In-Situ Resource Utilization in a Lunar Environment

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Abstract

In-situ resource utilization (ISRU) is a building strategy recently propounded as a cheap method of space infrastructure construction. ISRU involves using local resources, as opposed to those brought from Earth, in both production and construction of needed substances and structures. It is proposed here that advance utilization of lunar regolith would allow quick construction of cast basalt lunar structures by arriving astronauts or colonists. Methods for regolith casting and designs of structures built by this method are explored and evaluated, with a focus on early deployment.

Introduction

Regolith is the term for the layer of fine dust blanketing the Moon's surface. It has some valuable components including trapped oxygen, possible water, and the nuclear fusion fuel Helium-3. Due to its silicon- and aluminum-rich composition, "raw lunar soil may be fused at about 1550K, then allowed to cool and solidify into a very hard, exceptionally strong material. If cooling is virtually immediate, the liquid basalt becomes a polymeric substance very strong but also moderately brittle. If permitted to cool more slowly the material anneals into a far less brittle crystalline form." (1) This crystalline material is similar to superior Earth cast basalt, a material about as strong as cast iron. Such lunar cast basalt, along with the latest in lunar cement technology, would allow for strong lunar buildings. Requirements placed on this material include a general 1-meter thickness to shield radiation to below 5 rem and an ability to withstand *internal* pressure loads. (2) Fortunately, due to the weak gravity on the Moon, structures can be underbuilt relative to here on Earth.

Methods of Surface Processing

ISRU construction methods can be divided into three stages: automated fabrication with lightweight robots, a fixed human-supervised solar heater, and a full-scale factory.

1- In 1980, a "paving robot" was designed to melt regolith into a long flat surface, usable as a runway or highway. [Figure 1] (1) With some modifications, this robot could also serve to produce slabs of cast basalt. Power demands would be quite high to produce meter-thick slabs, however, and this robot would require either internal nuclear power, power beamed from orbit, or some hybrid of the two. For example, a 5x5x1 cubic meter slab would take about 40 megawatts in an hour (calculated from provided equations using Maple X). From the original design, one robot could produce 10800 square meters of 3-cm thick slabs in a year. Thus, the first approach requires a large quantity of power, while the second requires a large quantity of cement. (Lunar cement is already a proven product, if made from anorthite using steaming. (3)) This process would thus be slow in producing viable product. Fortunately, since the technology of the robot is rather simple, it could be launched in the extreme near future and produce enough building material by the time humans arrive. The automation would also be simple enough; a navigation algorithm similar to those used in automatic vacuum cleaners would also serve well on the moon to sweep available surface and avoid obstacles.

2- A more efficient method of producing thick slabs was proposed in 1990 alongside a plan for a regolith-based base. A fixed solar-focusing structure (with moving lenses) could quickly and efficiently fuse regolith to any reasonable size and thickness. According to Ethan Wilson Cliffton, inventor of this device, five slabs produced from it in one lunar day would suffice to construct a habitat module. This option, being of higher mass and complexity, would probably arrive with the first manned missions.

3- When humanity has arrived on the Moon for good, a full-scale production plant may be constructed. Its design will be based on design practices gained from experience building structures on the Moon.

Possible Structures

Cast regolith may be shaped into most conceivable lunar base designs, if a proper base unit can be devised. For example, a curved plate can produce cylindrical modules like those of the ISS, while a flat plate could reproduce most terrestrial structures. For the most efficiency and strength, however, a spherical structure is needed. Spherical sections could be cast without too much trouble [Figure 2] with the use of a mold. Also in the aforementioned figure is a scheme for reducing the amount of casting needed: if cast regolith is layered with raw regolith, the same radiation protection can be had with lower power requirements. Unfortunately, the proposed rover would not be able to mold its castings because of complexity limitations, so non-"boxy" structures would have to wait until the arrival of fixed melters. Preliminary studies show that the stresses on most structures due to self-weight and internal pressure are at least two orders of magnitude below maximum tolerances (see Data), so fused regolith should be a practical moon construction material.

