Architecting a Human Spaceflight Program

Presentation to PM Challenge

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Agenda

- Acknowledgements
- What is Architecting
- Constellation “Architecture”
- Human Exploration Architecture (HEFT) Architecting Effort
- Forward work in Human Spaceflight Architecting
- Summary

Acknowledgements

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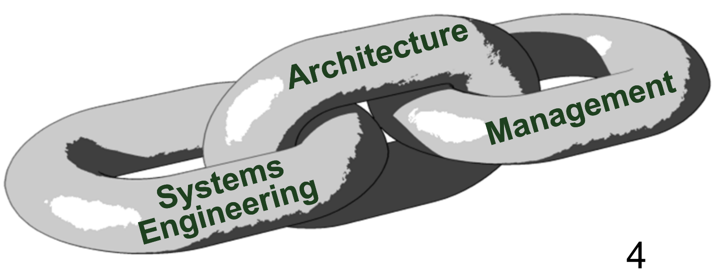
What is Architecture??

- Architecture is the fundamental organization of a system, embodied in its components, their relationships to each other and the environment and the principles governing its design and evolution (IEEE Std 1471-2000)
  - Links Systems Engineering & Management by balancing technical and programmatic considerations
- Architecture addresses <u>why</u> a system is the way it is and how this understanding of the system is to be sustained
  - It underlies the designs ability to meet objectives/constraints and satisfy stakeholders
  - A design is the embodiment of an architecture. Designs address what is to be built and how
- As systems become more complex the need for an effective architecting effort becomes essential
- Architectures are fractal

