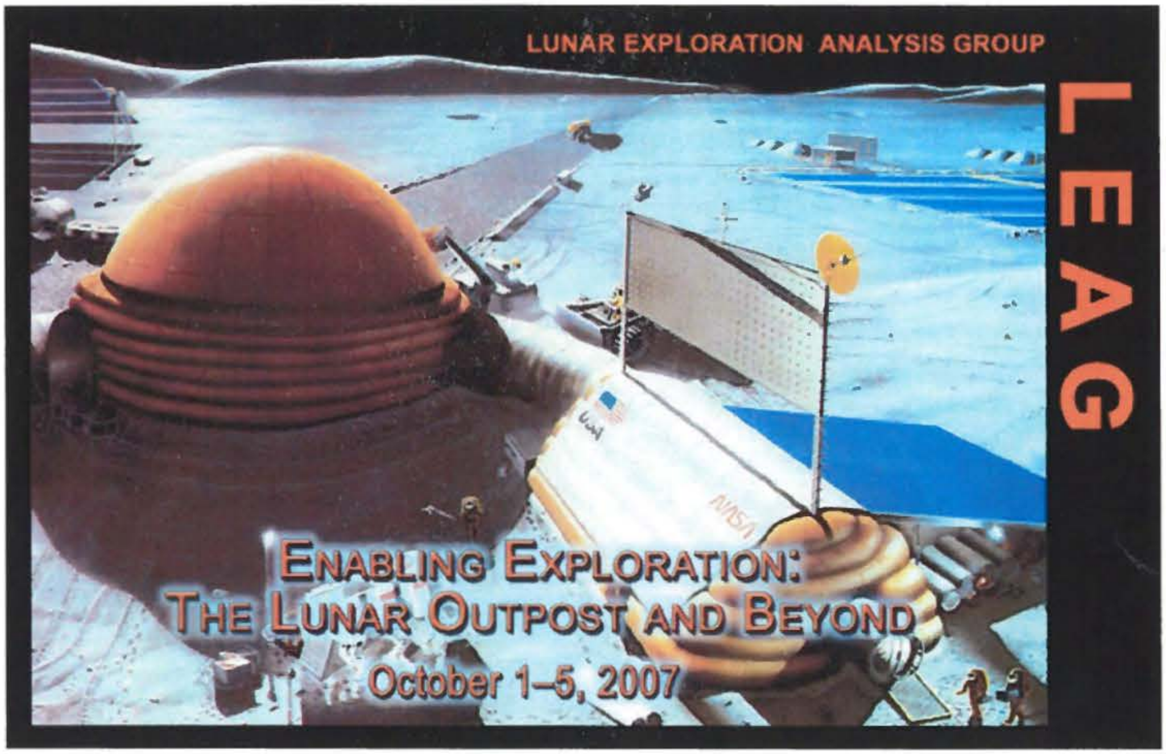

Executive Summaries

LEAG Annual Meeting
October 1–5, 2007
"Enabling Exploration: The Lunar Outpost and Beyond"

AGENDA

Sunday, September 30, 2007

4:00 – 6:00 p.m.	Registration, Southwest Grand Ballroom Foyer
6:00 – 8:00 p.m.	Welcome Reception, Southwest Grand Ballroom Foyer

Monday, October 1, 2007

PLENARY: COMMUNITY UPDATES
8:00 a.m. to 12:00 noon
Southwest Grand Ballroom C
Moderator: Clive Neal, University of Notre Dame

8:00 a.m.	Welcome and Logistics *Clive Neal, University of Notre Dame*
8:10 a.m.	Exploration Partnership Strategy Briefing *Marguerite Broadwell, NASA Headquarters*
8:50 a.m.	Exploration Science Mission Directorate Briefing *Doug Cooke, NASA Headquarters*
9:30 a.m.	Science Mission Directorate Briefing *Jim Green, NASA Headquarters*
10:10 a.m.	Space Operations Mission Directorate Briefing *W. Michael Hawes, NASA Headquarters*
10:50 a.m.	Lunar Architecture Team (LAT)-2 Briefing *Geoff Yoder, NASA Headquarters*
11:30 a.m.	Questions and Discussion *Clive Neal, University of Notre Dame*
12:00 noon	LUNCH, Southwest Grand Ballroom A/B

Monday, October 1, 2007 (continued)

WORKSHOP AND WORKING GROUP BRIEFINGS
1:30 p.m. to 5:15 p.m.
Southwest Grand Ballroom C
Moderator: Clive Neal, University of Notre Dame

1:30 p.m. Constellation Office Briefing
Jeff Hanley, NASA Johnson Space Center

2:15 p.m. Recommendations from the Workshop on Science Associated with the Lunar Exploration Architecture, Tempe, Arizona, 2/27–3/2, 2007
Brad Jolliff, NASA Advisory Council/Washington University

2:40 p.m. Report of the OSEWG Workshop
Kelly Snook, NASA Headquarters

3:05 p.m. Field Exploration and Astronaut Training Activities and Goals
Mark Helper, University of Texas, Austin, and Art Snoke, University of Wyoming

3:30 p.m. Report of the Lunar Dust Workshop
Daniel Winterhalter, Jet Propulsion Laboratory

3:50 p.m. Report of the National Research Council Space Studies Board Workshop
Mike Duke, Colorado School of Mines

4:10 p.m. The Things We Most Need to Learn at the Moon to Support the Subsequent Human Exploration of Mars
Brett Drake, NASA Johnson Space Center

4:40 p.m. Questions and Discussion
Clive Neal, University of Notre Dame

5:10 p.m. Overview of the Meeting and Meeting Product
Clive Neal, University of Notre Dame

5:15 p.m. ADJOURN

Tuesday, October 2, 2007

INTERNATIONAL PARTNERSHIPS
8:00 a.m. to 12:15 p.m.
Southwest Grand Ballroom C
Moderator: Paul Spudis, Applied Physics Laboratory, Johns Hopkins University

8:00 a.m.	Introduction *Paul Spudis*
8:05 a.m.	Update from the Canadian Space Agency (CSA) *Jean-Claude Piedboeuf*
8:35 a.m.	Update from the Agenzia Spaziale Italiana (ASI) *Sylvie Espinasse*
9:05 a.m.	Update from the European Space Agency (ESA) *Speaker TBD*
9:35 a.m.	Update from the Indian Space Research Organisation (ISRO) *Paul Spudis*
10:05 a.m.	Update from the Deutsches Zentrum für Luft- und Raumfahrt (DLR) *Walter Döllinger*
10:35 a.m.	Update from the British National Space Centre (BNSC) *Alan Smith*
11:05 a.m.	Update from the Japanese Aerospace Exploration Agency (JAXA) *Jun-ichiro Kawaguchi*
11:35 a.m.	Panel Discussion
12:30 p.m.	LUNCH, Southwest Grand Ballroom A/B

In Situ Resource Utilization and Outpost Sustainment Demonstrations
1:30 p.m. to 5:30 p.m.
Southwest Grand Ballroom C
Moderator: Jerry Sanders, NASA Johnson Space Center

1:30 p.m. Panel and Discussion Introduction

1:45 p.m. NASA ISRU Incorporation and Development Plans
Jerry Sanders, NASA Johnson Space Center

2:15 p.m. CSA Concepts and Plans for Sustained Lunar Exploration and Surface Operations
Jean-Claude Piedboeuf, Canadian Space Agency

2:45 p.m. SELENE Status and ISRU Activity in Japan
Kai Matsui, JAXA

3:15 p.m. ISRU and Potential Mass and Cost Impacts on Sustained Lunar Exploration
Bob Easter, Jet Propulsion Laboratory

3:45 p.m. ISRU Development Roadmap — AIAA Perspective
D. Larry Clark, AIAA Space Resources Technical Committee

4:15 p.m. International-Commercial Involvement in Lunar Robotic Mission
Rod Wilks, ATK

4:45 p.m. Panel Discussion Begins

5:30 p.m. ADJOURN

Wednesday, October 3, 2007

THE ROLE OF ROBOTIC MISSIONS
8:00 a.m. to 10:15 a.m.
Southwest Grand Ballroom C
Moderator: Jeff Taylor, University of Hawai'i

8:00 a.m. Basic Themes and Issues
Jeff Taylor, University of Hawai'i

8:10 a.m. Lunar Robotic Precursor Program Status
Tony Lavoie, NASA Marshall Space Flight Center

8:30 a.m. Scientific Contributions of Lunar Robotic Precursor Missions
Paul Spudis, Applied Physics Laboratory

8:50 a.m. The Pacific International Space Center for Exploration Systems (PISCES) as an Example of the Role that the States Can Play in Space Exploration
Frank Schowengerdt, University of Hawai'i

9:10 a.m. Small Spacecraft in Support of the Lunar Exploration Program
Pete Worden, NASA Ames Research Center

9:30 a.m. Proposal for a Lunar Exploration Science Campaign: A Commercial-leveraged, Science-focused, Frequent Lunar Mission Program
Robert Kelso, NASA Johnson Space Center, Greg Schmidt, NASA Ames Research Center

9:45 a.m. Discussion

COMMERCE: INCREMENTAL STEPS FROM EARTH TO LUNAR ENTERPRISE
10:30 a.m. to 12:15 p.m.
Southwest Grand Ballroom C
Moderator: Paul Eckert, Boeing Company

Introduction

10:30 a.m. Incremental Steps from Earth to Lunar Commerce: How to Do It, and How to Pay for It, One Step at a Time
Paul Eckert, Boeing Company

Incremental Infrastructure Development

10:50 a.m. Commercial Transportation and Lunar Surface Mining
Tom Taylor, Lunar Transportation Systems

11:10 a.m. Is a LEO Propellant Depot Commercially Viable?
Dallas Bienhoff, Boeing Company

11:30 a.m. Robotic Technologies for Lunar Exploration
Frank Teti, MDA

11:50 a.m. Toward a 1GWe of Solar Energy on and from the Moon by 2020
Klaus Heiss, High Frontier/Jamestown Group

12:10 p.m. The New Race to the Moon — Building Bridges for Lunar Commerce
Robert Richards, Optech Incorporated

12:30 p.m. Q&A

1:00 p.m. LUNCH, Southwest Grand Ballroom A/B

Incremental Application Development

2:30 p.m. Making the Moon Accessible to Everyone
Manny Pimenta, Lunar Explorer, LLC

2:50 p.m. Meteorite Collection on the Lunar Surface
Luke Erikson, Colorado School of Mines

3:10 p.m. Lunar Commercial Communications Enabled by the International Lunar Observatory/ ILO Association
Steve Durst, International Lunar Observatory Association

3:30 p.m. Q&A

4:00 p.m. BREAK

Wednesday, October 3, 2007 (continued)

COMMERCE: INCREMENTAL STEPS FROM EARTH TO LUNAR ENTERPRISE (CONTINUED)
10:30 a.m. to 12:15 p.m.
Southwest Grand Ballroom C
Moderator: Paul Eckert, Boeing Company

Government Facilitation
4:20 p.m. ESMD Commercial Development Strategy Overview
Ken Davidian, NASA Headquarters

4:40 p.m. Q&A

General Commercial Panel
4:50 p.m. Q&A and Moderator Summary

5:30 p.m. ADJOURN

POSTER SESSION I AND RECEPTION
6:00 p.m. to 8:00 p.m.
Southwest Grand Ballroom D/E

