National Aeronautics and Space Administration

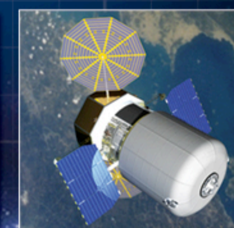
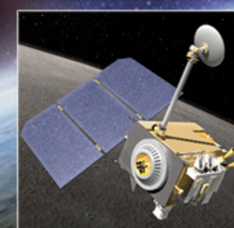
A New Space Enterprise of Exploration

Michael Patterson

FTD 1 Review

May 26th, 2010



Disclaimer

- This chart set was presented on May 26, 2010 at the NASA Exploration Enterprise Workshop held in Galveston, TX. The purpose of this workshop was to present NASA's initial plans for the potential programs announced in the FY2011 Budget Request to industry, academia, and other NASA colleagues. Engaging outside organizations allows NASA to make informed decisions as program objectives and expectations are established.

- The following charts represent at "point of departure" which will continue to be refined throughout the summer and the coming years. They capture the results of planning activities as of the May 25, 2010 date, but are in no way meant to represent final plans. In fact, not all proposed missions and investments fit the in budget at this time. They provide a starting point for engagement with outside organizations (international, industry, academia, and other Government Agencies). Any specific launch dates and missions are likely to change to reflect the addition of Orion Emergency Rescue Vehicle, updated priorities, and new information from NASA's space partners.

FTD 1 Needs – Goals – Objectives

- Technology Goal 6: *Advanced Space Propulsion*
  - Demonstrate High-Energy On-Orbit Stage for Application to NASA, DoD, and US Commercial Missions in Earth-Orbital, Cis-Lunar, and Deep Space

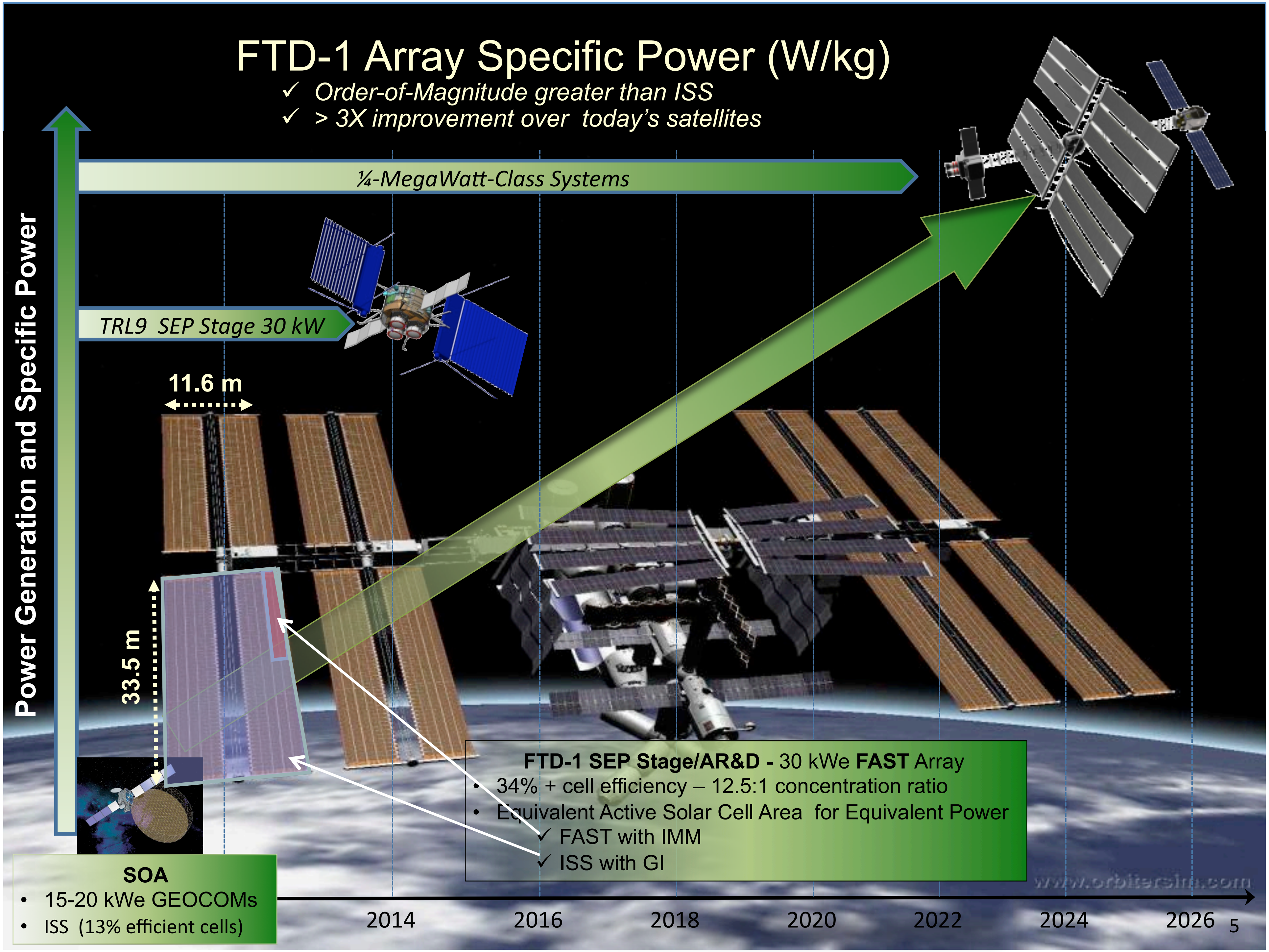
- Objective 6-1:
  - Demonstrate Advanced Electric/Ion Propulsion
  - Measure of Effectiveness: Demonstrate SEP propulsion and stage operations to leave Earth Orbit

