



Advanced Space Exploration

# LEO Propellant Depot: Servicing Impact on Space Missions



**NASA GSFC International Servicing Workshop**  
**March 24-26, 2010**

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# First, There was the Vision. . .

## *A Bold Vision for Space Exploration*



- ◆ Complete the International Space Station
- ◆ Safely fly the Space Shuttle until 2010
- ◆ Develop and fly the Crew Exploration Vehicle no later than 2014 (goal of 2012)
- ◆ Return to the Moon no later than 2020
- ◆ Extend human presence across the solar system and beyond
- ◆ Implement a sustained and affordable human and robotic program
- ◆ Develop supporting innovative technologies, knowledge, and infrastructures
- ◆ Promote international and commercial participation in exploration



*"It is time for America to take the next steps."*

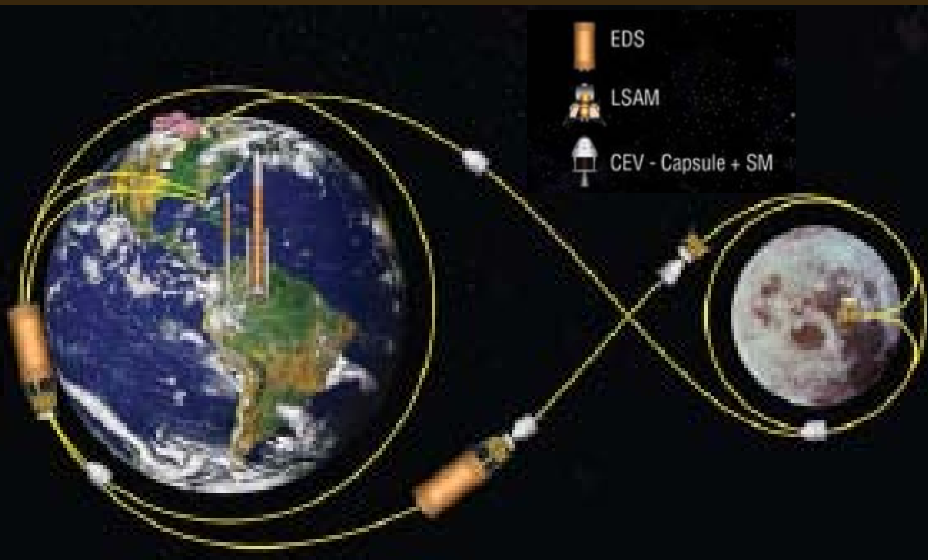
*Today I announce a new plan to explore space and extend a human presence across our solar system. We will begin the effort quickly, using existing programs and personnel. We'll make steady progress – one mission, one voyage, one landing at a time"*

*President George W. Bush –  
January 14, 2004*





# Then, the ESAS Final Report. . .



- 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

- 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**



Crew Exploration Vehicle



Exploration Departure Stage



CEV LV Upper Stage



Crew LV

Cargo LV



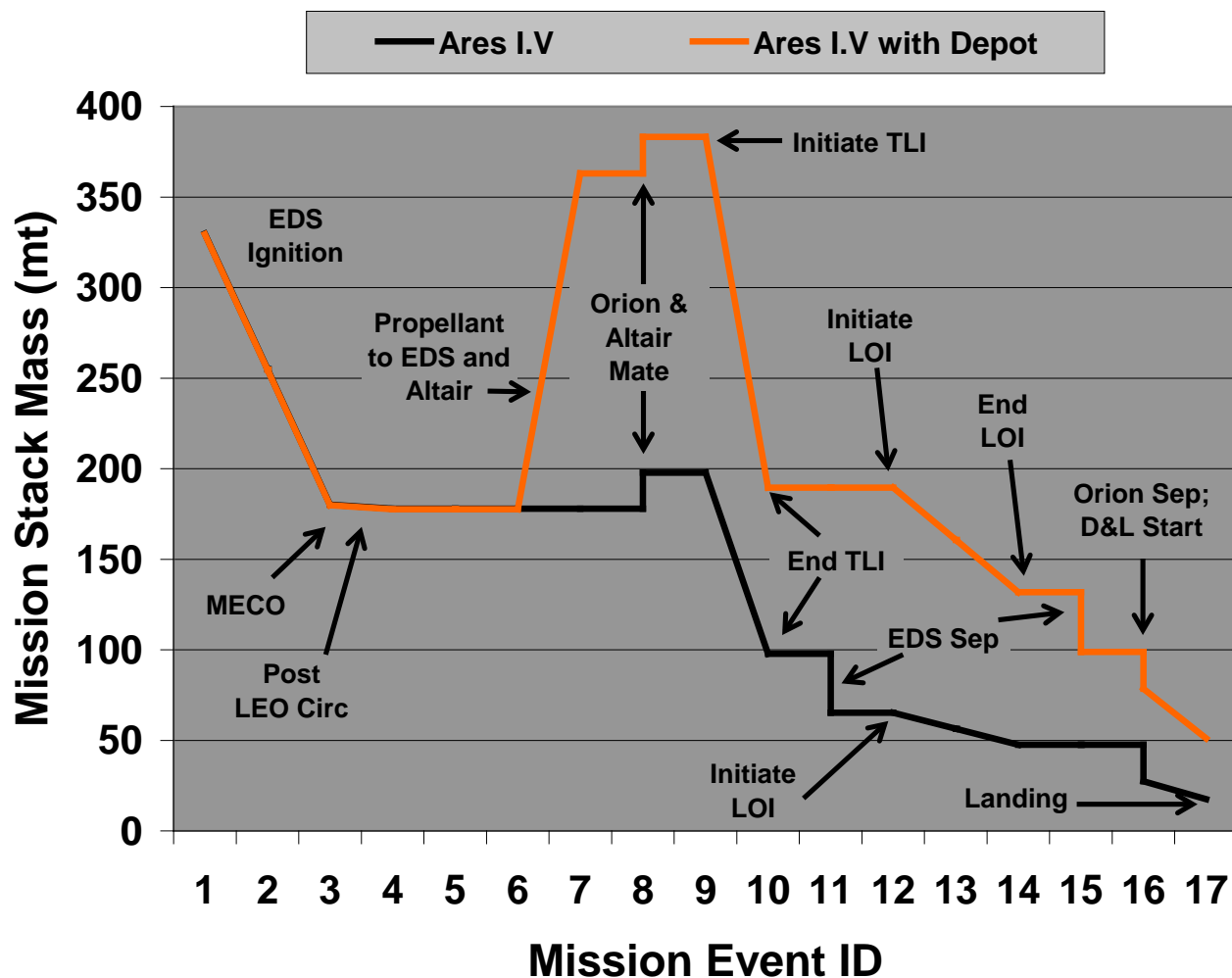
Lunar Heavy Cargo LV Upper Stage (EDS)



