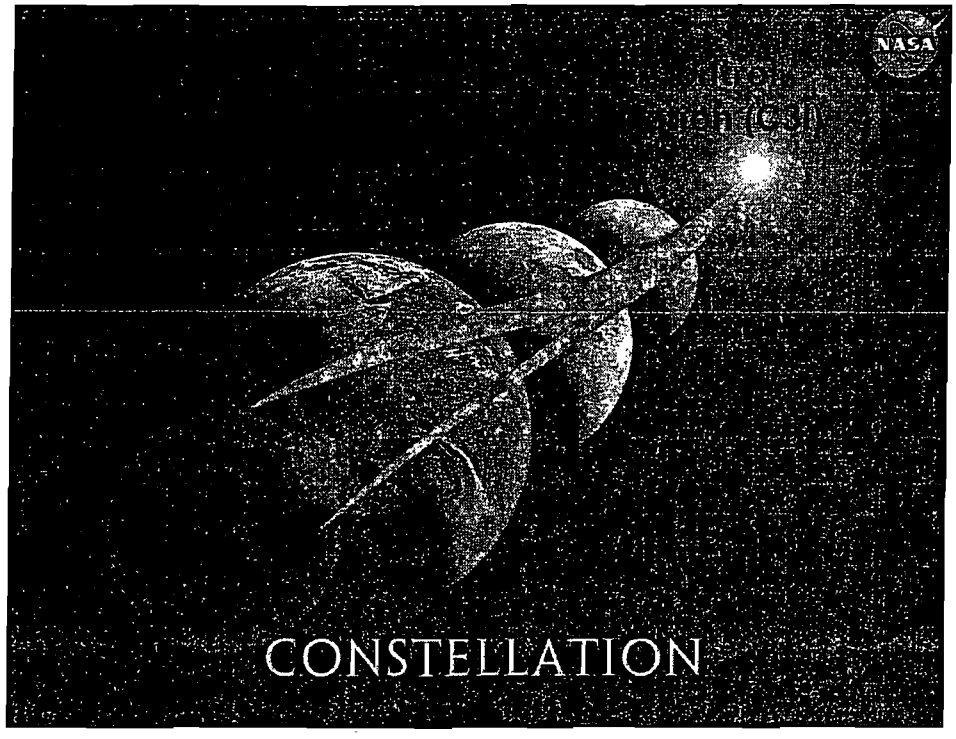
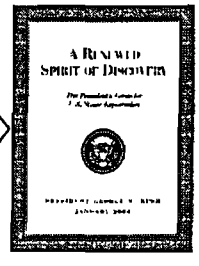


CONSTELLATION

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

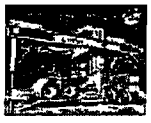
The Administrator shall establish a program to develop a sustained human presence on the Moon, including a robust precursor program to promote exploration, science, commerce and U.S. preeminence in space, and as a stepping stone to future exploration of Mars and other destinations.

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.

