Lunar Architecture Update

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Dr. Scott Hensley
Lunar, JPL

February 28, 2008
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Introduction

Doug Cooke
Deputy Associate Administrator
NASA Exploration Systems Mission Directorate

February 28, 2008
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.

Global Exploration Strategy Themes

- Human Civilization
- Scientific Knowledge
- Economic Expansion
- Exploration Preparation
- Global Partnerships
- Public Engagement

NASA Authorization Act of 2005
In addition to supporting the basic goals and objectives of the US Space Policy, the Architecture must have the following:

- **Programmatic Flexibility** – Adaptable to changes in national priorities and budgets over several election cycles

- **Participant Flexibility** – Adaptable to changes in external participation and their priorities (Commercial or International Partners)

- **Exploration Flexibility** – Adaptable to changes in exploration priorities and methods
Architecture Development Driven By A Strategy

Global Exploration Strategy Development

Themes & Objectives

National Priorities Defined
Reference Architecture & Design Reference
Mission
Outpost First at one of the Poles
Elements critical to US

Detailed Design

Operations Concept, Technology Needs, Element Requirements
Maintain flexibility

LAT-1
LAT-2

Architecture Assessment

Detailed Requirements Defined
Human lunar missions will be used to build an outpost initially at a polar site.

Preserve the option for an outpost at other lunar locations.

Preserve the ability to fly human sorties and cargo missions with the human lander.

Initial power architecture will be solar with the potential for augmentation with nuclear power later.

The US will build the transportation infrastructure, initial communication & navigation infrastructure, and initial surface EVA capability.

Open Architecture: NASA will welcome parallel development and development of lunar surface infrastructure by international and commercial interests.
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

** 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

** US/NASA Developed hardware
• Build on LAT 1 decisions, assessing a range of options
• Combine best features into a hybrid approach
• Attributes:
  – Enable lunar sustained presence early
  – Develop infrastructure while actively engaged in science and exploration
  – Ensure architecture supports broader range of Objectives
  – Support the establishment of Mars analog
  – Allow the earliest partnership opportunities for commerce and International Partners
  – Continuous and focused public engagement
Hybrid Approach to Options

- Surface Architecture-
  - Worked as a system with the transportation architecture (Ares I&V, Orion, and Lander)
  - Ares V shroud expanded to 10M dia. for lander packaging
  - Cargo lander utilized to transport major components to the surface
  - Outpost built up from only 2 or 3 modular habitat elements; each pre-integrated with power, life support, communications, etc.
  - Mobility capability that utilizes the ‘Leg-Wheel’ concept for unloading, transportation and emplacement of elements
  - Early delivery of small, agile pressurized rover
Extended Surface Exploration

- Wheel-on-leg surface carrier provides capability in addition to offloading and positioning surface elements:
  - Provides capability for mobile habitat
  - Mobile habitat drives robotically to new interim Outpost
  - Crew drives separately in pressurized rover to extended sortie site.
  - Habitat can be sent to sites for a visit from another crew and returns in super-sortie mode.
Summary

- Builds on architecture decisions presented at December 2006 Exploration Conference
- Utilizes the robust transportation system provided by Ares 1 and Ares 5
- Open architecture facilitates different modular functions and operations
- Early exploration
  - Reduced assembly through pre-integrated habitats
- Modular mobile habitation
  - Facilitates “super sortie” mobility for 100’s km distances from the outpost
  - Facilitates greater lunar access to capture exploration and science objectives beyond LAT1 results
- Early small pressurized rover
  - Augments EVA operations by allowing astronauts to explore in shirt sleeve environment using EVA judiciously
Lunar Architecture update
Constellation Lunar Study Status
Partnership Flexibility

Geoffrey Yoder
Director, Exploration Systems Mission Directorate
Integration Office
Topics

Status of CxLunar

Pressurized Rover features

Participant Flexibility
Architecture Driven By A Strategy
Where We Have Been and Next Steps

Global Exploration Strategy Development – Themes and Objectives

Architecture Assessment (LAT1) Dec 06 – Outpost first at one of the Poles, elements critical to US

