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LEAG Annual Meeting

October 1-5, 2007

Final Report

"Enabling Exploration: The Lunar Outpost & Beyond"

Meeting Goal: Define pathways to offset cost and risk of achieving the next steps in space exploration.

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Summary

The LEAG heard presentations from NASA on the current state of implementation of the Vision for Space exploration, including status of the Constellation program, robotic missions, surface systems, and agency divisions. Additionally, various study groups and committees also presented results of recent and current studies dealing with a variety of issues related to human lunar return.

Various members of the lunar community made presentations covering international cooperation, resource utilization, robotic missions, commercial aspects, sample return, field science and crew training, and outpost site selection. These solicited presentations were augmented by a variety of contributed poster presentations on missions, exploration, analysis, and supporting infrastructure associated with lunar return.

After each presentation, there was extensive discussions via Q&A, and panels were comprised of presenters to discuss more extensive issues. From these presentations and extensive discussion, several key issues emerged.

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Summary

Risk could be reduced by defining a unified pathway forward through an agency-embraced "mission statement".

Although the LAT work of the past 2 years has clarified many issues in lunar return, it still suffers from a lack of coherency because a unifying goal/reason for returning to the Moon is lacking. A "mission statement" is clearly needed. The LEAG believes that the mission was clearly stated in the Vision for Space Exploration and proposes the following as the mission statement for returning to the Moon:

"We are going to the Moon to explore and to learn how to live and work successfully on another world"

This requires that we think differently from Apollo and requires us to use what we find in space to create this new spacefaring capability - we must focus our efforts on becoming self-sufficient on the Moon. Thus, habitation and resource extraction and use become the primary objectives of the outpost. Sortie missions, while desirable for science, dissipate both hardware and human resources and thus should defer to outpost build-up.

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Summary

The lack of a recurring and frequent robotic exploration program to the Moon prior to human arrival presents serious obstacles to preparing for and then subsequently utilizing a lunar outpost.

The lack of follow-on robotic missions after the 2008 LRO orbiter seriously impacts our flexibility to plan for future human habitation and use of the Moon, especially in testing ISRU capabilities. Many ISRU processes are feedstock dependent. We need to experiment with different materials and processes to optimize the selection of techniques to be used on large scales, so as to decrease the risk to sustaining a lunar habitat. Additionally, robotic missions can emplace assets to be used by future crews at an outpost site. Teleoperated rovers can explore and prepare an outpost site prior to human arrival.

More importantly, the currently planned decade-long gap between LRO and human arrival de-links Orion and Ares from its destination. Even while the early Apollo spacecraft underwent fabrication and testing, robotic precursor missions continued to voyage to the Moon, collecting strategic data, but also keeping the agency focused on the destination.

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Summary

The ITAR regulatory regime creates an overhead cost for US collaborators on foreign missions. This bureaucratic burden increases the risk and cost of international collaboration.

Although a factor beyond agency control, the LEAG believes that the burden of ITAR compliance creates obstacles to enhanced international cooperation. International cooperation is highly desirable and a fundamental objective of the Vision. Technical interchange is essential for the planning, development, and execution of both robotic and human missions and activities. Although ITAR compliance is handled through a well-developed series of administrative procedures, their use increases the time and resources needed to execute these missions. Thus, international cooperation should be conducted in such a way as to minimize the need for ITAR compliance.

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Summary

The amount of returned lunar mass book kept in the Constellation architecture (100 kg) is inadequate for scientific and resource utilization research needs.

Each Apollo "J-mission" returned roughly 100 kg of lunar samples. This returned sample mass was the product of roughly 48 man-hours of geological exploration on each mission. When we return to the Moon, we will have four people on the Moon for seven days, potentially resulting in over 250 man-hours of exploration, a factor of more than five over the Apollo experience. More extensive exploration will result in more, not less collected sample mass , yet the same sample return mass as Apollo has been budgeted for Constellation. Total returned sample mass could be minimized through careful field work and perhaps by some minimal analysis while still on the surface. Nevertheless, this returned mass number should be increased by at least a factor of three (300 kg) to assure that we are able to fully take advantage of our greatly increased exploratory capabilities.

Meeting Outline

Day 1: Briefings and community updates.

Day 2: International Partnerships,
ISRU & Outpost Sustainment Demos.

Day 3: The Role of Robotic Missions,
Commerce: Incremental Steps from Earth to Lunar Enterprise.

Day 4: Sample Return and Lunar Exploration,
Role of Technology in Field Exploration & Astronaut Training.

Day 5: Site Selection and the Lunar Outpost.
Moderator Reports.

Poster Sessions Wednesday and Thursday,
6-8 p.m. in the Southwest Grand Ballroom D/E.

Abstracts and Presentation Summaries can be found at the LEAG web site.

