Deep Space Habitat Team: HEFT Phase 2 Efforts

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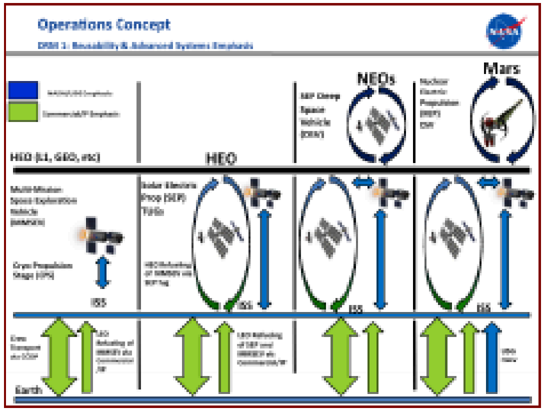
Human Exploration Framework Team (HEFT) Overview and Deep Space Habitat (DSH) Team Support

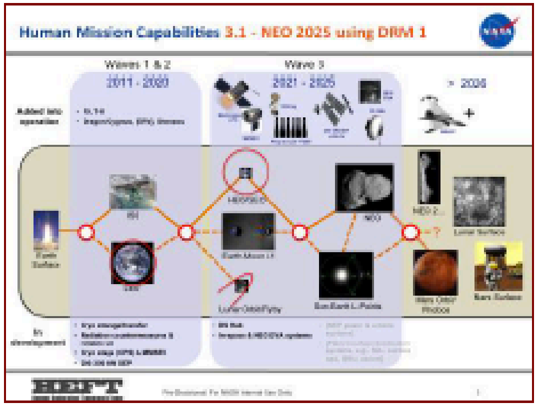
- **HEFT was a NASA-wide team that performed analyses of architectures for human exploration beyond LEO, evaluating technical, programmatic, and budgetary issues to support decisions at the highest level of the agency in HSF planning**
- **HEFT Phase I (April – September, 2010) and Phase II (September – December, 2010) examined a broad set of "Human Exploration of Near Earth Objects (NEOs)" Design Reference Missions (DRMs), evaluating such factors as elements, performance, technologies, schedule, and cost**
- **At end of HEFT Phase 1, an architecture concept known as DRM 4a represented the best available option for a full capability NEO mission**
  - Within DRM4a, the habitation system was provided by Deep Space Habitat (DSH), Multi-Mission Space Exploration Vehicle (MMSEV), and Crew Transfer Vehicle (CTV) pressurized elements
- **HEFT Phase 2 extended DRM4a, resulting in DRM4b**
  - Scrubbed element-level functionality assumptions and mission Concepts of Operations
  - Habitation Team developed more detailed concepts of the DSH and the DSH/MMSEV/CTV Conops, including functionality and accommodations, mass & volume estimates, technology requirements, and DDT&E costs
- **DRM 5 represented an effort to reduce cost by scaling back on technologies and eliminating the need for the development of an MMSEV**

HEFT Architecture Analysis Cycle Approach (Iterative)

