Human Spaceflight Architecture Team (HAT) Technology Planning

NAC Briefing

3/6/12

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Human Space Flight Architecture Team
Agenda

◆ HAT Overview
  • HAT History, Cycles, and CDF
  • Architecture, Destination, Element Analysis
  • ISECG & GER

◆ HAT Technology Development
  • Process & Products
  • HAT Cycle 2011-C “Quick-Look” Summary
  • ISECG Technology Assessment Team (TAT)
  • AES Technology Mapping Assessment
NASA’s Human Spaceflight Architecture Team (HAT)

- On-going, cross-Agency, multi-disciplinary, study team that conducts strategic analysis cycles to assess integrated development approaches for architectures, systems, mission scenarios, and Conops for human and related robotic space exploration.
  - During each analysis cycle, HAT iterates and refines design reference mission (DRM) definitions to inform integrated, capability-driven approaches for systems planning within a multi-destination framework.

- Key Activities in 2011
  - Prepared DRMs that frame key driving level 1 requirements for SLS & Orion MPCV
  - Developed technical content & mission definitions for discussion with the international community developing the Global Exploration Roadmap
  - Advanced Capability Driven Framework (CDF) concept including more extended reviews of both capabilities needed and development options.
  - Provided technical links between CDF and level 1 requirements for SLS/MPCV
  - Developed performance data for key decisions on SLS initial capability and upper stage options
Capability Driven Exploration

Capabilities required at each destination are determined by the mission. Capability-Driven Framework approach seeks to package these capabilities into a logical progression of common elements to minimize DDT&E and embrace incremental development.
Key Findings from Multiple Cycles

- It’s important to look at multiple DRMs to understand which cases drive requirements
- **SLS Performance**
  - 105t to LEO captures majority of DRMs; HAT input to Level 1 requirements
  - Payload volume remains a challenge for more complex missions
- **Developed a consistent set of ground rules, assumptions and margins across DRMs that must be regularly coordinated with the programs**
- **Activities at the destination need as much attention as the transportation components**
- **A focused technology investment program is needed to enable future missions; integration & dialogue with AES & OCT is critical to ensure priorities**
Primary Transportation DRMs

Select destinations used to drive transportation systems requirements and assess impacts of changes in mission assumptions

<table>
<thead>
<tr>
<th>Proposed Status</th>
<th>ISECG</th>
<th>DRM ID</th>
<th>DRM Title</th>
<th>Dest.</th>
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<tr>
<td>Cycle-C</td>
<td>N</td>
<td>LEO_UTL_2A</td>
<td>LEO Utilization - Non-ISS</td>
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<td>Cycle-C</td>
<td>Y</td>
<td>CIS_LP1_1A</td>
<td>Lunar Vicinity - EM L-1</td>
<td>E-M L1</td>
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<td>Lunar Vicinity - EM L-1 DSH Delivery</td>
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<td>Cycle-C</td>
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<td>CIS_LP1_1C</td>
<td>Lunar Vicinity - EM L-1 with Pre-deployed DSH</td>
<td>E-M L1</td>
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<td>Cycle-C</td>
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<td>Low Lunar Orbit</td>
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<td>LUN_SOR_1A</td>
<td>Lunar Surface Polar Access - LOR/LOR</td>
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<td>Minimum Capability, Low Energy NEA</td>
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<td>Minimum Capability, Low Energy NEA with Pre-deployed DSH</td>
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<td>Cycle-C</td>
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<td>Cycle-C</td>
<td>Y</td>
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<td>Full Capability, High Energy NEA with SEP and pre-deployed DSH</td>
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<td>MAR_SFC_1A</td>
<td>Mars Landing</td>
<td>Mars Surface</td>
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Full Capability, High Energy NEA (2008EV5) with SEP