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Meeting Questions

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Overarching Question:

How can risk/cost be reduced through cooperation and partnerships in tech-nological developments and demonstrations?

Session Questions:

International Partnerships

What are the synergies between the exploration goals of potential international partners and the Vision for Space Exploration?

What are the (perceived) obstacles to international cooperation in the Vision for Space Exploration and what are the solutions?

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Meeting Questions

ISRU & Outpost Sustainment Demos.

What are critical ISRU, surface operation, and transportation related demonstrations that are needed to transition from establishment of an Outpost to long-term sustainability of robotic and human lunar exploration?

What precursor demonstration missions would significantly reduce the cost and/or risk of establishing the Outpost and long-term robotic and human exploration of the moon and beyond?

What opportunities are there for private sector space and/or international partnerships in proving and integrating ISRU and other capabilities required for Outpost sustainability into the current NASA Lunar Architecture?

How do these opportunities support other international space agency and commercial space development objectives?

Meeting Questions

The Role of Robotic Missions

What can we learn from robotic missions before the next human landing?

What do we need to learn from robotic missions before lunar settlement and commercial development?

What role could be played by small, robotic lunar missions?

What role could state governments play in lunar exploration?

Can the CEV SIM Bay be used for deployment of robotic exploration missions?

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Meeting Questions

Commerce: Incremental Steps from Earth to Lunar Enterprise

What progress has been made regarding the themes and recommendations from the LEAG-2005 meeting and what are the key roadblocks (if any) preventing progress?

What opportunities are there for private sector participation within the current architecture?

How can increased private sector participation be better facilitated to ensure the sustainability of the outpost?

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Meeting Questions

Sample Return & Lunar Exploration

What technologies exist and what technologies need to be developed in order to reduce risk/cost for (1) robotic sample return, (2) human sample return, and (3) robotic-human sample return?

What analysis can be done on the surface robotically and with crew vs. required sample return?

What are the limiting technologies for analysis on the lunar surface versus sample return?"

What are the roles of NASA, non-US space agencies, and the private sector in sampling the Moon?

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Meeting Questions

Role of Technology in Field Exploration & Astronaut Training

What were the lessons learned from Apollo (i.e., what worked and what didn’t?)?

What technologies need to be developed to facilitate field operations for the establishment and maintenance of a lunar outpost, as well as for scientific exploration?

Site Selection & the Lunar Outpost

What are the drivers for the site of the lunar outpost and have they changed from the criteria previously used?

Building upon the wealth of material that has been previously published, what is the “ideal” site for operations, science, exploration, ISRU, commerce, and/or international cooperation?

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Briefings and Community Updates: Report

NASA is forming and Exploration Coordination Group to engage the 13 countries of the “Global Exploration Strategy” and other space agencies in human/robotic lunar activities.

International collaboration would be a way to address the overarching meeting questions, but th international community is receiving mixed signals - first it was to wait until after LAT-1, then after LAT-2…., etc. There was a sense of frustration on this issue from a least some of the international representatives present.

ITAR issues: ITAR cannot be avoided, but it can be navigated, but adds cost as everything has to be documented; ITAR case histories are being compiled (I.e., lessons learned); from the international perspective, ITAR is a nuisance, but has forced other countries to be less reliant on US technology.
Apart from ITAR, what other challenges on ISS with international collaboration? Interpretation of words (e.g., “very fast”), design features also. Care needed not to talk passed each other.