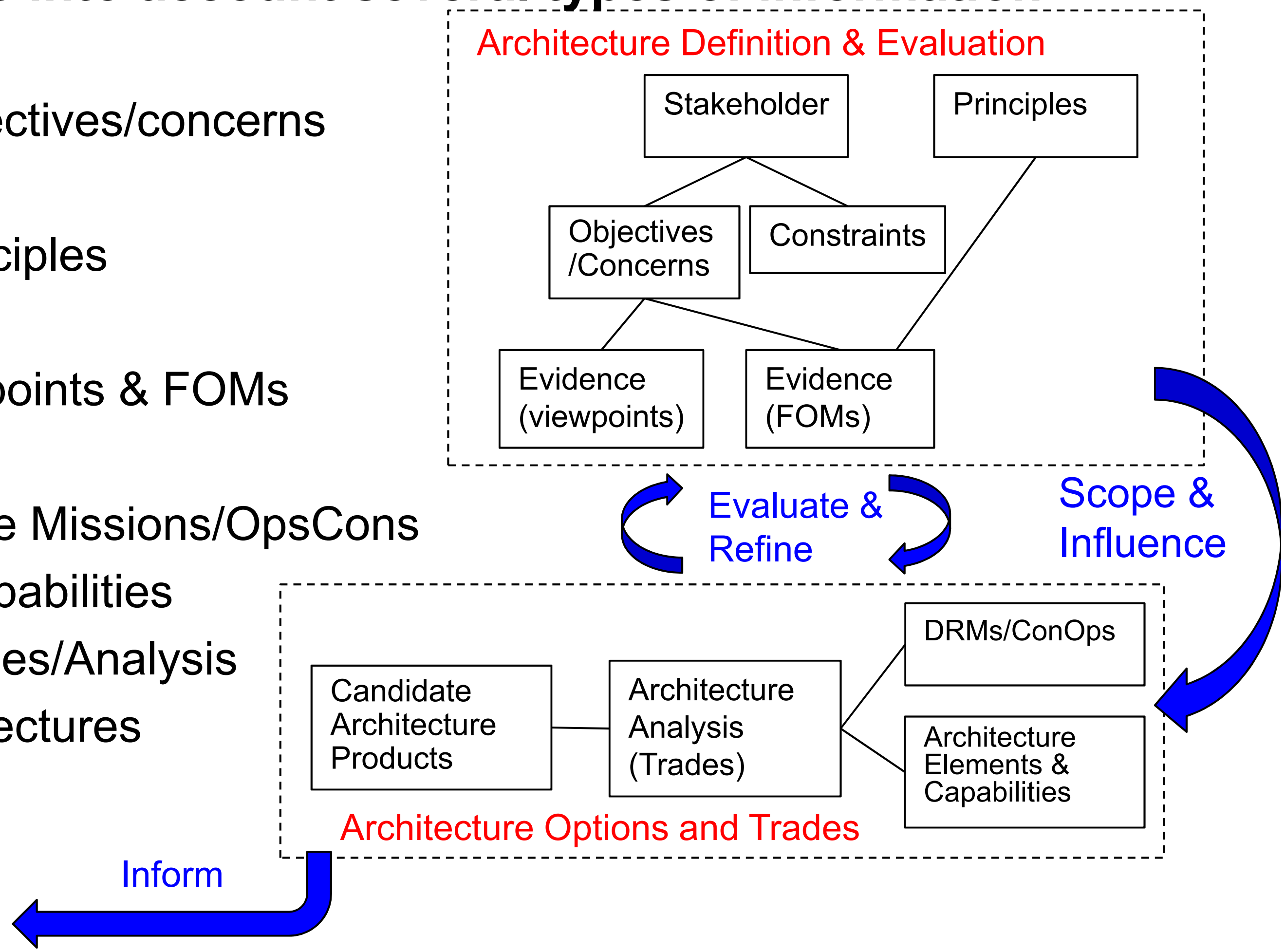


What Architecture Is Not!!

- Architecture is not a broad brush effort confined to early development
  - Dictates what possibilities are allowed, while still remaining faithful to stable concepts selected to fulfill system objectives
- Architecture is not opaque pictures, block diagrams, lists, or other schematic representations of the design
- Architecture is not requirements
  - Architecture provides the rationale for requirements
- Architecture is not fickle, or subject to routine refinement
  - Architecture provides a stabilizing influence through its well-considered form, expectations, rules, and attention to fundamentals

Components of Architecting

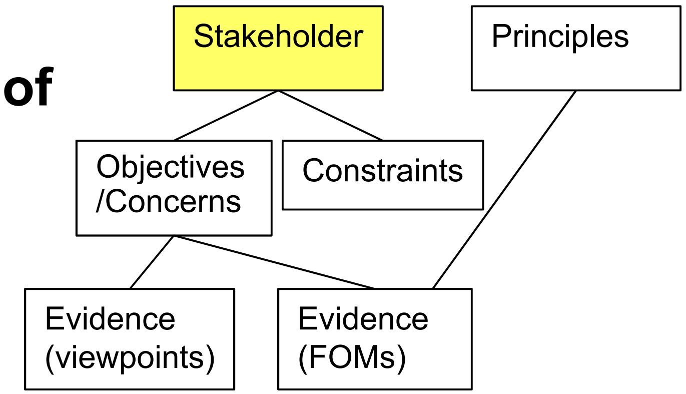
- **Architecture takes into account several types of information**
  - Stakeholders
  - Stakeholder Objectives/concerns
  - Constraints
  - Architecture Principles
