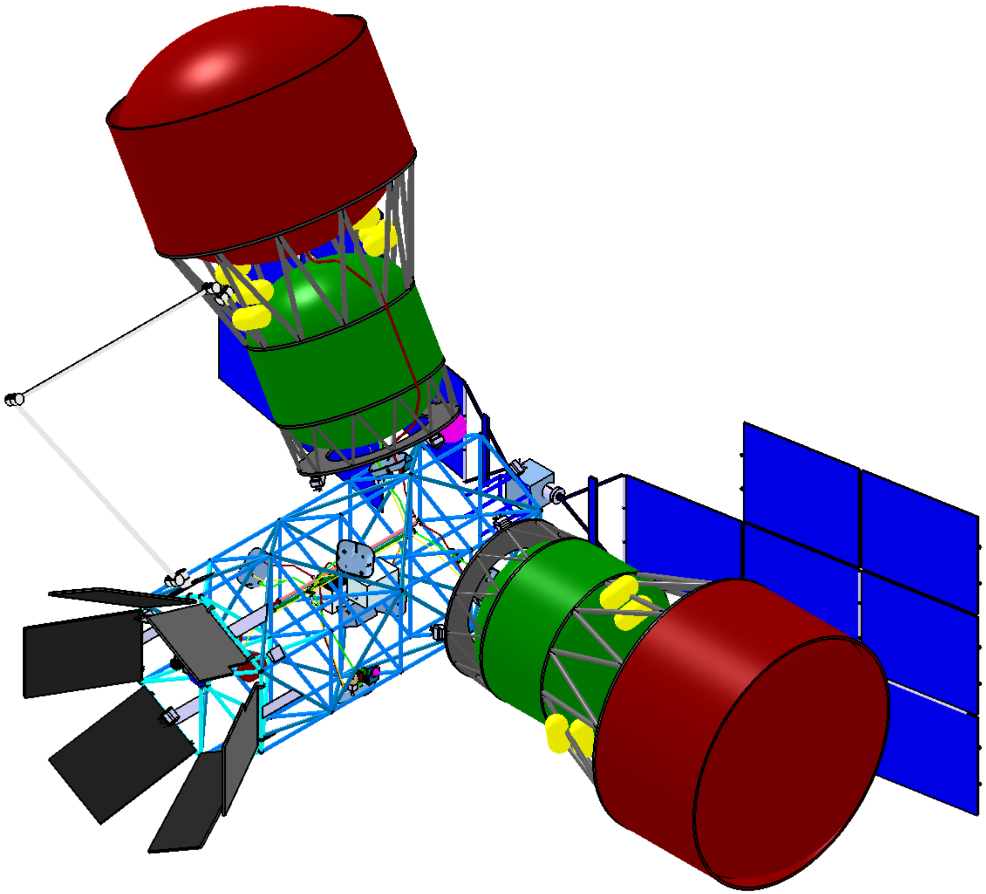
A LEO Propellant Depot Assembly Sequence - 2

Low-cost launch Space X Falcon 9-5.2



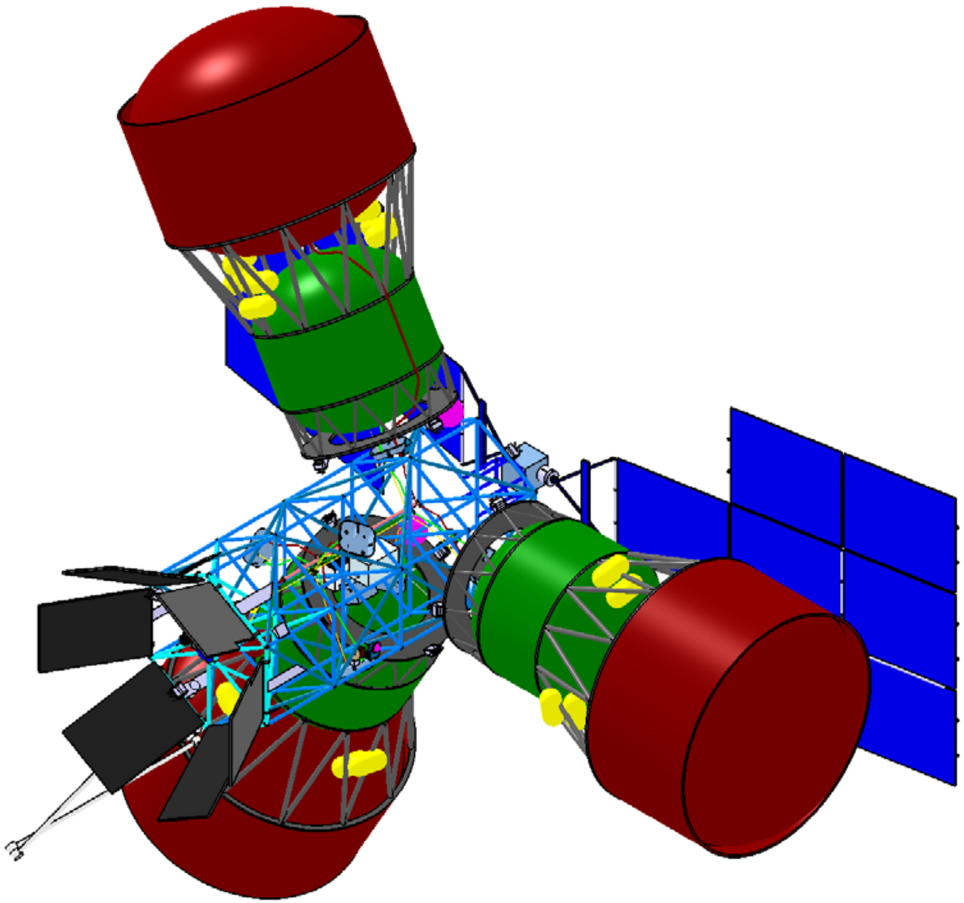
A LEO Propellant Depot Assembly Sequence - 3

