Space Decentral Mission Experiment:

Lunar Soil Autoconditioner (LSA) Project Concept

Revision: New

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Abstract

A common concept in the discussion of permanent Lunar bases is the possibility of growing indigenous food crops to sustain the local population. Numerous studies have been conducted on the general characterization of the Lunar regolith, and also the growing potential of simulated Lunar soils. Where information is generally sparse is the possibility of the reconditioning of regolith into workable farming soil. The time has have come to automate the best of the available state-of-the-art in this area of inquiry into a small, reliable, and efficient processing device for generation of soil stockpiles, where it is to used, on the Moon.

1. Constituency

1.1. Category 1—Robotic

This mission concept includes both uncrewed and rover operational components. The currently available technology for the small, low-mass internal components needed for material bed heating, soil mixing and sorting already exists, and has been employed in a number of forms for lander-based systems since at least the Viking landers of the 1970’s. This componentry has progressed in capability and sophistication until the more recent Martian explorations. The level of open-source technical availability of design details is a near-term goal for the project, and data-mining for this information could be completed within a 6-month timeframe, leading to design efforts for a prototype LSA within a 1-2 year horizon.

1.2. Category 2—Human Spaceflight Payload

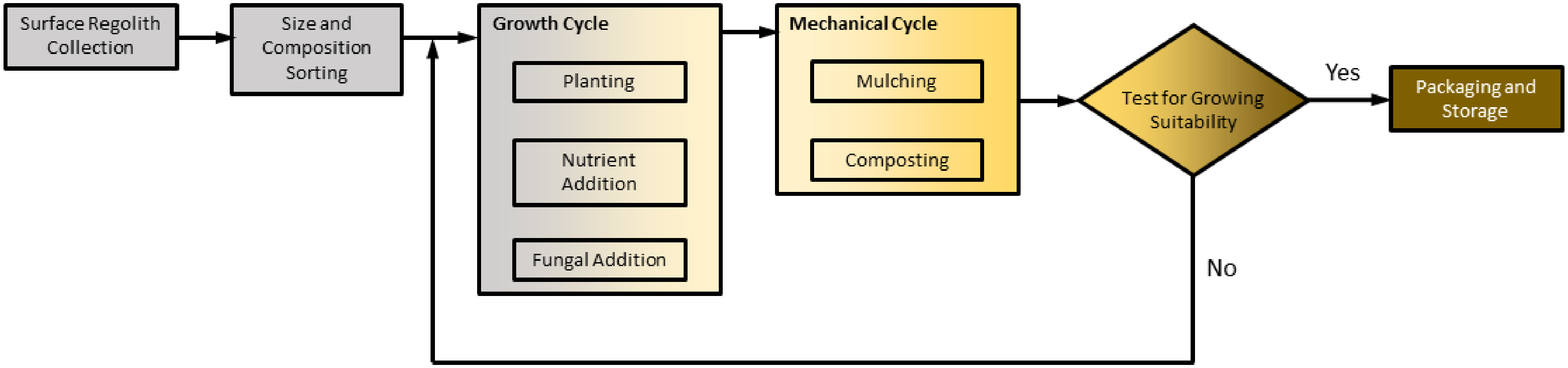
The LSA is not, per se, a Human Spaceflight Payload, but may be initially dependent on human-tended operation to complete certain mission objectives. A decrease in human-directed operational steps trending towards full roving and regolith-collection operations on the Lunar surface proportionally increases design complexity and reliability issues. It is expected that initial versions of the LSA device would be placed by human crew directly at each soil-conditioning location, then moved as needed. Later versions would acquire progressively more sophisticated levels of mobility and navigational autonomy. Systems trades between these factors along a spectrum of automated complexity are still needed, and would be estimated at a 2-3 month, part-time effort. Development and prototype design and testing efforts would be estimated at 1-2 years, dependent on initial development planning directed by the results of the trade study phase.

