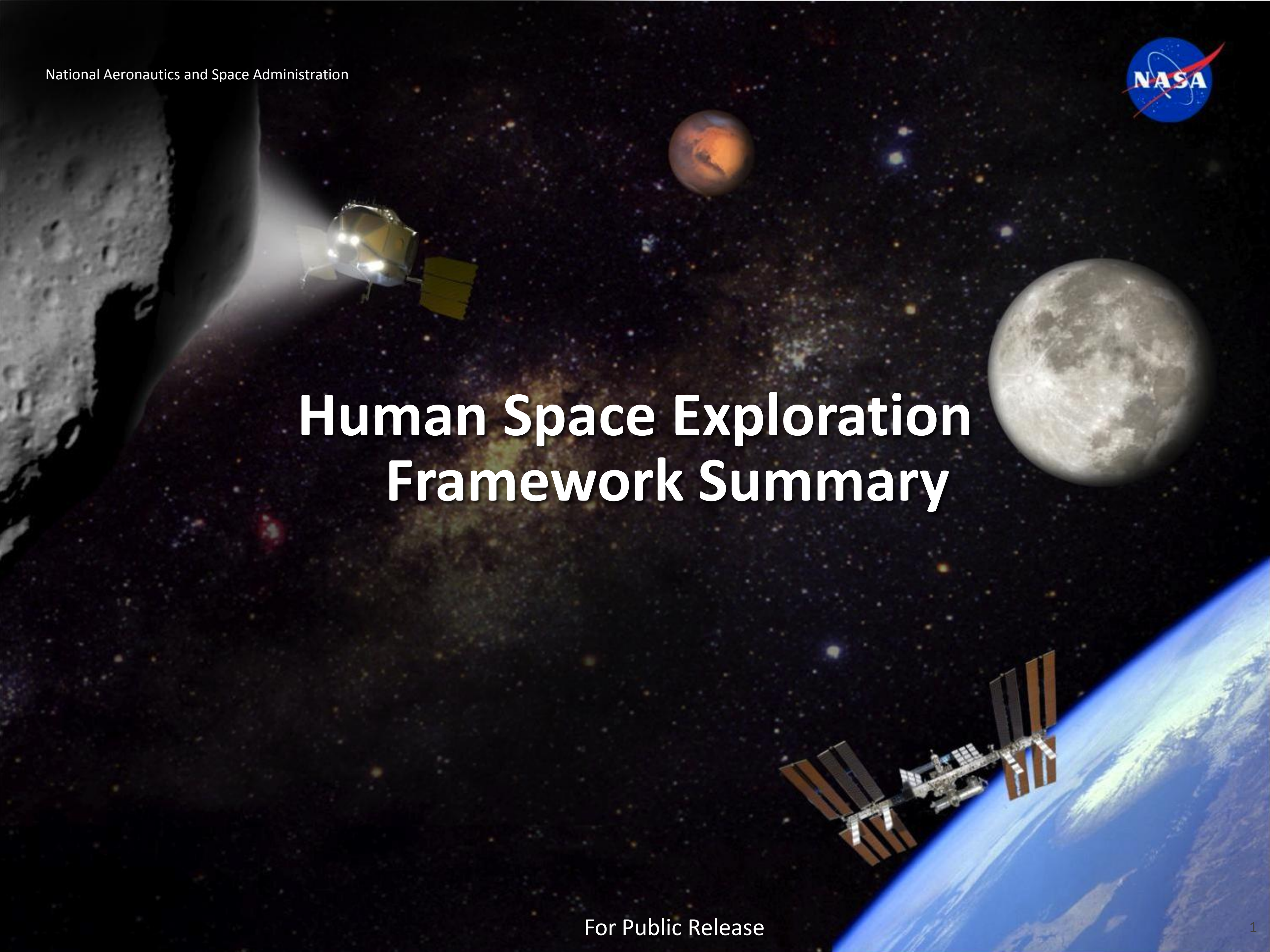


Human Space Exploration Framework Summary

For Public Release

Overview

- **Context and approach for human space exploration**
  - Key guiding principles
  - Figures of Merit
- **Capability-Driven Framework**
- **Technology**
- **Partnerships**
- **Affordability & Cost Analysis**
- **Summary**
  - Key takeaways
  - Forward work

Human Space Exploration Architecture Planning

- Human spaceflight (HSF) programs are complex and can occur on decadal timescales, yet funding is annual and political cycles occur on 2, 4, and 6-year intervals.

- Since 1969, 24 blue-ribbon panels have (re)assessed HSF strategy, and exploration concepts and technologies and national priorities have continued to evolve.

- Planning and program implementation teams established in February 2010, after the FY11 President's Budget Request and the NASA Authorization Act of 2010, needed integrated guidance.

NASA uses an ongoing, integrated HSF architecture decision-support function to develop and evaluate viable architecture candidates, inform near-term strategy and budget decisions, and provide analysis continuity over time.

Context: Policy, Process, and Law

- **2009: Review of U.S. HSF Plans Committee [Augustine Committee]**
- **2010: National Space Policy (28 June 2010)**
- **2010: NASA Human Exploration Framework Team (HEFT)**
  - Phase 1 (Apr-Aug 2010)
  - Phase 2 (Sep-Dec 2010)
- **2010: NASA Authorization Act**
  - Long-term goal: "To expand permanent human presence beyond low Earth orbit and to do so, where practical, in a manner involving international partners."
- **2011: NASA Human Space Exploration Architecture Planning (ongoing)**

Flexible Path for Human Exploration of Multiple Destinations

Review of U.S. Human Space Flight Plans Committee **(Augustine Committee)** ***defined "Flexible Path" as:***

"Steadily advancing…human exploration of space beyond Earth orbit…successively distant or challenging destinations…"

Destination options include:

- **Low Earth orbit (LEO) and the International Space Station (ISS)**
- **High Earth Orbit (HEO), Geosynchronous Orbit (GEO)**
- **Cis-lunar space (Lagrange/Libration points, e.g., L1, L2), lunar orbit, and the surface of the moon**
- **Near-Earth asteroids (NEAs), near-Earth objects (NEOs)**
- **The moons of Mars (Phobos, Deimos), Mars orbit, surface of Mars**

Can multiple paths get us where we want to go?

Can the program keep its basic shape despite unforeseen events?

Can milestones stretch out without the program breaking?

What is the Human Exploration Framework Team (HEFT)?

- **HEFT provides *decision support* to NASA senior leadership for planning human spaceflight exploration beyond LEO**

- ***Decision support* informs potential decisions**
  - Objective, consistent, credible, and transparent analyses

- **Multi-layered team tapped from throughout NASA**
  - From Strategic Management Council to technical subject matter experts
  - From all centers and headquarters

- **Analysis scope includes all architecture aspects: technical, programmatic, and fiscal**
  - Destinations, operations, elements, performance, technologies, safety, risk, schedule, cost, partnerships, and stakeholder priorities

- **HEFT prepares *architecture decision packages* for NASA senior leadership**
  - Objective sensitivity analyses, inclusive trade studies, integrated conditional choices
  - Draft multi-destination architectures that are affordable and implement stakeholder priorities
  - Neither "point solution" architectures, decision recommendations, nor decisions

NASA Guidance for its HSF Strategy

- **Make affordability a fundamental requirement** that obligates NASA to identify all content/milestones in budget, all content/milestones exceeding the available budget, and all content/milestones that could be gained through budget increases in a prioritized structure. Create and refine a culture of value, fiscal prudence, and prioritization.
- **Reward value-conscious performance, prudent risk assumption, and bold innovation, and incentivize the executive leadership** team to further create a "can-do" culture of excellence and a team of scientists, engineers, pioneers, explorers, and shrewd mission implementers.
- **Employ an executive leadership team to seek consensus that is fully empowered**, capable and willing to make decisions in the absence of consensus. Build a culture of empowerment, accountability, and responsibility.
- **Build on and apply design knowledge** captured through previously planned programs. Also **seek out innovative new processes**, techniques, or world-class best practices to improve the safety, cost, schedule, or performance of existing and planned programs, thereby enhancing their sustainability.
- **Leverage existing NASA infrastructure** and assets, as appropriate, following a requirements-based need and affordability assessment.