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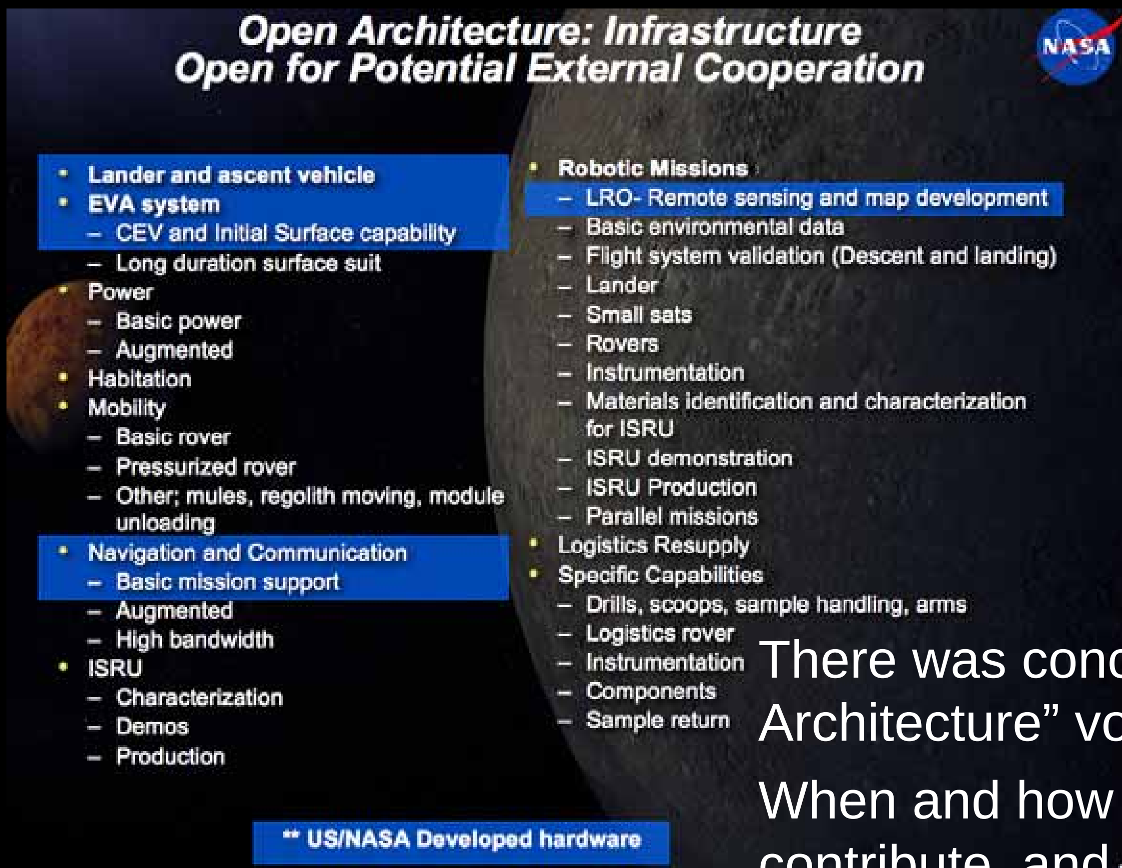
Briefings and Community Updates: Report



There was concern over the "Open Architecture" voiced by the community:

When and how will international partners contribute, and what will be the framework for such participation?

Mobility is critical, but not in blue. Who will do this? Given the fiscal realities can NASA do this if necessary?

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Briefings and Community Updates: Report

Simulants for toxicity testing are being produced, but the final product(s) is(are) not yet completed.

Lessons learned from the ISS need to be applied to the Outpost, especially hardware development (and limiting cost overruns) , making EVA capabilities easier at the outpost compared to Space Station, and in the handover from government to commercial management .

The capability of real time robotic teleoperation from Earth needs to be developed for mundane work.

A communications network needs to be established , especially for surface-surface communications during long EVAs.

There is a pressing need for the upgrading the Deep Space Network.

Need to reduce cost and risk, but without a precursor robotic program, this will have to be done through Missions of Opportunity by placing packages on spacecraft from other countries.

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Briefings and Community Updates: Report

SMD Lunar Science Strategy:

LRO is an ESMD mission, but SMD will take it over after 1 year.

- FY08: $22M; FY09: $45M; FY10: $65M, FY 11 & 12:$80M.
- Lunar Sortie Science Opportunities.
- Develop lunar mission concepts.
- LASER program jointly funded by SMD and ESMD).
- 60 proposals received for LRO Participating Scientist program.

LAT-2 Briefing - Community Comments: ISRU is not in the critical path but will be essential for sustainability and commercial development - there seems to be a disconnect.

Pressurized rover preserves the ability to go elsewhere as well as study around the outpost - capability for long range sorties would be science community consensus because of the different sites identified for different science objectives.

Role of robotics seems to be diminished from LAT-1 - with astronauts being inside during lunar night, teleoperations will be vital.

There needs to be better integration of human/robotic capability.

Briefings and Community Updates: Report

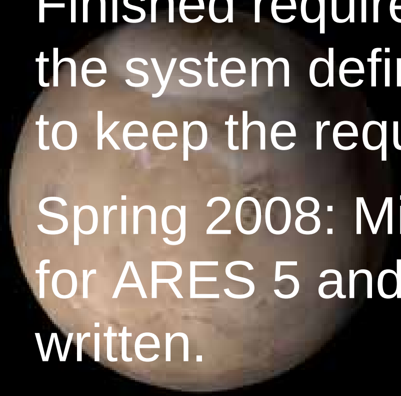
<u>LAT-2 Briefing - Community Comments (cont.):</u>
10-20 sites of scientific interest have been identified over the past 40 years; so there is a case for long-distance sorties from any outpost.

<u>Constellation Office Briefing - Comments</u>:

Mass allocated for sample return in the initial architecture is too low (see the CAPTEM document at www.lpi.usra.edu/captem). Up to 3 times the mass return by the Apollo J missions can be expected.

Transition plan for Shuttle retirement (keeping the workforce employed) is the lunar program. In 2011 Constellation will inherit the workforce from Shuttle.

