NASA’s Exploration Architecture

October, 2005
A Bold Vision for Space Exploration

♦ 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

“It is time for America to take the next steps.

Today I announce a new plan to explore space and extend a human presence across our solar system. We will begin the effort quickly, using existing programs and personnel. We'll make steady progress – one mission, one voyage, one landing at a time”

President George W. Bush – January 14, 2004
**Human Exploration Missions**

- **Crew to and from the lunar surface**
  - 7 day missions to anywhere on the surface
  - Crew rotation to lunar outpost

- **Cargo to the lunar surface**
  - One-way delivery of cargo to support longer duration missions

- **Crew to and from Mars**
  - 500 days on the surface

- **International Space Station resupply capability**
  – if commercial services are unavailable
  - Ferry crew up and down
  - Cargo up and down
Lunar Surface Activities

♦ Initial demonstration of human exploration beyond Earth orbit
  • Learning how to operate away from the Earth

♦ Conduct scientific investigations
  • Use the moon as a natural laboratory
    – Planetary formation/differentiation, impact cratering, volcanism
  • Understand the integrated effects of gravity, radiation, and the planetary environment on the human body

♦ Conduct in-situ resource utilization (ISRU) demonstrations
  • Learning to “live off the land”
  • Excavation, transportation and processing of lunar resources

♦ Begin to establish an outpost - one mission at a time
  • Enable longer term stays

♦ Testing of operational techniques and demonstration of technologies needed for Mars and beyond.....
High Priority Lunar Exploration Sites

1. Aristarchus Plateau
2. Oceanus Procellarum
3. Rima Bode
4. Mare Tranquillitatis
5. Mare Smythii
6. Central Farside Highlands
7. South Pole-Aitken Basin Floor

Near Side

Far Side
Possible South Pole Outpost

♦ The lunar South Pole is a likely candidate for outpost site

♦ Elevated quantities of hydrogen, possibly water ice (e.g., Shackelton Crater)

♦ Several areas with greater than 80% sunlight and less extreme temperatures

♦ Incremental deployment of outpost – one mission at a time
  • Power system
  • Communications/navigation
  • Rovers
  • Habitat and laboratory modules
Paving the Way – Robotic Precursor Missions

♦ Provide early information for human missions to the Moon
  • Key knowledge needed for human safety and mission success
  • Infrastructure elements for eventual human benefit
  • Scientific results to guide human exploration

♦ May be evolvable to later human systems

♦ Most unknowns are associated with the North and South Poles – a likely destination for a lunar outpost

♦ Key requirements involve establishment of
  • Support infrastructure – navigation/communication, beacons
  • Knowledge of polar environment – temperatures, lighting, etc.
  • Polar deposits – composition and physical nature
  • Terrain and surface properties
How We Will Get to Mars

♦ 4 – 5 assembly flights to low Earth orbit with a 100 metric ton class launch system

♦ Pre-deployed Mars surface outpost before the crew launches
  • Habitat and support systems
  • Power
  • Communications
  • Mars ascent / descent vehicle

♦ 180 day transit time to/from Mars
  • 6 crewmembers
  • Dedicated in-space crew transit vehicle
  • Dedicated Earth entry system (CEV)

♦ 500 days on the surface
  • Capability to explore large regions of the surface
  • Multi-disciplinary science investigations
  • In-Situ resource utilization
    − Consumables: Oxygen and water
    − Propellants: Liquid oxygen and methane
Servicing the International Space Station

♦ NASA will invite industry to offer commercial crew and cargo delivery service to and from the Station

♦ The CEV will be designed for lunar missions but, if needed, can service the ISS.

♦ Annually, the CEV system would be required to perform:
  • 2 crew flights
  • 3 pressurized cargo flights
  • 1 unpressurized cargo flight

♦ The CEV will be able to transport crew to and from the station and stay for 6 months
ESAS Charter

♦ (1) Complete assessment of the top-level Crew Exploration Vehicle (CEV) requirements and plans to enable the CEV to provide crew transport to the ISS and to accelerate the development of the CEV and crew-launch system to reduce the gap between Shuttle retirement and CEV IOC.

