Return to the Moon: Looking Glass 204

http://astronautics.usc.edu/concepts-studio/lookingglass.htm

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Abstract

As we lay down plans and ramp up development of transportation systems for returning people to the Moon, alternative concepts are being proposed for activities to conduct there in order to gain the experience necessary to prepare for more ambitious human interplanetary expeditions to Mars and beyond.

Fully employing NASA's Constellation transportation systems such as the Orion Crew Exploration Vehicle and the Altair Lunar Lander as baseline elements, the USC ASTE527 Return to the Moon: Looking Glass 204 Project pondered the following question:

What activities precisely can we do on the Moon, with crew and robots, that can immediately (very short timeframe-2015-2040) benefit not only the science and engineering community, but also humanity as a whole, on a permanent basis ?

The establishment of a sturdy cislunar communications system followed by critical crew rescue capability in the proximity of a primary lunar habitat are seen as the foundation blocks for this architecture. Once the foundation is reliably established, essential physical infrastructure to support the emplacement of a suite of permanent, evolvable observatories, long-range traverses to conduct geology and astrobiology, and critical crew support were addressed. Manned, pressurized rovers are essential in order for crew to access observatory sites to set up, calibrate and evolve these man tended facilities which are located along the proposed traverse route. Rovers and crew are also needed to deploy, service and evolve science payloads that are autonomously landed far apart in remote regions of the lunar globe.

Participants were tasked to create their own system concepts, which they thought were useful. They presented material on pertinent concepts listed below:

1. The Altair Descent Stage based Cislunar Communication System
2. A lunar surface CEV /Altair hybrid for Cislunar Ambulance
3. Astronaut Health and Critical Care
4. Lunar Landing Pads, Access Roads and Habitat Platforms/Dust Mitigation
5. Observatories: SPIDAR Concept for VLF Astronomy Using Craters
6. LunaRRT:Lunar Real-Time Teleoperations
7. ISRU: Processing and Use of Lunar Rocks for Infrastructure Development
8. Pressurized Lunar Rover – The Science and Service Cars
9. Lunar Power Peaks – Use of Mountain Peaks for Microwave Relays
10. A South Polar Geological and Astrobiological Traverse - with Twin Rovers
11. Inflatable Technology for Pressurized Rovers and Mobile Habitats
12. Concept for Outreach –LunarSS and Kaijuu

These activities will directly advance the experience necessary for interplanetary missions. The philosophy of crew and robots working together employing real-time telerobotics(RTT) to accomplish various buildup activities was preferred over the more conventional, economical, linear, robots first approach, in order to maintain high public interest that is crucial for such a high visibility project. The architecture recommends a substantial outreach component as well as international collaboration and US leadership in the new century.

Synopses of the topics listed above are presented here.

The unedited final project presentation slides may be viewed at:

http://astronautics.usc.edu/concepts-studio/lookingglass.htm

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Introduction

The USC ASTE 527 team project of Fall 2008 “Return to the Moon: Looking Glass 204” explored a variety of concepts for NASA’s plan to return people, first on one-week surface stays, extending them to 14 days, and eventually leading up to six month tours of duty.

Fully employing NASA transportation systems such as the Crew Exploration Vehicle and the Altair Lander as baseline elements, the USC ASTE527 Return to the Moon: Looking Glass 204 Project participants pondered the following question :

What precisely can we do on the Moon, with crew and robots, that can immediately (very short timeframe-2015-2040) benefit not only the science and engineering community, but also humanity as a whole, on a permanent basis ?

The USC team was tasked specifically to go beyond NASA’s Mars Forward technology development program, to propose on two more fronts, namely to :

1. Commission a variety of permanent assets that are useful not only to the scientists but also for all of humanity, and
2. Look at how this specific project might be commissioned quickly, between 2015-2040, to inspire a new generation of explorers.

This project is envisioned to happen between 2015 and 2040. Assuming two or three Altair missions every year, we expect between 50-60 Altair derived landers to be serviced around the lunar globe, with at least 50 of them in the vicinity of a south polar lunar settlement. They include both crew sorties and cargo missions. The other 10 landers would primarily be cargo landers with specialized science and logistics payloads to be commissioned in remote locations of the lunar globe. Substantial international participation is foreseen in all aspects including Earth-to-Moon transportation, landers and payloads.

While fully aware that the technologies involved might see dramatic improvements and unforeseen advances in a quarter century, from 2015-2040, the team chose to stay with baseline systems, allowing for natural evolution in reliability and performance.

It is in this context that the preliminary infrastructure development concepts proposed in this paper are portrayed.

Lunar Settlement in Polar Region

While satellites are still gathering crucial data, there is some consensus building within the space community, which suggest that the North and South Polar Regions might offer a better initial location for manned lunar operations.

The Malapert mountain range in the South Polar Region, the Malapert crater and environs have been discussed in recent literature as potential regions of interest to locate a lunar settlement. The Shackleton crater and environs, almost directly at the South Pole has also been targeted as a site of interest.

Pending more specific data from missions in progress including LRO/LCROSS, these two south polar locations were adopted as the sites of interest for the Fall 2008 USC project.

Return to the Moon: Looking Glass 204 Concepts

Following sections 1-12 are synopses of preliminary engineering system concepts presented as the Return to the Moon: Looking Glass204 Project and are intended as alternate choices for further investigation.

1. The Altair Descent Stage based Cislunar Communication System

A reliable and sturdy cislunar communication system is critical for lunar operations. High data rate transfer for a communication system is very important for the successful buildup of a lunar base. With humans now returning to the moon by 2020, the new technologies of today and the capabilities they possess will be a huge upgrade for cislunar communications as well as future interplanetary space missions.

The LG204 Communications system provides high data rate transfers and communication between Earth and the Moon. By providing a very high data rate (10 Gbps) through strategically placed antennae on mountain peaks in the south polar region of the lunar surface, LG204 offers the capability to provide information much more rapidly than any previous communications methods or systems. This in turn leads to far more agile, and effective strategic and tactical decision making and implementation during missions due to better communications and near-real-time data sharing among various elements and mission control. By using two 12 meter high-gain mesh antennae at Mons Malapert, deployed atop the spent descent stage of the first Altair cargo vehicle, a constant communication between the Earth and the Moon can be obtained which would lead to fulfilling the many needs to sustain life on the Moon (Fig.1). Some of these needs are: communication capabilities, high-speed data transfers, medical needs such as telemedicine, as well as educational outreach. This concept will explore the idea of a high-speed extension of communication to the Moon, utilizing advanced technologies proposed for Earth, and the many benefits of having such a system. The LG204 communication system is powered by 2 X 15kW solar arrays, which are unfurled and raised on 20m towers where they are synchronized for continuous 360^o solar disc tracking around the polar horizon

