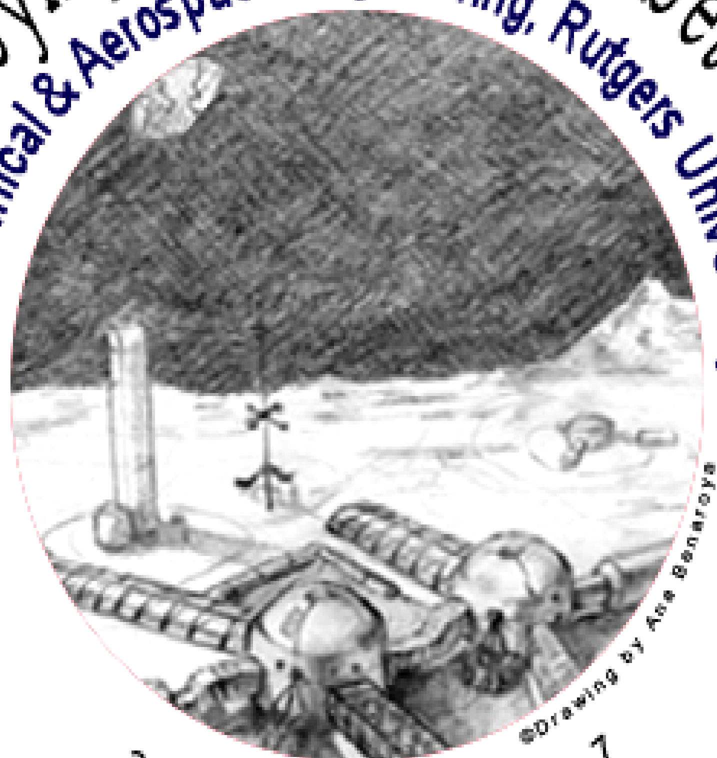
RUTGERS

THE STATE UNIVERSITY OF NEW JERSEY

Rutgers Symposium on Lunar Settlements

Mechanical & Aerospace Engineering, Rutgers University



3 - 8 June 2007

Haym Benaroya, Professor
Department of Mechanical & Aerospace Engineering
Director, Center for Structures in eXtreme Environments
Rutgers, the State University of New Jersey

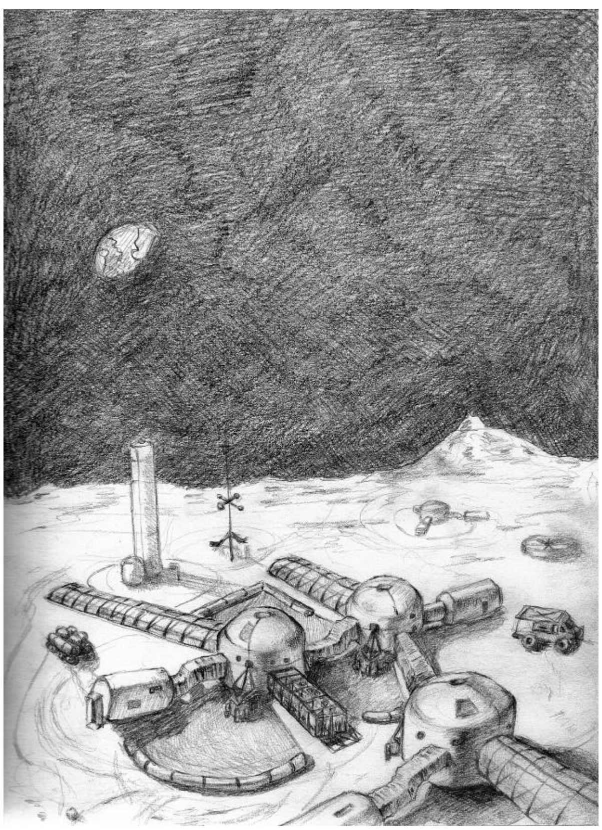
AIAA
American Institute of Aeronautics and Astronautics

RUTGERS SYMPOSIUM ON LUNAR SETTLEMENTS

ACKNOWLEDGEMENTS

There are many people whose efforts have made this Symposium an excellent meeting. Certainly first on this list must be Mrs. Patricia Mazzucco, whose tireless efforts in working with our vendors and local organizational matters, as well with many of the attendees truly made this meeting come together in such a nice way. We are grateful to Vice President for Academic Affairs Philip Furmanski for his enthusiasm as well as financial support for the Symposium. Similarly we are grateful to Rutgers University, the institution, for being the exciting and dynamic place that it is. Elan Borenstein is thanked for his significant efforts on creating our website and making sure we were properly set up for the Symposium. Tushar Saraf is appreciated for his work in preparing this Abstract Book. Paul Bonness is appreciated for his efforts at pulling together Symposium materials. Shefali Patel and Helene Press are thanked for their assistance and support with the Symposium preparations. Aiesha Jenkins is sincerely thanked for her supportive efforts during the Symposium. Professor Yogesh Jaluria, Chair of Mechanical and Aerospace Engineering, is acknowledged for his assistance and support for this endeavor. Kendra Cameron is thanked for her assistance in helping us gather promotional items for the attendees. Of course we are truly grateful to all the presenters who took time and expense to come to Rutgers and offer us some of their expertise. Finally, a personal thanks to Ana Benaroya, my daughter, for her illustration of a future lunar settlement that has become our Symposium logo.

Thank you,
Haym Benaroya.



RUTGERS SYMPOSIUM ON LUNAR SETTLEMENTS

3-8 JUNE 2007 RUTGERS UNIVERSITY

	SUNDAY 3 JUNE 07	MONDAY 4 JUNE 07	TUESDAY 5 JUNE 07	WEDNESDAY 6 JUNE 07	THURSDAY 7 JUNE 07	FRIDAY 8 JUNE 07
8 – 9		**8:00 Registration & Opening Ceremonies**	**8:00 Registration 8:30-9:15 James Logan**	**8:30 Registration**	**8:30-9:15 Bradley Edwards**	
9 – 10		**9:00 -10:00 Harrison Schmitt**	**9:15-10:00 Roger Launius**	**9:00-9:45 Rupert Gerzer** Bishop	**9:15-10:00 Paul Eckert**	9:00 SYMPOSIUM SUMMARY PANEL
10 – 11		Benaroya Grandl **10:40 COFFEE BREAK**	Howerton Rodiek **10:40 COFFEE BREAK**	Smirnov **10:40 COFFEE BREAK**	Han Palaia **10:40 COFFEE BREAK**	CLOSING Thoughts BY REMAINING ATTENDEES
11 – 12		Richards 1 Freeman Lundquist	Richards 2 Pearson Smithers	Das Giacomelli Banerji	Heiss Levy Lewandowski	AJOURNMENT
12 – 1		**LUNCH**	**LUNCH**	**LUNCH**	**LUNCH**	
1 – 2		**1:10-1:50 Larry Bell** **1:50-2:30 Lawrence Taylor**	**1:00-1:45 Brent Sherwood** **1:45-2:30 Terry Hart**	**1:30-2:15 George Nield**	**1:15-2:00 Harry Janes**	
2 – 3		**2:30** Jukola Konesky 1	**2:40** Rhoades	**2:20-3:00** Rowe	Maccone Durst	
3 – 4		Brandhorst **3:40 COFFEE BREAK**	Fisher Ruess **3:40 COFFEE BREAK**	Taylor **3:40 COFFEE BREAK**	Foing 2 Konesky 2 **3:40 COFFEE BREAK**	
4 – 5	**4 - 7 COFFEE & Registration**	Zacny Lowman Foing 1	Dunne Florek Gulak	Summers Spell Pimenta	Toklu Shevchenko	
5 – 6		Tirat-Gefen				
6 ++		**6 – 8 OPENING RECEPTION**	**6 – 11 SPECIAL EVENT EVE**	**6 – 9 ZIMMERLI BANQUET**	**ON YOUR OWN**	

DAY 1

Monday, JUNE 4, 2007 Morning Session

PLENARY SPEAKER

Harrison H. Schmitt, Ph.D.
Apollo Astronaut, US Senator, Entrepreneur
"Return to the Moon -Expanding the Earth's Economic Sphere"

Day 1 Morning Schedule:

- **8:00 - 9:00 am Registration & Opening Ceremonies**
- **9:00 - 10:00 am Harrison Schmitt**
- **10:00 - 10:20 am Haym Benaroya**
- **10:00 - 10:40 am Werner Grandl**
- **10:40 - 11:00 am COFFEE BREAK**
- **11:00 - 11:20 am R.D. Richards**
- **11:20 - 11:40 am Marsha Freeman**
- **11:40 - 12:00 pm Charles Lundquist**
- **12:00 - 1:00 pm LUNCH**

Return to the Moon-Expanding the Earth's Economic Sphere

HARRISON SCHMITT*

It has been suggested by the President's Science Advisor and the Administrator of NASA that it is time to include the Moon in the "economic sphere of the Earth." Both history and comparative analysis indicate that a privately financed and managed initiative would be the most efficient and productive approach to returning to the Moon in the foreseeable future and to accomplishing this long-term economic goal. Any large scale private initiative focused on a Return to the Moon will have as its ultimate aim a return on investment from production and sale of lunar resources, in particular helium-3 for fusion electric power plants on Earth. In addition to helium-3 for fusion power, sales of by-products from its production, such as hydrogen, water and oxygen to customers in space, will add to bottom line income as well as to investor return. The same can be said of ancillary services based on the existence of an investor-financed lunar settlement and the new space transportation systems required to establish and service that settlement.

*schmitt@engr.wisc.edu

Lunar Structures

HAYM BENAROYA*

While interest continues to increase with the nation's return to the Moon by astronauts for a permanent settlement there, the question of why we need to do this continues to be asked, even though answers abound. The brief list of whys follows:

- Safeguarding the species, by locating humans in off-Earth locations and for planetary defense for asteroid early warning and targeting;
- Attracting young Americans to the study of engineering, science and mathematics;
- Manifest destiny, competition against China, Europe and other space faring nations, staking a claim;
- Economic rewards such as resources, extraterrestrial site-specific benefits for industry, tourism, dual-use technologies;
- Science: astronomy, space and earth sciences, biological sciences;
- The Moon as a base for the development of "space legs" so humans can go to Mars and beyond, learn more about human and plant physiology, human psychology, in the space (radiation) and low-*g* environment, to learn how to "live off the land" in space;
- Creating an epic and positive vision for humanity as a balance to ward off societal pessimism, in particular for the coming generations, much as the New World and the West did during the Age of Exploration and the Westward Expansion in the United States. I believe this is the most forceful reason!

Concepts for lunar base structures have been proposed since long before the dawn of the space age. We will abstract suggestions generated during the past quarter century, as these are likely to form the pool from which eventual lunar base designs will evolve. Significant studies have been made since the days of the Apollo program, when it appeared likely that the Moon would become a second home to humans. Such studies continue today. While many ideas are futuristic and exciting, we must recognize the serious engineering and physiological issues that must be surmounted before a permanent and manned settlement exists on the Moon, and therefore that the first settlement is likely to be a very simple set of structures, but still very exciting.

*Department of Mechanical and Aerospace Engineering,
Director, Center for Structures in eXtreme Environments
Rutgers University
98 Brett Road, Piscataway, New Jersey 08854
benaroya@rci.rutgers.edu

Lunar Base 2015 – A Preliminary Design Study

WERNER GRANDL*
Architect & Civil Engineer

The Lunar Base 2015 – design study is a concept for the return of humans to the moon from 2015 to the end of the century. The proposed lunar station (Stage1) is built of 6 cylindrical modules, each one 17m long and 6m in diameter. 8 astronauts or scientists can live and work in the station. Each module is made of aluminium sheets and trapezoidal aluminium sheeting and has a weight of approximately 10.2 tonnes, including the interior equipment and furnishing. The outer wall of the cylinders is built as a double-shell system, stiffened by radial bulkheads to provide structural redundancy and for shielding. To protect the astronauts from micrometeorites, radiation and extreme temperatures, the caves between the two shells of the outer wall are filled with a 0.6m thick layer of regolith *in situ* by a small teleoperated digger vehicle. Using lunar material for shielding the payload for launching can be minimized. For launching the ARIANE 5 ESC-B rocket or a similar US or Russian launcher can be adapted. (12 tonnes payload required) For the flight from earth orbit to lunar orbit the modules can either be propulsed by a small rocket engine attached to each module or be moved by a "space tug" (one more flight is necessary). To land the modules on the lunar surface, a teleoperated "rocket crane" is used. This vehicle will be assembled in lunar orbit and is built as a structural framework carrying rocket engines, fuel tanks and teleoperated crawlers to land and move on the lunar surface. To establish the basic Stage 1 on the moon 11 flights are necessary: 1 flight- lunar orbiter, a small manned spaceship; 1 flight- manned lander and docking module for the orbiter; 1 flight- teleoperated rocket crane; 6 flights- lunar base modules; 1 flight- machinery: teleoperated digger vehicle, regolith ripper-excavator; 1 flight- scientific equipment, lunar rover, etc.

Extended version (future): Due to its modular design the Lunar Base can be enlarged in stages, finally becoming an "urban structure" for dozens of astronauts and tourists, always using the same launchers and machinery with current technology.

* A-3430 Tulln,
Dr.Billrothstrasse 6, Austria
archigran@gmx.at

The New Race to the Moon: Old World Ideas Versus New World Opportunities

R.D. RICHARDS*,
Excalibur Moon LLC

Between 1969 and 1972, twelve humans walked on another world. After the most awesome technological and psychological achievement of the human species, they left, never to return. Why? Was it a useless waste of human ingenuity on an Olympian folly? What caused humanity to abandon its first toehold on another world? More importantly, what is the basis to go back? What new forces and motivators are at play today that make the story a different one than the Apollo dead end?

Today there is a rebirth of interest in going back to the Moon among many nations. As co-chair of the International Lunar Conference in 2005, Bob Richards assembled the worlds' foremost scientists and policy makers to discuss humanity's return to the Moon. However while nations plan and strategize how to navigate the political minefields and conflicting national priorities that justify the value of the Moon to the everyday tax payer, there are some new kids on the block not so constrained. They are the privateers; visionaries too, however their driving metric for going to the Moon is sustainable business and commerce.

In this talk Bob Richards outlines how a carefully planned private Moon mission could set in motion the technological, political, legal and regulatory precedents that will allow humanity to rationally and peacefully embrace and develop the Moon as the world's eighth continent.

* 300 Interchange Way, Vaughan, Ontario
CANADA L4K 5Z8
rdr@optech.ca ;
www.robertdrichards.com

Krafft Ehricke's Moon: The Extraterrestrial Imperative

MARSHA FREEMAN*
Associate Editor, 21st Century Science & Technology

German-American space visionary Krafft Ehricke is well known for his statement: "It has been said, `If God wanted man to fly, He would have given man wings.' Today we can say, `If God wanted man to become a spacefaring species, He would gave given man a moon.' "

Over the course of more than thirty years, Krafft Ehricke laid the philosophical basis for man's exploration of the Solar System, and created exquisitely detailed plans for the human settlement and industrial development of the Moon. In 1957, in his "Anthropology of Astronautics," Ehricke proposed that only man places limits on himself; that not only the Earth, but the entire Solar System are man's rightful field of activity; and that by "expanding through the universe, man fulfills his destiny as an element of life, endowed with the power of reason and the wisdom of moral law within himself."