NEA_FUL_1A_C11C1 - Hybrid with HP HEO Aggregation and LP HEO Crew Rendezvous

**Transportation:**
- 2008EV5: Opportunity in 2024
- Crewed Mission Duration ~428 days
- Block 1 CPS (no LBO), Block 2 CPS (LBO)
- Entry Velocity exceeds MPCV capability (11.5 km/s)

**Destination:**
- Time at Destination: 28 d
- Cargo & FSE Mass: 500 kg
  - Type: TBD
- Resources/Trash left: 11.36 t
  - Type: 2 t Trash, SEV, Cargo & FSE
- Samples/Cargo at NEA Departure: 250 kg
  - Type: TBD
- Samples/Cargo returned to Earth: 100 kg
  - Type: TBD

**Sensitivities:**
- 2nd SEV, 1000 kg cargo + FSE
- 56 d at NEA, 2nd SEV, 1000 kg cargo + FSE

**Chart Notes:**
- Spacecraft icons are not to scale
- ΔV’s include 5% FPR (not applied to MPCV burns)
- RCS burns not displayed in chart
- Not all discrete burns displayed
- SEP transit includes 95% thrusting duty cycle

**HP-HEO 60,000 km**
- x 400,000 km
  - (12.7 day period)
- LP-HEO 407 km
- x 400,000 km
  - (10.6 day period)
- LEO 407 km
- x 407 km

**Earth Return VEI**
- 11.8 km/s

**Staging Location**
- of SEP & DSH is Target Dependent (TBD)

**Resources/Trash remains at NEA**

**Dock All Elements**

**SEP SM kick stage**

**CPS 1**
- SEP
- EDL
- MPAV-SM

**CPS 2**
- Kick Stage
- DSH checkout at HEO 9 d

**Circ burn by Kick Stage**
- ΔV = 0.205 km/s

**Raise by CPS 1**
- ΔV = 3.627 km/s
  - 12.7 d period

**Raise by CPS 2**
- ΔV = 3.283 km/s
  - 10.6 d period

**CPS 2 ΔV = 0.104 km/s**

**CPS 1 ΔV = 0.340 km/s**

**CPS 1 ΔV = 0.523 km/s**

**SEP Departure Burn C3 = 15 km/s²**

**MPCV-SM ΔV = 0.340 km/s**

**LEO 407 km x 407 km**

**CPS 2**
- Circ to 241 km by CPS 1
  - ΔV = 0.104 km/s

**CPS 1**
- Circ to 241 km by CPS 1
  - ΔV = 0.104 km/s

**234 d Transit**

**146 d Transit**

**28 d at NEA**
Five years prior to Human Lunar Return, cargo missions begin to deliver robotics and science equipment. The crew arrives with two large cargo landers and two small logistics landers, and spends 7 days on the surface. Over the next five years, a total of five crewed missions with surface stays of up to 28 days are completed.
## Elements Required By Destination

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<th>Required Element</th>
<th>Capability</th>
<th>For Destinations</th>
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<td>L1/L2</td>
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<td>Getting There</td>
<td>Space Launch System (SLS)</td>
<td>Launch</td>
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<td>Cryo Propulsion Stage (CPS)</td>
<td>High Thrust/Near Earth</td>
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<td>Solar Electric Propulsion (SEP)</td>
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<td>Nuclear Thermal Propulsion (NTP)</td>
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<td>Nuclear Electric Propulsion (NEP)</td>
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<td>Depot</td>
<td>In-Space Logistics</td>
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<td>Deep Space Habitat (DSH)</td>
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<td>Descent</td>
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<td>Surface Hab</td>
<td>Surface Habitation</td>
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<td>Working There</td>
<td>Multi-Mission Space Exploration Vehicle (MMSEV)</td>
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<td>Cargo Hauler</td>
<td>Cargo Mobility</td>
<td>Option</td>
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<td>Robotics and EVA Module (REM)</td>
<td>Logistics/Resupply</td>
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<td>Surface Rover</td>
<td>Surface Mobility</td>
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<td>EVA Suits</td>
<td>EVA (nominal)</td>
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<td>Coming Home</td>
<td>Ascent Vehicle</td>
<td>Ascent</td>
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<td>Orion</td>
<td>Crew Return</td>
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The first iteration of the GER was released Sept 2011