Human Space Exploration Guiding Principles

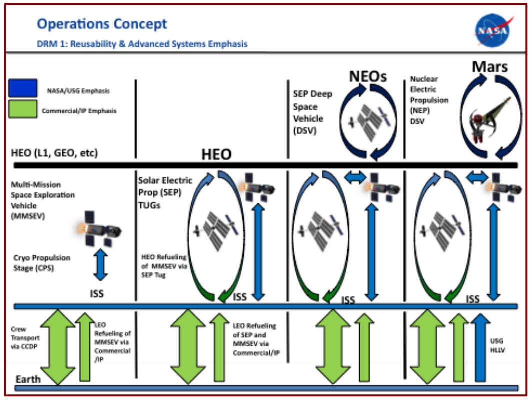
- Conduct a routine cadence of missions to exciting solar system destinations including the Moon and NEAs with Mars' surface as a horizon destination for human exploration
- Build capabilities that will enable future exploration missions and support the expansion of human activity throughout the inner Solar System
- Inspire through numerous "firsts"
- Fit within projected NASA HSF budget (affordability and sustainability)
- Use and leverage the International Space Station
- Balance high-payoff technology infusion with mission architectures and timeline
- Develop evolutionary family of systems and leverage commonality as appropriate
- Combine use of human and robotic systems
- Exploit synergies between Science and HSF Exploration objectives
- Leverage non-NASA capabilities (e.g., launches, systems, facilities)
- Minimize NASA-unique supply chain and new facility starts
- Pursue "lean" development and operations "best practices"

What Has HEFT Done?

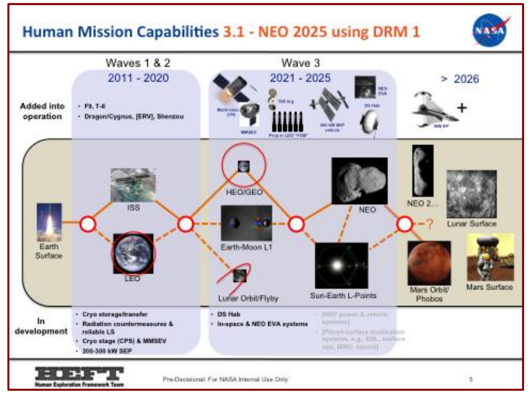
- HEFT was chartered in April 2010. The first phase concluded in early September 2010, and the second phase concluded in December 2010.
- HEFT established and exercised a consistent method for asking questions, comparing architecture alternatives, integrating findings and fostering cross-agency discussions.
- HEFT examined a broad trade space of program strategies and technical approaches in an effort to meet priorities from the White House, Congress, and other stakeholders.
- HEFT explored new affordability options and applied a refined cost analysis approach to do relative comparison of alternatives in order to hone and narrow the trade space.
- A smaller HEFT-like effort will continue for the foreseeable future since the HSF technical and programmatic environment will continue to evolve over time.

NASA HSF architecture must provide the flexibility to accommodate technical, programmatic, economic and political dynamics while enabling a safe, affordable and sustainable human space exploration program.

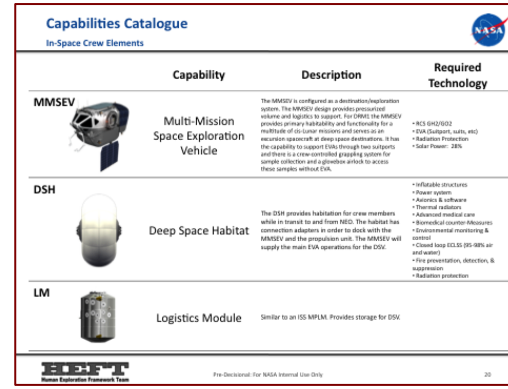
HEFT Architecture Analysis Cycle Approach (Iterative)



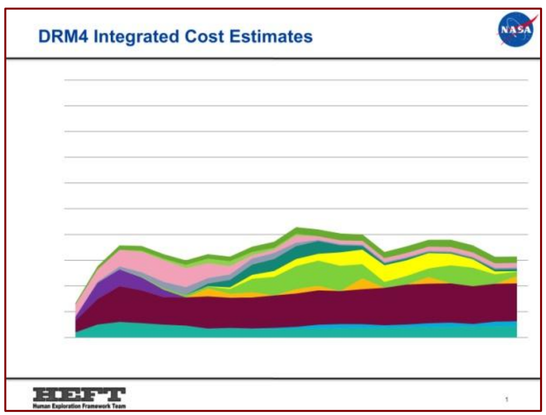
Technical Design Reference Mission



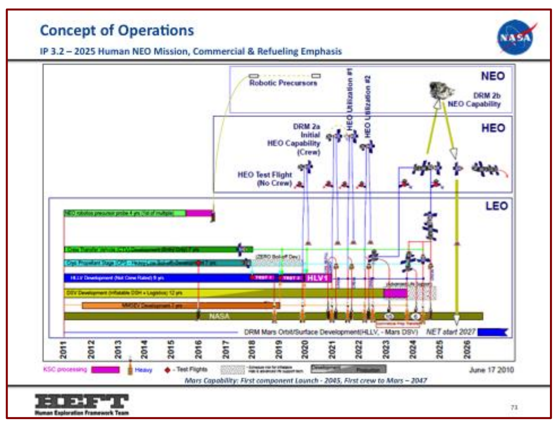
Investment strategy



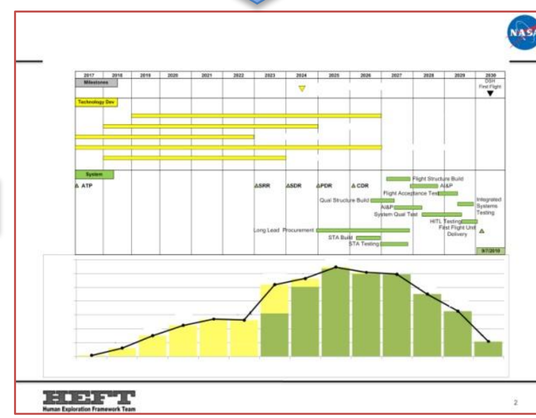
Element catalog



Non-optimized cost rollup through 2025



Integrated program schedule & flight manifest


Schedule and cost to develop and operate each element

Also addressed tech investment priorities & stakeholder concerns, objectives & constraints