Krafft Ehricke saw the exploration of space as based on an Extraterrestrial Imperative**;** that for mankind to grow and develop, a new "open world" was needed, not limited to the confines of Earth. Such an effort was not voluntary, but mandatory, he posited, because a growing world population and increasing standards of living would require new worlds and resources to explore and exploit. The only alternative would be increasing shortages of strategic materials and energy, increasing geopolitical conflicts, and, eventually, war.

A multi-decade approach to lunar development was proposed by Ehricke, who described the Moon as Earth's Seventh Continent. The most advanced technologies, based upon the use of nuclear fission power, automated and robotic systems, laser, and other directed-energy applications, would make industrial activity on the Moon, as, or more, productive than that on the Earth. With thriving lunar industries, mankind would no longer be limited to the resources of his home planet, and would have created the basis for the next steps in exploration, to Mars.

Krafft Ehricke's vision, his attention to engineering detail, and his incorporation of the most advanced technologies becoming available, should inform the methods being considered today for the approaching intensive robotic and then manned return to the Moon.

One can only imagine Ehricke's excitement were he alive today, at seeing the wide array of nations now planning the exploration and development of the Moon.

* P.O. Box 16285,
Washington DC, 20041, USA
(703)-777-7490
krafft@erols.com

Apollo Knowledge Transfer

CHARLES LUNDQUIST[1] & DENNIS WINGO[2*]

A perplexing social issue is how to convey knowledge and experience from the Apollo Program in a way that is efficiently helpful to present teams planning return missions to the moon. Such a transfer of know-how is hard even when there is a continuity of work-force, but the transfer is exceedingly difficult when an interval of some forty years must be bridged. Surely historical documents from the Apollo Program exist in many places and forms that are accessible with enough effort. Realistically, the present government and contractor team members are so pressed with current issues that they feel they can devote but little time to primary literature searches. They can be aided by their social community.

Recognizing its long-standing relationship with the NASA Marshall Space Flight Center and the Huntsville contractor community, the University of Alabama in Huntsville, UAH, has accepted a role as a repository for space information deserving preservation in a publicly accessible archive. One mode of operation has been acceptance of personal materials donated by retirees from the Marshall Center and other individuals. Many video oral-history interviews have been conducted. The collections at UAH related to lunar exploration include a Saturn V collection, a Lunar Roving Vehicle Collection, an Apollo mission collection, and documents from the activities of the Apollo Group for Lunar Exploration Planning, GLEP. The GLEP considered many factors that influenced landing site selection and investigation plans for each Apollo mission.

Fortunately, present lunar team members, and students who will become team members, have grown up in the era of computer data bases and they are skilled at accessing such information. This suggests that one obvious aid to them is to provide Apollo knowledge and experience in a computer searchable format. The Archives and Special Collections Department in the library at UAH is among many entities that recognized and implemented this option. While it is prohibitive to immediately scan in full all the available documents, a selection of the most pertinent ones can be provided online. The others can have an online finding guide and abstracts to allow needed documents to be identified and retrieved.

An issue faced by all archives, but particularly space archives, is the circumstance that some old records exist in electronic formats that have become obsolete. The archiving entity then has the task of transforming these records into a currently used format, preferably one that facilitates online access.

The authors fully recognize that providing online and in-library access to information is only one option in preserving and conveying the Apollo experience. Scholarly surveys of Apollo material is another. Given the scope of the past, present and future lunar exploration programs, and recognizing the large number of organizations involved, the information preservation and transfer task is indeed a challenging social problem.

*[1]Skycorp, 603 Dement St. NE,
Huntsville AL 35801;
wingod@earthlink.net
[2]Research Institute,
University of Alabama in Huntsville, AL 35899;
lundquc@email.uah.edu

DAY 1

Monday, JUNE 4, 2007 Afternoon Session

PLENARY SPEAKERS

Prof. Larry Bell
Director SICSA, University of Houston
"Surface Infrastructure Planning and Design Considerations for Future Human Lunar and Mars Habitation"

Prof. Lawrence A. Taylor
Director, Planetary Geosciences Institute
Department of Earth & Planetary Sciences
University of Tennessee, Knoxville
"Resource Utilization on the Moon: A Marriage of Science and Engineering"

Day 1 Afternoon Schedule:

- **1:10 - 1:50 pm Larry Bell**
- **1:50 - 2:30 pm Lawrence A. Taylor**
- **2:30 - 2:50 pm Päivi Jukola**
- **2:50 - 3:10 pm Gregory Konesky**
- **3:10 - 3:30 pm Henry W. Brandhorst**
- **3:40 - 4:00 pm COFFEE BREAK**
- **4:00 - 4:20 pm K. Zacny**
- **4:20 - 4:40 pm Paul D. Lowman Jr.**
- **4:40 - 5:00 pm Bernard H. Foing**
- **5:00 - 5:20 pm Yosef G. Tirat-Gefen**
- **6:00 - 8:00 pm OPENING RECEPTION**

Surface Infrastructure Planning and Design Considerations for Future Lunar and Mars Habitation

LARRY BELL
Professor/Director of SICSA*

This presentation discusses and illustrates ways that planning and design for habitable structures and human operations on the Moon and Mars differ in fundamental aspects from terrestrial circumstances on Earth. Key among these differences are severe launch and landing constraints upon equipment and element mass and volume; minimal or non-existent availability of surface construction and site preparation systems, tools and labor resources; limited and potentially periodic power tied to solar source conditions; and temperature extremes and dust impacting equipment reliability and maintainability.

The presentation also offers a variety of facility types and configurations that respond to different design strategies and mission applications. Included are both conventional and expandable (such as inflatable and telescopic) pressurized structures, each type correlated with special advantages and limitations. These respective benefits and constraints influence how they can be landed on the surface, maneuvered and deployed; alternative ways they can be grouped together to meet evolutionary site development requirements, and radiation protection countermeasure options. Examples draw upon numerous research and design studies undertaken by the Sasakawa International Center for Space Architecture (SICSA) over a period spanning more than two decades.

* Sasakawa International Center for Space Architecture (SICSA),
122 College of Architecture building,
University of Houston, Houston, TX 77204 – 4000
lbell@uh.edu

In-Situ Resource Utilization on the Moon: A Marriage of Science and Engineering

LAWRENCE A. TAYLOR*
Planetary Geosciences Institute

The establishment of a base on the Moon, with human occupancy, will necessitate the use of the indigenous resources on the Moon. Virtually everything we know about the Moon and its rocks and soils comes from the science that evolved from the Apollo Program, continuing today with sample studies and refinements of earlier remote-sensing data. It is this knowledge of the physical and chemical properties of lunar regolith that forms the basis for the engineering endeavors to make it possible to effectively "live off the land" in our exploration endeavors.

"Science enables Exploration, and Exploration enables Science." It is this synergy that must be fully appreciated, realized, and utilized for this massive lunar endeavor to be successful. The properties of the lunar rocks and soils that make up the regolith vary widely over the lunar surface. The spatial distributions of the regolith, mainly as to its chemistry, have been forth-coming from the successful remote-sensing efforts of the Lunar Prospector and Clementine Missions, using the Apollo samples as ground truths.

Lunar architecture plans are to produce supplies of liquid oxygen (LOX) and liquid hydrogen on the Moon. The sources of these volatiles on the Moon are well-known; different processes for recovery of oxygen necessitate special feedstocks, and our science has already given us much of this knowledge. Regions of ilmenite-rich mare are well known, with such a feedstock being one of the best for hydrogen-reduction to release oxygen from this $FeTiO_3$ mineral. The presence of solar-wind particles on the surfaces of all lunar regolith grains has also been known since Apollo. The step-wise heating of lunar soil will easily release the hydrogen, helium, carbon, nitrogen, and other elements from the soil. And because the solar-wind implantation is a surface phenomenon, the finer fractions of the lunar soil possess the largest amounts of solar wind /mass.

These examples illustrate the synergies and symbiotic relationships between lunar exploration, with its largely engineering clientele, and lunar science, with its effective geologic and geochemical community. The major endeavor before us is tremendous and will only be possible by the effective union of these two divisions of knowledge, funding, and expertise. Apollo came about so successfully and quickly because there was no large division in personnel and administration between the engineers and scientists. Post-Apollo evolution of NASA has promoted the separation of these expertises. It behooves us to start thinking more like 'materials scientists', who epitomize the effective marriage of engineering and science. Working together, as per Apollo days, is called for to accomplish our goals of a lunar base within our lifetimes.

* Earth & Planetary Sciences,
University Of Tennessee, Knoxville 37996
Email: lataylor@utk.edu

Urban Innovations for the Moon

PÄIVI JUKOLA*
Helsinki University of Technology, Finland

People as decision-makers in complex systems are the most critical element for system safety, reliability and performance. Their creativity, adaptability and problem solving capabilities are keys to effective performance. Design guidelines that decrease psychological and social stress factors can be critical to mission success even during short-term lunar missions. The importance of enjoyable home and work atmospheres, places for sport and cultural activities, increase during long-term assignments in isolated hostile environments. Sustainable urban development is a necessity for a larger population working and living on site. This article explores alternative strategies to create the first lunar technology park benchmarking similar investment projects on Earth.

According to the study in order to solve the financial, technical and cultural space exploration challenges it would be beneficial to direct more attention to human factors, behavioral finance theories and user-oriented design-principals. The most important customer is the taxpayer. Investors are more eager to invest when risks, profits and the outcome of the project are simple enough to understand and persuasively communicated. There is a need for detailed urban design drawings by architects to engage the public in interactive participation. Real estate development is a timely process that includes stakeholders from government officials to private investors and end-users, from engineers to architects and brand identity marketing experts. Feasibility studies and master plans are valuable tools when evaluating future scenarios for the experimental station concept. However, without timely discussion on international treaties and financial policies the public at large is less likely to give support for lunar projects.

The most severe environmental conditions cause death to the poorest on Earth every day. Lack of clean water and air, dust, extreme temperatures, waste management and energy efficient transportation are similar infrastructure challenges on the Moon. Sincere determination to solve ecological problems on Earth paves the way to environmental innovations in the lunar gravity. Recent virtual reality and technological innovations that allow end-users to manipulate elements of interior atmosphere according to one's own personal taste are valuable for astronauts in remote locations, or hospital patients and elderly living in institutions. Research on 3-D visual simulation of real world environments and motion flight simulators is useful for training and virtual tourism to Moon and Mars. Thus, technological transfer opportunities are significant either way.

* paivi.jukola@hut.fi
Helsinki University of Technology,
Finland

RUTGERS SYMPOSIUM ON LUNAR SETTLEMENTS
3-8 JUNE 2007 RUTGERS UNIVERSITY

Settlement Site Selection and Exploration Through Hierarchical Roving

GREGORY KONESKY
SGK Nanostructures, Inc*

While orbital reconnaissance is useful for initial lunar settlement site selection, it is no substitute for in-situ ground truth, which could be easily accomplished with teleoperated roving. The Mars Exploration Rovers (MER) experience with Sojourner in 1997, and Spirit and Opportunity in 2004 show how the selection of rover size influences the capabilities and nature of their respective missions. Smaller rovers can more closely explore a complex environment and tend to be more nimble, but at a cost of reduced payload capability. Larger rovers enjoy enhanced payload capabilities, but at a cost of being somewhat ponderous and difficult to maneuver in complex environments. The best of these extremes can be optimized by a hierarchical roving approach wherein a large rover carries a hierarchy of smaller specialized rovers. The large rover, in addition to serving as a transport for the collection of smaller rovers to a remote deployment site, also acts as a communications relay link and power recharge source for the smaller rovers. In a typical operational scenario, the smaller specialized rovers are deployed at a given site and execute their collective mission. They are then recovered by the large carrier rover and transported to the next site. Some of the benefits of hierarchical roving include greater situational awareness, redundancy, spatially distributed capability, and the opportunity for self-rescue. The large rover can also serve as an anchor point for tethered roving, permitting smaller rovers to negotiate steep slopes or down-hole exploration that would otherwise be inaccessible to a wheeled vehicle.

Design and operating experience with a test model carrier vehicle containing three smaller specialized rovers is discussed, as are the design tradeoffs. Test results from tethered rover operations are also presented.

* 3 Rolling Hill Rd.
Hampton Bays, NY 11946
g.konesky@ att.net

R U T G E R S S Y M P O S I U M O N L U N A R S E T T L E M E N T S
3 - 8 J U N E 2 0 0 7 R U T G E R S U N I V E R S I T Y

A Solar Electric Propulsion Mission with Lunar Power Beaming

HENRY W. BRANDHORST, JR.[1], JULIE A. RODIEK[2], MICHAEL S. CRUMPLER[3], MARK J. O'NEILL[4*]

As the NASA Vision for Space Exploration evolves, a key issue that affects lunar exploration is the ability to provide electric power at various surface locations. This power should be available through daylight times as well as at night. It is the purpose of this paper to describe an electric propulsion mission to the moon that will use laser power beaming to provide power to multiple locations on the lunar surface.

The major benefit of solar electric propulsion (SEP) is that more payload can be delivered to the moon for less cost that by chemical means. In addition, SEP allows orbital adjustment to permit a range of characteristics to fit the mission requirements at small fuel expenditures. However, one disadvantage of SEP is that it takes longer to reach the moon, but this is not a limiting factor for this case. This paper will describe a solar electric propulsion mission to the moon, insertion into an elliptical orbit and beaming laser power to the surface.

Many options exist for orbits around the moon that could be used for power beaming. Beaming power from the L1 point leads to a beaming distance of about 56,000 km. The constraints on laser power beaming over this distance lead to substantial losses. If a Molniya-type, highly elliptical orbit were chosen for the power beaming location, the apogee may be only about 12,000 km which substantially reduces beaming distance, hence losses. However the length of time the lunar surface site is in view becomes important in order to keep the mass of the energy storage system on the surface small. In the same way, circular orbits of varying heights will encounter the same view time issue. So maximum elevation of the beaming spacecraft, the precession of orbits around the moon and the perturbations of lunar gravity all combine to complicate the analysis, and the results of these options will be presented.

For both the laser beaming spacecraft and the lunar surface receiving photovoltaic array, the Stretched Lens Array (SLA) on the SquareRigger platform design will be used. For the orbiting spacecraft, triple junction cells will be used in the array. A single cell test module with a triple junction cell and overall efficiencies of 29% has been demonstrated for this case. For the surface array, GaAs cells will be used to receive the beamed laser power. Testing of GaAs solar cells with a ~800 nm laser under the SLA has yielded efficiencies over 45% at room temperature.

This equates to over 800 W/kg and 800 W/m2 at a 70-75ºC operating temperature that is typical of a solar array in GEO. Temperature of an array orbiting the moon will depend upon its altitude and view angle of the lunar surface. Of course, the lunar surface temperature will markedly impact the surface array and those results are included in this study. As cell efficiency increases, the amount of waste heat decreases thus leading to an overall temperature reduction for a lunar surface array. This paper will present the results using one and two beaming spacecraft that will beam power only when the target site(s) are in darkness and the satellite is in sunlight. The impact of the Van Allen trapped radiation belts on the solar array power output will also be presented. The amount of power delivered to the surface is dependent upon the power level of the SEP spacecraft and will be presented for a nominal 100 kW BOL array.

