Agenda

- Summary / Key Findings
  Steve Altemus

- DRM Review
  Kent Joosten

- Technology Feed Forward and Gaps
  Chris Culbert

- Launch Vehicle
  Angelia Walker

- Crewed Spacecraft
  Steve Labbe

- Cost Study History
  Rita Willcoxon

- Phase I Summary & Conclusions
  Steve Altemus

- Transition to Phase II
  John Olson
Summary of Phase I

- Developed an investment portfolio that strikes a balance of new developments, technology, and operational programs with an eye towards a new way of exploring.
- Created a point of departure DRM that is flexible and can evolve over time to support multiple destinations with the identified systems.
- Identified a minimum subset of elements needed to conduct earlier beyond LEO missions.
- Infused key technology developments that should begin in earnest and identified gaps which should help inform additional technology prioritization over and above the NEO focused DRM.
- Costed the DRM using traditional costing methodologies.
- Determined alternative development options are required to address the cost and schedule shortfalls.
Recommendations

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

- Development Path
  - 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
  - Leverage civil servant workforce to do leading edge development work

- Alternative Development Approaches
  - Take advantage of existing resources to initiate the development and help reduce upfront costs
    - Launch Vehicle Core Stage
    - Multi-Mission Space Exploration Vehicle
    - In Space Propulsion
      - Solar Electric Propulsion Freighter
      - Cryo Propulsion Stage / Upper Stage
    - Deep Space Habitation

- Launch Vehicle
  - Initiate development of a evolvable moderate SSP-derived in-line HLV 100 t class in FY2011

- Crewed Spacecraft
  - Develop an Orion-derived direct return vehicle and in-house developed Multi-Mission Space Exploration Vehicle
  - Do not develop a dedicated ISS ERV
  - Further trade CTV functionality and HLLV crew rating costs against Commercial Crew utilization for exploration

- Ground ops processing and launch infrastructure
  - Initiate ground ops system development consistent with spacecraft and launch vehicle development

- Technology Development
  - Focus technology development on near term exploration goals (NEO by 2025)
  - Revise investments in FTD, XPRM, HLPT, ETDD, and HRP and others to align with the advanced systems capabilities identified in the framework
  - Re-phase technology investments to support the defined human exploration strategy, mission and architecture
DRM Introduction

◆ Previous HEFT DRM analyses helped draw conclusions regarding system requirements for the NEO missions examined
  • In-space propulsion technology advances and high system reusability did not obviate need for higher capacity launcher (excessive number of commercial launches, DRM Set 1)
  • Commercial on-orbit refueling did not obviate need for higher capacity launcher (excessive number of commercial launches, DRM Set 2). Commercial launch rate available for exploration missions significantly limited by costs of infrastructure expansion.

◆ “Hybrid” DRM analysis (“DRM 4”) presented to Steering Council 17 August. Additional analysis performed to assess:
  • “Balanced” HLLV/Commercial launchers
  • Impacts of “moderate” HLLV capacity
  • Impacts of deletion of solar electric propulsion (SEP) technology/system
  • Qualitative assessment of SEP
Concept of Operations (NEO Crewed Missions, 100 t HLLV)
## In-Space Mission Elements for DRM 4

<table>
<thead>
<tr>
<th>Mission Element</th>
<th>CTV-ERV</th>
<th>MMSEV</th>
<th>DSH</th>
<th>Kick Stage</th>
<th>CPS</th>
<th>SEP</th>
<th>EPM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mass (kg)</strong></td>
<td>13,500</td>
<td>6,700</td>
<td>23,600</td>
<td>6,300</td>
<td>12,600</td>
<td>10,600</td>
<td>2,900</td>
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<tr>
<td>Diameter (m)</td>
<td>5.2</td>
<td>4.5</td>
<td>4.57</td>
<td>1.9</td>
<td>7.5</td>
<td>5.75</td>
<td>5.75</td>
</tr>
<tr>
<td>Length (m)</td>
<td>4.2</td>
<td>6.8</td>
<td>7.7*</td>
<td>3</td>
<td>12.3</td>
<td>9</td>
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<tr>
<td>Pressurized Vol. (m³)</td>
<td>18.4</td>
<td>12</td>
<td>115</td>
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<td>n/a</td>
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</table>

**NOTES:**
- Elements Not To Scale
- *Habitat length with adapters: 9.8 m
- **Inert mass shown for CPS, SEP and EPM
Systems Extensibility/Evolution for Other Destinations

<table>
<thead>
<tr>
<th>HEO/GEO</th>
<th>NEO</th>
<th>Lunar Orbit</th>
<th>Lunar Surface*</th>
<th>Phobos/Deimos</th>
<th>Mars*</th>
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</thead>
<tbody>
<tr>
<td>CTV</td>
<td>CTV</td>
<td>CTV+</td>
<td>CTV+</td>
<td>CTV+</td>
<td>CTV+</td>
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<tr>
<td>HLLV x1</td>
<td>HLLV x1</td>
<td>HLLV x2</td>
<td>HLLV +xN</td>
<td>HLLV +xN</td>
<td></td>
</tr>
<tr>
<td>MMSEV</td>
<td>MMSEV</td>
<td></td>
<td>Rover Cab, Ascent Cab?</td>
<td>MMSEV</td>
<td></td>
</tr>
<tr>
<td>CPS</td>
<td>CPS</td>
<td>CPSx2</td>
<td>CPSxN</td>
<td>CPSxN</td>
<td></td>
</tr>
<tr>
<td>Transit HAB</td>
<td></td>
<td>Surface Hab</td>
<td>Transit Hab+</td>
<td>Surface Hab, Transit Hab+</td>
<td></td>
</tr>
<tr>
<td>SEP</td>
<td></td>
<td>SEP+, or NEP</td>
<td>NEP</td>
<td></td>
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</tr>
</tbody>
</table>

* Additional systems required for these destinations
Campaign Profile

DRM 4: 100 t HLLV w/ Commercial Crew

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
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<tbody>
<tr>
<td>2011</td>
<td>MMSEV</td>
</tr>
<tr>
<td>2012</td>
<td>CTV</td>
</tr>
<tr>
<td>2013</td>
<td>SEP</td>
</tr>
<tr>
<td>2014</td>
<td>CPS</td>
</tr>
<tr>
<td>2015</td>
<td>DSH</td>
</tr>
<tr>
<td>2016</td>
<td>HLLV</td>
</tr>
<tr>
<td>2017</td>
<td></td>
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<tr>
<td>2018</td>
<td></td>
</tr>
<tr>
<td>2019</td>
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<td>2028</td>
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<td>2029</td>
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</tr>
<tr>
<td>2030</td>
<td></td>
</tr>
<tr>
<td>2031</td>
<td></td>
</tr>
</tbody>
</table>