Lunar Surface Access Module

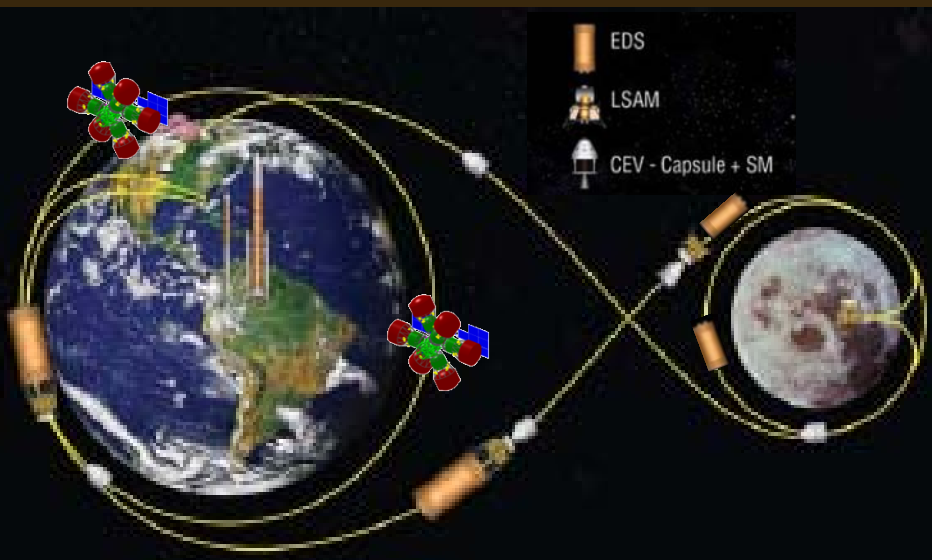
NASA's Exploration Architecture  
September, 2005

# Depot Impact on Constellation Lunar Mission Events and Mass



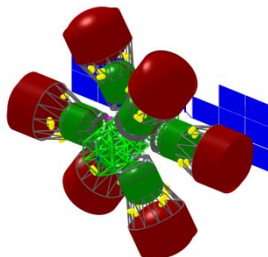
- One additional mating with propellant transfer
- 180 t additional mass at TLI
- EDS does TLI and LOI burn
- EDS released in LLO
- Altair tanks full in LLO
- 51 vs 18 t landed

# 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



Crew Exploration Vehicle



Exploration Departure Stage



CEV LV Upper Stage



Crew LV



Cargo LV



Lunar Heavy Cargo LV Upper Stage (EDS)

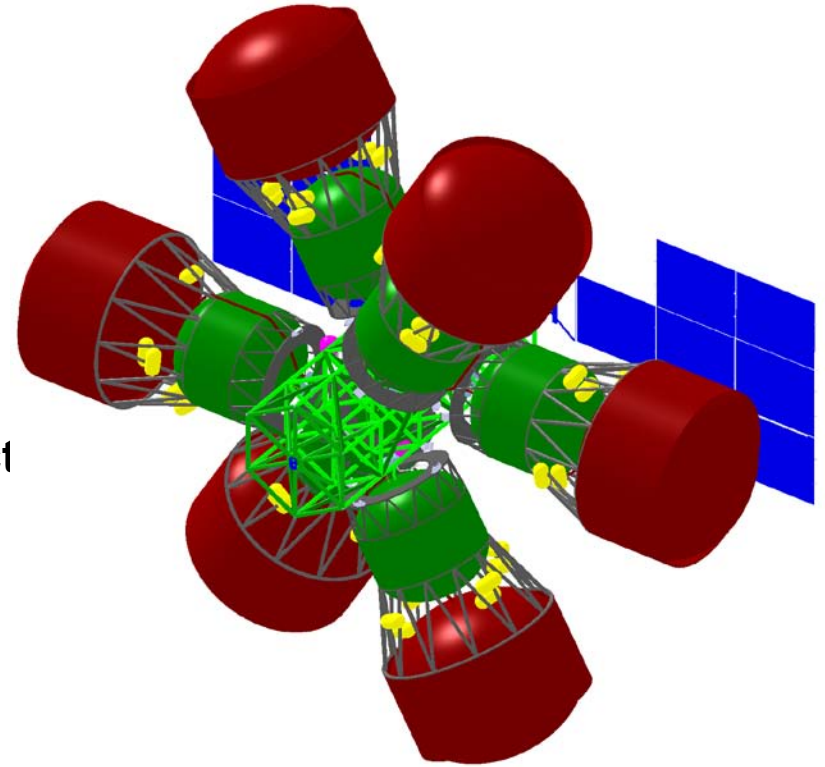


Lunar Surface Access Module

NASA's Exploration Architecture  
September, 2005

# 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



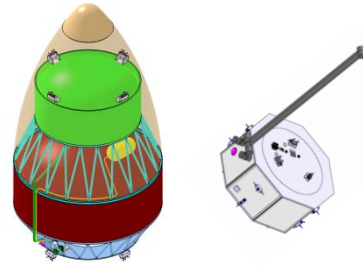
A Modular LEO Propellant Depot



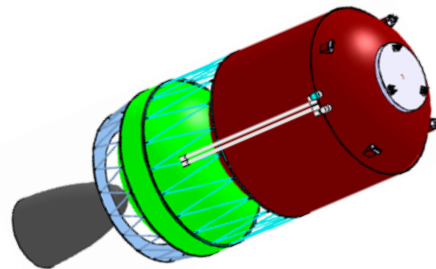
# A LEO Propellant Depot Architecture with Reusable Propellant Carrier and Depot Tug