♦ (2) Definition of top-level requirements and configurations for crew and cargo launch systems to support the lunar and Mars exploration programs.

♦ (3) Development of a reference exploration architecture concept to support sustained human and robotic lunar exploration operations.

♦ (4) Identification of key technologies required to enable and significantly enhance these reference exploration systems and a reprioritization of near-term and far-term technology investments.
ESAS Figures of Merit (FOM’s)

Safety and Mission Success
- Probability of Loss of Crew
- Probability of Loss of Mission

Extensibility/Flexibility
- Lunar Mission Flexibility
- Mars Mission Extensibility
- Extensibility to Other Exploration Destinations
- Commercial Extensibility
- National Security Extensibility

Programmatic Risk
- Technology Development Risk
- Cost Risk
- Schedule Risk
- Political Risk

Affordability
- Technology Development Cost
- DDT&E Cost
- Facilities Cost
- Operations Cost
- Cost of Failure
A Safe, Accelerated, Affordable and Sustainable Approach

- Meet all U.S. human spaceflight goals
- Significant advancement over Apollo
  - Double the number of crew to lunar surface
  - Four times number of lunar surface crew-hours
  - Global lunar surface access with anytime return to the Earth
  - Enables a permanent human presence while preparing for Mars and beyond
  - Can make use of lunar resources
  - Significantly safer and more reliable
- Minimum of two lunar missions per year
- Provides a 125 metric ton launch vehicle for lunar and later Mars missions and beyond
- Higher ascent crew safety than the Space Shuttle
  - 1 in 2,000 for the Crew Launch Vehicle
  - 1 in 220 for the Space Shuttle
- U.S. system capable of servicing the International Space Station
- Orderly transition of the Space Shuttle workforce
- Requirements-driven technology program
- Annual “go-as-you-pay” budget planning
NASA’s Exploration Roadmap

05  06  07  08  09  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25

- Robotic Precursors
- 1st Human CEV Flight
- 7th Human Lunar Landing
- Lunar Outpost Buildup
- Mars Development
- Commercial Crew/Cargo for ISS
- Space Shuttle
- CEV Development
- Crew Launch Development
- Lunar Lander Development
- Lunar Heavy Launch Development
- Earth Departure Stage Development
- Surface Systems Development
How We Plan to Return to the Moon
Mission Mode – “EOR-LOR”

♦ After launch, the elements that take the crew to lunar orbit perform an “Earth Orbit Rendezvous (EOR)”

♦ At the completion of lunar surface activities the elements perform a “Lunar Orbit Rendezvous (LOR)” and return to Earth
  • “Direct Return” eliminated because it increases crew system complexity, has small margins, has the greatest number of operations issues and highest sensitivity to mass growth

♦ High efficiency cryogenic lander propulsion is an enabler

♦ The Crew Exploration Vehicle only has to be qualified for one launch system

♦ Mode has the highest calculated mission reliability and safety
Crew Exploration Vehicle

- A blunt body capsule is the safest, most affordable and fastest approach
  - Separate Crew Module and Service Module configuration
  - Vehicle designed for lunar missions with 4 crew
    - Can accommodate up to 6 crew for Mars and Space Station missions
  - System also has the potential to deliver pressurized and unpressurized cargo to the Space Station if needed

- 5.5 meter diameter capsule scaled from Apollo
  - Significant increase in volume
  - Reduced development time and risk
  - Reduced reentry loads, increased landing stability, and better crew visibility
CEV Design Approach

♦ The CEV consists of a Command Module (CM), a Service Module (SM), and a Launch Abort System (LAS) and is sized for a lunar polar mission
  • CEV design baseline optimized for Exploration missions
  • NOT an OSP modified for Exploration destinations
  • Impacts for the CEV to access the ISS assessed

♦ Block 1a CEV performs a crew transfer mission to ISS
  • Extended-Duration Missions Including Crew Return (Soyuz-type approach)
  • Reduced delta-V propellant required (keep what LV allows)
  • Baseline is to use the Lunar SM with propellant offloaded, but an optimized SM was sized for comparison
  • New docking module will be required