[*1]Space Research Inst. 231 Leach Science Center, Auburn, AL 36849 brandhh@auburn.edu
[2]Space Research Inst. 231 Leach Science Center, Auburn, AL 36849 rodieja@auburn.edu
[3]Space Research Inst. 231 Leach Science Center, Auburn, AL 36849 crumpms@auburn.edu
[4]ENTECH, Inc., Keller, TX 76248 mjoneill@entechsolar.com

Drilling and Excavating Technologies for the Moon

K. ZACNY[1,2], J. CRAFT[1], S. FRADER-THOMPSON[1], K. DAVIS[1], B. GLASS[3], C. STOKER[3]

Reaching the cold traps at the lunar poles and directly sensing the subsurface regolith is a primary goal of lunar exploration, especially as a means of prospecting for future In Situ Resource Utilization efforts. As today's missions to space are highly cost driven, flight systems must deal with modest limits to mass and power. This means that robotic systems must become more "intelligent" and capable of performing difficult tasks autonomously.

For the past 20 years Honeybee Robotics has been developing various drills and other excavating systems for extraterrestrial applications (Mars, Moon, asteroids, etc.). These systems differ based on the required depth of penetration, size, mass, required power and the level of autonomy. There is no doubt that any drill system can be scaled down in size and mass, however, the most difficult part is drill autonomy.

Deep drilling with limited power is certainly a difficult task to automate, however, not impossible. This has been proven by two robotic drill systems the MARTE and the DAME drills. Together, these drills have proven the technologies necessary for low-powered, fully autonomous deep drilling on any planet or moon.

The presentation will focus on describing various drill technologies with a wide range of autonomy, as well as reporting drilling tests in lunar soil simulants. In addition an innovative method of mining lunar top soil currently being investigated by Honeybee will also be presented.

[1] Honeybee Robotics
460 West 34th Street, New York, NY 10001
[2] zacny@honeybeerobotics.com
[3] NASA Ames Research Center

RUTGERS SYMPOSIUM ON LUNAR SETTLEMENTS
3-8 JUNE 2007 RUTGERS UNIVERSITY

Malapert Mountain: A Recommended Site for a South Polar Outpost

PAUL. D. LOWMAN JR.*
Goddard Space Flight Center

The Moon's poles have emerged as scientifically and strategically valuable areas for a new lunar program as proposed by President George W. Bush in 2004. The Clementine missions showed that there are large areas of permanently-shaded terrain at both poles, but the southern one is more concentrated and well-defined. Consequently most interest has been focused on the South Polar Region and specifically on the crater Shackleton because it is thought to be in continual sunlight, and is close to the hydrogen-bearing shaded areas. However, Malapert Mountain appears to have several advantages over Shackleton.

It was shown by D. Schrunk and B. Sharpe that Malapert Mountain is sunlit 90% or more of the lunar year, whereas Lunar Orbiter 4 pictures show that the rim of Shackleton is only partly illuminated at any one time. Furthermore, the illuminated area varies over the lunar year, and no one site is continually sunlit.

Malapert Mountain is old, pre-Nectarian terrain, probably with a thick regolith saturated with implanted hydrogen and helium. It offers a broad and smooth landing area, demonstrably in continuous microwave visibility of Earth (for tracking and communications). It is close to permanently-shaded areas to the south, which should be easily reached by a vehicle driven down the south flank of Malapert Mountain.

Malapert Mountain, in summary deserves carefully study in light of mission safety, scientific importance, and evaluation of lunar resource.

* Goddard Space Flight Center, Code 698
Greenbelt, MD 20771
Paul.D.Lowman@nasa.gov

Smart-1 Highlights & Lunar Settlements

BERNARD H. FOING & SMART-1 TEAM*
ESA/ESTEC/SCI-S

SMART-1 is the first of Small Missions for Advanced Research and Technology as part of ESA science programme "Cosmic Vision". Its objective is to demonstrate Solar Electric Primary Propulsion (SEP) for future Cornerstones (such as Bepi-Colombo) and to test new technologies for spacecraft and instruments. The spacecraft has been launched on 27 Sept. 2003, as Ariane-5 auxiliary passenger, and spiraled out towards lunar capture on 15 November 2004. It then spiraled down towards lunar science orbit (300-3000 km) until March 2005. The SMART-1 mission orbited the Moon for a nominal period of six months, with 1 year extension until end of mission impact on 3 September 2006.

The spacecraft has carried out a complete program of technology and science measurements. There is an experiment (KaTE) aimed at demonstrating deep-space telemetry and telecommand communications in the X and Ka-bands, a radio-science experiment (RSIS), a deep space optical link (Laser-Link Experiment), and the validation of a system of autonomous navigation (OBAN). For lunar science, the payload includes a miniaturized high-resolution camera (AMIE) for lunar surface imaging, a near-infrared point-spectrometer (SIR) for lunar mineralogy investigation, and a very compact X-ray spectrometer (D-CIXS) with a new type of detector and micro-collimator which will provide fluorescence spectroscopy and imagery of the Moon's surface elemental composition.

We shall also present the highlights of lunar science results from SMART-1 payload, featuring many innovative instruments and advanced technologies with a total mass of some 19 kg. SMART-1 lunar science investigations include studies of the chemical composition of the Moon, of geophysical processes (volcanism, tectonics, cratering, erosion, deposition of ices and volatiles) for comparative planetology, and high resolution studies in preparation for future steps of lunar exploration. The mission addresses several topics such as the accretional processes that led to the formation of rocky planets, and the origin and evolution of the Earth-Moon system.

We shall discuss ongoing SMART-1 collaborations with upcoming missions, lessons for the future exploration, and results relevant to preparing a human lunar settlement.

* posTbus 299, 2200 AG Noordwijk
NL, EUROPE

Validation of Mission Critical Power and Control Systems for Lunar Settlement

YOSEF G. TIRAT-GEFEN[1] & JULIO C.G. PIMENTEL[2]

A future settlement on the Moon would use a massive number of semi-automated or fully-automated complex mission-critical systems dealing with issues in areas as diverse as environmental control, air quality management, radiation protection, and biomedical monitoring. These systems will be very expensive and difficult to test. In addition to that, no validation methodology would completely preclude hardware-in-the-loop testing of many of these subsystems. Power and control subsystems will be the backbone of many of these safety-critical systems. Therefore, the system degradation in the presence of transient or permanent faults should be fully accessed before final deployment. Also, the time and testing budget spent to set up and to fine-tune these systems will affect the overall economic feasibility of a mission. This work discusses the use of real time simulation for testing of power and control systems to be deployed in a lunar settlement. This simulation technology is capable of hardware-in-the loop validation. In other words, the system under test is able to operate in parallel and real-time with the simulator, where the latter drives and receives signals from the former through its analog and digital interfaces. Preliminary applications include subsystems in power electronics and biomedical monitoring. The simulator is based on a low cost reconfigurable computing infrastructure (e.g. embedded processors and field programmable gate arrays - FPGAs) and it is capable of having simulation steps on the order of 0.5 microseconds, which is enough to model several key electromechanical and power system modules. This work presents the simulator architecture and its implementation. We conclude with a discussion of how this technology could be leveraged with other approaches in safety-critical validation such as fault modeling and formal verification methods.

[1] Aerospace Division, Castel Research Inc. and George Mason University,
610 North Main Street, #288, Blacksburg, VA 24060
yosefgavriel@computer.org
[2] Dept. of Electrical and Computer Engineering, Laval University
Quebec, QC, Canada.

DAY 2

Tuesday, JUNE 5, 2007 Morning Session

PLENARY SPEAKERS

James S. Logan, MD, MS
Space Medicine Associates, Belcamp, MD.
"The Elephant in the Room: Biomedical Show-Stoppers for Long Duration Human Lunar Habitation?"

Roger D. Launius, Ph.D.
Chair, Division of Space History
National Air and Space Museum
Smithsonian Institution
"Why Go to the Moon? The Many Faces of Lunar Policy"

Day 2 Morning Schedule:

- **8:00 - 8:30 am Registration**
- **8:30 - 9:15 am James S. Logan**
- **9:15 - 10:00 am Roger D. Launius**
- **10:00 - 10:20 am Alex Howerton**
- **10:20 - 10:40 am Julie Rodiek**
- **10:40 - 11:00 am COFFEE BREAK**
- **11:00 - 11:20 am R.D. Richards**
- **11:20 - 11:40 am Jerome Pearson**
- **11:40 - 12:00 pm Gweneth A. Smithers**
- **12:00 - 1:00 pm LUNCH**

The Elephant in the Room: Biomedical Showstoppers for Long Duration Lunar Habitation?

JAMES S. LOGAN*
Space Medicine Associates, Belcamp, MD

The Vision for Space Exploration (VSE) envisions "permanent human presence" on the moon, first by establishing an "outpost" capable of supporting seven-day missions in 2020, then incrementally extending mission duration to as long as six months. NASA's Global Exploration Strategy team distilled the reasons for returning to the moon into six major themes (www.nasa.gov). The first theme is "Human Civilization: Extend Human Presence to the Moon to Enable Eventual Settlement," a truly daring goal considering the relative paucity of human lunar experience.

Six Apollo missions (1969-1972) cumulatively logged slightly less than 300 hours on the lunar surface including 81 total hours of lunar EVA. Since each Lander had a two-person crew, human beings now have almost 600 man-hours of lunar surface experience, approximately 162 of which are lunar EVA. Although the final and longest mission (Apollo 17) spent a little more than three days on the moon, the average lunar time per astronaut was only 2.08 days and the average lunar EVA time per astronaut was only 13.5 hours. While significant, these exposure times are not compelling from a biomedical perspective.

In contrast the current lunar concept of operations (CONOPS) consists of a crew of four placed on the lunar surface for variable durations living in a habitation 'element' performing frequent lunar EVA - two teams of two crewmembers doing 6-8 hour EVAs every other day for six days (on the seventh day the crew presumably rests). It is astonishing to realize the VSE CONOPS will surpass cumulative Apollo time on the moon early on day 7 of the first mission and surpass cumulative Apollo lunar EVA time by the middle of week two.

Even if NASA can return to the moon for significantly less than the cost of Apollo ($105-160 billion in inflation-adjusted 2007 dollars), the magnitude of the investment merits early, frequent and exhaustive analyses of VSE strengths, weaknesses, opportunities and threats.

Three questions are germane to assessing potential threats.

First, if the goal of VSE is long-term lunar habitation or even settlement, are there biomedical showstoppers that could potentially threaten the VSE or the current CONOPS? Second, in the past 35 years (since the return of Apollo 17), what have science and our operational space experience taught us that could better qualify or quantify potential threats? Third, what are the implications of the answers to the above on the viability and eventual success of the VSE or of permanent human lunar settlement itself?

* TelemedJL@cs.com

RUTGERS SYMPOSIUM ON LUNAR SETTLEMENTS
3-8 JUNE 2007 RUTGERS UNIVERSITY

Why Go to the Moon? The Many Faces of Lunar Policy

ROGER D. LAUNIUS,
National Air and Space Museum, Smithsonian Institution*

What is it about the Moon that captures the fancy of humankind? A silvery disk hanging in the night sky, it conjures up images of romance and magic. It has been counted upon to foreshadow important events, both of good and ill, and its phases for eons served humanity as its most accurate measure of time. This paper discusses the Moon as a target for Human exploration and eventual settlement. This paper will explore the more than 50-year efforts to reach the Moon, succeeding with space probes and humans in Project Apollo in the 1960s and early 1970s. It will then discuss the rationales for spaceflight, suggesting that human space exploration is one of the least compelling of all that might be offered. The paper will then discuss efforts to make the Moon a second home, including post-Apollo planning, the Space Exploration Initiative, and problems and opportunities in the 2004 Vision for Space Exploration.

* Division of Space History, National Air and Space Museum, Smithsonian Institution,
P.O. Box 37012, NASM Room 3557,
MRC 311, Washington, DC 20013-7012,
Voice: 202-633-2428, Fax: 202-786-2947, Cellular: 202-528-3278
launiusr@si.edu.

The Human Factor

ALEX HOWERTON
Business Development Manager, NASTAR Center*

Returning to the Moon is a noble and timely goal. There are many institutional and engineering challenges that have to be addressed, but no less important, and ultimately most important, are the human factors of the equation. If a successful Return to the Moon program is to be instituted, the human equation should be blended in at the outset.

The NASTAR Center is the National Aerospace Training and Research Center, located north of Philadelphia. Amongst other activities, we evaluate, train, and adapt people for spaceflight. This includes pilots, crews, and passengers, both government-sponsored and private. In addition, we support research into human factors and aeromedical issues of space launch physiology.

The NASTAR Center can support a Return to the Moon program in at least three distinct ways:

1) We can model the specific flight profile, including G exposure, of any flying vehicle, including the proposed CEV for President Bush's VSE. Pilots can train for launch with the precise sensory inputs, including G exposure, they will actually experience upon launch and reentry.

2) We offer training to private individuals planning for sub-orbital flights. The more people that experience spaceflight, the more will experience what Frank White has called "The Overview Effect." This can lead to deeper general public support for all space activity, including the Return to the Moon proposal.

3) We can support research and data collection into the human factors involved in the Return to the Moon program, including optimal flight characteristics, ergonomics, biomedical monitoring, aeromedical issues, and related projects.

Both from a technical point of view as well as a cultural/political point of view, The Human Factor has to be addressed early, as an integral part of any plan to Return to the Moon. This can help assure the long-term success of such a venture.

* ahowerton@etcusa.com
Office: 215-355-9100
Cell: 215-834-1759

Performance Projections for Solar Array Power Options on the Lunar Surface

HENRY BRANDHORST, JR.[1], JULIE RODIEK[2], MARK O'NEILL[3], MICHAEL ESKENAZI[4*]

In NASA's ambitious vision for space exploration, return visits to the moon are the initial focus. The Lunar Architecture Team has concluded that the first objective is a polar outpost site, the Shackleton Crater rim being a notable option. This is due to the high percentage of sunlight throughout the year, greater than 70%, allowing solar power to become the major power source.

Lunar solar arrays should have the following characteristics: high efficiency, light weight, high packaging density and be able to withstand the broad temperature swings on the moon. In addition, for those robotic missions that will explore the permanently dark polar craters, it is possible that beamed laser power may be an option to radioisotope powered rovers. Of course beamed laser power may also be applicable to providing power over the nighttime.

This study will demonstrate the capability of the Stretched Lens Array on the SquareRigger platform (SLASR) as the basis. The Stretched Lens Array (SLA) developed by ENTECH is a space solar array that uses refractive concentrator technology to collect and convert solar energy into useful electricity. At the present time this design has the following characteristics: specific power – 300 W/kg, areal power density – 300 W/m^2, stowed power – 80 kW/m3 and capable of high voltage (>600 V) operation.

One critical aspect of this study is the operating temperature on the moon and how it affects performance projections. Although a polar region seems certain for the first outpost, this study will take into account the wide temperature swings on the equator, and demonstrate that solar power is applicable for all lunar outpost sites. For equatorial sites the orientation of the solar array and the possible need to reduce the surface background will be included. Several surface treatments have been described in the past and will be used in this study.