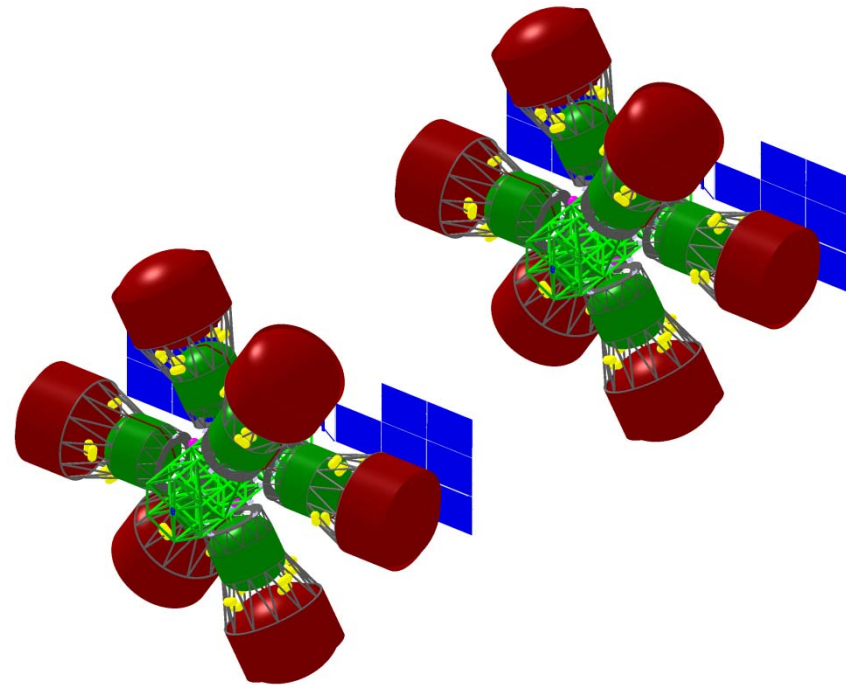
Low-cost launch provider  
Space X Falcon 9-3.6 shown



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



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



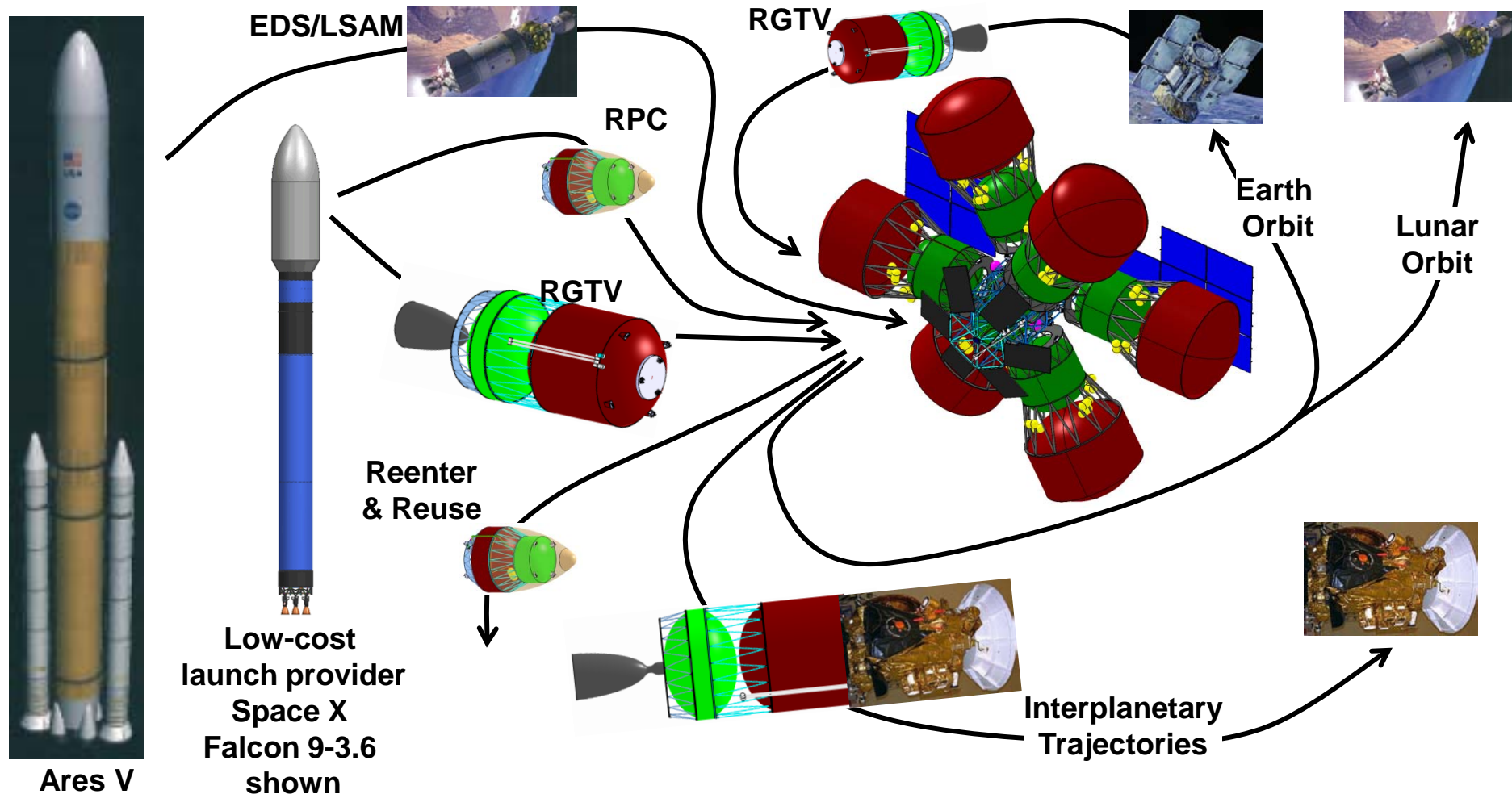
2 Modular Propellant Depots  
180 t capacity  
LOx/LH