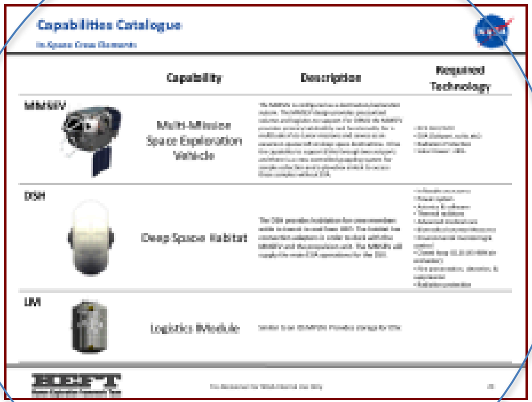
DSH Team Support



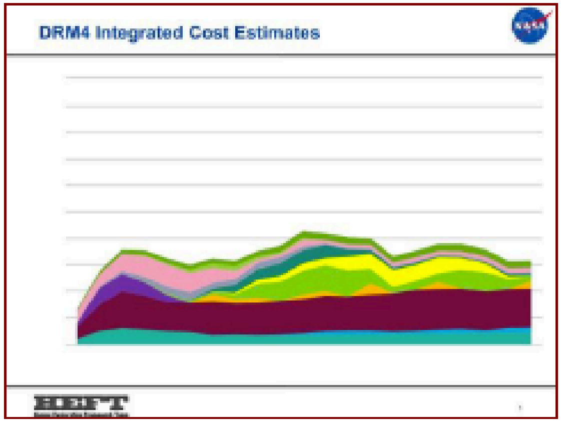
Technical Design Reference Mission



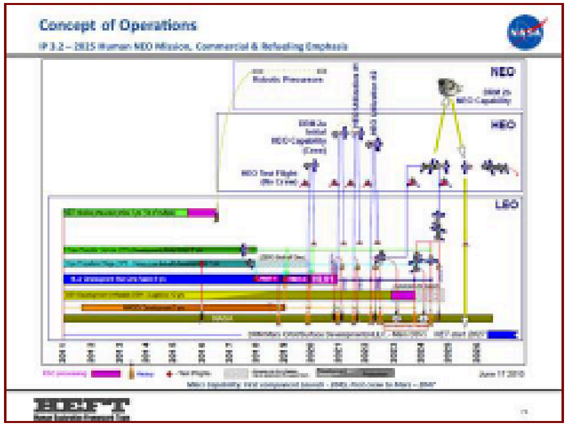
Investment strategy



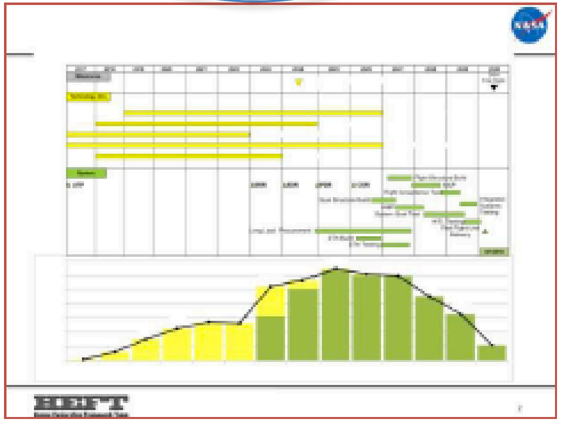
Element catalog



Non-optimized cost rollup through 2025

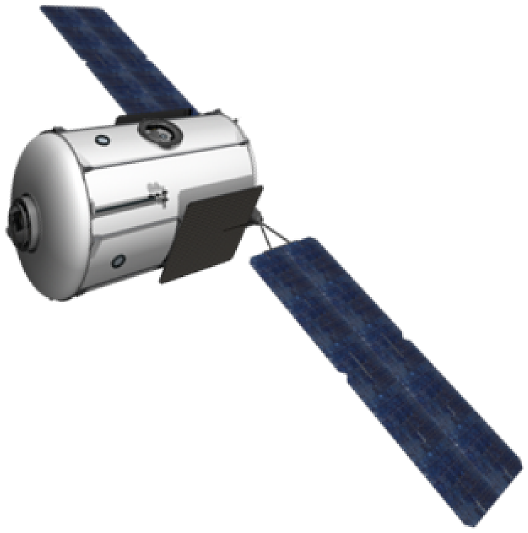


Integrated program schedule & flight manifest



Schedule and cost to develop and operate each element

DSH Element Description



Design Constraints/Parameters

Pressurized Vol.	115.0 m^3
Habitable Vol.	71.8 m^3
Crew Capacity	3
Crewed Mission Duration	365 d
EOL Solar power generation	17 kW
Total battery energy storage	26 kW-h
Number of Batteries	3
Depth of Discharge	80 %
ECLSS Closure - Water	Partially Closed
ECLSS Closure - Air	Partially Closed
Habitat Structure	Rigid Cylinder
Habitat Height	7.49 m
Habitat Diameter	4.57 m
Mass Growth Allocation	20%
Project Manager's Reserve	10%

Category	Mass, kg
Structure	**4,233**
Protection	**336**
Propulsion	**0**
Power	**1,108**
Control	**0**
Avionics	**453**
Environ./Active Therm	**7,752**
ECLSS	5,732
Air Subsytem	*1,345*
Water Subsytem	*1,250*
Food	*1,992*
Human Accommodations	*735*
Other	*411*
EVA systems	253
Thermal Control System	578
Crew Accommodations	1,189
Growth	**4,165**
DRY MASS SUBTOTAL	**18,047**
Non-cargo	**3,739**
Recreational Equipment	75
Crew Health Care	1,032
Personal Hygiene	96
Housekeeping Supplies	231
Operational Supplies	159
Maintenance Equip. & Spares	2,000
Photography Supplies	120
Sleep Accommodations	27
Cargo - Radiation Protection (waterwa	**2,055**
INERT MASS SUBTOTAL	**23,841**
Non-propellant	**0**
Propellant	**0**
TOTAL WET MASS	**23,841**

Description

The Deep Space Habitat provides habitation for crew members for long duration missions. The habitat has connection adapters in order to dock with the SEV, CTV and the propulsion unit(s). There is an internal bulkhead 2m from the aft dome with airlock services to act as a contingent airlock.