Posters are listed at the end of this agenda

Thursday, October 4, 2007

SAMPLE RETURN AND LUNAR EXPLORATION
8:00 a.m. to 12:00 noon
Southwest Grand Ballroom C
Moderators: Brad Jolliff, Washington University, and
Charles Shearer, University of New Mexico

8:00 a.m.	Exploring the Moon with Samples. Scientific and Exploration Importance of Sample Return and Buying Down Risk and Cost of Sample Return Missions *Charles Shearer, University of New Mexico*
8:30 a.m.	The Lunar Collection: Status and the Future *Gary Lofgren, NASA Johnson Space Center*
9:00 a.m.	Lunar Sample Return: Reprise *Harrison Schmitt, University of Wisconsin*
9:30 a.m.	Future of Lunar Sample Return: Robotics, Humans, and Robotic-Human Partnerships *Jeff Taylor, University of Hawai'i*
10:00 a.m.	Management of Future Lunar Samples: Back to Basics *Dean Eppler, NASA Johnson Space Center*
10:30 a.m.	Automated Subsurface Sample Acquisition Technologies for Lunar Exploration *Kiel Davis, Honeybee Robotics*
11:00 a.m.	Panel Q&A Discussion
12:00 noon	LUNCH, Southwest Grand Ballroom A/B

THE ROLE OF TECHNOLOGY IN FIELD EXPLORATION AND ASTRONAUT TRAINING
1:30 p.m. to 5:30 p.m.
Southwest Grand Ballroom C
Moderators: Mark Helper, University of Texas, Austin, and
Art Snoke, University of Wyoming

1:30 p.m. Interviews with Apollo Lunar Surface Astronauts in Support of Lunar Surface Exploration Systems Design
Dean Eppler, SAIC/NASA Johnson Space Center

2:00 p.m. Astronaut Training, What We Did, Why It Worked, and What Can Be Done Better
Gary Lofgren, NASA Johnson Space Center

2:30 p.m. Astronaut Geology Training
James Reilly, Astronaut

3:00 p.m. Arctic Mars Analogue Svalbard Expedition: Testing Robotic and Human Space Flight Instrumentation in the Arctic
Andrew Steele, Carnegie Institution

3:30 p.m. Mobile Lunar Landers and Their Implications for Science
Brian Wilcox, Jet Propulsion Laboratory

4:00 p.m. Collaborative Human-Robot Science Exploration on the Lunar Surface
Charles Weisbin, Jet Propulsion Laboratory

4:30 p.m. Panel Discussion

5:30 p.m. ADJOURN

POSTER SESSION II AND RECEPTION
6:00 p.m. to 8:00 p.m.
Southwest Grand Ballroom D/E

Posters are listed at the end of this agenda

Friday, October 5, 2007

SITE SELECTION AND THE LUNAR OUTPOST
8:00 a.m. to 12:15 p.m.
Southwest Grand Ballroom C
Moderator: Clive Neal, University of Notre Dame

8:30 a.m.	Lunar Site Selection Process Definition in LAT-2 *Robert Gershman, Jet Propulsion Laboratory*
9:00 a.m.	Lunar Outpost Site Selection: A Review of the Past 20 Years *John Gruener, NASA Johnson Space Center*
9:20 a.m.	Feed Forward to Mars: Implications for Lunar Outpost Site Selection and the Nature of the Activity to be Carried Out There *Dave Beaty, Jet Propulsion Laboratory*
9:40 a.m.	Site Selection for the Lunar Outpost *Jeff Plescia, Applied Physics Laboratory*
10:00 a.m.	Outpost Site Selection for In-Situ Resource Utilization *Bill Larson, NASA*
10:20 a.m.	Science Criteria for Lunar Outpost Site Selection and an Example *Brad Jolliff, Washington University*
10:40 a.m.	Site Selection and Commercial Opportunities *Rick Tumlinson, Space Frontier Foundation*
11:00 a.m.	Site Selection and Lunar Outpost: SMART-1 Results and ESA Studies *Bernard Foing, ESA/ESTEC*
11:20 a.m.	Synopsis of Presentations *Clive Neal*
11:30 a.m.	Panel Discussion
12:00 noon	LUNCH, Southwest Grand Ballroom A/B

Friday, October 5, 2007 (continued)

REPORT FROM MODERATORS AND GENERAL DISCUSSION
1:30 p.m. to 4:30 p.m.
Southwest Grand Ballroom C

1:30 p.m.	International Partners *Paul Spudis, Applied Physics Laboratory*
1:50 p.m.	Lunar Commerce *Paul Eckert, Boeing Company*
2:10 p.m.	In Situ Resource Utilization and Outpost Sustainment Demonstrations *Jerry Sanders, NASA Johnson Space Center*
2:30 p.m.	Robotic Missions *Jeff Taylor, University of Hawai'i*
2:50 p.m.	Sample Return *Brad Jolliff, Washington University, Charles Shearer, University of New Mexico*
3:10 p.m.	Field Exploration and Astronaut Training *Mark Helper, University of Texas, Austin, Art Snoke, University of Wyoming*
3:30 p.m.	Site Selection *Clive Neal, University of Notre Dame*
3:50 p.m.	Panel Discussion
4:30 p.m.	ADJOURN

POSTER SESSION I
Wednesday, October 3, 2007
6:00–8:00 p.m.

International Partnerships

Schneck T.
Toward a Standard Moon

Jaumann R. Spohn T. Hiesinger H. Jessberger E. K. Neukum G. Oberst J. Helbert J. Christensen U. Keller H. U. Mall U. Boehnhardt H. Hartogh P. Glassmeier K.-H. Auster H.-U. Moraira A. Werner M. Paetzold M. Palme H. Wimmer-Schweingruber R. Mandea M. Flechtner F. Lesur V. Haeusler B. Srama R. Kempf S. Hoerdt A. Eichentopf K. Hauber E. Hoffmann H. Koehler U. Kuehrt E. Michaelis H. Pauer M. Sohl F. Denk T. van Gasselt S.
Lunar Exploration Orbiter (LEO): Providing a Globally Covered, Highly Resolved, Integrated Geological, Geochemical and Gephysical Data Base of the Moon

ISRU, Outpost Sustainment, and Robotic Missions

Brown I. I. Jones J. A. Garrison D. Bayless D. Sarkisova S. A. Sanders G. B. McKay D. S.
Biotechnologies at Lunar Outpost and Beyond

Stillman D. E. Grimm R. E.
Scientific and Resource Characterization of Lunar Regolith Using Dielectric Spectroscopy

Heldmann J. L. Colaprete T. Wooden D. Asphaug E. Schultz P. Plesko C. S. Ong L. Korycansky D. Galal K. Briggs G.
Lunar Crater Observation and Sensing Satellite (LCROSS) Mission: Opportunities for Observations of the Impact Plumes from Ground-based and Space-based Telescopes

Colaprete A. Briggs G. Ennico K. Wooden D. Heldmann J. L. Sollitt L. Asphaug E. Schultz P. Christensen A. Galal K.
An Overview of the Lunar Crater Observation and Sensing Satellite (LCROSS) Mission — An ESMD Mission to Investigate Lunar Polar Hydrogen

Ennico K. Colaprete A. Wooden D. Heldmann J. L. Lynch D. Kojima G. Shirley M.
LCROSS Science Payload Ground Development, Test, and Calibration Results

Cooper B. L. Schrunk D. G.
ISRU Will Make the Difference Between Going Back to the Moon to Visit and Going Back to the Moon to Stay

Gertsch L. S.
Priorities for Demonstrating Lunar ISRU Capabilities

Elphic R. C. Kobayashi L. Allen M. Bualat M. Deans M. Fong T. Lee S. To V. Utz H.
Enabling Exploration: Robotic Site Surveys and Prospecting for Hydrogen

Miura Y.
Exploration of Carbon-bearing Materials on the Moon

Wang A. Ling Z. C. Jolliff B. L.
Planetary Raman Spectroscopy for Surface Exploration and In Situ Resource Utilization on the Moon

Weinberg J. D. Craig R. Earhart P. Gravseth I. Miller K. L.
Flash LIDAR Systems for Hazard Detection, Surface Navigation and Autonomous Rendezvous and Docking

Tietz S.
The Idea of a Student Built Lunar Orbiter

Garrick-Bethell I. West J. J. Lawrence d. J. Elphic R. C.
Rocket Dispersed Instruments: A Mission Architecture for Exploring Lunar Polar Hydrogen

Kring D. A.
Reducing the Risk, Requirements, and Cost of the Human Exploration Phase of the Constellation Program with Robotic Landers and Rovers

Duke M. B.
The Role of Robotic Missions in a Lunar Outpost Strategy

POSTER SESSION II
Thursday, October 4, 2007
6:00–8:00 p.m.

Private Sector Involvement

McKay D. S.
Commercial Development of the Moon: The Great Lunar Depository

Durst S. M. Mendell W. W. Gonella M.
Lunar Commercial Communications Enabled by the International Lunar Observatory/ILO Association

Davis K. Paulsen G. L. Zacny K.
Robotic Components and Subsystems Enabling Lunar Exploration: Status Update

Sample Return and Lunar Exploration

Jolliff B. L. Papanastassiou D. A. Cohen B. A.
Testing the Terminal Cataclysm Hypothesis with Samples from the South Pole-Aitken Basin

Field Exploration and Astronaut Training

Rask J. C. Heldmann J. Smith H. Battler M. Fristad K. Allner M. Clardy T. Clark O. Taylor C. Citron R. Corbin B. Negron G. Skok J. Taylor L. Centinello F. Duncan A. Fan A. Pavon S. Sutton W. Drakonakis V. Gilbert C. Graves S. Guzik G. Sahani R. McKay C. P.
The Spaceward Bound Field Training Curriculum for Moon and Mars Analog Environments

Clardy T. W. Fristad K. E. Rask J. C McKay C. P.
Establishment of a Wireless Mesh Network and Positional Awareness System in a Mars Analogue Environment

McKay C. P. Coe L. K. Battler M. Bazar D. Conrad L. Day B. Fletcher L. Green R. Heldmann J. Muscatello T. Rask J. C. Smith H. Sun H. Zubrin R.
Spaceward Bound: Field Training for the Next Generation of Space Explorers

Garrick-Bethell I. Weiss B. P.
Technology and Techniques for Paleomagnetic Studies at the Lunar Poles

Clark P. E. Lewis R. Leshin L.
Optimizing Instrument Packages for the Lunar Surface

Braham S. P. Pires M. P.
Lunar Surface Field Exploration Infrastructure Systems Requirements Development — Results of a Decade of Analog Lunar Surface Exploration

Williamson M-C. Hipkin V. Lebeuf M. Berinstain A.
Exploration Architecture Validation Through Analog Missions — A Canadian Perspective

Site Selection and the Lunar Outpost

Plescia J.   Spudis P.   Bussey B.   Elphic R.   Nozette S.   Phipps A.
Hydrogen: A Strategy for Assessing the Key Element for the Lunar Outpost

Fernandes V. A.   Cohen B. A.   Fritz J.   Jessberger E. K.
Return to the Moon: Ethical, Cultural and Social Aspects — Initial Approaches to These Complex Themes with a Geological Perspective

