CE&R Initial Concept Overview

13 September 2004
CE&R Initial Forum
Washington, D.C.
Agenda

- Proposed Objectives
- Initial Lunar System-of-Systems Concept
- Driving Architecture Issues
## Proposed Objectives

### Recommended Level 0 Objectives

**Science**

1. Develop and Demonstrate Methods, Technologies, and Systems for Human Exploration of the Solar System
2. Determine the Extent of Exploitable Resources on the Moon; Assess and Demonstrate In Situ Resource Use
3. Develop Methods to Mitigate Impact of Long-Duration Human Exposure to the Space and Lunar Environments
4. Determine the Origin of the Moon and Impact History of the Inner Solar System

**Econ**

5. Stimulate the High-Tech Industry in the United States
6. Enable Commercial Lunar Activities by Developing and Transferring Lunar Knowledge and Capabilities to Private Sector

**Security**

7. Develop and Maintain Autonomous Proximity Operations, Docking, Support, and Assembly Capability
8. Develop and Maintain Space Asset Human Servicing Capability in Near-Earth Orbits
9. Improve and Sustain the Nation’s Technical Workforce by Inspiring Students to Pursue Mathematics, Sciences, and Engineering
## Proposed Objectives

### Recommended Level 1 Spiral Objectives

**Bold Blue** – Meets a Specific Time-Based NASA Requirement

- **Major Contributor**: ○
- **Contributor**: □

<table>
<thead>
<tr>
<th>Spiral</th>
<th>Recommended Level 0 Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Security</td>
</tr>
<tr>
<td>1</td>
<td>1 2 3</td>
</tr>
</tbody>
</table>

- **Spiral 1**
  - Robotically Collect Topography, Gravity, Radiation, and Mineralogy Data by 2008 to Support Site Selection
  - Demonstrate Crew Exploration Vehicle (CEV) Earth Entry, Descent, and Landing System (EDLS) by 2008
  - Robotically Collect and Return Lunar Surface Samples by 2010
  - Robotically Qualify a Human-Rated CEV and Crew Launch Vehicle for Rendezvous, Docking, and EDLS by 2011
  - Demonstrate Crewed CEV Habitability, Egress, EVA, and Crew Transfer by 2012
  - Robotically Demonstrate 180-Day CEV On-Orbit Endurance by 2013

- **Spiral 2**
  - Qualify Exploration Transfer Stage by 2015
  - Deploy Space Weather Monitor by 2016
  - Qualify End-to-End Crew Transportation System by 2017
  - Conduct a Crewed Day / Night Stay on the Lunar Surface by 2018

- **Spiral 3**
  - Demonstrate Surface Nuclear Power Operation by 2019
  - Demonstrate Base Surface Operations and Logistics by 2020
  - Prove 180-Day Crewed Endurance by 2021
  - Conduct Long Duration Traverse / Science Exploration by 2022
  - Demonstrate Critical Mars Surface Functionality by 2022

- **Spiral 4**
  - Development and First Flight of 100t Class Launch Vehicle (2024)
  - Crewed LEO Demonstration of Mars Elements: Endurance and Latencies (2024 to 2026)
  - Crewed Demonstration of Mars Landing and Return Elements at the Moon (2026)
  - First Crewed Mars Flight (2027)
Three Spiral Initial Concept Established

- Credible Baseline Established Based on Concept Studies and Initial Trades
- Primary FOMs considered: Cost Profile, Safety, Prob. of Mission Success
- Broad Trade Space Defined

**Point-of-Departure Concept Features:**

- Safe human transport using Earth-Moon Lagrange point (EML1) rendezvous, for flexible lunar access and earth return
- Deliver unmanned cargo and surface systems using efficient direct trajectory.
- Elements launched, assembled in LEO into translunar vehicles like Mars missions in later spirals.
- Minimized number of unique elements.
- Flight elements sized to balance launcher development affordability, reliability.
- 55t commercially procured Atlas or Delta derivative launchers for cargo.
- Lunar exploration features both fixed and mobile assets, potential Mars architectures
Early Trades Show Affordability of Intermediate Launchers

- 130t Launcher Unaffordable in Early Development, No Cost Benefit Over 55t Class
- Reliance on Existing LVs Unaffordable Post-2016 Due to Launch Rates
- 55t Class Cheaper Than Reliance on Current Vehicles
Spiral One

Spiral 1, 2005-2014
Human Activities in LEO

- LRO
- LLO
- Uncrewed CEV Qual/Demo Flights
- Crewed Flight With EVA
- Crew Transfer
- SPA-SR Sample Return
- Delta II Class
- Human-Rated CLV
- Human-Rated CLV
- Recovery