1.3. Category 3—Expansion

The ability to pursue stable, productive in situ agriculture at human settlement sites within the solar system will be critical for the any expanded Lunar mission. Conceptually, the goal would be for an LSA to generate enough conditioned soil per month to sustain the growth needs of 4 crew. With an assumption of no less than 100 square feet of growing surface area at 0.5 feet depth for potatoes as a control crop, this would be a 50 cubic foot initial production need.

Broken down into a per month production schedule, this would be 4.2 cubic feet per month to achieve initial soil needs within the first year of operation. If it is assumed that each LSA was designed to produce nominally a 1 cubic foot package of conditioned soil per month, and 5 LSA units were in operation simultaneously, this results in a 60 cubic foot nominal production. This approach would provide a 20% production tolerance, allowing for inefficiencies in the LSA "fleet operations" and maintenance/repair downtime periods.

For continued expansion year-for-year, the LSA fleet could be expanded by another five (5) units per year, therefore increasing sustenance capabilities into the foreseeable future.



Lunar Soil Autoconditioner (LSA) Operation Process Diagram

2. Domain

2.1. Commercial Mission (COM)

An immediate commercial path for this mission is not expect unless a market was developed for selling or bartering conditioned soil amongst various colonization sites. That would be an interesting development to consider but is not in the near-term development horizon. As such, this is not a rationale for the purposes of this proposal.

2.2 In Situ Resource Utilization (ISRU)

LSA development and deployment is most definitely an ISRU mission, as it specifically reconditions Lunar regolith into an indigenous farming resource.

2.3. Operations Demonstration Mission (ODM)

The full development of the LSA technology is meant to result in an operational off-planet, Lunar-based fleet of LSA units performing their intended soil reconditioning function. However, the bulk of this initial proposal is to develop Earth-based prototypes of the system design tested in Lunar simulated conditions and with Lunar regolith simulant material. This would include, at a minimum, the use of Lunar-capable materials and design constraints in prototype construction, thermal vacuum chamber testing, and high-fidelity Lunar regolith simulant. Additional, related crop growth research programs would be complimentary to this hardware design and testing proposal.

2.4. Science Application and Advancement (SAA)

The design, construction, and testing of an LSA unit, combined with plant growth tests as a means of validation, would be of great value to both the advancement of applied engineering science and astrobotany. As such, the proposed project would qualify as an SAA effort.

2.5 Technology Demonstration Mission (TDM)

A TRL map of this project is not yet mature, but it is expected that would be no less than TRL-3 in initial application and would not be considered a successful project without fielding hardware satisfying TRL-6 within a thermal vacuum test apparatus. The ultimate goal would be to bring development of the LSA into a TRL-8 system to satisfy agricultural aspirations of a Lunar colony or long-term surface base camp.

3. The Value Proposition of a Space Mission

3.1. State of the Art

Insomuch that anyone has pursued the construction and automation of a device such as the LSA, there is not much to draw from. Two avenues have been approached in extraterrestrial soils of any kind: materials analysis and unmodified growing tests. In the former case, the NASA Surveyor program performed sample analysis in situ, providing good data on some varieties of available regolith mixtures. Significantly adding to these datasets are several robotic missions in the Soviet Luna program, including both in situ analysis and innovative sample returns. Of course, NASA sample collections from the Apollo missions have been extensively studied, classified, and simulated using Earthly soil analogs. Those Lunar simulants have been used in the second avenue of investigation, and surprisingly, indigenous Lunar soil appears to be usable for growing plant life, though not growth of a particularly fertile performance. Based on this baseline ability to germinate on some level, the LSA is expected to have a good starting point to the growing/tilling/composting/growing cycles expected to manufacture progressively richer soils. The foundational capability exists, which is incredibly fortunate.

Also of importance are similar soil growth studies using analog simulants of Martian soils. While these soils are chemically different in many ways in comparison to Lunar regolith or familiar Earthly soils, the robotic Mars missions to gain data to simulate these soils have provided definite collateral technological advances. These advances will be of great value in developing the LSA going forward.