Cooper B. L.
Possible Mafic Patches at Mons Malapert and Scott Crater Highlight the Value of Site Selection Studies

Jolliff B. L.   Zhang J.
Aristarchus Plateau as an Outpost Location

Fong T.   Deans M.   Bualat M.   Flueckiger L.   Allan M.   Utz H.   Lee S.   To V.   Lee P.
Analog Lunar Robotic Site Survey at Haughton Crater

Feed Forward to Mars

Heldmann J. L.   Levine J.   Garvin J.   Beaty D.   Bell M. S.   Clancy T.   Cockell C. S.   Delory G.   Dickson J.   Elphic R.   Eppler D.   Fernandez-Remolar D.   Gruener J.   Head J. W.   Helper M.   Hipkin V.   Lane M.   Levy J.   Millikan R.   Moersch J.   Ori G.   Peach L.   Poulet F.   Rice J.   Snook K.   Squyres S.   Zimbelman J.
Interim Results from the MEPAG Human Exploration of Mars Science Analysis Group (HEM-SAG)

Conley C. A.   Race M.
Planetary Protection and Implications for Lunar Mission Planning: Science, Technology, and Feed-Forward to Mars

Executive Summary

Date Prepared: Sept. 24, 2007
Presenter's Name: David W. Beaty
Presenter's Title: Mars Chief Scientist
Presenter's Organization/Company: NASA-JPL

Presentation Title

Feed Forward to Mars: Implications for Lunar Outpost Site Selection and the Nature of the Activity to be Carried Out There

Key Ideas

Over the past six months, a concentrated multi-disciplinary, multi-directorate (ESMD, SMD, ARMD, and SOMD) effort has been carried out to update our Mars human reference mission. Included within this analysis is evaluation of the probable objectives of the mission, implications for the kinds of sites on Mars that would be most useful, and assessment of the kind of activity that needs to be carried out there. A primary purpose of this study is to provide guidance to the lunar exploration program so that the heritage it establishes will be most useful to Mars.

Additional Information

Evaluation of the objectives of the human exploration of Mars requires a three-part analysis: 1). Objectives related to Mars planetary science that are most appropriately assigned to human explorers, 2) Objectives related to preparation for sustained human presence on Mars, and 3) Objectives related to non-Mars scientific objectives (astrophysics, heliophysics, etc.). For the purpose of this planning exercise, we have assumed a program of three missions. This has led to a series of important discussions about whether the three missions should be sent to the same site or multiple sites, the attributes of the site(s) that would make it attractive for a human landing, and the nature of the activity that would need to carried out at the one or more landing sites to achieve the various envisioned objectives.

Executive Summary

Date Prepared:	August 24, 2007
Presenter's Name:	Dallas Bienhoff
Presenter's Title:	Manager, In-Space & Surface Systems
Presenter's Organization/Company:	Advanced Space Systems / Boeing

Presentation Title

Is a LEO Propellant Depot Commercially Viable?

Key Ideas

Depot customers and needs.
Potential impact on customer mission
Depot concept
Business case boundary conditions

Supporting Information

Potential customers of a LEO propellant depot include NASA (lunar exploration, interplanetary probes, GEO delivery), DoD (GEO and HEO delivery), GEO launch service providers (comsats), Bigelow Aerospace, and Shackleton Energy Company. Studies conducted by Boeing in 2006 and 2007 addressed the impact a LEO propellant depot could have on the NASA ESAS architecture for lunar exploration. Solutions ranged from reducing heavy lift requirement 72% to increasing lunar landed mass 325% and depot capacities between 65 and 320 mt. For ESAS-defined systems, landed mass can be increased from 18 to 51 t with a 150 – 175 t depot in LEO. GTO, GEO and interplanetary mission capability can be increased 100 – 200% as well. A modular depot configuration and operational concept developed for the NASA ESAS lunar exploration missions includes a central core truss supporting six propellant tanks serviced by a reusable propellant carrier. Two depots are placed in a 28.5 degree orbit for redundancy and to support two annual lunar missions. Business case boundary conditions include LEO propellant value, LEO propellant sales price, propellant launch cost, depot installation cost, depot operations cost and initial need date.

Executive Summary

Date Prepared: August 29, 2007

Presenter's Name: D. Larry Clark
Presenter's Title: Chair
Presenter's Organization/Company: AIAA Space Resources Technical Committee

Presentation Title

ISRU Development Roadmap — AIAA Perspective

Key Ideas

The AIAA Space Resource Technical Committee has developed plans and timelines to develop In Situ Resource Utilization for lunar colonization. This roadmap incorporates NASA technology development for early missions up to and including the outpost. The SRTC roadmap also includes further developments that can support eventual commercialization of the products and support lunar colonization. This presentation will give an overview of the AIAA Space Resources Technical Committee lunar resource development roadmap that will enhance the NASA lunar exploration plan and provide a sustainable and affordable approach to exploration.

Executive Summary

Date Prepared: 27 August 2007

Presenter's Name: Ken Davidian
Presenter's Title: Commercial Development Strategy Lead
Presenter's Organization/Company: NASA HQ

Presentation Title

ESMD Commercial Development Strategy Overview

Key Ideas

NASA's Exploration Systems Mission Directorate (ESMD) understands the benefits to a thriving commercial space industry and has developed a strategy that will help the space agency accomplish its exploration goals through the acquisition of commercial space capabilities. This presentation gives the goals and rationale of the ESMD Commercial Development Strategy (ECDS). The statements of authority and of policy supporting this strategy are provided and the evolution from the more traditional NASA Technology Commercialization Policy to the ECDS is described. The barriers of entry targeted by the ECDS and its basic elements are given. An approach to identify candidate commercial space capability industries for development is also described.

Supporting Information

This presentation describes the standard framework with which to evaluate, prioritize, and select proposed ESMD programs, projects, and activities with respect to "encouraging commercial space capabilities".

At the level of NASA Headquarters (HQ), ESMD is responsible for all exploration-related activities across the agency. Programs and projects within ESMD must develop and execute tasks and activities that support NASA's exploration mission goals.

The ESMD Commercial Development Strategy (ECDS) is a comprehensive set of goals, approaches, strategic elements, and evaluation and selection criteria for program and project tasks and activities in fulfillment of the NASA Strategic Plan Goal 5, "Encourage the pursuit of appropriate partnerships with the emerging commercial space sector".

The ECDS has been developed and supported by individuals from other mission directorates and mission support offices within NASA HQ, as well as with significant contributions from ESMD personnel located at various NASA field centers throughout the country.

Executive Summary

Date Prepared: Sept. 21, 2007

Presenter's Name: Kiel Davis
Presenter's Title: VP, Engineering
Presenter's Organization/Company: Honeybee Robotics Spacecraft Mechanisms Corporation

Presentation Title

Automated Subsurface Sample Acquisition Technologies for Lunar Exploration

Key Ideas

This talk will present a brief overview of automated subsurface sample acquisition technologies for lunar exploration. The discussion will cover several subsurface sample acquisition strategies for in-situ analysis and sample return. A summary of recent and ongoing development work will be presented along with an outline of the key challenges that remain ahead.

Additional Information

Over the past 15 years, Honeybee Robotics has been involved with dozens of efforts to develop various subsurface access, sampling and sample handling technologies for the Moon, Mars and beyond. Perhaps most notably, Honeybee's Rock Abrasion Tools (RAT) have been operating since 2004 on the surface of Mars while the company's Icy Soil Acquisition Device (ISAD) is currently en route to the red planet as part of the Phoenix Mars Scout payload. Practical experiences and observations from both projects as well as many others will be shared.

Executive Summary

Date Prepared: August 16, 2007

Presenter's Name: Bret Drake, on behalf of the Mars Architecture Working Group
Presenter's Title: Chief Architect, Systems Engineering & Integration, Constellation Program
Presenter's Organization/Company: JSC, NASA

Presentation Title

The Things We Most Need to Learn at the Moon to Support the Subsequent Human Exploration of Mars

Key Ideas

The engineering and scientific heritage that will be established in the lunar exploration program over approximately the next two decades will be a critical component of the foundation for the subsequent human exploration of Mars. In order to optimize the value of that heritage, a very large multi-disciplinary, cross-organizational team of engineers and scientists, referred to as the Mars Architecture Working Group (MAWG), has been working on establishing a reference approach for the first three crewed missions to Mars. A primary purpose of this effort is to develop a specific understanding of the attributes of the lunar program that would be most beneficial to the safe and cost-effective conduct of human missions to Mars. MAWG has developed preliminary conclusions related to the transportation approach, the surface system, the design of the scientific system and surface science operations, human safety factors, and planetary protection.

Supporting Information

The Mars Architecture Working Group was chartered under the auspices of the Exploration Systems Mission Directorate, Science Mission Directorate, Aeronautics Research Mission Directorate, and the Space Operations Mission Directorate. During 2007, the Mars Architecture Working Group began the process of establishing better definition of potential strategies for the eventual human exploration of Mars. The MAWG was specifically chartered to:

Update NASA's human Mars mission reference architecture,
Establish a better understanding of key challenges including risk and cost drivers,
Identify ways to reduce the cost and risk of human Mars missions through investment in research, technology development and synergy with other exploration plans,
Assess the strategic linkages between lunar and Mars strategies, and
Develop a forward plan to resolve issues not resolved during 2007

This presentation will provide an overview of the key findings resulting from the MAWG 2007 study, specifically as they pertain to the lunar exploration strategy.

Executive Summary

Date Prepared:	24 Sept. 2007
Presenter's Name:	Steve Durst
Presenter's Title:	Partner
Presenter's Organization/Company:	International Lunar Observatory Association

Presentation Title

Lunar Commercial Communications Enabled by the International Lunar Observatory/ ILO Association

Key Ideas

Accomplishing the primary science/astrophysics mission of the International Lunar Observatory — to expand human knowledge of the Cosmos through observation from our Moon — will necessarily result in a telecommunications capability. This capability will fulfill primary astrophysical observation mission requirements, with additional capacity available for commercial applications.

Supporting Information

The ILOA is developing a market analysis of user demand for this lunar-based communications commodity. Beyond declaration of intended use of this capacity by affiliated Space Age Publishing Company's *Lunar Enterprise Daily*, a wide range of space — and non-space — enterprises, organizations and individuals may favor the global reach advantages of Cislunar broadcasting, advertising, publicity and transmission. Internet and e-mail .moon / .luna domains provide multiple applications and marketing opportunities. Lunar surface transportation, construction, mining and research operators and vendors are expected to follow and will be able to contract services through this established facility, streamlining surface operation requirements. The pioneering Lunar Commercial Communications Workshops sponsored by Space Age in California's Silicon Valley last January and July marked significant advances in lunar commercial communications understanding, and may help catalyze an entire new industry, expanding the domain of the human commercial telecommunications network by a factor of 1,000.

Executive Summary

Date Prepared: Sept 12, 2007

Presenter's Name: Bob Easter
Presenter's Title: Principal, Mission System Concepts
Presenter's Organization/Company: JPL Systems & SW Division

Presentation Title

ISRU and Potential Mass and Cost Impacts on Sustained Lunar Exploration

Key Ideas

Many uncertainties remain with regard to Lunar ISRU. But the potential exists to provide major savings in Launch mass needed for a given Lunar architecture, or alternatively, major increases in useful payload landed on the Moon for a given number of launches. This presentation will briefly review quantitative results of some analyses carried out in support of the recent LAT II activity, and what they suggest about how current uncertainties might be addressed.