- Indicates flight to LEO
- NEO Mission ConOps

NEO

E-M L1

HEO (No Crew)

HEO

E-M L1

NEO

CTV Test Flight

CTV Test at ISS w/ Commercial Crew

High-Speed Elliptical Reentry Test

Inflatable Demo

L1 mission w/~55 t of Oppo-lunity Payloads

Indicates flight to LEO

Pre-Decisional: For NASA Internal Use Only
Integrated Cost Estimates

DRM 4: 100 t HLLV w/ Commercial Crew & CTV-E Prime to Representative NEO
Introduction

- Previous HEFT DRM analyses helped draw conclusions regarding system requirements for the NEO missions examined
  - In-space propulsion technology advances and high system reusability did not obviate need for higher capacity launcher (excessive number of commercial launches, DRM Set 1)
  - Commercial on-orbit refueling did not obviate need for higher capacity launcher (excessive number of commercial launches, DRM Set 2). Commercial launch rate available for exploration missions significantly limited by costs of infrastructure expansion.

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  - Impacts of “moderate” HLLV capacity
  - Impacts of deletion of solar electric propulsion (SEP) technology/system
  - Qualitative assessment of SEP
Concept of Operations (NEO Crewed Missions, 100 t HLLV)

Results in CxP-like “1.5 launch” architecture along with associated issues

Low-boiloff CPS may not be required
DRM Hybrid: Chemical/SEP 100 t HLLV

Mass Allocation

Elements are not to scale
Elephant stands and element adapters will use unallocated mass
Concept of Operations (NEO Crewed Missions, 70 t HLLV)

L1 and beyond ops same as 100t option

Both stacks leave LEO at the same time

Could Potentially Replace One HLLV Launch
DRM Hybrid: Chemical/SEP 70 t HLLV

Mass Allocation

70 t HLLV

HLLV 2 has negative unallocated mass (-1.15t)

Elements are not to scale
Elephant stands and element adapters will use unallocated mass
## Comparison of Crew Launches

### Crew Launches

<table>
<thead>
<tr>
<th>Mass (t)</th>
<th>PjMR</th>
<th>Adapter</th>
<th>Unallocated</th>
<th>CTV-AE</th>
<th>MSEV</th>
<th>Kick Stage</th>
<th>CPS Prop</th>
<th>CPS Inert</th>
</tr>
</thead>
<tbody>
<tr>
<td>70t</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>75t</td>
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</tr>
<tr>
<td>85t</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100t</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
Concept of Operations
100 t HLLV – All Chemical In-Space Propulsion
## Risk Assessment Comparisons

<table>
<thead>
<tr>
<th>Area</th>
<th>SEP (100 t)</th>
<th>SEP (70 t)</th>
<th>Chem (100 t)</th>
<th>Chem (70 t)</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Unique Elements</td>
<td>7</td>
<td>7</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Total # of Elements</td>
<td>9</td>
<td>11</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td># Launches (HLLV)</td>
<td>3</td>
<td>5</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td># AR&amp;Ds</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>12</td>
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<tr>
<td># of Undocks</td>
<td>10</td>
<td>14</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td># Propellant Transfers</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>Chemical Prop Burns</td>
<td>7</td>
<td>9</td>
<td>14</td>
<td>19</td>
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<tr>
<td>Mission Lifetime</td>
<td>841 Days</td>
<td>930 Days</td>
<td>821 Days</td>
<td>1091 Days</td>
</tr>
<tr>
<td>Crew Time</td>
<td>394 Days</td>
<td>394 Days</td>
<td>371 Days</td>
<td>371 Days</td>
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<tr>
<td>IMLEO Mass (t)</td>
<td>254</td>
<td>262</td>
<td>537</td>
<td>591</td>
</tr>
<tr>
<td>NEO Arrival Stack Mass (t)</td>
<td>57</td>
<td>57</td>
<td>109</td>
<td>121</td>
</tr>
</tbody>
</table>
**Solar Electric Propulsion**

**Benefits & Highlights**

- "Gear" Ratio for SEP missions significantly better than chemical stages
- Mission flexibility – departure/return windows
- SEP affords more "graceful", less catastrophic propulsion system failure modes
- Substantial power available at destination and during coast periods
- Reusable architecture potential
**DRM Assessment Summary**

**Observations**

- **Balanced HLLV/Commercial launchers** – Reasonable balance of commercial and government launches achievable through robotic precursors, flagships and full-scale demos
- **Impacts of moderate HLLV capacity** – 100 t class launcher allows single launch of systems needed for crewed flight to HEO, reduces launches needed for NEO by ~50%
- **Impacts of solar electric propulsion** – SEP architecture reduces by half the mass to LEO and decreases sensitivity to mass growth by ~60%
- **Qualitative assessment of SEP** – offers unique mission flexibility, reduction in risk and extensibility to more ambitious exploration missions

**Top Priorities Looking Forward**

- Perform functionality trades amongst architecture elements, particularly CTV/MMSEV/Hab
- Understand CTV functionality and relationship to Commercial Crew through operational concept analysis including contingencies
- Trade reusability of key transportation/habitation elements
- Perform campaign analysis – other missions of interest and how well DRM elements and technologies play (e.g., CPS evolution to HLLV upper stage, or vice versa)
- Perform bottoms-up element design, layout and packaging for SEP, MMSEV and Hab including radiation protection strategies
Technology Feed Forward and Gaps

Steering Council
September 2, 2010
Summary

◆ Human missions to NEOs require a focused technology investment portfolio
  • The agency is already investing in every area needed to enable this class of mission, but emphasis must be put in the right areas
  • Latest DRM analysis adds Solar Electric Propulsion to other areas of early investment emphasis

◆ As definition of the mission profile matures and our understanding of the deep space environment improves, additional technology needs may be identified (e.g. radiation protection for hardware)

◆ Core improvements in the way NASA has always done business are needed in areas such as logistics management, hardware supportability, software development, and mission operations with limited ground support. While these improvements may not be directly technology related, they are critical to implementing the defined DRM.
## Technology Progress towards other Destinations