In regards to soil reconditioning, the currently available data is geared towards macro production for farming, on Earth in open-air settings. The LSA will aim to control the reconditioning environment in a smaller setting, where open-air environments do not exist. Environmental vagaries of wind, rain, and temperatures are monitored and adjusted as controlled variables. On the small scale of a Lunar base servicing the agricultural needs of a small population, the LSA would bring optimum efficiency to the soil improvement process. It is also a modular approach to the problem, insomuch that LSA units would be added to address any farming capacity increases needed to support expansion of the Lunar population. These efficiencies are not improvements over the state-the-art, per se, as the current state is dependent on the available environment. What LSA is intended to do is apply the optimum environmental controls as known for terrestrial farming, and thus provide an efficient and directly-targeted soil improvement cycle and a subsequently optimum growing soil product.

3.2. Purpose

The LSA unit converts Lunar regolith into usable farming soil. For long-term and/or permanent living on the Moon, an agricultural ecology must be established with which Earth-evolved biology is compatible. The LSA will address the particular deficiencies present with Lunar regolith by reconditioning the raw parent material into an actual soil that will support the growth of edible fruits and vegetables.

3.3. Benefit

The product at the initial proposed development phase is a flight-like prototype of the LSA technology, capable of providing re-conditioned Lunar soil simulant for use in terrestrial research in Lunar farming viability and technique. These terrestrial studies will provide validation of the prototype function and production of Lunar farming soil, leading to follow-on development phases for Lunar-based LSA proof-of-concept units, the production units to provide soil to Lunar habitation sites.

3.4. Customer

The customer for the LSA mission is ultimately the Lunar colony or long-term outpost agricultural organization, but the near-term customer will be the terrestrial researcher targeting improved methods of Lunar farming. For the near-term phase, the reconditioning of Lunar soil simulant will provide a growth medium most needed to enhance the accuracy of theoretical studies of Lunar agriculture. The goal would be to provide for the terrestrial researcher a soil that would most accurately simulate the products that could be provided with Lunar in situ resources.

3.5. Paying Customer

The initial phases of this project would be dependent on crowdsourcing, but as operational results validate the concept, National Aeronautics and Space Administration (NASA) and/or European Space Agency (ESA) would be targeted for funding. The latter entity may be particularly well-suited to the use of LSA units in pursuit of MoonVillage objectives. On a longer horizon, any future private Lunar colony program would benefit as a customer, as well.

3.6. End Users

The initial development phase will target terrestrial astrobotanists researching Lunar agriculture. Later development of operational LSA units will be Lunar colonists, be they governmental in charter or commercial/private in nature.

3.7 Platform

The space-bound platform for final operations for LSA units would be the Moon.

3.8. Enterprise

The primary immediate beneficiary of the LSA would be the NASA programs aimed at returning to human Lunar Exploration. Current known plans for food production are focused solely on products grown and processed on Earth and then transported to the Moon. Long-term exploration would benefit from an indigenous form of food production, and outright Lunar settlement will find it an essential activity. In the latter case, an actual definition of “settlement” isn’t satisfied until the ability to provide one’s own food is reliably achieved. In that regards, the LSA is meant to specifically fill a significant hole in the current NASA mission plan.

3.9. Other Customers or End Users

A similar system could be devised for use on Mars, though the chemical and geological makeup of the Martian regolith will differ in significant ways, as will the local environmental conditions, driving a somewhat unique design solution.

3.10 Improvement in the State of the Art

The only previous robotic missions to approach this sort of activity have been focused on sample collection and analysis, such as the initial Viking landers on Mars, to the current rovers there on the Red planet today, etc. Their operational directives drove designs that use robotic means, such as end effectors and drilling/scraping collectors, to provide a material sample. The sample is then subjected to a battery of tests to determine its basic mineralogic composition, possible other chemical content, and discerning if life may be present. While the continual advancement of these probes has resulted in very capable scientific apparatus with impressive abilities, their missions have been solely focused on analysis.

LSA is determined to be focused on regolith utilization, not analysis. Of course, basic mineralogical analysis would be of value to LSA operations, and previous state-of-the-art would be approached there, advanced as required to meet the mission needs. Likewise, certain developments in mobility technology, general robotic functionality, and efforts at quality control engineering would be of great use to the development and deployment of the LSA.

