RECENT WORK ON USE OF LUNAR MATERIALS FOR SPS CONSTRUCTION

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During 1978 and 1979 several workshops were held under the sponsorship of the Space Studies Institute. Experts in spacecraft design, rocket mission optimization, mass-driver design, chemical processing and industrial automation took part in these workshops. An earlier version of the results will appear, in part, in Astronautics and Aeronautics. The purpose of the workshops was to extend in a logical way the concepts of scaling and bootstrapping[1] studied earlier in 1976 and 1978 NASA studies on the use of nonterrestrial materials.[2,3] In the latest work, the group examined first the question of how small an operation could be mounted that would make a productive use of the lunar materials. In that operation, as far as possible only equipment being developed by NASA for other purposes would be used (the Shuttle itself, without augmentation, small crew workstations, spacesuits, a conventional chemically-powered orbital transfer vehicle, and whatever minimal tele-operators are developed in the course of the next few years).

The interim conclusion of the workshops was that the most cost-effective scenario would be one in which a very small installation would be put on the Moon: a mass-driver plus a small chemical process plant plus a small "machine-shop" would be located in orbit, probably about 2/3 of the way from the Earth to the Moon. By "machine-shop" is meant a partially-automated, general purpose production facility akin to a small job-shop, capable of making most (but not all) of the components of additional, identical mass-drivers, processing plants and machine-shops. On the basis of present-day commercial experience in industrial automation, the group concluded that it would be practical for the machine-shop to be about 90% automated. Many of the machines could be directed by human operators on Earth through radio and TV links, with local microprocessors to handle decisions only on a 3-second time scale, that being the round-trip time lag for signals between Earth and Moon. The machine-shop would produce only relatively simple, repetitive, heavy components. All electronics and all high-precision machine components would be brought from the Earth.

It was calculated that the system would have the capability of replicating about 90% (by weight) of its own components. Its human crew would be mainly for maintenance, especially for those unusual or unforeseeable failures that could now be repaired by remotely-directed equipment. The lunar facility would be installed by humans originally, but might only be revisited occasionally thereafter. Its purpose would be to export (via mass-driver) material to the space facility, and also to replicate locally additional mass-drivers, process plants and machine-shops.

To establish a baseline for the "leverage" gained through the use of lunar materials, an optimized electrical design was completed (3/80) for a small lunar mass-driver. The design took advantage of the six years of design development that have now gone into mass-drivers.[2,3]

Earlier, detailed work by the Lunar and Planetary Institute under NASA sponsorship (D. Criswell, Principal Investigator) had established that a chemical process plant on the lunar surface would be able to process at least 40 times its own mass per year.(4) The group budgeted six tons for such a plant, to yield in three months a total throughput of 60 tons, comprised mainly of an aluminum output of 8 tons, iron output of 3 tons, silicon output of 12 tons, and oxygen output of 24 tons.

Such a plant could provide sufficient feedstock for a machine-shop to replicate in 90 days an additional mass-driver, process plant and machine-shop. The total installation on the Moon would be 37 tons.

In the scenario of the workshop group, the lunar installation would be called upon to produce 33 tons of finished products in three months. The author had an opportunity to check the correspondence of that figure to the 6-ton mass of the machine-shop, in the course of a recent visit to Japan, and found that the 33 tons/6 tons rate of production assumed for the chemical process plant is well within current industrial practice on Earth. During the 90-day replication time, about four tons of specialized or labor-intensive components would have to be brought from the Earth to complete the replication of the facility. The liquid oxygen to bring that four tons from Shuttle altitude to the Moon is within the 24 tons of oxygen-output that the initial lunar facility would produce in that period.

On commissioning of the replica of the original installation, the throughput of material into space from the Moon would be doubled, to 4,700 tons/year. Six more doublings, over a period of less than two years, would bring the total throughput to 300,000 tons per year, with operation only during the lunar days. That 300,000 tons of lunar material in space would be more than sufficient to provide the metals, glasses and silicon needed for the construction of 90% to 96% of the mass of one Solar Power Satellite per year.(5) The process plant and machine-shop located originally in orbit, and its replicas, would operate in full-time sunlight. The table below shows the figures for the process plant.

Installation in space, to process initial throughput of 2340 tons/year	
Process plant mass	29 tons
Machine-shop mass	29 tons
Habitat mass	12 tons
Total mass	70 tons
Outputs in 90 days:	
Aluminum	82 tons
Iron	30 tons
Silicon	117 tons
Oxygen	230 tons

The initial installation in space is therefore more than capable of producing in 90 days the 63 tons of finished products that would constitute 90% of its mass, the remaining 10% for a replica being brought from the Earth. The oxygen produced by the original plant would be far more than required for supply of propellant to bring the necessary 7 tons of Earth-built components for the replica. With the 90-day replication time, the orbital facility, like the lunar facility, would be capable of growth to a value of 300,000 tons/year of throughput in seven doublings, or about two years.

The workshop group has not yet studied the optimization of the mix of products in space between replicas of the primary system and machinery designed for the production of SPS components. Presumably, in the simplest scenario, on reaching the 300,000 ton/year figure the entire output of the facility would be turned to the production of those machines. On the basis of the NASA-funded study(5) directed by R. Miller and D. Smith of M.I.T., the orbital facility could produce in one to two years most of the machines that would be needed for a steady production thereafter of one 10-GW SPS per year.

For the installations that would be replicated, the total amount of unique equipment for which R & D would have to be carried out would be approximately 15 tons. Using cost figures based on Shuttle experience (approximately $60 million per ton) the total investment required for establishment of the initial installations on the Moon and in space, for verification of the overall plan and initiation of the replication process, would therefore include one billion dollars for R & D and $0.4 billion for 16 Shuttle flights, needed to lift 107 tons of equipment and 340 tons of propellant to low Earth orbit. Total program investment to the point of first replication appears therefore to be well under five billion dollars.

The interim conclusion of the workshop group is that the concepts of scaling, bootstrapping, and replication appear certain to provide major cost savings in any program, such as that of the SPS, which requires the emplacement of large payloads in high Earth orbit. It is also clear that there is great value in an approach of that kind, which can achieve high return on a modest investment without exceeding the lift capabilities of the unaugmented Shuttle system. The workshop studies will continue, turning to a detailed examination of optimized growth scenarios and the details of equipment design.

At present (1980) mass-driver development is adequately funded at a level of $250,000 through the NASA Office of Propulsion and Power. Other than the mass-driver, the only item of equipment in the scaling and replication method that is without industrial precedent is the chemical processing plant. Therefore the Space Studies Institute will initiate a grant, approximately in September 1980, of approximately $100,000 (first year) for research and development on a bench-chemistry level system for the separation of simulated lunar soils into pure elements.

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REFERENCES

1. O'Neill, Gerard K., "The Low (Profile) Road to Space Manufacturing," March 1978 Astronautics and Aeronautics (A/A), Vol. 16, No. 3, pp. 18-32.

2. O'Neill, Gerard K., and O'Leary, Brian, eds., Space-Based Manufacturing from Nonterrestrial Materials, AIAA, New York, 1977.

3. Billingham, John, Gilbreath, William and O'Leary, Brian, eds., Space Resources and Space Settlements, NASA SP-428, NASA, Washington, DC, 1979.

4. Criswell, David, Extraterrestrial Materials Processing and Construction, NASA Johnson Space Center, Houston, Texas, 1978.

5. Miller, Rene H., and Smith, David, Extraterrestrial Processing and Manufacturing of Large Space Systems, CR-161293, NASA Marshall Space Flight Center, Huntsville, Alabama, 1979.