- Objective 6-2:
  - Demonstrate advanced high power lightweight solar array technology
  - Measure of Effectiveness: Demonstrate advanced array technology at a 30 kW capability

FTD 1 Mission Objectives

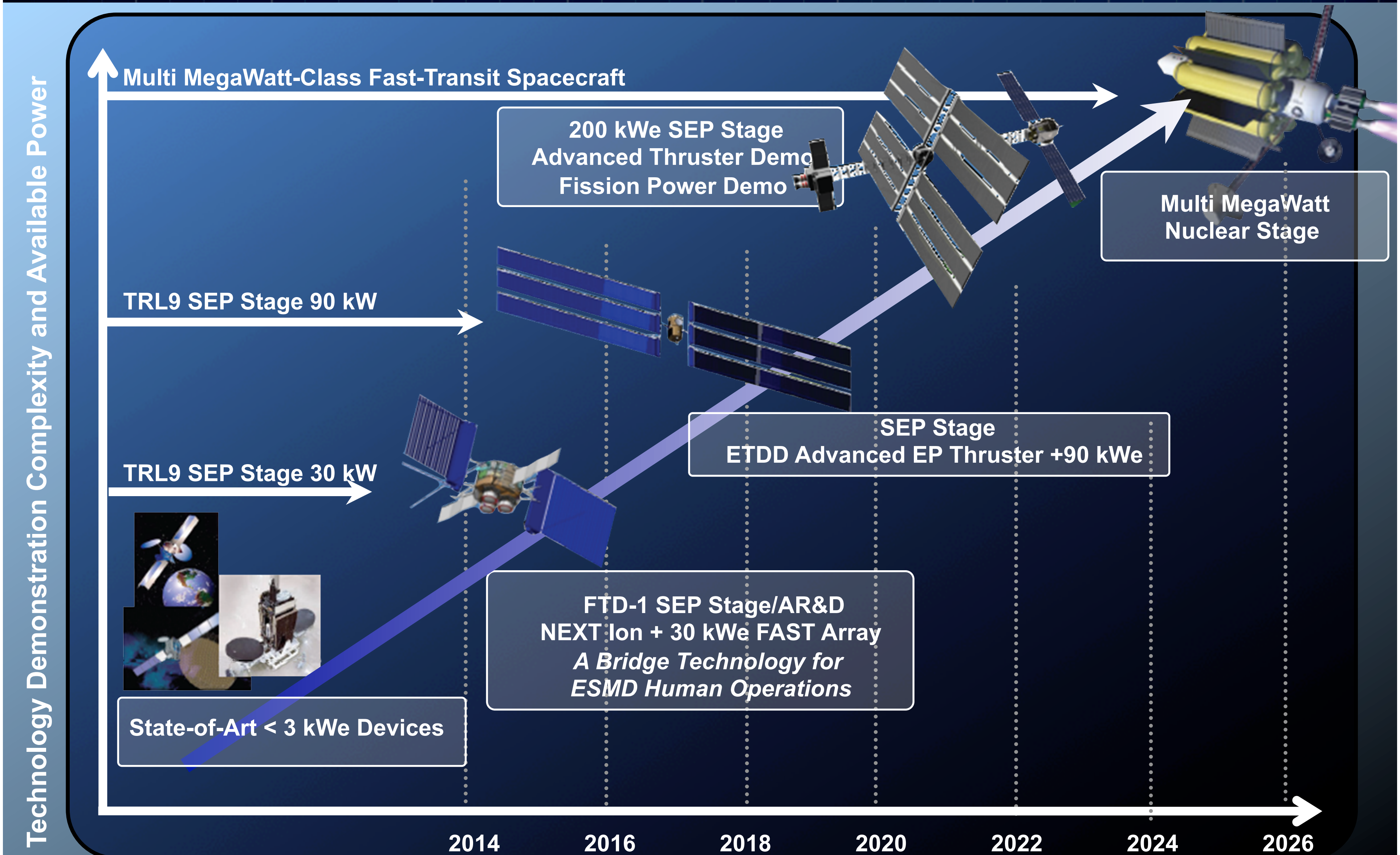
- The primary FTD 1 mission objective is to validate the advanced In-Space propulsion system operation as a **Solar Electric Propulsion Stage**
  – This involves demonstrating multi-engine 30 kWe system operations both in Earth-Space and Heliocentric-Space of the NEXT IPS and an advanced power system such as the Fast Access Spacecraft Testbed (FAST) High Power Generation Subsystem (HPGS)
  – Total mission duration of at least 24 months is expected, delivering a total delta-V capability in excess of 10 km/sec

- A secondary objective of FTD 1 is for the SEP Stage to provide a platform for early demonstration of Autonomous Rendezvous & Docking (AR&D) technologies