Finished requirements review phase for Orion and ARES 5. Now into the system definition reviews. Finishing the requirements and then try to keep the requirements set as stable as possible



Spring 2008: Mission Concept Review. From this the specific reqmnts for ARES 5 and lunar lander, lunar surface systems, etc., will be written.

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Briefings and Community Updates: Report

Constellation Office Briefing - Comments (cont.):

Status of Constellation software requirements - just starting up test bed labs for launch vehicle.

Return landing on land or sea? Both capabilities will be included, although landing on land is more costly due to more mass that needs to be taken to the Moon for the return. Landing in North America is feasible if “skip entry” capability is included.

NASA Advisory Council Tempe Workshop Report: It was the intent of the NAC to have feedback from this workshop into the architecture and planning. The workshop produced 35 recommendations.

The NASA response to the workshop report is still being formulated (at the time of the LEAG meeting).

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International Partnerships

Overarching Question:

How can risk/cost be reduced through cooperation and partnerships in technological developments and demonstrations?

What are the synergies between the exploration goals of potential international partners and the Vision for Space Exploration?

What are the (perceived) obstacles to international cooperation in the Vision for Space Exploration and what are the solutions?

Coordination of missions

Joint participation in missions

Overlap (of instruments, objectives): Boon or bane?

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International Partnerships
Presentations

- CSA
  - Canada wants to participate in VSE by drawing on its strength in robotics, mobility systems, Earth analog sites Lunar outpost and Mars sample return
- ASI
  - Near completion of study on scientific exploration of the Moon Geoscience, Astrophysics, Earth observations. Italian mission will not duplicate existing orbiters
- ISRO
  - Chandrayaan 1 getting ready for launch. Concept for Chandrayaan 2 is orbiter/rover (30-60 kg)
- BNSC
  - Two mission concepts under study. MoonLITE is orbiter/penetrator concept for global network. Moonraker is small soft lander and rover; objectives being defined now
- JAXA
  - Kaguya/SELENE has safely launched and inserted into lunar orbit. Japan objectives are robotic exploration of Moon and Japanese crew member at international lunar base. SELENE is a mission series; SELENE 2 is soft lander/rover with comm. relay (for a far side or polar landing)

International Partnerships

Issues discussed

- ITAR effects on cooperation
  - Greatly hinders cooperative work
  - Must comply with law; an overhead cost adding risk and cost to missions
  - Careful writing of TAA avoids largest pitfalls
- Duplication of efforts
  - Recognize that national goals and needs drive missions, so some duplication is inevitable
  - Some cross-checking and calibration between similar data sets is good; also, multiple datasets assure that dropouts are not disastrous
  - Should attempt to keep each other informed on mission plans so as to minimize unnecessary duplication

International Partnerships

Frameworks for Cooperation

- Models of international collaboration efforts
  - GEOSS, program of programs
  - International Conference; joint statement
  - COSPAR; resolution
  - ISS; international legal framework
  - New framework (Kawaguchi); credit exchange system for providing datasets, payload space

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International Partnerships

Miscellaneous observations

- Develop list of advanced second-generation sensors to fly on future orbital missions
- A lunar GPS system would greatly aid exploration; an opportunity for distributed international participation (could be established and added to by many nations over long period of time)
- International participation in the lunar outpost. Of great value to focus on those elements NASA is NOT base lining (e.g., mobility)

ISRU Session Findings

- It seemed that the major consensus was that ISRU was important for sustained human presence on the Moon
  - Landers & Surface System elements should be compatible with use of ISRU products
- Prospecting is desired to make ISRU better but ISRU should be location feedstock independent (at least early on)
- Lots of spin-in capability and expertise from mining industry and ‘green’ technologies for water recycling and bioprocessing of trash as well as spin-off back to mining and Earth industries
- Question of hydrogen/water at the poles seems to be very important for Outpost location and long-term sustained operation even if it is not utilized early - Also major science question. Long-term science possible if Outpost is nearby
- Significant payload mass increases to and from the Moon possible with ISRU and surface/orbital depots but may need to significantly change current Architecture concept from LAT I/II to obtain these benefits
- Space commercialization of the Moon is enabled by ISRU however lots of debate on how to commercialize ISRU and developing ‘markets’

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ISRU Session Findings

- ISRU is not just oxygen production for ECLSS or propulsion. Need to expand to cover solar energy and power growth for Moon and Earth, construction, terrain modification, etc.
- Early demonstration of ISRU capabilities is important for sustained human operations and commercialization. Eliminate concern of putting ISRU in 'critical path'.
  - An ISRU demonstration mission is highly desirable
  - Insertion into a highly linked deployment schedule is difficult
- **How much and when ISRU is needed is highly a function of what is the actual goal/purpose for the Lunar Outpost and NASA human exploration of the Moon**
- Group consensus was to 'push back' on NASA to raise importance of ISRU to the Lunar architecture objectives

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Robotics Session Findings

Important Themes

- There is a long list of measure-ments to make and tests to do before and after human missions.
- These will enhance lunar exploration.
- There are innovative ways of implementing missions that could lead to lower cost.