♦ Block 1b CEV performs “Progress” type pressurized cargo missions to ISS

♦ Cargo Delivery Vehicle utilizing a Block 2 SM performs unpressurized cargo delivery to ISS

♦ Block 2 CEV performs Lunar Missions

♦ Block 3 CEV performs Mars Missions (future)
1.5 Launch EOR-LOR  
5.5 m 32.5 deg CEV Block Comparison

<table>
<thead>
<tr>
<th>Block 1A</th>
<th>Block 1B</th>
<th>CDV</th>
<th>Block 2</th>
<th>Block 3</th>
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<tr>
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<td>ISS Press</td>
<td>ISS Unpress</td>
<td>Lunar Crew</td>
<td>Mars Crew</td>
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<tr>
<td>Crew Size</td>
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<tr>
<td>3 to 6</td>
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<tr>
<td>400</td>
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<td>Crew Module (kg)</td>
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<td>6,748</td>
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<td>EOR-LOR 5.5m Total Mass (kg)</td>
<td>EIR 5m Total Mass (kg)</td>
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<td>15,558</td>
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<td>16,371</td>
<td>18,551</td>
<td>22,909</td>
<td>TBD</td>
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Note 1: Cargo capability is the total cargo capability of the vehicle including FSE and support structure. A packaging factor of 1.29 was assumed for the pressurized cargo and 2.0 for unpressurized.
Launch Systems

♦ Rely on the EELV fleet for scientific and International Space Station cargo missions in the 5-20 metric ton range to the maximum extent possible.
  • New, commercially-developed launch capabilities will be allowed to compete.

♦ The safest, most reliable, and most affordable way to meet exploration launch requirements is a 25 metric ton system derived from the current Shuttle solid rocket booster and liquid propulsion system.
  • Capitalizes on human-rated systems and 85% of existing facilities.
  • The most straightforward growth path to later exploration super heavy launch.
  • Ensures national capability to produce solid propellant fuel at current levels.

♦ 125 metric ton lift capacity required to minimize on-orbit assembly and complexity – increasing mission success
  • A clean-sheet-of-paper design incurs high expense and risk.
  • EELV-based designs require development of two core stages plus boosters - increasing cost and decreasing safety/reliability.
  • Current Shuttle lifts 100 metric tons to orbit on every launch.
    – 20 metric tons is payload/cargo; remainder is Shuttle Orbiter.
    – Evolution to exploration heavy lift is straightforward.
Crew Launch Vehicle

♦ Serves as the long term crew launch capability for the U.S.

♦ 4 Segment Shuttle Solid Rocket Booster

♦ New liquid oxygen / liquid hydrogen upperstage
  • 1 Space Shuttle Main Engine

♦ Payload capability
  • 25 metric tons to low Earth orbit
  • Growth to 32 metric tons with a 5th solid segment
Lunar Heavy Cargo Launch Vehicle

- 5 Segment Shuttle Solid Rocket Boosters
- Liquid Oxygen / liquid hydrogen core stage
  - Heritage from the Shuttle External Tank
  - 5 space Shuttle Main Engines
- Payload Capability
  - 106 metric tons to low Earth orbit
  - 125 Metric tons to low Earth orbit using Earth departure stage
  - 55 metric tons trans-lunar injection capability using Earth departure stage
- Can be certified for crew if needed
Earth Departure Stage

- Liquid oxygen / liquid hydrogen stage
  - Heritage from the Shuttle External Tank
  - J-2S engines (or equivalent)

- Stage ignites suborbitally and delivers the lander to low-Earth orbit
  - Can also be used as an upper stage for low-Earth orbit missions

- The CEV later docks with this system and the Earth departure stage performs a trans-lunar injection burn

- The Earth departure stage is then discarded
Lunar Lander and Ascent Stage

♦ 4 crew to and from the surface
  • Seven days on the surface
  • Lunar outpost crew rotation