  - Figures of Merit
  - Evidence – viewpoints & FOMs
  - Design Reference Missions/OpsCons
  - Elements and capabilities
  - Architecture Trades/Analysis
  - Candidate Architectures
  - Decisions
  - Requirements.



Architecting is the art of balancing these elements (including as they evolve/change) to maximize the stakeholder satisfaction

Stakeholders

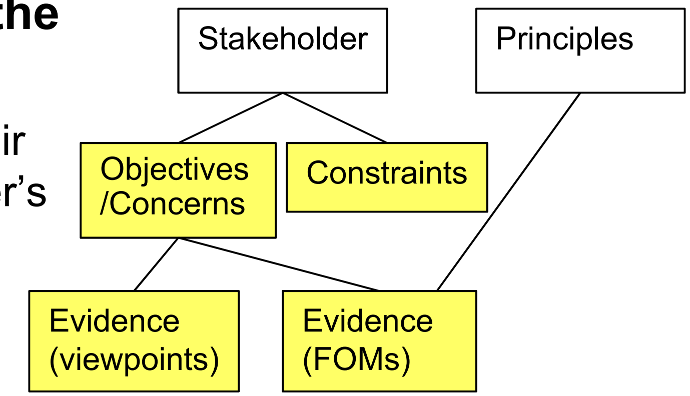
- **Influential people or groups who have something to gain or lose in the selection of architecture options.**



  - Essential for the full complement of stakeholders to be identified and engaged in the architecture process.
  - Influence can be drawn from many sources (legal, financial, advocacy, political, etc.)
  - Not merely titles, groups or organizations, but an actual person that the architect can engage and who is authorized to negotiate for the community they represent.