Feasibility

There are several limitations about the project that have yet to be worked around. Firstly, there is only one viable possibility for the power production needed to melt the regolith: solar power. Combustion is impossible on the moon, nuclear power may be too bulky to send to the Moon, and nuclear heating of the sort used on the Voyager probes is insufficient by several orders of magnitude. Electric heating is dangerous; because molten regolith is extremely conductive, any short-circuit would be disastrous, especially with astronauts around. Thus, solar power is the only available option. Because much power is needed, large dishes are needed. It can be seen from the Data section and the charts in the Figures section that a very large dish is needed to cast the regolith quickly. Thus, compromises have been adapted into the melter designs. For the rover, the objective has been changed from heating meter thicknesses at a time to heating successive layers to eventually achieve one meter thickness. For a hypothetical case of production of one cubic meter per day, a ten-meter diameter dish can be reduced to 7.7 meters or less if heating is done successively. Further gains in austerity may yet be achieved. For the fixed melter, there are two methods of improvement. The first is a repetitive-heating scheme similar to that of the rover, though this would necessarily make the installation's machinery more complex and thus more likely to jam. The second is to use several mirrors arranged in a circle on outriggers, similar to heliostat installations here on Earth. If these problems are not solved and the production of only thin panels of cast basalt is possible, there is still some merit to the concept: due to the reduced gravity on the Moon, structures may be insubstantially built compared to those here on Earth. In other words, those thin panels, while unusable on Earth, would be strong enough to make cheap and sturdy unpressurized structures, such as observatories or garages.

Discussion

Humanity is expected to return to the moon in 2020. In order to sustain a permanent manned presence on the moon, lunar structures must be deployed for life support. Such buildings will be extremely massive in order to survive the near-vacuum of the moon. For example, the vacuum-resistant and self-powered International Space Station currently has a capacity of three and weighs 183 megagrams, more than the Saturn V could lift. (4,5) Furthermore, it requires more thrust to move an object to the moon than just to Low Earth Orbit, where the ISS resides, and the current Delta IV-Heavy rocket can only carry 1/9th the load of the Saturn V. Thus, astronomical amounts of thrust, fuel and rocket-building would be needed to create a moon colony of any size in the near future. ISRU can reduce the number of launches needed to put man on the moon by drastically reducing the mass needed to be brought over. It has been discovered that lunar surface material can be quickly processed into a sturdy and resistant construction medium. Thus, if machinery dedicated to surface processing (which would be lighter than habitats) were first launched to the Moon, arriving astronauts could build their own habitats upon arrival.

Conclusion

A permanent human presence on the moon will require a specialized doctrine for lunar construction, or what is in effect a "building code" for the moon's environment. ISRU is the most logical technique to realize this code for two reasons: firstly, regolith can already handle the lunar environment; secondly, it requires the launch of less rockets than would be needed for prefabricated earth structures. Another example of the different building strategies needed for the moon is the building of structures that would not be stable on earth; due to the much weaker lunar gravity, they would be as strong on the moon as sturdier structures are on earth. Thus, cast regolith basalt production must begin as soon as possible in order for humans returning to the moon to work effectively towards a lunar base.

Data

Equation for power needed to cast basalt of dimensions x, y, z in time t:

$P=3.5068e^{9}*x*y*z/t+17081\frac{1}{2}*x*y$ [All parameters in SI units]Equation for dish diameter needed for a power output P:

$D=0.0375*\sqrt{(P)}$.

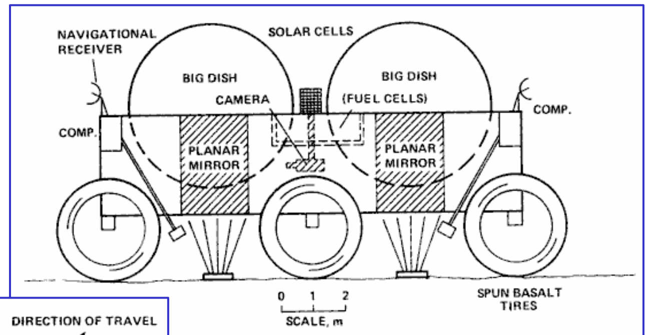
(Above equations derived from (1).)