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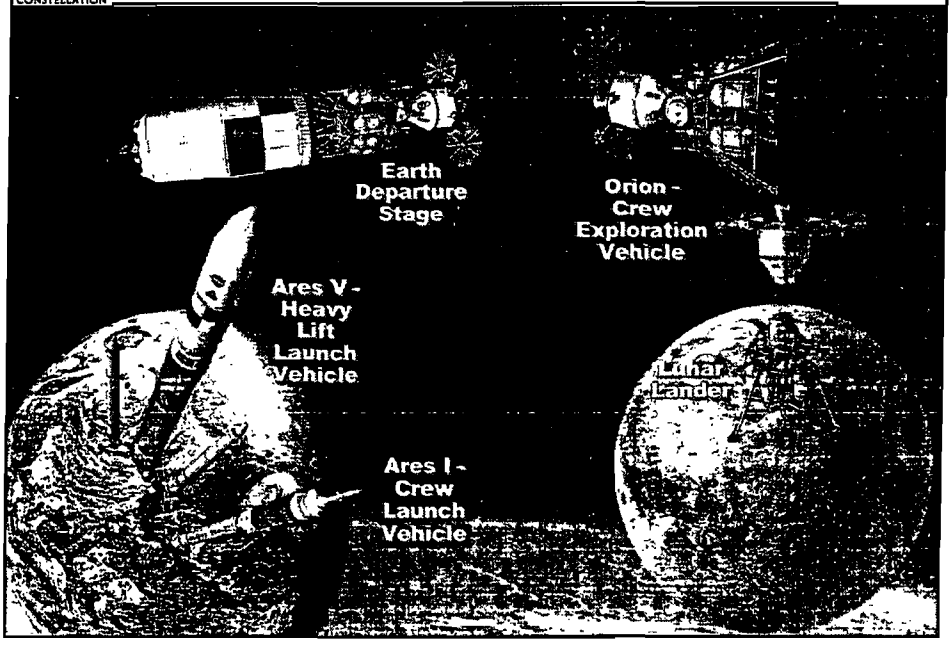
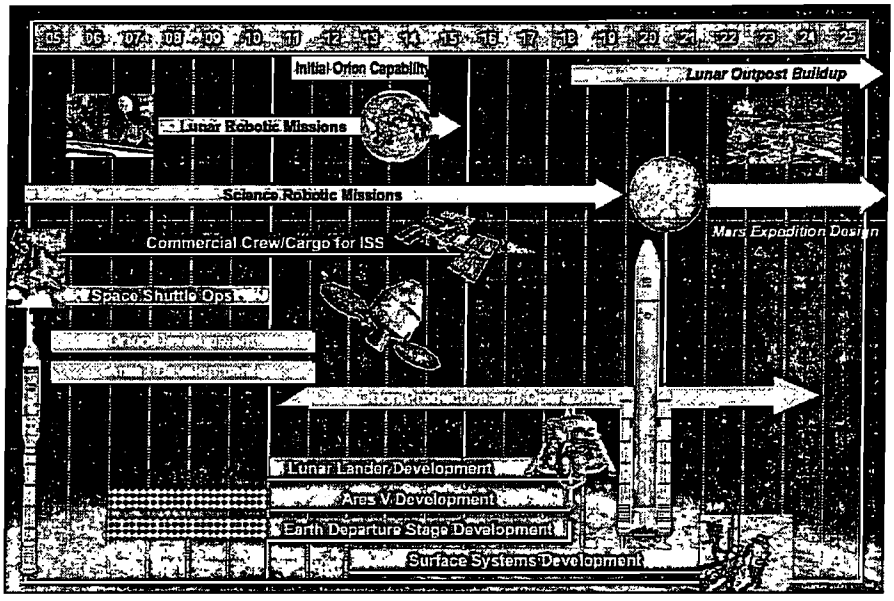
The Constellation Vehicles



The Exploration Roadmap



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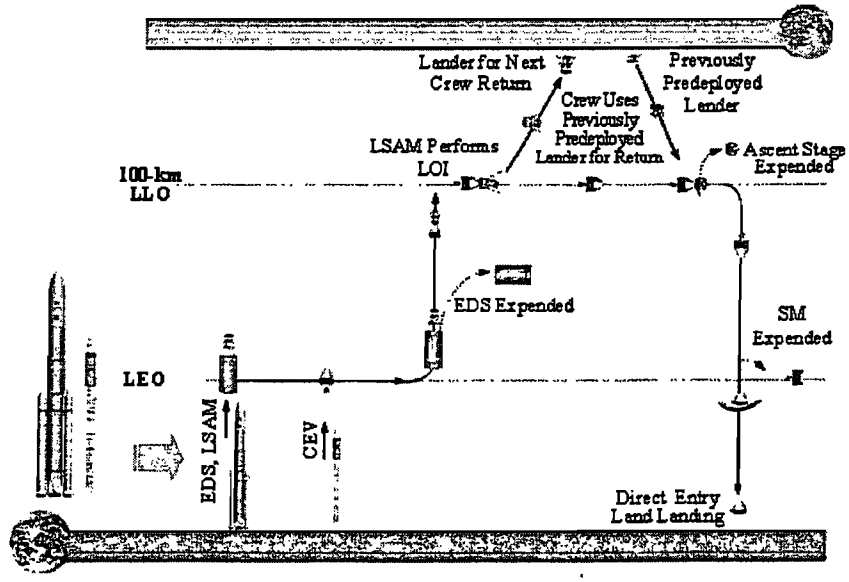
A Typical Constellation Mission