FTD-1 Array Specific Power (W/kg)
✓ Order-of-Magnitude greater than ISS
✓ > 3X improvement over today's satellites
¼-MegaWatt-Class Systems
TRL9 SEP Stage 30 kW
Power Generation and Specific Power
11.6 m
33.5 m
FTD-1 SEP Stage/AR&D - 30 kWe FAST Array
• 34% + cell efficiency – 12.5:1 concentration ratio
• Equivalent Active Solar Cell Area for Equivalent Power
✓ FAST with IMM
✓ ISS with GI
SOA
• 15-20 kWe GEOCOMs
• ISS (13% efficient cells)
2014
2016
2018
2020
2022
2024
2026
www.orbitersim.com

FTD-1 Roadmap for Advanced



FTD 1 Design Study

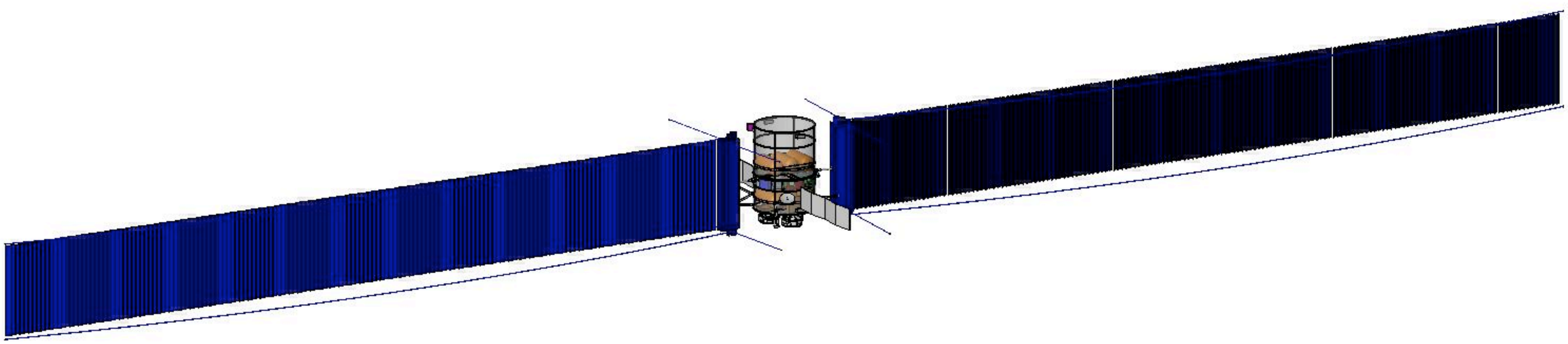
- A design concept was developed which demonstrates a Solar Electric Propulsion (SEP) Stage utilizing NASA's NEXT Ion Propulsion System and DARPA's FAST solar array technology for the first FTD Mission (demonstrate > 10 km/s ΔV)

- SEP Stage
  - A launch and target platform for AR&d demonstration
    - Delivery and drop-off of ARDV to orbit
  - Many mission options given a large ΔV capability
    - Spiral to Mars Deimos and Phobos

- Design update was executed
  Smaller launch vehicle, lighter weight ARDV (700 kg), updated science package, Spiral down to low Mars orbit and determine Xe margin

Top Level Definition

- Flight Demonstrate Multi-Mission Solar Electric Propulsion (SEP) Stage utilizing NEXT IPS and FAST HPGS Solar Arrays
  - 3+0 (3 Active simultaneous-firing thrusters, no spares, 3-String) NEXT Ion Propulsion System
  - Two 15 kWe HPGS arrays
- Mission
  - Launch to GTO
  - Sept. 2014 launch
- ARDV: Carry through launch, serve as target for/deliver to GEO
  - 1500 kg, 1 kW, independent spacecraft



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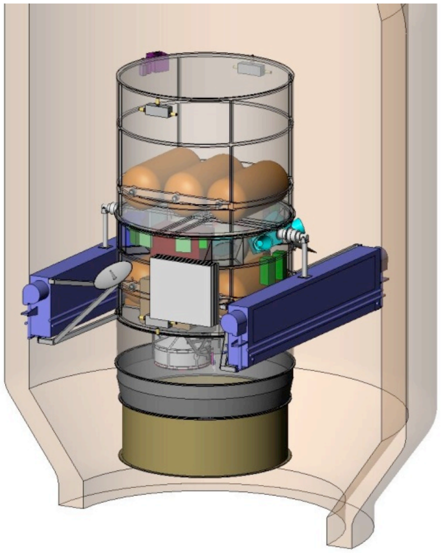