Detailed Design Concepts (LAT2) Aug 07 – Operations concepts, technology needs, element requirements

Lunar Capabilities Concept Review June 08 – Refinement of concepts in support of the transportation system

Lunar surface concept additional analysis cycles

Lunar Transportation system SRR

Lunar surface systems SRR

Element SRRs

Surface system concepts but no final designs
Suitports: allows suit donning and vehicle egress in < 10min with minimal gas loss

Two Pressurized Rovers: low mass, low volume design enables two pressurized vehicles, greatly extending contingency return (and thus exploration) range

Suit PLSS-based ECLSS: reduces mass, cost, volume and complexity of Pressurized Rovers ECLSS

Ice-shielded Lock / Fusible Heat Sink: lock surrounded by 2.5cm frozen water provides SPE protection. Same ice is used as a fusible heat sink, rejected heat energy by melting ice vs. evaporating water to vacuum.

Chariot-Style Aft Driving Station: enables crew to drive rover while EVA, also part of suitport alignment

Work Package Interface: allows attachment of modular work packages e.g. winch, cable reel, backhoe,
Modular Design: pressurized module is transported using Mobility Chassis. Pressurized module and chassis may be delivered on separate landers or pre-integrated on same lander.

Docking Hatch: allows pressurized crew transfer from Rover-to-Habitat, Rover-to-Ascent Module and/or Rover-to-Rover.

Dome windows: provide visibility as good, or better than, EVA suit visibility.

Exercise ergometer (inside): allows crew to exercise during translations.

Radiator on Roof: allows refreezing of fusible heat sink water on extended sorties.

Cantilevered cockpit: Mobility Chassis does not obstruct visibility.

Work Package Interface: allows attachment of modular work packages e.g. winch, cable reel, backhoe, crane.

Pivoting Wheels: enables crab-style driving for docking.
Suit Alignment Guides and Suitport Ingress/Egress

- Ring being swiveled up
- Stem rotated 90º so ring faces suit

Suitport Ingress / Egress

- Long guide cone
- Guide pin

- Turret at 85º
Why is a Pressurized Rover Necessary?

Kaguya Satellite - Lunar South Pole Image

Requires Pressurized rover to explore beyond 10 km from the outpost
Architecture Guidelines

• In addition to supporting the basic goals and objectives of the US Space Policy, the Architecture must have the following:

  – Programmatic Flexibility – The Architecture must be able to adapt to changes in national priorities and budgets over several election cycles

  – Participant Flexibility – The Architecture must be able to adapt to changes in external participation (Commercial or International Partner) and changes to their priorities

  – Exploration Flexibility – The Architecture must be able to adapt to changes in exploration priorities and changes in exploration methods
Since the announcement of the U.S. Space Exploration Policy in 2004, global interest in science and exploration of the Moon has steadily increased.

- **A multi-pronged approach in communicating the Exploration Policy and pursuing opportunities for cooperation**
  - Sponsored workshops and conferences in the US, and have participated in conferences overseas
  - Engaged the US Chamber of Commerce
  - Initiated multilateral dialogue with representatives of 13 science and space agencies around the world under the banner of the Global Exploration Strategy
  - Employed specific bi-lateral strategies on a country by country basis based on a particular partner’s capability and interests

- **Rationale**
  - Robust capabilities and redundant systems are key factors in a successful exploration program
  - Affordable exploration program that accomplishes as many goals as possible as early as possible is a program with active participation from international and commercial partners
Open Architecture
The Pieces of a Greater Mission

Human Missions to the Moon

US/NASA Developed initial capabilities
– Launch Vehicle Architecture
– Lunar Lander: ascent vehicle, descent vehicle, basic habitation
– Initial EVA system for CEV and an Initial Surface Suit
– Basic Navigation and Communication

Open for Cooperation

Systems and Capabilities Envisioned for an Outpost including Outpost enabled sorties
– Long duration surface suit
– Advanced, long-duration Habitation
– Augmented Power Systems
– Basic, unpressurized rover
– Pressurized rover
– Logistics rover
– Augmented, high bandwidth satellite communication/navigation
– Logistics Resupply
– ISRU Production