Ground Rules & Assumptions For DSH

- **Habitat Structure & Mechanisms**
  - Metallic, cylindrical habitat
  - 115 m3 pressurized volume
  - Secondary structure sized as 2.46 kg/m2 of habitat structural area
  - Integration structure 2% of habitat gross mass
  - 4 windows, 1 exterior hatch, 4 docking mechanisms
- **Protection**
  - 1 ¼ ” MLI covering external habitat surface for passive TCS
  - Cargo – Radiation Protection
  - 2” water-wall covering crew quarters only
    - Water included
- **Power**
  - 2 photovoltaic (3-junction GaAs) arrays each generating 7.5 kW EOL
  - EPCU 28 Vdc PMAD (92% efficient)
  - 3 Li-ion batteries
- **Avionics**
  - Leverage CTV for CC&DH, GN&C and communications
- **Thermal Control**
  - External fluid loop for heat acquisition using ammonia
  - Internal fluid loop for heat acquisition using 60% prop glycol/water
  - 6.5 kW heat acquired from MM cabin & avionics rejected using ISS-type radiators w/ 10 mil Ag-teflon coating
- **Crew Accommodations**
  - Standard suite for 180-360 day deep space transfer (ref. Human Spaceflight Mission Analysis & Design)
  - sink, freezer, microwave oven, hand/mouth wash faucet, washer & dryer, 2 vacuums, laptop, trash compactor, printer, hand tools & accessories, test equipment, ergometer, photography equipment, exercise equipment, treadmill, table
- **Reserves**
  - Margin growth Allocation - 20% of basic mass
  - Project Manager’s Reserve - 10% of basic mass
- **Internal bulkhead with airlock services**
  - For contingent EVAs after NEO ops

DSH Sizing Using EXAMINE

- ***EXAMINE = EXploration Architecture Model for IN-space and Earth-to-orbit***
  - An architecture modeling framework developed at NASA LaRC
  - Contains a collection of parametric performance and sizing tools and algorithms that enable users to model a variety of architectural element types
  - Originated from a collection of existing NASA spacecraft sizing toolsets including JSC's Envision, MSFC's MER database, and JSC's ALSSAT
  - Provides detailed architecture element -specific sizing in mass, volume, and power for Levels 1, 2, and (occasionally) 3 detail
  - Also provides a framework for integrated sizing across the architecture concept
  - Enables trades and studies to improve designs

- **DSH Team provided inputs to EXAMINE to size the DSH element, which was then integrated into the sizing of the architecture as a whole**

DSH ECLSS Assumptions for Modeling in EXAMINE (ALSSAT)

Water Management System

- Urine Collection System: ISS
- Water Recovery System:
  - Vacuum Compression Distillation: ISS
  - Multifiltration: ISS
  - Volatile Removal Assembly: ISS
  - Ion-Exchange: ISS
- Hygiene/Product Tank: ISS
- Microbial Check Valve: ISS
- Water Quality Management: ISS
- Water Delivery: ISS

Air Management System

- CO2 Removal: 4BMS
- CO2 Reduction: Sabatier
- O2 Generation: SPE\ISS
- Trace Contaminate Control: ISS
- Atmosphere Composition Monitoring Assembly : ISS
- N2/O2 Storage: Cryogenic
- Fire Detection/Suppression: ISS

Solid Waste Management System

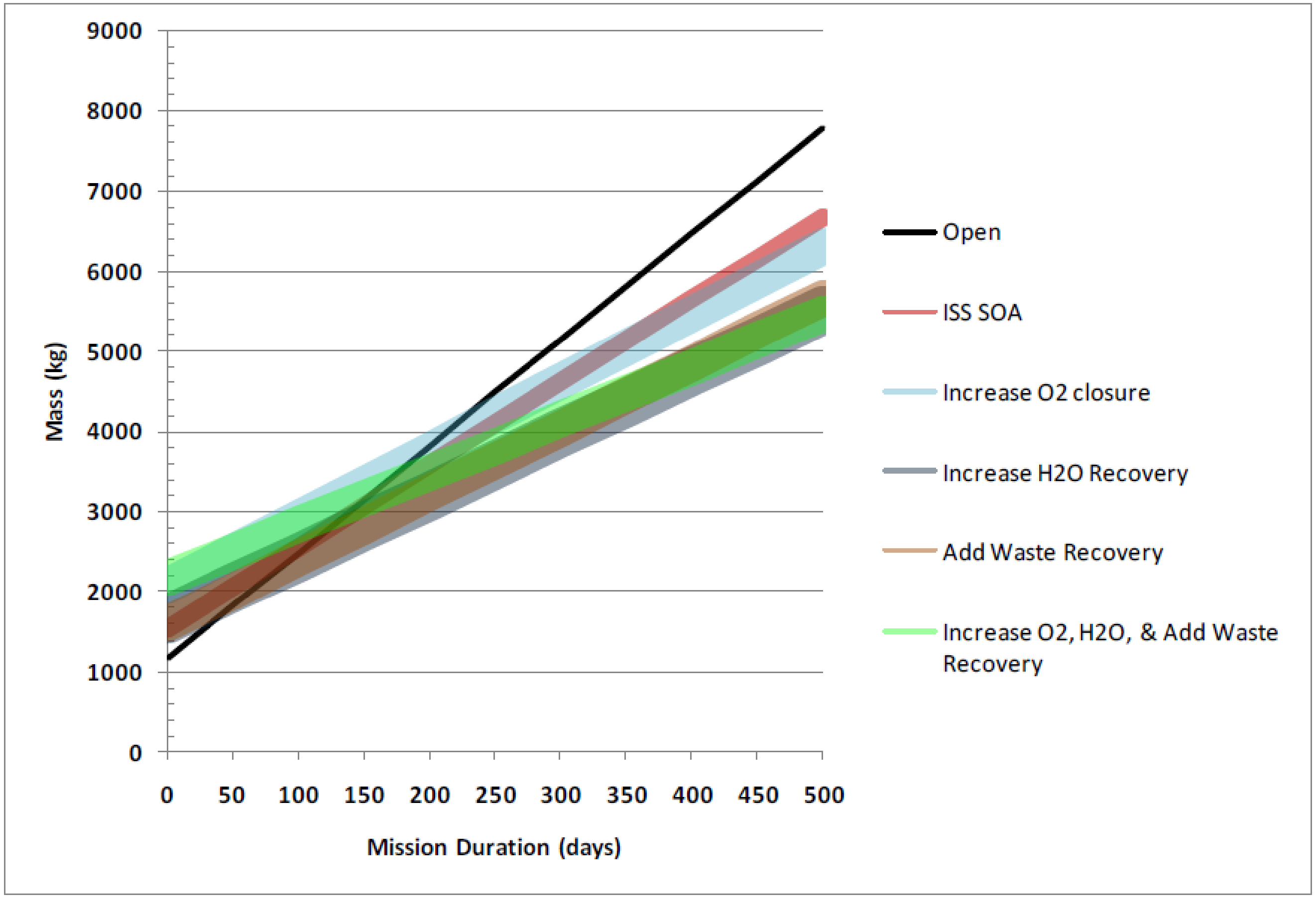
- Waste Storage
- Waste Collection Subsystem: ISS