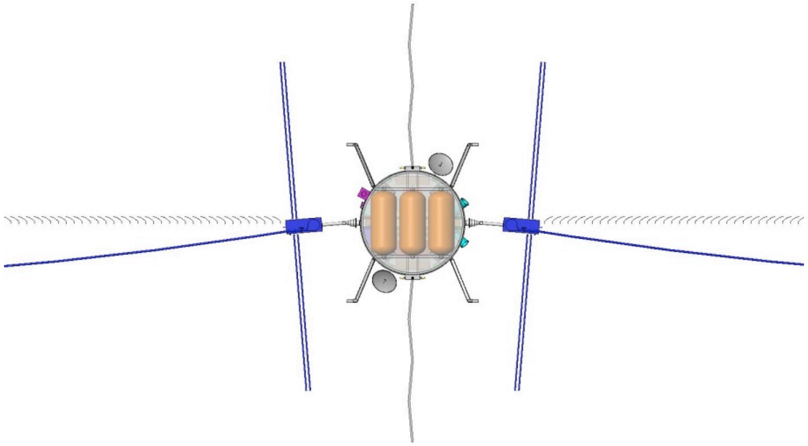

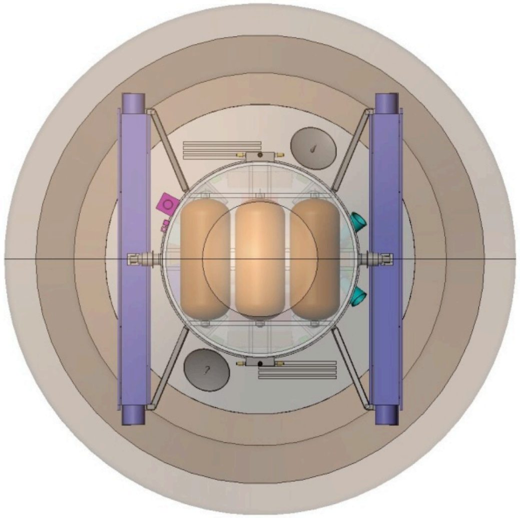

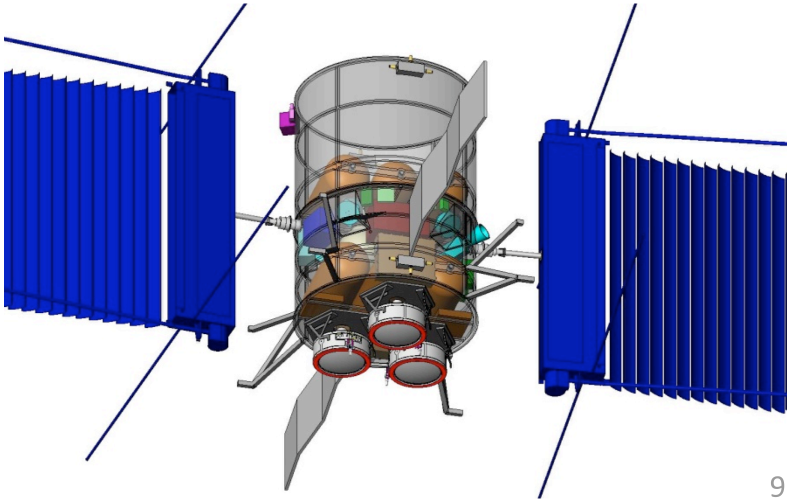