The projected performance of a 25-30 kW lightweight, high efficiency SLASR array using multijunction solar cells expected to be available in 2010 time frame will be determined for a lunar polar region with high daylight during the year, an equatorial location during the day and an array in a permanently shadowed crater relying on laser illumination. The latter array will have GaAs solar cells matched to a nominal 800 nm wavelength laser and be sized for about 500 W.

Energy storage issues will also be discussed along with how much power can be delivered to the lunar surface. A detailed plan of how to build up a lunar base incrementally will be demonstrated. Power projections will show that the SLA is a lightweight, reliable, and cost effective power option for all locations on the lunar surface.

[*1]Space Research Inst. 231 Leach Science Center, Auburn, AL 36849 brandhh@auburn.edu
[2]Space Research Inst. 231 Leach Science Center, Auburn, AL 36849 rodieja@auburn.edu
[3]ENTECH, Inc., Keller, TX 76248 mjoneill@entechsolar.com
[4]ATK-Space, Inc., Goleta, CA 93117 3

The Vision for Lunar Exploration: Results from the 2005 International Lunar Conference

R.D. RICHARDS*,
Co-Chair, ILC2005

The 2005 International Lunar Conference on the Exploration and Utilization of the Moon took place in Toronto on September 18-23, 2005. Leading scientists and space industry professionals from around the world gathered in Toronto to discuss and plan the world's return to the Moon. ILC 2005 featured presentations of senior representatives from NASA, ESA and CSA as well as the commercial sector to work toward a collaborative international lunar exploration framework.

ILC 2005 was the 7th conference of the International Lunar Exploration Working Group (ILEWG), a public forum sponsored by the world's space agencies to support "international cooperation towards a world strategy for the exploration and utilization of the Moon - our natural satellite" (International Lunar Workshop, Beatenberg (CH), June 1994).

The event was a catalyst and forum for senior stakeholders responsible for laying the framework for international space exploration. ILC 2005 cultivated ideas and inputs of scientists, engineers, policy makers, program managers and entrepreneurs from many nations and put these ideas into motion with concrete plans and roadmaps for a human and robotic future embracing the Moon, Mars and beyond.

This paper summarizes the proceedings of ILC 2005 and the resulting declaration of the world's collaborative Vision for Lunar Exploration.

* OPTECH INCORPORATED,
300 Interchange Way, Vaughan, Ontario
CANADA L4K 5Z8
rdr@optech.ca ;
www.robertdrichards.com

Lunar Frontier Transportation Options

JEROME PEARSON, JOHN OLDSON, HARRY WYKES *
Star, Inc.

An integrated transportation system is proposed from the lunar poles to the equator, to L1, to Earth orbit, using a lunar space elevator, a system of lunar tramways and highways, and electric vehicles. The system could be used to supply lunar equatorial, polar, and mining bases with non-time-sensitive cargo, and could transport large amounts of lunar resources to Earth orbit for construction, radiation shielding, and propellant depots. We present options for long-range lunar surface transport, including "cars, trucks, and trains," along with their infrastructures of "roads, highways, and tramways" that can provide the interface between the local transportation around a lunar base and the space transportation of rockets and space elevators. The Apollo Lunar Rovers proved that wheeled vehicles could move fairly efficiently over the unprepared lunar surface, and they demonstrated a battery-powered range of nearly 50 kilometers. However, they also demonstrated the problems of lunar dust. For building dustless highways, it appears particularly attractive to create paved roads by microwaving the lunar dust into a hard surface. For tramways, it would be possible to erect towers to support high-strength ribbons that would carry cable cars over the lunar craters; the ribbon might even be fabricated from lunar materials. Such a transportation system could connect the polar mines with the equatorial lunar space elevator base, send cargo capsules up the lunar space elevator to beyond the L1 Lagrangian point, and from there rockets could take the cargo capsules with lunar resources into Earth orbit for building space habitats and space hotels for cislunar space development. We examine the power and energy storage requirements for lunar surface vehicles, the design and effectiveness of lunar tramways, and the materials requirements for the support ribbons of lunar tramways and lunar space elevators. This transportation system concept is adapted from an invited presentation at the Moonbase Workshop in January in Washington, DC, sponsored by the High Frontier and Jamestown on the Moon organizations, and is based on the results of a NIAC-funded study on the lunar space elevator. A 4-minute video is also available.

* 3213 Carmel Bay Drive, Suite 200
Mount Pleasant, SC 29466-8513
Tel.: 843-856-3590
jp@star-tech-inc.com
www.star-tech-inc.com

A One-Piece Lunar Regolith-Bag Garage Prototype

GWENETH A. SMITHERS, MARY K. NEHLS,
MARY A. HOVATER, STEVEN W. EVANS [1]
J. SCOTT MILLER [2]
ROY M. BROUGHTON, JR., DAVID BEALE,
FATMA KILLINC BALCI [3*]

Shelter structures on the moon, even in early phases of exploration, should incorporate lunar materials as much as possible. We designed and constructed a prototype for a one-piece regolith-bag unpressurized garage concept, and, in parallel, we conducted a materials testing program to investigate six candidate fabrics to learn how they might perform in the lunar environment. In our concept, a lightweight fabric form is launched from Earth to be landed on the lunar surface and robotically filled with raw lunar regolith.

In the materials testing program, regolith-bag fabric candidates included: Vectran™, Nextel™, Gore PTFE Fabric™, Zylon™, Twaron™, and Nomex™. Tensile (including post radiation exposure), fold, abrasion, and hypervelocity impact testing were performed under ambient conditions, and, within our current means, we also performed these tests under cold and elevated temperatures. In some cases, lunar simulant (JSC-1) was used in conjunction with testing. Our ambition is to continuously refine our testing to reach lunar environmental conditions to the extent possible.

A series of preliminary structures were constructed during design of the final prototype. Design is based on the principles of the classic masonry arch. The prototype was constructed of Kevlar™ and filled with vermiculite (fairly close to the weight of lunar regolith on the moon). The structure is free-standing, but has not yet been load tested. Our plan for the future would be to construct higher fidelity mockups with each iteration, and to conduct appropriate tests of the structure.

*[1]Nasa/Marshall Space Flight Center, Huntsville, Alabama
[2]Qualis Corporation/Marshall Space Flight Center, Huntsville, Alabama
[3]Auburn University, Auburn, Alabama

DAY 2

Tuesday, JUNE 5, 2007 Afternoon Session

PLENARY SPEAKERS

Brent Sherwood
Manager, Opportunities Development
NASA Jet Propulsion Laboratory
"What Will We Actually Do On The Moon?"

Prof. Terry Hart
Professor, Lehigh University and past NASA Astronaut
"Working in Space"

Day 2 Afternoon Schedule:

- **1:10 - 1:45 pm Brent Sherwood**
- **1:45 - 2:30 pm Terry Hart**
- **2:40 - 3:00 pm Carlton L Rhoades**
- **2:50 - 3:10 pm Gary C. Fisher**
- **3:10 - 3:30 pm Florian Reuss**
- **3:40 - 4:00 pm COFFEE BREAK**
- **4:00 - 4:20 pm M. Dünne**
- **4:20 - 4:40 pm Jason R. Florek**
- **4:40 - 5:00 pm Yuriy Gulak**
- **6:00 - 11:00 pm SPECIAL EVENT EVENING**

What Will We Actually Do on the Moon?

BRENT SHERWOOD*

Descriptions are provided for eleven specific, representative lunar activity scenarios selected from among hundreds that arose in 2006 from the NASA-sponsored development of a "global lunar strategy." The scenarios are: pave for dust control; establish a colony of continuously active robots; kitchen science; designer biology; tend the machinery; search for pieces of ancient Earth; build simple observatories that open new wavelength regimes; establish a virtual real-time network to enable public engagement; institute a public-private lunar development corporation; rehearse planetary protection protocols for Mars; and expand life and intelligence beyond Earth through settlement of the Moon. Evocative scenarios such as these are proposed as a communications tool to help win public understanding and support of the Vision for Space Exploration.

*NASA Jet Propulsion Laboratory
4800 Oak Grove Dr, 301-355
Pasadena CA 91109
brent.sherwood@jpl.nasa.gov

Working in Space

TERRY HART*
Professor, Lehigh University
And
Former NASA Astronaut

Since the first cosmonauts and astronauts walked in space, we have been climbing a continuing learning curve of how people can work productively in space. The effects of weightlessness and the physical limitations of pressure suits and spacecraft designs continue to challenge crews as ever-more sophisticated tasks are being accomplished.

And while we have come a long way in our ability to work in space, much needs to be done if we are to return to the moon with a permanent presence and venture on to Mars. Such long-duration missions will put new challenges on engineers and crews to adjust to the physical and psychological demands of these missions. With international cooperation, these challenges will be met and crews will learn to work effectively as we establish a permanent presence in space.

* teh305@lehigh.edu

R U T G E R S   S Y M P O S I U M   O N   L U N A R   S E T T L E M E N T S
3 - 8 J U N E 2 0 0 7   R U T G E R S U N I V E R S I T Y

The Moon: First Line of Asteroid Defence

CARLTON L RHOADES*

Millions of asteroids orbit the sun and, during each orbit, may intersect Earth orbit. Hundreds of thousands of these are of the "small" 50 to 100 meter size that could provide another Meteor Crater example. The same event at that site today would put at risk Interstate 40, the Burlington Northern and Santa Fe railroad, major electrical power transmission lines, a major natural gas transmission line, and over 10,000 people. Other effects would include overloading of alternate routes between Greater Los Angeles and the Midwest, and interruption of the electrical and gas service to the large areas served. The cost to recovery could be in the tens of billions. The event at or near a metropolitan center anywhere in the United States would be a catastrophe with orders of magnitude greater casualties and costs. Less than one percent of these "small" asteroids have been identified. Those identified as Earth impactors must have an orbit alteration to mitigate the threat.

The Moon is the ideal platform to expedite identification of Earth orbit intersecting asteroids. The Lunar sky obstructed only by the Earth, the Sun, the zodiacal light, and the local horizon can be searched 24/7.

This paper will expand on development of a Moon based, remotely operated, asteroid search system. The expansion will consider use or upgrades of existing subsystem elements before considering new subsystem elements. The expansion will consider shielded and pressurized accommodations for use by occasional on site personnel. The elements are:

Determine optimal search qualities and select site(s) having those qualities.

Determine requirements for the system including Logistics, Search, and Support Equipment.

Design and construct the Logistics, Search, and Support Equipment.

Transport Logistics Equipment to selected site(s) and prepare the site(s) for use.

Transport the Search and Support Equipment to the selected site(s) for installation and checkout.

*35 S Broadway, Tacoma,
Washington, 98402.
rhoades11@comcast.net.

Horizontal or Vertical Cylindrical Habitat?

GARY C. FISHER*
The Mars Foundation

For the purposes of creating in situ habitable spaces for a Lunar settlement, cylinder-shaped structures covered with regolith present the best near-term option over alternatives, such as: spherical or domed shaped structures, excavated structures, lined lava tubes, and regolith covered masonry vaulted arches.

Cylindrical structures have various options besides length and diameter. For example: hemispherical or flat end caps; rigid or inflatable? Another option is whether you create a true cylinder, or go with a more ellipsoid or flattened cylinder. The primary consideration, however, is whether to stand the cylinder up vertically on an end, or lay it down horizontally on its side. This paper is primarily concerned with deciding between these two options.

While this paper is part of the ongoing research of the Mars Foundation to design the first permanent settlement on Mars, the subject matter is equally relevant to a Lunar base or settlement.

* P.O. Box 694
Bryn Athyn, PA 19009
GaryCFisher@comcast.net

RUTGERS SYMPOSIUM ON LUNAR SETTLEMENTS
3-8 JUNE 2007 RUTGERS UNIVERSITY

Structural Reliability Considerations for Lunar Base Design

FLORIAN REUSS
BENJAMIN BRAUN*

The National Aeronautics and Space Administration (NASA) recently announced to build a permanent lunar base by the year 2020 [1]. The erection of such an outpost on the Moon is not only a question of how to choose the most suitable structure for a lunar habitat as summarized and presented in [2]. But also the risk and safety of such structures need to be assessed in an appropriate manner. For the design on Earth, standards and codes (e.g. the family of American Standards or Eurocodes) exist that help the designer to analyze and design a safe structure. However, special uncertainties exist in lunar base design which can be assessed as a first step only on the basis of a decision analysis, namely a structural reliability analysis. It offers a way to allocate the available resources both most efficiently and in a sufficiently safe manner. Fundamentally, uncertainties can arise from an inherent randomness in loads and resistances, inadequate knowledge (e.g. influence of radiation on material properties) and statistical uncertainty due to sparse information. Such uncertainties imply the need to use statistical and probabilistic tools in the analysis and design process. The basic principles of structural reliability analysis [3], [4] are introduced here with special regard to the design of second and third generation lunar habitats. A further key aspect in designing robust structures for the lunar surface is redundancy i.e. component failure should not govern system failure. In this respect the reliability analysis is finally discussed on the level of the overall structural system.

[1] Dale, S.: Exploration Strategy and Architecture. Opening Keynote, 2nd Space Exploration Conference, Houston, Texas, December 4-6th , 2006

[2] Ruess, F.; Schaenzlin, J.; Benaroya, H.: Structural Design of a Lunar Habitat. Journal of Aerospace Engineering 19 (2006), No. 3, pp. 133-157

[3] Thoft-Christensen, P.; Baker, M.J.: Structural Reliability and its Applications. Springer Verlag, Berlin (1982)

[4] Ditlevsen, O.; Madsen, H.O.: Structural Reliabilty Methods. John Wiley & Sons, Chichester (1996)

* Dipl.-Ing. Florian Ruess ◦ Tiefer 8 ◦ 28195 Bremen ◦ Germany ◦ Flo@he-squared.com
Dipl.-Ing. Benjamin Braun ◦ Arndtstr. 33 ◦ 70197 Stuttgart ◦ Germany ◦ Ben@he-squared.com

AstroHab - A Multidisciplinary Payload for a Lunar Pre-Cursor-Mission

M. DÜNNE, K. SLENZKA*
OHB-System AG

Living of humans in extreme environments as e.g. moon and mars requires sustainable closed ecological life support systems (CELSS) as well as knowing more about the impact of different environmental conditions (mainly gravity, magnetism and radiation) on biological processes in larger time scales.

Essential steps before longer explorative missions are investigations in extreme environments on Earth, in LEO (ISS) and also a series of missions to the moon. Developed support technology can be verified without having exceeded the point of no return of astronauts. A first pre-cursor-mission to the moon will demonstrate the efficiency of developed life support technologies and increasing the knowledge about existing environmental conditions on the moon (which are more stable and relevant than at the ISS) as well of their impact on biological and other processes.

OHB-System, Bremen, Germany, is currently analysing in the Mona Lisa Initiative of German Space Agency DLR such a first pre-cursor-mission to push the lunar settlement significantly. Analysis is performed together with a scientific team, whose members are coming from several disciplines. R&D-Activities were started to develop main elements of CELSS. The general concept for AstroHab – the autonomous biological payload for this first pre-cursor-mission, was developed. AstroHab will consist of a biosolar energy supply unit as first CELSS-element, furthermore of an experiment bioreactor and a sensor unit, which will monitor the environmental conditions at the landing site as well as further experiment conditions in the bioreactors.