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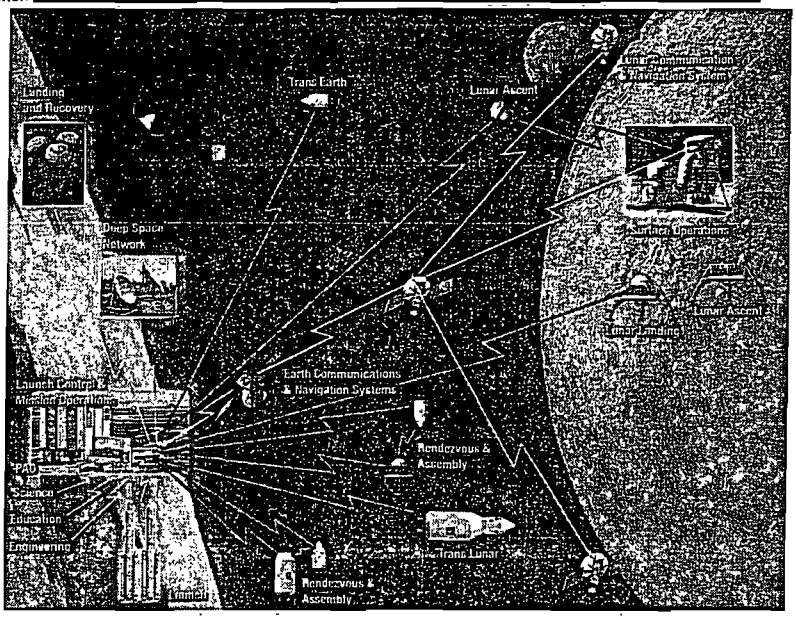
Communication During An Early Mission



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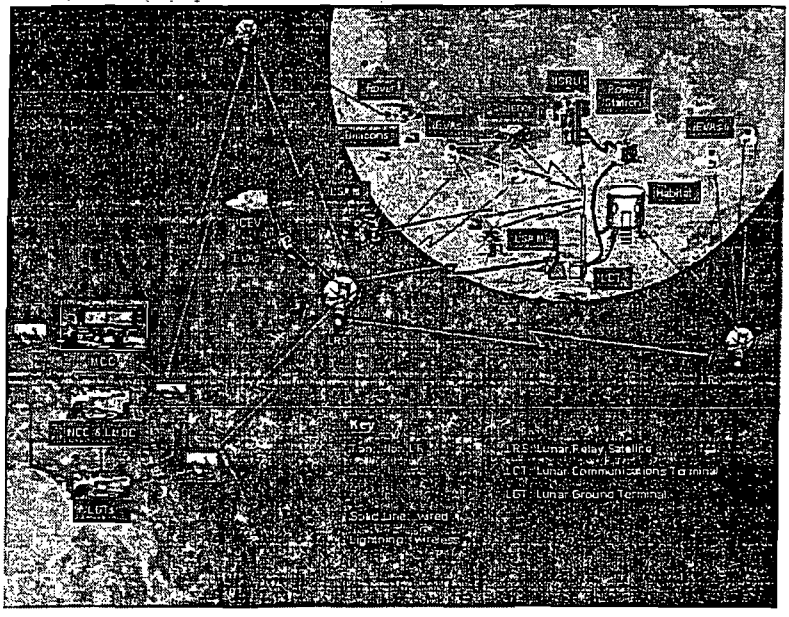
Communications During a Later Mission



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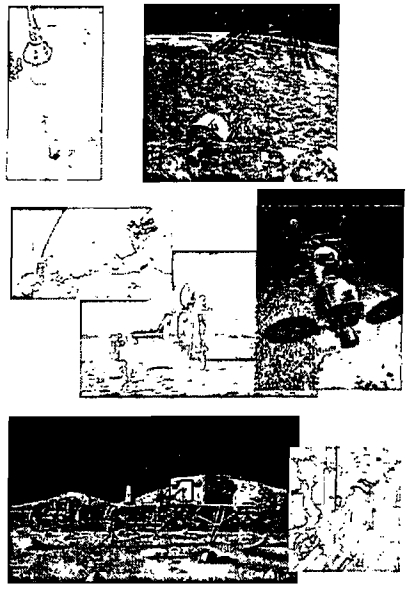
Constellation Capability Evolution