GER enhances international coordination and cooperation in human exploration by enabling discussion of these key areas
- Goals and objectives
- Technically feasible/programmatically implementable mission scenarios: Asteroid Next and Moon Next
- Near-Term opportunities for coordination and cooperation

GER is non-binding but reflects international consensus consistent with existing policies of 12 participating agencies, informs individual agency decisions

Next iteration planned for Sept 2012. Will reflect any available updates resulting from several key activities:
- Planned community engagement, including NASA GER Workshop and IAF/AIAA Global Space Exploration Conference
- ISS Program IEWG activities
- ISECG work on knowledge gaps for each destination, technology needs mapped to scenarios and potential gaps, early DRMs

The NASA technical contributions to GER scenarios are developed by the HAT team
Forward Work Issues and Concerns

◆ **In Space Propulsion**
  - Wide variety of options for how to provide in-space burns:
    - Cryo Propulsion Stage, new stage developed for long life in-space
    - Initial Cryo Propulsion Stage; off the shelf capability, limited life in space
    - Low thrust options for cargo like Solar Electric Propulsion
  - Trade space of mission capture, affordability, and partnerships is likely to be very complex

◆ **Technology & Capability priorities**
  - What are the best ways to utilize the agencies limited technology funding to enable a wide variety of future human spaceflight capabilities?
  - Early emphasis on ECLSS reliability and cryo technologies looks relevant to almost all destinations

◆ **Earth Moon Lagrange Point 2 Mission**
  - How does an L2 waypoint enable missions to other destinations?
  - Reviewing multiple approaches for how to take best advantage of capabilities deployed in cis-lunar space to prepare for missions to other destinations

◆ **Mars Mission**
  - How should eventual Mars mission influence earlier missions and investments?
  - Build Mars Design Reference Architecture 6.0; likely to take into FY13
  - Look at manned missions to Martian moons and how those can reduce mission risk and prepare for eventual human missions to Mars surface
Role in influencing human spaceflight technology dialogues & decisions

- Provides a CDF architecture driven assessment of technology development requirements ("technology pull") of the transportation & destination elements/capabilities across the spectrum of review cycle DRM’s
- Interfacing, integrating, and vetting inputs across the various stakeholders
  - Engineering & Systems disciplines
  - Technology developers (ETDD/OCT, HRP)
  - HAT Element & Destination Leads
- Providing a common reference set of products cross-linking data of interest
  - Technology Development ‘One-Pagers’ for each technology entry
    - Description & Performance Characteristics (why & what required)
    - Cost and time estimates, Current TRL level (how much & when required)
  - Summary matrix of mapping to element & destination needs (e.g. “green-wall”)
  - Note: All technologies mapped to OCT Technology Areas (TA’s)

Product Benefactors (activities & communities influenced)

- Technology developers for prioritization (e.g. OCT roadmaps)
- Technology prioritization inputs into AES review/selection process
- Technology demonstration candidate inputs into MCB Action #5 (ISS Utilization)
- NASA technology inputs for Global Exploration Roadmap (GER) for ISECG Technology Assessment Team (TAT)
- National Research Council (inputs into the OCT roadmap review)
- Analog testbeds planning
Technology Development Assessment: Technology Development Data Capture Process

**Strategy & DRMs**

**Element Data**

**Subject Matter Expert POCs**
(e.g. OCT, HRP, Element Leads, SE, etc.)

**Tech Dev ‘One-Pager’ Sheets**

**‘Tech Dev’ Summary Spreadsheet**
(per Strategy/DRM)

- Tech Dev Data for HAT Cost Team:  
  - Cost, Schedule, Phasing  
  - Applicable Elements (per DRM)
- OCT/HRP Data Inputs
- HEDS Data Inputs (e.g. AES priorities, Analogs, ISS demo candidates, etc.)
- ISECG Technology Dev Inputs
Regenerative Fuel Cells
Power Systems (OCT TA-3.1)

