Schafer Corporation
System Engineering and Integration Division

and

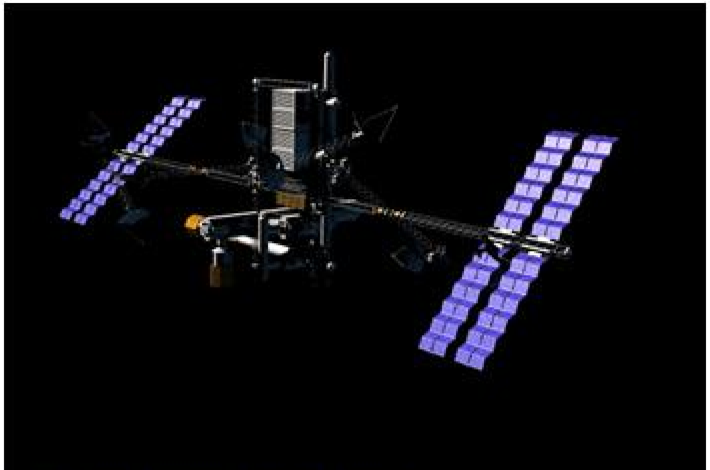
The Boeing Company
Phantom Works

September 13, 2004

Agenda

- Objectives
  - Influence of Vision for Space Exploration
  - SuperSystem analogies
  - Innovation
  - Summary of objectives
- Architecture
  - Concept overview
  - Features
  - Modeling, simulation, analysis
- Issues

Eagle Lunar Module, 1969



In-Space Module, Future Spiral

Objectives of the President's Vision

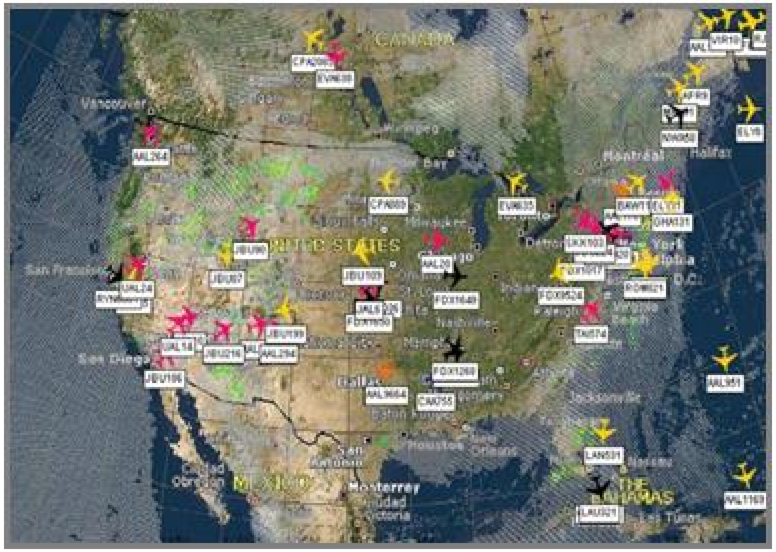
- *Implement a <u>sustained</u> and <u>affordable</u> human and robotic program*
- *Extend human presence across the solar system*
- *Develop the innovative technologies, knowledge, and infrastructures to explore and support decisions*
- *Promote international and commercial participation in exploration*