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Robotics Session Findings

Why do robotic precursor missions?

- **Strategic knowledge**
  - Important information on lunar environment and materials obtained before people return
  - Scientific and operational reconnaissance
- **Programmatic milestones**
  - Decade between LRO and first human landings
  - Sustain program with cadence of visible milestones
- **Emplacement of assets**
  - Pre-landed machines can prepare site, emplace equipment for later human use
- **Site Precedence**
  - Assets in orbit and landed payloads are statement of intent to use lunar resources

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Robotics Session Findings

Why do robotic precursor missions?

- Characterize processes and environments likely to be changed as a result of human presence (e.g., lunar atmosphere)
- Obtain information on unknown or poorly understood processes and history (e.g., polar deposits)
- Reconnoiter areas and sites to make subsequent human exploration more productive
- Explore to characterize, map, learn and understand (all sites)

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Robotics Session Findings

Important Measurements to Enhance Exploration

- **Useful Lunar Information**
  - **Dust characterization & mitigation**
  - **Landing site reconnaissance**
  - **Lunar model validation (tie to ground truth)**
  - **Local radiation measurement**
  - **Spacecraft charging evaluation**
  - **Regolith handling/site preparation**
  - **ISRU characterization and demonstration**
  - **Lighting perspective (permanent low incidence at poles)**

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Robotics Session Findings

Important Measurements to Enhance Exploration

- **Useful Lunar Information: Polar Volatiles**
  - Inventory of trapped ice;
  - Composition of ice;
  - Variability in ice composition;
  - State of volatiles (ices, amorphous compounds, separate phases, clathrates);
  - Spatial distribution of ice;
  - How ice binds soil grains;
  - Whether ice reacts with soil grains;
  - Geotechnical properties of ice-bearing regolith in cold traps;
  - Physical environment of polar regions.

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Robotics Session Findings

Technology Demonstrations

- Communications (surface mobile comm).
- Mechanisms (1/6G performance, dust impact on lifetime).
- Materials (dust compatibility).
- Thermal (surface influence, radiator dust exposure).
- Navigation and guidance (Precision Landing).
- Propulsion (system performance, plume interaction).
- Mobility (traction, dust impact).
- Power (Re-charging mobile robotic assets, fuel cell tech).
- Avionics (Open architecture, Rad hard).
- Cryo handling & storage (test demo).
- ECLSS (water loop performance in 1/6g, dust filters).
- ISRU on the lunar surface.

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Robotics Session Findings

Innovative Robotic Approaches: Multiple hard landers for polar studies

- Cover diversity of polar lighting conditions
  - Ideal dispersion is at least one in light, one in dark
- Assure sensor release (no null results due to inverted orientation)
  - Will need to clear H-bearing material on spacecraft for accurate measurement of regolith
- Mission Redundancy
  - Assure at least one probe works and gives ground truth

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Robotics Session Findings

Innovative Robotic Approaches: Small Spacecraft

- **Key Features**
  - Low Mission Costs ($50-100M), Short Schedule <24Months;
  - Low Mass < 300kg, Low Cost Launch Vehicles.
- **Benefits**
  - Lower Cost Enables Increased Number Of Missions;
  - Faster Learning Cycle, Leads to Lower Costs;
  - Demonstrate New Technology Sooner, Lowers Cost of Large Missions;
  - Lower Overall Program Risk by Providing Several Flight Opportunities;
  - Smaller Teams, Fewer Interfaces, Improved Collaboration.
- **Drawbacks**
  - Size, Mass Eliminate Some Missions for Small Spacecraft;
  - Higher Individual Risk Of Missions compared with $1B Spacecraft;
  - Use of “Yet To Be Proven” Launch Vehicles, or Fly as a Secondary Payload.

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Robotics Session Findings

Lunar Science Robotic Campaign

- Establish an aggressive lunar science campaign to the lunar surface.
- Enabled by commercial leveraging with NASA
  - Could follow approach to develop commercial orbital transportation system (COTS).
- Could lead to a near-term technology demonstration on the surface.
- Campaign (series of missions) would provide information needed for exploration and science.
- LEAG through NAC could define the campaign.

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Robotics Session Findings

Role of the States

- **Why should states get involved?**
  - Affordability demands State participation;
  - Sustainability demands State participation;
  - The public benefits more when States participate;
  - Industry is critical, but it has to make money;
  - The States can bring everything together.
- **Roles states can play**
  - Education;
  - Promotion (e.g., tax structures for business);
  - Recruitment and incubation of space business;
  - Build infrastructure.

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Commerce: Incremental Steps from Earth to Lunar Enterprise

Overarching Question:

How can risk/cost be reduced through cooperation and partnerships in technological developments and demonstrations?