Ground
Spiral Two

Spiral 2, 2010-2020
Humans Return to the Moon

SWM
LRO
SEL1
LLO
ETS
ETS/SM/RM Loiter
EML1
LEO
EELV-55
Delta II Class
Cargo Transport (Three launches per Module)
Crew Transport (Four launches per Crewed Surface Trip; 3 x 55t, 1 x CLV)
Recovery

Surface Hab Module
Lander Module
Spare
Hab Module (Crewed)
Lander With Ascent Stage
Rover

30-Day Stay, Crew of Four

Uncrewed Demo, Followed by Crewed Flight
Four Crew
Human-Rated CLV

Spiral Three

Spiral 3, 2015-2025
Extended Lunar Exploration and Mars Preps

Acronyms:
- EML1: Earth-Moon Lagrange Point 1
- EML2: Earth-Moon Lagrange Point 2
- LLO: Low Lunar Orbit
- LRO: Lunar Reconnaissance Orbiter
- ETS: Exploration Transfer Stage
- RM: Return Module (CEV)
- SEL1: Sun-Moon Lagrange Point 1
- SEP: Solar Electric Propulsion
- SM: Service Module (CEV)
- SWM: Space Weather Monitor
**Constellation Systems – Initial Concept**

**Surface System (SS)**
- Long-Term Habitat for a Crew of Four at the Base Location – 5m, 15t modules
- Supports Surface Science and Exploration
- Provides Crew Mobility
- Supports Infrastructure for Lunar Resource Utilization and Lunar Commerce
- Testbed for Future Mars Missions

**Robotic Precursor System (RPS)**
- Reduces Risks for Manned Missions
- Discovery or New Frontiers Class Incl./ Lunar Reconnaissance Orbiter (LRO) in 2008
- Sample Return Mission to the South Pole-Aitken Basin in 2010

**Ground System (GS)**
- Processes SoS System Elements for Flight
- C3I for CrTS, CaTS, and SS Elements
- Flight System and Crew Recovery Simulators
- Non-Toxic Propellants – all LH2/LOX
- Crew Recovery at Edwards AFB (Primary), White Sands (Secondary), Ocean (Contingency)
- Automated Mission Planning and Flight Operations with Integrated System Health Management

**Crew Transport System (CrTS)**
- Four Crew CEV
- Multifunctional Hab Module (HM)
- Long Duration Loiter
- ETS-1
- Human Rated Upper Stage
- Higher T/W
- Crew Launch Vehicle
- Uses ETS-1
- Atlas V Derived First Stage
- Two-Stage Lunar Lander
- Carries CEV HM
- Autonomous Ops
- ETS-2 (Exploration Transfer Stage)
- EML1/Earth Transfer
- Long Duration Loiter
- 55t non-crew launchers
- 5m P/L Fairings
- Commercially-Procured Standard Loads

**Cargo Transport System (CaTS)**
- Includes CrTS Common Elements, ETS-2, LM, and 55t Launch Capability
- Prepositions Lunar Base Modules
- ETS/LM/Cargo, Direct to the Moon for Efficiency
- JIMO-Derived Solar-Electric Tug Option in Spiral 3 – Affordability Trade

**In-Space System (I-SS)**
- Space-Based Space Weather Monitor (SWM) for Space-Weather Predictions and Status
- Far-Side Telecommunications Coverage Using Two-Ball EML2 Halo Constellation
- Optional Near-Side Constellation for Prox Ops
# System of Systems Trades

## Trade Area

<table>
<thead>
<tr>
<th>Trade Area</th>
<th>Trade Options</th>
<th>Initial Concept Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spiral 2 Base Crew Size</td>
<td>1 2 3 4 5 6 8 10</td>
<td>Two Buddy Teams, Affordability</td>
</tr>
<tr>
<td>Spiral 3 Base Crew Size</td>
<td>1 2 3 4 5 6 8 10</td>
<td>Two Buddy Teams, Affordability</td>
</tr>
<tr>
<td>Spiral 2 Unresupplied Base Endurance</td>
<td>5 days 15 days 30 days 60 days</td>
<td>Operations Over Entire Lunar Month</td>
</tr>
<tr>
<td>Spiral 3 Unresupplied Base Endurance</td>
<td>30 days 90 days 180 days 600 days</td>
<td>Threshold for Sustainable Operations</td>
</tr>
<tr>
<td>Crew Near-Earth Assy Orbit</td>
<td>None - Direct  LEO  MEO</td>
<td>Improved PLOC, Easy Abort to Earth</td>
</tr>
<tr>
<td>Cargo Near-Earth Assy Orbit</td>
<td>None - Direct  LEO  MEO</td>
<td>Easier, More Rapid Launch of Spares</td>
</tr>
<tr>
<td>Crew Near-Lunar Assy Orbit</td>
<td>None  Polar  EML1  Equatorial  Cycler  Deep Space</td>
<td>Safe, Earth, and Lunar Access/Logistics</td>
</tr>
<tr>
<td>Cargo Near-Lunar Assy Orbit</td>
<td>None  Polar  EML1  Equatorial  Cycler  Deep Space</td>
<td>Mass/Cost, 10% Lower dV Than EML1</td>
</tr>
<tr>
<td>Lunar Base Deployment Plan</td>
<td>Robotic Pre-Established Base</td>
<td>Crew Safety</td>
</tr>
<tr>
<td>Lunar Base Location</td>
<td>Equatorial Limb  Polar  Meridional  Far Side</td>
<td>Mare/Highlands Interface, Full Sky</td>
</tr>
<tr>
<td>Docking Port Type</td>
<td>Crew Specific  Common  Cargo Specific  Surface Specific</td>
<td>Flexibility, Evolvability / Extensibility</td>
</tr>
<tr>
<td>Avionics and Software Architecture</td>
<td>Modular Reconfigurable  Module Specific</td>
<td>Reliability, Mars Extensible</td>
</tr>
</tbody>
</table>