- **Initial ISS Capability**
  - Ares Crew Launch Vehicles (CLV)
  - Orion Crew Exploration Vehicles (CEV)
  - International Space Station (ISS)
- **Lunar Sortie & Outpost Buildup**
  - Cargo Launch Vehicles (CaLV)
  - 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)
- **Lunar Sortie & Outpost Buildup**
  - Cargo Launch Vehicles (CaLV)
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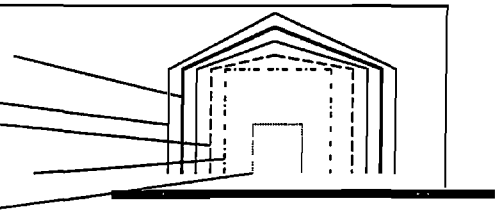
  - Power Stations
  - Science instruments
  - Logistics carriers
  - Communications relay satellites/terminals
  - Regolith Movers
  - Pressurized rovers
  - In-Situ Resource Units (O2 from Regolith)
- **Key Challenges for Exploration**
  - Ever Growing Complexity
  - Operations Costs
  - Life Cycle Costs
  - 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).

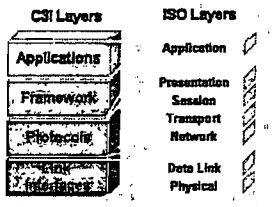
Key Defense: Architectural Shearing

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



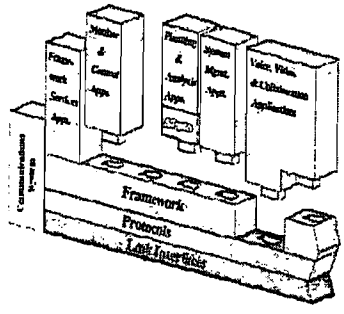
- **Different rates of change between layers can tear a building apart**
- **Defense: "Architectural Shearing" =**
  - ability to separate layers non-destructively
  - discipline about shear boundary, who decides, when changed

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).

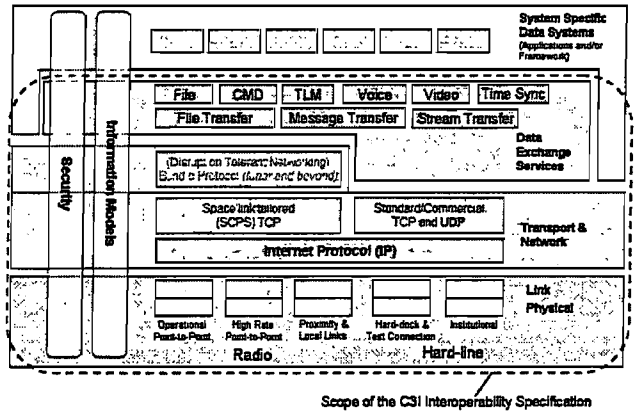
- **Interoperability**
  - Focus on standards and approaches that enable interoperability between systems.
  - Establish small set of interface standards & reduce possible number of interface combinations.
  - Requires interoperability at all layers: communications, networks, security, C2, and information.



C3I Architecture – Breaking It Down

C3I architecture decomposes into five main technical areas.

- **Command & Control**
- **Information**
- **Security**
- **Network**
- **Communications**

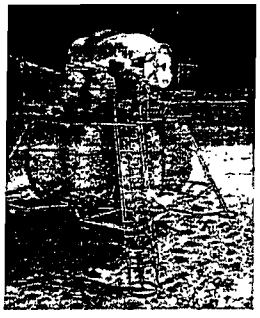


Scope of the C3I Interoperability Specification

C3I Communication Link Types

Constellation communications take many forms, so C3I link classes are defined based on operational use:

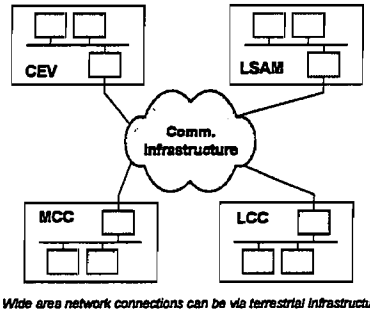
- **Point-to-Point (S-Band)**
  - High reliability, high availability command, telemetry and tracking
  - Operational voice, engineering data, "housekeeping"
  - Moderate data rates
- **High Rate (Ka-Band)**
  - High volume science & PAO data transfer
  - Non-operational data trunking
  - Lower availability, low criticality
- **Multipoint**
  - Surface area networks (multiple EVA crew and surface systems)
  - Robotic and science coordination, tele-presence 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)**
  - Umbilicals, 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.