Participant Flexibility Strategy
• Welcome parallel capabilities while seeking “open architecture” contributions
• Continue success of the Global Exploration Strategy through multilateral engagement in International Space Exploration Coordination Group (ISECG)
• Continue success of US Chamber of Commerce engagement
• Build on long-standing bilateral relationships while seeking new relationships when opportunities and conditions permit
Summary of Multilateral Activities to Date

- Following announcement of the Exploration Policy, NASA began to engage nations on a bilateral and multilateral basis to explain progress in implementing the Vision and to discuss potential partnerships.

- In April 2006, NASA initiated multilateral discussions aimed at developing a globally coordinated strategy for exploration – the Global Exploration Strategy:
  - Australia, Canada, China, the European Space Agency, France, Germany, Great Britain, India, Italy, Japan, Russia, the Republic of Korea and Ukraine.


- In November 2007, established the International Space Exploration Coordination Group (ISECG).
Summary of Bilateral Accomplishments to Date

- **European Space Agency (ESA)**
  - In May 2007, NASA initiated a dialogue with ESA’s exploration architecture team
  - NASA presented results of Lunar Architecture Team Phase 2 study to ESA’s exploration architecture team at ESTEC September 26-27
  - In January 2008, NASA and ESA have initiated a four-month “comparative architecture assessment” to outline potential collaborative scenarios utilizing respective human/robotic exploration capabilities

- **United Kingdom (BNSC)**
  - Administrator signed April 2007 joint statement with UK Department of Trade and Industry to establish joint study of potential lunar cooperation. Study results to be released soon

- **Germany (DLR)**
  - NASA Administrator/DLR Chairman signed a February 2007 joint statement expressing desire to discuss areas of exploration cooperation
Selected ESA Key Capabilities for Comparison

- Lunar logistics system;
- Crew transportation system;
- Human surface support and habitation;
- Orbital infrastructures in cis-lunar space;
- Communication/navigation systems.

Note: further definition and development of these capabilities is subject to decision at the next ESA Council meeting at ministerial-level the end this year.
### Objectives
- Demonstrate soft precision landing (500m)
- Transport robotic elements to lunar surface from LTO
- Deliver cargo to Lunar surface

### Interfaces
- Ariane 5 launcher
- Payload
- Surface infrastructures
- Comm/nav

### Timeframe
- First demo mission: 2016/17 with reduced payload capability
- Full capability: 2021
- Key decision points: 2011

### Limitation/ Needs
- Refinement of requirements for lunar logistics services
- Propulsion technology

### Main Functions
- Safely land on moon surface, any location, a net P/L mass of 1750 kg
- Deploy the P/L on surface
- Provide resources to the P/L (power, comm’s etc)
- Operative life: ~ 15 days
Lunar Logistic Lander
European Mission Scenarios

Potential payloads identified

- **Exploration rover**
  Robotic surface mobility and in-situ analysis

- **ISRU demonstration**
  Extraction and production of oxygen

- **Sample Return vehicle**
  Bring back a 1kg sample to Earth

- **Very deep driller**
  Mobility and very deep drilling capability (100 m)

Potential payloads identified

- **Deep driller rover**
  Mobility and deep drilling capability (10 m)

- **Exploration Hopper**
  Extended robotic surface mobility and sample collection capability

- **Low frequency radio astronomy**
  LOFAR telescope deployment

- **Logistics for pressurized rover**
  Deliver logistics of the pressurized rover

Mass 200 kg

1,500 kg
• US Chamber of Commerce
  – Engaged the US Chamber of Commerce
    • Actively engage US companies through a single focal point
    • Provides US industry expertise on a level playing field
  – Performing Architecture element standards evaluation
    • Described in following presentation by Sandy Coleman
U.S. Chamber of Commerce
Space Enterprise Council

Sandy Coleman
Director, NASA Exploration Program
ATK Washington Operations

February 28, 2008
Who Are We?

