Agenda

• Objectives
  – Influence of Vision for Space Exploration
  – SuperSystem analogies
  – Innovation
  – Summary of objectives

• Architecture
  – Concept overview
  – Features
  – Modeling, simulation, analysis

• Issues
Objectives of the President’s Vision

- Implement a sustained and affordable human and robotic program
- Extend human presence across the solar system
- Develop the innovative technologies, knowledge, and infrastructures to explore and support decisions
- Promote international and commercial participation in exploration

- Sustainability
  - SoS, SoMSS
  - Robustness to historical challenges, failures of system elements
- Affordability
  - Predictability
  - Absolute vs. relative measures of cost
  - Cost analysis vs. economic analysis
  - Marginal efficiency of investment
Architectural SuperSystem Analogies

- Commercial aircraft transportation
  - Hubs, spokes, routes
  - Platforms, payloads, crew, cargo
  - Figures of merit and measures of effectiveness (ASM, RPM, Load Factor, CASM, Stage Length)
  - Platform trades: RJ/737/747 vs. HSCT vs. A380

- Military campaign logistics
  - Strategic operational and tactical levels of support
  - Deployment of humans, platforms, resources to accomplish short and extended-duration missions
  - Sustainability and ISRU must be considered

SuperSystem Networks Emerge Larger and More Capable Than Individual Systems
Architectural Development and Evaluation - Innovation

- Technology infusion and technology harvest (spin-in)

- Identification of Drivers
  - Design, Schedule, Cost
  - Identify What is Important and What is Not
    - Focus on Drivers – Analysis, Test, Technology Investment
  - Evaluation Against Traditional and Non-Traditional FOMs

We Leverage DoD Program Experience and Methodologies
## Objectives

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Architectural Implications and Choices</th>
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<tr>
<td>Establish a robust, sustainable program of exploration</td>
<td>• Open Architecture for spiral upgrades&lt;br&gt;• Redundant/complementary HW and systems with overlapping functionality&lt;br&gt;• Pre-positioning of supplies&lt;br&gt;• Support human/robotic missions with cost effective transport&lt;br&gt;• Design for repair/maintenance&lt;br&gt;• Separate Crew and Cargo&lt;br&gt;• Use lessons learned from DoD</td>
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<td>Enable a self-sustaining market-based space economy</td>
<td>• Widen competition by increasing opportunities within a system of standards for packaging, power, thermal management, and communications to create economic diversity (including international participation)&lt;br&gt;• Adapt and “Spin-in” commercial technologies for wider application.&lt;br&gt;• Flexible logistics</td>
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<td>Foster U.S. national defense and economic security</td>
<td>• Frequent, assured access to space using variety of ELVs&lt;br&gt;• Increase international participation in exploration diverts intellectual resources from potentially destructive pursuits&lt;br&gt;• US development of robotics&lt;br&gt;• Modularity [compartmentalization] for flexible adaptation to new or emerging security objectives</td>
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Architecture Concept Overview

**Architectural Nodes**

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<tr>
<th>Architectural Nodes</th>
<th>Capabilities/Elements</th>
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<tbody>
<tr>
<td>Earth</td>
<td>Test &amp; Production, Launch, Mission Control/Support</td>
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<tr>
<td>LEO Gateway (Initially ISS)</td>
<td>Module Docking, Refueling, Stockpiles, Safe Haven, Medical, Robotic Services, Micro Gravity Science</td>
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<tr>
<td>L1 Gateway (Orbit L1 Point)</td>
<td>Module Docking, Refueling, Stockpiles, Safe Haven, Medical, Robotic Services, ComSat/NavSat, Sensor Network</td>
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<tr>
<td>Lunar (Evolving)</td>
<td>Long Term Habitat, In-Situ Processing (Feasibility), Long-Term Science, Extensible to Mars</td>
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<tr>
<td>Mars &amp; Beyond</td>
<td>Long Term Habitat, In-Situ Utilization, Long-Term Science</td>
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Gateway Concept Includes Architecture Nodes and Transport Modes
## Architecture Features