Supporting Information

Much of this information will be available in the final report of the LAT II ISRU FET.

Executive Summary

Date Prepared: 24 September 2007

Presenter's Name: Paul Eckert, Ph.D.
Presenter's Title: International & Commercial Strategist
Presenter's Organization/Company: The Boeing Company, Space Exploration

Presentation Title

Incremental Steps from Earth to Lunar Commerce: How to Do It, and How to Pay for It, One Step at a Time

Key Ideas

Incremental business models start small and involve a gradual buildup, both financially and technically, moving through a series of milestones. At each milestone, existing investors and partners have the opportunity to enter or exit, base on performance and future prospects. Such approaches may help avoid the formidable challenges of all-or-nothing, large-scale ventures that require major investment at the outset.

Supporting Information

Several organizations may be cited that are to at least some extent practicing an incremental approach. In the area of space infrastructure, The Boeing Company has worked with several other companies to create a concept for incremental buildup of propellant depot infrastructure. A multidimensional technical and economic capability, gradually developing a variety of Earth as well as space applications, can be found at the Canadian company MDA. Another Canadian enterprise, Optech, incrementally leverages the company's core expertise in lidar and laser-based surveying, and a strategic partnership with MDA, to offer a variety of space lidar solutions for planetary exploration, orbital operations and science. The Jamestown Group has a step-by-step process for enabling major electrical power generation using lunar materials. Examples of incremental commercial applications that might benefit from space infrastructure include multimedia efforts of the Lunar Explorer venture, the Kronos concept of meteorite prospecting on Earth laying a foundation for an expanding prospecting effort on the Moon, and the International Lunar Observatory effort in pursuit of an incremental approach to raising private capital and creating a lunar installation. Government efforts can facilitate both commercial infrastructure and application development. At NASA, new approaches are being developed to meet this challenge. The initiatives noted above represent only a sampling of industry and government initiatives working to apply or support well-founded, step-by-step approaches to commercial success.

Executive Summary

Date Prepared: 9/5/07

Presenter's Name: Dean Eppler
Presenter's Title: Senior Scientist
Presenter's Organization/Company: Constellation Lunar Surface Systems Project Office/SAIC

Presentation Title

Interviews with Apollo Lunar Surface Astronauts in Support of Lunar Surface Exploration Systems Design

Key Ideas

A series of focused interviews was conducted with a group of the Apollo astronauts who conducted lunar surface operations between 1969 and 1972. The purpose of the interviews was not to record verbatim memories, but rather to engender informed responses on the design of future lunar extravehicular system hardware and operations practices based on the real-world experience of these men. The topics discussed were mission approach and structure; EVA suits, including suit breathing gas, and suit & habitat operating pressure; portable life support system design; management of lunar regolith; EVA suit gloves; the use of automation in suit/PLSS function; information, displays and controls; the use of manned rovers; EVA tools; operational procedures and philosophy; pre-mission training; and general comments. Results of these interviews are wide-ranging, but a number of common themes emerge: 1) simplicity must be the overriding philosophy in the design of all systems; 2) the crew's time on the surface must be less rigidly scheduled, to allow more complete investigation of each site visited, and to allow for real-time response to unexpected discoveries; 3) training should be hard and as close to reality as possible to ensure crewmembers are familiar with the stresses and strains of a long lunar surface mission, and to achieve the best sustained mental performance; and, 4) emphasis should be given on the integration of the crew, equipment and facilities as a total system, not as a disintegrated set of systems that the crew has to kluge together in real time on the lunar surface.

Executive Summary

Date Prepared:	9/5/07
Presenter's Name:	Dean B. Eppler
Presenter's Title:	Senior Scientist
Presenter's Organization/Company:	Constellation Surface Systems Project Office/SAIC

Presentation Title

Management of Future Lunar Samples: Back to Basics

Key Ideas

The wholesale differences between the Apollo Missions and the Lunar surface science activities implicit in NASA's proposed lunar architecture argue for a logical re-evaluation of handling of samples on the lunar surface. This evaluation must be based on potential lunar mission sets, on a consideration of what capabilities different mission sets will place on the lunar surface, and the time available to execute sample handling in-situ. Even with the most optimistic return sample mass, the sample mass and petrologic variety implicit in multi-week lunar surface stays argues that some level of sample analysis and description must take place on the surface in order to select the correct sample suite for Earth return. The trade space that can be mapped out is relatively straightforward, but requires careful consideration of 1) what analytical capability may be reasonably brought to the lunar surface; 2) what accommodations must be undertaken to both protect sample quality and minimize introduction of regolith into pressurized spaces; and, 3) what sample handling capability can reasonably be developed, taking into account lunar surface downmass, realistic robotic technology, realistic surface outfitting penalties on crew time, and budgetary realities for hardware development.

Executive Summary

Date Prepared:	August 30, 2007
Presenter's Name:	Luke Erikson*
Co-Authors:	D. Baker*, W. L. Rance*, E. Spahr†, A. Abbud-Madrid*, and M. B. Heeley*
Presenter's Organization/Company:	*Colorado School of Mines †College of William and Mary

Presentation Title

Meteorite Collection on the Lunar Surface

Key Ideas

A key requirement for successfully exploring and understanding the solar system is the availability of material samples for analysis. The best lunar science is occurring today due to advancing laboratory techniques coupled with the lunar samples retrieved during the Apollo missions. It is clear extra-terrestrial samples are valuable – unfortunately using current retrieval technologies the amount retrieved is often negligible and the cost of collection is prohibitive. As part of the 2007 Lunar Ventures competition Kronos Technologies submitted a proposal describing a novel sample retrieval technology to collect larger and more diverse meteorite samples.

Approximately 10 million sizable meteorites have impacted the Earth during the last 200 years and there is significant evidence that the meteorite impact rate on the Moon is much higher. Based on published results a plan is formulated to actively detect and collect meteorites impacting the Earth. With the Earth as the initial focus, our preliminary studies suggest a natural progression to the Moon.

Field trials could begin in the American Southwest by analyzing data from a variety of sources. Candidate impacts can be detected in a variety of ways such as seismic data and satellite imagery. Evidence suggests computer algorithms could successfully discriminate meteorite impacts from human and natural geologic activities to produce candidate sites for retrieval. During the site search other sensors can be used, including active seismic surveys, magnetic detection and visual inspection.

Each successful recovery mission on Earth would provide a specimen and the opportunity to refine the detection and collection techniques for later deployment on the lunar surface.

Executive Summary

Date Prepared: September 12, 2007

Presenter's Name: Bernard Foing
Presenter's Title: **Site Selection and Lunar Outpost: SMART-1 Results and ESA Studies**
Presenter's Organization/Company: *Senior Research Coordinator, ESA ESTEC /SCI-S Postbus 299,2200 AG Noordwijk, The Netherlands*

Presentation Title **Site Selection and Lunar Outpost: SMART-1 Results and ESA Studies**

We shall discuss relevant SMART-1 results and ESA studies relevant to the preparation for site selection and lunar outposts:

Key Ideas

- Science and exploration drivers

- SMART-1 results on sites in South and North Polar regions

- Thermal, power, survival and geographical constraints

- Technical constraints on landing, communication, access and mobility

- Resources exploitation, lunar protection and sustained development

- Concepts for precursor robotic landers, rovers,and sample return missions

- Possible precursor payload and investigations

- International coordination and ILEWG roadmap: From a precursor robotic village to human outposts

- From lunar local outpost to regional and global exploration

Additional Information

These points will also be discussed at the ILEWG 9th conference on Exploration and Utilisation of the Moon, in Sorrento, Italy, 22–26 October 2007.

Links:
http://sci.esa.int/smart-1
http://Sci.esa.int/ilewg
http://Sci.esa.int/iceum9

Executive Summary

Date Prepared: 9/20/07

Presenter's Name: Bob Gershman

Presenter's Title: Assistant Program Manager, JPL Exploration Systems Engineering

Presenter's Organization/Company: JPL

Presentation Title

Lunar Site Selection Process Definition in LAT-2

Key Ideas

The objective was to lay out the process for selecting the location(s) of the lunar outpost(s), including: identifying steps and approximate schedule, identifying criteria and data needed to evaluate candidate sites, and assessing existing plans for data acquisition and processing. A preliminary version of the process was defined and key schedule milestones were identified. High and medium priority site selection criteria were identified and strawman requirements established. Adequate data collection plans were found for all but one requirement, but issues regarding adequate data registration were raised. Also, a need for near term iteration with evolving lunar architecture and lander design was identified.

Executive Summary

Date Prepared:	September 6, 2007
Presenter's Name:	John E. Gruener
Presenter's Title:	Lunar Outpost Site Selection: A Review
Presenter's Organization/Company:	NASA Johnson Space Center

Presentation Title

Lunar Outpost Site Selection: A Review of the Past 20 Years

Key Ideas

This presentation will review efforts by the space exploration community over the past 20 years in regards to site selection for lunar outposts. Operational, science, resource utilization, and international/commercial interests will in lunar outpost site selection be discussed. The presentation will begin with work conducted in the mid-1980's in association with a symposium on Lunar Bases and Space Activities of the 21st Century, and then will proceed through the Space Exploration Initiative (SEI) and First Lunar Outpost (FLO) design study in the early 1990s, the Exploration Systems Architecture Study (ESAS) in 2005, and will end with the current lunar exploration architectures being studied within NASA's Exploration Systems Mission Directorate (ESMD).

Supporting Information

The primary documents that will be referenced during the presentation are: Lunar Bases and Space Activities of the 21st Century, Lunar and Planetary Institute, 1985; Geoscience and a Lunar Base: A Comprehensive Plan for Lunar Exploration, NASA Conference Publication 3070; A Site Selection Strategy for a Lunar Outpost: Science and Operational Parameters, NASA workshop report; and Exploration Systems Architecture Study (ESAS) Final Report, NASA. All of these reports can be found on the internet at http://www.lpi.usra.edu/lunar_resources/documents.shtml.

Executive Summary

Date Prepared: September 14, 2007

Presenter's Name: Dr. Klaus P. Heiss
Presenter's Title: Executive Director
Presenter's Organization/Company: The Jamestown Group of High Frontier

Presentation Title

Toward a 1GWe of Solar Energy on and from the Moon by 2020

Key Ideas

The key to the economic Space Exploration will be commodities with "zero mass" and transported at the "speed of light".

Amongst these the possibility of gathering and transmitting Solar Energy on and from the Moon will be opening Space beyond purely academic and bureaucratic interests. A private approach is outlined, with specific milestones and financial requirements.

Interest in such applications worldwide is intense. Investments by Governments are not needed, other than providing an affordable Space transportation infrastructure and a manned presence on the Moon. Both are critical bottlenecks holding up US enterprise on the Moon, the Gateway to Cis- and Trans-Lunar Space.