Description
- Long duration energy storage is required for extended surface missions to store solar energy and provide power during low insolation. Applicable to Lunar or Mars surface applications requiring high power and/or long sortie durations.
- RFC system includes a fuel cell and an electrolyzer, each of which can be used independently for power/water generation and H2/O2 generation, respectively. Electrical power can be used for any vehicle. Water and O2 can be used for life support for crewed vehicles. Also applicable to ISRU.
- Technology development includes reducing the number of ancillary components to increase reliability and operational lifetime, and reduce parasitic power losses, mass, and volume.

Performance characteristics
- Power generation >10 kWe for 8 hours or more
- Operable with reactants at >2000 psi to reduce tank volume
- Round trip energy conversion efficiency > 50%
- Minimize mass (TBD Wh/kg)
- Operational life >10,000 hours

Applicable to these Capabilities/Elements; Destinations/Con-Ops
- Driving: Surface Elements, CPS (fuel cell tech advancement, sub-set of regen fuel cell); Lunar Surface
- Beneficiary: MPCV (TBR), DSH, Lander; NEAs

Current TRL Level: 2-3 (regenerative fuel cell), 4 (primary fuel cell), 2 (electrolyzer)

ISS Technology Demonstration:
- Technology would provide operational enhancement capability by providing a small amount of electrical power or clean water and oxygen.
Regenerative Fuel Cells
Power Systems (OCT TA-3.1)

Cost to infuse into standard DDT&E cycle: $xM

- Fuel cell TRL 6 Engineering Model and associated testing: $xM, y years
- Electrolyzer TRL6 Engineering Model and associated testing: $xM, y years
- Integration of Fuel Cell and Electrolyzer and associated testing: $xM, y years

- Significant Demos included in cost
  - Ground testing, including lifetime testing of all TRL6 hardware.

ISS demo beneficial; costs not included above.
Nominal ISS demo costs:
  - $xM for manufacture, qualification & acceptance, certification of flight readiness, and ISS integration. ISS demo could include primary fuel cell with conventional electrolyzer for earlier infusion.

Cost and schedule based on OCT GCD SPS project plan assuming:
  - nominal 3 kW regenerative fuel cell,
  - fuel cell:electrolyzer operating ratio of 1:2,
  - operable from 1 – 10 kW.

Cost Fidelity: (X, Y)
NASA Space Technology Roadmap (STR) Technology Area Breakdown Structure

Human Spaceflight Architecture Team
### Technology Development Assessment: 2011-C TechDev Summary (per OCT TA grouping)

<table>
<thead>
<tr>
<th>TA#</th>
<th>Technology Area (TA) Description</th>
<th>Tech Dev Entries</th>
<th>Element Driving (Pull)</th>
<th>ISS Demo Candidates</th>
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<tr>
<td>1</td>
<td>Launch Propulsion</td>
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<td>Space Power &amp; Energy Storage</td>
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<td>Robotics, Tele-Robotics, and Autonomous Systems</td>
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<td>Communication &amp; Navigation</td>
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<td>Thermal Management Systems</td>
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*Note: * indicates Element trade-space dependent

**Total:**

- Tech Dev Entries: 68
- Element Driving (Pull): 61
- ISS Demo Candidates: 32
## Technology Development Assessment: 2011-C TechDev Summary (per Element)