Additionally to contributing to humans' ambition of exploring existing frontiers, activities serve as a technology and scientific driver in general.

An overview of AstroHab and the status of current R&D activities will be given.

* Universitätsallee 27-29, 28359 Bremen (Germany).
duenne@ohb-system.de,
slenzka@ohb-system.de,
Phone: +49 421 2020716

Extension of Terrestrial Excavation Mechanics to Lunar Soil

JASON R. FLOREK*
Department of Mechanical & Aerospace Engineering
Rutgers University

This presentation focuses on extending models for cutting and moving terrestrial soil for use with lunar soil. This area is of particular importance since nearly all lunar base designs call for some form of regolith shielding for protection against radiation and micrometeorite impact. Before such shielding can be constructed, the forces associated with digging and excavating regolith must be well understood.

It has been shown that Earth-based analyses do not directly translate for use with lunar soil. Required forces do not just simply scale by one-sixth due to the reduced lunar gravity. Furthermore, papers that make similar extensions typically assume a single value for the important lunar soil properties (e.g., cohesion or internal friction angle). Most studies do not take into account the variability of these parameters with depth or the uncertainty associated with the property values. In contrast, those studies that account for this variability tend to ignore how the parameters relate with one another. For example, the aforementioned properties are both related to soil density, while failure surface angle is a function of the rake and friction angles. Published parameter studies tend to make these quantities independent of one another.

As such, here, appropriate ranges of parameter values are considered for input to various two- and three-dimensional excavation models. Parameter dependencies and uncertainties are also accounted for, resulting in a more realistic calculation of the forces required to cut and move lunar soil. Comparisons are made between these forces and those required to move lunar simulants in both a 1 g and 1/6 g environment. Additionally, recommendations are made for which contributing factors can be ignored in a simplified analysis.

* 98 Brett Road,
Piscataway, NJ 08854-8058
jflorek@eden.rutgers.edu.

Heat Pipes: How to Increase the Capillary Heat Transfer Limit?

Y. GULAK*
CSXE, Rutgers University

Heat pipes are popular heat transport devices in the aerospace and ground-based applications that provide high efficiency in transferring the thermal energy. They operate on a closed two-phase cycle, in which the heat of evaporation of the working fluid is carried out between the heat source and the heat sink. Typically, heat pipes are light-weight and do not require external power.

The performance of low and moderate temperature heat pipes might be limited due to several well-known factors, the most important of which are the capillary and boiling limitations. In the talk, we discuss the possibility of maximizing the capillary transfer limit by designing the wick whose porosity is allowed to vary along the heat pipe length. An optimal porosity distribution is then calculated as a solution of a non-smooth optimization problem for zero, Moon, and Earth gravity heat pipe's working conditions.

*CSXE, Rutgers University
ygulak@jove.rutgers.edu

DAY 3

Wednesday, JUNE 6, 2007 Morning Session

PLENARY SPEAKER

Prof. Rupert Gerzer
Director of the Institute of Aerospace Medicine
German Aerospace Center (DLR), Cologne-Porz
"Travel Medicine: Medical Suggestions for Trips to Moon and Mars"

Day 3 Morning Schedule:

- **8:00 - 8:30 am Registration**
- **9:00 - 9:40 am Rupert Gerzer**
- **9:40 - 10:00 am Sheryl L. Bishop**
- **10:00 - 10:20 am Igor Smirnov**
- **10:00 - 10:40 am Satadal Das**
- **10:40 - 11:00 am COFFEE BREAK**
- **11:00 - 11:20 am Gene Giacomelli**
- **11:20 - 11:40 am Prasanta Banerjee**
- **12:00 - 1:00 pm LUNCH**

Travel Medicine: Medical Suggestions for Trips to Moon and Mars

RUPERT GERZER*
Director, Institute Of Aerospace Medicine
German Aerospace Center

Going to Moon and staying on a Moon habitat for an extended time period or even going to Mars poses several challenges for medicine: keeping the crews healthy despite weightlessness or reduced gravity, keeping them motivated, protecting them from hazards like radiation or fine dust, supporting them during emergencies and providing an effective and affordable habitat including closed loop regeneration systems.

Presently, astronauts on a long term mission in weightlessness are supposed to do physical exercise for about 150 min per day in order to counteract negative weightlessness effects. Still, they have problems post flight like orthostatic intolerance and bone and muscle loss. Thus, novel countermeasures are needed. One such method might be artificial gravity: a short arm centrifuge with a radius shorter than 3 m could be very useful. The astronaut – with head in the centre – would spin, and at the same time, he/she could do additional exercise like leg vibration and/or ergometer or treadmill training. Due to the gravity vector, especially the lower body would be accelerated, thus strongly stimulating the vascular system in the lower body and training vascular resistance to pressure. At the same time working and being vibrated would give a combined stimulus to the musculoskeletal and cardiovascular systems. Thus, such a method might be able to reduce daily training to less than an hour and be more effective than present methods.

Special emphasis should be given to radiation protection. Both, external shielding by new materials and technologies and internal shielding by supporting molecular radiation protection mechanisms of the human body are necessary. This will also include selection of those astronauts, who are most likely to have high physiological resistance to cancer.

The biggest challenge in medicine for the future of human spaceflight is the development of a "digital astronaut" system that involves an intelligent storage of personal medical information of the respective astronaut on the one side, and up-to-date medical knowledge on the other side, and that is able to give individualized support in case of an emergency. Such systems are needed in terrestrial medicine as well, will enable individual support of people wherever needed and improve homecare of aged people and long term patients dramatically.

Habitats for astronauts will make the development of affordable bioregeneration systems important. Results can also be applied on earth for many applications.

In summary, medical care for astronauts on long term missions in space or on stations on Moon or Mars requires the development of many new technologies and applications that are also urgently needed on earth. Due to the many unresolved tasks, we should initially focus on the development of systems that help to keep astronauts on such missions healthy and thus contribute to the task to improve the possibilities for human presence in space.

*Linder Hoehe,
51147 Cologne, Germany
rupert.gerzer@dlr.de

Here to Stay: Designing for Psychological Well-Being for Long Duration Stays on Moon and Mars

SHERYL L. BISHOP*
University Of Texas

Current psychological and sociocultural considerations for Moon and Mars bases are embedded within a complex matrix of long duration issues that have been demonstrated to significantly impact on human behavior and performance. Planning for psychological health for long duration stays rather than short duration task accomplishment profiles is further complicated by the need to address both flight issues as well as station issues. Long duration Moon missions will allow us to develop and test effective structural and procedural countermeasures for group and individual well-being that address both in-flight and planetside factors related to: 1) a reliance on technology for life support and performance; 2) physical and social isolation and confinement; 3) high risk and associated cost of failure; 4) high physical/ physiological, psychological, psychosocial, and cognitive demands; 5) human-human, human-technology, and human-environment interfaces; and 6) requirements for team coordination, cooperation, and communication.

The fundamental challenge to developing effective countermeasures for long duration missions is that space missions are not truly psychologically comparable to any other undertaking humans have ever attempted differing most notably in the enormous distance to travel, the unique separation from the rest of humanity and the extraordinary environmental demands. Most current support strategies used to foster crew morale and psychological well-being were developed on Mir and ISS and rely on intensive ground-based support which may be ineffective for missions whose profiles will be as characterized by the length of stay as it is the list of tasks to accomplish.

A broad spectrum of social psychological and behavioral research has contributed to the emerging realization that many of the negative psychological factors of long duration Moon/Mars missions (e.g., prolonged isolation, confinement, exposure to unpredictable and unknown extreme environment, reliance on closed loop environmental system) could be mitigated by designing habitats that thoughtfully countered some of these impacts. Instead of a focus on mere survivability, efforts to promote and sustain elements that contribute to human thriving appears to be far more productive. The intersection of psychology and psychosocial factors with habitat design allows us to implement psychological support in a non-intrusive, holistic environmental modality that is preventive in orientation rather than palliative. The present paper discusses those psychological factors amenable to a thoughtful and proactive integration into support systems and countermeasure environmental elements, including enabling technologies on the horizon that would significantly contribute to the successful psychological adaptation of long duration space inhabitants.

* University Of Texas Medical Branch At Galveston, Texas
301 University Blvd. #1150
sbishop@utmb.edu

RUTGERS SYMPOSIUM ON LUNAR SETTLEMENTS
3-8 JUNE 2007 RUTGERS UNIVERSITY

MRET Activated Water and its Succesful Application for Prevention Treatment and Enhanced Tumor Resistance in Animal Oncology Models

IGOR SMIRNOV, Ph.D. *
Global Quantech Inc.

Objectives: The goal of this investigation was to study the effect of MRET water for the prevention and treatment of two kinds of oncology diseases on mice (laboratory models of Ehrlich's ascites tumor and Sarcoma ascites form). MRET Water is produced with the help of patented (US Patent No. 6,022,479), non-chemical Molecular Resonance Effect Technology (MRET). The anomalous electrodynamic characteristics and viscosity of MRET water provide some evidence regarding the possible effect of MRET water on electrical activity and proper function of the cells.

Methods: The ability of animals for tumor resistance was studied in the experiments conducted on 500 mice (22 groups with 20 mice in each and 10 groups with 5 mice in each group) with the help of the following methodology:
a) study of possible anti-tumor effectiveness of "preventive" administration of different fractions of MRET water; mice received MRET water during 2 weeks before tumor cell transplantation and after transplantation;
b) study of possible anti-tumor effectiveness of "therapeutic" administration of different fractions of MRET water; mice received MRET water after tumor cell transplantation;
c) investigation of functional citotoxic activity of lymphocytes containing natural killer cells (NK-cells) isolated from spleens of mice (without tumors) which received MRET water; lymphocytes were incubated with tumor target cells.

Results: The experimental results confirm that consumption of all types of MRET water leads to the significant inhibition of tumor growth and suppression of mutated tumor cells. The best results were observed in the groups of mice on MRET water activated for 30 minutes (optimal regime). The resulting decrease of the Total Number of Viable Tumor Cells was **76%** in "preventive treatment" group and **55%** in "therapeutic treatment" group. The observed average survival time of mice which received optimal activated water in "preventive treatment" regime increased **by 61.7%** compare to the control group. The increase of **cytotoxic index** in both regimes (**21 days and 14 days** of application of activated water for mice without tumors) **by 26% and 10%** respectively was observed only in the groups of mice under MRET water activated for 30 minutes.

Conclusions: The significant positive effect of MRET activated water on tumor resistance of animals was observed in the process of this investigation *in vivo* in all groups of mice on different fractions of activated water. The significant anti-tumor effect of MRET Activated distilled water on mice was close to the action of the chemotherapy agents and allowed to avoid the side effects that typically follow chemotherapy treatment of oncology. The application of activated water can be quite promising approach for non-drug stimulation of NK-cells immunization vaccines.

* Global Quantech, Inc., San Marcos, CA 92078, USA
Tel. (760)510-1333; FAX (760)510-1999
igor@gqusa.com

A Simple Differential Production Method of Silicon Utilizing Organisms for Future Use in Lunar Settlements

SATADAL DAS*
Peerless Hospital & B. K. Roy Research Centre

Silicon utilizing organisms are probably the fittest living creatures having a capacity of survival in extraterrestrial situations where they can tolerate more environmental stress and strain than their equals on Earth. One can also classify them according to their silicon utilizing capacity very easily.

Silicon utilizing organisms can thrive in sodium metasilicate (SM) solution as high as up to 4% concentration. To confine common silicon utilizing organisms from the environment for future use in lunar settlements one has to prepare SM solutions of four different concentrations- 0.5%, 1%, 2% and 4%. After preparation of such solutions in plastic containers one has to keep them in a greenhouse for as long as 5 years. Different varieties of organisms will grow in different concentrations- from a light green color growth in 0.5% SM solution, yellow color growth in 1% SM solution, orange color growth in 2% SM solution and a scanty whitish color growth in 4% SM solution. Besides many unknown microorganisms, algae are present in every solution but are of different kinds. Diatoms of diverse varieties are found in profound numbers in 0.5% and 2% SM solutions; plenty nocardioforms are also found in 1% SM solution and scanty fungi are usually present in 4% SM solution.

During growth of silicon utilizing organisms in SM solutions there are many biochemical changes in the medium. While hardness of the water can not be measured in silicate solutions, pH is almost neutral in 2% solution , while it is always higher even after 5 years in other silicate solutions, Chlorides are very high in 4% solution. There is about 50% increase of sulfate and 25-50% increase of nitrate in all the SM solutions, marked increase and decrease (both about 4 times) amount of iron in 2% and 4% solutions respectively. These changes are probably due to disparity growth of organisms in different concentrations of silicate.

A simple protocol may be followed to use these silicate-utilizing organisms in lunar settlements.After providing minimum essential requirements for life in lunar extraterrestrial situation, these organisms may be utilized. In the initial venture antibiosis between various species should be prevented. Thus phytoplankton should be used before zooplanktons. Diatoms of Eu-eurytherm variety of *Nitzschia* and *Chaetoceros* group may be selected initially. Then golden algae grown in 2% and then in 0.5%SM solutions may be scattered to boost up the algal inhabitants. Then important silicon utilizing plants (specific silicon utilizing strains) like horsetails, grasses, lilies, silver vase, spider plant and following that organisms (only extremophile variety) like rotifers, tardigrades, nematodes, protozoa, fungi and bacteria may be added which will live in close association of small silicon utilizing plants and this process may continue. As it is not practicable to carry all essential nutrients for lunar settlements creation of such biosphere is essential for future survival of inhabitants in lunar settlements.

* Peerless Hospital & B. K. Roy Research Centre
76 Satyen Roy Road, Kolkata- 700034, India
E-mail: drsatdas@hotmail.com

Development of a Lunar Habitat Demonstrator

PHIL SADLER[1], GENE GIACOMELLI[2],
LANE PATTERSON[3] & ROBERTO FUFARO[4*]

The NSF Amundsen-Scott South Pole Station is recognized as one of the best analogs for a future Lunar or Martian surface effort. The station and crew of over 50 individuals being physically isolated for 8 months at the coldest and most remote environment on Earth is a valuable asset with a high degree of mission fidelity for future Lunar and Martian surface efforts. We at the University of Arizona's Controlled Environment Agriculture Center (UA-CEAC), in cooperation with Sadler Machine Co. (SMC) have constructed, delivered (in 2004), and continue to remotely support operation of the South Pole Food Growth Chamber (SPFGC) for the NSF's Office of Polar Programs civilian operations contractor, Raytheon Polar Services Company. The SPFGC provides the isolated winter crew with a continuous supply of a multitude of fresh hydroponic grown produce and salad crops from an artificially lit (24 square meter) growth chamber located inside the station building. From lessons learned from this effort we developed the Cable Culture growing system for use in future inflatable membrane structure Lunar and Mars greenhouse modules, while trying to achieve the lowest ESM number. In 2005 UA-CEAC/SMC fabricated a conceptual Mars Greenhouse to demonstrate the deployment and operation of this Cable Culture growing system. With the change in focus from a Mars Mission to a Lunar Base, we are constructing 4 demonstration Lunar Greenhouse modules to further develop the Cable Culture growing system and demonstrate water recycling and air revitalization using ALS/CELSS technology. This life support/greenhouse component is highly integrated with the total habitat and required us to develop an entire conceptual Lunar habitat, which is in progress. Our conceptual Lunar habitat consists of six module trains radiating from a central hub and is designed to be deployed autonomously with crops growing by the time the human crew arrives.