What progress has been made regarding the themes and recommendations from the LEAG-2005 meeting and what are the key roadblocks (if any) preventing progress?

What opportunities are there for private sector participation within the current architecture?

How can increased private sector participation be better facilitated to ensure the sustainability of the outpost?

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Commerce Session Findings

What progress has been made regarding the themes and recommendations from the LEAG-2005 meeting, and what are the key roadblocks (if any) preventing progress?

2005 Recommendation. NASA needs to encourage participation and partnership with the private sector as it plans and implements the Vision for Space Exploration. There needs to be a clear interface between NASA and the private sector.

2007 Update. Progress has been made in opening up communication between NASA and the private sector, in programs like COTS and Centennial Challenges, as well as other Innovative Partnerships activities and procedures. Public consultation associated with NASA's international exploration strategy development has also been helpful. However, more needs to be done to integrate commercial viewpoints into the details of NASA planning, especially with regard to government resource allocation in lunar exploration initiatives.

Commerce Session Findings

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2005 Recommendation. There needs to be development of solid business plans for lunar and cis-lunar commerce. At present the government is the only identified customer.

2007 Update. A number of commercial initiatives continue to move forward, as evidenced by the speakers on the 2007 LEAG commercial panels. However, industry needs to seek out non-government customers more actively, rather than primarily waiting for the next government contract. Although government involvement may legitimately be necessary for many business ventures to achieve initial viability, that is no justification for passive and permanent reliance on public funding when alternatives exist.

2005 Recommendation. Decrease the cost of access to space. Many enterprises require inexpensive access to LEO and the Moon.

2007 Update. International launch capabilities offer increasing options, but legal and policy constraints may limit the extent to which such assets can be used, especially by U.S. entities. Entrepreneurial launch companies are moving forward with projects intended to decrease the cost of U.S. means to achieve space access, and NASA has played a role in encouraging this development by inaugurating the Commercial Orbital Transportation Services (COTS) program. However, it is unclear what the result of such efforts will be, and in the interim the cost of space access continues to be a major obstacle to lunar commerce.

Commerce Session Findings

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2005 Recommendation. Specific commercially relevant applications of technologies must be tested on the Moon. Thus, robotic and human missions to the Moon need to provide opportunities for such commercial experiments

2007 Update. Considerable interest still exists on the part of industry regarding inclusion of commercially-oriented payloads in government lunar missions. However, uncertainly with regard to NASA's intentions, concerning the timing and capabilities of lunar lander or rover missions, has left the commercial sector without the opportunity to attract private investment for concrete projects. Fully commercial lunar missions, as well as commercial collaboration with government lunar efforts outside the U.S., may offer additional options, but the availability of such opportunities remains to be seen

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Commerce Session Findings

2005 Recommendation. Although lunar commerce should not be permanently dependent on government involvement, near-term business and investor interest would be facilitated by greater clarity from NASA, regarding its potential role as customer and infrastructure developer.

2007 Update. NASA has made progress both in supporting development of commercial space transportation capabilities and in planning to purchase such services (e.g., COTS Phases I and II), and such an approach is being considered for additional infrastructure areas, such as communications. A new commercial strategy within NASA/ESMD may also have potential to encourage an increase in space activity relevant to lunar commerce. However, the outcome and impact of NASA initiatives on lunar commerce is far from certain.

Overarching Conference Question. How can risk/cost be reduced through cooperation and partnerships in technological developments and demonstrations?

Summary of Answers. Government and industry can work together, beginning with dialogue and extending through cost-sharing and ride-sharing arrangements, as well as commercially-relevant R&D initiatives and commercially-friendly infrastructure development. Government can play a particularly important role by simply purchasing goods and services from commercial sources, as a supplement to the traditional procurement of government-unique items

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Commerce Session Findings

Additional General Questions

What opportunities are there for private sector participation within the current architecture?

Summary of Answers. NASA's published depiction of lunar architecture elements, with an identification of the subset that current priorities dictate that the Agency itself will do, has clarified where a number of commercial opportunities for development of supporting activities might exist. However, it is not clear the extent to which NASA will include commercial activity in accomplishment of its core priority functions or the extent to which the Agency will facilitate commercial efforts to develop adjacent or supporting activities

How can increased private sector participation be better facilitated to ensure the sustainability of the outpost?

Summary of Answers. NASA can structure programs so that they allow for early and ample commercial sector input in planning. Beyond this, the Agency can create opportunities for commercial participation in program implementation, so as to encourage: development of multiple customers in addition to NASA, private investment in addition to public funding, and design of infrastructure to maximize commercial as well as government use.