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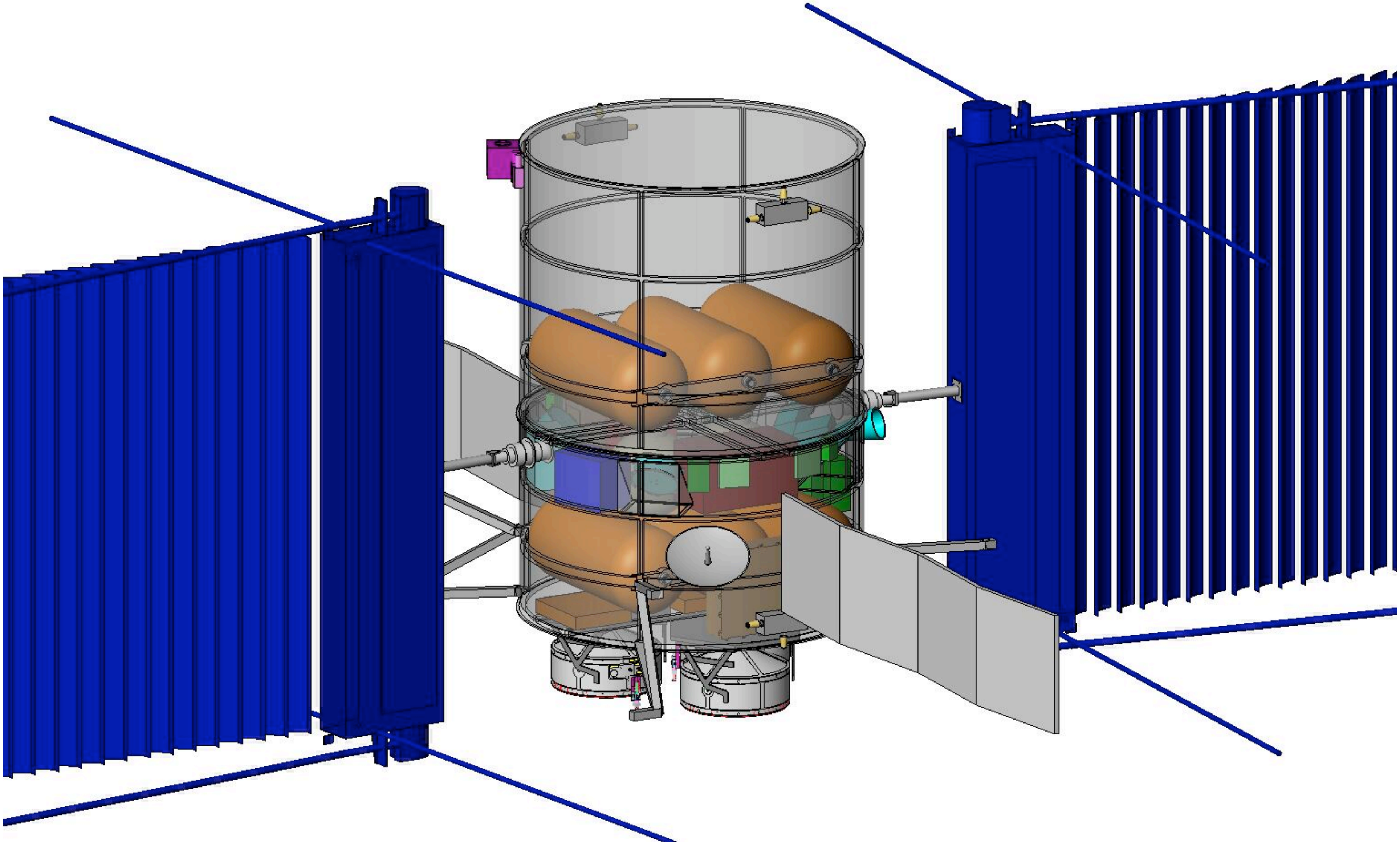
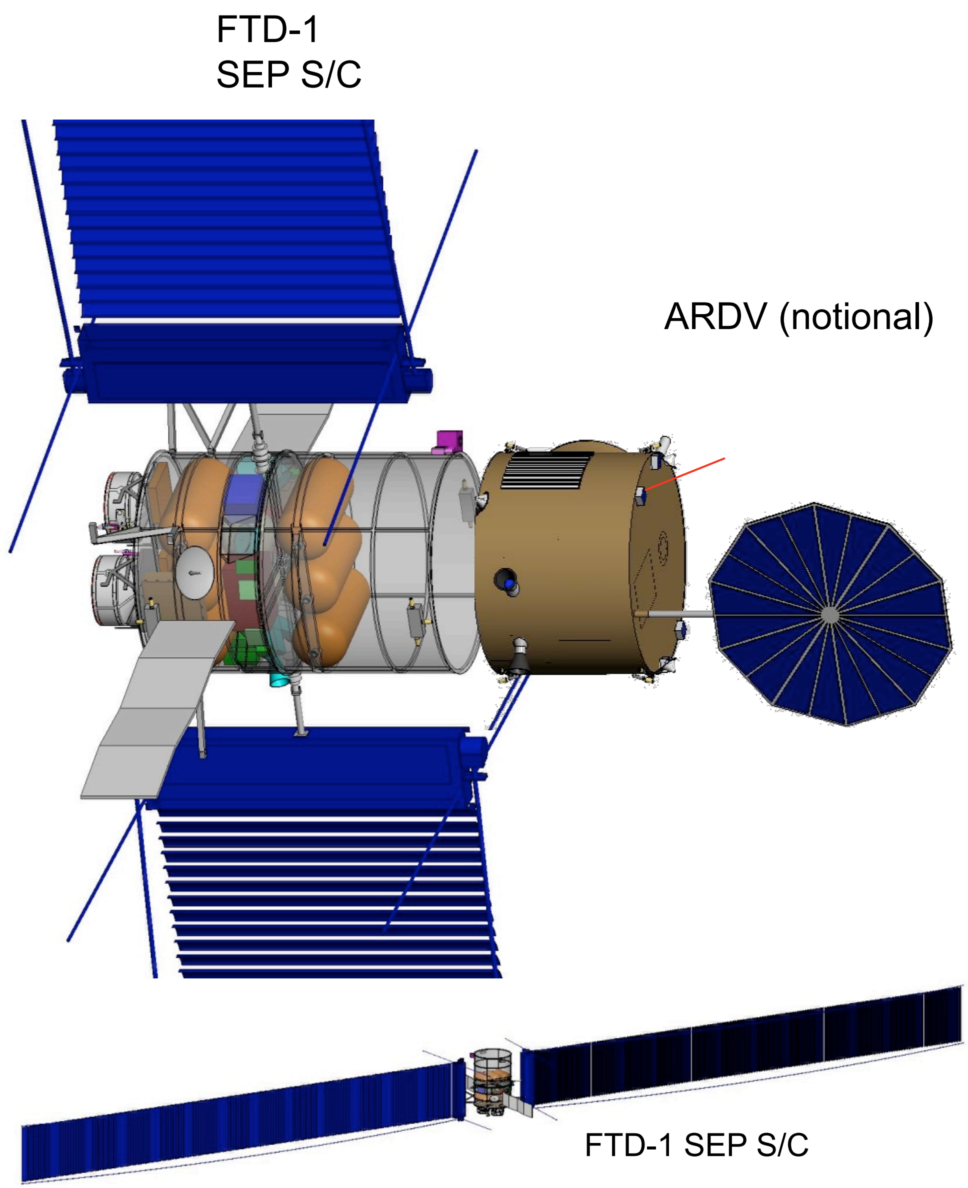