♦ Global access capability

♦ Anytime return to Earth

♦ Capability to land 21 metric tons of dedicated cargo

♦ Airlock for surface activities

♦ Descent stage:
  • Liquid oxygen / liquid hydrogen propulsion

♦ Ascent stage:
  • Liquid oxygen / liquid methane propulsion
Architecture Recommendations

♦ CEV
  • 5.5 meter diameter blunt body, Apollo-derivative capsule
  • 32.5 degree SWA
  • Nominal Land Landing (Water Back-up) Mode
  • CEV Reusable for 10 Missions, Expendable Heatshield
  • Pressure-fed LOX/Methane SM propulsion, sized for lunar mission (1450 m/sec TEI ΔV)

♦ Crew Launch Vehicle
  • 4 Segment RSRB
  • 1 SSME Upper Stage

♦ Cargo Launch Vehicle
  • Shuttle-derived, in-line ET-diameter with 5 Block II SSMEs
  • 5 Segment RSRBs
  • Upper Stage/ Earth Departure Stage w/ 2 J-2S+

♦ EOR-LOR Mission Mode, “1.5 launch”

♦ Global Lunar Access with Anytime Return

♦ South Pole Lunar Outpost Using an Incremental Build Approach

♦ 2-stage LSAM
  • LOX-Hydrogen descent propulsion (1100 m/sec LOI + 1850 m/sec Descent ΔV)
  • Pressure-fed LOX-Methane ascent propulsion
  • Airlock
  • Up to 7 day surface sortie capability
Open Architecture Approach

♦ Architecture Decision is Actually Series of Decisions
♦ Make Only Final Decisions that are Required Now
  • CLV and CaLV Family, Payload, and Acquisition Approach
  • CEV Requirements and Acquisition Approach
♦ Make Preliminary Decision About Other Architecture Elements and Lunar Mission Modes Which can be Modified as Required
♦ Select Approaches that Have Maximum Flexibility and Growth Potential
  • SDVs Provide Large Payload Growth Potential for Lunar/Mars Missions
  • Selecting Large Volume CEV Enables Crew and Mission Growth
  • Specialized Mission Modules Can Be Used With CEV to Add Capability
    – Servicing and Assembly
  • Selecting LOX-Based Propulsion Systems Enables Lunar ISRU
  • Selecting Methane-Based Propulsion Systems Provides Mars Extensibility
  • Commercial Providers Could Launch Cargo/Crew to ISS and Propellant/Cargo to LEO and Moon
  • Internationals Could Provide Lunar Surface Systems (Hab, Rover, etc.)
“We leave as we came, and God willing, as we shall return, with peace and hope for all mankind.”

— Eugene Cernan, Commander of the last Apollo mission
Questions?
Potential Commercial Opportunities

♦ Commercial services for space station crew/cargo delivery and return
♦ Purchase launch / communications services as available
♦ Innovative programs to encourage entrepreneurs
  • Centennial challenges prizes
  • Low-cost sub-orbital and orbital launch demo
  • Independent space station cargo re-entry demo
  • Independent crew transport demo
  • Space station cargo pathfinder demo
♦ Propellant delivery to low Earth orbit for lunar missions
  • Propellant depot in low Earth orbit
  • Propel earth departure stages/lunar lander after on-orbit transfer
  • Continual commercial replenishment as available
  • Government guaranteed purchase on delivery a certain price
Potential International Opportunities

- Continue International Space Station cooperation refocused on human exploration
- Purchase of additional international partner transportation assets for the Space Station
- Coordination of lunar robotic pre-cursor missions
- Cooperate on variety of lunar surface systems
  - Habitats
  - Rovers
  - Power and logistics
  - Science and in-situ resource utilization equipment
- Cooperation on Mars pre-cursor/science missions
- Preparation for joint human Mars missions
Our Destiny is to Explore!

- The goals of our future space flight program must be worthy of the expense, difficulty and risks which are inherent to it.
- We need to build beyond our current capability to ferry astronauts and cargo to low Earth orbit.
- Our steps should be evolutionary, incremental, and cumulative.
- To reach for Mars and beyond we must first reach for the moon.