Low-cost launch Space X Falcon 9-5.2



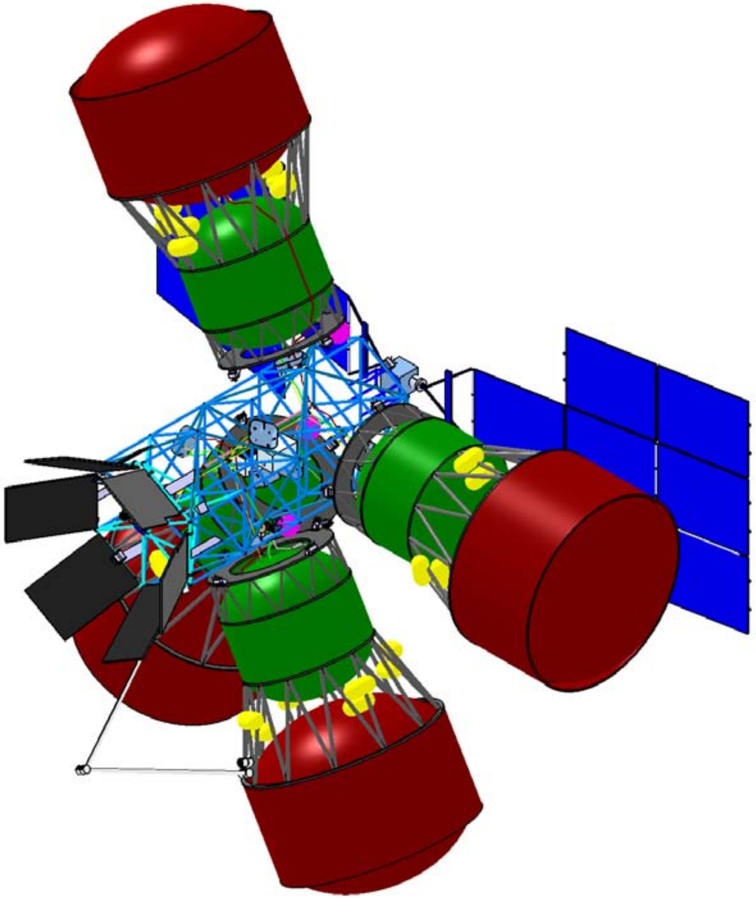
A LEO Propellant Depot Assembly Sequence - 4