3.11 Who Pays

The initial phases of this project would be dependent on crowdsourcing, but as operational results validate the concept, NASA and/or ESA would be targeted for funding. The latter entity may be particularly well-suited to the use of LSA units in pursuit of MoonVillage objectives. As such, the basis of their ability to pay for the mission is governmental largess. Commercial interests would also be able to purchase these units, which would be on the basis of commercial funding determined by the end user. As spending on space in the private sector is ramping up during the recent few years, it is credible to consider that such funding could be obtained.

3.12. Competition

There is not very much competition for the LSA system noted at this time, though it is obvious that this line of inquiry is on the minds of researchers worldwide. An existing study from 2014 addresses the ability to use simulated Lunar and Martian regoliths as growing media, with the simulants used as-is:
https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0103138

There is also a 2006 study out of Kiev, Ukraine titled “Growing pioneer plants for a Lunar base” that supports the study above, and does add beneficial microbial populations to their Lunar soil simulant to good results. That paper can be found here: https://www.sciencedirect.com/science/article/pii/S027311770500267X

The closest direct competition for the LSA I have found so far is here:

http://blogs.discovermagazine.com/d-brief/2013/11/25/nasa-plans-to-grow-first-plants-on-the-moon/#.XCZuv81MFPY

This NASA mission has yet to fly, and is behind it’s anticipated late 2015 mission date. It also does not recondition Lunar soil in its mission plan. **LSA is better because it directly addresses the use of regolith, instead of imported growing soils. The growth and recomposting approach to in situ soil availability is not only crucial to mature farming techniques on the Moon, it is also only addressed by the LSA concept at this time.**

3.13 Market

There are two markets for the LSA concept, Internal and External.

Internal: The Space Decentral efforts in creating a space infrastructure would be served well by the development of agricultural media derived from the places we settle. In the case of the Moon, existing Space Decentral efforts such as Lunar Habitation design and the Coral regolith construction system would be joined by the LSA as part of a growing body of work in defining a cohesive Lunar settlement strategy.

External: As of the time of this writing, the only other credible Lunar usage planning is underway with NASA. The NASA programs are chiefly concerned with re-constituting and improving the ability to return to the Moon with a permanent presence. Adjacent technologies such as Lunar agriculture are understandably secondary to the immediate needs of establishing foothold missions, with support logistics provided entirely from Earth. As stability to that primary mission leads to a robust and permanent base architecture, indigenous agricultural capability will become important. The LSA would be **uniquely positioned** in that limited market as an advanced means of providing that capability, if pursued immediately to keep pace with the development of the market.

3.14 Technical Fit and Market Fit

The primary, initial market for the LSA will be the NASA Return-To-the-Moon program now underway, as previously discussed. In this current market case, a private effort to develop such a logistical resource will free up equivalent funding within the NASA program that could be up to three times the normal contract value. The assumptions leading to this conclusion are based on threefold advantages:

1. Leaner operational modes in the engineering phases of design, analysis, and test.
2. Faster design and testing cycles facilitated by a much smaller but focused product team.
3. Reduced business overhead versus that typical of NASA and NASA contractors.

Secondary markets will also benefit from the learning experiences in developing the initial units for the primary market and also from incremental model changes as more and more LSA devices are produced. That is to say that developmental costs in a product-improvement regime will be a natural result, based on the primary market as a starting point.

Initial investment funding is well-leveraged in this order of development and production for the markets anticipated.

4. Procedures for the Evaluation Process

4.1 Single Role

Once the Space Cooperative agrees on the final text of the solicitation for the Mission Concept Experiment, participants in the mission concept experiment may partake of one role but not more than one. All members of the Space Cooperative and Space Decentral may participate in the mission concept process as either proposers or as evaluators, but not as both. To avoid conflict of interests, members who propose concepts must recuse themselves from the evaluation process. Conversely, members who plan to evaluate the proposals must refrain from participating in any of the concept proposal teams.