Food System

- Shuttle Training Menu

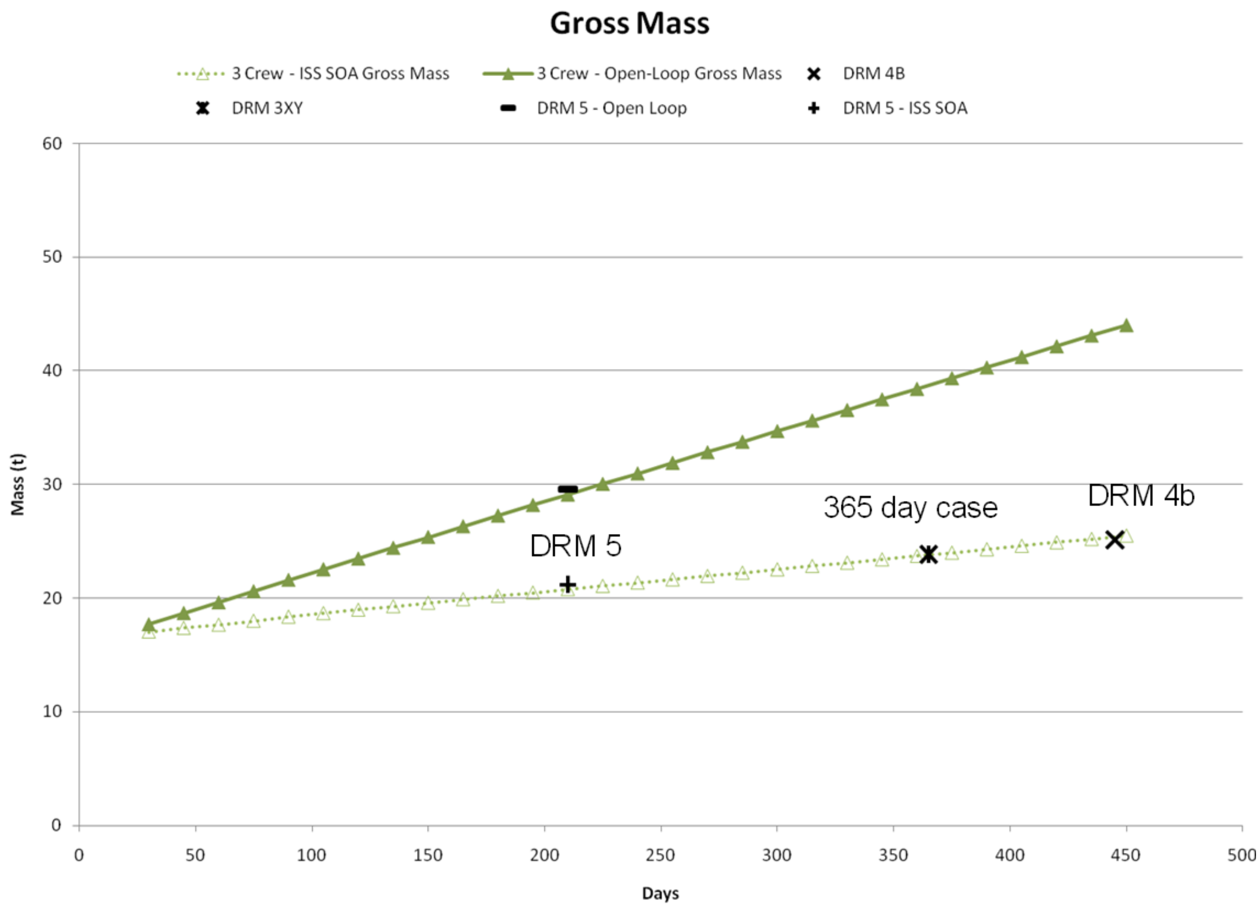
ECLSS Loop Closure Break-Even Assessment: Mass Mission Durations: 0-500 days