<table>
<thead>
<tr>
<th>Technology Area</th>
<th>HEFT DRM 4</th>
<th>DRM 4</th>
<th>Other Crew Destination</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Near-Earth Objects</td>
<td>EM-L1 / Lunar Orbit</td>
<td>Mars Orbit</td>
</tr>
<tr>
<td><strong>Propulsion Technologies</strong></td>
<td>~</td>
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<td>~</td>
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<tr>
<td>Heavy Lift Propulsion Technology</td>
<td>~</td>
<td>~</td>
<td>~</td>
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<tr>
<td>In-Space Chemical Propulsion</td>
<td>~</td>
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<tr>
<td>High Efficiency In-Space Propulsion</td>
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</tr>
<tr>
<td>Cryogenic Fluid Management (e.g. zero boil off)</td>
<td>~</td>
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<tr>
<td>Cryogenic Fluid Transfer</td>
<td>☑</td>
<td>☑</td>
<td>☑</td>
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<tr>
<td><strong>Technologies for Human Health &amp; Habitation</strong></td>
<td>~</td>
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<td>~</td>
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<tr>
<td>Life Support and Habitation</td>
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<tr>
<td>Exploration Medical Capability</td>
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<td>Space Radiation Protection</td>
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<td>Human Health and Countermeasures</td>
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<td>Behavioral Health and Performance</td>
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<tr>
<td>Space Human Factors &amp; Habitability</td>
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</table>

**Symbol Legend**
- Technology development complete
- Additional tech. dev. required
- Technology is applicable to this destination
- Not Applicable
- Need more data
## Technology Progress towards other Destinations (cont’d)

<table>
<thead>
<tr>
<th>HEFT DRM 4</th>
<th>DRM 4</th>
<th>Other Crew Destination</th>
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<tbody>
<tr>
<td>Technology Area</td>
<td>Near-Earth Objects</td>
<td>EM-L1 / Lunar Orbit</td>
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<tr>
<td><strong>Power Technologies</strong></td>
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<td>High Efficiency Space Power Storage</td>
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<td>High Power Space Electrical Pwr Generation</td>
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<td><strong>Entry Descent &amp; Landing Technologies</strong></td>
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<tr>
<td>High Speed Earth re-entry (&gt; 11 km/s)</td>
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<tr>
<td>Aeroshell &amp; Aerocapture</td>
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<td>Precision Landing</td>
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<td><strong>EVA &amp; Robotics Technologies</strong></td>
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<tr>
<td>Surface Mobility</td>
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### Symbols

- **Technology development complete**
- **Additional tech. dev. required**
- **Technology not developed**
- **Technology Required for this destination**
- **Technology is applicable to this destination**
- **Not Applicable**
- **Need more data**
## Technology Progress towards other Destinations (cont’d)

<table>
<thead>
<tr>
<th>HEFT DRM 4</th>
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<th>Other Crew Destination</th>
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<tr>
<td><strong>Technology Area</strong></td>
<td>Near-Earth Objects</td>
<td>EM-L1 / Lunar Orbit</td>
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<tr>
<td>Software &amp; Electronic Technologies</td>
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<tr>
<td>Autonomous Systems</td>
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<td>☀️</td>
</tr>
<tr>
<td>Advanced Avionics/Software</td>
<td>☀️</td>
<td>☀️</td>
</tr>
<tr>
<td>Advanced Nav/Comm</td>
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<td>☀️</td>
</tr>
<tr>
<td>Other Technologies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advanced Thermal Control &amp; Protection Systems</td>
<td>~</td>
<td>~</td>
</tr>
<tr>
<td>Automated Rendezvous and Docking</td>
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<tr>
<td>Supportability &amp; Logistics</td>
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<tr>
<td>Lightweight Materials &amp; Structures</td>
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<tr>
<td>Environment Mitigation (e.g. Dust)</td>
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<tr>
<td>In-Situ Resource Utilization</td>
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### Symbol Legend
- ☀️ Technology development complete
- ☯️ Additional tech. dev. required
- ☀️ Technology not developed
- ~ Technology Required for this destination
- ☐ Technology is applicable to this destination
- ☐ Not Applicable
- ☐ Need more data
Demonstrate Spacecraft buses with increasing power & decreasing specific mass to enable advanced electric and plasma propulsion spacecraft that will decrease trip times to Mars and beyond. Each demonstration spacecraft bus has immediate application & payoff to other mission objectives. NEP power system technologies are extensible to surface power.
Key Observations

◆ No wasted technology investments
  • Every technology needed to enable a human NEO mission also is needed for other human destinations

◆ There are technologies needed for other destinations NOT needed for a human NEO mission; technology gaps

◆ Gap technologies that represent unique NASA needs will require the agency to sustain key core competencies for future missions
  • Precision landing
  • Aeroshell/aerocapture
  • Space Nuclear Power
  • ISRU
Launch Vehicle

Steering Council
September 2, 2010
Launch Vehicle

♦ Issue
  • An HLV is central to any robust human exploration program
  • Delaying a decision on HLV configuration and requirements to 2015 limits NASA’s options and hampers planning
  • There is no benefit to delaying work on the HLV, no technology needed for capability development
    - Industry RFI Response

♦ Risk if unresolved
  • NASA will lose an opportunity to build from the existing flight-proven systems
  • Losing the capability to build an SSP-derived HLV will require the development of new manufacturing, processing, and launch infrastructure at additional cost and schedule risk.

♦ Recommendation
  • Accelerate the HLV decision – moderate HLV
  • Initiate a Shuttle-derived inline HLV Program beginning in FY2011
    - Initial 90 – 100 t range
    - Defer upper stage to Block II

Note: An RP-based HLV (100-120 t) and a replacement for the (Russian) RD-180 is higher cost to NASA and therefore requires supplemental funding from DoD to offset increased costs

<table>
<thead>
<tr>
<th>Key Trade</th>
<th>27.5' Inline</th>
<th>33' Inline</th>
<th>33' RP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry</td>
<td>Shuttle ET diameter</td>
<td>Saturn V heritage 33’ diameter</td>
<td>Saturn V heritage 33’ diameter</td>
</tr>
<tr>
<td>Booster</td>
<td>4 or 5 segment PBAN booster, evolvable to HTPB</td>
<td>5 segment PBAN booster, evolvable to HTPB</td>
<td>1.25 m lbf RP engines on boosters</td>
</tr>
<tr>
<td>Core Stage Engine</td>
<td>SSME (RS-25D) transitioning to RS-25E</td>
<td>RS-68B evolvable to RS-68B E/O</td>
<td>1.25 m lbf thrust class LOX/RP-1 engine</td>
</tr>
<tr>
<td>Upper Stage Engine</td>
<td>RL10A4-3</td>
<td>J-2X</td>
<td>J-2X-285</td>
</tr>
</tbody>
</table>
Moderate HLV Options –70 t to 100 t Comparison

