Architecture Driven By A Strategy

Global Exploration Strategy Development

National Priorities Defined

Architecture Assessment

Detailed Requirements Defined

Detailed Design

Reference Architecture & Design Reference Mission

Operations Concept, Technology Needs, Element Requirements

Themes & Objectives
What are the Big Lunar Architecture Questions?

• What are the US priorities and phasing for what we will achieve at the moon?
• How do priorities drive important decisions?
  – Outpost vs. Sorties
  – Landing site(s)
  – Architecture flexibility to address lower US priorities or far-term interests
• What infrastructure is required to support priorities?
  Considerations:
  – Schedule/flight rate
  – Cost/available budget
• What will we plan on developing ourselves?
  – Critical path hardware to achieve primary objectives
  – Allowing for parallel developments from commercial and/or international communities
• What level of limiting resources will allow for optimum realizable capability?
  – Enabled by basic NASA transportation architecture
  – Down-mass and up-mass at the Moon
  – Power
Key Decisions: Sortie vs. Outpost

• Three Top Themes Drive to an Outpost:
  – “Exploration Preparation”
  – “Human Civilization”
  – “Economic Expansion”

• Better enables “Global Partnerships”
• Allows development and maturation of ISRU
• Results in quickest path toward other destinations
• Many science objectives can be satisfied at an outpost as well
Outpost Site Location

Outpost Site: Polar

- **Safe**
  - Provides good opportunities to return
  - Opportunity to abort to surface

- **Cost Effective**
  - High percentage of sunlight
  - Allows use of solar power
  - Relatively low energy return to Earth

- **Resources**
  - Oxygen
  - Enhanced hydrogen (possibly water)
  - Potentially other volatiles

- **Flexibility**
  - Allows incremental buildup using solar power
  - Enhanced surface daylight ops
  - One communication asset (with backup)
  - More opportunities to launch

- **Exciting**
  - Not as well known as other areas
  - Offer unique, cold, dark craters
South Pole:
- Three areas identified with sunlight for more than 50% of lunar day
- One zone receives 70% illumination during dead of southern winter
- Lit areas in close proximity to permanent darkness (rim of Shackleton)

North Pole:
- Three areas identified with 100% sunlight
- Two zones are proximate to craters in permanent shadow
- Data taken during northern summer (maximum sunlight)
The area of Shackleton Crater rim illuminated approximately 80% of the lunar day in southern winter, with even better illumination in southern summer (Bussey et al., 1999).

Note: ‘Red Zone’ = 750 m x 5 km (personal communication with Paul Spudis)
Shackleton Crater Rim with Notional Activity Zones

- **Power Production Zone**: 50-60%, 60-70%, >70%
- **Resource Zone**: 100 Football Fields Shown
- **Habitation Zone**: ISS Modules Shown
- **Landing Zone**: 40 Landings Shown
- **Monthly Illumination (Southern Winter)**
  - 50-60%
  - 60-70%
  - >70%
- **To Earth**
- **Observation Zone**
- **South Pole (Approx.)**
- **Potential Landing Approach**
- **Potential Landing Approach**

To Earth

Observation Zone

South Pole (Approx.)

Resource Zone (100 Football Fields Shown)

Power Production Zone

Habitation Zone (ISS Modules Shown)

Landing Zone (40 Landings Shown)

Monthly Illumination (Southern Winter)

- 50-60%
- 60-70%
- >70%
Lander Basic Architecture

• Design Goals
  – Minimize Ascent Module mass
  – Minimize Descent Module mass
  – Maximize landed “payload” mass
  – Simplify interfaces
  – Move functions across interfaces when it makes sense

Point of Departure Only
Human Sortie Missions: Lander Capability

- The LAT lander (augmented with extra fuel cells) is capable of reaching all of the top ten ESAS sites with a crew of two for 7 days with substantial science cargo.
- The LAT lander is also capable of reaching all but three of the ESAS top ten sites with a crew of 4 assuming a 3 MT surface hab augmentation of the ascent module which reduces available science payload.

<table>
<thead>
<tr>
<th>Site</th>
<th>Latitude</th>
<th>Longitude</th>
<th>LOI DV (m/s)</th>
<th>2 Crew 7 days</th>
<th>4 crew 3 days*</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Pole</td>
<td>89.9 S</td>
<td>180.0 W</td>
<td>845</td>
<td>4,254</td>
<td>853</td>
</tr>
<tr>
<td>Far Side South Pole Aitken Basin</td>
<td>54.0 S</td>
<td>162.0 W</td>
<td>1,060</td>
<td>982</td>
<td>-2,426</td>
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<tr>
<td>Orientale Basin Floor</td>
<td>19.0 N</td>
<td>88.0 W</td>
<td>873</td>
<td>3,799</td>
<td>396</td>
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<tr>
<td>Oceanus Procellarum</td>
<td>3.0 S</td>
<td>43.0 W</td>
<td>857</td>
<td>4,058</td>
<td>656</td>
</tr>
<tr>
<td>Mare Smythii</td>
<td>2.5 N</td>
<td>86.5 E</td>
<td>848</td>
<td>4,205</td>
<td>803</td>
</tr>
<tr>
<td>W/NW Mare Tranquilitatis</td>
<td>8.0 N</td>
<td>21.0 E</td>
<td>902</td>
<td>3,336</td>
<td>-67</td>
</tr>
<tr>
<td>Rima Bode</td>
<td>13.0 N</td>
<td>3.9 W</td>
<td>905</td>
<td>3,289</td>
<td>-114</td>
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<tr>
<td>Aristarchus Plateau</td>
<td>26.0 N</td>
<td>49.0 W</td>
<td>865</td>
<td>3,928</td>
<td>526</td>
</tr>
<tr>
<td>Central Far Side Highlands</td>
<td>26.0 N</td>
<td>178.0 E</td>
<td>939</td>
<td>2,761</td>
<td>-643</td>
</tr>
<tr>
<td>North Pole</td>
<td>89.5 S</td>
<td>91.0 E</td>
<td>845</td>
<td>4,254</td>
<td>853</td>
</tr>
<tr>
<td>Aristarchus Science Station</td>
<td>26.0 N</td>
<td>49.0 W</td>
<td>865</td>
<td>4,645</td>
<td>1,247</td>
</tr>
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</table>