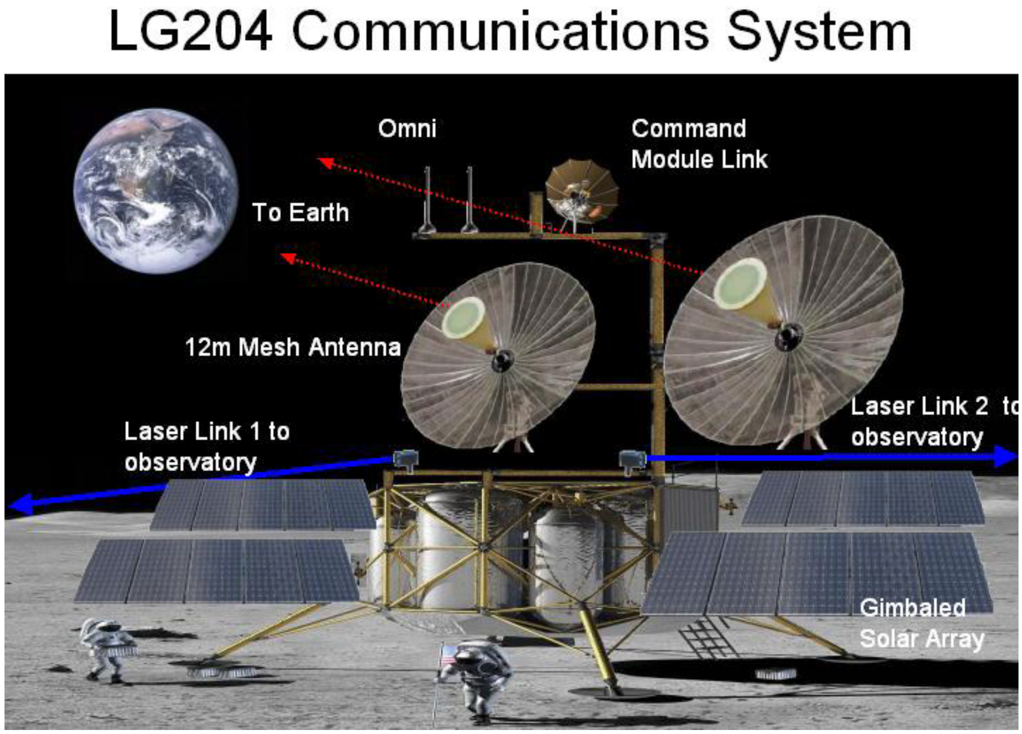

Fig.1 **The Cislunar Communication System.** *The use of the spent descent stage of the first Altair cargo lander as the sturdy platform for a highly capable Earth-Moon telecom station is suggested as a possible concept in this architecture. Free-space laser links and tall relay towers are suggested to overcome the short lunar horizon distance to link up and network to various observatories and science payloads. 30kW solar arrays are unfurled (as shown) and then raised on twin 20m booms where they are synchronized with solar disc for 360^0 tracking (not shown) around the south polar horizon.*

2. A lunar surface CEV /Altair hybrid for Cislunar Ambulance and Lunar Surface Fuel Depot

The critical first-priority in any crewed mission is to return the crew safely back to Earth. This has been a key consideration in the past and on future space missions. Because of that fact, it is the top priority for the success of the USC Looking Glass 204 Observatory Project.

The goal of this concept is to provide a robust and reliable escape route directly from the lunar surface to Earth, without the need for orbital rendezvous, which is deemed difficult, especially with impaired crew.

This concept is based on the design of a crew rescue vehicle called the Cislunar Ambulance. This vehicle is proposed to be sent to the moon in the first designated cargo flight followed by another cargo flight that will carry enough fuel for the ambulance to return back to Earth. The Cislunar Ambulance is a version of the ESAS-CEV. It is a basic, stripped down CEV module with just enough capability to keep the crew alive during the 3-day trajectory back to Earth. See Fig.2

Since fuel was a big concern, a short case study is also presented on the concept of an initial capability lunar surface fuel depot. Fuel caching is proposed as the simplest mode for initial operations. Storable fuels are preferred for handling simplicity, and solids and hybrid solids also need to be studied further in performance vs. reliability and ease of storage and safety trades.

Knowing that the Cislunar Ambulance will have to depart the moon under quick and undetermined circumstances, the return-to-Earth trajectory and re-entry and touchdown may be anywhere on the globe. This is a critical concept issue that will require international collaboration as the rescue vehicle could land anywhere on Earth. A possible solution for such collaboration is presented in this concept as well. This concept maintains that firmly establishing an Assured Crew Rescue Capability is essential for a manned Lunar Mission and the CEV based architecture is a very interesting concept requiring feasibility analyses and detailed engineering study.

Several proposals suggest the use of the International Space Station as a node for initiating lunar missions. In an alternative return-to-Earth trajectory needing further investigation, the CEV aerobrakes into LEO, using atmospheric “skip and steer maneuvers” to make necessary plane changes and orbit trims to finally dock with the International Space Station. From there, the crew would use ISS transport to return to Earth.

Fig.2 **The Cislunar Ambulance** *A modified CEV is a candidate for a Moon-Earth emergency rescue system. A modular lunar surface fuel caching system deployed in advance of crew arrival is used to enhance the energy requirements for a direct return-to-Earth high-energy trajectory.*

3. Astronaut Health and Critical Care

Flight surgeons monitor the health of STS and ISS crew round the clock. These methods and protocols may be evolved for longer endurance missions to the Moon and beyond.

At the outset, it is clear that failures and accidents are not a matter of if, but when. When crew subjected to stressful situations in extreme environments during endurance missions suffer from ailments, or when accidents occur, they must be able to tend to a variety of medical emergencies on-site, before resorting to the last mission abort measure.

It is known that prescreening cannot always detect conditions and anomalies, which can present symptoms during the mission. Emergencies could range from tooth-related illness to food poisoning, appendicitis, inhalation of moon dust or other contaminant to aneurisms, concussion from accident or cardiac arrest. Rover mishap, EVA accident or micrometeoritic puncture could lead to sudden depressurization of habitable volume, and particle radiation from anomalously large solar flares can have severe to lethal consequences for crew.

How do we treat an incapacitated or immobile crew member in a spacesuit ? What are the devices and modifications needed to carry crew to an examination setup and what are the intermediate procedures, which could be administered to an unresponsive, suited crew member ? What are the systems needed to transfer immobile crew from site quickly into an emergency rescue spacecraft for an abort-to-Earth mission and how might we accomplish this for multiple incapacitated crew ? The idea of implanting resuscitation systems in crew garment was pondered. Dermal patches for a variety of drug delivery were discussed. Creative use of g-suits was discussed.

Is it possible to build-in nanotechnology devices and instrumentation into the suit to assist not only in monitoring vitals but also to do minimally invasive procedures on suited crew ? Is it possible to do real-time blood work and metabolomic analyses on breath and perspiration, besides closely monitoring heart rate variability ? What instruments are available to physically examine a fully suited crew member ?

NASA is using telemedicine, and experiments are underway to advance this technology to assist in crew health monitoring. A lunar telemedicine facility, with the capability to perform surgery could be a very useful system for endurance class missions. Fig.3 shows such a facility as well as state-of-the-art Zeus telerobotic system in use in hospitals today.

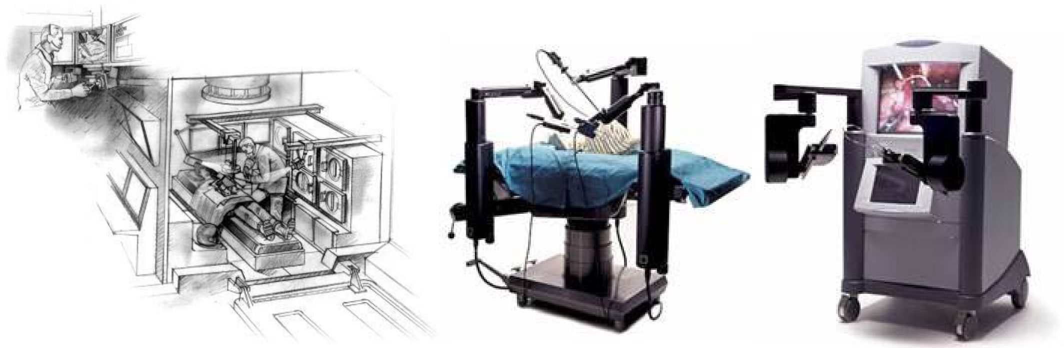

Fig.3 **Telemedicine:Telesurgery Facility** *A lunar telesurgery in progress with Earth based surgeon(upper left) and lunar crew assisting in the theater(left) and the Zeus telerobotic system(right-credit Zeus Corp)*

The concept for an epidermal patch or band containing an end-to-end pathology lab-on-a-chip was proposed. Utilizing a nano-optical technology based microscope, automated sample extraction, slide specimen preparation, scanning and high resolution image transmission to mission control, such an invention could provide a pathologist with critical real-time diagnostics on crew condition.

Finally, the concept that all lunar crew be trained to some level of medical expertise was discussed.

4. Lunar Landing Pads, Access Roads and Habitat Platforms/Dust Mitigation

Dust suppression is a critical issue with regard to Altair operations as well as surface vehicles in the proximity of the habitat. Dust and debris thrown up by ascending, descending and over-flying spacecraft as well as propellant ejecta can be expected to degrade exposed payloads such as telescope elements and photovoltaic arrays.