>70 t

Initial Capability > 70 t
4 Segment PBAN SRBs
27.5’ dia Core Stage using 3 RS-25D
No Upper Stage

Payload Trade Options
- 10 m shroud (baseline)
- 8.4 m shroud
- Orion Crew Capable

OR

~100 t

Initial Capability ~100 t
5 Segment PBAN SRBs
27.5’ dia Core Stage using 5 RS-25D
No Upper Stage

US Engine Trade Options
- RS-25E
- J-2X
- NGE (RL10 replacement)

Evolves to

>130 t

Ultimate Capability >130 t
5 Segment HTPB Composite SRBs
27.5’ dia Core Stage using RS-25E
Upper Stage evolved from CPS

5 seg PBAN SRB to Composite HTPB SRBs
Evolution Options

◆ **4/3 (70 t) Vehicle Evolution**
  - 76 t with 4/3 vehicle in cargo configuration
  - 85 t capability with 4/3 vehicle and a RS-25 D Upper Stage
  - ~105 t capability with 4/3 vehicle, US, and HPTB/Composite case SRB’s
  - Performance analysts' recommendation
    - 1st stage under-thrusted for super heavy lift
    - Add another pair of 4 segment boosters

◆ **5/5 (100 t) Vehicle Evolution**
  - 101 t with 5/5 vehicle in cargo configuration
  - 127 t with RS-25 US
  - >140 t with RS-25 US and HPTB/composite case SRB’s

*Starting with 3 engine core and 4 segment motors requires both core and motor evolution to achieve > 130 t*
# Cost Concept Comparison of Major Discriminators

Cost through FY17 - $B

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<tr>
<th></th>
<th>100 t</th>
<th>70 t</th>
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<tr>
<td>ATP to First Flight</td>
<td>7.5 years</td>
<td>7 years</td>
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<tr>
<td>Core Stage (DDT&amp;E + Production)</td>
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<td>4.8</td>
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<tr>
<td>RS-25D Sustaining</td>
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<td>0.8</td>
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<tr>
<td>RS-25E (DDT&amp;E + Production)</td>
<td>0.7</td>
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<tr>
<td>4 Segment SRB Sustaining</td>
<td>0</td>
<td>2.8</td>
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<tr>
<td>5 Segment SRB (DDT&amp;E + Production)</td>
<td>3.0</td>
<td>0</td>
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<tr>
<td>First Flight w/RS-25E’s</td>
<td>FY23</td>
<td>FY25</td>
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<tr>
<td><strong>Total Cost thru FY17</strong>*</td>
<td><strong>11.6</strong></td>
<td><strong>11.0</strong></td>
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*Costs do not include reserves & FTEs, and do not fully fund to the first test flight*
Moderate HLV Vehicle Discriminators

70 t vs. 100 t

**70 t**

- 4 Segment PBAN SRBs
- 27.5’ dia Core Stage using 3 RS-25D
- No Upper Stage

- RS-25E development may be deferred
- 5 flights with 15 RS 25-D units
- NEO mission flight rate and schedule determines production limits
  - 15 engines per NEO mission (DRM 4)
  - Production rates of 20/yr achievable
- 4 segment motors (RSRM)
  - Obsolescence issues (asbestos) may need to be addressed – possible delta qual of 1-5 additional motors
  - Would require new avionics (could use RSRMV avionics)
- ATP to first-flight – 6 years

**100 t**

- 5 Segment PBAN SRBs
- 27.5’ dia Core Stage using 5 RS-25D
- No Upper Stage

- RS-25E development required up-front
- 3 flights with 15 RS 25-D units
- NEO mission flight rate and schedule determines production limits
  - 15 engines per NEO mission (DRM 4)
  - Production rates of 20/yr achievable
- 5 segment motors (RSRMV)
  - Obsolescence not an issue; 5 motors planned for qual, may be less
  - Heritage hardware assessed to new environments and loads
  - Parachutes challenges (in work)
  - New avionics suites (in work)
- ATP to first-flight – 6.5 years
- MPS more complex (DDT&E forward work)
  - May lead to more MPTA testing
- Base heating more challenging (DDT&E forward work)
Required Ground Operations Modifications for Any Shuttle-Derived HLV

Current FSS height & MLP flame hole do not support either HLV configuration.

KSC Facility Large Cost Drivers:
• Manifest (flights per year, spacing, etc.) determines KSC Infrastructure
• Flight Hardware Configuration
  • Reusable hardware increases facility footprint
• Ship to Integrate Flight Hardware minimizes KSC facility footprint

Mods required for either HLV Option
• New Tower for high-elevation access
• New ML Base (similar cost to MLP mods) with Tower (driven by rollout stabilization and LV/spacecraft rollout purge requirements)
• VAB platform mods to meet access requirements
• Pad flame deflector mods (based on engine configuration)
• Structural reinforcement driven by tower, vehicle & ML base weight
  • Pad, Pad Slope, Crawler, Crawlerway, VAB, etc.
• Facilities & GSE must be brought into compliance with current construction standards & codes (VAB life safety & fire suppression)
• GHE recovery system may be required (out-years)
Heavy Lift Launch Vehicle (HLLV) Recommendation

◆ **Initiate a 100 t class Shuttle-derived moderate HLLV**
  - Accommodates difficult NEO crewed missions with less risk
  - Defers Upper stage to Block II and evolve US from CPS
  - Utilizes experienced workforce
  - Hardware has demonstrated reliability and performance
  - More payload capability for the investment

◆ **Further Launch Vehicle trades should be completed by HLPT Team at MSFC**

◆ **Perform a trade of the feasibility of Cryogenic Propulsion Stage (CPS) evolution to Upper Stage (HEFT Phase II)**
  - Evolution of the CPS from the current Ares I Upper Stage design is feasible to evolve to an earth departure stage (EDS) with modest CFM requirements
  - CPS design could build on existing elements of Ares I US for early demonstration
  - Extensibility for longer loiter required for CPS is feasible
Crewed Spacecraft - Revised Approach