## Key Trade Options

- Proposed Initial Concept
- Key Trade Options
Surface System Trades

<table>
<thead>
<tr>
<th>Trade Area</th>
<th>Trade Options</th>
<th>Initial Concept Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Setup Assy and Control</td>
<td>Robotic, Teleoperated Ground Controlled, Crew</td>
<td>Flexibility, Affordability</td>
</tr>
<tr>
<td>Habitat Construction</td>
<td>Rigid Deployable, Inflatable, Landed Modules, Translunar Tanks</td>
<td>Rigid Modules Proven on ISS</td>
</tr>
<tr>
<td>Habitat Radiation Shielding</td>
<td>Regolith “Insulation”, Prefabricated shield, Underground</td>
<td>Reduces Landed Mass of Modules</td>
</tr>
<tr>
<td>Extent of Hab Rad Shielding</td>
<td>Fully Shielded Habitat, Safe-Haven Shelter</td>
<td>Balanced Design Maximizes Safety/kg</td>
</tr>
<tr>
<td>Spiral 2 Base Power Source</td>
<td>RTG, Photovoltaic, Nuclear, From EML1, Fuel Cell</td>
<td>Affordable Initial Lunar Night Capability</td>
</tr>
<tr>
<td>Spiral 3 Base Power Source</td>
<td>RTG, Photovoltaic, Nuclear, From EML1, Fuel Cell (Backup)</td>
<td>Lunar Sustainability, Mars Extensibility</td>
</tr>
<tr>
<td>Base Power Storage</td>
<td>Fuel Cells, Batteries, Mechanical</td>
<td>More Robust, Less Complex</td>
</tr>
<tr>
<td>Ingress-Egress Methods</td>
<td>Air/Dust Locks, Depressurize Hab Module, Via Pressurized Rover</td>
<td>Reduces Risk, Inc Crew Safety</td>
</tr>
<tr>
<td>Landing Zone Separation</td>
<td>None (Land in Place), 1 km, 3+ km</td>
<td>Crew Safety and Base Sustainability vs Mobility</td>
</tr>
<tr>
<td>Base Element Offload/Transport</td>
<td>None (Land in Place), Self-Mobile, Dedicated Transporter</td>
<td>Safety and Requirements Simplicity</td>
</tr>
<tr>
<td>Crew Mobility Enablers</td>
<td>None, Short-Range Rovers (Unpress), Mobile Labs (Long Range)</td>
<td>Logistics Affordability, Science Quality</td>
</tr>
<tr>
<td>Mobility Control</td>
<td>Autonomous, Crew Operated, Base Operated, Ground Operated</td>
<td>Safety and Exploration Quality</td>
</tr>
<tr>
<td>Surface EVA Spacesuit</td>
<td>Orlan Derived, Shuttle Derived, New Robotic Enhanced, Exterior Only W Airlock UF</td>
<td>Commonality, Cost</td>
</tr>
</tbody>
</table>