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<tr>
<th>Element</th>
<th>Driving Technologies</th>
<th>OCT Technical Areas</th>
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<td>MPCV</td>
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<td>SLS</td>
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<td>DSH</td>
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<td>Surface Elements</td>
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<td>Autonomous Systems, Human Health/Life Support/Hab, ISRU, Power &amp; Energy Storage, Robotics/Tele-Robotics</td>
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<tr>
<td>Other</td>
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<td>Element Examples (NTP, NEP, Ground Ops, In-Space Comm Relays)</td>
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## Technology Development Assessment: 2011-C TechDev Element Mapping (1/3)

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<td>Oxygen-Rich Staged Combustion (ORSC) Engine Technology</td>
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**Notes:**
- D-note: Development notes
- D: Development
- REM: Ready for Mission
- NTR: Not Tested Ready
- NEP: Not Expected Possible
- Depot:
  - Depot-D: Depot Delivery
  - Depot-W: Depot Wait

**Human Spaceflight Architecture Team**

21
## Technology Development Assessment: 2011-C TechDev Element Mapping (2/3)

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<th>Title</th>
<th>MPCV</th>
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**Human Spaceflight Architecture Team**

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### Human Spaceflight Architecture Team
ISECG (Int’l Space Exploration Coordination Group)

◆ Technology Assessment Team (TAT)
  • Sub-Team with representation from partner agencies
  • Active participation with NASA, CSA, JAXA, DLR, CNES, (ESA)
  • Chaired by CSA

◆ Process & Products
  • Participating partners share their critical technologies development in the form of the GTDM spreadsheet template (GER Technology Development Map)
  • Data contents include: Title, OCT TA Category, Description, Performance Characteristics, Element Mapping, Mars Mapping, and applicability to ISS Demonstrations
  • 209 technology development entries (no consistent breakdown of level of detail)
  • Preliminary results show potential areas of partnership opportunities (mutual areas of tech development interest)
    - Regenerative fuel cell, Battery Technologies, Autonomy, Autonomous Rendez-vous and Docking systems, Mobility systems, Communication systems, Human health, ECLSS, Radiation, Thermal Protection Systems
  • GTDM available (post Jan 2011 Montreal workshop)
HAT/AES Technology Development Mapping

◆ Follow-on meeting from the AES/OCT brief on 2/3/12, and subsequent action, to identify technology development alignment between AES (Advanced Exploration Systems) projects and HAT identified technologies

◆ Spreadsheet generated for first step in the assessment process, with further details to be included after further insight into AES projects definitions

◆ Addition of OCT & HRP mapping to be considered for inclusion with the mapping spreadsheet (follow-up discussions with applicable POC’s)

◆ Use of the assessment, along with SAID’s technology prioritization/ranking activity, to inform the technology development program offices (AES, OCT, HRP, Analogs, etc.)
Backup Charts

- Backup Charts
  - HAT Cycle 2011-C Technology Development Entries (Summary Charts)
### Launch Propulsion Systems - Earth to LEO Launch Propulsion Systems (Space Access.)
Enhance existing solid or liquid propulsion technologies by lower development and operations costs, improved performance, availability and increased capability.

<table>
<thead>
<tr>
<th>TA #</th>
<th>Technology Development Entry</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2</td>
<td>Oxygen-Rich Staged Combustion (ORSC) Engine Technology</td>
</tr>
<tr>
<td>1.2</td>
<td>Advanced, Low Cost Engine Technology for HLLV</td>
</tr>
</tbody>
</table>

### In Space Propulsion Technologies - Advancements in conventional and exotic propulsion to improve thrust performance levels, increase payload mass and reliability, and lower mass, volume, operational costs, and system complexity for primary propulsion, reaction control, station keeping, precision pointing, and orbital maneuvering.