Steering Council
September 2, 2010
Crewed Spacecraft/ERV – As presented July 13th

◆ Issue
  • HEFT assessments identified a functional requirement for a crewed exploration spacecraft
  • Developing an Orion-derived exploration vehicle
    – Provides a clear exploration spacecraft focus
    – Leverages CxP investment, maintaining Agency momentum, and preserves prime contractor relationship
    – Can yield an ISS ERV via Block development
  • No dedicated ISS ERV in any exploration DRMs
    – ERV development is a sub-optimum detour in the path to an exploration spacecraft
    – ERV development reduces available budget for key systems and tech development by more than $2.0B

◆ Risk if unresolved
  • Pursuing an ISS ERV diverts near term resources that could be better aligned with advancing human (beyond LEO) exploration

◆ Recommendation
  • Switch Focus to develop an Orion-derived exploration spacecraft using a block approach
    – Do not develop a dedicated ISS ERV
  • Development Path
    – Orion-derived direct return vehicle and in-house developed exploration craft
      – Manage the Orion-derived exploration spacecraft to fit the available budget using rigorous design-to-cost targets
      – Implement lean in-house development of the MMSEV
  • Alternative Development Path
    – Orion block 2 vehicle
    – with airlock and robotic elements
Crew Transfer Vehicle Functionality Considerations

- Hybridized DRM-4 utilizes either an Ascent/Entry (CTV-AE) or Entry only (CTV-E)

Propulsion System Reqs.

Extended Quiescent Period

Contingency Abort Support

Crew Support Duration

Ascent Aborts

Entry, Descent & Landing

Pre-Decisional: For NASA Internal Use Only
There are natural capability break points that suggest several CTV options
- Future assessment to refine these is required to fully define CTV functionality

CTV-E: minimal EOM (only) function
- Does not provide support for (on-orbit) contingency abort functions

CTV-AE: provides ascent/entry
- Must include the Ascent Abort (LAS) capability/functionality
- Provides CM/SM crewed support (LEO to HEO / DSV sep thru EDL / Cont. Abort Reqs.)

CTV-E*: entry + (on orbit) contingency abort functions
- CTV-E* is a reduction of system capability from CTV-AE
  - Eliminates the Ascent Abort (LAS) capability/functionality
- Maintain SM functionality to cover crewed support & contingency abort requirements
## Crew Transfer Vehicle (CTV) Options – Capabilities

<table>
<thead>
<tr>
<th>CTV Configuration</th>
<th>CTV-E</th>
<th>CTV-E*</th>
<th>CTV-A/E</th>
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</thead>
<tbody>
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<td>Crew in CTV during ascent?</td>
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<td>Yes</td>
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<tr>
<td>Ascent Abort (Pad to LEO)</td>
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<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>No. of Crew - Delivery of Crew to LEO / Return from beyond LEO</td>
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<tr>
<td>Ascent/On-orbit Crew Support (hrs)</td>
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<td>0 / 216</td>
<td>12+ / 216</td>
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<tr>
<td>Crew Support For EDL &amp; Recovery (hrs)</td>
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<td>40</td>
<td>40</td>
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<td>Quiescent Time (days)</td>
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<td>400</td>
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<td>TBD</td>
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<td>1500+</td>
<td>1500+</td>
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<tr>
<td>Entry Speed for Entry Descent &amp; Landing – EDL (km/s)</td>
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<td>&lt;11.8</td>
<td>&lt;11.8</td>
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<tr>
<td>EDL &amp; Recovery System (water landing)</td>
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<td>Yes</td>
<td>Yes</td>
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<tr>
<td>RCS Control for EDL</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Contingency (In Space) Abort</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
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</table>
Minimum CTV-E capability implies certain conditions

- All beyond LEO missions require CTV-E, MMSEV & CPS + Comm. Crew launch
- LEO to L1 crew support (~4 days) off-loaded to the MMSEV
- No stand alone in-space contingency abort support *(insufficient crew support time)*
  - Requires combination with MMSEV and CPS

Additional implications

- Does not support early beyond LEO mission w/CTV only *(insufficient crew support time, insufficient Delta-V)*
- Places Commercial Crew in Critical Path for exploration missions
- CTV-E is not on path to provide Commercial Crew alternative
Crew Transfer Vehicle (CTV) Recommendation

- **Open the trade on the CTV-E functionality design and development approach**
  - Optimize the CTV-E* performance and functionality allocation for DRM 4
    - Understand CTV capabilities needed through operational concept analysis including contingencies
    - In-depth trades must be performed before CTV capabilities are established
      - Preliminary capability assessment is approximately “Orion (Lunar) – LAS”

- **Therefore, consider the CTV-E* approach as an updated point of departure**
  - Strengthens the on-orbit contingency abort requirements support
  - Preserves an Agency option for Commercial Crew Alternative
  - Would yield “early” beyond LEO flight capability when combined w/HLV & CPS

- **HEFT follow on activity to establish best acquisition/development approach**
  - Stretched development cycles (consistent w/HEFT manifest) results in sub-optimal CTV cost estimates – further exacerbated when combined with existing contract
  - HEFT Phase 2 must address the practical programmatic aspects for CTV-E* development
Cost Study History
Executive Summary

Steering Council
September 2, 2010
Introduction

◆ Created 16 scenarios based on DRM team products
◆ Formed catalog of capabilities
◆ Estimated costs for each capability
  • Used analogies and models for costs
  • Identified technology developments required
  • Used system and technology experts
  • Used estimates from Launch Services Program (LSP) for commercial launches
  • Performed in-family check of similar historical capabilities
◆ Developed schedules with cost phasing
◆ Provided data to Manifest team to create missions
◆ Developed sandcharts
◆ Supported multiple cost reviews
  • Two with HEFT Red team
  • Independent cost consultant
  • SSP and CxP programs and projects
◆ Iterated viable scenarios to fit potential budget bogey
◆ Determined that Strategy 3, DRM 2 had most potential to fit within the budget
**Budget Bogey for HEFT Analysis (June 23, 2010)**

- Based on FY11 President’s Budget, assume OMB budget escalation beyond FY15
- Start with SOMD + ESMD + Space Technology

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<td>ESMD + SOMD + ST {OCT}</td>
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<td>11,096</td>
<td>11,295</td>
<td>11,499</td>
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</table>

- Items removed to arrive at available for HEFT
  - Constellation Closeout, portion of Space Flight Support, ISS, Shuttle, Space Technology

