CE&R CA-1 Architecture Design & Analysis at Andrews Space

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www.andrews-space.com
Approach to CA-1

- Andrews will leverage its cost, performance, and operations experience base to define architecture and CEV requirements that best address the exploration goals and objectives:
  - Alternate Access to Station
  - DARPA Small Launch Vehicle Program
  - DARPA Hypersonic Weapons System Program
  - Orbital Space Plane
  - Next Generation Launch Technology
  - 3rd Generation RLV
  - 2nd Generation RLV
  - Space Exploration Initiative

We look forward to working with NASA and Industry to establish a common set of requirements
Exploration Architecture Derivation Process

Problem Definition
- Stakeholders
- Architecture Objectives
- System Requirements

Option Space
- Node Placement
- Element Options

Solution
- Architecture Definition
- Architecture Implementation
- Requirements Verification

Problem definition derived from stakeholders short and long-term objectives

Option Space surveyed for
- Node placement options
- Historic, present, and projected element capabilities

Solution based on understanding of the problem
## Stakeholders

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Government Civilian Agencies</td>
<td>A government agency (or collection of agencies) with a primary mission of government functions/social activities (e.g. legislature, executive, judiciary).</td>
</tr>
<tr>
<td>Government Defense Agencies</td>
<td>A government agency (or collection of agencies) with a primary mission of military activities aimed at people outside its own constituency (e.g. intelligence gathering, force projection, force deflection, military logistics).</td>
</tr>
<tr>
<td>Commercial Service Providers</td>
<td>A grouping of people with a primary objective of achieving profit by providing services or goods to others (e.g. launch service providers, satellite manufacturers, etc.).</td>
</tr>
<tr>
<td>Commercial Customers</td>
<td>A grouping of people with an interest of acquiring goods or services obtained through space activities for the purpose of achieving profit (e.g. telecommunications companies, remote imaging brokers, etc.).</td>
</tr>
<tr>
<td>General Public Customers</td>
<td>Any individual (or group of individuals) not acting with the primary goal of obtaining profit or affecting social change (e.g. individuals, non-profit organizations, etc.).</td>
</tr>
</tbody>
</table>

To successfully return to the Moon and Mars, we (NASA & Industry) must appeal to ALL stakeholders.
Andrews has identified **scientific**, **economic** and **military** objectives.

<table>
<thead>
<tr>
<th>Objective</th>
<th>Definition</th>
<th>Stakeholders</th>
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</thead>
<tbody>
<tr>
<td>Human Outpost</td>
<td>Establish a sustainable human outpost on the Lunar surface, with growth path to a crewed Mars mission.</td>
<td>⚫</td>
</tr>
<tr>
<td>Robotic Exploration</td>
<td>Allow for sustainable robotic exploration of all bodies in the solar system.</td>
<td>⚫</td>
</tr>
<tr>
<td>Natural Observation</td>
<td>Allow for the observation of objects both within and outside the solar system (planets, stars, etc).</td>
<td>⚫</td>
</tr>
<tr>
<td>Commercialization</td>
<td>Provide a growth path for the transition of government activities to private enterprise via economically attractive opportunities for the sustainable involvement of private enterprise in the development, manufacturing, and operations of space systems.</td>
<td>⚫</td>
</tr>
<tr>
<td>Commercial Transport</td>
<td>Provide economically attractive, sustainable access to space resources for the transport of data, goods, people, and energy to/from and through space.</td>
<td>⚫</td>
</tr>
<tr>
<td>Public Involvement</td>
<td>Provide opportunities to the general populous to contribute to space activities, and experience and interact with the space environment.</td>
<td>⚫</td>
</tr>
<tr>
<td>Military Logistics</td>
<td>Assured access to space for deployment of force projection systems, and movements of logistics.</td>
<td>⚫</td>
</tr>
<tr>
<td>Military Intelligence</td>
<td>Provide nationally assured access to orbital locations for the placement of observation systems.</td>
<td>⚫</td>
</tr>
</tbody>
</table>

**GC** = Government Civil  
**GD** = Government Defense,  
**CS** = Commercial Services  
**CC** = Commercial Customers  
**GP** = General Public
Goals of Human Space Activities

1. Capable
2. Sustainable
3. Affordable
4. Reliable (Safe)

Establish a permanent human presence off Earth.

Enable utilization of extraterrestrial resources.

Explore space and broaden our understanding of nature.
What is “Sustainability”? 