*Assumes extra habitation module to accommodate 2 extra crew @ 3 mT*
**Potential Option: Occasionally Trade additional Sample Return for a Crewmember**

- Apollo Lunar Sample Return Container filled with various uniform sized samples
- Void fraction = percentage of “air”

<table>
<thead>
<tr>
<th>Density</th>
<th>Void Fraction</th>
<th>Resulting Mass*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lunar Regolith (1.5-1.8 g/cm³)</td>
<td>0%</td>
<td>24.3 kg – 29.1 kg</td>
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<tr>
<td>2-cm spherical dia Rock (3.0-4.0 g/cm³)</td>
<td>26%</td>
<td>35.9 kg – 47.9 kg</td>
</tr>
<tr>
<td>8-cm spherical dia Rock (3.0-4.0 g/cm³)</td>
<td>50%</td>
<td>24.3 kg – 32.4 kg</td>
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<tr>
<td>Monolithic Rock (3.0-4.0 g/cm³)</td>
<td>10%</td>
<td>43.7 kg – 58.4 kg</td>
</tr>
</tbody>
</table>

- Mass – 6.7 kg
- Dimensions – 48 cm x 30 cm x 20 cm
- Interior volume – 16,000 cm³
- Container held 30-50 kg for Apollo 15-17 missions

Key Points: Outpost Build up

Starts 6 month increments

Point of Departure Only – Not to Scale
Human lunar missions will be used to build an outpost at a polar site.

The ability to fly human sorties and cargo missions with the human lander will be preserved.

Initial power architecture will be solar with the potential augmentation of nuclear power at a later time.

Robotic missions will be used to:
- Characterize critical environmental parameters and lunar resources.
- Test technical capabilities as needed.

The ability to fly robotic missions from the outpost or from Earth will be a possible augmentation.
NASA Implementation Philosophy

- The US will build the transportation infrastructure and initial communication & navigation and initial surface mobility
- Open Architecture: NASA will welcome external development of lunar surface infrastructure
- The US will perform early demonstrations to encourage subsequent development
- External parallel development of NASA developed capabilities will be welcomed
Open Architecture: Infrastructure
Open for Potential External Cooperation

• Lander and ascent vehicle
• EVA system
  – CEV and Initial Surface capability
  – Long duration surface suit
• Power
  – Basic power
  – Augmented
• Habitation
• Mobility
  – Basic rover
  – Pressurized rover
  – Other; mules, regolith moving, module unloading
• Navigation and Communication
  – Basic mission support
  – Augmented
  – High bandwidth
• ISRU
  – Characterization
  – Demos
  – Production

** Robotic Missions
  – LRO- Remote sensing and map development
  – Basic environmental data
  – Flight system validation (Descent and landing)
  – Lander
  – Small sats
  – Rovers
  – Instrumentation
  – Materials identification and characterization
    for ISRU
  – ISRU demonstration
  – ISRU Production
  – Parallel missions

** Logistics Resupply

** Specific Capabilities
  – Drills, scoops, sample handling, arms
  – Logistics rover
  – Instrumentation
  – Components
  – Sample return

** US/NASA Developed hardware
Post-Buildup Opportunities

NASA will have developed the capabilities required to enable various future paths. Agency decision: Which future path(s) to take?

Capabilities
- Mature transportation system
- Closed loop habitat
- Long duration human missions beyond LEO
- Surface EVA and mobility
- Autonomous operations
- Advanced robotic missions
- Minimize reliance on Earth via In-Situ fabrication and resource utilization
- Enhanced by Commercial and International Partners

Agency Decision on Future Path(s)

Humans to Mars

NASA Follow-on Strategy

Expand Lunar Outpost Site Exploration

Expand Lunar and/or Outpost via Commercial International Partners

Human Exploration of Other Lunar Sites via Sorties

Mars
Forward Work (January – July 07)

Using current architecture as a point of departure

- Update objectives that drive the architecture
- Coordinate lunar exploration plans with interested communities
  - Find opportunities to collaborate
- Refine campaign and architecture concepts
- Refine element hardware concepts
- Develop Mars Reference Mission
- Update and baseline ESMD Requirements
- Continue to engage academia, the private sector, and other stakeholders in defining a sustainable program of exploration