# LEO Propellant Depot Assembly and Operations





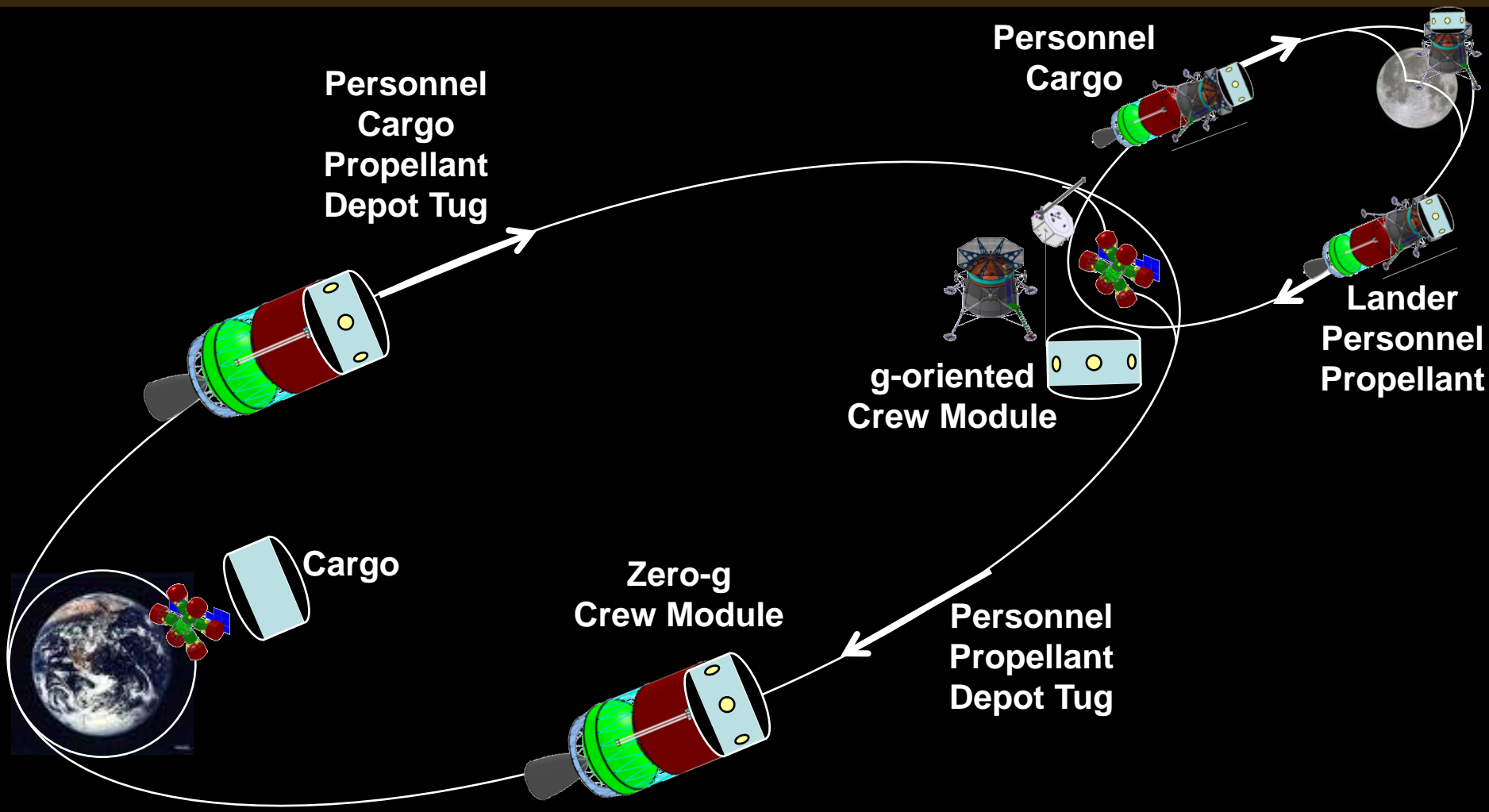
# A LEO Propellant Depot Operational Concept: A Hub for Exploration and HEO Missions