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Commerce Session Findings

Summary and Conclusions

Incremental business models reduce risk by starting small and moving through a series of financial and technical milestones, at which investors and partners have the opportunity to enter or exit, based on past performance and future prospects. Several organizations are practicing some form of incremental approach that can facilitate development of lunar commerce:

Boeing – collaborated with others to create a concept for incremental buildup of propellant depot architecture;

Lunar Transportation Systems - commercial transportation and lunar surface mining

MDA Canada – multidimensional technical and economic capability, gradually developing a variety of Earth as well as space applications

Optech - has incrementally leveraged core expertise in lidar and laser-based surveying, as well as a strategic partnership with MDA, to offer a variety of space lidar solutions for planetary exploration, orbital operations, and science.

Jamestown Group - advocates a step-by-step process for enabling major electrical power generation using lunar materials.

Commerce Session Findings

Summary and Conclusions (cont.)

Examples of incremental commercial applications that might benefit from space infrastructure development include the:

- Surface simulation efforts of the **Lunar Explorer** venture;
- **Kronos** concept of meteorite prospecting on Earth leading to similar activity on the Moon;
- **International Lunar Observatory** initiative to raising private capital for creation of a lunar facility.

Government efforts can facilitate both commercial infrastructure and application development. At NASA, new procedural approaches are being inaugurated to meet this challenge, especially with regard to government purchase of commercial services. Future progress depends on pursuit of innovative options that will both facilitate accomplishment of government missions and maximize opportunities for commercial growth.

Sample Return & Lunar Exploration

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Overarching Question:

How can risk/cost be reduced through cooperation and partnerships in technological developments and demonstrations?

What technologies exist and what technologies need to be developed in order to reduce risk/cost for (1) robotic sample return, (2) human sample return, and (3) robotic-human sample return?

What analysis can be done on the surface robotically and with crew vs. required sample return?

What are the limiting technologies for analysis on the lunar surface versus sample return?"

What are the roles of NASA, non-US space agencies, and the private sector in sampling the Moon?

Sample Return & Lunar Exploration Session Findings

Why go to the Moon?

We are going to work and learn how to live on another planet.

The Moon has unique significance for all space applications for a reason that to my amazement is hardly ever discussed in popular accounts of space policy. The Moon is the closest source of material that lies far up Earth's gravity well. Anything that can be made from Lunar material at costs comparable to Earth manufacture has an enormous overall cost advantage compared with objects lifted from Earth's surface. The greatest value of the Moon lies neither in science nor in exploration, but in its material.

John Marburger, 44th Robert H. Goddard Memorial Symposium, March 15, 2007, Keynote Address

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Sample Return & Lunar Exploration Session Findings

Science might not be the (or a) driver, but science will be one of the key legacies.

Sample return is important – Samples are a key legacy of exploration and they are a "gift that keeps on giving."

- new science questions;
- new analysis techniques;
- exploration – enabling issues, safety;
- ISRU – process development, resource assessment;
- other uses, e.g., education, political, public outreach.

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Sample Return & Lunar Exploration Session Findings

What technologies exist and what technologies need to be developed in order to reduce risk/cost of lunar sample return?

- Identify technology linkages/commonalities among different styles of missions (non-SR & SR) at system and subsystem levels.
- Apollo provides a starting point for sample return collection, handling, curation. How successful were these approaches?
- Special environmental sample containers, container seals.
- What level of sample culling and curation on lunar surface is needed?
  - Dictates technologies and infrastructure needed.
  - Will effect potential sources of sample contamination.

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Sample Return & Lunar Exploration Session Findings

What technologies exist and what technologies need to be developed in order to reduce risk/cost for:

- Robotic sample return:
  - Sample collection tools (mobility, analysis, drilling, high-grading, context);
  - Robots for dangerous sampling activities and routine activities;
  - Human sample return
- Astronaut in the loop always enhances exploration. Geologic context, decision making……
  - Mass issues;
  - outpost sample analysis (lab in the hab) and sample “prep” – remains an issue;
  - Capabilities to make decisions about sample disposition;
  - Sample “caching” at the Outpost.
- Robotic-human sample return:
  - Long-range roving with sample collection;
  - Teleoperation.

Sample Return & Lunar Exploration Session Findings

How to reduce risk & cost with technology development?

- Precision landing.
- Sample containment/preservation.
- Coring & manipulation.
  - Sampling subsurface:
    - Don’t forget Apollo coring experience/knowledge;
    - Coring/drilling polar regolith;
    - Controlled or deep regolith stratigraphy.
- Contamination mitigation.
- On-surface curation.

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Sample Return & Lunar Exploration Session Findings

What are the limiting technologies for analysis on the lunar surface versus sample return?

