Reference concepts derived from stakeholder objectives, historical data, and timing / sequence constraints.

7 Design Reference Cases

Key Aspects of DRC1

- Global access
- Launch anytime
- Landing location determined from robotics
- Nominal crew of 4
- Surface excursions of 10 days
- Lunar base grows for 1-year tours of duty (up to 8 crew)
- Commercial opportunity potential after 2020
Boeing Highlights

- Architecture driven from the Vision, lunar exploration objectives, lunar resource utilization, and national security
- Numerous architecture / design trades

Architecture Summary
- Earth-Moon L1 Rendezvous
- LEO aggregation of elements
- Reusable lunar module
- Single stage LM
- Anytime returns; L1 gateway
- Trip time extended by L1 operations
- 14 days - continuous/long duration lunar stays

Trade Results show masses needed in LEO for various cases

Assumption & Ground rules:
- Lunar polar water ice may be accessible
- Necessary technologies at TRL 6 by PDR
- Two launch providers
- ETO capability limited to 2045+ MT LV
**Lockheed Martin Highlights**

**Guiding Principals**
- Simultaneously address all Vision Objectives
- Start with Mars and work backwards
- Answer fundamental questions to determine post-2025 future of exploration on Moon, Mars, Beyond

**Numerous trades being conducted**

**Exploration Approach**
- Mars robotic precursors (orbiters and landers) already leading the way
  - Pursuing water/life clues
  - Providing global access to H2O ice at poles/near poles
  - Soon to be performing combined science, ISRU, engineering testbed missions
  - Improving rover duration and speed
- Human missions likely to use fixed, near-equatorial site for surface stays of 30-630 days
  - Near the most desirable sites
  - Low altitude to minimize entry/descent/landing difficulty
  - Enables incremental build-up
  - Most energy/mass efficient location
  - More favorable thermal environment (20°C to -140°C)
  - Safest approach
  - Best solar fluence

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**POD Lunar Architecture Features (2018 -2023)**

- **Remote operations** as warranted (e.g., robotic H2O pilot at southern pole if ice is found)
- **Solar Flare/Warning System(s)**
- **Sun**
- **Direct Earth reentry and water recovery operations**
- **Consolidated Mission Control**
- **ETR launch operations**
  - Cargo-only missions (Two 70mT)
  - Crew missions (Two 70mT or 70mT combined with single stick)
- **LEO automated rendezvous and assembly**
- **Low Lunar Orbit (LLO) CEV/LSAM staging**
- **TBD on-orbit CEV/LSAM lifeboats for anytime rescue**
- **Communications via direct nearside broadband + global narrowband TC&C minisats**
- **TBD on-orbit CEV/LSAM lifeboats for anytime rescue**
- **Reconnaissance Orbiters (e.g. LRO)**
- **Surface Science (e.g. geoscience networks)**
- **Crew field work**
- **Ground processing** (crew, samples, systems)
- **Roving robotic explorers**
  - Sample returns (e.g. Moonrise @ Aitken Basin)
  - Astronomical observatory proof of concepts
- **Locked Martin Highlights**
  - Guiding Principals
    - Simultaneously address all Vision Objectives
    - Start with Mars and work backwards
    - Answer fundamental questions to determine post-2025 future of exploration on Moon, Mars, Beyond
  - Numerous trades being conducted
  - Exploration Approach
    - Mars robotic precursors (orbiters and landers) already leading the way
      - Pursuing water/life clues
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**Normalized Cost for 5 Missions**

- **2-Stage expendable LSAM LLO rendezvous (POD)**
- **2-Stage expendable LSAM L1 rendezvous**
- **1-Stage reusable LSAM LLO rendezvous**
- **1-Stage reusable LSAM L1 rendezvous**

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**Lockheed Martin Highlights**

**Guiding Principals**
- Simultaneously address all Vision Objectives
- Start with Mars and work backwards
- Answer fundamental questions to determine post-2025 future of exploration on Moon, Mars, Beyond

**Numerous trades being conducted**

**Exploration Approach**
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  - More favorable thermal environment (20°C to -140°C)
  - Safest approach
  - Best solar fluence
Northrop Grumman Highlights

♦ Guiding Principles
  • Simultaneously address each of the Vision Objectives
  • Start with Mars and work backwards
  • Answer the fundamental questions to determine the post-2025 future of exploration on Moon, Mars, and Beyond

♦ Numerous trades being conducted

♦ Exploration Approach
  • Polar landing site
  • 180 days surface duration
  • Safe-haven abort; Implicit Rescue with Responsiveness
  • 0-4 crew members

♦ Mars preparation has two components
  • Technology demonstration and test
  • Operational experience: “Lessons Learned”
♦ Vision Mapped to Objectives, Missions, Functions, and Requirements

♦ Numerous trades being conducted

♦ Example Habitation Alternatives
  • Multiple Outpost Capability Anywhere on Lunar Surface?
  • Lunar Logistics Base: Establish Single Lunar Base and Provide for Distributed Exploration Capability?
  • Lunar Orbiter: Provide 90 Day Capable Lunar Orbiter With Surface Excursion Capability Anywhere on Lunar Surface?