This concept explores several architectural elements relating to developing essential preliminary infrastructure for humans on the lunar surface during the first several missions keeping dust suppression in focus.

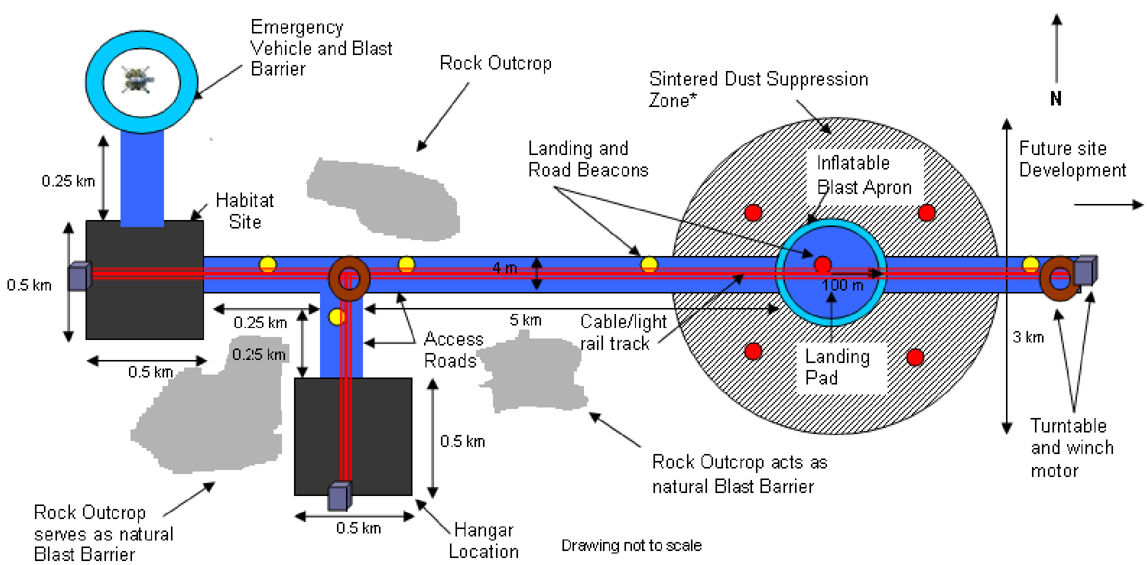

Fig.4 **South Polar Lunar Settlement Site Plan (Not to Scale)** *A schematic site plan concept for lunar settlement. Activities in this zone need to pay careful attention to dust issues, and dust control, mitigation and suppression methods are foremost considerations for lunar settlement architects and designers.*

Concepts discussed include certain selection criteria aspects for lunar habitat location, and a variety of architectural elements, which can ameliorate the effects of lunar dust during Altair operations and routine surface vehicle movement around the primary lunar settlement.

These elements include a microwave sintered landing zone around a hard, paved and topped landing pad for repeated service use, inflatable structures for blast aprons, a light rail system with pallet and winch and gantry support for lander and payload transport from landing pad to hangar or habitat, a hard, topped dust-free platform on which to erect the habitat and allied structures, and a built-up access road from the habitat area to the hangar and landing pad. An emergency exit route from habitat to a standby escape vehicle is also depicted. See Fig. 4. A dust monitoring system and alarm as well as a dust cleaning rover attachment are suggested.

5. Observatories: SPIDAR-Concept for VLF Astronomy Using Craters

The primary focus of returning people to the Moon is to reliably advance and hone Mars Forward technologies and experience. However this endeavor requires an immense amount of funding at a time when the US and global financial systems are tremendously strained. In our view, this issue naturally prompts the question "What can be done to establish "permanent science assets" with immediate returns on this investment, not only for the science community, but for all of humanity ?" This presentation makes the case for a proposal to deploy several astronomical observatories around the lunar globe Fig.6, using a crew of four astronauts, in concert with on-site telerobotics with reusable on-board tools. The focus of this presentation is on the specific types of observatories and payloads, which exploit the unique advantages of the lunar environment, particularly around the South Pole. An original concept for an observatory operating in the very low frequency(VLF) band below 30MHz is described See Fig.5. The primary motive for the South Pole Isolated Dipole Array (SPIDAR) is to learn about our universe through a relatively unexplored spectral window in astronomy. Top-level system architecture is described, including array emplacement at a potential location in the Schrodinger basin. A rough estimate of key system performance capabilities is also shown. We believe that, if planned accordingly, a series of unique and highly capable observatories could be commissioned synergistically, even while executing NASA's Mars Forward technology development missions, using systems proposed by the agency, during the early return-to-Moon manifest.

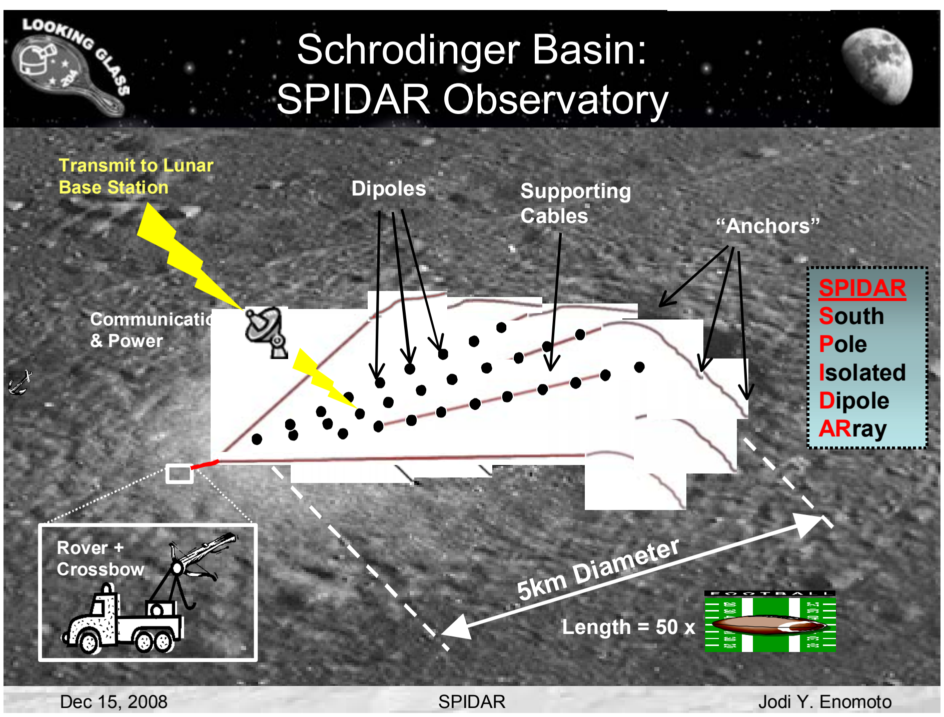

Fig.5 **The South Pole Isolated Dipole Array(SPIDAR) VLF Observatory at Schrödinger basin** *is proposed to explore the relatively unknown Very Low Frequency(VLF) window of the electromagnetic spectrum.A mechanical cross bow/harpoon attachment on Service Car is used to tow lines carrying dipoles over and across the crater rim where each line is anchored before the next harpoon firing procedure.*

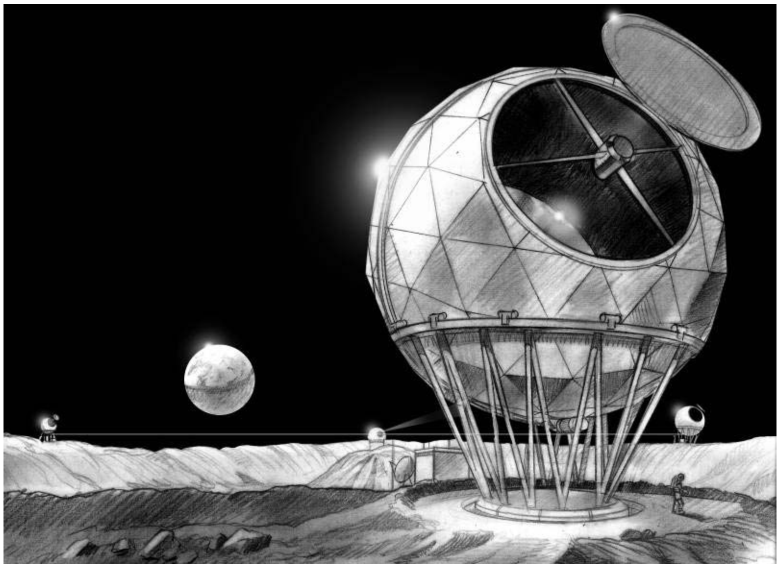

Fig.6. **Telescopes on the Moon.** *Eventually, Large Optical Interferometry Observatory may be erected on a suitable crater with optical elements around the rim and the image integration facility at the central peak*