A committed and long term lunar effort is needed, and we need to begin that investment now!
**CEV Overview - Crew Module**

**Functions**
- CM attitude control propulsion (GO2/Ethanol)
- Docking system (LIDS)
- Contingency EVA
- Crew Accommodations
- Avionics: DMS, C&T, GN&C, VHM
- Life Support and Thermal Control
- Earth Atmospheric Entry and Recovery
CEV Overview – Service Module

♦ Avionics
  • Health sensors, embedded processors

♦ ECLSS/ATCS
  • 60% propylene glycol / 40% H₂O single-phase fluid loop, 4 x 7 m² body-mounted radiator

♦ Power
  • 2 x 4.5 kW Solar Arrays

♦ Propulsion
  • 1 x 15,000 lbf pressure-fed LOX/Methane OMS engine @ 362 s Isp, 24 x 100 lbf Lox/Methane RCS engines @ 315 s Isp, Al-Li graphite wrapped Lox/Methane tanks @ 325 psia, gaseous helium pressurization

♦ Structure & Mechanisms
  • Graphite epoxy composite skin & stringer/ring frames construction, pyros

♦ Thermal Protection
  • Insulation
2-stage LOR LSAM with Single Crew Cabin and Integral Airlock

Lunar Surface Access Module (LSAM)
- 2-stage, expendable
- LOX/H2 Descent Stage performs LOI, nodal plane change and lunar descent
  - RL-10 derivative throttleable engines
- LOX/Methane ascent stage
  - Same engine as CEV SM
  - ISRU compatible
- Single volume crew cabin with integral airlock
- 2700 kg + cargo capability
4 Segment SRB with 1 SSME Crew

**Delivery Orbit**
- 30 x 160 nmi @ 28.5°
- Delivery Orbit Payload: 59,898 lbm, 27.2 MT
- Net Payload: 53,908 lbm, 24.5 MT
- Insertion Altitude: 59.5 nmi
- T/W @ Liftoff: 1.38
- Max Dynamic Pressure: 576 psf
- Max g’s Ascent Burn: 4.00 g
- T/W Second Stage: 1.03

**Delivery Orbit**
- 30 x 160 nmi @ 51.6°
- Delivery Orbit Payload: 56,089 lbm, 25.4 MT
- Net Payload: 50,480 lbm, 22.9 MT

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**GLOW**
- 1,775,385 lbf
- Payload: 5 m diameter CEV
- Launch Escape System: 9,300 lbm

**Booster Stage (each)**
- Propellants: PBAN
- Useable Propellant: 1,112,256 lbm
- Stage pmf: 0.8604
- Burnout Mass: 180,399 lbm
- # Boosters / Type: 1 / 4 Segment SRM
- Booster Thrust (@ 0.7 secs): 3,139,106 lbf
- Booster Isp (@ 0.7 secs): 268.8 s

**Second Stage**
- Propellants: LOX/LH2
- Useable Propellant: 360,519 lbm
- Propellant Offload: 0.0 %
- Stage pmf: 0.8882
- Dry Mass: 38,597 lbm
- Burnout Mass: 45,022 lbm
- # Engines / Type: 1 / SSME
- Engine Thrust (100%) @ Vac: 469,449 lbf
- Engine Isp (100%) @ Vac: 452.1 s
- Mission Power Level: 104.5 %

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**Payload**
- Launch Escape System: 5 m diameter CEV
- 9,300 lbm

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**Vehicle Concept Characteristics**
- 30 x 160 nmi @ 28.5°
- 59,898 lbm, 27.2 MT
- 53,908 lbm, 24.5 MT
**Flexibility for Later Growth or “1.5 Launch”**