<table>
<thead>
<tr>
<th>Transport Modes</th>
<th>Human (Prioritize Safety)</th>
<th>Cargo (Optimize For Cost/Risk)</th>
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<tbody>
<tr>
<td>Earth to LEO (Most Costly)</td>
<td>Human-Rated ELV Systems; CEV-Mod-E (Capsule + Abort Tower)</td>
<td>Existing ELVs; Distribute Risk; Fully Autonomous, Standardized Packaging</td>
</tr>
<tr>
<td>LEO to/from L1 Gateway to/from Lunar Orbit</td>
<td>CEV-Mod-L (Capsule, Crew Habitat, Resource Module, Propulsion)</td>
<td>Efficient (e.g. Electric Propulsion) Convoys to achieve Stockpiles</td>
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<tr>
<td>Orbit to/from Surface (Moon/Mars)</td>
<td>Lander, Rover, Hopper, Ascent Stage</td>
<td>Autonomous, Robotic Procedures In-Situ Fuel Source</td>
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<tr>
<td>Gateway (LEO or L1) to/from Interplanetary</td>
<td>CEV-Mod-I (Capsule, Crew Habitat, Resource Module, Power, Extended Propulsion)</td>
<td>Efficient (e.g. Electric Propulsion) Prepositioning of Supplies/Backup</td>
</tr>
<tr>
<td>LEO to Earth (Highest Risk)</td>
<td>CEV-Mod-E (Capsule); Position Backups in LEO</td>
<td>Adapt Proven, e.g. Discoverer Capsules, for Specimen Return (Ballistic Recovery)</td>
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Platform/Vehicle Designs Are Driven by Transport Mode and Payload

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Architectural Modeling and Analysis - Innovation

- Modeling and simulation of architectures
  - Traditional – aero-performance & orbital mechanics based
  - Industrial – represent architecture process flows
    - Analyze flow of vehicles/platforms, crew, and cargo along nodal network
    - Similar to transportation models, warehouse management, inventory optimization

- Information Architecture, behavior modeling
  - Based on Systems Engineering methods appropriate for designing information-intensive systems
  - A single system definition that supports requirements definition, system development, testing, verification, and fielding/operation of the system

- Recognize and stimulate contributions of individuals
  - Promote innovative techniques

Our Team and Individual Experiences Provide Innovation
Cost Modeling and Analysis

- **Objective**
  - Estimate architecture costs and CEV spiral 1 costs
  - Make early use of cost estimates in evaluation of architecture exploration and refinement
    - Investigate sensitivities and drivers
  - Perform bi-directional economic impact analysis
    - Effects of architectural element choices and performance on architecture costs
    - Effects of architecture element choices on sustainability of program and economic/industrial base

- **Philosophy**
  - Recognize predictability of architecture costs
  - Understand importance of relative vs. absolute costs

- **Plans**
  - Expand cost modeling toolset with resources, data, benchmarking from Boeing and NASA sources
  - Perform cost/performance analysis as early as possible

Cost Modeling and Analysis is an Important Part of Our CE&R Program
### Issues - Enhancing Program Success

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<tr>
<th>Historical Challenges</th>
<th>Architectural Features Motivated to Respond to Difficulties</th>
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<tr>
<td>Program Funding Fluctuations</td>
<td>Incremental approach to development. Spiral Development and use/qualification of commercially components to achieve capability</td>
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<tr>
<td>Program Redirection – Political Changes</td>
<td>Develop an adaptable architecture composed of overlapping functionality to allow system flexibility and evolution</td>
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<td>Instability of International Partnerships</td>
<td>Segment missions based on critical US economic and security requirements and non-critical items to international participation</td>
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<tr>
<td>Volatile Science Objectives</td>
<td>Standard equipment interfaces and payload accommodations, use of science peer review process modeled on Hubble Space Telescope</td>
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<td>Public program support diminishing with time</td>
<td>Provide inspiration through regular significant events, establish broad contractual base, broad involvement and extensive education</td>
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<tr>
<td>Lack of predictable access to exploration data / results</td>
<td>Distributed nodes, vehicles, and sensors paired with high bandwidth data paths to provide abundant amounts of data</td>
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**Our Architectural Choices Apply Lessons Learned from Historical Challenges**
Issues – Focus Areas for CE&R

- Architectural analysis and evaluation
  - Apply more comprehensive models, and additional FOMs
  - Investigate performance and robustness with non-traditional models
  - Perform excursions around concept, and refinement
  - Investigate sensitivities for a variety of missions, campaigns
- Architectural modeling and simulation
  - Pursue traditional and non-traditional means to predict and assess
  - Support SBA activities and workshops
    - Apply and sustain M&S throughout life cycle
    - Virtual life cycle product validation prior to production
    - Sharing of models and data among industry and government stakeholders
- Technology evaluation
  - Investigate benefits from H&RT programs, other sources
  - Generate technology infusion plan
- Risk assessment
  - Update assessments and mitigations from pre-award activities

These Focus Areas Will Govern Our CA1 Activities
Summary

- Described Objectives, Architecture, and Issues
- Our concept is consistent with the President’s Vision
- We have developed our CE&R execution plan and are committed to the success of the program and look forward to working with NASA