6. Lunar Real-Time Teleoperations

Building and maintaining a permanent lunar habitat will require an extensive amount of work on the surface. In order to accomplish this task, it will be essential for an environment where robots and astronauts can work together efficiently. The far distance to the moon creates a signal time delay, making Earth-based telerobotics limited in capability and precision. This architecture proposes a lunar operated telerobotics network be created to produce an efficient working environment. From the LunaRTT module, (see Fig.7) astronauts can control robotic equipment without leaving the safety of the habitat. This will allow for continuous surface work with excellent supervision and control over robots and without the limitations of human EVA.

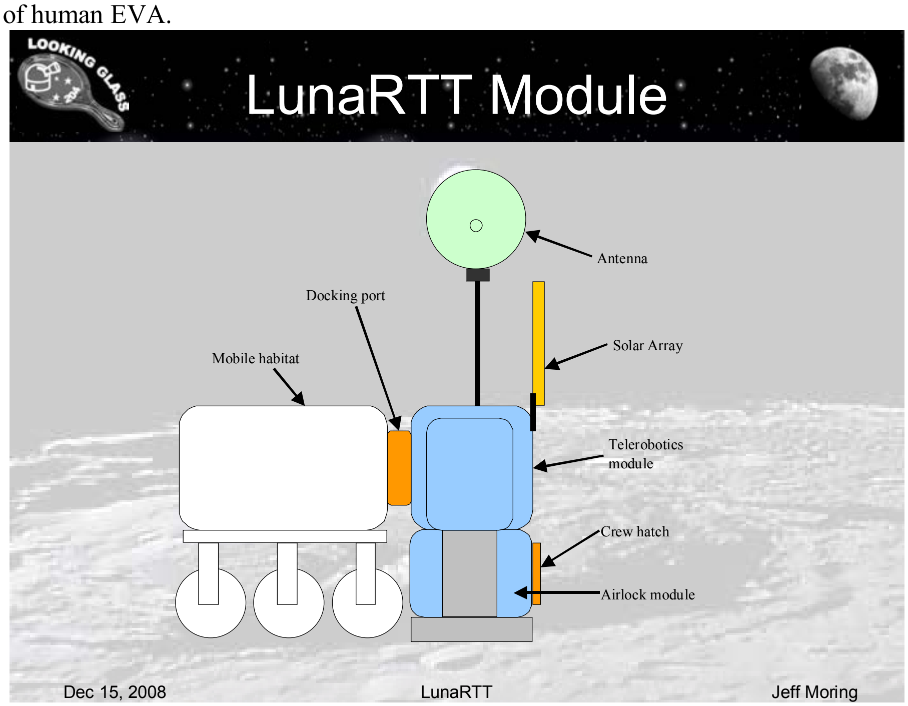

Fig.7 **Lunar Real-Time Teleoperations** *Schematic of Lunar Real-time Teleoperations Cabin docked to pressurized rover. Risky EVA is minimized while supervision of telerobotic systems for fast and efficient settlement buildup is enhanced.*

7. ISRU:Processing and Use of Lunar Rocks for Infrastructure Development

The current NASA Exploration Systems Architecture Study (ESAS) describes the implementation of the Vision for Space Exploration, meant to return humans to the Moon by 2020. In-Situ Resource Utilization (ISRU) is a component of this architecture to allow long-term human presence on the moon and would start with technology demonstrations during pre-cursor missions. Oxygen, water, and spacecraft propellants will be extracted by chemical processing of the lunar regolith; items like solar arrays may be constructed from extracted metals and minerals.

While there are brief discussions about using raw surface materials directly, such as lunar rocks, these systems are not described in any detail. However, for the purposes of the Looking Glass 204 missions, uses of these raw materials will be of more benefit than demonstrations of the other ISRU chemical processing technologies. Lunar rocks can provide the means for basic construction at the main base site: aggregate base layers for landing pads and roads, shade walls, berms, and unpressurized domes for hangars.

After the lunar rocks are collected, they need to be transported to the processor. To avoid the rover traction difficulties of low lunar gravity and the regolith consistency, as well as the damaging lunar dust, a cable-car system is proposed. The system would be erected around the edge of the landing pad clearance site and along the roadside, leading to the initial habitation location and rock processor. The processor would produce smaller aggregates for use as base layers for landing pads and roads. The processor would also be able to shape the rocks into roughly hewn, cube-shaped blocks (See Fig.8) for use in shade walls, berms, and unpressurized domes for storage and hangars, employing an advanced space technology twist to the ancient building method of dry-packing.

In this method of construction, blocks of rock are fitted together without cement or mortar and held together in pure compression, by virtue of their mass, employing gravity. Pins and keystones are employed to lock these building blocks in place for better structural integrity against accidental lateral or torsional forces. It is possible to build vaults and arches which span several tens of meters, taking advantage of low lunar gravity, allowing to create a wide variety of unpressurized structures for varied uses.

Examples of such compressively loaded structures on Earth, which have withstood the ravages of time include the Pyramids of Egypt, the cities of the Incas and Mayas, the great temples of south-east Asia and India, and those classic Greek and Roman buildings, many of them serviceable to this day.

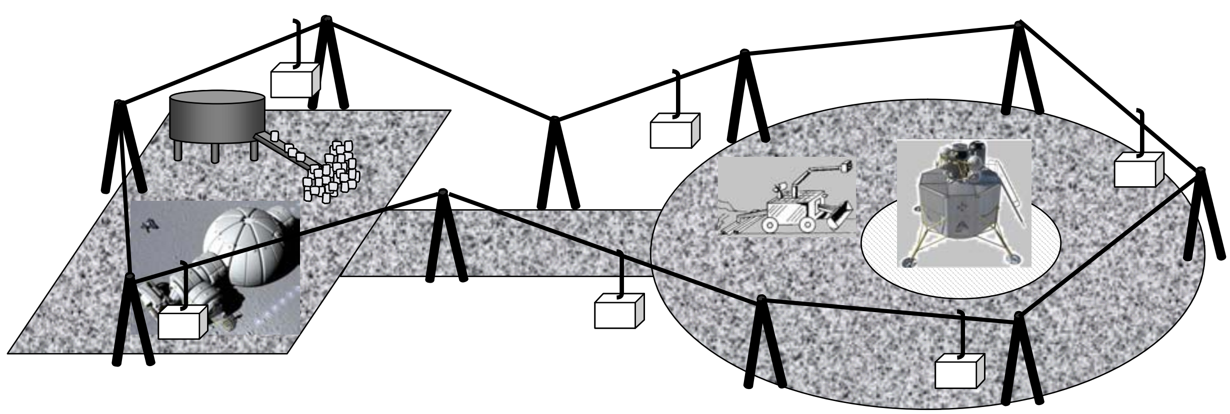

Fig.8 **ISRU:Use of Lunar Rocks for Infrastructure Development** *ISRU Rock Processing for aggregates for road and platform base layers and mechanical production of rough-hewn blocks for building use, in a new twist for advanced technology, employing the ancient yet sturdy "dry-packing" method of construction*

8. Power Generation – Lunar Power Peaks

Easy access to power is vital to every mission and this is especially true for human exploration of the lunar South Pole. NASA's plans for exploring the Moon with humans will require multiple mobile assets with large power needs that cannot be fulfilled simply by solar power or fuel cells. This ability to transfer large amounts of power is essential if astronauts are to venture far from a central base. Laser power beaming that takes advantage of the up to eight-kilometer high, elevated regions of the lunar South Pole may offer one solution. Power from a large nuclear reactor could be transferred throughout the polar region without erecting large towers, but rather by placing small laser transmitters and photovoltaic receivers at natural peaks and ridges. This would dramatically increase the range and broaden the activities that could be done by astronauts on the Moon by providing sufficient power where it is needed, when it is needed. See Fig.9.

