The NASA Exploration Vision

- Complete the International Space Station
- Safely fly the Space Shuttle until 2010
- Develop and fly the Crew Exploration Vehicle no later than 2014 (goal of 2012)
- Return to the Moon no later than 2020
- Extend human presence across the solar system and beyond
- Implement a sustained and affordable human and robotic program
- Develop supporting innovative technologies, knowledge, and infrastructures
- Promote international and commercial participation in exploration

NASA Authorization Act of 2005

The Administrator shall establish a program to develop a sustained human presence on the Moon, including a robust precursor program to promote exploration, science, commerce and U.S. predominance in space, and as a stepping stone to future exploration of Mars and other destinations.
Themes of NASA Exploration Program

**Human Civilization**
Extend human presence to the Moon to enable eventual settlement.

**Global Partnerships**
Provide a challenging, shared and peaceful activity that unites nations in pursuit of common objectives.

**Scientific Knowledge**
Pursue scientific activities that address fundamental questions about the history of Earth, the solar system and the universe - and about our place in them.

**Economic Expansion**
Expand Earth's economic sphere, and conduct lunar activities with benefits to life on the home planet.

**Exploration Preparation**
Test technologies, systems, flight operations and exploration techniques to reduce the risks and increase the productivity of future missions to Mars and beyond.

**Public Engagement**
Use a vibrant space exploration program to engage the public, encourage students and help develop the high-tech workforce that will be required to address the challenges of tomorrow.

**The Constellation Vehicles**

- **Earth Departure Stage**
- **Orion - Crew Exploration Vehicle**
- **Ares V - Heavy Lift Launch Vehicle**
- **Ares I - Crew Launch Vehicle**

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The Exploration Roadmap

A Typical Constellation Mission
Communication During An Early Mission

Communications During a Later Mission
**Constellation Capability Evolution**

- **Initial ISS Capability**
  - Ares Crew Launch Vehicles (CLV)
  - Orion Crew Exploration Vehicles (CEV)
  - International Space Station (ISS)

- **Lunar Sortie & Outpost Buildup**
  - Cargo Launch Vehicles (CLV)
  - Earth Departure Stage (EDS)
  - Lunar Surface Access Module (LSAM)
  - EVA crewmembers
  - Unpressurized rovers
  - Habitation modules
  - Robotic rovers
  - Power Stations
  - Science instruments
  - Logistics carriers
  - Communications relay satellites/terminals
  - Regolith Movers
  - Pressurized rovers
  - In-Situ Resource Units (O2 from Regolith)

**Constellation Challenges**

- **Initial ISS Capability**
  - Ares Crew Launch Vehicles (CLV)
  - Orion Crew Exploration Vehicles (CEV)
  - International Space Station (ISS)

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- **Key Challenges for Exploration**
  - Ever Growing Complexity
  - Operations Costs
  - Life Cycle Costs
  - Flexibility to Support Broad Scope of Activities

- **Key Focus Areas**
  - Commonality
  - Interoperability
  - Flexibility
  - Evolvability

- **Operations Challenges**
  - Support simultaneous operations of multiple, diverse systems
  - Support increasing automation
  - Support migration of functions from ground to lunar base
The C3I Vision

- All Systems (space and ground based) will be able to communicate with (and through) any other System
  - Network infrastructure (routers and radios)
  - Security infrastructure (encryption, key management, information assurance tools)
  - Information infrastructure (information model & framework)

- All Systems will contain a minimal set of unique data interfaces, any of which will be capable of flowing system data (including voice, video, telemetry, instrument data, etc..)

- Integrated System costs will be minimized through the use of open architectures, well defined industrial / open standards, and common product-line based systems

- "Plug-n-Play" interfaces will developed to help facilitate the continual Systems evolution expected over the multi-decade life of the program
  - The evolution of Systems will allow the introduction of new requirements and the timely leveraging of technology advances
  - System designs will be constructed to allow the addition and/or removal of elements or element features with minimal impact to the System or integrated Systems

- Anyone, anywhere, can access any system or system information from anywhere in the Cx architecture (as constrained by the appropriate security policies).

Key Defense: Architectural Shearing

- Consider layers of structural architecture
  - site
  - structure
  - skin
  - services
  - space plan
  - stuff

- Different rates of change between layers can tear a building apart

- Defense: "Architectural Shearing" =
  - ability to separate layers non-destructively
  - discipline about shear boundary, who decides, when changed
C3I Overview

- **Layered approach**
  - Isolates change impacts (enabling evolution)
  - Based on industry standards.
  - Includes publish & subscribe messaging framework (enabling plug-n-play applications by establishing well defined data interfaces).