4.1.1. Lead Proposer or Principal Investigator

J. Craig Beasley

4.2 Management and Team

Program Manager – J. Craig Beasley

A veteran of the Shuttle, Shuttle/Mir, ISS, and Orion programs, Craig Beasley is a design and systems engineer with three decades of work on many human spaceflight endeavors. Trained specifically as a Mechanical Engineer from Texas A&M University, he applies a down-to-earth approach to otherworldly challenges. From turning wrenches at the base of one the largest thermal-vacuum testing chambers in the world, to working the spacewalk consoles for ISS EVA missions, or guiding meetings over spacecraft configuration and design, he tackles puzzles where he finds them. Craig has bridged his wide body of work into a Masters of Mechatronic Systems Engineering from the University of Denver, learning to dive deeply into systems concerns and produce the right solutions. A native of Houston where he still lives and works, Craig is active in his local community while also lending his hand to non-government engineering efforts of many kinds, with the loving (if sometimes overindulgent) support of his family.

Two Additional Designers/Analysists are expected during future growth of the team, reaching an eventual split of an even 33.3% of SDN token values during progression of the project effort.

Commitment Levels:

Project Manager: No less than 15 Hrs Per Week
Designers/Analysts: No less than 10 Hrs Per Week

4.7. Budgets

The proposal conveys a concept development, “pre-phase A” description of the mission or project on a fixed budget.

For the purposes of this proposal, an initial estimate of Labor and External Costs has been prepared, with labor costs most significantly detailed. External in this vernacular refers to materials, fabrication, and external specialized labor as needed. The estimate of Labor Cost is currently expected at a baseline of $73,000 minimum as a baseline, and a possible overage of roughly 25%, bringing an expected maximum Labor Cost of $91,000. With a Fixed Cost of $250,000 (as described in section 4.7.1), that leaves an External Cost range between $159,000 and $177,000. A detailed chart showing how this estimate is derived can be found in the proposal appendix.

5. Appendix

Labor Costs					
Task No.	**Title**	**Resource**	**Hours**	**Rate**	**Extended Cost**
1	Initial Design	Project Lead	120	$50.00	$6,000.00
2	Initial Design	Designer #1	120	$40.00	$4,800.00
3	Pre- Preliminary Design Review (PDR) Presentation	Project Lead	4	$50.00	$200.00
4	Detailed Design - PDR	Designer #1	240	$40.00	$9,600.00
5	Project Management	Project Lead	240	$50.00	$12,000.00
6	PDR	Project Lead	8	$50.00	$400.00
7	PDR	Designer #1	8	$40.00	$320.00
8	Detailed Design - Complete Design Review (CDR)	Designer #1	360	$40.00	$14,400.00
9	Long-Lead Procurement	Project Lead	20	$50.00	$1,000.00
10	Stress/Thermal Analysis	Designer #2	120	$40.00	$4,800.00
11	Subcomponent Test Operations	Project Lead	80	$50.00	$4,000.00
12	Complete Design Review (CDR)	Project Lead	16	$50.00	$800.00
13	CDR	Designer #1	16	$40.00	$640.00
14	CDR	Designer #2	4	$40.00	$160.00
15	Follow-Up Procurement	Project Lead	40	$50.00	$2,000.00
16	Assembly	Project Lead	60	$50.00	$3,000.00
17	Assembly	Designer #1	60	$40.00	$2,400.00
18	Assembly	Designer #2	60	$40.00	$2,400.00
19	System Testing	Project Lead	60	$50.00	$3,000.00
20	Post-Test Review	Project Lead	8	$50.00	$400.00
21	Post-Test Review	Designer #1	8	$40.00	$320.00
22	Post-Test Review	Designer #2	8	$40.00	$320.00
23	**Milestone - LSA Prototype Validated**	-	-	-	

Tot. Labor Hrs **1492**

$72960.00 **Total Labor Cost**

Total Allocated Project Funding $250,000.00

Total Funding Less Total Labor **$177,040.00** **External Costs**

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