Supporting Information

www.JamestownOnTheMoon.org , www.Moonbase-USA.org, www.Moonbase-Italia.org

Executive Summary

Date Prepared: 9/3/2007
Presenter's Name: Brad Jolliff
Presenter's Title: Science Committee Member
Presenter's Organization/Company: NASA Advisory Council / Washington University

Presentation Title

Recommendations from the Workshop on Science Associated with the Lunar Exploration Architecture, Tempe, Arizona, 2/27–3/2, 2007

Summary

The workshop addressed science objectives in astrophysics, Earth science, heliophysics, planetary science, and planetary protection for return-to-the-Moon planning. The workshop resulted in an assessment and prioritization of science objectives within the context of the developing lunar exploration architecture. This presentation will also address recommendations made to NASA by the Advisory Council stemming from the workshop findings.

Summary of Findings

High priorities for astrophysics include (1) meter-wavelength radio observations from the radio-quiet lunar farside to seek evidence of the strongly red-shifted 21-cm H line from the early universe and (2) laser-ranging retroreflectors or transponders to probe gravitational theory.

For Earth science, the Moon would provide a unique, stable, and serviceable platform for global, long-term, full-spectrum views of Earth to address climate variability, pollution sources and transport, natural hazards, and changes in the terrestrial cryosphere. Such observations would complement and provide synergetic context for current orbital assets (LEO, GEO, GPS).

For heliophysics, the Moon is a unique vantage point from which to better understand the Sun-Earth space environment. The analysis of lunar regolith will provide a history of the Sun. Work is needed to develop predictive capabilities for solar radiation events to safeguard human exploration activities and to better understand the dust-plasma environment at the lunar surface.

Key objectives from a planetary science perspective fall into four main themes. (1) Moon as a recorder of the impact history of the inner solar system; (2) Moon as a recorder of early planetary differentiation processes (key to understanding the Moon's interior is a geophysical network, especially to better determine global seismic structure); (3) the potential record of volatile deposition processes and the possibility of concentrated volatile-element deposits in permanently shaded craters; (4) better delineation of the character and distribution of potential resources and improved understanding of potential hazards to sustained human presence. Some of these objectives can be accomplished at a polar outpost site whereas others require access to multiple locations and sample collection.

Lunar exploration will not require special planetary protection controls; however, it will provide the opportunity for an integrated test bed of technologies and methods needed to protect samples and to understand and control mission-associated contamination on long-duration expeditions such as to Mars.

Concerns raised by the science subcommittees include the need to access more than one lunar location, surface mobility, transportation infrastructure to deliver payloads and to return materials to Earth, and adequate crew training and time on the surface to devote to specialized science experiments and in-situ resource utilization work. Participants stressed the need for a robust robotic precursor program to support scientific exploration and prepare the way for human missions. A mix of human and robotic exploration, space hardware design, and orbiting and landed laboratory science payloads are needed to maximize science return.

Executive Summary

Date Prepared:	9/24/2007
Presenter's Name:	Brad Jolliff
Presenter's Title:	Research Associate Professor
Presenter's Organization/Company:	Washington University

Presentation Title

Science Criteria for Lunar Outpost Site Selection and an Example

Summary

Science criteria for a lunar outpost site are dominated by lunar and planetary science objectives, but also include consideration of other NASA science endeavors such as astrophysics, heliophysics, earth science, planetary protection, and environmental characterization. Some of the objectives relate purely to science, whereas others relate integrally to exploration. Many can and should be done at any outpost location.

Key lunar and planetary science objectives relate to (1) the impact record over the Moon's history as a record of Solar System events, (2) the internal structure and dynamics of the Moon, (3) composition and evolution of the lunar crust and mantle, (4) nature and history of solar emissions, galactic cosmic rays, and local interstellar medium through investigation of buried layers within the lunar regolith, and (5) investigation of polar volatile deposits.

The first phase of Lunar Architecture development focused on a polar outpost site (South Pole, rim of Shackleton Crater). In this presentation, the Aristarchus region will be presented as an example of a non-polar, potential outpost site. Briefly, the Aristarchus region includes the Aristarchus crater, which appears to have excavated material significantly different from the Apollo and Luna sites. The region includes a large pyroclastic deposit that differs from the volcanic glass deposits of Apollo 15 and 17, and thus provides a key new capability to probe the deep lunar interior. The region includes a variety of volcanic features such as the prominent Valles Schröteri lava channel, Cobra Head vent, and compositionally different and distinctive basalts of western Oceanus Procellarum. Also located nearby are large craters spanning a range of ages that could be dated to help calibrate lunar chronostratigraphy (Aristarchus, Herodotus, Prinz). Key scientific targets lie within range of long-distance rovers from an Aristarchus outpost location. Young basalts to the northwest, near Lichtenberg Crater, could be sampled and dated to constrain lunar volcanic history. To the N-NE of the Aristarchus Plateau lie volcanic domes, including the Rümker Hills, Mairan Domes, and Gruithuisen Domes. These volcanic constructs differ spectrally and compositionally from materials sampled by Apollo and Luna, and may represent an important phase of lunar volcanic activity that is as yet little known. Long-distance traverses to access these geologic sites could serve also to place geophysical stations (seismic, heat flow nodes) as part of a regional network. Heat flow and subsurface structure are key to testing hypotheses about the Procellarum KREEP Terrane.

For Astrophysics, access to the radio-quiet environment of the lunar far side lies just over 1000 km to the west of Aristarchus; however, a retroreflector or transponder network deployed from an Aristarchus outpost could help to achieve new tests of gravitational theory. The site has a view of Earth, so high-priority observations and long-term monitoring of Earth and Sun-Earth interactions could be done from this location. Direct observations of the Sun from this location could be carried out during the daytime. Because Aristarchus is a volcanic terrain, access to paleoregolith as a record of solar activity and radiation history would be available through impact crater ejecta, rille walls, or local excavation and drilling.

For the eventual development of lunar resources, the site is located near vast expanses of ilmenite-bearing basalt. Thus an outpost site in this region could eventually be developed for large-scale regolith mining for oxygen, metals, and solar-wind volatiles.

Executive Summary

Date Prepared:	September 21, 2007
Presenter's Name:	Robert M. Kelso
Presenter's Title:	Manager, Commercial Space Development
Presenter's Organization/Company:	Commercial Crew/Cargo Program, NASA-JSC
Presenter's Name:	Greg Schmidt
Presenter's Title:	Associate Director, Strategic Planning
Presenter's Organization/Company:	Entrepreneurial Space Directorate, NASA-Ames

Presentation Title

Proposal for a Lunar Exploration Science Campaign: A Commercial-leveraged, Science-focused, Frequent Lunar Mission Program

Key Ideas

(1) Establishing an aggressive lunar science campaign to the lunar surface
(2) Enabled by commercial leveraging with NASA
(3) Leading to a near-term technology demonstration on the surface.

Additional Information

Proposal for a Lunar Exploration Science Campaign: A commercial-leveraged, science-focused, frequent lunar mission program

Greg Schmidt (ARC, Gregory.Schmidt@nasa.gov), Dan Rasky (ARC), Rob Kelso (JSC), Bruce Pittman (ACES)

The advent of the entrepreneurial space industry has brought a great deal of interest in the commercial potential of space from a growing number of economic sectors. In particular, the nascent entrepreneurial launch industry has attracted a great deal of private funding, which NASA's Commercial Orbital Transportation System (COTS) seeks to leverage to provide needed future logistics access to the International Space Station. The growing industrial interest in these opportunities has led to the creation of numerous industry groups and events, most notably the Space Commerce Roundtable (www.spacecommerceroundtable.com).

Interest in the commercial potential of the moon is high, and a number of companies have invested internal resources (sometimes in the millions of dollars) in exploring potential business models. Examples of companies which have invested such resources, made recent announcements or approached NASA with relevant lunar interests include both traditional and non-traditional aerospace companies such as Cisco, Raytheon, Space Systems Loral, Ecliptic, EDS, Rocketplane-Kistler and SpaceDev1[1]. Several of the ideas that have been discussed, including lunar communications, infrastructure (including surface access), and entertainment, have attracted significant investment. If NASA could use this commercial interest to achieve its lunar science and exploration goals this could be an ideal public/private partnership for increasing science return and lowering net costs to NASA while achieving commercial objectives for industry.

1[1] See 8/23/07 press release: http://www.spacedev.com/press_more_info.php?id=184

The newly released National Research Council study, "The Scientific Context for Exploration of the Moon," provides the NASA framework for science missions to the moon under which all collaborative efforts with industry should be structured. The "Prioritized Science Concepts" in this document form the fundamental platform from which NASA SMD will negotiate collaborative missions with industry. Furthermore, commercial partnerships should leverage upon current NRC report-inspired studies such as the effort to determine which prioritized science concepts can be addressed by small spacecraft (ranging from, for instance, distributed networks of small seismometer stations to in-situ sample analysis and eventual sample return). The objective of commercial partnerships is not to add science goals to NASA but rather to accomplish these goals more quickly, reliably and at a lower cost than NASA could do alone. From industry's point of view, the goal to develop viable business plans which will monetize collaborative lunar science efforts with SMD.

Commercialization is a key imperative from an agency perspective. Goal 5 of the NASA Strategic Plan (February 2006) states "Encourage the pursuit of appropriate partnerships with the emerging commercial space sector." Given the increased commercial interest in the moon as noted above, a great deal of opportunity exists to form such partnerships with SMD to leverage NASA resources while enabling the commercial space sector to grow. The more recently released "Global Exploration Strategy Framework" signed by NASA and 13 other space agencies around the globe (May 2007) states "Space exploration… offers significant entrepreneurial opportunities by creating a demand for new technologies and services. These advances will encourage economic expansion and the creation of new businesses."

Executive Summary

Date Prepared: 9/19/07

Presenter's Name: William E. Larson
Presenter's Title: ISRU Deputy Project Manager
Presenter's Organization/Company: NASA

Presentation Title

Outpost Site Selection for In-Situ Resource Utilization

Key Ideas

From an ISRU perspective there are several criteria that drive Outpost site selection. What are the products of interest to the Architecture? Are these resources available at the Outpost site selected? What are their concentrations in the Regolith? Are they reasonably accessible and what is the topography? Are the environmental conditions conducive to ISRU production systems?

Additional Information

The presentation will discuss the current ISRU needs of the Lunar Architecture as bounded by NASA's Lunar Architecture Team studies and how the criteria mentioned above will affect outpost site selection. It will also discuss longer term opportunities for ISRU insertion into the architecture how initial site selection will affect our ability to provide products to the Outpost.

Executive Summary

Date Prepared: August 15, 2007

Presenter's Name: Tony Lavoie
Presenter's Title: Program Manager, LPR Program
Presenter's Organization/Company: NASA – Marshall Space Flight Center

Presentation Title Lunar Precursor Robotic Program Status

Key Ideas

The presentation will consist of the current portfolio of activities within the Lunar Precursor Robotic Program (LPRP). Presently, this includes the Lunar Reconnaissance Orbiter (LRO) and Lunar CRater Observation and Sensing Satellite (LCROSS), as well as the effort to produce useful ground software tools related to the lunar environment for engineering use in mission planning as well as designing, developing, and operating lunar surface systems for Human return to the Moon.

Supporting Information

The LPR Program is the host program for the Exploration Systems Mission Directorate's (ESMD) lunar robotic precursor missions to the Moon. The program includes two missions, LRO and LCROSS. Both missions will provide the required lunar information to support development and operations of those systems required for Human lunar return. LPRP is developing a lunar mapping plan to create the capability to archive and present all data from LRO, LCROSS, historical lunar missions, and international lunar missions for future mission planning and operations. LPRP is also developing its educational and public outreach activities for the Vision for Space Exploration's first missions. LPRP is working closely with the Science Mission Directorate as their lunar activities come into focus.