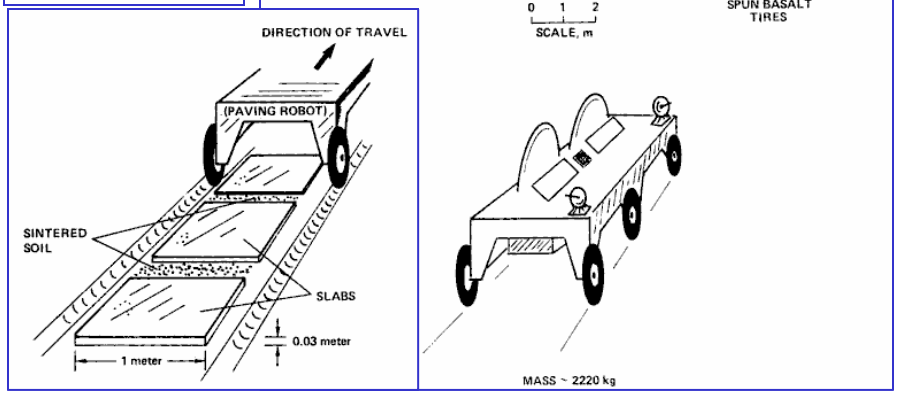
Cast Regolith Parameters from (1)

Density	2690 kg/m^3
Tensile Strength	$3.5e^{7}$ N/m^2
Compressive Strength	$5.4e^{8}$ N/m^2
Young's Modulus	$1.1e^{11}$
Mohs Strength	8½
Melting Point	1550K
Thermal Conductivity	0.8 W/m*K
Molten Resistivity	$1e^{-4}$ Ω*m

Figures

Figure 1: A Regolith Melting Robot (Source 1)