Key Initial Findings

- **No single solution achieved all of the objectives**
  - There is no "magic architectural bullet"
  - Lean system development approaches will be essential
- **Compromise is key to forward progress and sustainability**
  - Satisfying all major stakeholders, while desirable, is not feasible
- **A 15-year analysis horizon is too short**
  - Understanding the impacts of a series of exploration missions and the potential value of system reusability requires a longer view
- **New technologies are required for sustainable human exploration beyond LEO**
  - Key technology investments are applicable to multiple destinations
  - "Technology priority" investment strategy highlighted key technology investment need
- **Human-rated heavy-lift launch and an exploration-class crew vehicle are desired for human exploration beyond LEO**
  - Initial analysis shows a 100t-class evolvable to about 130t human-rated launch vehicle is best option of those studied (based upon performance, reliability, risk, and cost, but not operations affordability)
  - Needed for planet-surface-class missions and all but nearest deep-space missions
  - Current designs, however, may not be affordable in present fiscal conditions, based on existing cost models, historical data, and traditional acquisition approaches. Affordability initiatives are necessary to enable these and other content needed for exploration
  - Exploration-class heavy lift and crew launch systems dominate the program content and cost profile for years
  - An exploration crew vehicle requires additional capabilities as compared to a LEO-class crew vehicle
  - Staging for deep space missions is best done in HEO at the Earth-Moon Lagrange (L1) point
- **Some major choices and elements can be delayed or re-phased**
  - Examples: the type of Mars-class propulsion and whether lunar surface operations should precede Mars
  - A flexible path strategy preserves options for future stakeholders

Early Findings Drove Analysis of Key Issues

- **Launch vehicle options**
  - Analysis areas included: implications for readiness date, cost risk, alignment with national propulsion objectives, potential development of partnerships, and use of existing NASA expertise, alternatives to Expendable Launch Vehicles (ELVs) alone and propellant depots
  - Assessed key trade for heavy lift between affordable DDT&E* vs. affordable annual cost
  - Evaluated cost uncertainty, complexity, and launch rate for commercial propellant launch
- **Crew vehicle options**
  - Assessed: system options for ascent/descent capsule and destination operations vehicle
  - Addressed implications of Orion derivatives and commercial crew launch for exploration
  - Analyzed development pace of radiation mitigation, reliable Environmental Control Life and Support System (ECLSS), and deep space habitat system
- **Advanced Propulsion: electric propulsion trip time**
  - Electric propulsion is key for achieving affordable missions to an asteroid or similar long-range destinations, however there are important considerations for number of units needed vs. time to first asteroid mission
  - Electric propulsion can’t be used for crew transit through the Van Allen radiation belts and there are also issues associated with long-duration spacecraft operations within the belts
- **Cost profile**
  - Complete accounting of all elements and reconciliation of assumptions
  - Conservative projection of available budget
  - Getting through the “budget keyhole” constrained by near-term budget liens

Affordability is essential; sustainability and flexibility are key drivers for investment in pursuit of inspirational objectives that return true value to the nation and improve life on Earth.

*Design, Development, Test & Evaluation

Focus of On-going HSF Architecture Refinement Work

- **Leverage HEFT's "analysis engine" to conduct and validate key trades**
  - Elements: heavy-lift launch vehicle (HLLV) options, crew vehicles, in-space systems, ground-based elements
  - Locations: cis-lunar staging; cis-lunar, trans-lunar, and real asteroid targets
  - Alternative providers: critical-path partnerships with other domestic and international agencies, balanced reliance on commercial launches of propellant, in-space elements, and exploration crew
  - Sensitivity analyses to understand impact of varying key assumptions
- **Use decision trees used to lay out the option space and to drive which branch to analyze; iterate process and identify most fruitful branches**
- **Define multiple architecture alternatives that "work" based upon key Figures of Merit (mission and stakeholder drivers)**
  - Based on coherent, implementable assumptions and concepts of operation
  - Options that fit the budget and meet stakeholder objectives on acceptable schedules
  - Refine concepts of operations that address the spectrum of operations, including destination operations, aborts, and contingencies

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

General Decision Tree Analysis Approach (Notional)

W – Strategies

1. Fixed initial conditions
2. Near-Earth Asteroid (NEA) in 2025
3. Others (including Capability-Driven Framework)

X – DRM's / Missions

1. DRM-4
2. "Easy" NEA
3. DRM Lunar
4. HEO/GEO
5. DRM Mars *(Orbit)* / Phobos and Deimos

Y – Elements / Capabilities Trades

1. HLV: SDV, LOX-RP
2. CTV: Orion Derived E' and Ascent/Entry
3. Commercial Crew
4. In-space Elements: CTV/ SEV / DSH functionality split
5. SEP Configuration / Propellant
6. Ops Trades
7. Others

Z- Opportunities*

1. Partnerships
2. # of Crew
3. Phasing / Budgets
4. Affordability:
   - In House Development
   - Insight/Oversight
   - Fixed/Recurring Costs
   - Others

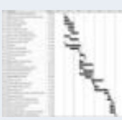
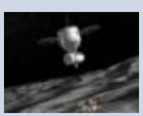
** Envision 2-3 Affordability Configurations per Element*

W : X : Y : Z – Filtered to control number of cases

- HLV=Heavy Lift Vehicle
- SDV=Shuttle-Derived Vehicle
- LOX-RP= Liquid Oxygen-Rocket Propellant (Kerosene)
- CTV=Crew Transportation Vehicle
- SEV=Space Exploration Vehicle
- DSH=Deep Space Habitat
- SEP=Solar Electric Propulsion

Figures of Merit (FOMs) Areas

- **FOMs are quantitative or qualitative expressions representing the value of a given system. FOMs ensure that each architecture or trade space option is evaluated with the same parameters and they go hand-in-hand with ground rules & assumptions, and help to mature decision options.**

FOM Area		Top-Level (Proxy) FOMs
	Affordability	• DDT&E cost • Annual recurring cost • Annual savings from affordability strategies • Cost risk
	Sustainability	• Number of key events in the architecture/manifest • Assumed element production & flight rates (min/max) • Number of partner launch opportunities • Number and scope of partner element opportunities • Destinations accessible (with no added DDT&E) • HSF capability sustainment?
	Safety & Mission Success	• Mission probability of loss of crew (LOC) • Mission probability of loss of mission (LOM)
	Schedule	• Crewed U.S. access to LEO and ISS capability date • First beyond LEO mission date • First NEA mission date
	Benefits	• Number of destinations visited by type • Percentage of NEA population accessible • Mass delivered /returned • Crewed days beyond LEO • Percentage of Mars technologies demonstrated • Alternate destinations accessible (with added DDT&E)

Inspiration for current and future generations remains an important intangible FOM.