Executive Summary

Date Prepared:	9-20-07
Presenter's Name:	Gary Lofgren
Presenter's Title:	Lunar Curator
Presenter's Organization/Company:	NASA-JSC

Presentation Title

Astronaut Training, What We Did, Why It Worked, and What Can Be Done Better

Key Ideas

The mission specific geologic training of the Apollo astronauts was centered around field exercises with a minimum of classroom study. The number of field trips varied from a single trip for the Apollo 11 crew to approximately 20 trips over a 2 year period for each of the J missions, Apollo's 15, 16, and 17. The complexity and the degree to which the field exercises mimicked the mission protocols increased dramatically from the early missions to the later J missions. The crews were taught to systematically observe everything from the far distance to the near ground and to develop a vocabulary in common with those to whom they are communicating, i.e., capcom and science back room. Most of the field exercises were focused on specific mission objectives designed to give the astronauts background to fully understand the scientific objectives and the rational to fulfill these objectives. Another equally important, but more mundane field training goal was to make the routine tasks, such as sampling and documentation, as automatic as possible. Every effort was make to visit terrestrial geologic localities that mimicked the geologic problems of the lunar landing site on the moon as well as possible. The emphasis, however, was on finding good problem solving exercises. One of the few classroom activities was to learn basic lunar rock types by direct observation of Apollo lunar samples.

Based on the Apollo experience on the moon and the advances in technology, I can think of several technologies that need to be developed to facilitate field operations at a lunar outpost and for scientific exploration. Sample documentation was one of the most cumbersome and time consuming tasks. There are several technologies that could make this task less cumbersome. Some kind of digital imaging techniques for documenting sampling and other activities in addition to improved imaging from a rover would reap high benefit in freeing astronauts to these laborious tasks. Some kind analytical tool to help astronaut discriminate rock types in the field would significantly increase the scientific return on their activities. If large boulder that exhibit complex geologic relationships are encountered, a tool that allows easy sampling of large boulders would be of great benefit, An example is the hand held drill used to extract samples at precise locations similar to what is used for obtaining orientated samples paleomagnetic studies. New sample containers that reduce the container weight are needed. Small sample containers for totally sealed samples similar to the Apollo SESC container, but with better seals are needed. Once samples are collected they need to has a s working area (glover box?) to examine samples and to hi-grade for return to Earth. The use of high quality imaging and a simple analytical tool such as XRF would be efficient and could involve scientists on earth to assist in the hi-grading.

Executive Summary

Date Prepared:	8-10-07
Presenter's Name:	Gary Lofgren
Presenter's Title:	Lunar Curator
Presenter's Organization/Company:	NASA-JSC

Presentation Title

The Lunar Collection: Status and the Future

Key Ideas

I will present the current state of the Lunar Collection. How much of the samples has been used for analysis and what remains for future study. The Lunar Sample Laboratory is approaching 30 years old. We have been renewing and replacing aspects of the facility to keep the it functioning at the highest level; these efforts will be summarized. I will also review the standards for curation and discuss how they have provided for the preservation of the samples. There will be a brief discussion of the kinds of samples collected and the lessons learned from their collection. These lessons will be applied to the collection of samples in the future.

Executive Summary

Date Prepared:	2007/08/15
Presenter's Name:	Kai Matsui
Presenter's Title:	SELENE Project Team
Presenter's Organization/Company:	JAXA

Presentation Title

SELENE Status and ISRU activity in JAPAN

Key Ideas

The up-to-date status information of SELENE critical phase and data distribution strategy will be explained. And ISRU community of Japan proposed some missions to SELENE-2 landing mission. I'll explain the proposed ideas and their technology development roadmap.

Supporting Information

SELENE will be launched on Sep 13th by Mitsubishi H-2A rocket.
If everything goes as planned, SELENE will be put into orbit around the moon during LEAG meeting.

The ISRU community of Japan actively works the detail technology development planning and proposes their ideas to JAXA. Their Ideas include technology development roadmap, ISRU related tasks in lunar robotic phase, its priorities and specific mission proposals. My presentation will show the summary of them.

Executive Summary

Date Prepared: 2007-08-29

Presenter's Name: Jean-Claude Piedbœuf
Presenter's Title: Head Technology Requirement and Planning
Presenter's Organization/Company: Space Technologies/Canadian Space Agency

Presentation Title

CSA Concepts and Plans for Sustained Lunar Exploration and Surface Operations

Key Ideas

This presentation will present some potential Canadian's roles in space exploration. It will describe some key promising technologies and will present a possible roadmap of Canada's activities in space exploration.

Supporting Information

Canada has been and is still active in space exploration. Canada has been involved in space robotics for more than 25 years through the Space Shuttle and International Space Station (ISS) manipulators. Canada is now also involved in space exploration through NASA's Phoenix Scout mission, the Mars Science Laboratory and ESA's ExoMars mission. Technologies that are critical for space exploration like surface robotic mobility systems, active 3D vision, drilling, guidance for landing, autonomy and in space rendezvous and docking are being actively developed in Canada. In addition, the Canadian Analogue Network is supporting the demonstration of these technologies in an environment similar to Mars and Moon.

Based on the national consultations, CSA has been developing a roadmap for its potential contribution to space exploration missions. This roadmap details the infrastructure contribution and discusses the science opportunities. The Earth and the ISS are used as analogues for Moon and Mars exploration while the Moon itself is a test bed for future human exploration of Mars. Our Moon focus will be robotic precursor missions and critical infrastructure contributions that will pave the way for a Canadian astronaut on the Moon. For Mars exploration, the near to medium term focus is science using robotics. A key principle is that these contributions should start early, be scalable and be transferable from one mission to the other.

Executive Summary

Date Prepared:	August 15, 2007
Presenter's Name:	Manny Pimenta
Presenter's Title:	President & Founder
Presenter's Organization/Company:	Lunar Explorer, LLC

Making The Moon Accessible to Everyone

Key Ideas

Lunar Explorer is committed to doing whatever is in our power to help bring about the long overdue birth of a true Space Faring Civilization. We will do this primarily through creating personal experiences of Space accessible to every living man, woman and child and sharing a bold and hopeful vision of the future that is within reach. Our message is that Space Settlement is the greatest adventure in all of Human history; that Space Settlement holds the keys to our Survival and our Prosperity; and that each and every person has the capacity to participate and to contribute significantly to making it happen in this generation. We will inform, educate, inspire and motivate people into taking action

Supporting Information

We have taken the best available NASA data on Lunar topography (from the 1994 Clementine mission) and created the most complete, accurate and realistic model of the Moon possible. It's the first time this has ever been done. You will get to see the Moon in a way that only the astronauts who have been there have ever seen it before.

Our intention is to continue to perfect the simulation until it is visually indistinguishable from actually being there. We also want to use Lunar Explorer to promote a bold and inspiring vision of near future Space Settlement by creating an interactive simulation of the first large scale permanent Lunar settlement on Malapert Moutain, near the Moon's South Pole.

Executive Summary

Date Prepared: 31 August 2007

Presenter's Name: Jeff Plescia
Presenter's Title: Planetary Scientist
Presenter's Organization: Applied Physics Laboratory / Johns Hopkins University

Presentation Title

Site Selection for the Lunar Outpost

Key Ideas

The objective of establishing a permanent presence on the Moon in the form of an outpost will result in a set of site selection requirements different from those of the Apollo program or of robotic missions to Mars.

Environmental conditions (e.g., thermal loading and background temperature, solar illumination) are likely to be key criteria for the site selection since they will drive the system designs.

In situ resource potential will be an important criteria in site selection. A decision about how those resources will be used – volatiles for making-up for losses in the life support system versus fuel production or sunlight for solar power – can significantly influence the site selection.

Scientific objectives are unlikely to be a driver in site selection.

Supporting Information

The Vision for Space Exploration calls for the establishment of permanent presence on the Moon, to learn about the Moon, the Earth-Moon system, the solar system, and the universe by exploration of the Moon; to acquire the skills and develop the systems on the Moon that we need to become a multi-planet species; and to harvest and use the material and energy resources of the Moon to create a new space-faring capability. In order to achieve those goals, an appropriate permanent site must be selected for the lunar outpost.

There are a variety of aspects to the outpost site that must be considered in its selection: among these are the physical properties and topography, environmental conditions (thermal, solar, radiation), and resources.

The physical properties and topography of the Moon are understood well enough that we know that a site with appropriate characteristics (stability for construction, safe landing zones, etc.) could be selected now. We understand the frequency of small craters, the locations of rocks, and the geotechnical properties of the regolith. Differences in those properties would influence the site selection only in the context of the specific location of structures (tens to hundreds of meters) rather than the regional location of the outpost (hundreds of km).

There are several different types of environmental issues that must be considered. Some of these are global in extent and not location-specific, such as the radiation environment or micrometeorite flux. While the flux at any given moment will vary across the surface, averaged over time, all of the surface experiences the same flux. On the other hand, the thermal and lighting conditions are latitude specific. At the equator, the temperature ranges from +107°C during the day to -153°C at night (a range of 260°) with two weeks of sunlight and two weeks of darkness, and a solar elevation ranging from 0° to 90°. At the poles, the sun is never more than about 1.7° above the horizon, the average temperature is more stable (-50°C ± 10°C), and areas of permanent shadow and areas with extended periods of sunlight (perhaps permanent or near permanent sunlight) exist. These issues will have significant impact on the design of the habitat and power systems for the outpost. At present we have a good understanding of the environment at the equator; we have a poorer understanding of the polar environment. Systems could be designed to operate anywhere with our present understanding; the penalty would be a design that would have to accommodate the uncertainties. A considerably better understanding of the polar environment will be gained through LRO and other international lunar missions to be launch this and next year.

The use of *in situ* resources may be one of the biggest drivers on site selection. The first issue to be resolved is the extent to which such resources would be used. Would they be used to generate oxygen to compensate for losses in the life support system, or will hydrogen and oxygen be produced to supply fuel for trips to and from the Moon and then beyond? If the former, then the efficiency of the process and the grade of the resource ore may not be important. On the other hand, if the latter, then the efficiency and the grade are critical. The potential for resources is the one key area where we lack sufficient information at present, particularly for the polar areas. The upcoming lunar missions will provide some additional information, but we will still lack non-model-dependent information on the form, distribution and composition of resources in polar regions. It is assumed, based on morphology, that the polar regions would be "anorthositic highlands" and have a composition similar to the Apollo 16 site, but it would be important to confirm this. It is known from Lunar Prospector that enhanced hydrogen occurs in the polar areas, but whether that hydrogen is uniformly distributed or sequestered in permanently shadowed areas and whether it is in the form of H or H_2O are unknown and can not be definitively determined from orbit. *In situ* analysis must be conducted. If resources are to be used for fuel production, then there may be a trade in the site selection wherein the proximity to a high grade ore is traded against the proximity to a site that has better solar power potential such that it is the overall energy budget of operations and production that is the deciding factor.

In order to optimize the design of surface systems and resource utilization, as well as to reduce fiscal, technical and programmatic risk, the selection of a site must be made only after all of the relevant information is in hand. In some cases, robotic missions to explore potential outpost sites to collect *in situ* information will be required; in other cases, those robotic missions may serve to validate conclusions derived from orbital and Apollo data.