FTD 1 SEP Spacecraft

- Simple 1666 mm Thrust tube design
- Compact stowage keeps FTD-1 below separation plane for ARDV and future payloads
- Propulsion: Operate all NEXT engines
  - 1000 kg Xenon in 6 tanks (capable of 1500 kg)
- Power
  - Two Advanced 15 kW array (small separate arrays for 28V housekeeping), 3500 Whr Li-Ion battery for shadow periods
- Thermal
  - Deployable radiators: radiators for three PPUs & housekeeping(~2000Wth)
- Communications: X-band LGA for Earth Communications, Ka-Band 0.5 MGA for Mars

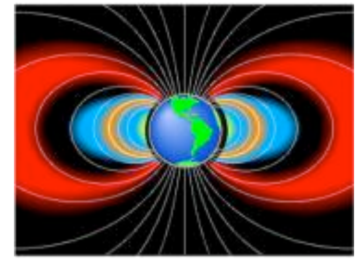


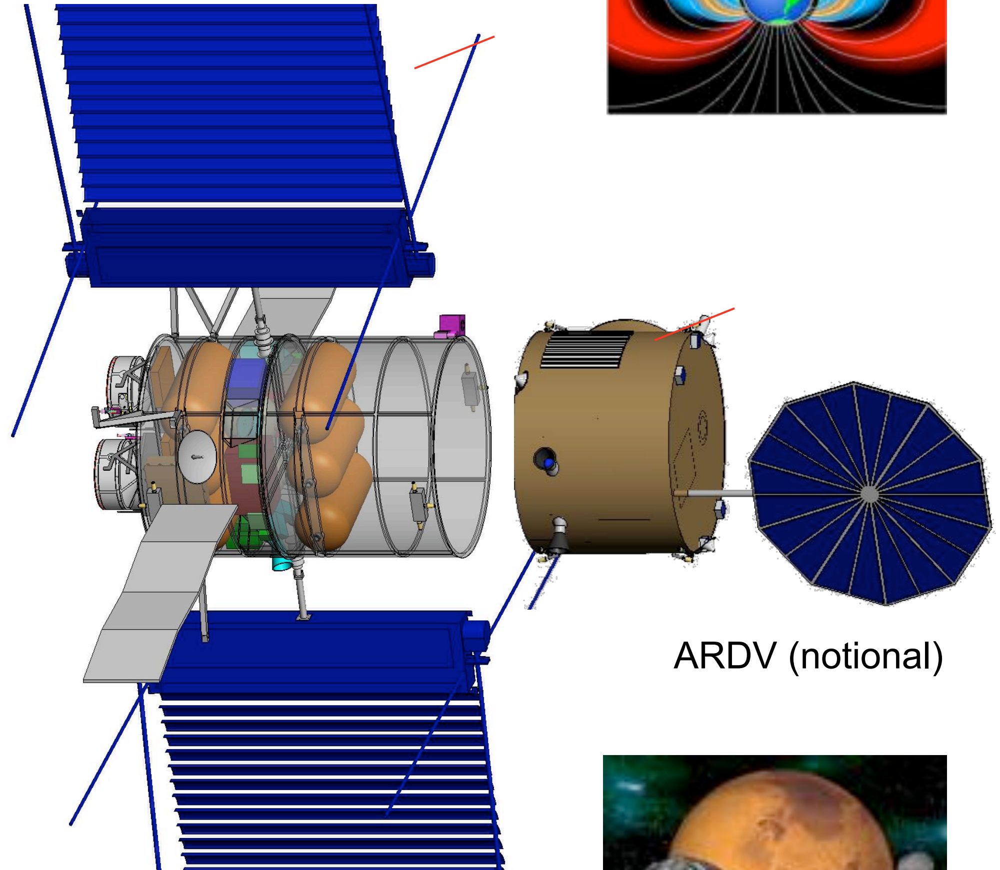
Mission Concept-of-Operations

- launch to GTO
  - 185 km x 35786 km, 28.5° inclination
- Use ARDV ACS system to lift perigee from 185 km to 300 km
  - Minimizes drag, allows for deployment and checkout of arrays and EP system
- Use SEP to spiral FTD 1 and ARDV to GEO Equatorial
  - Gather radiation impact data on systems using engineering instrumentation
- In GEO Deploy, and interact with ARDV (simulated docking)
  - Final deployment of ARDV
- FTD 1 SEP spacecraft spiral to
  - Mars Deimos
  - Mars Phobos

- Potential Secondary Science/Mission Targets & Objectives
  - Mars – Deimos and back to Earth (12/03/15 – 12/01/18; 1100 days; 1000 kg Xe for Heliocentric Phase)
  - Mars – Deimos flyby and then to Mars-GEO (17,000 km)

FTD 1
SEP S/C





ARDV (notional)

Mission Analysis Details

- Mission assumptions:
  - Late 2014/Early 2015 departure date
  - 3 NEXT thrusters, 90% duty cycle, 300W bus power

- Trajectory Legs
  - ARDV Performs chemical delta-V to boost perigee to 300 km
  - SEP Stage transfers from GTO to GEO
  - ARDV detached, SEP stage transfers from GEO to escape
  - SEP Stage performs heliocentric transfer to Mars
  - SEP rendezvous with Mars and Spirals down to 9300 km orbit (Phobos)

RFI Description

- NASA is seeking information through this RFI to improve its understanding of:
  - Potential spacecraft bus designs;
  - Bus delivery schedule; and
  - Mission concepts

  for demonstration of an advanced In-Space Propulsion system/Solar Electric Propulsion (SEP) Stage