[*1]CEO, Sadler Machine Co, Tempe, AZ SadlerMachineCo@aol.com
[2]Director, The University of Arizona Controlled Environment Agriculture Center, Tucson, AZ, giacomel@ag.arizona.edu
[3]Graduate Student, Agricultural & Biosystems Engineering, The University of Arizona, Tucson, AZ, lane12345@rocketmail.com
[4]Assistant Research Professor, Aerospace & Mechanical Engineering, The University of Arizona, Tucson, AZ, robertof@email.arizona.edu

Possible Use of Ultra-Diluted Medicines for Health Problems During Lunar Missions

PRASANTA BANERJI, SATADAL DAS, GOBINDA CHANDRA DAS, PRATIP BANERJI*

Conventional medicines are probably not suitable for addressing health problems in lunar missions due to the fact that they are not utilized by the system properly in their optimum dose which is necessary in space.

Thus one should investigate whether ultra-diluted medicines, with proven efficacy, may be used without these problems in space. Ultra-diluted medicines are non-toxic, with extended shelf-life, non-addictive, with negligible weight and volume, low cost, and easily administrable. We have classified ultra-diluted medicines, for use in lunar missions, into different groups according to their roles in different health problems. These classifications have been done as per their proven actions, on different health problems matched with our long experiences on different patients with similar health problems, in the earthly environment.

Following our classification we prepared one combination medicine (PBHRF-1), which may be administered to the astronauts from a week before the start of the mission, containing *Lycopodium clavatum* 30c, *Symphytum officinalis* 200c, *Berberis vulgaris* 200c, *Nicotiana tabacum* 200c, Fluoricum Acidum 200c, *Coffea arabica* 200c, *Ruta graveolens* 6c, Calcarea Phosphorica 3X, Kali Muriaticum 3X and Ferrum Phosphoricum 3X. These medicines are incorporated in lactose globules (5 grain ~ 0.324 g) and are to be taken 3 to 4 doses in a day.

This combination medicine will prevent and alleviate different health problems in space such as: 'fluid shift' (stuffy nose, headache, puffy face, facial oedema), bone loss, renal stone formation, destruction of anti-gravity muscles, early motion sickness in space, protection from radiation, destruction of RBC, immuno-suppression (due to reduced action of lymphocytes), mental stress, insomnia etc. Similarly another medicine, PBHRF-2 (a combination of *Aconite napellus* 200c and *Crataegus oxyacantha* 3X in same dosage) may be used to prevent health problems like cardiac deconditioning during return to earth. These ultra-diluted medicines can be used easily in space as they are least affected by gravitation, radiation and thermal changes during space missions.

* PBH Research Foundation,
10/3/1 Elgin Road, Kolkata 700020, India.
pbhrf@vsnl.com

DAY 3

Wednesday, JUNE 6, 2007 Afternoon Session

PLENARY SPEAKER

Dr. George C. Nield
Deputy Associate Administrator for Commercial Space Transportation
FAA/AST-2
"*Commercial Spaceports - An Overview and Status Update*"

Day 3 Afternoon Schedule:

- **1:30 - 2:15 pm George C. Nield**
- **2:20 - 3:00 pm William J. Rowe**
- **3:00 - 3:20 pm Tom Taylor**
- **3:40 - 4:00 pm COFFEE BREAK**
- **4:00 - 4:20 pm Richard L. Summers**
- **4:20 - 4:40 pm Chester S. Spell**
- **4:40 - 5:00 pm Manny Pimenta**
- **6:00 - 9:00 pm ZIMMERLI BANQUET**

Commercial Spaceports: An Overview and Status Update

DR. GEORGE C. NIELD
Deputy Associate Administrator for Commercial Space Transportation, Federal Aviation Administration*

Although near-term missions to the moon are likely to be conducted by NASA or comparable government agencies from other nations, commercial entities will one day provide the majority of the necessary transportation services. Even today, non-federal spaceports play an important role in supporting our country's space programs. The purpose of this presentation is to review the statutory authority for the regulation of spaceports, to summarize the applicable federal regulations, and to provide a status update on the activities of current and proposed commercial launch and reentry sites.

* FAA/AST-2, 800 Independence Ave, S.W.,
Room 331, Washington, DC 20591.
george.nield@faa.gov

Moon Dust May Simulate Vascular Hazards of Urban Pollution

WILLIAM J. ROWE, M.D. FBIS*
Former Assistant Clinical Professor of Medicine,
Medical University of Ohio at Toledo

A long duration mission to the moon presents several potential cardiovascular complications. To the risks of microgravity and hypokinesia, and the fact that pharmaceuticals cannot be always depended upon in the space flight conditions, there is a possible additional risk due to inhalation in the lunar module of ultra fine dust (<100nm). This may trigger endothelial dysfunction by mechanisms similar to those shown to precipitate endothelial insults complicating ultra fine urban dust exposure. Vascular constriction and a significant increase in diastolic blood pressures have been found in subjects inhaling urban dust within just two hours, possibly triggered by oxidative stress, inflammatory effects, and calcium overload with a potential magnesium ion deficit playing an important contributing role. Both Irwin and Scott on Apollo 15, experienced arrhythmias, and in Irwin's case associated with syncope and severe dyspnea with angina during reentry. After the mission both had impairment in cardiac function, and delay in cardiovascular recovery, with Irwin in addition having stress test-induced extremely high blood pressures, with no available stress test results in Scott's case for comparison. It is conceivable that the chemical nature or particle size of the lunar dust is sufficiently variable to account for these complications, which were not described on the other Apollo missions. This could be determined by non-invasive endothelial-dependent flow-mediated dilatation studies in the lunar environment at various sites, thereby determining the site with the least endothelial vulnerability to dysfunction. These studies could be used also to demonstrate possible intensification of endothelial dysfunction from inhalation of ultra fine moon dust in the lunar module.

*Keswick, Virginia 22947, USA
rowerun@aol.com

Lunar Commercial Logistics Transportation

WALTER P. KISTLER[1] & BOB CITRON[2]
Lunar Transportation Systems, Inc. Bellevue, Washington, USA

TOM TAYLOR[3]
Lunar Transportation Systems, Inc. Las Cruces, New Mexico, USA*

This paper offers a commercial perspective to new lunar transportation and proposes a logistics architecture that is designed to have 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 paper's perspective is from an author's perspective of remote site on Earth and some of the problems experienced in logistics that didn't always work. The planning and control of the flow of goods and materials to and from the moon's surface may be the most complicated logistics challenge yet to be attempted. The price paid, if a single system does not work well is significant. On the Alaskan North Slope, we had four different logistics transportation systems and none work successfully all the time. The lessons learned will be discussed and solutions proposed. The industrial sector has, in the past, invested large sums of risk money, $20 billion for example, in resource recovery ventures like the North Slope of Alaska, 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 the $20 billion in private sector funds used to recover oil assets above the Arctic Circle.

The moon is estimated to be 50 times more remote than Prudhoe Bay, Alaska, the early transportation to the moon is 100 to 1,000 times more expensive than to the Arctic and the lunar environment is more severe than the Arctic, but some of the logistics lessons learned in the Arctic can potentially work again on the moon. 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 architecture is based on refueling a fleet of fully reusable spacecraft at several locations in cislunar space, which creates a two-way highway between the Earth and the Moon. This architecture offers NASA and other exploring nations more than one way to meet their near term strategic objectives with commercial space transportation, including sending small payloads to the lunar surface in a few short years, sending larger payloads to the lunar surface in succeeding years, and sending crews to the Moon and back to the Earth by the middle of the next decade. 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.

* [1] President, 227 Bellevue Way, N.E. #259, Bellevue, Washington 98004
[2] CEO, 227 Bellevue Way, N.E. #259, Bellevue, Washington 98004
[3] Vice-President, 3705 Canyon Ridge Arc, Las Cruces, New Mexico 88011
taylort@mac.com

An Analysis of the Interface between Lunar Habitat Conditions and an Acclimatized Human Physiology as Defined by the Digital Astronaut Program

RICHARD L. SUMMERS. MD
THOMAS G. COLEMAN, PHD
University of Mississippi Medical Center*

BACKGROUND: The physiologic acclimatization of humans to the lunar environment is complex and requires an integrative perspective to fully understand the requirements for settlement habitat conditions. A large computer model of human systems physiology (Guyton/Coleman/Summers Model) provides the framework for the development of the Digital Astronaut used by NASA in the analysis of biologic adaptive mechanisms. The model provides a means for the examination of the interface between a lunar adapted human physiology and potential habitat environments.

METHODS: The current model Digital Astronaut Program contains over 4000 equations/variables of biologic interactions and encompasses a variety of physiologic processes of interest to humans during spaceflight. The model is constructed on a foundation of basic physical principles in a mathematical scheme of interactions with a hierarchy of control that forms the overall model structure. Physiologic relationships derived from the evidence-based literature are represented as function curves within this structure. Different physiologic systems and body organs are connected through feedback and feedforward loops in the form of algebraic and differential equations to create a global homeostatic system. The model also contains a biologic-environment interface with external conditions such as temperature, barometric pressure, atmospheric gas content and gravity. During computer simulation studies, the predicted physiologic responses to a habitat environmental change are tracked over time.

RESULTS: Computer simulations using the model have been found to accurately predict the physiologic transients seen during entry into, prolonged exposure to, and return from the microgravity and bed rest environments. Computer simulation studies suggest that humans with a lunar adapted physiology would be more vulnerable and less tolerant to extreme changes in habitat temperature, humidity and atmospheric oxygen content as compared to an equivalent earth-based setting.

CONCLUSIONS: An analysis of the interface between proposed lunar habitat conditions and an acclimatized human physiology as defined by the Digital Astronaut Program may be important to reduce potential health risks. This system can be used as a tool in the technical planning and design of lunar settlements.

* University of Mississippi Medical Center
2500 North State Street
Jackson, MS 39216
rsummers@pol.net

The Mental Health Implications of Working in a Lunar Settlement

CHESTER S. SPELL*
School Of Business-Camden, Rutgers University

One of the feasibility issues of a lunar settlement concerns the effect of working in such an environment on people. The focus here is on the long-term implications for the mental health of the base workforce and how working in isolation for extended periods might influence their overall depression and anxiety levels. This is important because a wealth of research in the psychological, management and occupational health literature has found clear correlations between mental health of workers and productivity (National Mental Health Association, 2005) and that poor mental health over the long term is associated with cardiovascular disease and other physical problems (Suls & Bunde, 2005).

Most of the prior research on mental health and working conditions has not examined situations similar to the isolated and otherwise extreme working conditions of a lunar settlement. The research that exits concerns environments like remote mining towns in Australia, where for decades it has been known that women suffer high rates of neurotic problems (Sharma & Rees, 2007). A study of workers at McMurdo Station in Antarctica and the Amundson-Scott South Pole Station revealed higher levels of depression after one year of working in the confined and isolated conditions (Palinkas, Johnson, & Boster, 2004).

Recent research (Spell & Arnold, in press) found that anxiety and depression of individuals working in teams was related to what co-workers thought about their working conditions, above and beyond their own feelings. In other words, attitudes can spread among group members like a 'social contagion' and potentially lead to reduced mental health among other team members. While this research was not conducted in an isolated environment, under such conditions it is likely that social interaction among team members is even more critical since team members are the only source of support. While relatively scant attention has been paid to this issue, the studies to date suggest that the link between isolation and worker mental health may be a critical one for a lunar base.

* Rutgers University, Camden, New Jersey 08102
Phone: (856) 225-6922 Fax: (856) 225-6231
cspell@camden.rutgers.edu

Malapert Base

MANNY PIMENTA
President
Lunar Explorer*

The design and construction of the first large scale Lunar base is explored.

Current designs for Lunar outposts tend to focus on the near term Return To The Moon missions and are therefore limited in capacity, scope and vision.

The ultimate stated goal of all space activity should be the evolution of Humanity into a Space Faring civilization. The clear demarcation point that we have achieved Space Faring Civilization status is the establishment of the first large scale, permanent off planet colony. The logical location for this first space colony is the Moon.

Malapert Base is intended to show what is technologically possible to achieve within the next two decades in terms of our first true extra terrestrial colony.

It is further intended as a bold, compelling and inspiring vision of our future in Space; one which will connect with individuals in deep personal way, giving them a stake in its achievement and opportunities to contribute and participate.

Malapert will be based on existing or near term technologies, and it is intended as an economically self sufficient venture – a critical requisite for permanency.

The only critical path assumption made is that the cost of launching material to LEO will be drastically reduced to some arbitrary enabling level within the next 10 to 15 years.

* (732) 221-3392

DAY 4

Thursday, JUNE 7, 2007 Morning Session

PLENARY SPEAKERS

Bradley Edwards, Ph.D.
Carbon Designs Incorporated
"*Space Elevator for the Moon*"

Paul Eckert, Ph.D.
International and Commercial Strategist
Boeing IDS - Space Exploration
"*Attracting Private Investment for Lunar Commerce: Toward Economically Sustainable Development*"

Day 4 Morning Schedule:

- **8:30 - 9:15 am Bradley Edwards**
- **9:15 - 10:00 am Paul Eckert**
- **10:00 - 10:20 am Seon Han**
- **10:20 - 10:40 am Joseph E. Palaia**
- **10:40 - 11:00 am COFFEE BREAK**
- **11:00 - 11:20 am Klaus P. Heiss**
- **11:20 - 11:40 am F. Lévy**
- **11:40 - 12:00 pm B.E. Lewandowski**
- **12:00 - 1:00 pm LUNCH**

Space Elevator for the Moon

BRADLEY C. EDWARDS, Ph.D. *
Black Line Ascension

The Apollo program was one of man's most impressive achievements. However, in spite of this the program failed to become self-sustaining. Since Apollo our technology has advanced in many areas but we have been unable to reduce the cost of getting to space. Considering these realities the Moon / Mars initiative has an ambitious set of goals. The U.S. has tried extremely similar programs before (1970s, 1989) and failed. This paper summarizes a NASA proposal for an exploration program based on an innovative Earth-to-space transportation system, the space elevator. This program would enable inexpensive (over 90% savings on launch costs), high-capacity (3000 tons/year) delivery of cargo and crews to the moon, Mars and other solar system destinations. The proposed program has the potential to create a sustainable and affordable program for exploring the solar system. The spin-off from this program will be commercially valuable infrastructure with existing, ready customers, international interest and endless possibilities for scqientific studies.