- 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

Our Architecture Objectives Are Based on the President's Vision

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



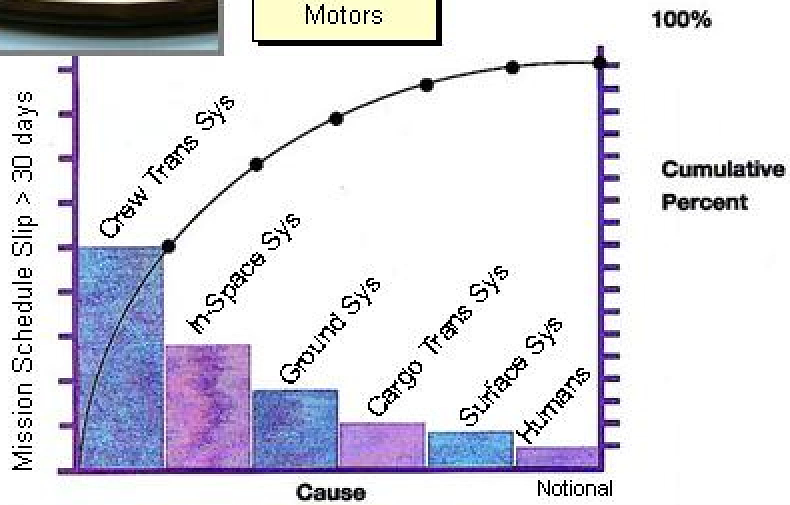
- Military campaign logistics
  - Strategic operational and tactical levels of support
  - Deployment of humans, platforms, resources to accomplish short and extended-duration missions
  - Sustainability and ISRU must be considered

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



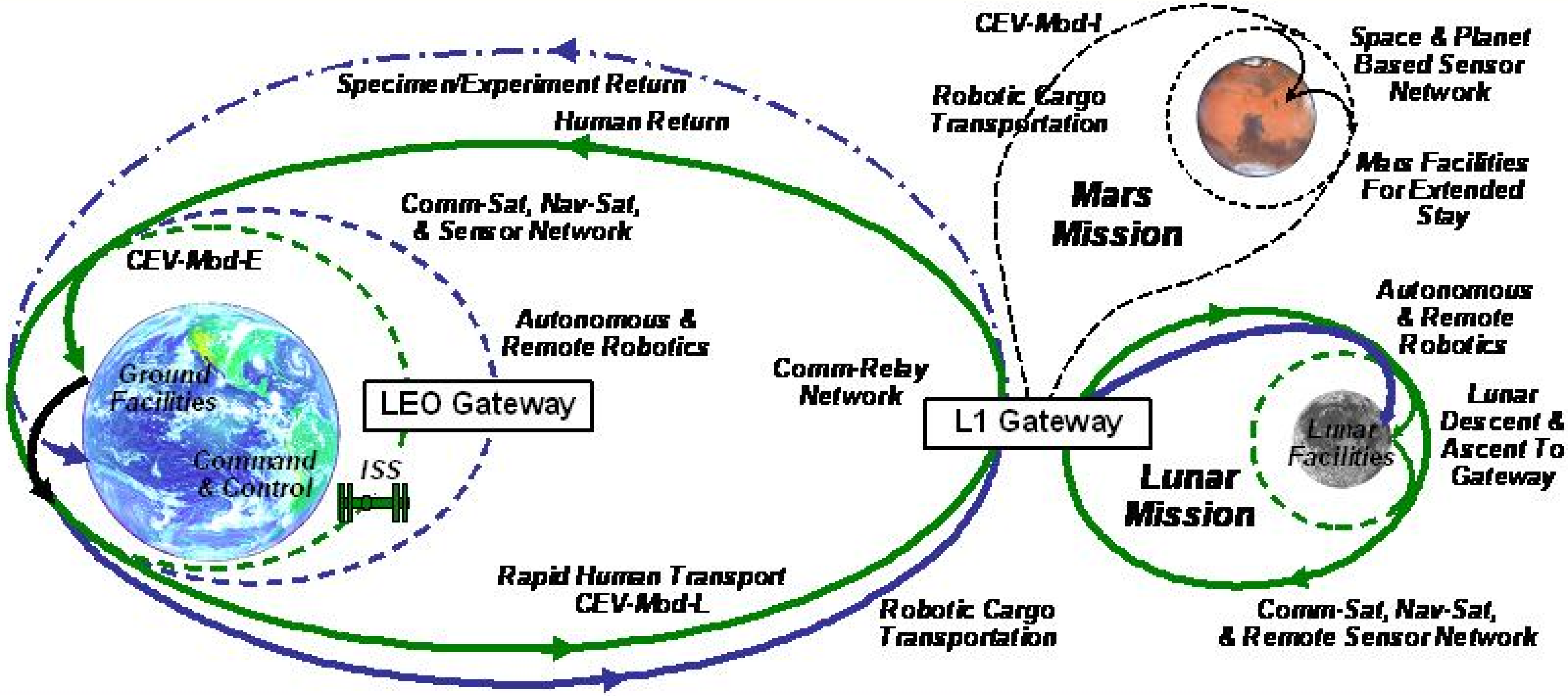
We Leverage DoD Program Experience and Methodologies