<table>
<thead>
<tr>
<th>TA #</th>
<th>Technology Development Entry</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>LOX/Liquid Methane Cryogenic Propulsion System - Pressure Fed</td>
</tr>
<tr>
<td>2.1</td>
<td>LOX/Liquid Methane Cryogenic Propulsion System - Pump Fed</td>
</tr>
<tr>
<td>2.1</td>
<td>LOX/Liquid Methane Reaction Control Engines</td>
</tr>
<tr>
<td>2.1</td>
<td>Non-Toxic Reaction Control Engines</td>
</tr>
<tr>
<td>2.2</td>
<td>Electric Propulsion &amp; Power Processing</td>
</tr>
<tr>
<td>2.3</td>
<td>Nuclear Thermal Propulsion (NTP) Engine</td>
</tr>
<tr>
<td>2.4</td>
<td>Unsettled Cryo Propellant Transfer</td>
</tr>
<tr>
<td>2.4</td>
<td>In-Space Cryogenic Liquid Acquisition</td>
</tr>
</tbody>
</table>
Space Power and Energy Storage - Improvements to lower mass and volume, improve efficiency, enable wide temperature operational range and extreme radiation environment for space photovoltaic systems, fuel cells, and other electrical energy generation, distribution, and storage technologies.

<table>
<thead>
<tr>
<th>TA #</th>
<th>Technology Development Entry</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>300 kWe Fission Power for Electric Propulsion</td>
</tr>
<tr>
<td>3.1</td>
<td>High Strength/Stiffness Deployable 10-100 kW Class Solar Arrays</td>
</tr>
<tr>
<td>3.1</td>
<td>Autonomously Deployable 300 kW In-Space Arrays</td>
</tr>
<tr>
<td>3.1</td>
<td>Fission Power for Surface Missions</td>
</tr>
<tr>
<td>3.1</td>
<td>Multi-MWe Nuclear Power for Electric Propulsion</td>
</tr>
<tr>
<td>3.1</td>
<td>Regenerative Fuel Cell</td>
</tr>
<tr>
<td>3.2</td>
<td>High Specific Energy Battery</td>
</tr>
<tr>
<td>3.2</td>
<td>Long Life Battery</td>
</tr>
</tbody>
</table>

Human Spaceflight Architecture Team
**Robotics, Tele-robotics & Autonomous Systems** - Improvements in mobility, sensing and perception, manipulation, human-system interfaces, system autonomy. Advancing and standardizing interfaces for autonomous rendezvous and docking capabilities to facilitate complex in-space assembly tasks.

<table>
<thead>
<tr>
<th>TA #</th>
<th>Technology Development Entry</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.3</td>
<td>Telerobotic control of robotic systems with time delay (w/ Demos)</td>
</tr>
<tr>
<td>4.5</td>
<td>Autonomous Vehicle Systems Management</td>
</tr>
<tr>
<td>4.5</td>
<td>Common Avionics</td>
</tr>
<tr>
<td>4.6</td>
<td>Automated/Autonomous Rendezvous and Docking, Prox Ops and Target Relative Nav</td>
</tr>
<tr>
<td>4.7, 6</td>
<td>Crew Autonomy beyond LEO</td>
</tr>
<tr>
<td>4.7</td>
<td>Robots Working Side-by-Side with Suited Crew (w/ Demos)</td>
</tr>
</tbody>
</table>

**Communications and Navigation** - Technology advancements to enable higher forward & return link communication data rates, improved navigation precision, minimizing latency, reduced mass, power, volume and life-cycle costs.

<table>
<thead>
<tr>
<th>TA #</th>
<th>Technology Development Entry</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.2</td>
<td>High Data Rate Forward Link (Flight) Communications</td>
</tr>
<tr>
<td>5.4</td>
<td>High Rate, Adaptive, Internetworked Proximity Communications</td>
</tr>
<tr>
<td>5.4</td>
<td>In-Space Timing and Navigation for Autonomy</td>
</tr>
<tr>
<td>5.5</td>
<td>Quad Function Hybrid RF/Optical Comm, Optical Ranging, RF Imaging System</td>
</tr>
</tbody>
</table>
### Human Health, Life Support and Habitation Systems

Improvements in reliability, maintainability, reduced mass and volume, advancements in biomedical counter-measures, and self-sufficiency with minimal logistics needs for long duration spaceflight missions. Advancements in space radiation research, including advanced detection and shielding technologies.