A complete set of stakeholders will represent widely different communities, all of whom have the potential to significantly impact the success of your program

Stakeholder Objectives/Concerns & Constraints

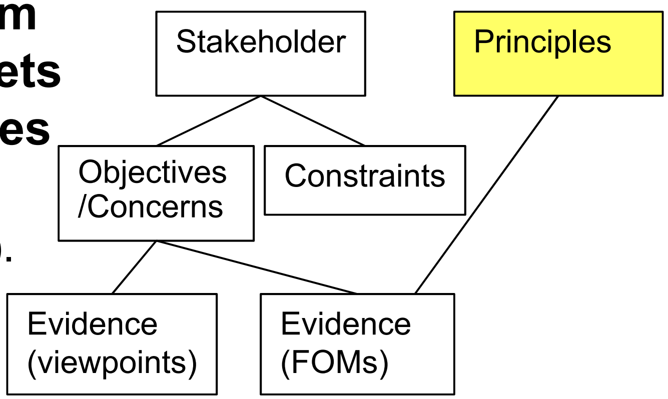


- **Objectives/Concerns are the criteria by which the success of an architecture is measured**
  - Architectures are never better than the quality of their objectives and how well they capture the stakeholder's concerns.
- **Requires a clear definition of:**
  - Stakeholder's Objectives and/or Concerns:
    - Whats: Performance, functionality, quality, cost, reliably…
    - Hows, e.g. how the system comes together, or is operated, or relates to other developments:
  - Stakeholder-owned Constraints that restrict the valid architecture solutions
  - An agreed-upon set of actionable and objective Evidence that will be used to show the stakeholder how the architecture addresses their inputs
    - **Viewpoints: budget, mission timeline, partnership allocations**
    - **Figures of Merit (FOMs): affordability (DDT&E, recurring), sustainability (ability to engage public, science return, etc.)**
- **Architects job is to help stakeholders express all of these concretely.**

Stakeholder inputs are hard to gather, and will be diverse, conflicting and dynamic. Balance and compromise are essential to success.

Architecture Principles

- **The fundamental rules and guidelines that inform and support the way in which an organization sets about fulfilling its business & technical objectives**
  - Fundamental concepts used to help make decisions on key trades (can have a big impact on architecture).
  - Often distilled from previous experiences
    - Success ← Wisdom ← Experience ← Mistakes
  - Examples: TLYF-FLYT, Maintain adequate margin, routine cadence of missions, Inspire through numerous "firsts", leverage commonality, etc.



- **A good principle is… what you really care about**
  - Well substantiated
  - Clear about applicability and application,
  - Relatively easy to explain, and
  - Stable (slow to change)
- **Principles foster order, structure, elegance**
  - Commitment to fundamentals
  - Basis for architectural integrity

A good principle is worth fighting for, and the last thing you're willing to give up.

Example Apollo Architectural Principle

"I believe this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth" (5/25/61), while this was clearly the prime objective, from a prime stakeholder, from this statement came many of the principles that guided Apollo

- Attend to the economic, political, and the social interfaces with key stakeholders
- Plan well and make decisions rapidly
- Establish and maintain an effective communication system across the program
- To minimize spacecraft complexity, weight, cost, and schedule, the level of redundancy should depend on the factors of criticality, flight experience, and technology maturity
- Share responsibility for achieving reliability between NASA and contractors. Infuse reliability into the design early in the life cycle
- Focus on the nominal and work a limited, smartly chosen set of contingencies based on probabilities of occurrence
- Test to failure to understand margins