Objectives

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

Our Objectives Result in Architectural Implications and Choices

Architecture Concept Overview



Architectural Nodes	Capabilities/Elements
Earth	Test & Production, Launch, Mission Control/Support
LEO Gateway (Initially ISS)	Module Docking, Refueling, Stockpiles, Safe Haven, Medical, Robotic Services, Micro Gravity Science
L1 Gateway (Orbit L1 Point)	Module Docking, Refueling, Stockpiles, Safe Haven, Medical, Robotic Services, ComSat/NavSat, Sensor Network
Lunar (Evolving)	Long Term Habitat, In-Situ Processing (Feasibility), Long-Term Science, Extensible to Mars
Mars & Beyond	Long Term Habitat, In-Situ Utilization, Long-Term Science

Gateway Concept Includes Architecture Nodes and Transport Modes

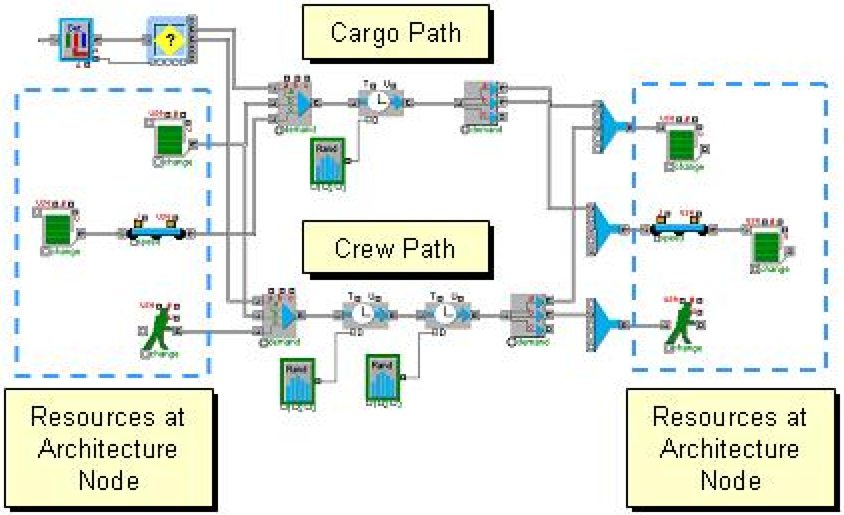
Architecture Features

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

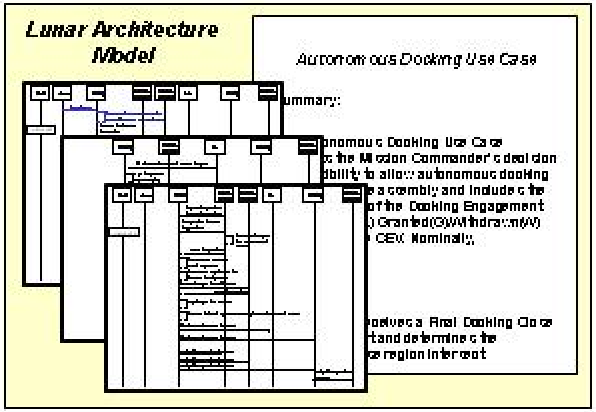
Platform/Vehicle Designs Are Driven by Transport Mode and Payload

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 <u>individuals</u>
  - Promote innovative techniques



Our Team and <u>Individual</u> 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