♦ Observations
  • Coupling of Lunar Base Selection and Lunar Abort/Safe Haven Capability
  • It’s Primarily a Transportation and Logistics Problem
  • Lunar/Mars Operations Need to Be Compatible and Traceable
  • Need a Budget Strategy at Spiral Transitions to Ensure Sustainability
Vision for Space Exploration drives exploration strategy
- Common infrastructure elements across missions
- Not dependent on changes to political viability of a single mission

Numerous trades being conducted
- Mission architecture related
- System sensitivities
- Technologies

Applicability of Lunar Operations to Mars Exploration Identified

Key Architectural Construct
- Initial basing at South Pole
- Low-Lunar Orbit staging for cargo
- L1 staging for crew
- Lunar regolith used for crew protection from lunar environment
- Launch vehicle strategy being traded
- 3 crew members provide the operational and safety margins desirable at minimum cost
- Critical technologies identified
SAIC Highlights

♦ Study Status
  • Preliminary analysis of Initial Concept for Technical Solution (ICTS) 20-mission campaign is complete
  • Conservative assumptions have been made throughout this preliminary analysis
  • Results indicate that the baseline campaign is both feasible and achievable
  • Additional trade studies are underway

♦ Campaign Studies Conducted
  • Mass Flow
  • Loss of Mission / Loss of Crew
  • Risk Mitigation Measure
  • Launch Manifest Trades

♦ Figures of Merit Assessments
  • Safety & Mission Success: LOM & LOC risks have been identified and initial values generated
  • Effectiveness: Being explored
  • Extensibility: Campaign is based around developing long-duration mission capability without resupply (in preparation for Mars surface missions) and selected subsystems
  • Affordability: Under development
**Stakeholder Value Analysis Approach:**
- Stakeholders identified (14)
- Stakeholder needs defined (~90)
- Exploration objectives (24)
- Technical architecture proximate measures (~18)
- Indicator metrics (~40)

**Mars Back Emphasis**

**QFD Tool utilized to screen options**
- For over 600 itineraries, and fixed technology/operational decisions, optimization determines best mix of technologies

**Numerous architecture, system, and technology trades being conducted.**

**Key Findings to Date**
- A sustainable exploration program must focus on delivering value throughout its lifetime to all stakeholders
- A Mars-back focus should be maintained throughout the architecture and mission development process
Schafer Highlights

**Architecture Overview**
- Emphasizes Gateway Architecture
- Architecture Fosters In Situ Resource Utilization (ISRU)
- L1 Refueling and resupply
- Direct return from lunar surface
- Off Earth Robotic Assembly, Set-up, and Operation For All Infrastructure
- Robotic Reconnaissance Missions Select Near Lunar Equator And South Pole Locations For Probable Extended Presence And Continued Exploration
- Assume One Crewed Mission Per Year Over 5-year Campaign In Spiral-2

**Drivers and Sensitivities**
- CEV Mass Strongly Influences Propellant Required
- Radiation Shielding Of CEV Is Severe Penalty
- Launch Of Propellant Mass To LEO Dominates All Architectures
- CONUS Landing Stresses CEV For Direct Return
- LV Capabilities And Lift Mass To LEO
- CEV Crew Size
- Reliability Of Storage And Transfer Of Cryo Propellant In Space
- ISRU Propellant Or LunOX Production Effectiveness For Future Spiral-3 Missions
- Abort Scenarios For Crew Safety Determine Size And Mass Of L1 Infrastructure
**SpaceHab Highlights**

♦ **Architecture Overview**
  - Maximize system modularity to the greatest extent possible
  - Each element will have the capability to operate alone or in conjunction with other elements
  - All non-crewed elements are launched on commercial Expendable Launch Vehicles (ELVs) with a lift capability of at least 15 metric tons.
  - The Crew Exploration Vehicle (CEV) is launched on a human rated launch system.
  - The CEV is sized to accommodate four crewmembers.
  - Reuse of systems

♦ **Key Technologies Identified to Date**
  - Automated Rendezvous, Proximity Operations and Docking (ARPOD)
  - Liquid Cryo Propellant Management
  - Extended-duration power generation (Nuclear Power)
  - Interplanetary communications relay
  - Regenerative ECLSS
  - Radiation Shielding
t-Space Highlights

♦ An Engine for Free Enterprise
  • Pay-for-results rather than pay-for-analysis
  • Businesses can grow from earnings
  • NASA-commercial partnerships will build a more resilient system
  • With NASA as an enabling partner, firms can transform space into a net generator of tax revenues instead of an endless consumer of them

♦ An Open Frontier
  • Government leadership rather than government ownership
  • Flotilla expeditions, not single vehicles
  • Smaller, simpler vehicles
  • For the first 20-40 expeditions, it will be cheaper to use more propellant than to create new optimized vehicles (lunar lander)
  • Simplicity equals reliability
  • Enable commercial passenger markets

♦ Mission Definition
  • Land at south pole quickly
  • Each expedition builds in-space infrastructure
  • Public must see understandable value