Unofficial CxP Architectural Principles

- "Give overriding priority to crew safety, rather than trade safety against other performance criteria, such as low cost and reusability"
- Meet Loss of Crew (LOC) and Loss of Mission (LOM) performance, based on analysis supported by testing
- Launch and landing crew survival must be robust
- Human exploration starts beyond LEO and the moon is a key stepping stone
- Establish and maintain adequate performance margins across all mission phases (Note: all margins are not equal)
- Separate cargo from crew and provide significantly more payload than Apollo
- Utilize heavy lift launch vehicles to maximize long term reliability by minimizing the number of needed launches
- Minimize gap between end of Shuttle program and new system
- Maintain and grow existing national aerospace supplier base
- Minimize lifecycle costs for sustainability based on appropriate, stable funding

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  - Evidence – viewpoints & FOMs

  - Design Reference Missions/OpsCons
  - Elements and capabilities
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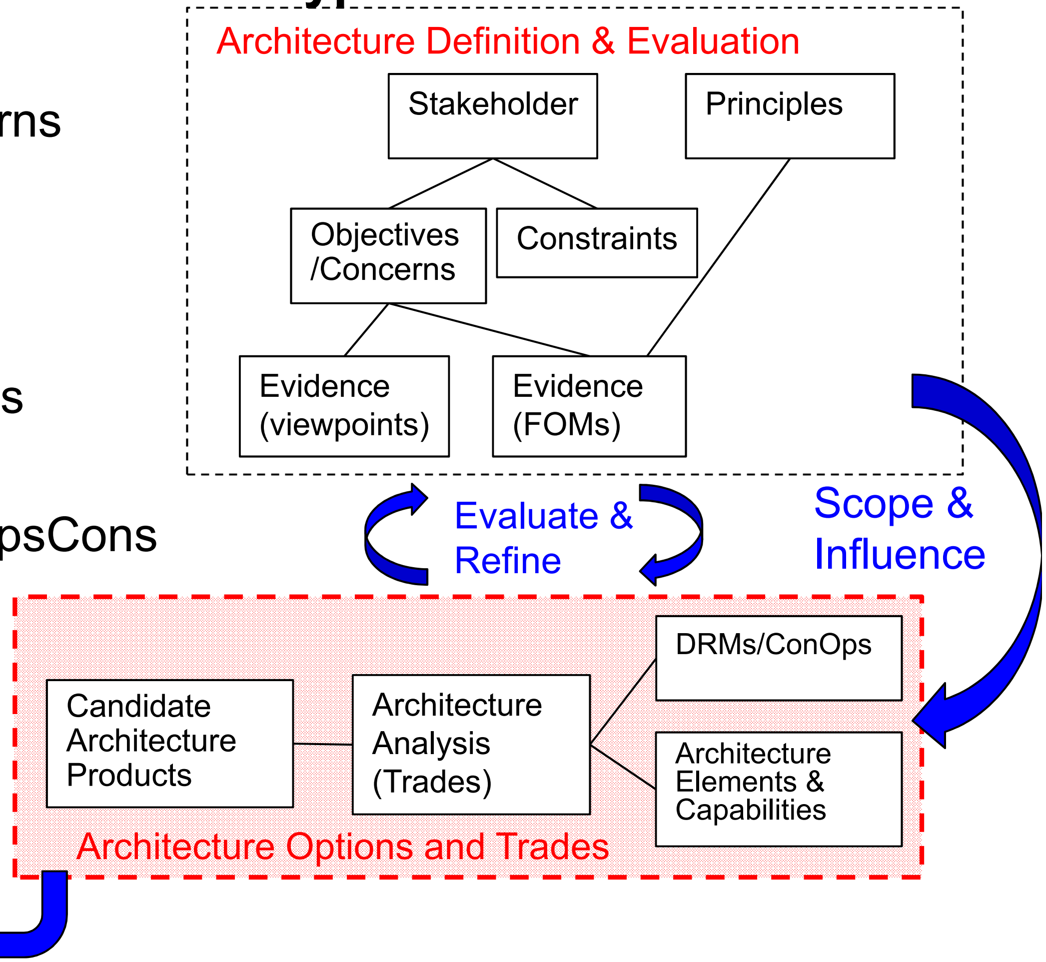
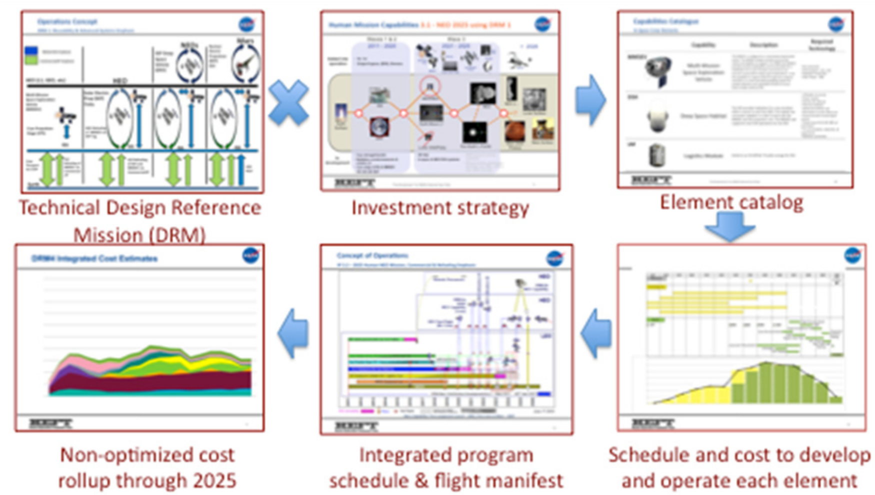
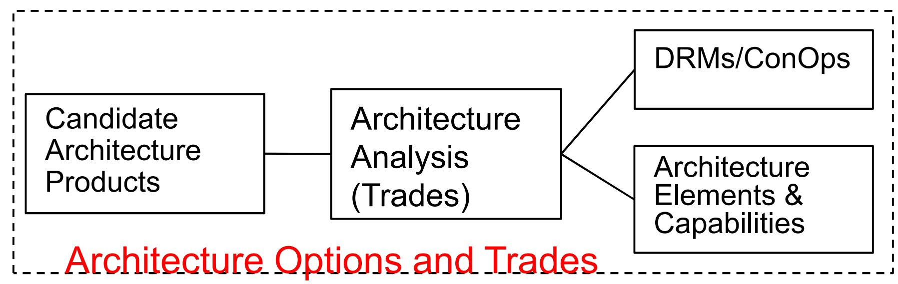