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

Our Architectural Choices Apply Lessons Learned from Historical Challenges

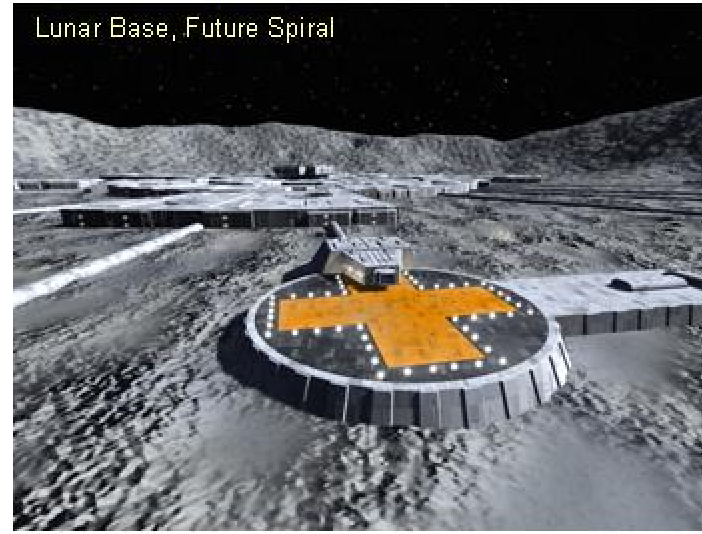
Issues – Focus Areas for CE&R

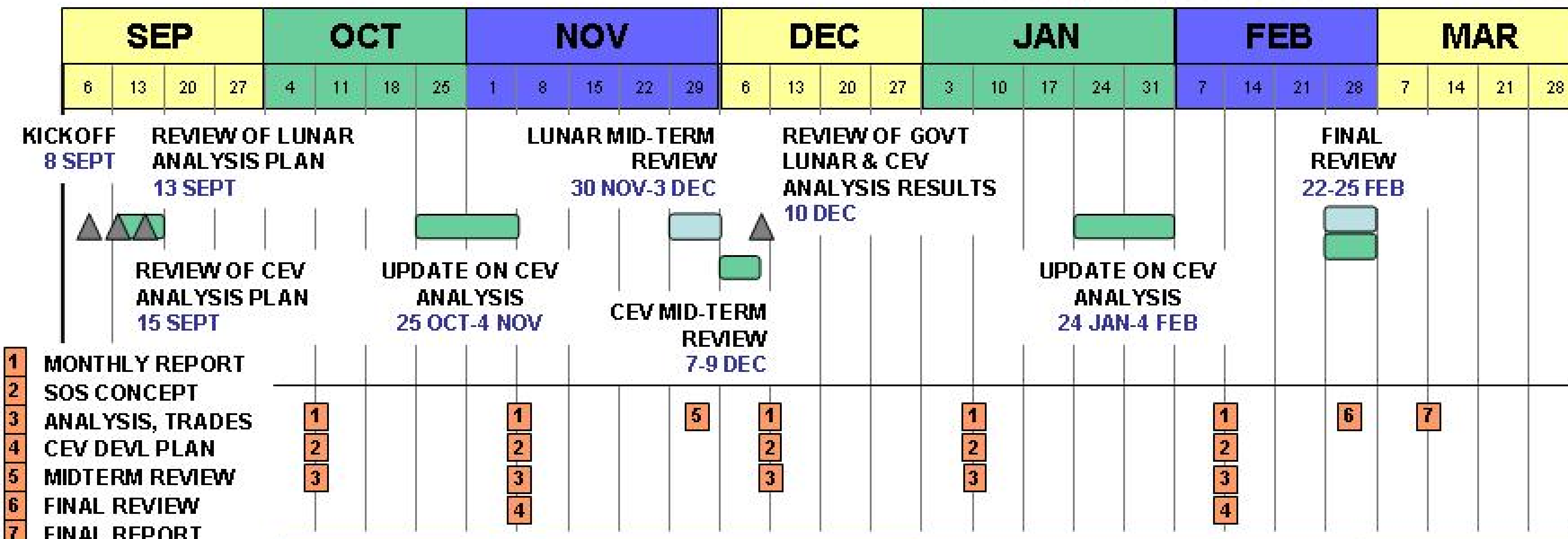
- Architectural analysis and evaluation
  - Apply more comprehensive models, and additional FOMs
  - Investigate performance and robustness with non-traditional models
  - Perform excursions around concept, and refinement
  - Investigate sensitivities for a variety of missions, campaigns
- Architectural 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





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