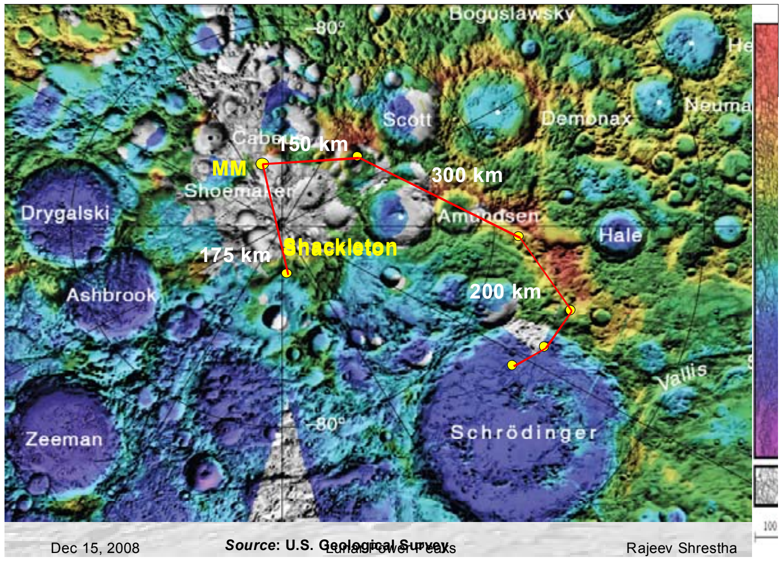

Fig.9 **Lunar Power Peaks** *Power beaming uses the natural peaks and ridges in long line-of-sight segments of the South Polar Region to transfer power using lasers to needed locations in the Looking Glass Project*

9. Surface Transportation on the Moon: Lunar Science and Service Rovers

Global mobility is essential for further exploration of the Moon. Both short and long traverses must be conducted in the future to gather science data, aid in In Situ Resource Utilization(ISRU), and help in the construction and establishment of lunar infrastructure. Keeping in mind that crew safety is the highest priority, these future rover vehicles must be able not only to survive the harsh lunar environment, but they must also be extremely reliable, provide navigation data to the operator, be equipped with robust tools, transport large cargo, and be capable of science data analyses while in traverse.

The Lunar Science and Service Rovers is a set of two pressurized rovers aimed at meeting these requirements. Each crew cabin and chassis is identical, making the design modular. (See Fig.10)

The Science Car is really a mobile habitat, which is capable of sustaining a crew of four over a single mission duration of one month. In addition to the basic living quarters, the Science Car is equipped with a Science Laboratory where two people can work at one time, conducting experiments while in traverse. Science tool kit would also include ground penetrating radar and acoustic probes for gathering information on subsurface morphology, and with twin rover support, it may be possible to enhance high resolution data.

The Service Car is aptly named because it is the workhorse of the two rovers. This vehicle contains tools for construction and exploration, which include a drill, winch, crane, backhoe, front-end loader, robotic manipulator arms, and a crossbow harpoon launcher for setting up an observatory at Schrodinger basin. This rover also has a stowage area for hauling rocks and other samples collected while in traverse. See Fig.10.

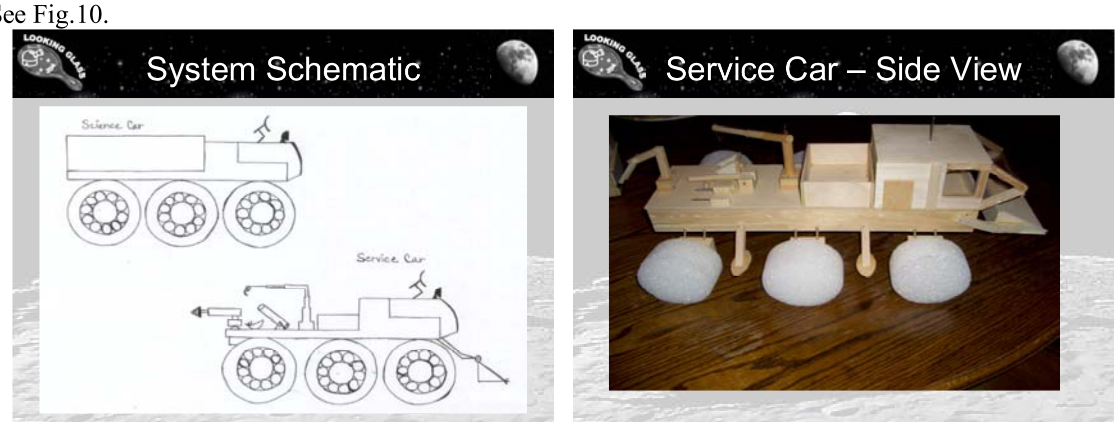

Fig.10 The **Lunar Science and Service Cars** *are versatile rovers that feature highly modular systems which fit on the same chassis(like Chariot?) and is capable of supporting a crew of four over one month traverses. Large wheels are recommended to cope with the rugged terrain on lunar highland traverses.*

10. Geological and Astrobiological Traverse

Project Looking Glass' primary goal is to return humankind to the moon and, at the same time, establish something permanent. Among various ideas, it was suggested that this should come in the form of facilities that would give precious data back to the scientific community and also inspire a new generation of young explorers. This will mainly be accomplished through the introduction of multiple observatories setup throughout the moon. These observatories will provide valuable information about outer space as well as the Earth. However, the time spent on the moon should be taken advantage of to study the geology of the lunar surface and potentially solve many of the questions that still puzzle scientists today. This project proposes that while there, the crew take part in a traverse. While on this traverse, the crew will aim to explore and take geological samples and gather subsurface morphology data of the region in order to better understand the composition for lunar buildup applications as well as the history of the moon. Craters will be examined in the hope that the cold traps there will yield clues to the formation of the moon or provide a source of water ice for future lunar bases. See Fig.11.

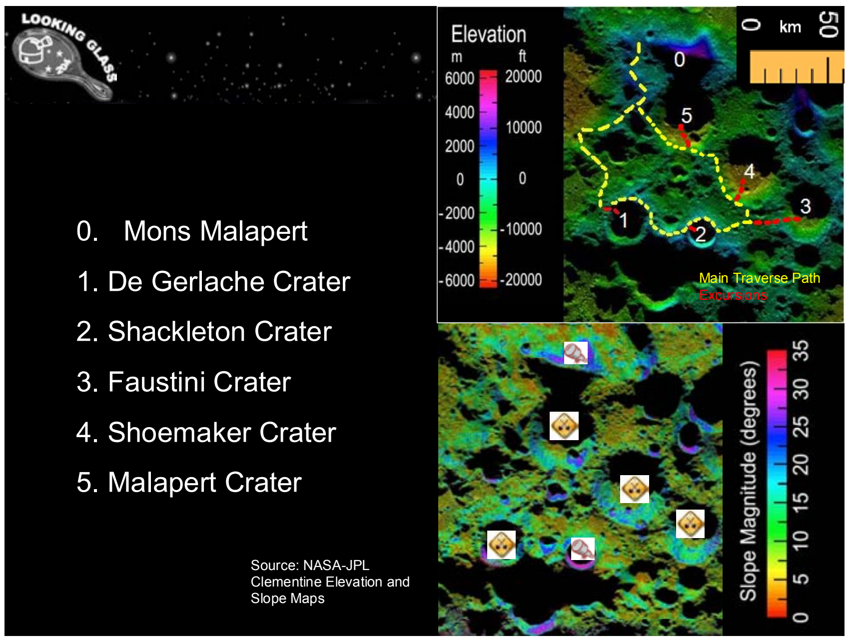

Fig.11 **Geological and Astrobiological Traverse** *A South Polar Traverse with twin rovers which offer mutual support and safety, (not to mention dynamic, crew-to-crew and rover-to-rover camera angles, for great high definition science and media footage!) will explore craters and unique South Polar features while also assisting in observatory and habitat infrastructure establishment, all under the watchful eye of the orbiting CEV which would pass periodically over the traverse and activity areas every 90 minutes.*

11. Inflatable Technology for Rovers and Mobile Habitats-Magic Envelope

For return to the Moon in 2020, how to provide crew with comfortable living spaces on the lunar surface is a critical issue. We assume that in the first few missions, four crew are going to live on the Moon for 7 days and start to establish observatories in the South Polar Region. They will have two pressurized rovers, and the Altair lander will serve as a temporary habitat.