Strategies and Design Reference Missions (DRMs)

- **Four different strategies were developed in the HEFT Phase 2 Architecture Analysis Cycle.**
  - Strategies 1, 1’ and 2: Built an integrated manifest with the respective element schedule and cost data
  - Strategy 3: Capability Driven Framework not manifested in HEFT 2 [Early Forward Work in Jan 2011]

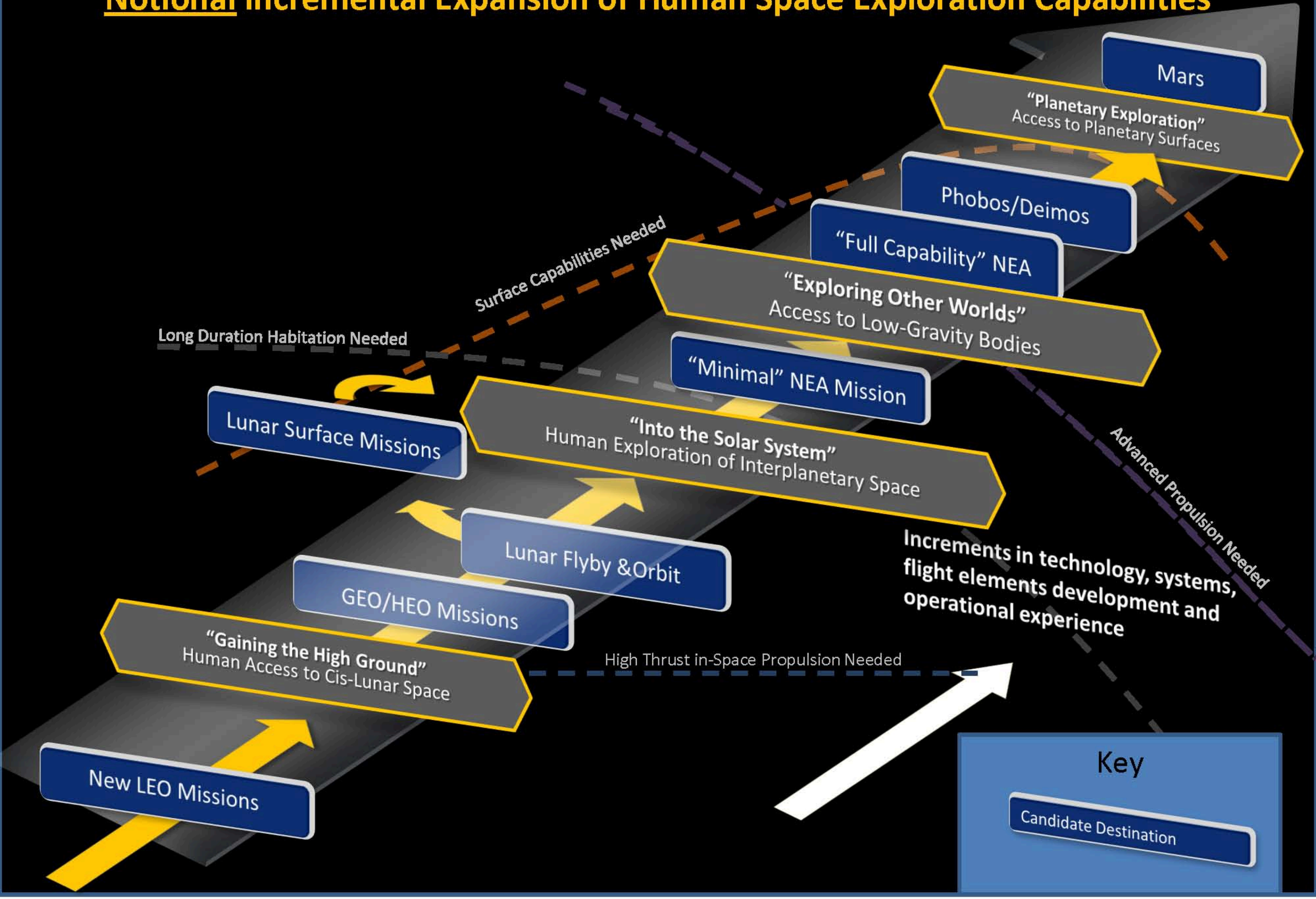
Strategy	Description	DRM	Simple Result Description
1 – Fixed Initial Conditions: Mission to a NEA when Affordable	A fixed cost and initial milestone-constrained assessment, consistent with the NASA 2010 Authorization for the DRM 4B *(NEA mission)* only. Manifest changed to incorporate HLLV test flight. Utilized updated design & cost estimates, that include some lean development options	4B	Over-constrained. Does not meet all schedule, budget, and performance requirements. Results heavily dependent upon budget availability and phasing.
1 Prime – Affordability Centric	Same as Strategy 1. Combines Expendable Launch Vehicles flights into an HLLV flight. Utilized updated design and cost estimates that include some lean development options	4B	Small improvement, but still didn’t close on budget in out-years. Key insights into necessary affordability measures.
2 – NEA by 2025	Deadline and cost-constrained assessment to reach a NEA by 2025 utilizing a “minimal” set of systems/elements and an “easy” target	5B	Not prudent: Sprint with minimum capability mission to asteroid too costly for sustained benefit/ROI.
3 – Capability-Driven Framework	Journey, not destination. Builds capabilities that enable many potential paths w/DRMs to GEO, L1/2, Lunar, NEA< Mars Orbits/Moons	Multiple	Departure from long-standing destination-focused approach – **Best path given constraints.**

Capability-Driven Framework Overview

- **Objective: Facilitates a capability-driven approach to human exploration rather than one based on a specific destination and schedule**
- **Evolving capabilities would be based on:**
  - Previously demonstrated capabilities and operational experience
  - New technologies, systems and flight elements development
  - Concept of minimizing destination-specific developments
- **Multiple possible destinations/missions would be enabled by each discrete level of capability**
- **Would allow reprioritization of destination/missions by policy-makers without wholesale abandonment of then-existing exploration architecture**

A Capability-Driven Framework enables multiple destinations and provides increased flexibility, greater cost effectiveness, and sustainability.

Notional Incremental Expansion of Human Space Exploration Capabilities



Capability-Driven Framework Approach

- **Establish "Mission Space" defined by multiple possible destinations**
  - Define Design Reference Missions to drive out required functions and capabilities
- **Utilize common elements across all DRMs**
  - Size element functionality and performance to support entire mission space
  - Common element and DRM analyses still in work, appears feasible
- **Assess key contingencies and abort scenarios to drive out and allocate any additional key capabilities to element(s)**
  - Iterate element sizing and functionality to ensure key contingency and abort scenarios are addressed
- **Establish key driving requirements for common elements**
  - Establish technology needs for each element
- **Identify key decision points for element/capability phasing**
  - Decision trees/paths for transportation architecture and destination architecture
- **Assess various manifest scenarios for costing and other constraint analysis**
  - Select various strategies for acquisition approach and affordability
- **Actively seek international and commercial involvement where possible**

Costing not completed, additional work required to complete integration of Capability-Driven Framework assessment