Executive Summary

Date Prepared: 24 Sep 2007

Presenter's Name: Dr. Robert D. Richards
Presenter's Title: Director, Space Technology
Presenter's Organization/Company: Optech Incorporated

Presentation Title

The New Race to the Moon — Building Bridges for Lunar Commerce

Key Ideas

The announcement of the Google Lunar X PRIZE has sparked a worldwide interest in commercial lunar development. The challenge presented is for business innovation as much as technical innovation. New partnerships and ways of doing business in space will need to be forged to reach the goal of sustainable lunar commercial enterprise.

Supporting Information

Today there is a rebirth of interest in going back to the Moon among many nations. The worlds' foremost scientists and policy makers are actively engaged in discussions about humanity's return to the Moon. The announcement of the Google Lunar X PRIZE has sparked a worldwide interest in commercial lunar development. The challenge presented is for business innovation as much as technical innovation.

While nations continue to plan and strategize how to navigate the political minefields and conflicting national priorities that justify the value of the Moon to the tax payer, some new players are contemplating new approaches not so constrained. They are the privateers; visionaries with a different set of priorities. Their driving metric for going to the Moon is sustainable business and commerce.

This presentation outlines how carefully planned private Moon missions could set in motion the financial, technological, political, legal and regulatory precedents that will build bridges for sustainable lunar commerce; allowing humanity to rationally and peacefully embrace economic principals while supporting scientific goals in the development of the Moon as the world's eighth continent.

Executive Summary

Date Prepared: 8-23-2007

Presenter's Name: Gerald Sanders
Presenter's Title: NASA ISRU Incorporation and Development Plans
Presenter's Organization/Company: NASA-Johnson Space Center

Presentation Title

NASA ISRU Incorporation and Development Plans

Key Ideas

The incorporation of In-Situ Resource Utilization (ISRU) capabilities into the buildup and operation of a lunar Outpost can have a significant impact on the affordability and sustainability of lunar exploration and permanent human presence on the Moon. Early development and demonstration of ISRU hardware and capabilities, along with laboratory and field demonstrations with other critical and linked Surface Systems is required to minimize long-term costs and maximize the benefits of ISRU for human exploration of the Moon and beyond.

Supporting Information

The ISRU phasing and capability incorporation strategy developed during LAT Phase I & II is based on the premise that while ISRU is a critical capability and key to successful implementation of the US Vision for Space Exploration, it is also an unproven capability for human lunar exploration and can not be put in the critical path of architecture success until it has been proven. However, at the same time, the lunar architecture needs to be open enough to take advantage of ISRU when proven available. From this, the following ISRU capabilities and phasing was determined to be most beneficial for establishing an Outpost for sustained human presence while incrementally proving and building confidence in ISRU fulfilling critical mission needs:

- Excavation & site preparation (i.e. radiation shielding for habitats, landing plume berms, landing area clearance, hole or trench for habitat or nuclear reactor, etc.)
- Pilot-scale oxygen production, storage, & transfer capability (replenish consumables)
- Pilot-scale water production, storage, & transfer capability – assuming hydrogen source/water is accessible
- Scavenge descent propellants (oxygen, hydrogen, and fuel cell water)
- Fuel cell reactant production, storage, & transfer capability

ISRU can be integrated into Outpost habitat and lunar surface system functions and needs without being in the 'critical path' since early mission consumables could still be brought from Earth if ISRU is shown to be not technically feasible or not beneficial from a mass or cost perspective. ISRU oxygen and water production would be complementary to life support by providing a functional backup and providing makeup for consumables that were not completely regenerated. ISRU would also provide consumables for open systems, like Extra Vehicular Activity (EVA) suits, and could potentially utilize trash as an in-situ feedstock. If properly coordinated early, ISRU could utilize similar functions, technologies, and modules with life support, fuel cell power, and EVA systems to provide a robust surface architecture, and minimize development and deployment mass and cost. With the ability to produce mission consumables, ISRU could also off-set uncertainties in development and deployment of other lunar architecture transportation and surface elements. For example, the impact of life support system development not meeting the water and air recycling loop closure requirements could be mitigated with ISRU. Once demonstrated in terrestrial field tests and possibly robotic precursors, and demonstrated early in the Outpost, ISRU production and use can be expanded with increased confidence in both ISRU and lunar transportation elements, such that in-situ propellant for lunar ascent might be possible.

Executive Summary

Date Prepared: 8/9/07

Presenter's Name: Harrison H. Schmitt
Presenter's Title: Lunar Sample Return: Reprise
Presenter's Organization/Company: Self

Presentation Title

Lunar Sample Return: Reprise" will be a discussion session with the LEAG related to questions about Apollo sample collection, documentation, and return issues and how improvements can be made in a return to the Moon.

Key Ideas

Collect some big samples as well as small ones.

Automate documentation with rover and helmet mounted stereo video systems that include real-time ranging, high resolution modes, and integration with navigation data and voice activated, heads up displays in the EVA suit.

Develop in situ measurements of those parameters that may be affected by sample exposure to spacecraft cabin and/or terrestrial contamination.

Supporting Information

N/A

Executive Summary

Date Prepared:	August 14, 2007
Presenter's Name:	Frank Schowengerdt
Presenter's Title:	Director of PISCES
Presenter's Organization/Company:	University of Hawai'i at Hilo

Presentation Title

The Pacific International Space Center for Exploration Systems (PISCES) as an Example of the Role that the States Can Play in Space Exploration

Key Ideas

The states can play key roles in space exploration beyond the traditional courting of aerospace and technology companies. Examples include establishment of space-related infrastructure, creation and support of research centers and educational programs in institutions of higher education and making unique natural assets available for use by the space exploration community. The initiative taken by the State of Hawai'i in stepping forward to establish and fund PISCES exemplifies all of these roles.

Supporting Information

On June 7th, 2007, the Governor of Hawai'i signed into law legislation authorizing the creation and funding of the Pacific International Space Center for Exploration Systems (PISCES) at the University of Hawai'i at Hilo. This new center is being built on partnerships between academia, industry and the governments of space-faring nations. PISCES will support space exploration and settlement, but it will also benefit the people of Hawai'i through economic development on the Big Island and throughout the State; directly by attracting new businesses, and indirectly by enhancing educational opportunities in science, math and engineering, thereby bolstering the technical workforce needed to attract additional high-tech industry to the State. PISCES will feature a simulated lunar outpost located in the volcanic terrain of the Big Island, where research will be conducted, new technologies will be tested, students will be educated, astronauts will be trained and the public will be invited to experience first-hand what it will be like to live and work on the Moon. Areas of emphasis include ISRU, Surface Operations, Robotics, Solar Energy and Education. Preliminary plans include the establishment of a degree program in Space Operations Technology at the University of Hawai'i at Hilo. The center will be the target of a major fundraising campaign in its early years, with a goal of being independent of State funding within five years.

Executive Summary

Date Prepared: August 14, 2007

Presenter's Name: Charles Shearer
Presenter's Title: Sr. Research Scientist, Research Professor
Presenter's Organization/Company: Institute of Meteoritics, University of New Mexico

Presentation Title

Exploring the Moon with Samples.
Scientific and Exploration Importance of Sample Return
and Buying Down Risk and Cost of Sample Return Missions.

Key Ideas

(1) Overview of Session
(2) Sample return is an exceedingly important component of lunar exploration.
(3) Samples provide a unique data set that is critical for understanding the Moon.
(4) Information about large scale planetary-solar system processes can be extracted from the robotic return of small sample volumes.
(5) Sample science and sample return has a symbiotic relationship with orbital science, surface science, and resource utilization.
(6) Samples placed within a planetary and geologic context by orbital and human observations is extremely valuable.
(7) Sample return fits within a variety of architectures for human exploration of the Moon.
(8) Risk and cost of sample return missions are perceived as being more expensive than other planetary missions. How can we buy down risk and cost?

Executive Summary

Date Prepared: 16 August 2007

Presenter's Name: Paul D. Spudis
Presenter's Title: Planetary Scientist
Presenter's Organization/Company: Applied Physics Laboratory

Presentation Title

Scientific contributions of lunar robotic precursor missions

Key Ideas

Robotic missions can acquire scientific information to make our return to the Moon safer and more productive. New orbital missions, hard landing probes, soft landing spacecraft, surface rovers, networks and sample returns all can provide important information and gain operational experience in the lunar environment. In addition, data from robotic probes are important to prepare for the characterization and utilization of local resources, a principal objective of lunar return.

Supporting Information

New orbiters carrying advanced, second-generation sensors include global imaging radar, microwave radiometry, VHF sounding, UV spectroscopy, others

Hard landers could include penetrators or crushable microspacecraft. Carry surface analysis instruments (neutron, mass spectrometers; XRF)

Soft landers can analyze a single site in detail and deploy other instruments or spacecraft

Rovers can conduct traverses and explore a region, making measurements and images along the route.

Networks of surface instruments can characterize the global Moon (seismic, heat flow) and study the lunar exosphere

Sample return mission can collect reconnaissance samples of sites in preparation for human study or to site where people won't be going.

Executive Summary

Date Prepared: 24 September 2007

Presenter's Name: Andrew Steele
Presenter's Title: Arctic Mars Analogue Svalbard Expedition: Testing Robotic and Human Space Flight Instrumentation in the Arctic
Presenter's Organization/Company: Carnegie Institution of Washington

Presentation Title

Arctic Mars Analogue Svalbard Expedition: Testing Robotic and Human Space Flight Instrumentation in the Arctic

The Arctic Mars Analogue Svalbard Expedition (AMASE) has spent 5 years testing a range of instrumentation for robotic and manned missions to Mars. During this time many lessons have been learned on the applicability of analogue testing to space flight applications. This presentation is a summary of the instrumentation tested and lessons learned.

Key Ideas

Analogue testing is an intrinsically necessary part of space flight instrument and protocol development. The lessons learned during these activities have a direct relevance to the ability for instruments and humans to meet the science goals of exploration.

Executive Summary

Date Prepared: August 16, 2007

Presenter's Name: G. Jeffrey Taylor and Paul D. Spudis
Presenter's Title: Professor of Planetary Science
Presenter's Organization/Company: University of Hawai'i at Manoa

Presentation Title

Future of Lunar Sample Return: Robotics, Humans, and Robotic-Human Partnerships

Key Ideas

The intricacy of sample-return missions depends on the complexity of the geologic target. Simple sites, such as a young lava flow, can be done with a simple lander that grabs a sample, perhaps sieving to an optimum size range. More geologically complex sites require more sophisticated sampling, using human powers of observation and problem solving, field mapping and measurements, and re-visits to sites to assure that they are properly understood. Such field work can be done directly by humans or through teleoperation of robots equipped with high-definition vision systems and other tools. A key issue is deciding for which targets simple sample returns are insufficient.