- Founded in 2000 out of a joint NASA/DOD conference focusing on commercial space

- Now focus on all aspects of the space industry
  - Commercial
  - Civil
  - National Security

- Affiliated with the U.S. Chamber of Commerce
  - USCC represents 3 million businesses and 1,500 Chambers of Commerce
  - SEC can tap into the USCC’s wide swath of resources
• For the past two years, the Council has hosted NASA Lunar Exploration Architecture workshops

• Output from these workshops has been directly incorporated into NASA’s Lunar Architecture Plan

• Council agreed to work with NASA on Lunar Standards
  • To identify where standards would be of value
  • Candidate sources of those standards
Scope and Focus of Effort

• Focus on commercial standards that assist ESMD in areas that have long term applicability to the lunar architecture

• Enabling Commercial Off The Shelf (COTS) type solutions are of particular interest

• Identify what would be best served by U.S. vs International standards
Space Transportation Working Group

- ATK
- The Boeing Company
- Honeywell
- Lockheed Martin
- Northrop Grumman
- Orbital
- Raytheon
- United Space Alliance

We encourage wide industry participation
Lunar Outpost / 2030
<table>
<thead>
<tr>
<th>Interface Functional Needs</th>
<th>NASA Lunar Surface Element</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressurized mechanical interfaces (docking ports, airlocks/suitlocks, interconnects/couplings)</td>
<td>Long Duration Suit</td>
</tr>
<tr>
<td>Living Habitat</td>
<td>Work Habitat</td>
</tr>
<tr>
<td>Health Habitat</td>
<td>Power Systems</td>
</tr>
<tr>
<td>Surface Transportation &amp; Handling Systems</td>
<td>Communication &amp; Navigation</td>
</tr>
<tr>
<td>Resupply</td>
<td>SRU Production</td>
</tr>
<tr>
<td>Emergency Egress Systems</td>
<td>Surface Construction &amp; Maintenance</td>
</tr>
<tr>
<td>Pressurized mechanical interfaces (docking ports, airlocks/suitlocks, interconnects/couplings)</td>
<td>X</td>
</tr>
<tr>
<td>Unpressurized mechanical interfaces (attachments/adapters, connectors, grapples, plugs and sockets, handles, hard/soft points)</td>
<td>X</td>
</tr>
<tr>
<td>Atmosphere/Environmental (pressure, temperature, composition, humidity, trace gases and contaminants, ionization, radiation shielding &amp; hardening, environmental monitoring)</td>
<td>X</td>
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<tr>
<td>Water (purity, sterility, sterilization approach, electric conductivity, ion balance, isotope composition, trace minerals)</td>
<td>X</td>
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<tr>
<td>Power (voltage, AC/DC, frequency, stability/tolerances)</td>
<td>X</td>
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<tr>
<td>Communications protocol (formats, bandwidth, frequencies, waveforms, encryption, clock speed and timing accuracy)</td>
<td>X</td>
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<tr>
<td>Diet (water content/food dehydration, storage temperature, nutrient content, composition, caloric value, vitamins, minerals)</td>
<td>X</td>
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<tr>
<td>Reactants and working media (fuels/propellants, lubricants, CO2 removal agents, detergents and cleaners, disinfectants, cooling fluids, catalysts)</td>
<td>X</td>
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<tr>
<td>Materials (mechanical/chemical/electrical properties, outgassing characteristics, UV resistance, radiation resistance and penetrability)</td>
<td>X</td>
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<tr>
<td>Anthropometry (size ranges, weight ranges, metabolic rates, reaction times, cognitive capabilities and perception, vision, hearing, reach, strength)</td>
<td>X</td>
</tr>
<tr>
<td>Waste Management &amp; Recycling (human, non-human, planetary protection)</td>
<td>X</td>
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</table>
Will the power and life support modules of the US Surface Suit be interchangeable with International Partner suits?