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

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

# 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**

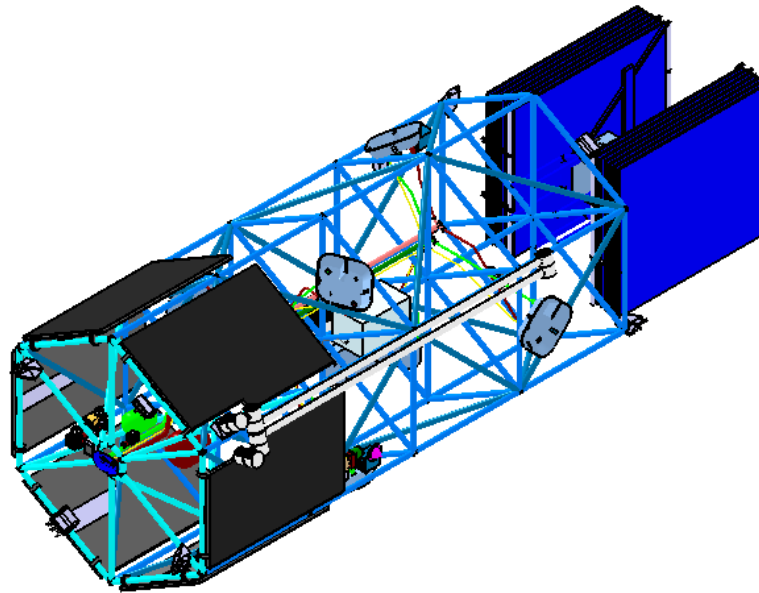


# Assembly Sequence Slides for Print Versions

# A LEO Propellant Depot Assembly Sequence – 1a



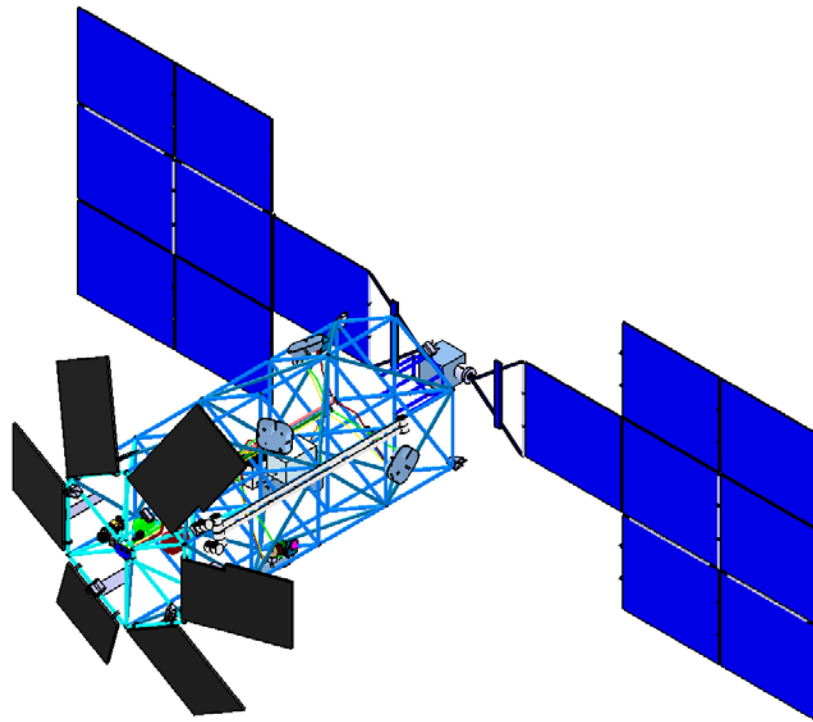
Low-cost  
launch  
Space X  
Falcon 9-5.2



Initial Launch  
As Released

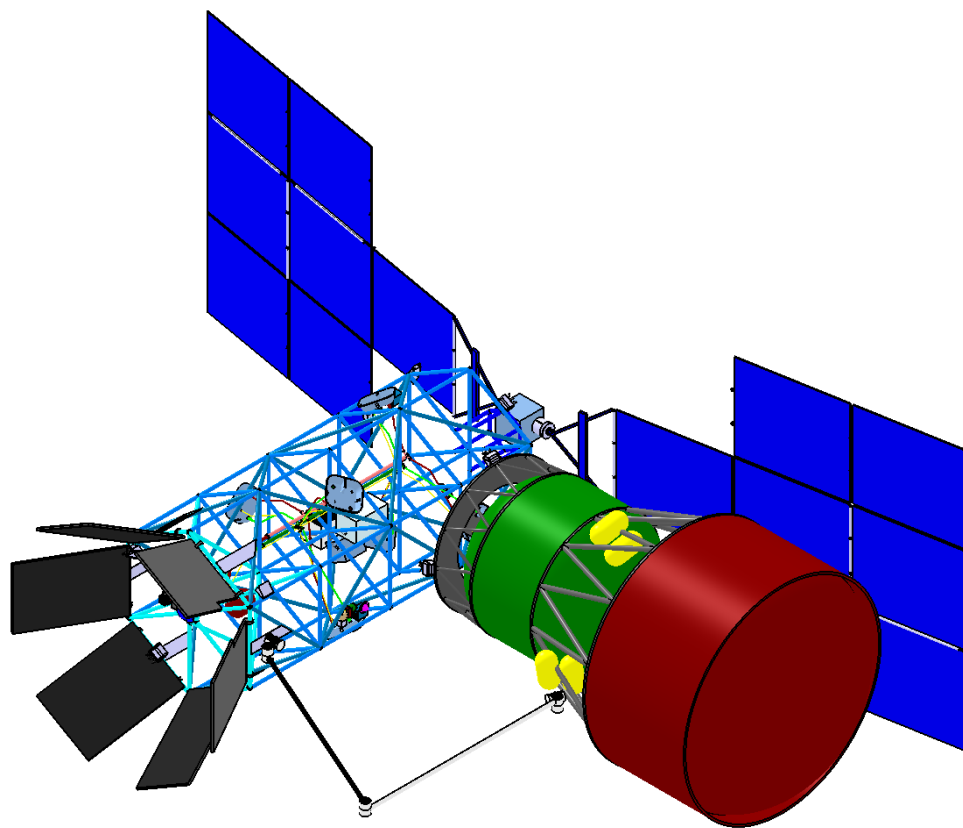
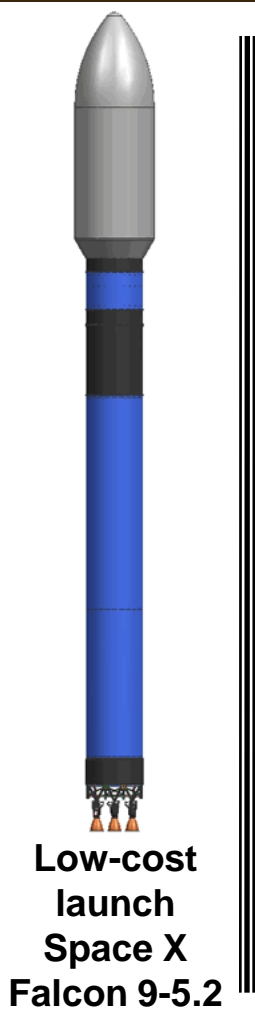