- Loop-closure equipment mass can be offset by resulting consumables savings as mission durations increase
- Uncertainty (10-20% shown here) clouds predictions of precisely when particular approaches become most beneficial
- For NEO-class missions (~450 days), distinguishable life cycle mass benefits begin to appear



Sizing Trend Lines for DSH

- The model used to size the DSH was used to generate trendlines for mass, pressurized volume and habitable volume as a function of crew and duration



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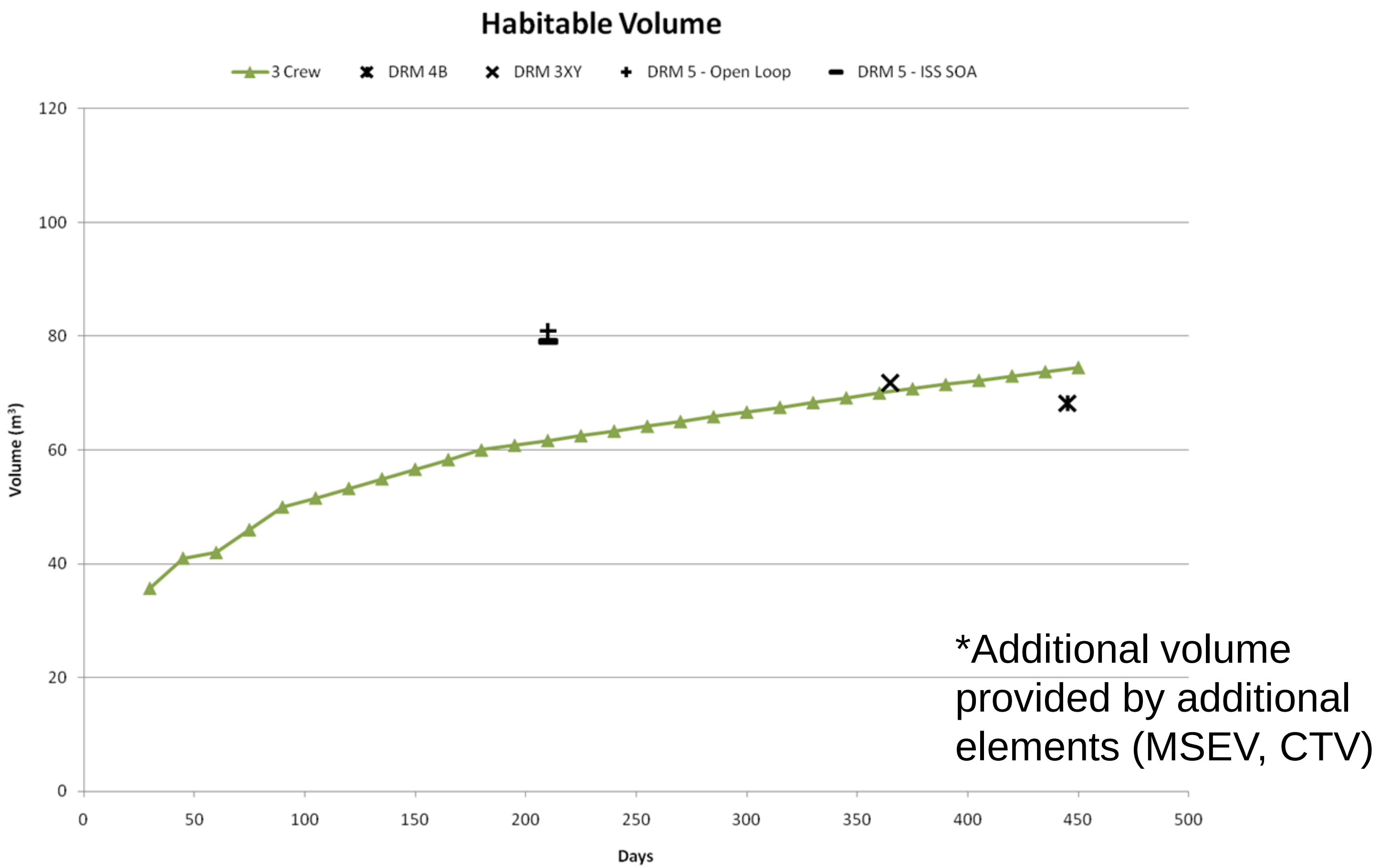