However, the habitable volume of the reference Altair lander and rovers cannot provide sufficient space for comfortable living while crew move around doing their jobs around the vicinity of the settlement. We also know that carrying heavy systems and equipment is a problem, whether during launch or while moving from place to place on the Moon.

A new concept for living on the Moon during initial operational phase called Magic Envelope is proposed. See Fig.12. It employs inflatable technology to create a lighter weight, better mobility, multi deployment mobile habitat typology and attempts to provide larger spaces and more productive habitable volumes for astronauts during their tour of duty.

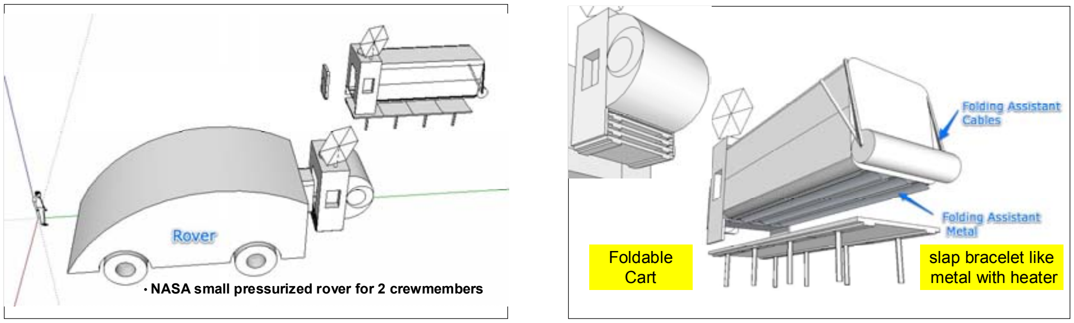

Fig.12 **Rovers and Mobile Habitats-Magic Envelope** *Magic Envelope is a deployable and retractable caravan-type mobile habitat that attempts to provide larger habitable volume for crew in a mobile environment.*

12. Concept for Outreach-LunarSS and Kaijuu

Students in the US are lacking interest in Math and Science as expressed in educational statistics. University graduates in Science and Engineering, especially in astronautics and aerospace related education, continue to decline. If the NASA space program or even the private industry do not succeed in inspiring the future generation, all efforts and US legacy of these programs will be lost to other countries and consequently will slow humanity's progress in technology and knowledge of space.

Astronomers, employing World Wide Web technology, routinely use observatories around the world without being on site. Several new initiatives like Google Earth, Google Sky and Virtual Telescope now allow users to remotely access and operate facilities and download requested information for further study and analysis.

The Lunar Space Scope Project Concept (Lunar SS) proposes to extend this technology to the university and K-12 school student. It promises to engage them through the Internet to take their own astronomy and lunar pictures or test data to be analyzed right in their classroom:

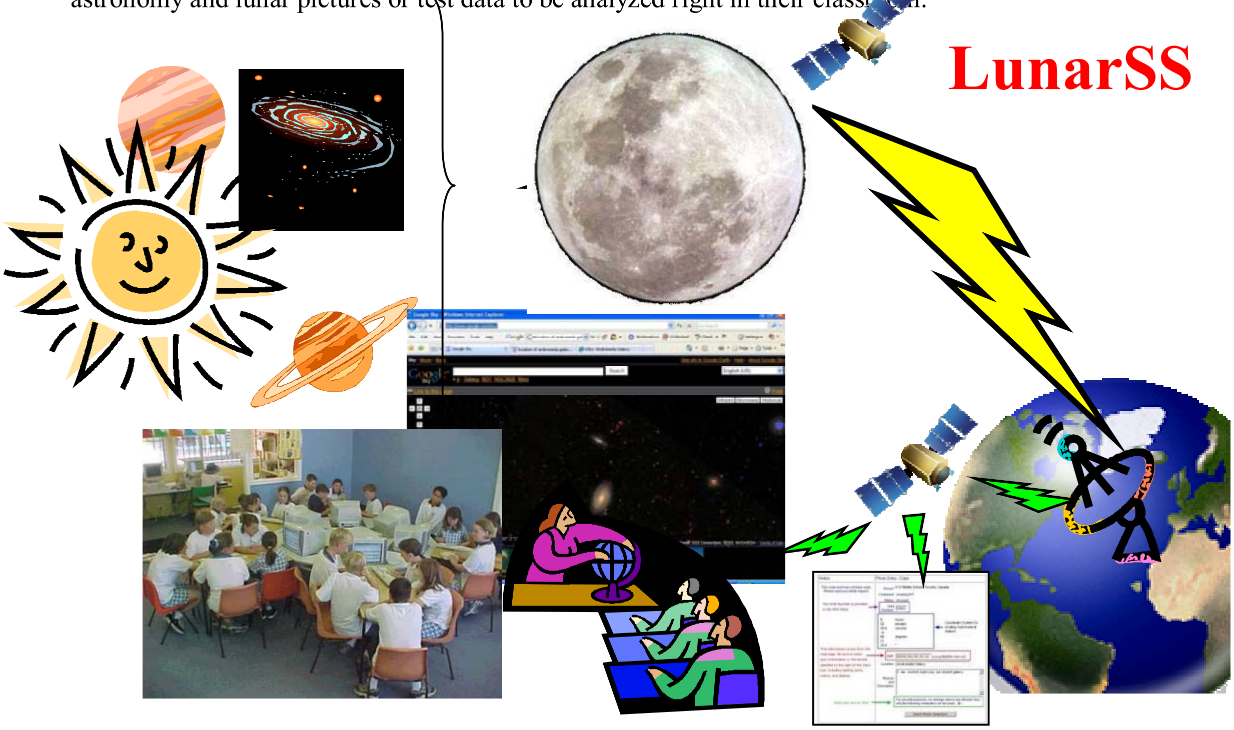

Fig.13 **LunarSS Project** *will allow K-12 students to interact with real-time data from lunar observatories*

The project will consist of an Observatory Operations Team, a Web Team, and a School/Education Team that will organize the program to create a student request system. Many observational tools will be used to provide a wide range of pictures and data – digital cameras, infrared detectors and cameras, spectrometers, spectrographs, radiation detectors, seismic detectors, and temperature sensors. Each sensor would be activated by the student through the request system and data returned to them for their analysis and learning experience.

Students can learn Astronomy, Astrobiology, and any other subject the educator deems applicable to the class subject as well as fun and engaging. If the students find something new, they can submit a request to name their own galaxy, quasar, or other astronomical feature. How then will these students resist achieving interstellar travel to reach their own astronomical features? See Fig.13.

With the ongoing activities of successful 2004 Mars Rovers and current competition of Google Lunar X Prize, telerobotic rovers are a key element in any future space exploration. Rovers collect the vital information needed to allow humans to venture into the space environment.

A child starts with a simple remote control car as one of their childhood toys – the child develops the skills to control something with a simple handheld device; learns to analyze the motion of the vehicle to do their will; forms goals of jumping over obstacles; learns to troubleshoot flipping the toy car over. These skills are the basis for the Remote Control Rover - Kaijuu. Kaijuu is translated as Monster in Japanese. This rover would be able to collect samples, data, excavate, explore, or any other task that can be willed by the student. Students can adapt to the time delays, and quickly command Kaijuu to complete tasks to help with a class project, assist scientists to collect information, and gain the experience for other space adventures. Students will have the opportunity to do something "out of this world" as well as contribute to the effort of understanding extraterrestrial environments. See Fig.14

Fig.14 **Kaijuu Project** *will engage the students in lunar teleoperations by command and control of a multipurpose robotic rover as a pilot project before providing more services to the younger generation of explorers*.