In the proposed program costs are broken down into system and delivery costs. From Koelle's lunar model, a lunar laboratory with an average crew of 69 would cost $57B over 40 years. Delivery costs run $20B in capital expense and $1B/year in operating costs for two space elevators capable of delivering 3000 tons per year to the moon. This capacity is more than sufficient for the lunar laboratory scenario. The large mass capacity of the elevator will allow crewed components to be over-designed, and carry ample propellant surpluses, allowing for greater mission flexibility, robustness, safety and ultimately, sustainability. In our proposed effort, redundant fuel, supplies, habitats, rovers, parts and CEVs can be placed in geosynchronous and lunar orbits and on the lunar surface to provide multiple back-ups for the exploration endeavors. . In addition, we have investigated the possibility of a commercial revenue generation from the excess launch capacity. Program expenditures are estimated to be $68B primarily spent between 2005 and 2023 but with revenue generation these can be reduced substantially.

* 2414 1st Ave., Seattle WA 98121,
brad_edwards@yahoo.com

RUTGERS SYMPOSIUM ON LUNAR SETTLEMENTS
3-8 JUNE 2007 RUTGERS UNIVERSITY

Attracting Private Investment for Lunar Commerce: Toward Economically Sustainable Development

PAUL ECKERT
Space Exploration, IDS, The Boeing Co.*

Established and startup companies are collaborating in an international consortium designed to promote the growth of space commerce, extending from Earth to the Moon. Firms engaged over the past two years have included The Boeing Company, Lockheed Martin Corporation, Northrop Grumman Corporation, Honeywell International, Raytheon Company, Mitsubishi Corporation, and Alcatel Alenia Space, as well as startups including Transformation Space Corporation and Lunar Transportation Systems. These companies have recognized that entrepreneurial innovation by startup companies–profitably applying existing technology to meet customer needs in a marketplace–is at least as important as efforts to develop new technologies in the laboratory. The global industry consortium is also working to encourage development of truly commercial, self-sustaining space activity involving non-government customers, rather than simply extending government contracting. Because government and established company resources are usually insufficient to ensure the initial viability of new firms, early funding must generally come from angel investors—wealthy individuals for whom creating a legacy of innovation is often more important than making a profit. Personal relationships are a far more potent means of gaining the interest of such individuals than are more impersonal methods. In addition, description of new space-related opportunities should be in terms investors can understand. It is particularly important to attract investment for relatively low-cost commercial Earth-to-orbit transportation systems serving the International Space Station (ISS), because such systems may constitute the first step toward development of commercial Earth-to-moon (i.e., cislunar) transportation capabilities. Affordable and reliable cislunar transportation services are among the most important factors enabling sustainable lunar development. International interoperability of systems is an equally vital factor in assuring commercial sustainability.

*1215 S. Clark St., Suite 1500, MC: 793C G031
Arlington, VA 22202
paul.a.eckert@boeing.com

Design of a Space Elevator

SEON HAN*

Texas Tech University

The purpose of this work is to present the design issues that must be considered in designing a space elevator from dynamic standpoint. A space elevator is modeled as a long cable that is anchored on the Earth. The dynamic forces that the elevator is subject to are the tidal forces due to the Sun and the Moon, the gravitational attraction from the Earth, and the environmental load due to wind modeled as a point load near the bottom of the elevator. In this study, the two counterweights are added. The first one is placed at the outer end, and the second at geosynchronous orbit. The first one is added so that a shorter cable can be used, and the second to make the system stable. The basic design parameters are the total length of the cable which subsequently determines the counterweight, the counterweight at the geosynchronous orbit, the cross-sectional area, and the constant stress level if the cross-sectional area is tapered.

In this work, both the tapered and un-tapered cables are considered. It was suggested in the past that the cross-sectional area be tapered (largest cross-sectional area at geosynchronous orbit) so that the stress level along the cable is constant. This is done so that any material can support its own weight under gravity. However, not any material with tapered area can be used because the required taper ratio (the area at geosynchronous orbit equals the area at Earth's surface) can be unreasonably large for materials with low specific strength and low constant stress level. Carbon nanotubes have a high specific strength so that taper ratio for the carbon nanotubes can be as low as 1.5, and they are strong enough so that un-tapered cable can support itself under gravity.

So far, the dynamics of a space elevator have rarely been considered in its design. Considering from statics and quasi-statics points of view, the cross-sectional area and stress level may be determined from the desired carrying capacity of the elevator. The static analysis provides no criterion for setting the counterweight at the geosynchronous orbit and the cable length except that it must extend beyond geosynchronous orbit. One obvious limiting factor is that it is difficult to send a large counterweight into space using traditional rockets. Other design constraints on the basic design parameters come from dynamics. In this work, three criteria will be considered:

1. The fundamental frequencies must be such that they are well away from the forcing frequencies
2. The dynamic load due to moving elevator must not induce resonance
3. The fundamental frequency when an elevator car is parked along the cable must be away from the forcing frequencies.

* MS 1021, Department of Mechanical Engineering,
Texas Tech University, Lubbock, Texas 79409
seon.han@ttu.edu.

Stepping Stones to Mars Settlement

JOSEPH E. PALAIA, IV*
VP Operations/R&D and Co-Founder,
4 Frontiers Corporation

The 4Frontiers Corporation is an emerging space commerce company focused on Mars settlement as well as other inner solar system development. Early activities include the development of profitable space technologies (including those applicable to the lunar domain), consulting for key manufacturers and government agencies, and engaging in public entertainment and education. These expanding activities will lead to the creation of a Mars settlement mockup / tourist attraction which will introduce the public to the company's vision as well as its space technology innovations. Early emphasis will be placed on developing those technologies having common application to both the Lunar and Mars systems.

*18655 Autumn Lake Blvd.
Hudson, FL 34667
Phone: 508-532-0617
joe@4FrontiersCorp.com

Private Property Rights and the Economic Exploration of the Moon - Hammurabi, Tyrolean Homesteads and the Outer Space Treaty

KLAUS P. HEISS
Executive Director, High Frontier, Inc*

Key Words: Property Rights, Economic Development, Benefits to Mankind, Homesteading, Law and Economics, Competition, Origin of Legal Codes, Precautionary Principle, Foundation of Freedom, Roots of Totalitarianism.

There is a common objective by all participants in the discussion of the Outer Space Treaty ("OST") and related issues: assured benefits to all mankind. The question is: how does one best assure this. The answer advanced herein is the affirmation and assurance of unencumbered private property – rather than central, national or global committee planning constructs of national (sometimes secret) and international Space bureaucracies, with economic opportunities postponed *ad infinitum*. Precedents are given throughout history, chief amongst them the Code of Hammurabi and the Tyrolean *Höferecht* tradition of homesteading.

Mankind has a moral obligation to bring about economic and beneficial uses of Space so that indeed mankind can benefit, as without such uses nobody will benefit. The historically proven way is through private property rights.

We have the further moral obligation to bring about the earliest possible settlement of and in Outer Space, if only for the "Precautionary Principle" increasingly advocated by some in other contexts, so as to assure the very survival of mankind, given the great unknown cataclysmic disasters that periodically hit Earth over eons past. Herein we should follow the example set by Jamestown and the spectacular economic development of the North American continent – in contrast to the barren *latifundi* of aristocratic, royal or nationalized precedents elsewhere.

The purpose of "laws" is to enable useful human activities, not to prohibit or prevent them. Indeed, law and order are the very foundations of freedom and free markets, including the enforcement of laws, if necessary by force: the enforcement of freely entered contracts is the enabling instrument of the working of markets and the freedoms to which all of us aspire to and which some of us already cherish.

* klaus.heiss@verizon.net

RUTGERS SYMPOSIUM ON LUNAR SETTLEMENTS
3-8 JUNE 2007 RUTGERS UNIVERSITY

Indoor Air Quality Implications of ^{222}Rn from Lunar Radon

F. LÉVY*
J. FARDAL**

Recently interest has grown in resuming lunar exploration with the possible establishment of long-term bases. Due to payload costs and the scale of permanent bases, there is a compelling need to employ *in situ* resources, leading to extensive use of lunar soil, or regolith, in such bases. Regolith is prone to ^{222}Rn exhalation. We modeled two scenarios for radon exhalation in regolith–based lunar construction. We examined the potential for human health risks due to ^{222}Rn decay-product exposure in such closed, hermetically sealed environments where lunar inhabitants would potentially have direct, long-term contact with regolith. We found the potential for significant health concerns, but more detailed data on the physical properties of regolith-aggregate concrete and its ^{222}Rn exhalation rates is required to accurately determine radon emanation and diffusion coefficients.

*MS student and corresponding author
The University of Texas at Austin
Civil, Architectural and Environmental Engineering Department
1 University Station C1700, Austin, Texas 78712-0273
info@francoislevy.com

**14300 Tandem Blvd. #124, Austin, TX, 78728
jfardal@earthlink.net

Human Power Generation to Augment Lunar Settlement Power Sources

B. E. LEWANDOWSKI[1], K. J. GUSTAFSON[2], D. J. WEBER[3*]

Electrical power is a critical issue as the lunar settlement is designed and developed. A plentiful power source is necessary in order to carry out the mission, but at the same time, uploading consumable power sources must be minimized due to the significant cost. This conflict in requirements will be particularly evident at the initial stages of settlement development. Dependence on vehicle power will be the greatest prior to when a permanent power grid can be established at the settlement. Even as permanent power is established, there will continue to be a need for mobile power sources. Examples of items needing mobile power include electronic sensors within EVA suits, mobile communication devices and power tools. Recharging methods will be needed for the power sources of these mobile devices.

A significant amount of energy is dissipated by the human body as it interacts with the environment. For example, heat is radiated from the skin. Mechanical energy is dissipated into the ground during walking and into structures and equipment that is touched. Arm and leg joints in motion house kinetic energy. During each breath the weight of the chest wall is displaced over a distance and air is expired at a higher temperature and pressure than the surrounding atmospheric air. It is possible to harness this dissipated energy and convert it into electricity through low mass energy conversion methods, such as thermoelectric, electromagnetic, piezoelectric and electrostatic methods. Humans are also capable of doing work on objects and can generate electricity through hand cranking and shaking motions, during bicycling and by manipulating objects in other ways.

Some examples of Earth based human power generation concepts include heel strike generators [1; 2] and inductive backpack generators [3] that harvest energy during walking or running. Research exists on the conversion of human kinetic motion to electricity [4; 5] and bicycle power generators are commercially available products [6]. An activity performed in space by the astronauts that is well suited for energy harvesting with these methods is exercising. Astronauts exercise in space to counteract the deleterious effects of the reduced gravity environment, such as loss of bone and muscle mass and reduction of aerobic capacity [7]. Energy harvesting methods such as heel strike generators and generators embedded into the exercise equipment could be used to generate significant amounts of power. This power could augment the consumable power sources that must be expensively uploaded by extending their life time or by increasing their reliability, or it could be used to recharge the power sources of mobile electronic devices. This additional power would be particularly useful during the initial stages of lunar settlement development

[1] Kymissis, J., Kendall, C., Paradiso, J., and Gershenfeld, N., "Parasitic power harvesting in shoes," *Wearable Computers, Second International Symposium on*, 1998, pp. 132-139
[2] Shenck, N. S. and Paradiso, J. A., "Energy scavenging with shoe-mounted piezoelectrics," *Micro, IEEE*, Vol. 21, No. 3, 2001, pp. 30-42
[3] Rome, L. C., Flynn, L., Goldman, E. M., and Yoo, T. D., "Generating electricity while walking with loads," *Science*, Vol. 309, No. 5741, 2005, pp. 1725-1728
[4] Niu, P., Chapman, P., Riemer, R., and Zhang, X., "Evaluation of motions and actuation methods for biomechanical energy harvesting," *Power Electronics Specialists Conference, IEEE 35th Annual*, Vol. 3, 2004, pp. 2100-2106
[5] von Buren, T., Lukowicz, P., and Troster, G., "Kinetic energy powered computing - an experimental feasibility study," *Wearable Computers, Seventh International Symposium on*, 2003, pp. 22-24
[6] Anonymous, 2007, http://www.windstreampower.com/
[7] Buckey, J. C., *Space Physiology*, Oxford University Press, Inc., New York, 2006

[*1]Bioscience and Technology Branch, NASA Glenn Research Center, Cleveland, Ohio
[2]Dept. of Biomedical Engineering, Case Western Reserve University, Cleveland, Ohio
[3]Dept. of Physical Medicine & Rehabilitation, University of Pittsburgh, Pittsburgh, Pennsylvania

DAY 4

Thursday, JUNE 7, 2007 Afternoon Session

PLENARY SPEAKER

Dr. Harry W. Janes
Research Professor
Cook College, Rutgers University
"Bioregenerative Life Support: Closing The Life-Support Loop: What Is Stopping Us?"

Day 4 Afternoon Schedule:

- **1:15 - 2:00 pm Harry W. Janes**
- **2:00 - 2:20 pm Claudio Maccone**
- **2:20 - 2:40 pm Steve M. Durst**
- **3:00 - 3:20 pm Bernard H. Foing**
- **3:20 - 3:40 pm Gregory Konesky**
- **3:40 - 4:00 pm COFFEE BREAK**
- **4:00 - 4:20 pm Y. Cengiz Toklu**
- **4:20 - 4:40 pm V.V. Shevchenko**
- **6:00 - ON YOUR OWN**

Bioregenerative Life Support: Closing the Life-Support Loop: What is Stopping Us?

HARRY W. JANES*
Research Professor,
Department of Plant Biology and Pathology
Rutgers University

Life support designs for short-term manned space flight missions have relied primarily on storage of materials before launch, physicochemical technologies, and on re-supply. Longer missions leading to manned exploration of the solar system with bases established on the moon and missions to Mars require a life support system that cannot be based solely on these physicochemical technologies. When re-supply is impossible and long-term storage is impractical, these technologies simply cannot regenerate food from waste. Therefore, any life support system for extended missions must include green plants capable of generating food, oxygen and potable water. Additionally, systems to degrade waste and re-supply minerals must be developed around and integrated with the plant growing system. These systems will require use of microorganisms and will probably be aided by physicochemical processes. The goal of bioregenerative life support is to emulate in space the life-sustaining processes of earth. The challenge in developing this system is to not only understand the subsystems involved but to blend them in such a way that we can create a model of earth's system that is both reliable and small.

For long-term space exploration, where stand-alone habitat systems are absolutely required, the U.S. has recently halted the process of developing the enabling technologies. For almost 30 years, NASA has funded bioregenerative life-support research for space applications, but because of recurring policy and funding changes, the agency has not been able to bring to fruition breakthroughs that are needed for sustained human survivability in isolated or extreme environments. Management decisions have resulted in a disjointed program with frequent stops, restarts, and direction changes. Faculty from seven leading universities, with over 150 years of advanced life support experience are currently developing the Habitation Institute as a multi-institutional scientific partnership with the objective of advancing the basic research necessary to develop the technologies required for long-duration space travel.