5 Segment RSRB / 5 SSME Core+Upperstage

### Vehicle Concept Characteristics

**GLOW** 6,393,975 lbf
- Payload Envelope L x D: 39.4 ft x 24.5 ft
- Shroud Jettison Mass: 10,522 lbm

### Booster Stage (each)
- Propellants: HTPB
- Useable Propellant: 1,434,906 lbm
- Stage pmf: 0.8664
- Burnout Mass: 221,234 lbm
- # Boosters / Type: 2 / 5 Segment SRM
- Booster Thrust (@ 0.7 secs): 3,480,123 lbf @ Vac
- Booster Isp (@ 0.7 secs): 265.4 s @ Vac

### First Stage
- Propellants: LOX/LH2
- Useable Propellant: 2,215,385 lbm
- Propellant Offload: 0.0 %
- Stage pmf: 0.9113
- Dry Mass: 194,997 lbm
- Burnout Mass: 215,258 lbm
- # Engines / Type: 5 / SSME Blk II
- Engine Thrust (100%) @ SL: 375,181 lbf
- Engine Isp (100%) @ SL: 361.3 s
- Mission Power Level: 104.5 %

### Earth Departure /Upperstage
- Propellants: LOX/LH2
- Useable Propellant: 457,884 lbm
- Propellant Offload: 0.0 %
- Stage pmf: 0.9039
- Dry Mass: 42,645 lbm
- Burnout Mass: 48,640 lbm
- # Engines / Type: 2 / J-2S+
- Engine Thrust (100%) @ Vac: 274,500 lbf
- Engine Isp (100%) @ Vac: 451.5 s
- Mission Power Level: 100.0 %

### Delivery Orbit

**Delivery Orbit**
- TLI (EDS Suborbital Burn)
- Gross Payload: 133,703 lbm 60.6 MT
- Net Payload: 120,333 lbm 54.6 MT

**Delivery Orbit**
- 30 x 160 nmi @ 28.5°
- Gross Payload: 322,520 lbm 146.6 MT
- Net Payload: 274,120 lbm 124.6 MT
“Mission Architecture”, as defined in this study, trades different ways of allocating functionality to flight elements, and different ways to allocate energy changes and mass to those elements.

In this context, the architecture "trade tree" is kept to a reasonable size. It would involve:

1) Deep space staging location(s): none; L-point; LLO; Lunar Surface
2) Earth-orbital staging location(s): none; LEO; ISS; HEO
3) Lunar surface latitude/longitude/lighting capabilities desired: Equatorial only; Polar; Mid-latitude; far side
4) Abort strategies: “anytime return” from the lunar surface; orbital loiter; surface loiter

Equal in weight to the Mission Architecture is the Surface Architecture – the duration, location and centralization of lunar surface activities. These are addressed in a separate presentation and detail a number of high-level questions?

- What is the content of the science, resource utilization, and Mars-forward technology demonstrations and operational tests?
- Where are the highest priority sites?
- Do the scope of activities require a permanent outpost, and if so, how is it configured and how is it deployed?
Lunar Architecture capabilities are driven, in part, by the duration, location and centralization of lunar surface activities

- Number of sites to be visited (1 → many)
- Location of these sites (constrained latitude/longitude bands → global access)
- Duration of surface activities (~week-long sorties → permanently inhabited outpost)
- Centralization of assets (Apollo-class sorties with local mobility → mobile camp with predeployed logistics caches → Single outpost w/ regional mobility)
- Required infrastructure (power, communication, habitation, mobility, resource utilization, science)

An initial strategy was chosen that begins with global-access, short-duration sortie missions, and transitions quickly to deployment of a permanent outpost.

- Chosen to enable early missions to test transportation systems, allow short scientific sorties to a small number of diverse sites, and extended development timelines for high-cost outpost systems
- This is a singular point in the multi-dimensional duration/location/centralization trade space
Lunar Sortie Crew Missions
Surface Operations Concept