- NASA is seeking spacecraft bus concept(s) which provide for rapid design, development, integration, and test, and which accommodate the requirements of the advanced NEXT propulsion and advanced array technologies
  - *A concept which readily accommodates future advancements/ improvements in the propulsion element (higher power electric propulsion thrusters) and power system (increases in array power up to 90-200 kWe) is essential*

RFI Description

- The intention is to develop and demonstrate a space-based SEP Stage:
  - Build a new capability that will dramatically enhance the performance of existing launch vehicles by minimizing the requirement for on-orbit propellant
  - Deliver a multi-mission capability to enable cost effective missions while reducing risks
  - Deliver an asset that can be leveraged by a variety of customers for missions within Earth orbit, Cis-lunar, NEOs, and deep space robotic science missions

  - Of interest is a capability to immediately support Deep-Space science missions, Earth-orbital missions of national interest, and Earth-orbital commercial operations
    - *Demonstrate multi-engine 30 kWe system operations both in Earth-Space and Heliocentric-Space*
    - *Mission duration of at least 24 months, delivering a total delta-V capability in excess of 10 km/sec*

RFI Description

- General recognition of the schedule challenge to support CY14 launch; requires PDR in early CY11
  - *Rapid bus procurement, such as that afforded by the Rapid Spacecraft Development Office Rapid II schedule would be required with duration of less than 36 months*
  - *Studies should address to what extent an off-the-shelf bus could be implemented*

- NASA is seeking further definition of potential secondary payloads and science targets of opportunity beyond Earth-orbit to fully demonstrate the total impulse capabilities of the SEP Stage

- Payload delivery capability and propulsion system total impulse and delta-V capabilities for operations beyond Earth-orbit should be assessed by considering several launch vehicle options

FTD 1 Technical Point of Contact

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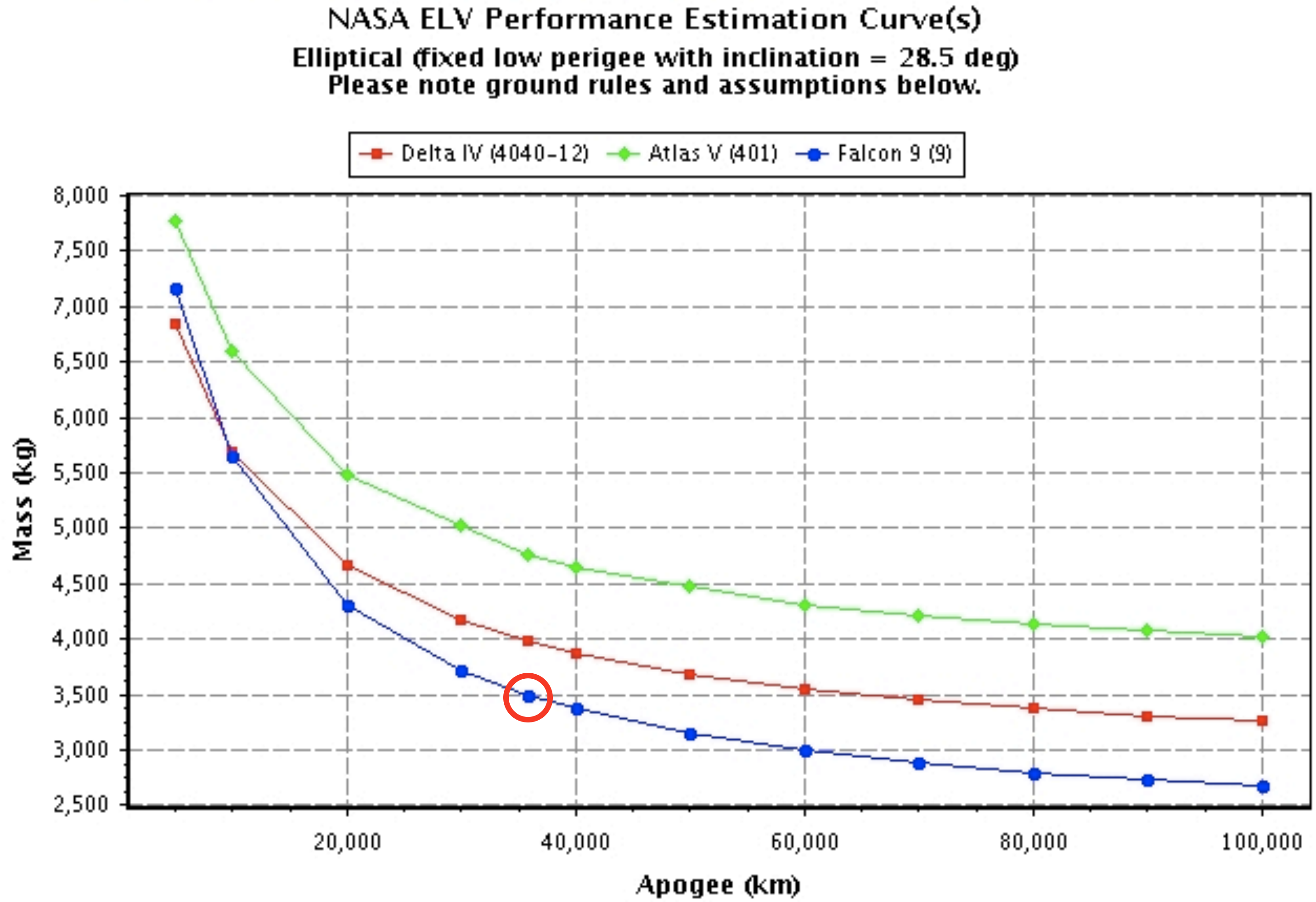
Technical Information – Backup Charts