By engaging the students, we can inspire them to learn more about space and increase their desire to be there. LunarSS and Kaijuu are just the initial, pilot concepts.

Conclusion

Several system concepts for a speedy lunar return in the 2015-2040 timeframe are presented, with an eye toward establishing permanent, evolvable assets on our celestial neighbor. These assets are intended return data both to the scientific community as well as to an aspiring young generation of explorers in schools and universities. The proposed assets include a suite of observatories and science and technology experiments. Extended rover traverses of the South Polar Region are proposed. Twin modular rovers, namely the Science Car and the Service Car are used to support the buildup of the lunar habitat infrastructure as well as the various observatories. It may be possible to achieve this result in a synergetic approach that simultaneously carries out NASA's Mars Forward technology development missions on the lunar surface.

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This paper presents the concepts created in the ASTE527 Space Exploration Architectures Concept Synthesis Studio, a 3-unit graduate elective offered by the Dept.of Astronautics in the Viterbi School of Engineering at the University of Southern California, in the 2008 Fall semester.

This is primarily a design experience course, which deals with concepts creation, considered a prime function of the system architect, who strives to provide alternate choices to the client.

Most of the participants in this studio are from the industry, seeking an advanced degree or professional development. Some of them are full-time graduate students from various branches of engineering and medicine and architecture, all seeking an interdisciplinary, synthesis-oriented approach to problem solving.

This 15-week program, met once a week in 3-hour meetings which included guidance in critical concepts creation methods and several inspirational lectures from agency and industry professionals, all grappling with the same conceptual problems as the studio participants.

Students were tasked to create their own concepts during the first half of the program, and then they tackled a more complex, partitioned team project (Looking Glass 204) that required information exchange and coordination. Visualization was stressed and participants were encouraged to build models of their concepts. Both midterm and final projects were reviewed by faculty and experts from the agency and industry who provided feedback.

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" ….ce n'est rien sans 1'esprit, c'est tout avec l'idee."
– note from Victor Hugo to Auguste Bartholdi on the completion of the Statue of Liberty, May 13, 1885

Bibliography

Aldridge E.C., Fiorina C.S., Jackson M.P., Leshin L.A., Lyles L.L., Spudis P.D., Tyson N.D., Walker R.S., and Zuber M.T. (2004) A Journey to Inspire, Innovate, and Discover: Report of the President's Commission on Implementation of United States Space Exploration Policy. U.S. Govt. Printing Office, Washington DC, 60 pp.ISBN 0-16-073075-9.

Alred, John etal.,(1989) Lunar Outpost, Johnson Space Center JSC-23613 8/89

Alred, J., Roberts, M.,(1988)., Lunar Base Launch and Landing Facility Conceptual Design, Eagle Engineering Report No.88-178, Contract NAS9-17878, March, 1988.

Augustine N.,(1990) Chairman, Report of the Advisory Committee On the Future of the U.S. Space Program December 1990, NASA History Division, Washington, D. C. December 17, 1990

Bell, L., Trotti, G., Neubek, G., & Binder, A. (1989). *Manned Lunar Outpost (MLO): A NASA/USRA Sponsored Study.* Houston, TX, USA: School of Architecture, University of Houston. Benaroya, H. (2007). *Lunar Structures.* Rutgers Symposium on Lunar Settlements.

Bush,G.W.,(2004). *President Bush Announces New Vision for Space Exploration Program* . Retrieved from The White House: http://www.whitehouse.gov/news/releases/2004/01/20040114-3.html

Conolly, John(2007) Presentation Slides : Kickin' Up Some Dust, NASA Lunar Lander Office, February 2007.

Cooke, D., Yoder G., Gernhardt M etal.,(2006) Lunar Architecture Tier 2 Presentation, AIAA Space 2006 Conference, Long Beach CA.

Doggett, William; Dorsey, John; Collins, Tim; King, Bruce; Mikulas, Martin,(2008) A Versatile Lifting Device for Lunar Surface Payload Handling, Inspection & Regolith Transport Operations, Space Technology and Applications International Forum-STAIF 2008

Eagle Engineering(1988) Lunar Base Launch and landing facility conceptual design . Report No.88-178, Contract NAS9-17878, March, 1988. 100 p

Eckart, Peter., (2006) The Lunar Base Handbook: An Introduction to Lunar Base Design, Development, and Operations, 2nd Edition. McGraw-Hill. 860 pages.

Eckart, Peter.,(1996) Spaceflight Life Support and Biospherics, Microcosm/Kluwer Publishers, ISBN 0-7923-3889-8

Fijany, A.,(2003) NASA Sharpens Underground Image of World Trade Center Area Volume 11, Number 1 Spring 2003 • Advanced Technologies , Aerospace Technology Innovation, NASA JPL.

Gaier, J.,(2005) "The Effects of Lunar Dust on EVA Systems During the Apollo Missions", *NASA TM-2005-213610*, NASA-Glenn Research Center, March 2005.

Gaier, J., and Jaworske, D.,(2007) "Lunar Dust on Heat Rejection System Surfaces: Problems and Prospects", *NASA/TM-2007-214814*, NASA-Glenn Research Center, 6 June 2007.

Griffin,M.(2007). *Why Explore Space?* Retrieved from NASA: http://www.nasa.gov/mission_pages/exploration/main/griffin_why_explore.html

Jolliff B.L., L.R. Gaddis, C.R. Neal, C.K. Shearer, R.C. Elphic, J.R. Johnson, L.P. Keller, R.L. Korotev, D.J. Lawrence, P.G. Lucey, J.J. Papike, C.M. Pieters, G. Ryder, P.D. Spudis, and L.A. Taylor (2000) New Views of the Moon: Understanding the Moon Through the Integration of Diverse Datasets EOS, Transactions American Geophys. Union, vol. 81. No. 31, 349, 355-356.

Kennedy, K. J. (2007). The Lunar Lander "HabiTank" Concept. *International Conference on Environmental Systems (ICES).* Chicago, USA: Johnson Space Center.

Lofgren, G. (2005). *Sintering, Melting, and Crystallization of Lunar Soil With An Experimental Petrologic Point of View* . Retrieved from Lunar Regolith Simulant Workshop: http://est.msfc.nasa.gov/workshops/lrsm2005_program.html

Lumpkin, F., *et al.*,(2007) "Plume Impingement to the Lunar Surface: A Challenging Problem for DSMC", presented at the *Direct Simulation Monte Carlo, Theory, Methods, and Applications Conference*, Santa Fe, NM, 30 September – 3 October 2007.

Marburger, J. (2008). *46th Robert H. Goddard Memorial Symposium.* Retrieved from Office of Science and Technology Policy (OSTP), Excutive Office of President: http://www.ostp.gov/galleries/speeches/jhm%20Goddard%20Symposium%20030608.pdf

Mary-Linda Adams.,(1996) The Use of 3D Seismic-Source Imaging for Making Ground Water Management Decisions, Resolution Resources, Virginia.

McKay, Christopher P., Yvonne A. Clearwater, Albert A. Harrison(1991). From Antarctica to Outer Space :Life in Isolation and Confinement / edited by - Springer- Verlag,. - xv, 410 p. : 25 cm. (Based on papers presented at the conference, The Human experience in Antarctica : applications to life in space.)

Mendell Wendell W.,(1985) Edited by Lunar Bases and space activities of the 21st century /. - Lunar and Planetary Institute, 1985.24 cm. Papers from a NASA-sponsored, public symposium hosted by the National Academy of Sciences in Washington, D.C., Oct. 29- 31, 1984 ISBN 09428620233

Metzger, P., *et al*.,(2008) “Cratering and Blowing Soil by Rocket Engines During Lunar Landings,”presented at the *6th International Conference on Case Histories in Geotechnical Engineering*, Arlington, VA, 11-16 August 2008.