Architecture Options and Trades

- Products and processes vary for different projects & architecture levels.
  - Cx Architecture provided by ESAS
  - HEFT started in 2010 to define a new HSF architecture.
- DRM/OpsCons - define the missions, cross-system capabilities (including new technologies), and how you expect to operate in order to meet the objectives & constraints.
- Elements - parameters and capabilities needed to support the DRMs
- Architecture analysis – integrates the results, aligns with constraints, and generates:
  - products representing the candidate architecture

HEFT Analysis Engine





Essential to evaluate the impact of various candidate architectures on Stake-holder concerns/objectives, constraints, and architecture principles – measured by FOMs

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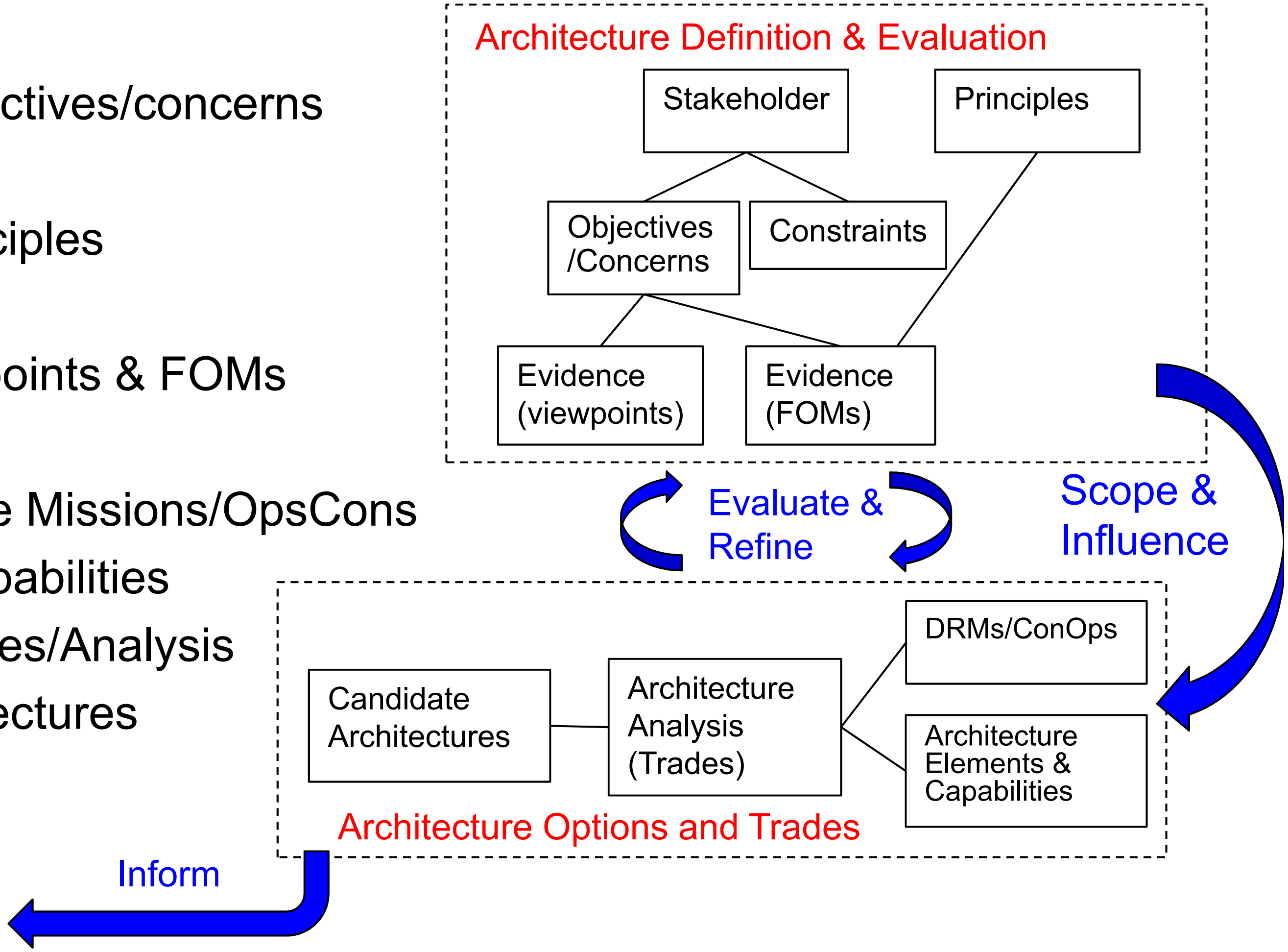


Architecting is the art of balancing these elements (including as they evolve/change) to maximize the stakeholder satisfaction. Adherence of the design to the architecture must be continually maintained.

CxP Architecture

- **ESAS was the architectural foundation of CxP**
- **Unfortunately, ESAS was not robust to funding shortfalls or changes in stakeholder priorities**
- **Budgets**
  - Cx optimized for full lifecycle costs, but NASA budgeting is done annually.
  - The full budget never materialized and was insufficient to maintain the integrity of the ESAS architecture - resulted in schedule delays, de-scopes, etc.
  - Ultimately, the ESAS architecture was found to not meet stakeholder needs
- **Stakeholder priorities**
  - Election of 2008 significantly changed stakeholders and their priorities
    - Commercial cargo and crew to ISS
    - Key stakeholders didn't find the Moon compelling and were interested in other priorities
- **HEFT was created to rearchitect HSF based on new stakeholder concerns/requirements.**

All of these issues are still on the table. We need to clearly understand stakeholder objectives/concerns and use them to drive the architecture (not be driven by them)

Rearchitecting HSF

- Planning and program implementation teams established following the FY11 President's budget request which directed major changes in HSF direction and implementation.
- Human Exploration Framework Team (HEFT) stood up to develop a new human spaceflight architecture responsive to new stakeholder priorities
  - Engage stakeholders and solicit their concerns, objectives, and constraints.
  - Identify key NASA objectives and HSF guiding principles
  - Identify key figures of merit
  - Develop and evaluate viable architecture candidates, around a broad trade space of program strategies and technical approaches
  - Inform near-tem strategy and budget decisions
  - Provide analysis continuity over time.
- Initial work done by HEFT concluded in 2010, work will be continued by human exploration architecture team in 2011 and beyond.