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<tbody>
<tr>
<td>Constellation Closeout (in ESMD)</td>
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<td>600</td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
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<tr>
<td>Part of Space Flight Support - proxy for SCAN, LSP, RPT, SO (in SOMD)</td>
<td>700</td>
<td>700</td>
<td>665</td>
<td>632</td>
<td>600</td>
<td>570</td>
<td>542</td>
<td>515</td>
<td>489</td>
<td>464</td>
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<tr>
<td>Shuttle (in SOMD)</td>
<td>989</td>
<td>86</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
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<td>Space Technology</td>
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<td>1,064</td>
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<td>1,261</td>
<td>1,284</td>
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</table>

- Results in Available Budget for HEFT

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<tbody>
<tr>
<td>2,782</td>
<td>4,497</td>
<td>5,177</td>
<td>5,431</td>
<td>5,526</td>
<td>5,660</td>
<td>5,801</td>
<td>5,943</td>
<td>6,085</td>
<td>6,229</td>
<td></td>
</tr>
</tbody>
</table>

Pre-Decisional: For NASA Internal Use Only
Sandchart History

**DRM 2B**

**Step 1**
Development of all capabilities started in 2011

**Step 2**
Focused on NEO ASAP and staggered developments to fit within available budget

**Step 3 Presented to Bolden**
Developed hybrid DRM2B MMSEV In-house, Delta IV throughout issue drove cost

**Step 4**
Deleted one HEO mission, different balance of HLLV & Delta IV to better fit within available budget

**Step 5**
Used existing contracts for HLLV & CTV-E reduced CCDEV by $2B
# Revised HEFT Budget Bogey Line (August 15)

## “Original” Budget Bogey for HEFT

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<tbody>
<tr>
<td></td>
<td>$2,782</td>
<td>$4,497</td>
<td>$5,177</td>
<td>$5,431</td>
<td>$5,526</td>
<td>$5,660</td>
<td>$5,801</td>
<td>$5,943</td>
<td>$6,085</td>
<td>$6,229</td>
</tr>
</tbody>
</table>

## Proposed adjustments:
- Using existing contracts, $1.8 B for CxP closeout was added back into budget bogey
  - Assumed Pratt & Whitney J2-X is $100K in FY11
  - Boeing Upper Stage close-out costs were included in FY10 Program Termination Liability (PTL)
- Stranded Human Space Flight costs removed in FY11
- Soyuz or commercial crew rides costs removed between FY2016-FY2020
- Cost removed for additional shuttle flight in June 2011

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## “Revised” Budget Bogey for HEFT

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<td>$5,143</td>
<td>$5,285</td>
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DRM 4 Cost Summary

Steering Council
September 2, 2010
Campaign Profile

DRM 4: 100 t HLLV w/ Commercial Crew

Indicates flight to LEO
Integrated Cost Estimates

DRM 4: 100 t HLLV w/ Commercial Crew & CTV-E Prime to Representative NEO

Program Integration
Robotics Precursor
CTV
CPS
MMSEV
DSH
SEP
Commercial Crew Development
Commercial
HLLV
Mission Operations
Ground Operations and Infrastructure Development

$ in Millions

$20,000
$18,000
$16,000
$14,000
$12,000
$10,000
$8,000
$6,000
$4,000
$2,000
$0

Years
2011
2013
2015
2017
2019
2021
2023
2025
2027
2029
2031
### 2011-2018 Cost Estimates

**DRM 4: 100 t HLLV w/ Commercial Crew & CTV-E Prime to Representative NEO**

- Robotic Precursor in 2018
- SEP 30 kWe test flight in 2017
- CPS Flagship in 2017
- Launch HLLV 100 t Test Flight
- Commercial Crew Development Complete

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HEFT
Human Exploration Framework Team

Pre-Decisional: For NASA Internal Use Only
## 2019-2026 Cost Estimates

**DRM 4: 100 t HLLV w/ Commercial Crew & CTV-E Prime to Representative NEO**

- CTV-E flight test to ISS with launch on HLLV and with Crew launching on Commercial Crew in 2019
- Robotic Precursor 2 in 2021
- SEP Full-scale Development Test in 2022 on EELV
- First test flight of CTV-E and CPS in HEO in 2022
- Inflatable Hab LEO demo flight in 2024 on EELV
- CTV-E, CPS, and MMSEV HEO flight with crew launching on commercial crew in 2024
- SEP L-1 flight in 2026

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<th>2021</th>
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### Notes:
- MO: $35 in 2019 due to one-time MO development costs.
- Total Delta for MO: $(1,893) in 2020, $(2,057) in 2021.
### 2027-2031 Cost Estimates

DRM 4: 100 t HLLV w/ Commercial Crew & CTV-E Prime to Representative NEO

- L-1 Mission of CTV-E, CPS, MMSEV with Crew launching on Commercial Crew in 2027
- First crewed mission to a NEO in 2031
  - Sequence of three heavy launches starting in 2029 that position all the hardware and crew in HEO

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Delta: $227 $(72) $519 $1,538 $1,649
Phase I Summary & Conclusions

Steering Council
September 2, 2010
Phase 1 Recommendations

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

◆ Development Path
  • 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
  • Leverage civil servant workforce to do leading edge development work

◆ Alternative Development Approaches
  • Take advantage of existing resources to initiate the development and help reduce upfront costs
    - Launch Vehicle Core Stage
    - Multi-Mission Space Exploration Vehicle
    - Solar Electric Propulsion Freighter
    - Cryo Propulsion Stage/Upper Stage
    - Deep Space Habitat

◆ Launch Vehicle
  • Initiate development of a evolvable moderate SSP-derived in-line HLV 100 t class in FY2011

◆ Crewed Spacecraft
  • Develop an Orion-derived direct return vehicle and in-house developed Multi-Mission Space Exploration Vehicle
  • Do not develop a dedicated ISS ERV
  • Further trade CTV functionality and HLLV crew rating against Commercial Crew utilization for exploration

◆ Ground ops processing and launch infrastructure
  • Initiate ground ops system development consistent with spacecraft and launch vehicle development

◆ Technology Development
  • Focus technology development on near term exploration goals (NEO by 2025)
  • Revise investments in FTD, XPRM, HLPT, ETDD, and HRP and others to align with the advanced systems capabilities identified in the framework
  • Re-phase technology investments to support the defined human exploration strategy, mission and architecture
DRM/Architecture – Key Observations/Recommendations