Example DRM Mission Space to Common Element Mapping

D	Driving Case
R	Required Elements
B	Back-Up Capability

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

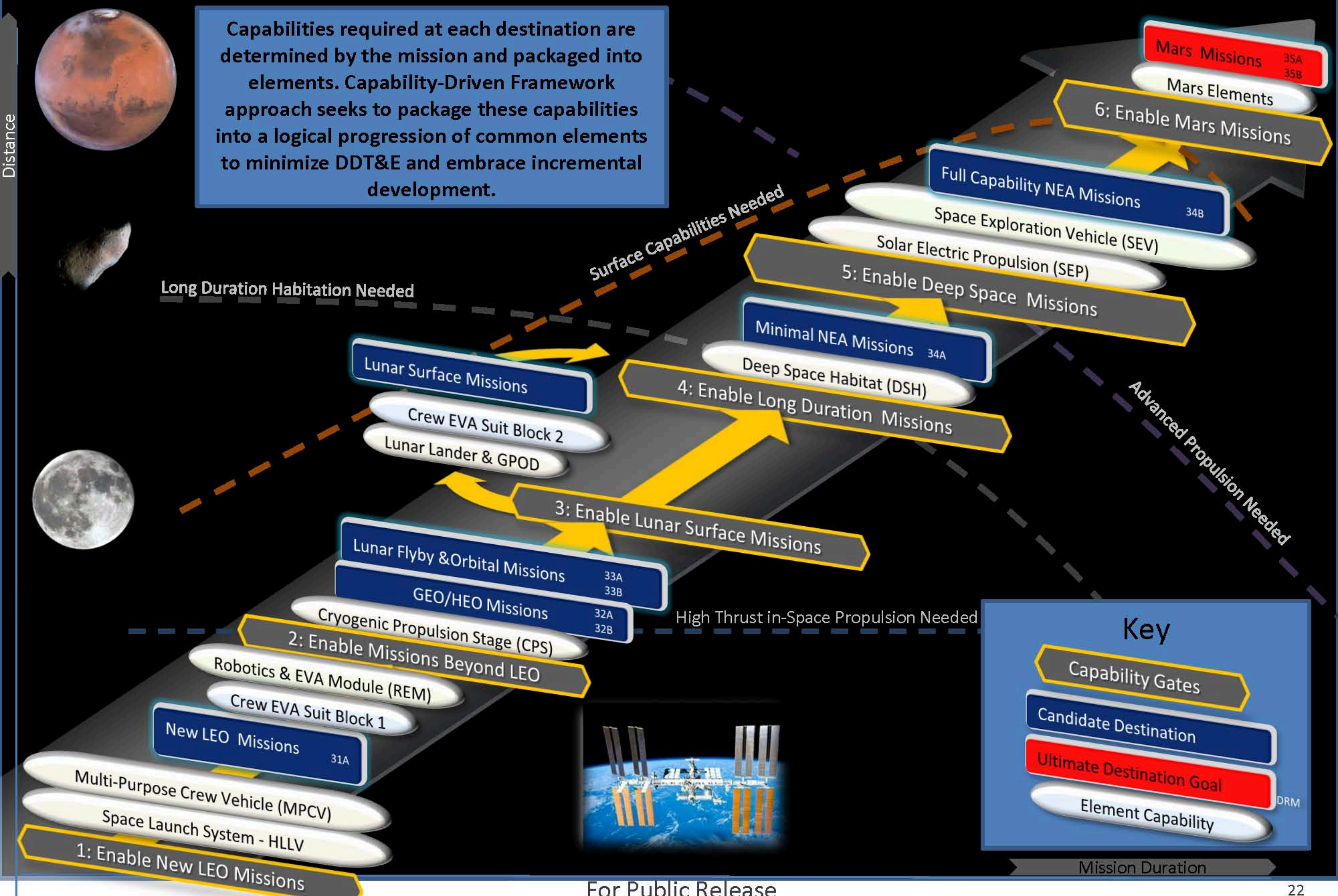
Driving: There is something in this DRM that is "driving" the performance requirement of the element.
Example : Entry speeds for MPCV driven by NEO DRM.

Required: This element must be present to accomplish this DRM.
Example : SEV required for Full Capability NEO, but not for other DRMs

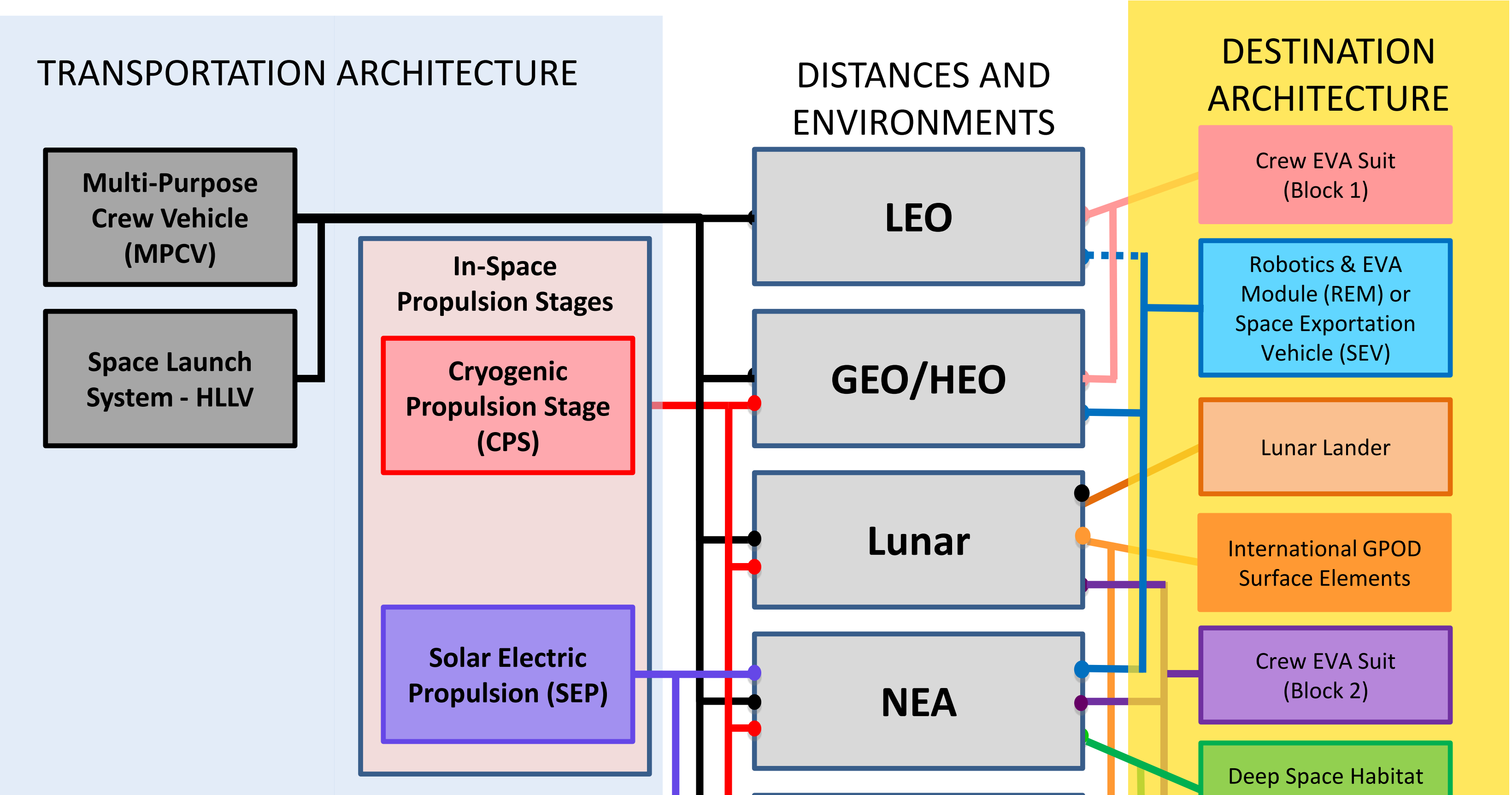
Flexible mission space analysis validates that several fundamental building blocks, including the SLS and MPCV, are needed to support multiple destinations.