# A LEO Propellant Depot Assembly Sequence - 1b



**Initial Launch  
Deployed**

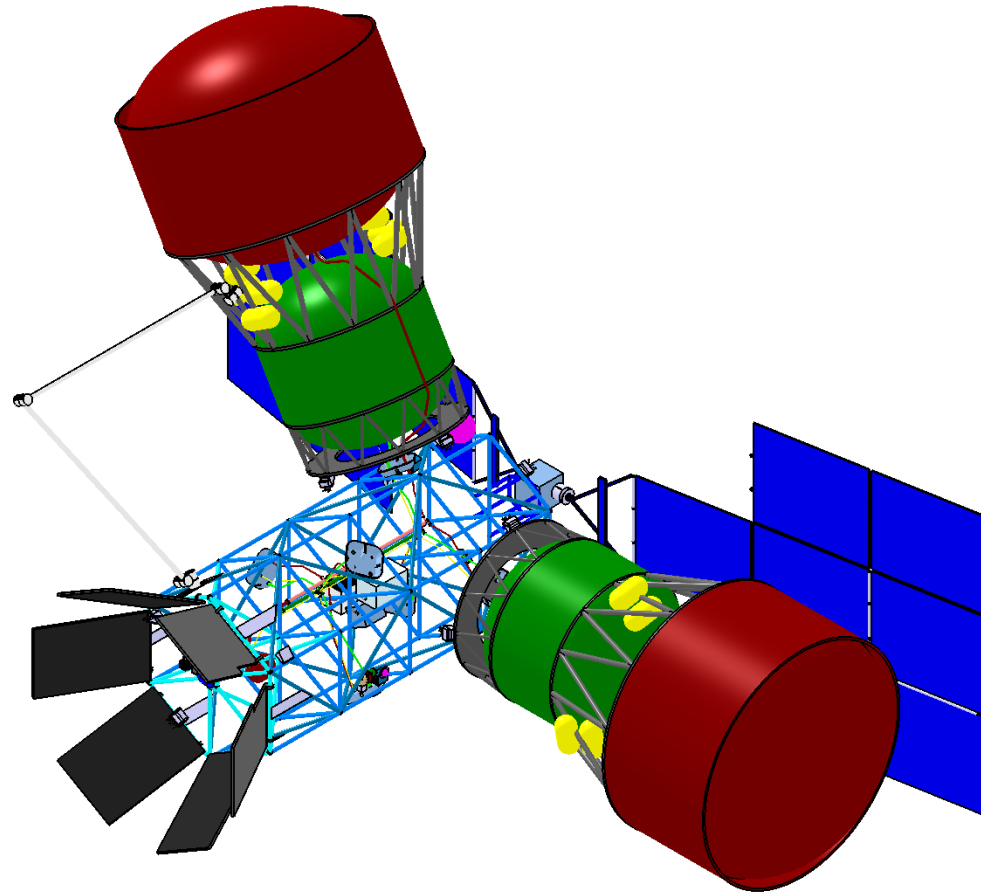
# A LEO Propellant Depot Assembly Sequence - 2



# A LEO Propellant Depot Assembly Sequence - 3



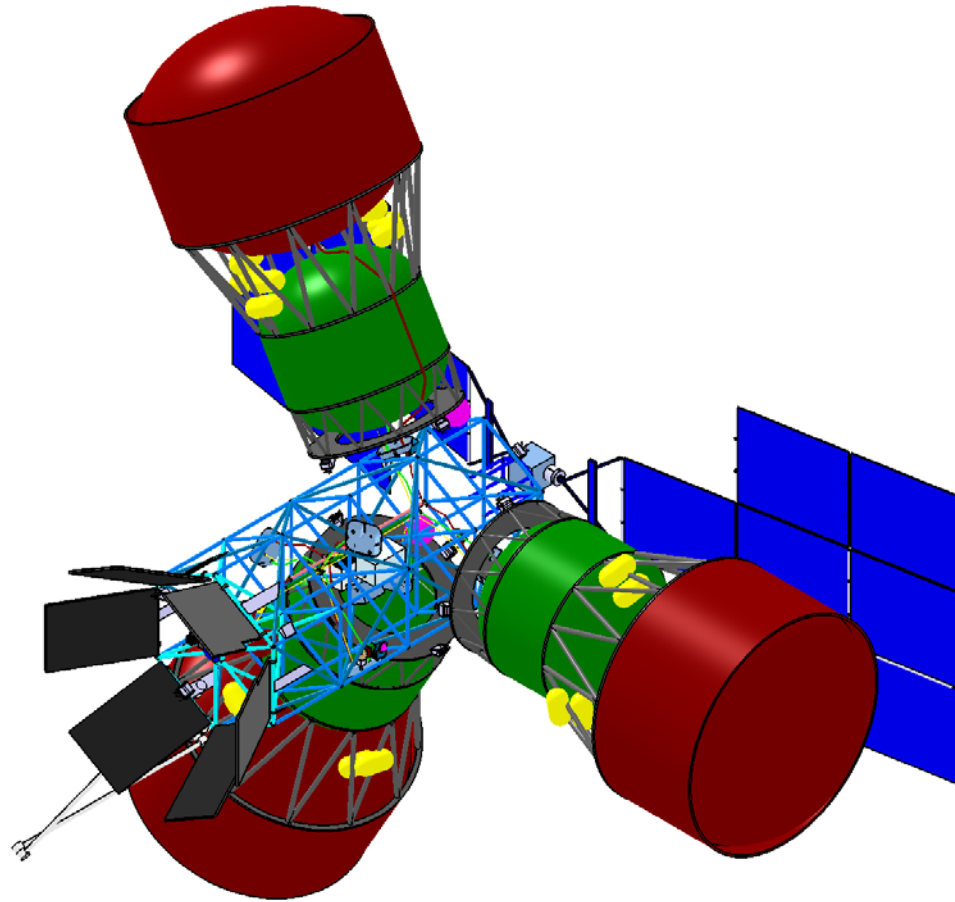
Low-cost  
launch  
Space X  
Falcon 9-5.2