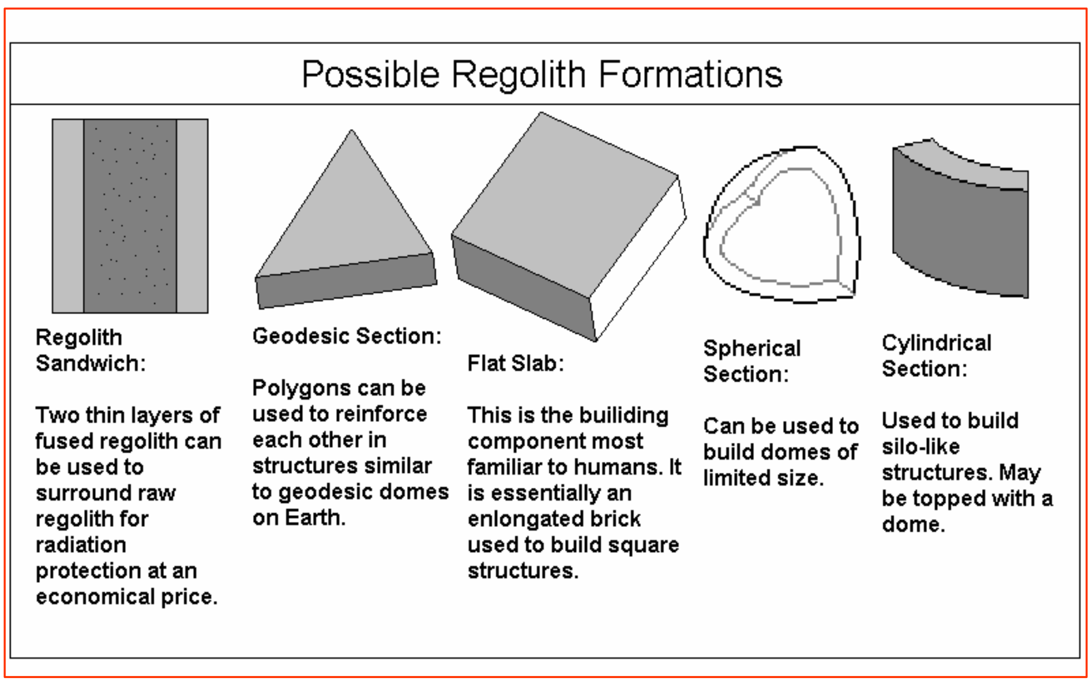


Figure 2: Structure Options

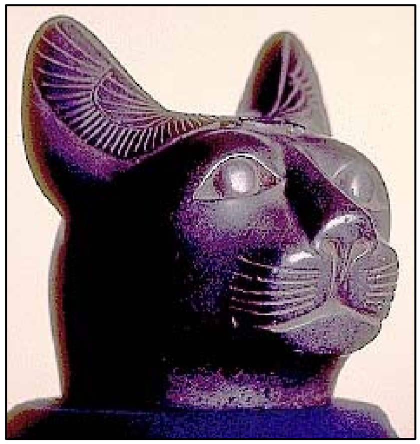
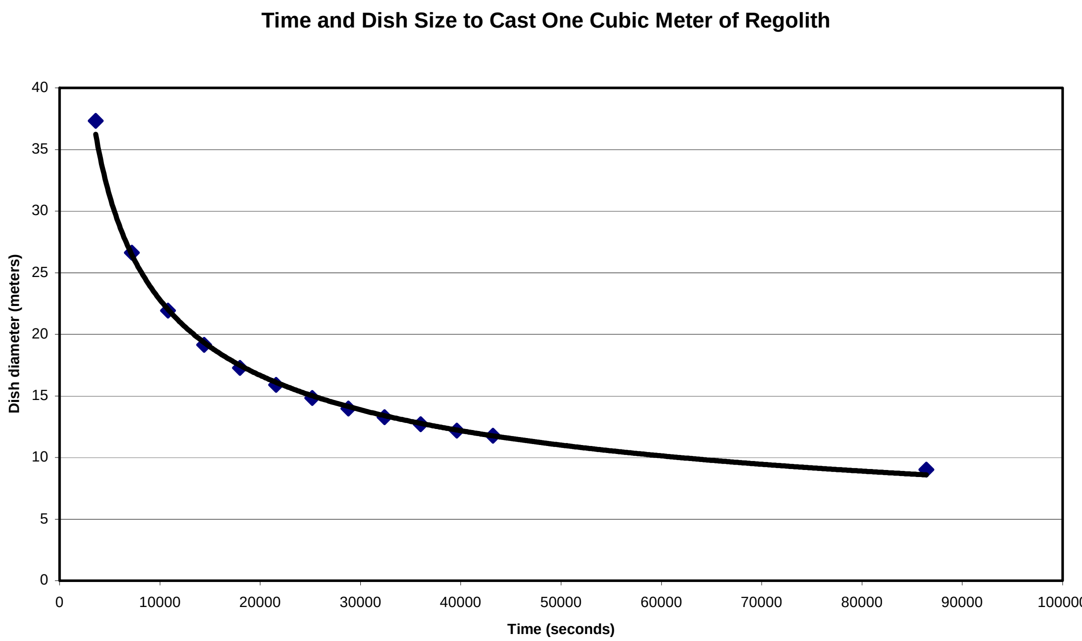
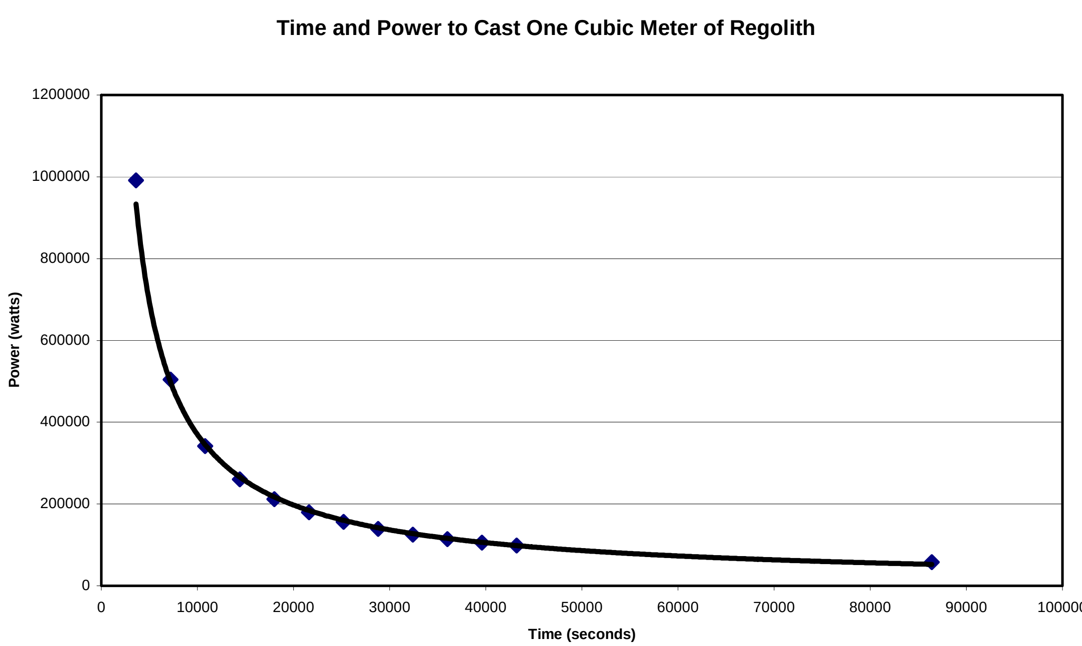