Supporting Information

As described by us previously [1,2], geologic field work, including sampling for study in laboratories, can be divided into two broad categories: (1) Reconnaissance, which can be done by either automated devices or humans, and (2) field study, which requires human observational ability, intelligence, and experience. Reconnaissance provides a broad characterization of the geologic features and processes on a planetary body. It often asks specific questions, such as determining the absolute age of the youngest lava flow on the Moon, thus helping to quantify age determination based on crater counts. In contrast, field studies have more ambitious goals: to understand planetary geologic processes and units at all levels of detail. This means that field studies are long-duration and iterative, and absolutely require humans. It is risky to work in the harsh human environment and expensive to transport humans to all field sites, so a compromise is to use a robotic-human partnership through the use of telepresence in which the human geologist is transported electronically into the robotic field geologist.

(1) Spudis, P.D. and Taylor, G.J. (1992) The roles of humans and robots as field geologists on the Moon. *The Second Conference on Lunar Bases and Space Activities of the 21st Century* (W.W. Mendell, ed.), NASA Conf. Pub. 3166, 307-313.

(2) Taylor, G.J. and Spudis, P.D. (1990) A teleoperated, robotic field geologist. *Engineering, Construction, and Operations in Space II* (S.W. Johnson and J. P. Wetzel, eds.), 246-255. ASCE, New York.

Executive Summary

Date Prepared: 13 Aug 07

Presenter's Name: Thomas C. Taylor
Presenter's Title: Vice President
Presenter's Organization/Company: Lunar Transportation Systems, Inc.

Presentation Title

Commercial Transportation and Lunar Surface Mining

Key Ideas

Commercial Transportation of Non-Essential Cargo
Logistics Development of Company Town and Lunar Resource Recovery
How can risk/cost be reduced through cooperation and partnerships in technological developments and demonstrations?

Supporting Information

Lunar Transportation Systems, Inc. offers a commercial logistics perspective to lunar mining, base operations, camp consumables and the future commercial sales of propellant from lunar mining operations. Our goal is a logistics architecture proposed with sustainable growth over 50 years, financed by private sector partners and capable of cargo transportation in both directions in support of lunar resource recovery. The author's perspective includes 5 years in remote sites and lessons learned in logistics. Lunar logistics may be the most complicated logistics challenge yet to be attempted. The price paid, if a single system does not work well is significant. In Alaska, we had four different logistics transportation systems and none work successfully all the time. The private sector has, in the past, invested large sums of risk money, $20 billion for example, in resource recovery ventures, when the incentive to do so was sufficient to provide a return on the risk investment. Stimulating an even larger private investment is needed for the moon's resource development. The development of the moon can build on mankind's successes in remote logistics bases on Earth and learn from Alaskan oil experience. The proposed commercial lunar transportation architecture uses new innovations for modularity and flexibility leading to reduced development and logistics costs, faster development schedule, and better evolvability. This new trade lunar route for mankind utilizes existing Expendable Launch Vehicles (ELVs) available and a commercially financed small fleet of new trans lunar and lunar Lander vehicles. This commercial transportation offers ways for small payloads early & larger payloads later. Commercially, this new lunar logistics route permits capability and technology growth as the market grows, offers affordable transportation for the commercial sector and the later recovery of lunar resources. After NASA moves on to other destinations in our solar system, commercial markets and this "in place" commercial logistics system can service, stimulate and sustain a lunar commercial market environment.

Executive Summary

Date Prepared: September 24, 2007

Presenter's Name: Frank Teti
Presenter's Title: Manager, Autonomous Robotics
Presenter's Organization/Company: MDA

Presentation Title

Robotic Technologies for Lunar Exploration

Key Ideas

Robotic technologies will form a key element of future lunar missions, both civilian and commercial. Through the management of a broader portfolio of robotic technologies with specific applications in both space and terrestrial markets these technologies can be contributed to lunar activities at cost effective commercial prices.

Supporting Information

Key examples from MDA's robotic portfolio will be presented included spin-in and spin-out technologies in 3D vision, mining vehicles, medical robotics and aircraft ice detection.

Executive Summary

Date Prepared:	August 13, 2007
Presenters' Name:	Charles Weisbin
Presenters' Title:	Deputy Program Manager
Presenters' Organization:	Jet Propulsion Laboratory

Presentation Title

Collaborative Human-Robot Science Exploration on the Lunar Surface

Charles Weisbin, Alberto Elfes, Jeff H. Smith, Hook Hua,
Joe Mrozinski, Kacie Shelton

Key Ideas

The problem addressed is the allocation of tasks among humans and robots to most productively achieve mission goals. With support from NASA's Directorate Integration Office of the Exploration Systems Mission Directorate, and in coordination with the Surface Operations/ EVA Focus Element of the Lunar Architecture Team, we have developed the methodology, implemented and validated the software and conducted analyses of trades between conducting activities EVA, IVA and robotically teleoperated from earth.

The activities studied were science based (i.e. sample acquisition, geological context survey, coring, raking etc.) and productivity measured in terms of task time completion. (we're currently looking at other measures such as cost, quality etc.). A scenario in which astronauts identify interesting geological sites, and lay beacons for subsequent sample coring by earth based teleoperated robots avoids the necessity of astronauts performing time-consuming drilling operations allowing them to use their time more productively.

Supporting Information

Approach:

1. Identify
   - **agents** : astronauts on the moon, robots operating autonomously or controlled from earth,
   - **activities** (move, carry, deploy, etc.),
   - **resources** (tools, vehicles, power, etc.)
2. Identify **constraints** (ex: EVA is done in pairs for M hours/day; robots need recharging after N hours, etc.)

3. Define **figure of merit** to be optimized (ex: maximize science productivity)
4. Define **starting configuration state S** (e.g. astronauts unsuited in habitat, with pressurized and unpressurized vehicle, etc..
5. Define **goal configuration state G** (e.g. 6 science activities at each of two sites completed; agents and resources at their starting configuration)
6. Search for **optimal allocation sequence of tasks** to available agents in parallel and/or sequential order.
    - **a.** Starting from S, generate all the new possible configurations
    - **b.** Evaluate each new configuration using FOM, select best alternative that does not violate any constraint
    - **c.** Repeat until Goal is reached

Mission Scenarios

The mission objective is to complete rock sampling, geological context survey, raking of samples, soil sampling, drive tube sample, and core drill sample at each of two science sites 10 and 20 km from the habitat respectively.

The study showed that having astronauts conduct 5 of the tasks directly, but leaving beacon markers at locations for earth based teleoperated robots to drill and acquire samples at these locations and bring them back to the habitat would save almost two hours per day of EVA time which could be productively used for other tasks. It would take 7.5 hours/day of teleoperated robot time (and associated ground operations).

Current Capability

- Our planning software approach is **independent of the specific problem being solved**
- The software **gives the user freedom to specify agents, actions, resources, parameters, constraints, start and goal states, and the objective function to be optimized**
    - Many of the large-scale planners discussed in the literature focus primarily on scheduling activities already associated with agents, tools, etc.; our approach considers alternative assignments of agents, tools, etc.
- Using constraints and a "smart" objective function, an multi-hour search of 30,000+ nodes was reduced to hundreds of nodes searched in a few seconds.
- This methodology can be applied to **conduct systematic comparisons of different mission architectures from the point of view of mission efficiency**

Executive Summary

Date Prepared: 5 September 2007

Presenter's Name: Brian H. Wilcox
Presenter's Title: Principal Investigator, ATHLETE robot
Presenter's Organization/Company: JPL

Presentation Title

Mobile Lunar Landers and their Implications for Science

Key Ideas

As part of the NASA Lunar Architecture Team, one of the options considered (Option 4) was to make some or all of the lunar landers mobile. The presenter was a member of the Option 4 study team, and will describe the architectural and science implications of making landers mobile.

Supporting Information

A lunar lander can be made mobile using a mobility system as little as 5-8% of landed mass. Mobile landers can move well away from the landing zone, preventing ejecta damage to other assets. They can congregate and dock together, eliminating the need to separate, handle, and transport large payloads, as well as any "civil engineering" tasks associated with site preparation and emplacement. They have integrated power and communications elements, so that such elements don't need to be emplaced on the surface along with their attendant power and communications cables that pose a risk if laid out on the surface. Perhaps most importantly, mobile landers can be used as "Winnebagos" for long-range exploration. Scenarios will be described where one Winnebago and one small pressurized rover can explore thousands of kilometers, and two Winnebagos and two small pressurized rovers can provide global-scale exploration (e.g. visiting the 10 "ESAS sites" selected for their scientific and/or resource interest).

Executive Summary

Date Prepared: 22 August 2007

Presenter's Name: Rodney (Rod) Wilks
Presenter's Title: ATK Exploration Beyond LEO Manager
Presenter's Organization/Company: ATK

Presentation Title

International-Commercial Involvement in Lunar Robotic Mission

Key Ideas

Significant costs of all needed lunar robotic exploration missions discourage full participation from various space agencies. International-Commercial collaboration can enable full participation at significantly reduced cost.

Supporting Information

The full scope of what is required to prepare for manned exploration of the moon and to conduct significant worthwhile science missions is beginning to emerge. To sufficiently help drive down the risk of landing crews on the lunar surface and to conduct statistically sound scientific assessments of the moon, significant resources have to be made available. For most if not all space agencies, the cost of such missions prohibit their total participation. This presentation will discuss alternative ways that could be used to allow full participation by interested space agencies and commercial interest. The presentation will cover proposed collaboration efforts between the various space agencies. This collaborative effort should lead toward a common international architecture that can be used as a basis for cost and data sharing. Further it will cover some ideas about how launch and landing cost can be reduced by using a common design framework that could be the standard for all types of robotic and cargo delivery missions. By using a common design framework and sharing both cost and data between participating agencies or commercial customers, the envisioned scope of lunar robotic and cargo type missions can be conducted at a significantly less cost to each participant.

Executive Summary

Date Prepared: August 17, 2007

Presenter's Name: Dr Pete Worden
Presenter's Title: Director
Presenter's Organization/Company: NASA Ames Research Center

Presentation Title

Small Spacecraft in support of the Lunar Exploration Program

Key Ideas

This paper analyses the ability of small, low cost spacecraft to deliver scientifically and technically useful payloads to lunar orbit and the lunar surface, in particular precursor mapping, infrastructure and in-situ resource utilization functions, that are necessary prior to human return as part of the Vision for Space Exploration

Supporting Information

This paper is based upon a technical study of the NASA-Ames Research Center's Small Spacecraft. Following an overview of the generalized capabilities of small spacecraft in comparison to the objectives of the robotic lunar exploration program, the paper documents the mission planning and overall spacecraft design for lunar missions. The study shows that spacecraft subject to the constraints laid out, within a budget of < $100 Million and which can be launched on one of the next generation affordable launch vehicles such as Falcon-1 or Minotaur-V, can deliver payloads of 5-50 kg to the lunar surface or 10-200 kg payload to lunar orbit. The payloads carried would be capable of covering most of the functions of lunar missions that are needed prior to human arrival, as identified in NASA's Lunar Robotic Architecture Study, with the exception of the bulk ISRU tasks of the 'Lander Rover' (In-situ Resource Utilization (ISRU)) mission. The key advantages of smaller spacecraft are reduced cost and schedule. These missions include Laser Communications demonstration, validation of frozen orbits, high altitude dust measurements, high resolution neutron spectrometer measurements, precision landing, dust characterization, lighting and thermal ground truth at different locations, regolith composition and thickness and radiation shielding characteristics, small ISRU demonstrators, effects of lunar environment on life and mechanical structures, lunar astronomy, micro rover demonstrations