# A LEO Propellant Depot Assembly Sequence - 4



Low-cost  
launch  
Space X  
Falcon 9-5.2

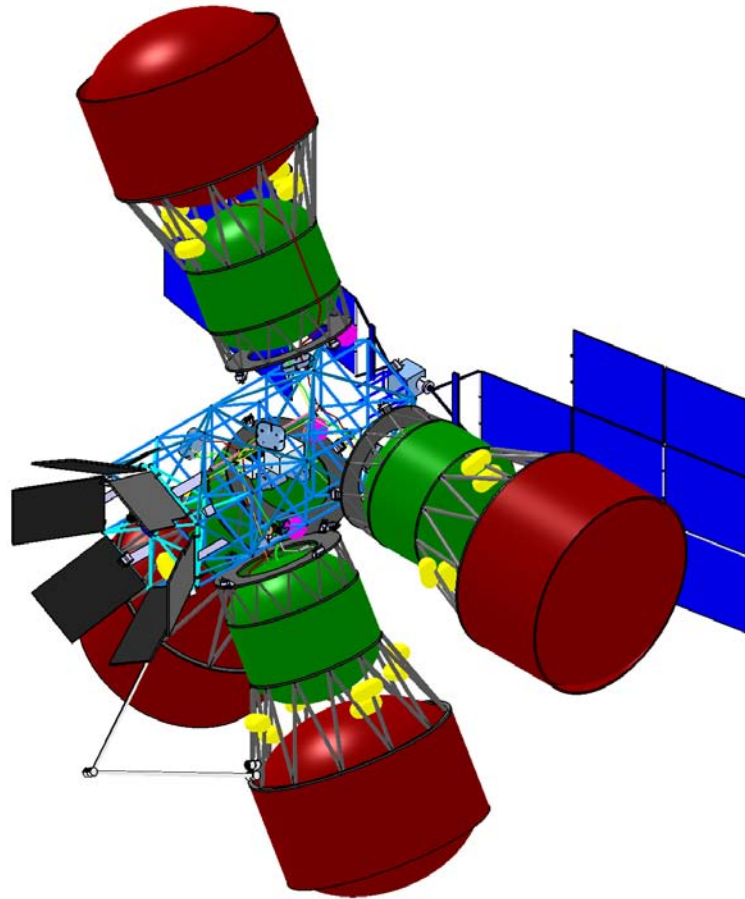




# A LEO Propellant Depot Assembly Sequence - 5



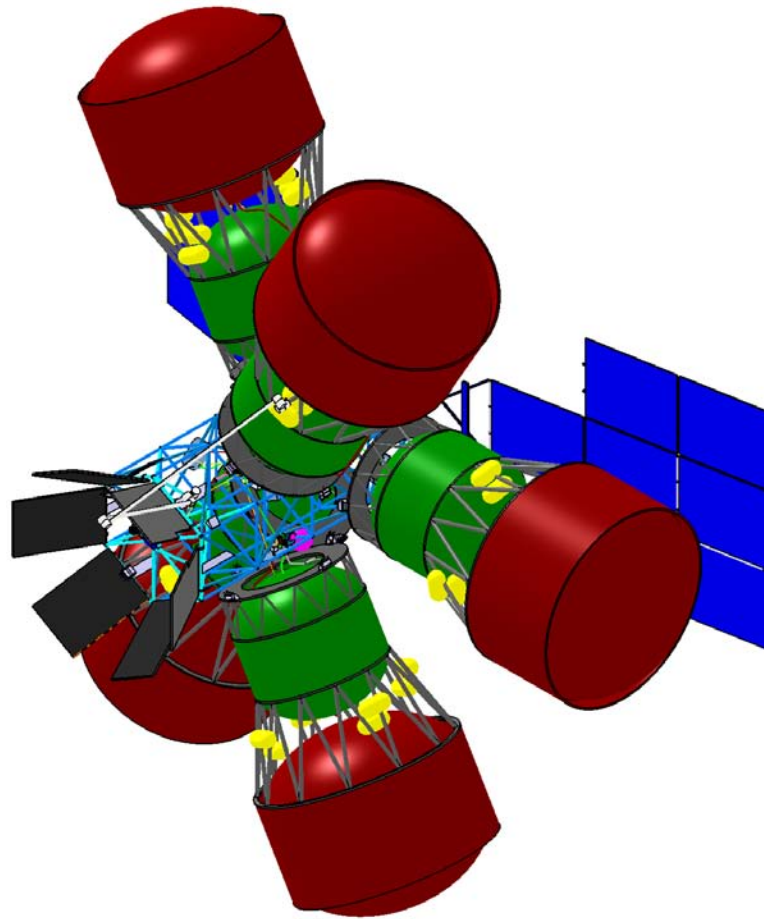
Low-cost  
launch  
Space X  
Falcon 9-5.2