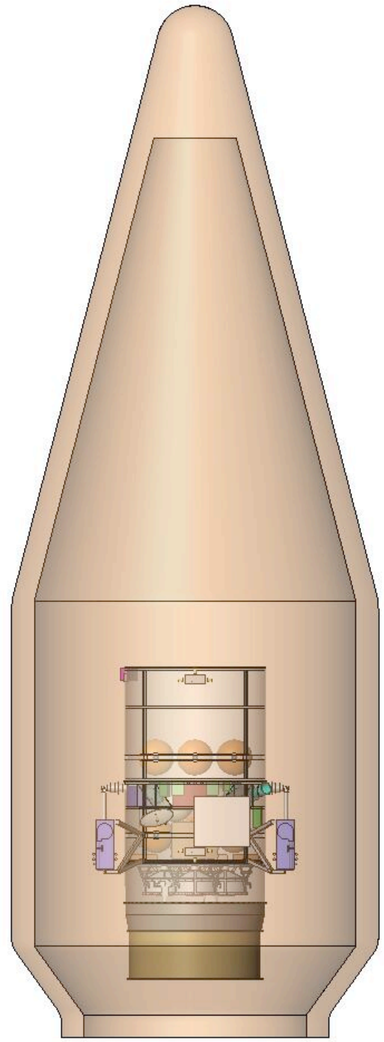
Top Level Spacecraft Masses

Spacecraft Master Equipment List Rack-up (Mass) - FV1				COMPASS S/C Design	
WBS	Main Subsystems	Basic Mass (kg)	Growth (kg)	Total Mass (kg)	Aggregate Growth (%)
06	**FV1 - Flagship Vehicle 1**	**2324**	**242**	**2566**	
06.1	**FAST - NEXT Spacecraft Bus**	**2324**	**242**	**2566**	
06.1.1	**Instrumentation**	10	2.0	**12**	20%
06.1.2	**Avionics**	36	6.8	**43**	19%
06.1.3	**Communications and Tracking**	55	14.2	**70**	26%
06.1.4	**Guidance, Navigation and Control**	66	14.0	**80**	21%
06.1.5	**Electrical Power Subsystem**	377	119.1	**496**	32%
06.1.6	**Thermal Control (Non-Propellant)**	84	15.2	**99**	18%
06.1.7	**Structures and Mechanisms**	235	53.8	**288**	23%
06.1.8	**Propulsion and Propellant Management**	384	17.0	**401**	4%
06.1.9	**Propellant**	**1077**		**1077**	
	Spacecraft Adapter (Stays with ELV Stage)	42	11	53	
	Estimated Spacecraft Dry Mass	**1205**	**232**	**1436**	**19%**
	Estimated Spacecraft Wet Mass	2282	232	2514	
System LeveL Growth Calculations					**Total Growth**
	Spacecraft Adapter (Stays with ELV Stage)	42		53	
	Dry Mass Desired System Level Growth	1205	361	**1566**	**30%**
	Additional Growth (carried at system level)		130		**11%**
	Total SEP Stage Wet Mass with Growth	2282	361	**2644**	

- Total Basic Dry Mass: 1205 kg (removing the 42 kg adaptor); Total Basic Wet Mass: 2282 kg
- Estimated Dry mass: 1436 kg; Estimated Total Wet mass: 2514 kg (from MELs)
- Bottoms up growth on dry elements: 232 kg. = 19% of Basic dry mass
  - Requires additional 11% mass carried at system level to meet 30% growth on dry mass requirement
- Total Wet mass with 361 kg (30%) growth: **2644 kg**

Launch Vehicle





Atlas 401 Assumed – Atlas 511 would also work

Falcon 9 launch capability will limit ARDV to about 700kg Wet

Launch to GTO from Cape Canaveral

Launch mass sufficient for FTD 1 with margin

Mission Analysis Details

Mission Phase	Phase Duration (days)	Phase Propellant (kg)	Solution Method
Leg 1: ARDV Perigee Raise	N/A	24	Impulsive DV
Leg 2: GTO to GEO	~159 *	204	Edelbaum
Leg 3: 30 Days testing with ARDV	30	N/A	
Leg 4: GEO to Escape	~96 *	108	Sauer-Melborne
Leg 5: Heliocentric cruise to Mars rendezvous	500***	359	MALTO
Leg 6: Mars spiral capture to 9,300 km semi-major axis* **	~123*	67	Sauer-Melborne
Totals	908	1051 (Xe only)	

* Includes 20% time margin on an Edelbaum or Sauer-Melborne analytic approximation
** Flight Time includes 50 extra days assuming observation of Deimos
*** Non-optimal Mars trajectory: allows for up to 6 months of contingency time for launch slips or delays in GTO to GEO