<table>
<thead>
<tr>
<th>TA #</th>
<th>Technology Development Entry</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1</td>
<td>Closed-Loop, High Reliability, Life Support Systems</td>
</tr>
<tr>
<td>6.1</td>
<td>High Reliability Life Support Systems</td>
</tr>
<tr>
<td>6.2</td>
<td>Deep Space Suit (Block 1)</td>
</tr>
<tr>
<td>6.2</td>
<td>Lunar Surface Space Suit (Block 2)</td>
</tr>
<tr>
<td>6.2</td>
<td>Mars Surface Space Suit (Block 3)</td>
</tr>
<tr>
<td>6.2</td>
<td>Suit Port</td>
</tr>
<tr>
<td>6.3</td>
<td>Long Duration Spaceflight Medical Care</td>
</tr>
<tr>
<td>6.3</td>
<td>Long-Duration Spaceflight Behavioral Health</td>
</tr>
<tr>
<td>6.3, 6.1</td>
<td>Deep Space Mission Human Factors and Habitability</td>
</tr>
<tr>
<td>6.3</td>
<td>Microgravity Biomedical Counter-Measures for Long Duration Spaceflight</td>
</tr>
<tr>
<td>6.3</td>
<td>Microgravity Biomedical Counter-Measures - Optimized Exercise Equipment</td>
</tr>
<tr>
<td>6.4</td>
<td>Fire Prevention, Detection &amp; Suppression (reduced pressure)</td>
</tr>
<tr>
<td>6.4</td>
<td>In-Flight Environmental Monitoring</td>
</tr>
<tr>
<td>6.5</td>
<td>Space Radiation Protection – Galactic Cosmic Rays (GCR)</td>
</tr>
<tr>
<td>6.5</td>
<td>Space Radiation Protection – Solar Particle Events (SPE)</td>
</tr>
<tr>
<td>6.5</td>
<td>Space Radiation Shielding – SPE</td>
</tr>
</tbody>
</table>

**Human Spaceflight Architecture Team**
**Technology Development Assessment:**

**2011-C Element TechDev Entries Summary (5/7)**

**Human Exploration Destination Systems** - Technology advancements with In-Situ Resource Utilization (ISRU) for fuel production, O2, and other resources, improved mobility systems including surface, off-surface and Extravehicular Activity (EVA) and Extravehicular Robotics (EVR), advanced habitat systems, and advancements in sustainability & supportability technologies.

<table>
<thead>
<tr>
<th>TA #</th>
<th>Technology Development Entry</th>
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<tbody>
<tr>
<td>7.1</td>
<td>In-Situ Resource Utilization (ISRU) - Lunar: Oxygen/Water Extraction from Lunar Regolith</td>
</tr>
<tr>
<td>7.1</td>
<td>In-Situ Resource Utilization (ISRU) – Mars: Oxygen from Atmosphere &amp; Water</td>
</tr>
<tr>
<td>7.2</td>
<td>Supportability and Logistics</td>
</tr>
<tr>
<td>7.3</td>
<td>Anchoring Techniques &amp; EVA Tools for u-G Surface Operations</td>
</tr>
<tr>
<td>7.3</td>
<td>Surface Mobility</td>
</tr>
<tr>
<td>7.5, 4.7</td>
<td>Mission Control Autonomy beyond LEO</td>
</tr>
<tr>
<td>7.5</td>
<td>Dust Mitigation</td>
</tr>
</tbody>
</table>

**Entry, Descent & Landing Systems** - Human-class capabilities for Mars entry, descent, and landing: low mass high velocity Thermal Protection Systems (TPS), atmospheric drag devices, deep-throttling engines, landing gear, advanced sensing, aero-breaking, aero-capture, etc. Soft precision landing capability, e.g., for Moon and NEA’s.