Goal: Sustained Space Program
- Smooth funding demand
- Steady funding supply

Goal: Sustained Industry Support
- Steady availability of funding
- Commercial Opportunities

Goal: Sustained Public Support
- Regularly spaced visible program milestones
- Visible growth towards Public Space Access

Goal: Smooth Required Funding
- Step-ladder (modular) development approach
- Commercialization of mature elements, enabling development of the next level

Sustainability Requirements
- Modular approach
- Commercialization of mature elements
- Regular milestone achievements
- Growth towards commercial Public Space Access
Affordable - Lessons Learned from NASA AAS

Life Cycle Cost Based on:
- 100,000 lb of annual cargo to ISS
- Recovery of ~50% of ISS cargo (downmass)
- Six Years of Operations
- NASA EELV Pricing

Launch cost accounts for 2/3 of total life cycle cost (including launch portions of the cost of failure).
ETO Segment Impact on Architecture

Goal: Sustained Space Presence
- Sustained, crewed Moon / Mars Exploration requires capacity beyond existing ELVs
- Sustainability requires commercial viability

Goal: Commercially Viable ETO
- Requires low cost to orbit

Goal: Low Cost to Orbit
- Requires high flight rate
- Requires reusability

Goal: High Flight Rate
- Requires high reliability
- Requires high versatility

Goal: High Versatility
- Need medium & heavy lift
- Requires booster with support for various upper stages

Goal: High Reliability
- Requires HTHL

Solution: TSTO HTHL RLV
Long Term Impact of Near Term ETO Strategy

Project Constellation


Avg Payload Size
Fight Rate
Reliability Reqmt
Cost to Orbit

Space Exploration (Government)  Space Utilization (Commerce)

Shuttle C / Heavy Lift

Medium Lift + Rendezvous

Medium ELV + Small RLV

Heavy RLV

Sustained Expansion Requires
- Versatile Payload Size
- High Flight Rate / Reliability
- Low cost to orbit
- Growth Path to Reusability

Technology Advancements
<table>
<thead>
<tr>
<th>Title</th>
<th>Options</th>
<th>Motivation</th>
<th>FOMs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crew Size</td>
<td>Any Integer (0-6+)</td>
<td>Number of humans at any given system within the architecture has a high impact on operations, cost, capability, launch requirements, etc.</td>
<td>- Milestone Frequency</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Gov. Campaign Cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Suitability to Habitation</td>
</tr>
<tr>
<td>Node 1 Location</td>
<td>Moon Direct LEO Hub</td>
<td>First staging node has a key impact on the safety, evolvability, and capability of the architecture; strongly drives ETO lift requirements, and determines dependencies on autonomous rendezvous and docking technologies.</td>
<td>- Emergency Access Time</td>
</tr>
<tr>
<td></td>
<td>L1 Hub</td>
<td></td>
<td>- Payload Mass Fractions</td>
</tr>
<tr>
<td></td>
<td>LLO Hub</td>
<td></td>
<td>- Milestone Frequency</td>
</tr>
<tr>
<td></td>
<td>Lunar Surface Hub</td>
<td></td>
<td>- Gov. Campaign Cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Resource Availability</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Suitability to Habitation</td>
</tr>
<tr>
<td>Node 2 Location</td>
<td>Mars Direct Phobos Earth/Mars Cycler</td>
<td>Similar to A1 the placement (or absence) of an intermediate node to support crewed Mars missions has a high impact on all aspects of the architectures potential to successfully meet the desired exploration objectives.</td>
<td>- Emergency Access Time</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Payload Mass Fractions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Milestone Frequency</td>
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<td></td>
<td></td>
<td>- Resource Availability</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Suitability to Habitation</td>
</tr>
<tr>
<td>ISRU Selection</td>
<td>No ISRU</td>
<td>This trade will identify what segments of the transportation architecture will benefit from the use of local resources. It also investigates what specific substances are worthwhile extracting (e.g. water, methane, CO, O2, etc.).</td>
<td>- Integrated Payload Limit</td>
</tr>
<tr>
<td></td>
<td>ISRU &amp; Non-ISRU</td>
<td></td>
<td>- Payload Mass Fractions</td>
</tr>
<tr>
<td></td>
<td>All ISRU segments</td>
<td></td>
<td>- Annual ETO manifest</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Commercialization Potential</td>
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<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>------------------------------------------------</td>
</tr>
<tr>
<td>ETO</td>
<td>(E)ELV only RLV only Heavy Lift Mixed Fleet Time Phased</td>
<td>Lifting materials out of Earth's gravity well is a formidable obstacle towards the expansion of human space activities. An ill-defined approach to the ETO segment can potentially doom an entire architecture. In this trade all ETO options will be evaluated.</td>
<td>- Int. Payload Limit - Payload Mass Fractions - Annual ETO Capacity - Annual Loss Rate - ETO Cost - Commercialization Potential</td>
</tr>
<tr>
<td>Orbital Mechanics</td>
<td>Classic Orbits N-Body Orbits</td>
<td>Multi-body orbital mechanics trajectories have the potential to significantly reduce Δv requirements and widen launch windows, but come at a price of increased transit times.</td>
<td>- Integrated Payload Limit - Payload Mass Fractions - Annual ETO Capacity - Milestone Frequency - Emergency Access Time</td>
</tr>
<tr>
<td>Robotic Autonomy</td>
<td>Autonomous Teleoperated</td>
<td>Teleoperation has the advantages of reduced technology risk and human-in-the-loop decision capability. However, in order for teleoperation to be feasible node placements must be adjusted to account for light-speed lag time.</td>
<td>- Milestone Frequency - Gov. Campaign Cost - Annual Loss Rate - Commercialization Potential</td>
</tr>
<tr>
<td>Power Source</td>
<td>Nuclear Power Solar Power Mixed Power</td>
<td>Nuclear power offers higher power densities and improved performance for electric propulsion vehicles, but comes at the cost of increased technology risk, development time, and socioeconomic cost/risk.</td>
<td>- Integrated Payload Limit - Payload Mass Fractions - Annual ETO Capacity - Government Funding Profile - Milestone Frequency - Campaign Cost</td>
</tr>
</tbody>
</table>
Earth/Moon L1 Transportation Hub