♦ Sorties do not depend on pre-deployed assets and can land at any location on the Moon
♦ Four crew members lives out of landed spacecraft for up to 7 days
♦ EVAs can be conducted every day with all crew members
  • Crew can work as two separate teams simultaneously
♦ Unpressurized rovers for surface mobility (2 for simultaneous but separate EVA ops) gives crew approximately 15-20 km range from lander
♦ Sortie mission surface activities focus on three activities
  • Lunar science (geology, geophysics, low frequency radio astronomy, Earth observations, astrobiology)
  • Resource identification and utilization (Abundance, form and distribution of lunar hydrogen/water deposits near lunar poles; geotechnical characteristics of lunar regolith)
  • Mars-forward technology demonstrations and operational testing (autonomous operations, partial gravity systems, EVA, surface mobility)
Outpost Deployment Strategy

- Power system and backbone of comm/nav are landed first
- Habitat, logistics, ISRU, and other surface infrastructure land and plug in to the power and comm/nav systems established on the first flight
- An uncrewed, fueled ascent stage lands prior to the first crew’s arrival – allows for the presence of two fueled ascent stages during crewed rotations at the habitat
- During the course of designing the outpost, a number of design principles drove the selection of implementations
  - Landed elements should not move unless absolutely necessary
  - Autonomous activities (e.g. locomotion, payload manipulation) should only be performed if absolutely necessary
  - Required crew operations for Outpost deployment should be limited and simple
  - Landed elements should be delivered on common cargo descent stages
  - Common functions (e.g. power distribution) should be performed by common means
  - Logistics supply chain should require minimal crew time and robotic manipulation
Lunar Mission Mode Taxonomy

Earth Orbit Node

YES
EOR-LOR (Dual Rendezvous)

NO
LOR
- Apollo (Single launch)
- EIRA (Split mission)

Lunar Orbit Node

YES
- EOR-Direct Return (Original Von Braun)

NO
- Direct-Direct (No Rendezvous) - FLO

- Libration point eliminated as RNDZ node based on FY04/05 ESMD studies
  ➔ Equivalent site access, anytime abort conditions can be met via low-LOR with less delta-V and less IMLEO mass.
- Direct-Direct eliminated based on single launch vehicle required to lift 200+ mt.
Analysis Cycle 2: Architecture Comparison with Increasing Technology, 5.5 m, 25° Sidewall CEV

Increasing Performance and Margin

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<tr>
<th>CEV Radiation</th>
<th>Descent Propulsion</th>
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<tr>
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EIR (LOR) EOR-LOR EOR-Direct Return

Increasing Performance and Margin
ISS – Moon – Mars Architecture Linkages

**Crew Exploration Vehicle**
- 4 crew Earth-moon transfer

**Earth-to-Orbit Transportation**
- Safe crew launch
- 125 mt-class Heavy Payload Launch
- Large Volume Payloads

**Technology Maturation**
- ISRU Systems
- Oxygen-Methane propulsion (CEV SM, LSAM ascent)

**Operations and Systems**
- Autonomous operations
- Partial gravity systems
- EVA, Surface mobility

**AR&D**
- Autonomous operations

**ISS – Moon – Mars Architecture Linkages**

- Mars 6 crew departure and return
- Safe crew launch
- Multiple, Heavy Payload Launches
- Large Volume Payloads

- 3 to 6 crew + payload
- Crew rotation
- ISS cargo

- Safe crew launch
- Oxygen-Methane propulsion (CEV SM)

- ISRU Systems
- Oxygen-Methane propulsion (CEV SM, Mars lander)

- Autonomous operations
- Partial gravity systems
- EVA, Surface mobility
Flight Test Plan Overview

Low Lunar Orbit

 indicaes Human Mission

Launch Abort Test No U/S

2009 - 2011 2017 - 2018
The Moon - the 1st Step to Mars and Beyond….

♦ Gaining significant experience in operating away from Earth’s environment
  • Space will no longer be a destination visited briefly and tentatively
  • “Living off the land”
  • Human support systems

♦ Developing technologies needed for opening the space frontier
  • Crew and cargo launch vehicles (125 metric ton class)
  • Earth ascent/entry system – Crew Exploration Vehicle
  • Mars ascent and descent propulsion systems (liquid oxygen / liquid methane)

♦ Conduct fundamental science
  • Astronomy, physics, astrobiology, historical geology, exobiology

Next Step in Fulfilling Our Destiny As Explorers