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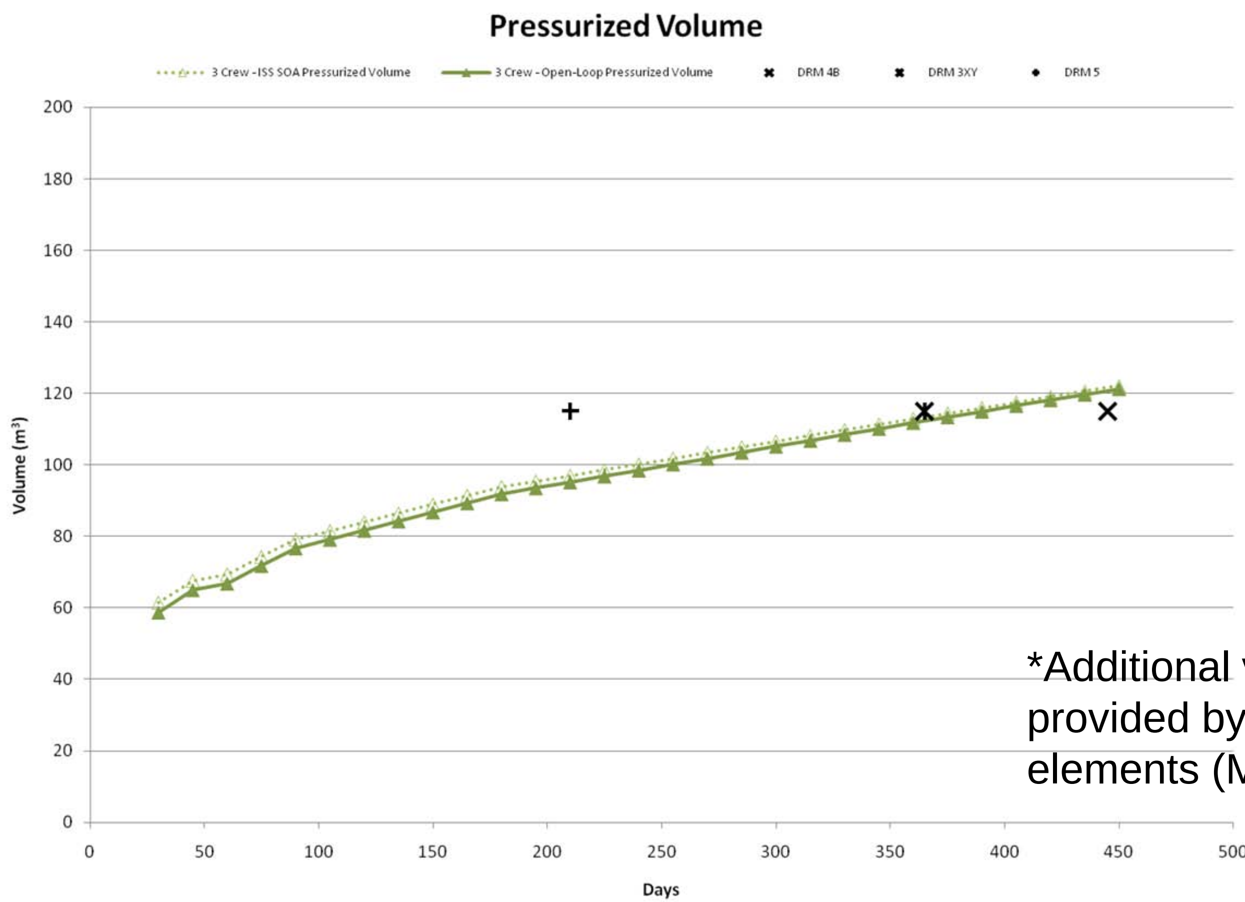


*Additional volume provided by additional elements (MSEV, CTV)

Technology Mapping

(DSH team provided input to Technology team to identify the technologies and research programs which must be undertaken to provide the capability required by the missions outlined in Strategies 1, 2, and 3)

	Applicable System						**Tech Dev Element**
Technology Entries for HEFT II (Strategy 3 Initial Mapping): Rev 12/14/10	CTV	CPS	MMSEV	SEP	DSH	Other	
LO2/LH2 reduced boiloff flight demo (FTD-2/Cryostat)		X					CPS
LO2/LH2 reduced boiloff & other CPS tech development		X					CPS
Energy Storage	X	X	X	X			CTV
Fire Prevention, Detection & Suppression (for 8 psi)	X		X		X		CTV
Environmental Monitoring and Control	X		X		X		CTV
TPS -- low speed (<11.5 km/sec; Avcoat)	X						CTV
Behavioral Health					X		DSH
Biomedical Countermeasures Optimized Exercise (Countermeasures H/W)					X		DSH
Human Factors and Habitability					X		DSH
High Reliability Life Support Systems (ECLSS)	X		X		X		DSH
Long Duration Medical					X		DSH
Biomedical countermeasures					X		DSH
Space Radiation Protection – Galactic Cosmic Rays (GCR)	?		X		X		DSH
Space Radiation Protection – Solar Proton Events (SPE)	?		X		X		DSH

Technology Mapping (continued)