Cx Systems Form a Wide Area Network

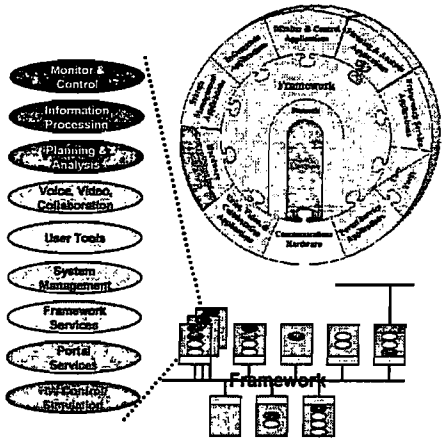


Wide area network connections can be via terrestrial infrastructure, umbilical hard-lines, or wireless (RF) links. Systems act as network nodes that route and relay traffic (as in a mesh network)

- **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 mode/list capability).
    - Ensures received commands are authenticated, decrypted, and verified against acceptance criteria.

Command & Control Applications

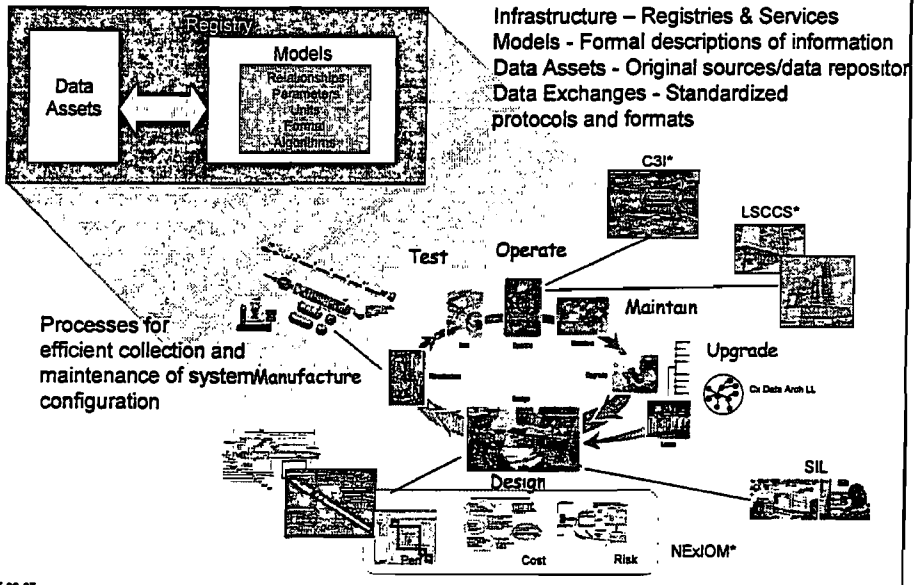
- **Framework-based applications**
  - Uses standard interface to access data.
  - Allows for use anywhere on the framework (i.e. reusable, migratable)
- **Data-driven applications**
  - Recommend generalized applications that may be used with multiple elements (to prevent sustaining unique tools for 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.



Evolution Option
Can initially leverage legacy applications using framework adapters w/ investment in native framework-based applications.

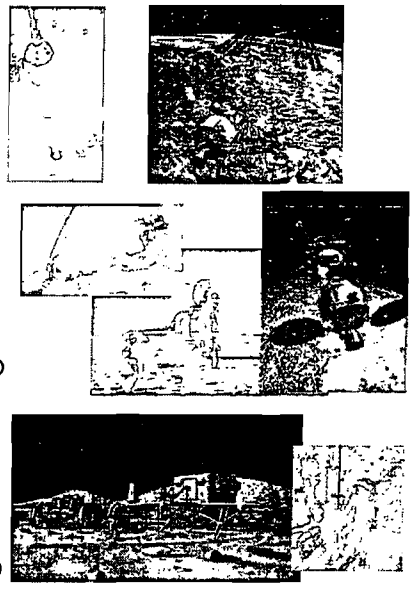
Framework-based applications allow for common building blocks resulting in less code to develop/maintain and reduces development time for new capabilities.

Information Architecture



C3I 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 C3I Framework and Cmd/Ctrl components (software)
  - Common communications adapter product line
  - Limited dynamic network routing.
  - Limited C3I Framework based flight software.
- **Lunar Outpost** (common adaptive systems)
  - C3I 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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