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

Human Spaceflight Exploration Stakeholders & representative objectives, concerns and constraints

- **White House**
  - Define specific and achievable milestones
  - Allow astronauts to reach space sooner & more often, travel farther & faster for less cost.
- **NASA administration**
  - Development of commercial ability to deliver cargo and crew to LEO/ISS
- **Congressional Authorization**
  - Heavy lift launch vehicle , MPCV for beyond LEO
- **Public**
- **Science Community**
- **NASA Centers**
- **Commercial/Industry Partners**
- **International Partners**
- **Others**

Need to refine/analyze stakeholder inputs and define robust HSF architecture that addresses conflicting inputs

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"

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***

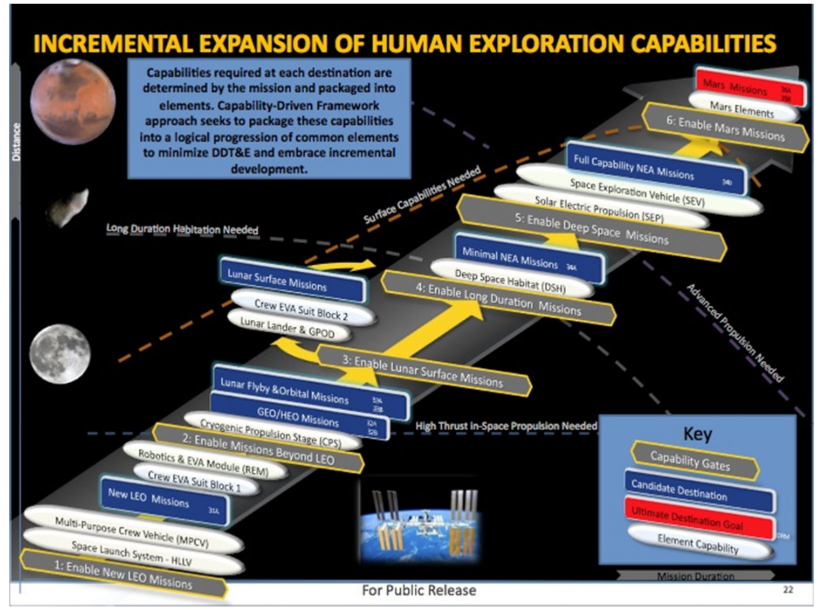
W : X : Y : Z – Filtered to control number of cases

- 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

Capability-Driven Framework Overview

♦ **Objective: Facilitate 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, and the promise of greater cost effectiveness and sustainability.

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 assure key contingency and abort scenarios are addressed
- **Establish key driving requirements for common elements**
  - Establish technology needs for each element
- **Identify key technology drivers/needs and phasing by looking across all of the DRMs (both push and pull)**
- **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

Scenarios and costing not completed, additional work required to develop a HSF architecture using the capability-driven framework

Key HEFT Architecture Findings

- **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
- **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
- **Achieving reduction in development, operations, and infrastructure costs is critical to success of future HSF architecture**
- **Partnerships are imperative to enabling our exploration goals.**
- **Compelling, overarching mission goals are necessary to justify high-risk human spaceflight exploration beyond LEO.**

What's next?

- **On-going human space exploration architecture team is being used to complete the architecture work started by HEFT**
- **Will conduct and validate key trades using HEFT tools and analysis engine**
  - Starting with building blocks of SLS, and MPCV and building outward using the Capability Driven Framework
  - Develop scenarios/strategies
- **Will continue to address key stakeholders, principles and FOMS**
  - Clarify stakeholders and concerns
  - Address affordability
  - Explore significant partnership opportunities (commercial and IP)
  - Technology needs and priorities

Conclusions

- For architectures to be successful they need to be constructed with and for sustained stakeholder engagement, understanding and support
- There are many and sometimes conflicting architectural drivers for human spaceflight systems but the primary ones are crew safety, performance and resources (budget/schedule)
- Good architecting is more art than science and does not occur without strong support and commitment from the top
- NASA is very good at engineering, but its programs, human and robotic, need sound, well crafted architectures to assure designs and implementation can and will meet stakeholder needs and achieve sustainable long term success


Questions?
www.nasa.gov