- Architecture nodes are placed based on an evaluation of critical node characteristics

- Environmental factors (gravity topography, resources, etc) are key drivers in node suitability

- Operational characteristics such as Time-to-Safety (or “forward basing”) are additional factors

### Identified Nodes

<table>
<thead>
<tr>
<th>Node</th>
<th>Type</th>
<th>Altitude</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEO</td>
<td>2-600</td>
<td>Low Earth Orbit</td>
<td></td>
</tr>
</tbody>
</table>

### Node Attributes

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Energy</td>
<td>The specific energy (expressed as ideal A from the Earth's surface) at the Earth.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Node</th>
<th>Accessibility</th>
<th>Gravity</th>
<th>Stability</th>
<th>Resources</th>
<th>MMOI</th>
<th>Radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESN</td>
<td>Poor</td>
<td>1.00</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
<td></td>
</tr>
<tr>
<td>LEO</td>
<td>Good</td>
<td>0</td>
<td>Poor</td>
<td>Poor</td>
<td>Medium</td>
<td>Good</td>
</tr>
</tbody>
</table>

Andrews chose the L1 Node based on:

- Gateway between Earth / Moon / Mars and other planetary bodies
- Increases the number of launch opportunities between Earth and Moon / Planets
- Low amount of station keeping ΔV (∼10 m/s per year)
- Supports Earth / L1 Gateway / Moon communications infrastructure
L1 Cargo / Logistics for LLT Pickup

New Elements:
- ETO: RCB (RLV first stage)
- CEV: CSP (Commercial LEO)
- CSM Derived: Commercial Station, CER, Lunar Habitat, Phobos Node
- In-Space: L1-Phobos Tug, LDH @ L1 Station (TransHab)
- Robotic: Mars / Phobos Explorers
- DOD: Space Operations Vehicle

Serviceable GEO Platforms

Commercial Mini-Station

Cargos / Logistics (U/PLC)
2020 - 2035

New Elements:
- Commercial L1 / Lunar Travel (ESP)
- CSM Derived: LEO Business Park
- Humans to Mars:
  - NEP or ISRU&LOX/LH
  - TransHab derived from L1 station
  - Lander evolved from Lunar CPL
  - ISRU derived from Lunar ISRU
  - Mars Rovers, Teleoperated from Phobos

Commercial Missions
NASA Missions
Military Missions

LLO
L1
LMO
LEO
GEO
CSP
CPL
LSN & ISRU
CER
Lunar Base
Human Missions to Mars / Phobos
Solar Power LEO-L1 Tug (LLT)
L1 Cargo / Logistics for LLT Pickup
Commercial LEO Business Park
Serviceable GEO Platforms
EUS
RCB
LEO
GEO
CSP
CPL
LSN & ISRU
CER
Lunar Base
Human Missions to Mars / Phobos
Solar Power LEO-L1 Tug (LLT)
L1 Cargo / Logistics for LLT Pickup
Commercial LEO Business Park
Serviceable GEO Platforms
EUS
RCB
Modular Element Families

- Reduces individual launch mass requirements
- Reduces development time (heritage utilization)
- Reduces overall cost (smaller number of unique systems)
- Reduces technology risk (interchangeable backup options)
Architecture Tasks Summary

- Identify Stakeholder Objectives and Requirements
- Determine and Characterize (FOM) Option Space
- Define Baseline Architecture Candidate
- Expand to additional Stakeholders / Objectives and iterate to determine Impact
- Define and Execute Trades to Optimize Design
- Perform Detail Analysis and determine FOM Values

Stakeholders
Objectives
Requirements
Options
Criteria
Expansion
Operations
Development
Design
Selection

NASA
Project Constellation
ANDREWS SPACE
**Summary**

- **Advanced Orbital Mechanics:** Transportation Hub at Earth/Moon L1 for superior “time-to-safety” and gateway to low $\Delta v$ trajectories throughout the Solar System.
- **ISRU:** Use of local bulk resources (water, regolith) reduces payload requirements.
- **Modular System-of-Systems:** Standardized interfaces for “plug & play” functionality, diverse technology base reduces program risk.
- **Exploration enables Commercialization:** Elements are extensible in support of Public Space Access, the most critical factor for a sustained space program.