◆ Observations
  - **Balanced HLLV/Commercial launchers** – Reasonable balance of commercial and government launches achievable through robotic precursors, flagships and full-scale demos
  - **Impacts of moderate HLLV capacity** – 100 t class launcher allows single launch of systems needed for crewed flight to HEO, reduces launches needed for NEO by ~50%
  - **Impacts of solar electric propulsion** – SEP architecture reduces by half the mass to LEO and decreases sensitivity to mass growth by ~60%
  - **Qualitative assessment of SEP** – offers unique mission flexibility, reduction in risk and extensibility to more ambitious exploration missions

◆ Top Priorities Looking Forward
  - Perform functionality trades amongst architecture elements, particularly CTV/MMSEV/Hab
  - Understand CTV functionality and relationship to Commercial Crew through operational concept analysis including contingencies
  - Trade reusability of key transportation/habitation elements
  - Perform campaign analysis – other missions of interest and how well DRM elements and technologies play (e.g., CPS evolution to HLLV upper stage, or vice versa)
  - Perform bottoms-up element design, layout and packaging for SEP, MMSEV and Hab including radiation protection strategies
Observations

• Human missions to NEOs require a **focused** technology investment portfolio
• As definition of the mission profile matures and our understanding of the deep space environment improves, additional technology needs may be identified
• There are technologies needed for other destinations NOT needed for a human NEO mission – i.e., technology gaps
• Gap technologies that represent unique NASA needs will require the agency to sustain key core competencies for future missions

Recommendations

• Focus technology development toward a NEO destination
• Revise investments in FTD, XPRM, HLPT, ETDD, and HRP and others to align with the advanced systems capabilities identified in the framework
• Re-phase technology investments to support the defined human exploration strategy, mission and architecture
Launch Vehicle, Spacecraft, and Ground Operations - Recommendations

◆ **Spacecraft**
  - Develop an Orion-derived direct return vehicle and in-house developed Multi-Mission Space Exploration Vehicle
  - Consider the CTV-E* approach as an updated point of departure
  - Continue the trade on the CTV functionality design and development approach
  - Further trade CTV functionality and HLLV crew rating against Commercial Crew utilization for exploration

◆ **Launch Vehicle**
  - Initiate development of a 100 t class Shuttle-derived moderate HLLV
  - Perform a trade of the feasibility of Cryogenic Propulsion Stage (CPS) evolution to Upper Stage
  - Any further Launch Vehicle trades should be completed by the implementing program organization

◆ **Ground Operations**
  - Initiate ground ops system development consistent with spacecraft and launch vehicle development
  - Initiate trades associate with major infrastructure cost drivers
Significant Integrated Trade Remaining

◆ How does USG ascent capability via CTV and HLV compare to Commercially provided ascent capability for exploration
  • Several Key Factors need to be evaluated
    – Performance, operational complexity, affordability, schedule, stakeholder values, political landscape, Agency risk posture, HSF capabilities, etc.

◆ Recommend Steering Council provide a relative weighting of the relevant FOMs
  • HEFT 2 can develop the decision package for Steering Council/Agency review

◆ USG Human Rated Ascent Capability
  • Single launch decreases LOM
  • Single launch to HEO mitigates on orbit loiter and boil-off requirement
  • Mission complexity reduced with no rendezvous and dock in LEO
  • Single launch reduces GO launch infrastructure to a single launch capability
  • Single Launch to HEO mitigates launch window constraints
Affordability - the most significant challenge moving forward

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

◆ 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

◆ Adopt Alternative Development Approaches
  • Leverage civil servant workforce to do leading edge development work
  • Specifically, take advantage of existing resources to initiate the development and help reduce upfront costs on the following element:
    - Launch Vehicle Core Stage
    - Multi-Mission Space Exploration Vehicle
    - Solar Electric Propulsion Freighter
    - Cryo Propulsion Stage/Upper Stage
    - Deep Space Habitat

◆ There are 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
HEFT Transition to Phase II

Steering Council
September 2, 2010
**PROJECT TITLE**
HEFT Phase II: Driven by Agency Needs and Phase I Results

**Inputs:**
*From Steering Comm: High-level “Why?” + Key Priorities & Assumptions*
*HEFT Phase I Results*

1. Refine FOMs and establish Architecture Level 0 Requirements
2. Perform Architecture and DRM performance refinement across all elements
3. Establish top-level functionality across architectural elements, optimizing interfaces, interoperability, and commonality where possible
4. Set Technology/Capability priorities, phasing & needed performance
5. Develop architecture element Level 1 requirements
6. Create a high-level multi-destination CONOPS for the architecture/systems
7. Address partnership opportunities and considerations

**Outputs:** Draft Architecture Baseline and CONOPS
*including cost, schedule and performance*
HEFT Phase II Key Tasks

◆ Support program implementation, budget, and alternative/skunkworks acquisition & dev planning efforts

◆ Hone strategic decision timelines, provide timely/actionable recommendations, and track decisions

◆ Pervasive and Timely 2-way Communication:
  • Brief HEFT Phase I results & collect feedback
  • Provide frequent, timely, and direct communication with HEFT oversight elements, internal stakeholders, and broad community (external stakeholders); Use all mediums
  • Share progress and opportunities with NASA’s external stakeholders, including commercial, international and academic partners to foster advocacy, cooperation, and collaboration;
  • Vigorously pursue internal and external input → Participatory Exploration Engagement and Refinement (PEER)
HEFT Phase II Implementation Plans

◆ Maintains the general elements and structure of HEFT
  • Cross-agency direct participation (MDs, HQ elements, Centers, Programs)
  • Leverages Engineering Structure and Expertise
  • ESMD (and SOMD) provides regular oversight and direction: All final decisions and documentation approved at Administrator level with regular reporting to the SMC
  • Steering Committee includes Current makeup + 4 Ops CtrDirs, Provides regular review
  • Integration Team: Each member leads a sub-team, regular briefings
  • Sub-teams: Integrated System Analysis / DRM, Ops / Infrastructure, Partnerships, Communications, Crew Vehicle (CV), Launch Vehicle (LV), In-space (IS), Tech Dev (TD) and Cost
  • Red / Independent Review Team & Consultants Team
  • Located in, and funded by ESMD, but Agency function for HSF Exploration