- **Interoperability**
  - Focus on standards and approaches that enable interoperability between systems.
  - Establish small set of interface standards & reduce possible number of interface combinations.
  - Requires interoperability at all layers: communications, networks, security, C2, and information.

C3I Architecture - Breaking It Down

C3I architecture decomposes into five main technical areas.

- **Command & Control**
- **Information**
- **Security**
- **Network**
- **Communications**
C31 Communication Link Types

Constellation communications take many forms, so C31 link classes are defined based on operational use:

- **Point-to-Point (S-Band)**
  - High reliability, high availability command, telemetry and tracking
  - Operational voice, engineering data, "housekeeping"
  - Moderate data rates

- **High Rate (Ku-Band)**
  - High volume science & PAO data transfer
  - Non-operational data trunking
  - Lower availability, low criticality

- **Multipoint**
  - Surface area networks (multiple EVA crew and surface systems)
  - Robotic and science coordination, telepresence and tele-operation

- **Contingency (UHF)**
  - Highly reliable, low rate communication
  - Provide critical voice to support crew in recovering from an anomaly
  - Compatibility with international and US distress alerting and SAR systems

- **Internal Wireless (802.x)**
  - Portable equipment connections (PDAs, PCs)
  - Vehicle sensors and instrumentation
  - Crew bio-telemetry
  - Adaptive logistics (equipment location & status, resource monitoring)

- **Hard-line (1394b)**
  - Multicast, GSE interfaces, Inter-System connections

Network-Based Systems:
Network of Networks

- **Internet Protocol (IP) Packet Format**
  - All communications paths use common IP protocol.
  - Includes IP Quality of Service (QoS) capabilities for priority data transmission.
  - Includes address based routing through the network.

- **Wide area network**
  - Comprised of communications links between systems (MCC, LCC, CEV, LSAM, etc.)
  - Includes both terrestrial, hard-line, and RF links.

- **Local area networks**
  - Ideal assumes each system contains some configuration of a local IP network.
  - Gateway function ensures efficient/appropriate communications across wide area (inter-system) links.
    - Sends voice, commands, telemetry, video, data per priority scheme (consider this like current telemetry modem list capability).
    - Ensures received commands are authenticated, decrypted, and verified against acceptance criteria.
Command & Control Applications

- **Framework-based applications**
  - Uses standard interface to access data.
  - Allows for use anywhere on the framework (i.e., reusable, migratable)

- **Data-driven applications**
  - Recommend generalized applications that may be used with multiple elements (to prevent sustaining unique tools for each element).
  - Common, generalized applications should increase reliability over time (smaller code base applied to a broader operational profile) compared to stovepipe applications.
  - Tied to information model/management system.

- **Service Interfaces**
  - Network centric “service-oriented” interfaces allow for access of common services from anywhere on the network.

Information Architecture

- Infrastructure – Registries & Services
- Models – Formal descriptions of information
- Data Assets – Original sources/data repository
- Data Exchanges – Standardized protocols and formats

Processes for efficient collection and maintenance of system/manufacture configuration
C31 Architectural Phasing

- **Orion to ISS (common interfaces)**
  - Common communications frequencies, formats, & protocols
  - IP network based command, telemetry, voice, video, and files.
  - Static network routing.

- **Lunar Sortie (common systems)**
  - Common ground control systems based on common C31 Framework and Cmd/Ctrl components (software)
  - Common communications adapter product line
  - Limited dynamic network routing.
  - Limited C31 Framework based flight software.

- **Lunar Outpost (common adaptive systems)**
  - C31 Framework based flight software.
  - Dynamic network routing.
  - Adaptive, demand-driven communications.
  - Disruption/Delay Tolerant Networking (DTN)

Lessons Learned

- Operations concepts are highly effective for:
  - Developing consensus
  - Discovering stakeholder needs, goals, objectives
  - Defining behavior of system components (especially emergent behaviors)

- An interoperability standard can provide an excellent lever to define the capabilities needed for system evolution

- Two categories of architectures are needed in a program of this size
  - Generic - Needed for planning, design and construction standards
  - Specific - Needed for detailed requirement allocations, interface specs

- A wide variety of architectural views are needed to address stakeholder concerns
  - Physical
  - Information (structure, flow, evolution)
  - Processes (design, manufacturing, operations)
  - Performance
  - Risk
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