Proposed Initial Concept
Key Trade Options
# Crew Transportation System Trades

<table>
<thead>
<tr>
<th>Trade Area</th>
<th>Trade Options</th>
<th>CLV</th>
<th>Initial Concept Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crew Launch Vehicle (CLV)</td>
<td>EELV-M</td>
<td>EELV-H</td>
<td>Safety: Propulsion, Staging, and Abort</td>
</tr>
<tr>
<td></td>
<td>Atlas V CCB + ETS</td>
<td>Zenit S1 + ETS</td>
<td>Smaller, Lower-Cost RM, Multifunction HM</td>
</tr>
<tr>
<td>Crew Accom Partitioning</td>
<td>Separate RM and HM</td>
<td>Single Crew Space</td>
<td>Flexibility, Evolvability/Extensibility</td>
</tr>
<tr>
<td>Service Module Partitioning</td>
<td>Integrate SM with RM</td>
<td>Maintain Separate Module</td>
<td>Flexibility, Mars Extensibility</td>
</tr>
<tr>
<td>Docking Port Hardware</td>
<td>LIDS Derived</td>
<td>Existing (APAS/Russian)</td>
<td>Flexibility, Mars Extensibility</td>
</tr>
<tr>
<td>ETS and Lander Propulsion Safety</td>
<td>Engine-Out Capability</td>
<td>Increased Engine Reliability</td>
<td>Redundancy for Crew Safety</td>
</tr>
<tr>
<td>CLV Launch Pad</td>
<td>Mod Atlas Pad</td>
<td>Mod Shuttle Pad</td>
<td>Optimized for Safety, Avoids Access Conflicts</td>
</tr>
<tr>
<td>Crew Trans Propellant Tanks</td>
<td>Composite</td>
<td>Metal</td>
<td>Lower Mass/System Cost, Insulation/MMOD Benefits</td>
</tr>
<tr>
<td>Crew Trans Lunar (ETS) Propulsion</td>
<td>LOX/LH₂</td>
<td>Nuclear-Electric</td>
<td>Lowest Risk, Fast Transfer</td>
</tr>
<tr>
<td>Crew Lander Configuration</td>
<td>Staged</td>
<td>Reusable</td>
<td>LV Limited, Crew Safety</td>
</tr>
<tr>
<td>Crew Lander Propulsion</td>
<td>Storable</td>
<td>LOX/Ethanol</td>
<td>Lower Mass and System Cost</td>
</tr>
</tbody>
</table>

**Key Issues**

- Proposed Initial Concept
- Key Trade Options
# Cargo Transporation System Trades

## Trade Area

<table>
<thead>
<tr>
<th>Cargo Translunar Propulsion</th>
<th>Cargo Lander Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOX/LH₂</td>
<td>Same as Crew Trans (No Ascent)</td>
</tr>
</tbody>
</table>

## Trade Options

<table>
<thead>
<tr>
<th>Spiral 2 Noncrew LV System</th>
<th>Noncrew Launch Procurement</th>
<th>Maximum LEO Launch Mass</th>
<th>Cargo Load Size Standardization</th>
<th>Cargo Translunar Propulsion</th>
</tr>
</thead>
<tbody>
<tr>
<td>EELV-H</td>
<td>Commercial</td>
<td>30t</td>
<td>Mission Specific</td>
<td>LOX/LH₂</td>
</tr>
<tr>
<td>EELV Derived</td>
<td>NASA</td>
<td>40t</td>
<td>Crew Trans Driven Std</td>
<td>Nuclear-Electric</td>
</tr>
<tr>
<td>Shuttle Derived</td>
<td>Mission Specific</td>
<td>55t</td>
<td>Surface Sys Driven Std</td>
<td>Solar-Electric</td>
</tr>
<tr>
<td>New Heavy Lift</td>
<td>Mostly Fixed Size (55t)</td>
<td>70t</td>
<td></td>
<td>Nuclear-Thermal</td>
</tr>
<tr>
<td>International</td>
<td>Reusable/Refuel</td>
<td>90t</td>
<td></td>
<td>Reusable/Refuel</td>
</tr>
<tr>
<td>Hybrid</td>
<td>Refueling or High Isp Cargo Propulsion</td>
<td>130t</td>
<td></td>
<td>Refueling or High Isp Cargo Propulsion</td>
</tr>
</tbody>
</table>

## Initial Concept Rationale

- **Affordable Development**
- **Competition for Multiple Units, Lower Cost**
- **Balance of Affordability / Reliability**
- **Commonality for Affordability / Reliability**
- **Commonality for Affordability / Reliability**
- **Commonality for Affordability / Reliability**

---

**Key Issues**

- Proposed Initial Concept
- Key Trade Options
Driving Architecture Issues

- Scope of Initial and Evolved Lunar Infrastructure
- CEV Crew Size / Crew Exchange Manifesting
- Staging Approach
- Viability of In-Situ Resource Utilization
- Non-Crewed Spacelift Payload Size vs. Number of Flight Elements
  - Larger: Fewer launches, Simpler in-space ops, Traditionally more reliable
  - Smaller: Higher flight rate > Requires reliable multi-element in-space operations and responsive-spacelift
- Effectiveness of Refueling / Reusable Elements
  - Higher payoff for Lander and Transfer Stages
  - Propellant modules vs. Propulsion modules vs. Propellant transfer
  - Reuse of tankage – surface habitats, in-situ resource storage
- Effectiveness of High Isp Propulsion Transfer for Lunar Missions
- Engaging Broader Communities – Effect on Requirements