◆ Near Term Forward Schedule
  • HEFT Phase 1 Final Summary outbriefs following Steering Committee Meeting on 9/02/10
    – Strategic Context and Top Outcomes from HEFT Phase I (Key Decisions, Trades, Results)
    – SMC/WH/Congress briefings soonest for concurrence with Phase I results/Phase II plans
  • Initial 3 month period of focused surge effort, then smaller, sustained long-term refinement work

◆ Notional Phase 2 Schedule: Mon, 13 Sep 2010 – Wed, 8 Dec 2010
**Relationship Diagram**

- **HEFT**
  - Architecture Process
  - **Steering Committee**
    - NGOs, Cost, Schedule, Constraints, Other priorities
  - **Integration Team**
    - Architecture: Destinations, DRMs, Priorities, Roadmaps
- **ESMD Programs**
  - Formulation and Implementation
  - **ESMD**
  - **Formulation/Study/Program Teams**
    - Budget, Other Constraints, Oversight
    - Implementation Plans, Program Execution
  - **Program Requirements, Functionality, Phasing, Priorities**
  - **Implementation Plans, Including Breaks/Issues**

**Why? Where? What? When?**

**How?**

Pre-Decisional: For NASA Internal Use Only

NASAWATCH.COM 67
Backup
## DRM 2B Cost Summary

**Constant FY10 Dollars**

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*lower fidelity estimates*
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First Launch of CTV-E scheduled for 2019

### Financial Graph

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Deep Space Habitat (DSH)

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8/20/2019
SSC Discriminators for 70 and 100 t vehicles

- No issues for engine testing
- Stage testing: relative to 70 t HLV, the 100 t HLV requires more extensive mods to SSC B-2
  - stage mounting
  - flame deflector robustness
  - propellant feedlines and valves,
    - per April 2010 assessment for 5-engine MPTA type hotfire series
  - Current ROM of $60 M

No discriminators between vehicles – minor cost impact for B-2 modifications (may be necessary in long term)
HEFT Phase II Overview

◆ **HEFT Goal:** Create an *evolvable and flexible architecture* for our Human Space Exploration Enterprise that defines the *strategy, capabilities, and technical plan* NASA needs to send people to *explore multiple destinations* in the Solar System in an inspiring, safe, efficient, affordable, and sustainable way.

◆ **HEFT Approach:** *Continue the HEFT process*, evolving into a long term, permanent NASA activity to support human space flight strategic architecture and support planning
  • For the next 3 months in HEFT Phase II, team will leverage the output of the first iteration of the HEFT process and define/refine the HSF Exploration Architecture
  • Outcome of the process will be an architecture that includes *recommendations for Human Spaceflight elements, capabilities and multi-destination missions* for 5, 10, 15, and 20 year horizons, with a *steady cadence of bold firsts and Mars as the ultimate destination*

◆ **HEFT Impact:** Influence the FY11/12 and FY2013+ budget negotiation and allocation process
  • Provide an executable and credible strategic HSF architecture
  • Communicate a strategy that
    – Integrates all the moving parts and answers the questions: *“Why?”, “What?”, “Where?” and “When?”*
    – Meets diverse stakeholder needs
    – Clarifies viable options, implications, and inter-relationships
Detailed HEFT Deliverables (Phase II)

- **Refined FOMS & Agency Level 0 requirements**
- **Key follow-on trade studies and required forward work from HEFT Phase I**
- **Refined destinations and compelling rationale (where and why):**
  - Assess Flexibility: Vehicle/payload capabilities, destination opportunities, mission adjustments
  - Assess Extensibility: Early missions; Mars orbit, Mars surface, other beyond NEO capabilities
- **Refined DRMs as part of a multi-destination Architecture:**
  - Breakdown of flight elements and top-level functionality
  - Optimized interfaces, interface controls, commonality, and interoperability
  - Refined mission scenario and operations definitions: launches, departure staging, in-space integration, activities/events, transits/durations, destination operation plans, and contingencies/robustness
  - Refined element definitions: systems, mass, power, performance, technologies
  - Refined systems, elements and technologies requirements; Phasing, TRL/IRL maturation
- **Level 1 architecture NGOs and requirements**
- **Refined technology and systems development plans:**
  - Refine the needed technology development paths: tech dev, testing, and demos
  - Technology and vehicle/element performance/demonstration targets & milestones
  - Phased technology, vehicle and element dev plans balancing affordability, efficiency & schedule
Detailed HEFT Deliverables (Phase II) - continued

◆ Develop clear measurable strategies & approaches for alternative lean/skunkworks acquisition and development
  • Provide specific cost, schedule, and performance-based needs

◆ Refined integrated mission design and planning (CONOPS):
  • Manifesting / sequencing of: missions, launches, vehicles, elements and block developments
  • Ground and in-space operations infrastructure and support requirements and assets
  • Mission operations, communications, navigation and IT requirements and assets
  • Manufacturing, supply chain, resources requirements, assets and availability

◆ Assessment of partnership opportunities and considerations:
  • Technologies, vehicles and/or elements
  • Internationals, Other Government Agencies, industry/commercial, academia

◆ Refined cost assessments
  • Refined DDT&E, First Unit and Production for: systems, elements, vehicles & technologies
  • Cost margins, uncertainty assessment and validation assessment; Cost phasing and sand charts

◆ Recommendations
  • Updated launch vehicle, crew vehicle and in-space elements recommendations
  • Updated commercial launch (crew, cargo, HEX element and propellant) strategies
  • Updated technology development plans
HEFT Phase II Activities (Longer Term)

◆ Support transition from approved HEFT results to programmatic implementation
  • Synergy and interaction with Program(s) implementation strategy
◆ Continue iterative refinement of overall human exploration strategy
◆ Periodic assessment of program status against strategy – support PPBE process
◆ Periodic assessment of technology progress against strategy, including impacts to strategy from “game-changing” technologies and relevant on-ramps/off-ramps
◆ Support Reports Required by Law— to be supported, or led as appropriate
◆ Prepare responses to Congressional direction as needed
◆ Support, refine and participate in lean development concept development/application
◆ Identify internal Agency and external interfaces
◆ Develop long-term staffing and organizational approach:
  • Centralized Command/Leadership, Reach-back to Centers/Contractors for detailed execution
  • Rely on existing Agency organizations and structure; Examples – OCE / OSMA Technical Steering Committees for technical analyses, ESMD DIO, OCT Tech planning; Leverage current HEFT people
  • Detailees from Centers, engage younger employees across all disciplines as much as possible since they ultimately have to “own” the results