Low-cost launch Space X Falcon 9-5.2



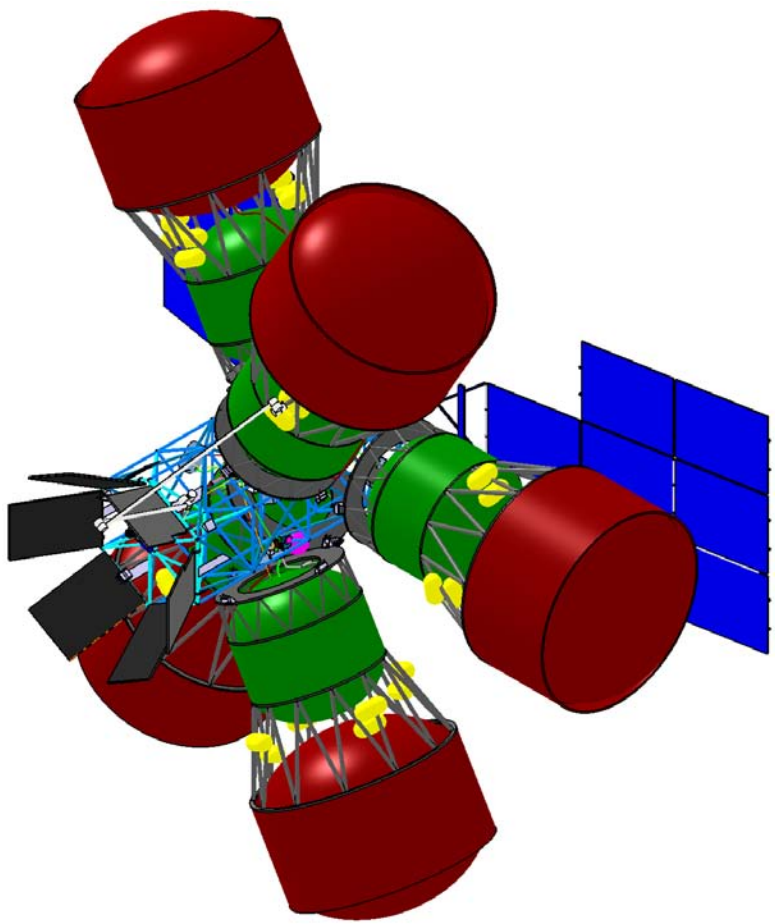
A LEO Propellant Depot Assembly Sequence - 5

Low-cost launch Space X Falcon 9-5.2



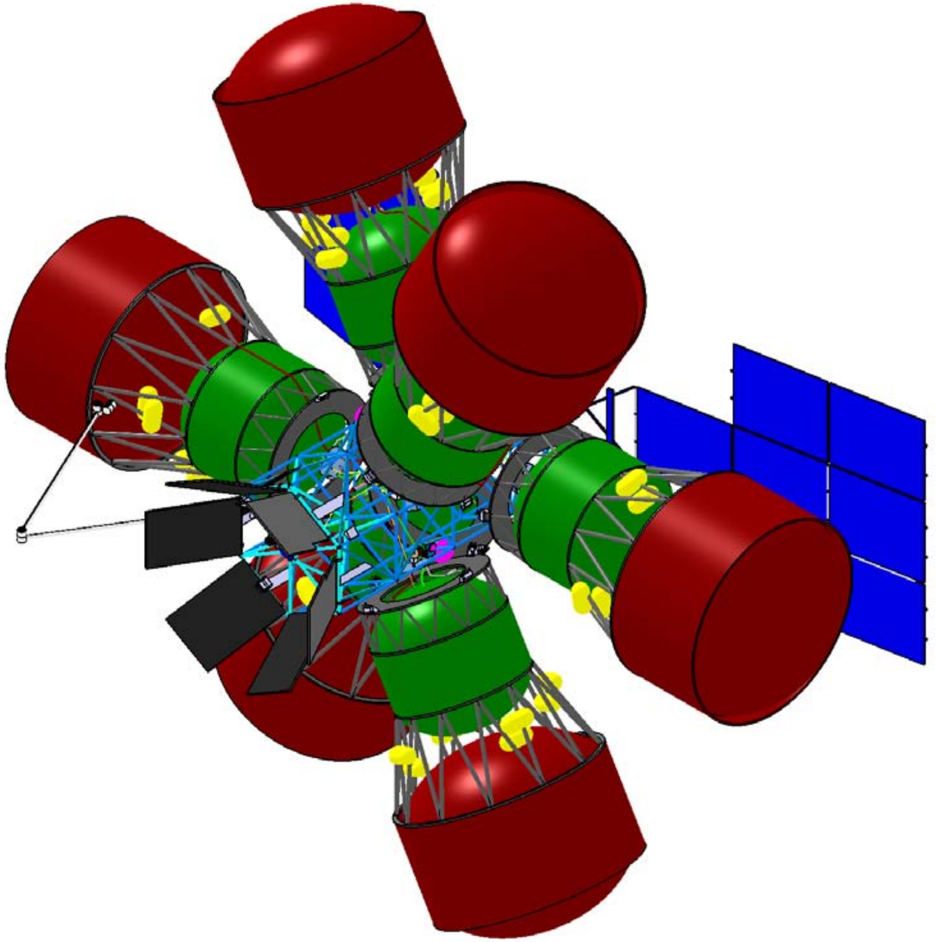
A LEO Propellant Depot Assembly Sequence - 6

Low-cost launch Space X Falcon 9-5.2



A LEO Propellant Depot Assembly Sequence - 7

Low-cost launch Space X Falcon 9-5.2



Refueling the EDS/Lander Vehicle from Depot

- LPD RMS berths EDS & LPD
- Single mating interface
- Transfer prior to Orion mate
- LOx and LH to EDS & Lander
- ~25 t transferred to Lander
- ~155 t transferred to EDS
- 2 depots for redundancy
- 12-month depot refill cycle