Emergency Egress Systems

INTERFACE STANDARDS
• Mechanical Interfaces
• Atmosphere/Environmental
• Water
• Power
• Communications Protocol
• Materials
### Sample of Standard Evaluation Living Habitat

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<th>H-M-L</th>
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<td><strong>Anthropometry</strong> (size ranges, weight ranges, metabolic rates, reaction times, cognitive capabilities and human, non-human, planetary protection)</td>
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**Likely to exist when needed**

- Pressurized mechanical I/F
- Unpressurized mechanical I/F
- Waste Management / Recycling
- Atmosphere / Environmental Materials
- Reactants / Working Media
- Power Communication Protocol
- Water Anthropometry
- Diet

**Applicable to ESMD International Partner Long Duration Needs**

- **Lowest Applicability**
  - Diet

- **Highest Applicability**

- **Lowest**
  - Water Anthropometry
• Evaluated all 11 architectural elements for value of standards and when needed

• Next step is to identify candidate sources to develop the standards

• Hosting a Lunar Architecture Workshop on April 1, 2008 at the Chamber with NASA participation

• SEC/Industry results to ESMD in May 2008

• This is the first step for industry involvement in the Lunar Architecture structure – encourage wide industry participation
Goldstone Solar System Radar
Lunar Polar Topography

Dr Scott Hensley
February 28, 2008
The Goldstone Solar System Radar (GSSR)

- **A unique NASA facility** for high-resolution ranging and imaging of planetary and small-body targets
  - One transmitting, multiple receiving antennas for interferometry
  - 500 kW X-band transmitter
  - Very sensitive maser receiver

- **Provides a wide variety of information**
  - Simultaneous, co-registered radar image and topography - even in Lunar unlit areas
  - Surface characteristics, structure and composition
  - Orbits, rotations, spin axis

- **Leverages DSN assets for radar Mission support and radar science**
  - Deep Space Network (DSN) primary function is communication and nav for space missions beyond low Earth orbit
Incidence angle, $\iota$, to the south polar region of the moon is at near grazing incidence angles of 80°-90°. Thus the ground projected range resolution is nearly equal to the range resolution of 18 m.
<table>
<thead>
<tr>
<th>Measurement Source</th>
<th>Date</th>
<th>Polar Coverage</th>
<th>Topography</th>
<th>Spatial Resolution</th>
<th>Height Resolution</th>
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<tbody>
<tr>
<td>Lunar Orbiter 4</td>
<td>1967</td>
<td>Yes</td>
<td>No</td>
<td>No topography</td>
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<td>Apollo 15-17 Lidar &amp; Radar</td>
<td>1971-1972</td>
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<td>1994</td>
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<td>Clementine / Stereo Imager</td>
<td>1994</td>
<td>Yes</td>
<td>Yes</td>
<td>1 km</td>
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<td>Lunar Prospector</td>
<td>1998</td>
<td>No imaging</td>
<td>No</td>
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<td>GSSR</td>
<td>1997</td>
<td>Yes</td>
<td>Yes</td>
<td>150 m</td>
<td>50 m</td>
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<td>Arecibo</td>
<td>2006</td>
<td>Yes</td>
<td>No</td>
<td>No topography</td>
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</tbody>
</table>

Only Clementine & GSSR measured polar topography
Data Acquisition

- Three ~90 min. acquisitions of Lunar South Pole data at optimum librations
- DEM processing to 40-m pixels, 5-m height accuracy complete
- Image processing to 20-m pixels nearly complete
- Being tested for planimetric, topographic accuracy against Unified Lunar Control Net, orbital photography
Fills in Gaps in Solar Illumination Imagery

Clementine stereo topography

GSSR data overlay
GSSR Image of South Pole Region

To Earth
Enlargement of Shackleton Rim Area

Kilometers 6420
Digital Elevation Map of Lunar South Pole Region
Height Error Map
Contour Map

Contour lines: Each color cycle represents 2 km in elevation change.
Slope Map

Slope Magnitude (deg)

Kilometers
Shackleton Rim Area Detail

Elevation Contours

Slopes

Elevation Change (km)

Slope Magnitude (deg)

0 2 4

0 10 20 30