Technology Entries for HEFT II (Strategy 3 Initial Mapping): Rev 12/14/10	Applicable System						Tech Dev Element
	CTV	CPS	MMSEV	SEP	DSH	Other	
Space Radiation Shielding – GCR & SPE	?		X		X		DSH
Electrolyzers					X		DSH
Vehicle Systems Mgmt		X	X	X	X		DSH
Crew Autonomy		X	X	X	X		DSH
Mission Control Autonomy		X	X	X	X		DSH
Common Avionics (Autonomous Systems)	X	X	X	X	X		DSH
Thermal Control	X		X		X		MMSEV
Robots Working Side-by-Side with Suited Crew (w/ Demos)	X		X		X		MMSEV
Telerobotic control of robotic systems with time delay (w/ Demos)	X		X		X		MMSEV
Mechanisms for Long Duration, Deep Space Missions	X	X	X	X	X		MMSEV
NEA Auto Rendezvous, Prox Ops, and Terrain Relative Nav			X				MMSEV
Dust Mitigation	X		X		X	Surface	

Technology Mapping (continued)

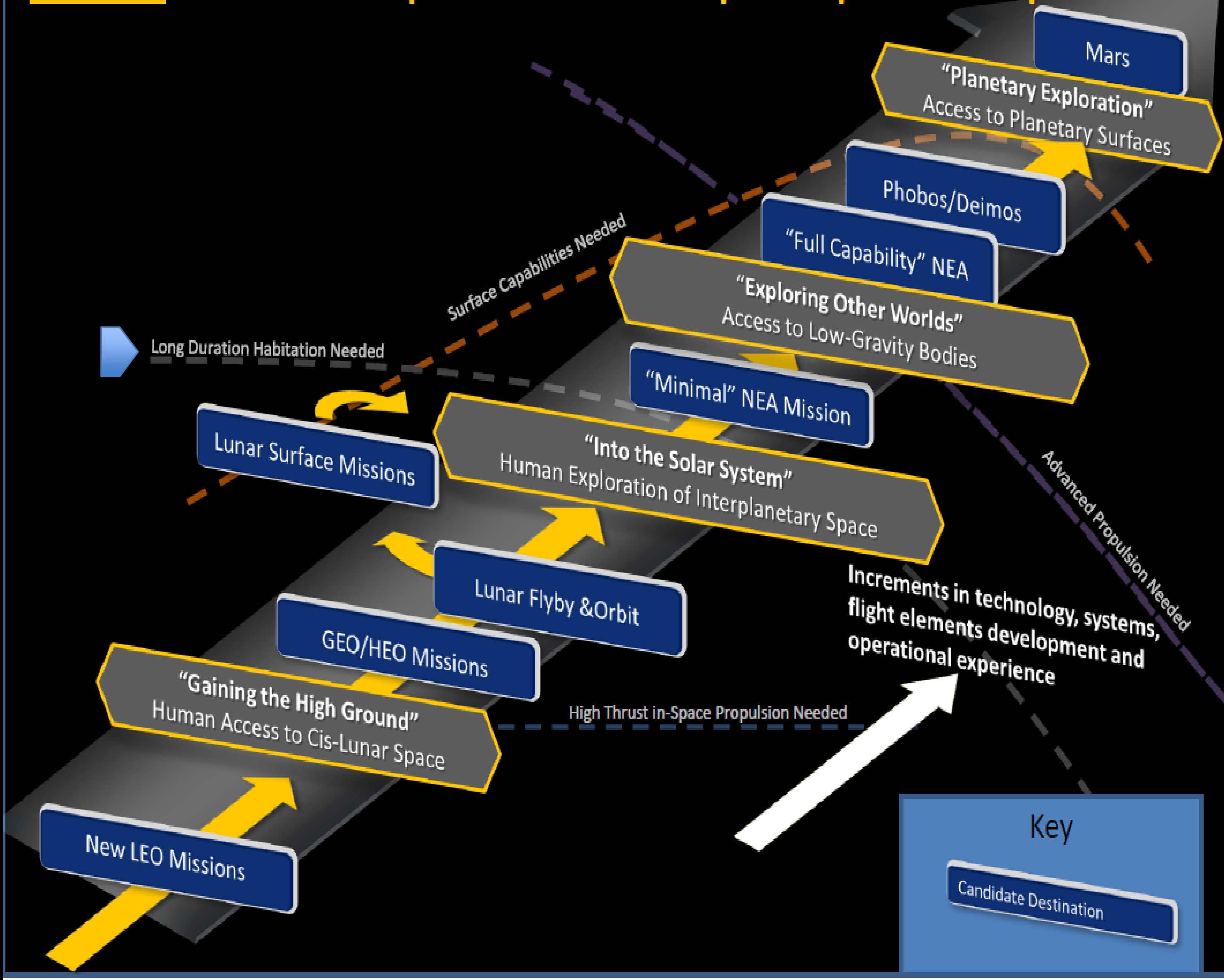
	Applicable Element						Tech Dev Element
Technology Entries for HEFT II (Strategy 3 Initial Mapping): Rev 12/14/10	CTV	CPS	MMSEV	SEP	DSH	Other	
Autonomously Deployable 300 kW Solar Arrays				X			SEP
SEP demo (FTD-1)				X			SEP
Solar Electric Propulsion (SEP) Stage				X			SEP
Suitport			X		?	EVA	EVA
Deep Space Suit (Block 1)	?		X		X	EVA	EVA
NEA Surface Ops (related to EVA)			X			EVA	EVA
Proximity Communications	X	X	X	X	X	EVA	TTCN
In-Space Timing and Navigation for Autonomy	X		X		X		TTCN
High Data Rate Forward Link (Flight)					X		TTCN
Ground Systems: Cryo Fluid Mgmt						Gnd	Gnd Ops
Ground Systems: Corrosion Detection & Control						Gnd	Gnd Ops
Ground Systems: Wiring Fault Detection & Repair						Gnd	Gnd Ops
Ground Systems: ISHM/FDIR						Gnd	Gnd Ops