NASA's Exploration Systems Architecture Study(2005).*Exploration Systems Mission Directorate(ESMD)NASA Headquarters, Washington DC.,* NASA-TM-2005-214062.

NASA Office of Exploration Technical Studies Report(1988), Technical Memorandum NASA-TM-1988-4075, Vol1-3, NASA Hq. Washington DC.

NASA Office of Exploration(1989) "Report of the 90-Day Study on Human Exploration of the Moon and Mars", National Aeronautics and Space Administration, November 1989.

New Frontiers in the Solar System : An Integrated Exploration Strategy(2003) – The National Academies Press, 2003.xv, 232 p.

O'Brien, B., (2009) Direct active measurements of movements of lunar dust: Rocket exhausts and natural effects contaminating and cleansing Apollo hardware on the Moon in 1969, *Geophys. Res. Lett.*, 36, L09201

Renewed Spirit of Discovery. (2004). Retrieved from The White House: http://www.whitehouse.gov/space/renewed_spirit.html

Review of NASA's Exploration Technology Development Program: An Interim Report (2008) National Research Council, prepublication report, ISBN-13: 978-0-309-11943-6

Ride, S.K.(1987) NASA Leadership and America's Future in Space, A Report to the Administrator National Aeronautics and Space Administration, NASA History Division, August 1987

Roberts, L.,(1996) “The interaction of a rocket exhaust with the lunar surface”, *The Fluid Dynamic Aspects of Space Flight, AGARDograph 87*, Vol. II, Gordon & Breach, 269-290, 1996.

Rudisill, M., Howard, R., Griffin, B., Green, J., Toups, L., & Kennedy, K. (2008). *Lunar Architecture Team - Phase 2 Habitat Volume Estimation: "Caution When Using Analogs"* . Earth and Space Conference. Long Beach, CA, United States : Johnson Space Center; Langley Research Center.

Schmitt, Harrison H. (2006). Return to the Moon: Exploration, Enterprise, and Energy in the Human Settlement of Space, Praxis Publishing. 336 pages.

Schrunk, David, Sharpe Burton, Cooper Bonnie, and Thangavelu Madhu (2007). The Moon: Resources, Future Development, and Settlement, Second Edition, Springer-Praxis Books. 608 pages.

Simon,Tom and Sacksteder,Kurt.,(2007)NASA In-SituResource Utilization Development and Incorporation Plans, Technology Exchange Conference, Galveston Texas, NASA JSC and NASA GRC, November 2007.

Smith, D. J., Roberson, L. B., Mueller, R. and Metzger, P.,(2008) "Rapidly Deployable blast barriers for Lunar Surface Operations," *Joint annual meeting of LEAG-ICEUM-SRR*, # 4045, Cape Canaveral, FL, Oct. 2008.

Spampinato, P. (2008). *Expandable Habitat Structures for Long Duration Lunar Missions.* Denver, CO: 3rd Space Exploration Conference and Exhibit.

Spudis P.D., Stockstill K.R., Ockels W.J., and Kruiff M. (1995) Physical environment of the lunar south pole from Clementine data: Implications for future exploration of the Moon. *Lunar Planet. Sci*. XXVI, 1339-1340.

Spudis P.D. (2008) Lunar Polar Exploration: Questions, Issues, and Missions. *Lunar Planet. Sci*. XXXIX, 1359.

Spudis P.D. (2008) Lunar Exploration, Past and Future. Special Volume on the 50th Anniversary of the National Aeronautics and Space Administration, Washington DC, 118-127.

Stafford T.P.,(1991) America at the Threshold: Report of the Synthesis Group on America's Space Exploration Initiative (1991)U.S. Government Printing Office, Washington D.C., May 1991.

Taylor G.J. and Spudis P.D., eds. (1990) Geoscience and a Lunar Base: A Comprehensive Plan for Lunar Exploration. NASA Conference Publication 3070, 73 pp.

Taylor, L. A., & Meek, T. T. (2005). Microwave Sintering of Lunar Soil: Properties, Theory, and Practice. *Journal of Aerospace Engineering, ASCE Research Library* , 188-196.

Taylor, L. (2005). *The Geotechnical Properties of the Lunar Regolith: From Equator to the Poles* . Retrieved from Lunar Regolith Simulant Materials Workshop: http://est.msfc.nasa.gov/workshops/lrsm2005_program.html

Thangavelu M., Dorrington G.E.,(1988) MALEO: Modular Assembly in Low Earth Orbit;Strategy for Return to the Moon, ST88-15 International Astronautical Federation Conference, Bangalore, India

Thangavelu M.,(1992) Logistics for the Nomad Explorer Assembly Assist Vehicle:An Architecture for Rapid Global Lunar Infrastructure Establishment, IAF92-0743, 43rd IAF and World Space Congress, Washington DC.

Thangavelu M., etal., The Exploration of Mars:Crew Surface Activities(1999) Space Exploration Studio Team Project, Aerospace Engg. USC.
http://www.lpi.usra.edu/publications/reports/CB-979/usc.pdf

Thangavelu M.,(2000) Lunar Rock Structures, Return to the Moon II, pp106-08 Proceedings of the Lunar Development Conference, Las Vegas, NV. Edited and published by the Space Studies Institute, NJ.

Thangavelu M.etal., (2003), Elements of Sustainable Lunar Base in the South Polar Region, International Lunar Conference, Hawaii, http://www.spaceagepub.com/pdfs/Khaled.pdf

Thangavelu M., etal., (2005) USC Hercules Program for Return to the Moon, AIAA-2005-6791 Space 2005, Long Beach, California, Aug. 30-1, 2005, University of Southern California, Los Angeles, CA 90089
http://astronautics.usc.edu/hercules.htm

Thangavelu, M., etal., (2007) Return to the Moon : Jules Verne Project Fall 2006 Team Project, ASTE527 Space Exploration Architecture Concept Synthesis Studio, Astronautics and Space Technology Division(ASTD), University of Southern California, CA 90089-1191

Thangavelu, M., etal (2007) Human Space Activities : The Next Fifty Years USC School of Architecture Faculty Adviser : Madhu Thangavelu, AIAA Space 2007 Conference, September 2007, Long Beach, California Arch 599 Graduate Seminar in Human Space Exploration, Fall 2006, School of Architecture, University of Southern California. Los Angeles, CA 90089-1191

Thangavelu, M.,(2008) Critical Strategies for Return to the Moon: Altair Dust Mitigation and Real-Time Teleoperations Concepts, *Joint annual meeting of LEAG-ICEUM-SRR*, # 4056, Cape Canaveral, FL, Oct. 2008, Astronautics Dept., Viterbi School of Engineering and School of Architecture, University of Southern California, CA 90089-1191.

The Global Exploration Strategy:The Framework for Coordination. (2007). Retrieved from NASA: http://www.nasa.gov/pdf/178109main_ges_framework.pdf

Toups, L., & Kennedy, K. J. (2008). *Constellation Architecture Team-Lunar: Lunar Habitat Concepts*. AIAA SPACE 2008 Conference and Exposition, 9-11 Sep. 2008. San Diego, CA, United States : Johnson Space Center .

Wagner, S.,(2006) "The Apollo Experience Lessons Learned for Constellation Lunar Dust Management", *NASA/TP-2006-213726*, NASA-Johnson Space Center, October 2006.

Wilcox, B., et al.,(2007) "Athlete: A Cargo Handling and Manipulation Robot for the Moon," *Journal of Field Robotics*, Volume 24 Issue 5, Pages 421 – 434, Wiley InterScience 2009, NASA/JPL, California Institute of Technology, Pasadena, CA, 2007

Wilson, T. W. (2005). *REGOLITH SINTERING: A SOLUTION TO LUNAR DUST MITIGATION?* Lunar and Planetary Science XXXVI .

Woronowicz, M.,(2008) Modeling of Lunar Dust Contamination Due to Plume Impingement, Sixth International Planetary Probe Workshop, Atlanta, SGT Inc., 7701 Greenbelt Road, Greenbelt, Maryland 20770, michael.s.woronowicz@nasa.gov, http://hdl.handle.net/1853/26387