- Precision of analysis – age dating and context analyses
- Astronaut assist – instruments, suits (glove dexterity), data systems
- Telerobotics
- Lab-in-Hab issues and contamination

- What are the technological challenges for future automated lunar sample return?
    - Cryogenic samples
        - Collection
        - Collection without modification
        - Sample transfer
        - Environmental control
        - Containment – need work on vacuum seals, contamination prevention
        - Maintaining integrity through return to Earth
    - Oriented samples
    - Drilling rocks and regolith – volcanic & paleoregolith layers

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Sample Return & Lunar Exploration Session Findings

- Different categories of samples to address science and exploration questions
  - Samples that are best returned to Earth (rocks, regolith, special samples):
    - Polar volatiles for science.
  - Samples that are best analyzed in-situ:
    - Polar regolith;
    - Regolith to determine reactivity.
- What are the key sample types needed to advance our understanding of the Moon?
  - Materials for dating lunar craters and terranes;
  - Volatiles at the poles;
  - Volcanic materials to sample the lunar interior:
- What questions are better addressed with samples on the surface vs. returned to Earth?
  - Note: collection & return strategy dictated by the question to be addressed.
  - But… we do not always foresee good questions that will be asked.

Sample Return & Lunar Exploration Session Findings

Exploration Issues

- Analysis of physical properties & for ISRU:
  - In-situ vs. return.
- Utilization of lunar resources:
  - Are samples required or nice to have?
  - Assumes we know what we are looking for. Sometimes we get surprises. Better to have the samples.
- Need a contamination Czar:
  - consider science <u>and</u> exploration issues;
  - Alteration/contamination of 'pristine' nature of samples by exposure to atmosphere is a concern.

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Sample Return & Lunar Exploration Session Findings

What are the roles of NASA, non-U.S. space agencies, and the commercial sector in sampling the Moon?

NASA:

- Expensive robotic and human sample return missions.
- Infrastructure to carry out these missions.
- Curation and allocation of samples for current and future science-engineering communities.

Non-U.S. Space Agencies:

- Sample return missions are ideal for multi-national collaboration.
- Development of sample return and handling technologies
- Sharing of samples

Commercial Sector:

- Contribution to the development of SR subsystems
- Mini-SR missions with well focused goals.

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Role of Technology in Field Exploration & Astronaut Training (FEAT) Session Findings.

What were the lessons learned from Apollo (i.e., what worked and what didn't?)?

What technologies need to be developed to facilitate field operations for the establishment and maintenance of a lunar outpost, as well as for scientific exploration?

FEAT Near-term Goals

- Provide a venue for field geologists to contribute to preparations for lunar field work.
- Foster communication between field geoscientists and field technologists.
- Assist in the development of a field geologic training program.
- Capture wisdom of Apollo Program veterans.
- Recruit young field geoscientists for future work.

http://www.lpi.usra.edu/leag/

FEAT Session Findings
Lessons Learned

Train together (astronauts, back-room scientists Capcom, HQ personnel, and engineers) Capcom, HQ personnel, and engineers).

Field trips to analog sites as well as other interesting localities (volcanic fields, impact sites, etc.).

Focus on problem-solving.

Develop a common language, emphasize clear and accurate communications in regard to geologic features and rocks.

Find mentors that can relate to the astronauts.

Include geophysical field techniques and data analysis in the training.

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FEAT Session Findings
Lessons Learned

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Train astronauts to observe detailed relationships (e.g., contacts within boulders, overall geologic context).

Use potential analytical tools in the field (analog demonstrations).

Have astronauts interact with robotic systems during training.

Importance of debriefing field trip after initial study of an area.

FEAT Session Findings
Observations about Field Technologies

Keep is simple, but scientifically useful.

Relieve astronauts of detailed sample documentation by employing new technologies.

Use potential analytical tools in the field during training (e.g., hand-held XRF, portable Raman spectrometer, digital microscopy).

Importance of the work bench and rock splitter near the habitat for sample high grading.

Use of telepresence technology in field training.

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Site Selection & the Lunar Outpost Session Findings

What are the drivers for the site of the lunar outpost and have they changed from the criteria previously used?

Building upon the wealth of material that has been previously published, what is the “ideal” site for operations, science, exploration, ISRU, commerce, and/or international cooperation?

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Site Selection & the Lunar Outpost Session Findings

Site Selection: process needs to be open, build on history, and be inclusive of all stake-holders.

There needs to be an ISRU demonstration mission for sustainability and Mars feed forward.

ISRU can be enabling without being in the critical path. It can be done anywhere, but S Pole is favorite although the nature of the H deposits are unknown. ISRU can be used to mitigate ΔV issues and feed forward.

Mars feed forward requirements:
learn to live off the land, mobility, ISRU.
Outpost site should provide this.

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Site Selection & the Lunar Outpost Session Findings

Sustainability should promote growth - need resources and products for commercial investment.

Commerce: site needs to be resource/energy rich; provide entertainment/public engagement value; be accessible to areas of scientific interest.

NASA: site exploration that provides on-ramps for commercial development.

Need a forum better than COTS to facilitate strong private-public partnerships - no tokenism.