Key Technical Architecture Observations To Date

- Advanced in-space propulsion (e.g., solar electric propulsion {SEP}) is a big enabler: Reduces launch mass by 50% (factor of 2) and mass growth sensitivity by 60%
- A balance of ELVs and HLLVs is optimal for varying mission needs
- Shuttle-derived HLLV option (100t-class evolvable to ~130t for deep space, full capability missions) meets more current FOMS than other options, although out-year affordability is still a fundamental challenge for long term exploration. Alternative design analysis continues to be part of NASA's strategy, coupled with an assessment of possible affordability initiatives.
- HLLV and crew vehicle should be a human-rated system
- ELV-only solution not optimal given all factors
- Staging at HEO or Earth-Moon L1 for deep space missions better than LEO
- Crew Transportation Vehicle (CTV) full ascent and entry capability is needed
- Additional capability, such as the MMSEV needed for EVA and robotics capability
- High reliability ECLSS is desired over fully closed loop ECLSS except for Mars missions
- In-Situ Resource Utilization (ISRU) is an enabler, particularly for surface missions
- Modularity and commonality aid key affordability FOM

- HLLV=Heavy Lift Launch Vehicle
- CTV=Crew Transportation Vehicle
- MMSEV=Multi-mission Space Exploration Vehicle
- EVA=Extravehicular Activity
- SEP=Solar Electric Propulsion
- ECLSS=Environmental Control and Life Support Systems

Notional Incremental Expansion of Human Space Exploration Capabilities



Example DRM Mission Space to Common Element Mapping

DRM TITLE	MINIMUM ELEMENTS									
	Commercial LV	SLS - HLLV	MPCV	CPS	REM/SEV	EVA Suit	Lunar Lander & Elements	DSH	SEP	Mars Elements
LEO missions	R	B	B			R				
HEO/GEO vicinity without pre-deploy		D	D	D	D	R				
HEO/GEO vicinity with pre-deploy	R	R	R	R	D	R				
Lunar vicinity missions		R	R	R		R				
Low lunar orbital mission		R	R	R		R				
Lunar surface mission		R	R	D		D	D			
Minimum capability NEA		R	R*	D	D	R		R		
Full capability NEA		D	D*	D	D	D		D	D	
Martian moons: Phobos/Deimos		R	R*	R		D		R	R	
Mars landing		D	R*	R		D		R	D	D

* MPCV entry velocity could be driven by these missions for certain targets, if selected.

D	Driving Case
R	Required Elements
B	Back-Up Capability

D/R/B Element allocations based on Authorization Act and other conditions. Different constraint basis would result in different element allocations/options.

Driving: There is something in this DRM that is "driving" the performance requirement of the element.
Example : Entry speeds for MPCV driven by NEO DRM.
Required: This element must be present to accomplish this DRM.
Example : SEV required for Full Capability NEO, but not for other DRMs

Flexible mission space analysis validates that several fundamental building blocks, including the SLS and MPCV, are needed to support multiple destinations.

- LV=Launch Vehicle
- SLS=Space Launch System
- MPCV=Multi-person Crew Vehicle
- CPS=Cryogenic Propulsion Stage
- REM=Robotics & EVA Module
- EVA=Extravehicular Activity
- DSH=Deep Space Hab
- SEP=Solar Electric Propulsion

Key Takeaways

- **The Capability-Driven Framework:**
  - Is the most viable approach given the cost, technical and political constraints
  - Provides a foundation for the agency's needed technology investments
  - Enables common elements to support multiple destinations
  - Provides flexibility, greater cost-effectiveness and easy integration of partnerships
- **NASA-wide transformational change is required to significantly improve affordability and meet budget constraints**
- **Beyond LEO destinations require:**
  - Development of a HLLV and MPCV as the key core elements
  - An investment in advanced space propulsion and long-duration habitation (including high-reliability ECLSS and radiation protection)
  - Robotic precursors for human near-Earth asteroid mission
- **Authorization Act-driven HSF architecture still presents a fundamental forward challenge to close on budget and schedule**
- **Partnerships are imperative to enabling our exploration goals**
- **Compelling, overarching mission goals are necessary to justify high-risk human spaceflight exploration beyond LEO**