<table>
<thead>
<tr>
<th>TA #</th>
<th>Technology Development Entry</th>
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<tbody>
<tr>
<td>9.1 - 9.4</td>
<td>Entry, Decent, and Landing (EDL) Technologies - Mars Exploration Class Missions</td>
</tr>
<tr>
<td>9.1 – 9.4</td>
<td>Entry, Decent, and Landing (EDL) Technologies – Earth Return</td>
</tr>
<tr>
<td>9.3</td>
<td>Precision Landing &amp; Hazard Avoidance</td>
</tr>
</tbody>
</table>

*Human Spaceflight Architecture Team*
### Technology Development Assessment: 2011-C Element TechDev Entries Summary (6/7)

**Modeling, Simulation, Information Technology & Processing** - Advancements in technologies associated with flight & ground computing, integrated s/w and h/w modeling systems, physics based models, simulation and information processing.

<table>
<thead>
<tr>
<th>TA #</th>
<th>Technology Development Entry</th>
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<tbody>
<tr>
<td>11.2</td>
<td>Advanced Software Development/Tools</td>
</tr>
</tbody>
</table>


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<tr>
<th>TA #</th>
<th>Technology Development Entry</th>
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</thead>
<tbody>
<tr>
<td>12.3</td>
<td>Mechanisms for Long Duration, Deep Space Missions</td>
</tr>
<tr>
<td>12.1, 12.2</td>
<td>Inflatable: Structures &amp; Materials for Inflatable Modules</td>
</tr>
<tr>
<td>12.1, 12.2</td>
<td>Lightweight Structures and Materials (HLLV)</td>
</tr>
<tr>
<td>12.1, 12.2</td>
<td>Lightweight Structures and Materials (In-Space Elements)</td>
</tr>
<tr>
<td>12.1, 12.2</td>
<td>Lightweight Structures and Materials (Manufacturing Techniques/Technologies)</td>
</tr>
<tr>
<td>12.3</td>
<td>Low Temperature Mechanisms</td>
</tr>
</tbody>
</table>

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**Ground & Launch Systems Processing** - Technologies to optimize the life-cycle operational costs, increase reliability and mission availability, improve mission safety, reduce mission risk, reducing environmental impacts (i.e. green technologies).

<table>
<thead>
<tr>
<th>TA #</th>
<th>Technology Development Entry</th>
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</thead>
<tbody>
<tr>
<td>13.1</td>
<td>Ground Systems: Low Loss Cryogenic Ground Systems Storage and Transfer</td>
</tr>
<tr>
<td>13.2</td>
<td>Ground Systems: Corrosion Detection &amp; Control</td>
</tr>
<tr>
<td>13.3</td>
<td>Ground Systems: Fault Detection, Isolation, and Recovery</td>
</tr>
<tr>
<td>13.3</td>
<td>Ground Systems: Wiring Fault Detection and Repair</td>
</tr>
</tbody>
</table>

**Thermal Management Systems** - Technology advancement for cryogenic systems performance & efficiency, effective thermal control systems for heat acquisition/transport/rejection, and increase robustness and reduce maintenance for thermal protection systems.

<table>
<thead>
<tr>
<th>TA #</th>
<th>Technology Development Entry</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.1</td>
<td>In-Space Cryo Propellant Storage (Reduced Boil Off Lox LO2/Zero Boil Off LH2)</td>
</tr>
<tr>
<td>14.2</td>
<td>Thermal Control</td>
</tr>
<tr>
<td>14.3</td>
<td>Robust Ablative Heat Shield (Beyond Lunar Return) - Thermal Protection System</td>
</tr>
<tr>
<td>14.3</td>
<td>Robust Ablative Heat Shield (Lunar Return) - Thermal Protection Systems</td>
</tr>
</tbody>
</table>

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