Figure 3: An example of Cast Basalt

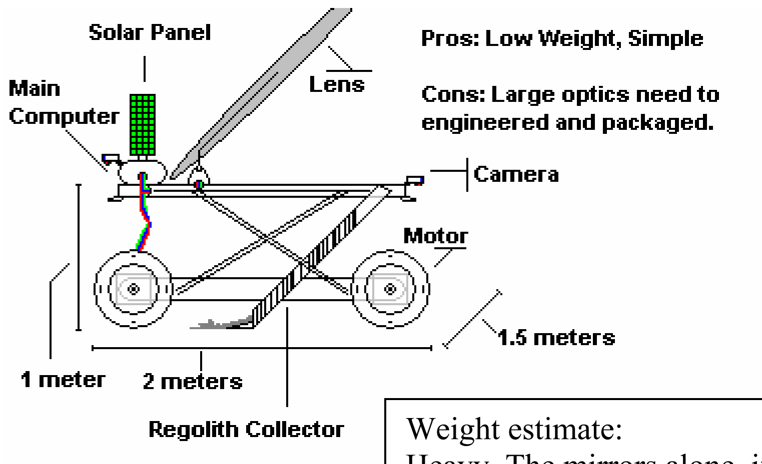




Current Models

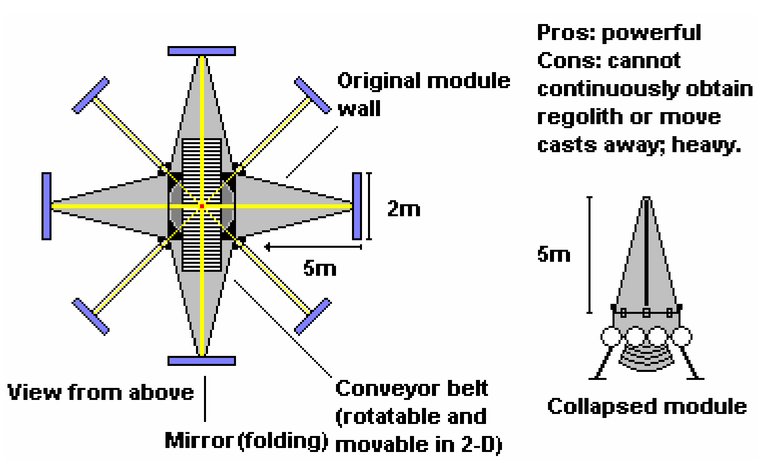
Rover-type regolith fuser:
The top platform moves up with the rising height of the cast basalt slab. The regolith collector is an expandable tube that delivers to the top of the slab.

Weight estimate:
About the mass of the average car. Although it is larger, much of it is empty space. It should be able to be launched by the Delta IV-Heavy rocket.



Heliostat-type regolith fuser:
The conveyor belt moves around to place different areas of raw regolith at the focus of the eight light beams.

Weight estimate:
Heavy. The mirrors alone, if made of aluminum, may mass 3T all by themselves. However, if other components can be reduced to less than 6T in weight, the Delta rocket can also launch this as a load. Also, since the heliostat is integrated into the rocket stage, mass reduction is facilitated.



References and Acknowledgements

1) Appendix 5-C, Proceedings of the 1980 NASA/ASEE Summer Study. NASA report CP-255 (unclassified) Nov 1982. http://wikisource.org/wiki/Advanced_Automation_for_Space_Missions:Appendix_5C 20 Jul 05

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3) Horiguchi, T. *et alii* "Behavior of Simulated Lunar Cement Mortar in Vacuum Environment." *Space '98.* p 571. 1998. Reston, VA: American Society of Civil Engineers.

4) "International Space Station." http://en.wikipedia.org/wiki/International_Space_Station Wikipedia, the free Encyclopedia. 26 Jul 05

5) "Saturn V Rocket." http://en.wikipedia.org/wiki/Saturn_V Wikipedia, the free Encyclopedia. 26 Jul 05

Image credit: "Bast." http://www.goddess-gallery.com/ggimages/egypt/670.jpg The Goddess Gallery. 26 Jul 05.

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