- 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

INCREMENTAL EXPANSION OF HUMAN EXPLORATION CAPABILITIES



Transportation and Destination Architectures for Flexible Path



* MPCV Service Module derived Kick Stage utilized in some DRMs

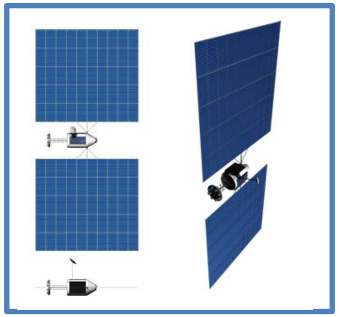
Elements based on Authorization Act and other conditions. Different constraint basis would result in different elements, but capabilities represented would be unchanged.

Notional Architecture Elements

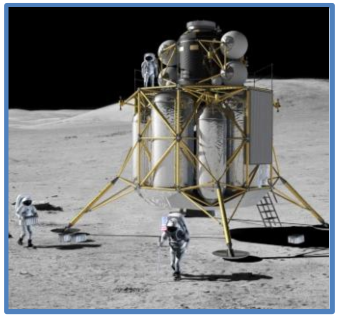
Space Launch System (SLS)-HLLV

Multi-purpose Crew Vehicle (MPCV)

Cryogenic Propulsion Stage (CPS)



Solar Electric Propulsion (SEP)

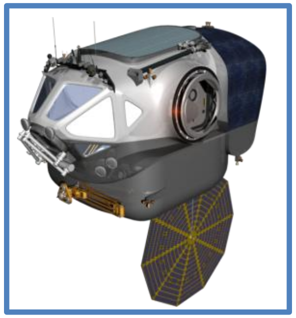


Lander

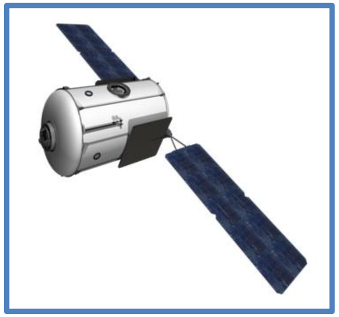
Mars Elements

Graphics are Notional Only – Design and Analysis On-going

EVA Suit



Multi-Mission Space Exploration Vehicle (MMSEV)



Deep Space Habitat (DSH)

Robotics & EVA Module (REM)

Kick Stage

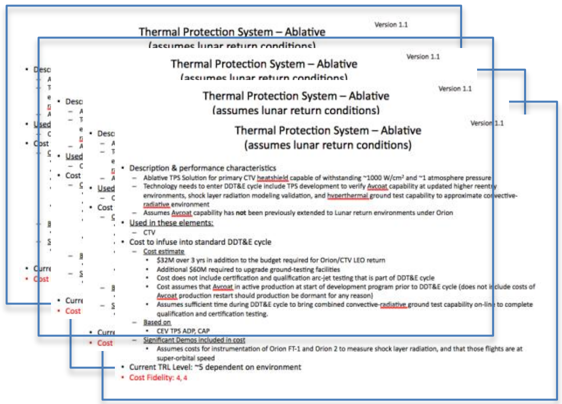
NEA Science Package

Technology Development Data Capture Process

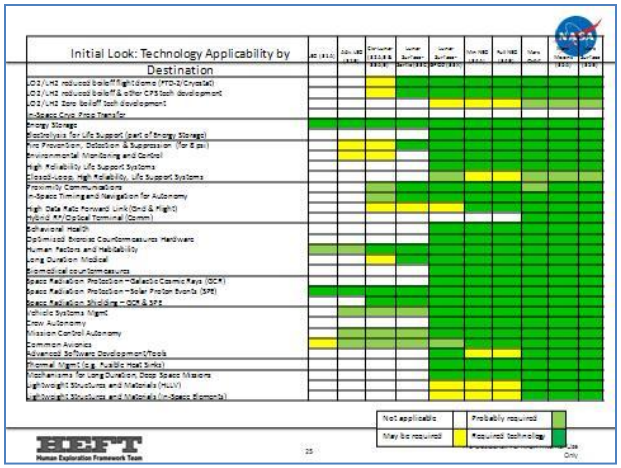
Strategy & DRMs

Element Data

'Tech Dev' Sheets

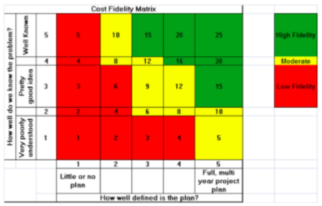


'Tech Dev' Summary Spreadsheet
(per Strategy/DRM)



Subject Matter Expert POCs

Cost Fidelity



<u>Tech Dev Data for Cost Team:</u>

- Cost, Schedule, Phasing
- Applicable Elements (per Strat/DRM)

For Public Release

Technology Applicability to Destination Overview (1)

	LEO (31A)	Adv. LEO (31B)	Cis-Lunar (32A,B & 33A,B)	Lunar Surface - Sortie (33C)	Lunar Surface - GPOD (33X)	Min NEA (34A)	Full NEA (34B)	Mars Orbit	Mars Moons (35A)	Mars Surface (35B)
LO2/LH2 reduced boiloff flight demo										
LO2/LH2 reduced boiloff & other CPS tech development										
LO2/LH2 Zero boiloff tech development										
In-Space Cryo Prop Transfer										
Energy Storage										
Electrolysis for Life Support (part of Energy Storage)										
Fire Prevention, Detection & Suppression (for 8 psi)										
Environmental Monitoring and Control										
High Reliability Life Support Systems										
Closed-Loop, High Reliability, Life Support Systems										
Proximity Communications										
In-Space Timing and Navigation for Autonomy										
High Data Rate Forward Link (Ground & Flight)										
Hybrid RF/Optical Terminal (Communications)										
Behavioral Health										
Optimized Exercise Countermeasures Hardware										
Human Factors and Habitability										
Long Duration Medical										
Biomedical countermeasures										
Space Radiation Protection – Galactic Cosmic Rays (GCR)										
Space Radiation Protection – Solar Proton Events (SPE)										
Space Radiation Shielding – GCR & SPE										
Vehicle Systems Mgmt										
Crew Autonomy										
Mission Control Autonomy										
Common Avionics										
Advanced Software Development/Tools										
Thermal Management (e.g., Fusible Heat Sinks)										
Mechanisms for Long Duration, Deep Space Missions										
Lightweight Structures and Materials (HLLV)										
Lightweight Structures and Materials (In-Space Elements)										

Not applicable		Probably required	
May be required		Required technology	

Technology Applicability to Destination Overview (2)