# A LEO Propellant Depot Assembly Sequence - 6



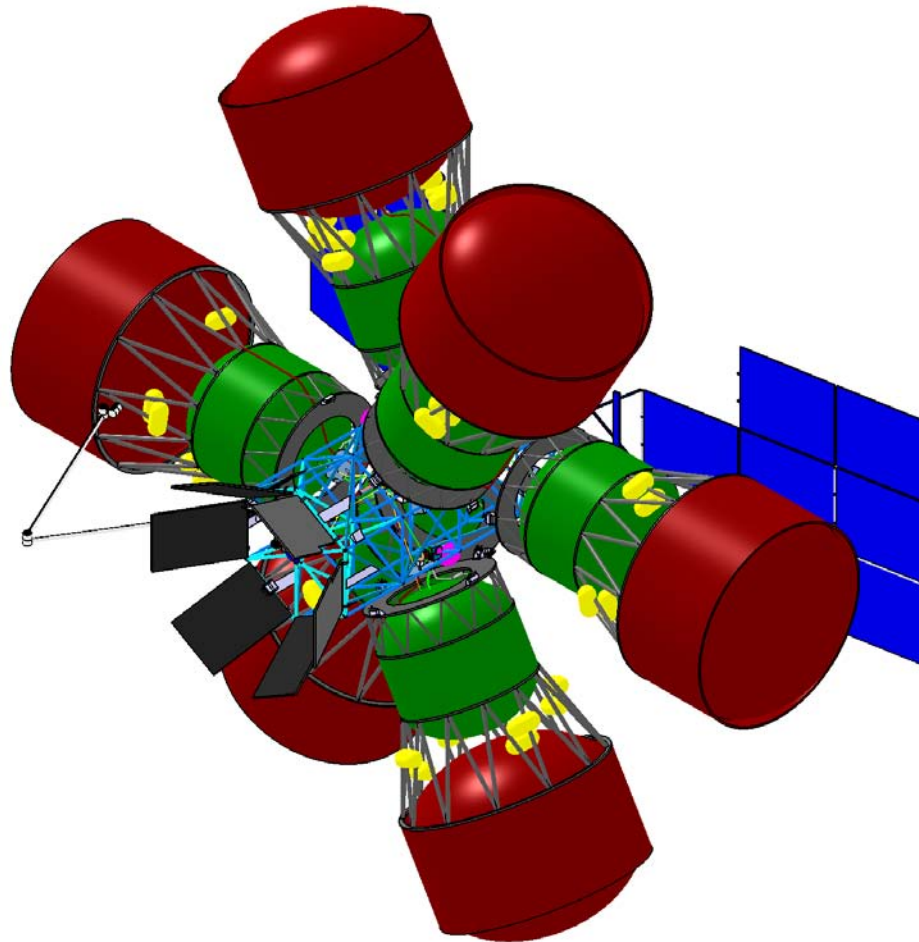
Low-cost  
launch  
Space X  
Falcon 9-5.2



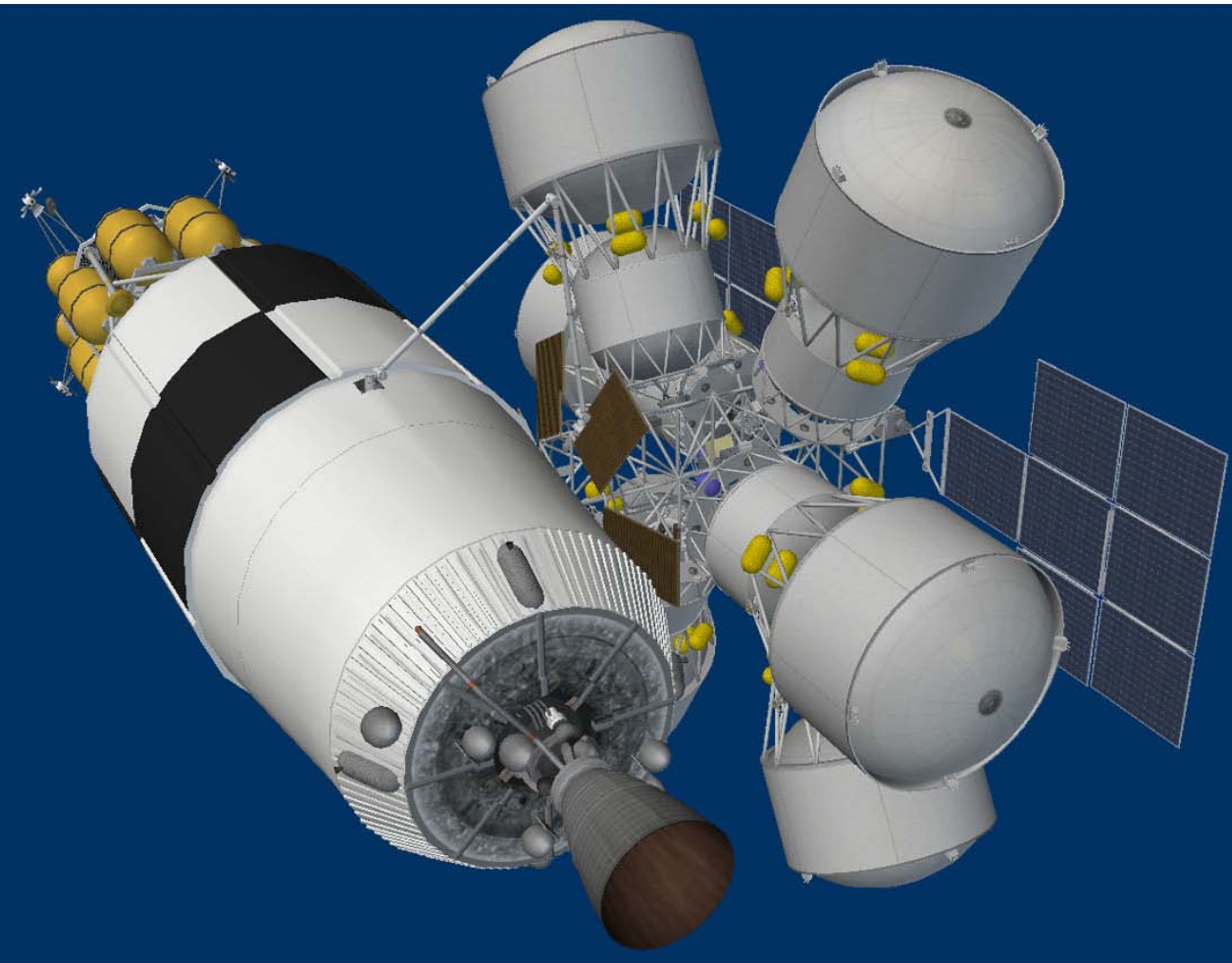
# A LEO Propellant Depot Assembly Sequence - 7



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