---

*Rutgers University,
New Brunswick, NJ 08901

R U T G E R S S Y M P O S I U M O N L U N A R S E T T L E M E N T S
3 - 8 J U N E 2 0 0 7 R U T G E R S U N I V E R S I T Y

Protecting the Farside of the Moon for the Benefit of all Humankind

CLAUDIO MACCONE
International Academy of Astronautics*

The need to keep the Farside of the Moon free from man-made RFI (Radio Frequency Interference) has long been discussed by the international scientific community. In particular, in 2005 this author reported to the IAA (International Academy of Astronautics) the results of an IAA "Cosmic Study" where he reached the conclusion that the center of the Farside, specifically crater Daedalus, is ideal to set up a future radio telescope (or phased array) to detect radio waves of all kinds that it is impossible to detect on Earth because of the ever-growing RFI. In this paper we propose the creation of PAC, the Protected Antipode Circle. This is a large circular piece of land about 1820 km in diameter, centered around the Antipode on the Farside and spanning an angle of 30 deg in longitude, in latitude and in all radial directions from the Antipode, i.e. a total angle of 60 deg at the cone vertex right at the center of the Moon. There are three sound scientific reasons for defining PAC this way:

1) PAC is the only area of the Farside that will never be reached by the radiation emitted by future human space bases located at the L4 and L5 Lagrangian points of the Earth-Moon system (the geometric proof of this fact is trivial);

2) PAC is the most shielded area of the Farside, with an expected attenuation of man-made RFI ranging from 15 to 100 dB or higher;

3) PAC does not overlap with other areas of interest to human activity except for a minor common area with the Aitken Basin, the southern depression supposed to have been created 3.8 billion years ago during the "big wham" between the Earth and the Moon.

* Home address: Via Martorelli 43, Torino (Turin), I-10155, Italy.
E-mail: clmaccon@libero.it

The International Lunar Observatory Association (ILOA) 2007 and Lunar Settlement

STEVE M. DURST
Space Age Publishing Company *

Originating in Hawaii near the center of the Pacific hemisphere, the ILOA in 2007 has been endorsed by and seeks membership from institutes, individuals and enterprises to realize, place and operate a multifunction astrophysical observatory near the Moon's south pole as early as 2010. The ILOA also seeks to help support a follow-on human service mission to that facility and to parellel robotic village facilities that constitute the emerging lunar base settlement. The ILOA is an Earth-Moon interglobal enterprise with projected membership from major spacefaring powers Canada,China, India, Japan, Europe, Russia, Brazil, Crescent Moon Countries, USA and others representing the great majority of the planet's people.

Primarily an observatory for radio, submillimeter, infrared and visible wavelength astrophysics, for other non-astronomical observations, and for some geophysical science, the ILO also will function as a solar power station (with silicon photovoltaic research), communications center (with varied commercial broadcast possibilities), site characterizer (solar wind, radiation, temperature, duration; micrometeorites, ground truth), property claim agent, virtual dynamic nexus, toehold for lunar base build-out and settlement, and Hawaii astronomy booster.

Facilitating the continuing rise of excellence for Mauna Kea observatories through interglobal interaction, the ILOA is incorporating in Hawaii as a 501 (c) (3) non-profit to serve as the enabling, executive, governing, directing vehicle for the ILO. ILOA initial assets consist of, at least, 4 professional technical feasibility research studies, space/lunar flight-tested instruments, industrial partner service advances, 2 international astronomy center MOUs, ILOA News, Hawaii / Mauna Kea office maintenance, and directors' employment through financial reserves. ILOA 2007 progress and developments will be updated through at least 6 major ILOA presentations in China, America, India, and Europe, including the ILOA Founders Meeting on Hawai`i Island 4-8 November and the ILOA Founders Meeting Preliminary Session at the International Astronautical Congress in Hyderabad 26 September. Supporting humanity's ascent to multi-world species and to interstellar, galaxy exploration, the ILOA has a promising outlook and future well worth and advancing and pursuing.

* ILOA, 65-1230 Mamalahoa Highway D-20,
Kamuela, Hawaii, 96743, USA
Phone 808-885-3473, Fax 808-885-3475
news@spaceagepub.com

ILEWG Roadmap from Precursors to Lunar Settlements

BERNARD H. FOING*
ILEWG Executive Director

We discuss the rationale and roadmap from robotic precursors to lunar settlements.

We report on recent activities, and on previous ILEWG conferences, recommendations and declarations, including from the last ILEWG 8th conference at Beijing in July 2006. We shall cover issues debated by tasks groups within the ILEWG forum:

- **Science opportunities:** clues on the formation and evolution of rocky planets, accretion and bombardment in the inner solar system, comparative planetology processes (tectonic, volcanic, impact cratering, volatile delivery); records of astrobiology, survival of organics; astronomy and space science; past, present and future life; early Earth samples

- **New instrumentation:** Remote sensing miniaturised instruments; Surface geophysical and geochemistry package; Instrument deployment and robotic arm, nano-rover, sampling, drilling; Sample finder and collector.

- **Technologies for robotic and human exploration**: Mecha-electronics-sensors; Tele control, telepresence, virtual reality; Regional mobility rover; Autonomy and Navigation; artificially intelligent robots, Complex systems, Man-Machine interface and performances.

Living off the Land: Establishment of permanent robotic infrastructures, Environmental protection aspects; solutions to global Earth sustained development; Life sciences laboratories; Support to human exploration; Permanent lunar settlements.

*C/O ESTEC/SCI-S,
posTbus 299, 2200 AG Noordwijk, NL
http://sci.esa.int/ilewg/

Lunar Optical Data Links

GREGORY KONESKY*
SGK Nanostructures, Inc.

Ongoing future lunar activities and settlement efforts will require substantial bandwidth both for the transmission and reception of large volumes of data, imagery, communications, remote teleoperation, etc. High bandwidth lunar optical data links can be broadly grouped into two categories: inter-lunar site, and Moon-to-Earth.

Inter-lunar site optical communications benefit from the absence of atmospheric effects that plague terrestrial counterparts with attendant absorption, scattering, beam wander, and pulse spreading. However, lunar dust presents its own set of concerns due to its highly abrasive nature, wide particle size distribution, and strong electrostatic attraction to surfaces. Long distance communication is limited, after local topology, by the surface curvature of the Moon, whereas atmospheric effects predominate in terrestrial optical links. Various design examples of inter-lunar optical data links, for both stationary and mobile sites, are presented as are dust mitigation approaches and the general rigors of the lunar environment.

A Moon-to-Earth optical data link can be established using only a 1 Watt laser on the Moon, transmitted through a 1 meter aperture (at 830 nm) and received on the Earth also by a 1 meter aperture, and yet produce a net positive link margin. In practice, however, a smaller aperture would be used on the Moon, and supplanted by a larger aperture on the Earth for obvious economic reasons. Terrestrial atmospheric effects are fortunately limited to only the last few kilometers of beam propagation and can be largely negated, within limits, by adaptive optics. Alternatively, optical data link reception can be affected in Earth orbit. The design tradeoffs between these two approaches are considered in terms of the overall system complexity and link availability. Design examples of Moon-to-Earth optical links with various transmitter powers, apertures, and operating wavelengths are considered in terms of link budget. The origins of atmospheric effects on beam propagation will be considered, as will the extent to which these can be dealt with by adaptive optics. Demonstrated design examples of adaptive optic systems, and their applicability to a Moon-to-Earth data link are discussed. Difficulties of an Earth-to-Moon optical data link are also considered.

* 3 Rolling Hill Rd, Hampton Bays, NY 11946
g.konesky@att.net.

Comparison between Terrestrial and Lunar Mining

Y.CENGIZ TOKLU
Mechatronics Engineering Department, Bahcesehir University
Istanbul, Turkive*

One big issue in lunar settlement is the supply of all types of necessities on the Moon. The difficulties in supply from the Earth make it obligatory to build and operate plants on the Moon to produce most of the necessities using lunar resources as raw material. This makes mining on the Moon an operation of primordial importance.

Mining on the Moon will have its own characteristics as compared to mining on the Earth. The first difference will come from the fact that substances are likely to be more uniformly distributed on the surface of the Moon as compared to the Earth. Thus it is probable that there will not be different mines for different raw materials and almost all substances will be extracted from the same source with serial or parallel processes. The other differences between lunar mining and terrestrial mining will originate mainly from environmental differences like those in gravitation, and existence and non-existence of atmosphere.

These differences will result in new advances in mining technologies, mining equipments and extraction processes which, at the end, will effect positively the way of life on the Earth and elsewhere.

* cengiz.toklu@gmail.com

RUTGERS SYMPOSIUM ON LUNAR SETTLEMENTS
3-8 JUNE 2007 RUTGERS UNIVERSITY

Lunar Resources for Rescue of Mankind in XXI Century

V.V. SHEVCHENKO*
Sternberg Astronomical Institute, Moscow University

At the outside of the atmosphere, the Earth receives about 1/2,200,000,000 of the solar radiation, about 1.8×10^{17} J/s (joule per second) or 180×10^{15} W. About 50% of the incoming solar energy is received by the Earth's environment. It equals about 90×10^{15} W or 90000 TW. The essential increasing of the additional energy will destroy system of our environment completely. In results of many ecological investigations it has been found that the permissible level of the energy production inside Earth's environment is about 0.1% of solar energy received by Earth's surface. The value is about 90 TW (90×10^{12} Watt). Any estimation of future electricity requirements depends on the assumptions of the population growth and energy usage. An analysis of the known data indicates that simple representation of the population growth tendency is an exponential regression. In near future expected world's population will become level at about 10 billion people. From different sources the world energy use per capita at present corresponds to about 1.7 kW of power per person and general world energy consumption is about 3.3×10^{20} J/y or ~ 10 TW of capacity. The general prognosis shows that total energy use (and production) in the world will increase by a factor of two (to about 20 TW) by 2040. If this tendency is preserved, the total energy production in the world will approach about 55 TW by the end of the century. A more complicated calculation has been carried out in which allowance is made for the effect of energy usage growth (per capita) with time. Simple estimates are that in the 2050 timeframe the world will require nearly 40 TW of total capacity, and more than 110 TW will be required in 2100. It means the permissible level of the energy production inside Earth's environment will be exceeded in the near future. But it is obviously that the processes destroying Earth's environment in global scale will begin before it – after middle of century. Hence, the first result of the practical actions for rescue of the Earth's environment must be obtained not late than in 2020 – 2030. The only way to resolve this problem consists in the use of extraterrestrial resources and industrialization of the space. The nearest available body – source of space resources and the space industrial base is the Moon. The most known now space energy resource is lunar helium-3. Very likely, the lunar environment contains new resource possibilities unknown now. So, the lunar research space programs must have priority not only in fundamental planetary science, but in practical purposes too.

*MOSCOW 119992
RUSSIA
shev@sai.msu.ru

Possible Applications of Photoautotrophic Biotechnologies at Lunar Settlements

BROWN I.I.[1*], JONES J.A.[3], GARRISON D.[1], BAYLESS D.[2], SARKISOVA S.[1], ALLEN C.C.[3], MCKAY D.S.[3]
[1]Jacobs Sverdrup ESCG, [2]University of Ohio, [3]NASA Johnson Space Center,

A major goal for the Vision of Space Exploration is to extend human presence across the solar system. With current technology, however, all required consumables for these missions (propellant, air, food, water) as well as habitable volume and shielding to support human explorers will need to be brought from Earth. In situ production of consumables (In Situ Resource Utilization-ISRU), such as propellants, life support gas management, as well as habitat and support system construction materials, will significantly facilitate human hopes for exploration and colonization of the solar system, especially in reducing the logistical overhead such as recurring launch mass.

The life support, fuel production and material processing systems currently proposed for spaceflight are not completely integrated. . The only bioregenerative life support system that has been evaluated on a habitat scale by NASA employed only traditional crop production. This has been proposed as a segment for bioregenerative life support systems, even though the efficiency of higher plants for atmospheric revitalization is generally low. Thus, with the release of the NASA Lunar Architecture Team lunar mission strategy, the investigation of air bioregeneration techniques based on the activity of photosynthetic organisms with higher rates of CO_2 scrubbing and O_2 release appears to be very timely and relevant. Future systems for organic waste utilization in space may also benefit from the use of specific microorganisms. This janitorial job is efficiently carried out by microbes on Earth, which drive and connect different elemental cycles. It is possible that bioregenerative environmental control and life support systems will be capable of converting both organic and inorganic components of the waste at lunar settlements into edible biomass.

The most challenging technologies for future lunar settlements are the extraction of elements (e.g. Fe, O, Si, etc) from local rocks for life support, industrial feedstock and the production of propellants. While such extraction can be accomplished by purely inorganic processes, the high energy requirements of such processes drive the search for alternative technologies with lower energy requirements and sustainable efficiency. Well-developed terrestrial industrial biotechnologies for metals extraction and conversion could therefore be the prototypes for extraterrestrial biometallurgy.

Despite the hostility of the lunar environment to unprotected life, it seems possible to cultivate photosynthetic bacteria using closed bioreactors illuminated and heated by solar energy. Such reactors might be employed in critical processes, e.g. air revitalization, element extraction, propellant (oxygen and methane) and food production. The European Micro-Ecological Life Support System Alternative (MELiSSA) is an advanced idea for organizing a bioregenerative system for long term space flights and extraterrestrial settlements.

We propose additional development and refinement of the MELiSSA system by the employment of *Spirulina* strains with increased productivity of essential amino acids, immunomodulators as well as by the addition of biometallurgy and fuel production to the life support cycle. Such a synthesis of technological capability, as embodied in a lunar surface ISRU bioreactor, could decrease the demand for energy, transfer mass and cost of future lunar settlements.

*igor.i.brown@nasa.gov

RUTGERS SYMPOSIUM ON LUNAR SETTLEMENTS
3-8 JUNE 2007 RUTGERS UNIVERSITY

Scaling and Sizing Aspects for Resource Utilization Devices to Support Development of the Moon and Mars Exploration

BEE THAKORE*

With the new wave of exploration targeted at extending lunar missions to support humans and preparing towards a permanently occupied human outpost, the role of in- situ resources utilization (ISRU) is becoming apparent. Several studies have indicated that use of ISRU devices may provide significant cost effectiveness over a given time of operation. With the lack of demonstration mission, one link still remains to be investigated further: what is the best means for such devices to be scaled up to cater with an increased demand of products.

This paper mainly focuses on use of space resources to harness oxygen, hydrogen and water on the Moon, as the processes, technologies and economics for these near-term 'derived products' are better understood.

Strategies for extending a new-sufficient supply of space resource derived products to those that can be commercially mined is not the main focus, but are included for comparison of increased energy, mobility and operating robustness required. Finally, a role of such a strategy in preparing a demonstration mission for Moon and that for an ISRU device for large scale water production on Mars is discussed.

* International Space University
beethakore@yahoo.co.uk

International Cooperation Models for the Development of Settlements on the Moon

RYAN ZELNIO*
George Mason University

It is widely recognized that the development of a lunar settlement cannot be done by the United States alone due mainly to the costs associated with such a large endeavor. However, getting the international community to join such an effort will be a challenging endeavor. This paper examines four frameworks for international cooperation that have been used in past international space endeavors. Frameworks examined will include cooperative models like CEOS, GEOS, & ILEWG, augmented models like Cassini, interdependence models like the International Space Station and integrated models like Intelsat and the European Space Agency. Examples of each framework used in prior cooperative international space ventures will be examined with a discussion on their pros and cons. This paper shall then discuss the application of the frameworks to lunar development.

There have been many changes in the political landscape since the last major space cooperative project, the ISS, has been put together in the early 1990s. Russia's economic and industrial base is now on much better footing, the technology maturity of the Europe Union and Japan is much greater than it was before, and China has emerged as space power. What this means and how it impacts future cooperative models will be discussed.

*ryjaz@yahoo.com