	LEO (31A)	Adv. LEO (31B)	Cis-Lunar (32A,B & 33A,B)	Lunar Surface - Sortie (33C)	Lunar Surface - GPOD (33X)	Min NEA (34A)	Full NEA (34B)	Mars Orbit	Mars Moons (35A)	Mars Surface (35B)
Robots Working Side-by-Side with Suited Crew		Required technology	Probably required	Probably required	Required technology	Required technology	Required technology	Probably required	Required technology	Required technology
Telerobotic control of robotic systems with time delay					Required technology	Required technology	Required technology	Probably required	Required technology	Required technology
Surface Mobility				Required technology	Required technology					Required technology
Suitport		May be required	May be required	Probably required	Required technology		Required technology		Required technology	Probably required
Deep Space Suit (Block 1)		Required technology	Required technology			Required technology	Required technology	May be required	Required technology	
Surface Space Suit (Block 2)				Required technology	Required technology					Required technology
NEA Surface Ops (related to EVA)							Required technology		Required technology	
Environment Mitigation (e.g., dust)				Required technology	Required technology	Probably required	Probably required		Probably required	Required technology
Autonomously Deployable very large Solar Arrays							Required technology	Required technology	Required technology	Required technology
SEP demo							Required technology	Required technology	Required technology	Required technology
Solar Electric Propulsion (SEP) Stage							Required technology	Required technology	Required technology	Required technology
Fission Power for Nuclear Electric Propulsion (NEP)								May be required	May be required	May be required
Nuclear Thermal Propulsion (NTP) Engine								May be required	May be required	May be required
Fission Power for Surface Missions					May be required					Required technology
Inflatable Habitat Flight Demo (flight demo launch)								Probably required	Probably required	Probably required
Inflatable Habitat Tech Development (including demo)								Probably required	Probably required	Probably required
In-Situ Resource Utilization (ISRU)					Probably required					Required technology
TPS -- low speed (<11.5 km/sec; Avcoat)			Required technology	Required technology	Required technology	Required technology	Required technology	Required technology	Required technology	Required technology
Thermal Protection System (TPS) -- high speed						May be required	May be required	Probably required	Probably required	Probably required
NEA Auto Rendezvous, Prox Ops, and Terrain Relative Nav				Probably required	Probably required	Required technology	Required technology		Required technology	Required technology
Precision Landing				Probably required	Probably required					Required technology
Entry, Decent, and Landing (EDL)						May be required	May be required	Required technology	Probably required	Required technology
Supportability and Logistics								May be required	May be required	Probably required
LOX/Methane RCS				May be required	May be required					Probably required
LOX/Methane Propulsion Stage - Pressure Fed				May be required	May be required					Probably required
LOX/Methane Propulsion Stage - Pump Fed				May be required	May be required					Probably required
In-Space Chemical (Non-Toxic Reaction Control System)						May be required	May be required		May be required	
HLLV Oxygen-Rich Staged Combustion Engine	May be required	May be required	May be required	May be required	May be required	May be required	May be required	May be required	May be required	May be required

Not applicable	(white)	Probably required	(light green)
May be required	(yellow)	Required technology	(dark green)

Capability-Driven Framework: Technology Strategy

- **The Capability-Driven Framework (CDF) offers an opportunity for a more complete look at technology needs over a longer span of time. It has the inherent benefit of not stranding technologies that result from only considering a single destination.**

- **Technology investment:**
  - Total amount will depend on the set of DRMs that are chosen
  - We will attempt to follow the structure that the DRM team has been using to build the decision framework
  - Many of the DRMs represent new discussion and so will require more work to understand what kind of technology advancement is required

- **Some technologies are likely to be required to enable the full set of DRMs in CDF (i.e., environment [e.g., dust] mitigation, supportability & logistics, communication technologies)**

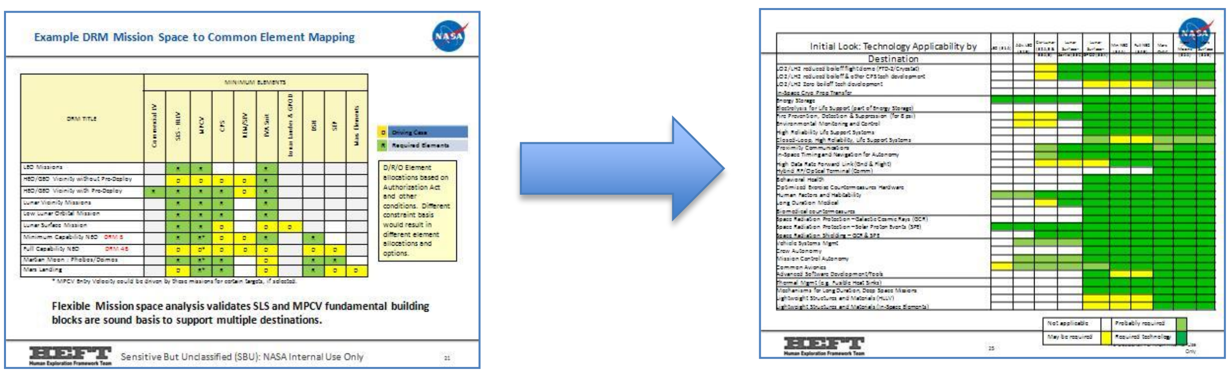
Key Technology Observations

- **More forward work is required for the HEFT Technology Team to align with other technology investments**
  - Need Crossflow with DoD/DARPA technology investments (tied to NASA strategies)
- **Total cost for exploration-focused technology development investments are $0.5-1B per year -- a relatively small portion of the total life cycle costs**
- **Majority of needed technologies can be matured in 3 to 8 years; some key Mars technologies require longer lead time**
- **Wide range of areas require technology maturation, but most specific technology needs require less than $500M to mature**
- **Some technologies are likely required to enable the full set of DRMs in the Capability-Driven Framework**
- **DRMs that only consider one mission/destination create an incomplete picture of agency technology needs**
- **Exploration (ETDD & HRP) programs are well aligned with HEFT direction**

- ETDD = Exploration Technology Development and Demonstration
- HRP= Human Research Program

Capabilities, Technology and Partnerships

- **DRM-Element matrices represent sets of functional capabilities and technologies packaged into specific elements**
  - There are many examples of potential common capabilities or technologies that apply across multiple elements
  - Detailed capability identification enables discussion on several topics



- **DRM-Element matrices being extended to additional detail to identify specific capabilities and technologies to drive out technology roadmap, potential common capabilities and partnership opportunities**

Partnerships Overview

- **Definition:**
  - A partnership is an agreement between NASA and one or more entities that provides tangible benefit and shares cost, equity, and/or risk between all parties.
    - For international partners this should be done on a no-exchange of funds basis
- **National Space Policy mandates that NASA:**
  - "Expand international cooperation"
  - "Energize competitive domestic industries"
  - "Strengthen inter-agency partnerships"
- **Potential benefits to NASA and/or the Nation**
  - Economic incentive (expansion, prosperity, innovation)
  - Enhancement through foreign technology and ideas
  - Enabling new domestic industries
  - Promotion of foreign policy interests
  - Affordability
    - Able to achieve missions that would otherwise be unaffordable
  - Sustainability
  - Schedule acceleration
  - Ensuring domestic space industrial base viability
  - Avoiding domestic capital investments which are significant and sustained
  - Multiple users – spreads cost base

Partnership Opportunities

- **Partnerships = International, Interagency, Commercial**

- **The Capability-Driven Framework enables on-ramps for:**
  - Partnerships that ***Expand*** the architecture
    - Characterized by adding elements and functional capabilities to the architecture that would not be otherwise funded for development, thus enabling missions that otherwise would not be possible
  - Partnerships that ***Enable*** the architecture
    - Characterized by partners that develop elements that enable missions sooner than could otherwise be accomplished
  - Partnerships that ***Enhance*** the architecture
    - Characterized by partners developing technologies or systems that enhance the existing or planned element capabilities within the architecture

International, Interagency, and Commercial Partnerships

- **Interagency partnership opportunities: DoD/IC, FAA, DOE, NSF, DHS, NIST**
- **DoD/IC promising potential partnership areas:** In-space propulsion (Solar Electric Propulsion), range modernization, Technologies, Industrial base, Landing, recovery, and medical operations support, communications
- **Commercial partnerships:** “Traditional,” Entrepreneurial, and “Non-Traditional”
- **Key Areas of Potential Interest:** Cargo and crew transportation, in-space habitation, communications, in-situ resource utilization, propellant transfer, storage, and re-supply

- DoD=Department of Defense
- IC=Intelligence Community
- FAA=Federal Aviation Administration
- DOE=Department of Energy
- NSF=National Science Foundation
- DHS=Department of Homeland Security
- NIST=National Institute for Standards and Technology

Affordability - Most Significant Challenge Moving Forward

- **<u>Affordability</u>: The ability of NASA to safely execute missions within the available funding constraints (long term and short term).**
  - Program/Project Management, Risk Management Culture, Systems Engineering, Workforce/Infrastructure, Acquisition Approaches
- **Opportunities to address affordability in program/project formulation and planning**
  - Levy lean development approaches and "design-to-cost" targets on implementing programs
  - Identify and negotiate international partner contributions
  - Identify and pursue domestic partnerships
- **Traditional development**
  - Balance large traditional contracting practices with fixed-price or cost challenges coupled with in-house development
  - Use the existing workforce, infrastructure, and contracts where possible; address insight/oversight, fixed-costs, cost analysis and cost estimation
- **Adopt alternative development approaches**
  - Leverage civil servant workforce to do leading-edge development work
  - Attempt to minimize use of NASA-unique infrastructure, seeking instead to share infrastructure costs where feasible.
  - Specifically, take advantage of existing resources to initiate the development and help reduce upfront costs on the following elements: Multi-Mission Space Exploration Vehicle, Solar Electric Propulsion Freighter, Cryo Propulsion Stage, Deep Space Habitat

In order to close on affordability and shorten the development cycle, NASA must change its traditional approach to human space systems acquisition and development.

Affordability Activities as Part of the HSF Planning

- **Affordability meetings with industry**
  - Received input from NASA contractors on how to reduce costs, maintain quality/performance, and improve our affordability

- **Affordability practices summit (Federal Government only)**
  - Explored concepts and processes that will increase program affordability

- **Near-term strategies for affordability "Blue Sky" meetings in D.C.**
  - Brainstormed concepts to enable affordable, near-term missions; topics include utilizing ISS to support exploration, and concepts for near-term flight demonstrations

Elements of Affordability

Program/Project Management	Risk Management Culture	Systems Engineering	Workforce/ Infrastructure
Planning for Vision vs. near term execution, funding stability	Maintain Crew Safety as Highest Priority	Clear Requirements/Rationale at the Right Level	Program / Project/ Line Leadership & Incentives
Clear, Simple Reporting and Accountability/Authority	Rapid Prototyping Hardware Demonstration	Cost Effective Architecture/ Design/Ops	Right People for the Role at the Right Time
Business/Contractual Relationships, Methods & Incentives	Clear Delegation of Authority	Streamline Reviews & Approvals	Long-term skill maintenance/development
On-Ramp Modern Tools & Technology	Decision Making Velocity	Industry vs. Government Standards	Use In-House Capability for in-line Program Work
Smaller Projects / Periodic Achievable Milestones	Early Identification & Resolution of Key Risks	Cost Requirements & Estimating	Align NASA Infrastructure with Future Mission Needs
Robust Margin (Performance, Cost, and Schedule)	Technical Oversight & Insight – Crisp Interface	Clear, Simple Interfaces Between Hardware and Org Elements	Minimize NASA Unique Industry Infrastructure

Industry Affordability Input

- **HEFT Affordability Team requested industry input**
  - Approaches for more cost-effective development and operation of human spaceflight missions
  - Priority must be maintaining safety
  - Opportunity to provide input advertised openly through NASA Acquisition Internet Service (NAIS)
- **Submissions were received and if requested, meetings were held with industry to discuss their input**
- **Submissions were received from:**
  - Aerojet, ATK, Ball, Blue Origin, Dynetics, SpaceX, Hamilton Sundstrand, Honeywell, Georgia Tech, Paragon, L3 Communications, Space Partnership International, Valador, Lockheed Martin, KT Engineering, Boeing, Pratt and Whitney Rocketdyne, Orbitec, Northrop Grumman, United Launch Alliance, Florida Turbine Technologies, Johns Hopkins University Applied Physics Lab, RAND, Space Partnership, and United Space Alliance

Industry Input – Major Themes

- **Key tenets and recurring themes identified in industry submissions:**
  - Systems engineering is more than requirements tracking and documents
  - Model, test and fly early and often
  - Use small lean projects with highly competent empowered personnel
  - Push decision authority to the lowest level. Trust them to implement and don't second guess (over-manage)
  - Maintain aggressive schedules
  - Manage cost and schedule as well as technical performance (maybe even more so)
  - Keep it simple
  - Dramatically minimize fixed costs (the key driver of mission cost)
  - Oversight/Insight model has to change

Focused, Realistic and Stable Requirements + Capable, Connected and Incentivized Lean Teams + Short Schedules = Low cost

Key Cost and Budget Analysis Overview

- **Innovative cost analysis approach enables significant insight into programmatic issues, thereby allowing us to address issues and develop solutions**
- **Authorization Act-driven HSF architecture does not yet close on budget and schedule**
  - The "big four" elements (SLS, MPCV, Commercial/Crew, Technology) comprise the majority of the budget
- **To close on affordability, the agency consensus is to:**
  - Embrace the Capability-Driven Framework with a "go-as-you-pay" approach
  - Maintain the "big four" and set challenging cost targets to fit within the available budget
    - Requires forward analysis with a resolved budget
  - Pursue agency transformation and aggressively implement applicable affordability practices
  - Vigorously pursue partnerships as part of the solution
  - Leverage innovative "NASAworks," lean development, and other infrastructure/ workforce efficiency measures in order to further improve our affordability posture

A Capability-Driven Framework allows NASA to increment or decrement prioritized investments based upon direction and available budget.

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**

Human Spaceflight Architecture Forward Work

- **Continue Development of Capability Driven Framework**
  - Continue launch and crew vehicle architecture trades (SLS, MPCV, CCDev*)
  - Continue iteration and refinement of DRM definition and analysis
    - Develop more detailed destination capability descriptions for each DRM
  - Initiate integrated capability-driven approach for multi-destination elements
    - Incremental approach for developing element; utilize modular approach to avoid redundant capability development; fewer elements = lower cost
    - Map technology developments based on destination and element
- **Continue assessment of affordability options**
  - Affordability strategies can be applied to possible multiple architecture implementations; for example, use of civil servants for early development could be applied to many possible common elements
- **Continue engagement with Partnership, Technology, Operations, Elements and other HEFT teams to refine approach and define scenarios for further assessment**
- **Identify and prioritize key technology and capability investment areas for NASAworks and other lean development approaches**
- **Hone Concept of Operations, to include key objectives and refine abort/contingency planning**

* CCDev = Commercial Crew Development

NASA Human Spaceflight Exploration Summary

- The Capability-Driven Framework is the NASA approach to meeting the nation's goals and objectives for HSF Exploration in a dynamic policy and budget environment
- NASA has a short-, mid-, and long-term human and robotic spaceflight exploration plan consistent with law and policy
- Affordability, technology development, and partnerships are enablers
- Important forward work has begun, much remains
- Investments in HSF exploration will be leveraged across the government, industry, and public sectors for National benefit
- Significant global, interagency, and commercial cooperation opportunities exist and NASA will continue to engage

Capability-Driven Framework shows that bold, smart, affordable, and sustainable opportunities exist -- We must implement them now!