A COSTING STRATEGY FOR MANUFACTURING IN ORBIT USING EXTRATERRESTRIAL RESOURCES

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At the First Space Resource Utilization Roundtable we presented abstracts [1,2] discussing the technology of Acoustic Shaping, and its relevance to the development of a Space-based economy. This paper extends the work to study the impact of lunar-based materials on the construction of orbital infrastructure needed for long-term missions. It suggests ways of dealing at a rudimentary level with the uncertainties in cost estimation encountered in considering such endeavors.

In [1] we argued that a key to the development of civilization in space is a space-based marketplace. Such a marketplace, where both suppliers and consumers are located away from Earth, would remove the need to compete in earth-based markets, along with the constraint of launch costs from Earth. The established criteria for Space-based business enterprise are [3-7]:

1. The existence of an Earth-based market where high prices can be commanded for an extended period (e.g. drug and crystal manufacture), or mass-market delivery at a low per-customer cost (e.g., communication or solar power delivery utilities).
2. A 3-to-5 year Return on Investment is seen as essential for space-based business concepts [8].

In [2], we described the technology of "acoustic shaping" where particles of arbitrary shape and materials could be induced to fill surfaces of specified shape, using resonant acoustic fields in a container. This was proposed for inexpensive moldless manufacturing of the bulky panels, shields and enclosures needed for space-based infrastructure. The economics of any start-up company in the business of space-based construction [1], encounters the usual problem that there is little infrastructure away from earth. This results in a huge initial cost, incurred for several years before any return on investment. The solution to this problem, was argued to be a national-level investment in some rudimentary items of infrastructure, specifically two items:

1. An electromagnetic launcher on the Moon
2. Pressurized orbital workspace modified from expended Main Tanks of STS missions.

In this paper we consider how the presence of such items affects cost of building other infrastructure. We assume that lunar-based generation of solar cells and power-beaming utility stations are viable, with markets located on Earth, in orbit, and on the Moon. Customers for lunar-based power would include prospectors extracting metals, oxygen / hydrogen; these would generate substantial amounts of loose regolith and other by-products. Such materials form the raw materials for construction of panels suitable for orbiting vehicles, using acoustic shaping in microgravity. The raw materials needed for space-based construction could come either from Earth or from the lunar surface.

A vehicle of the "Mars Cycler" type proposed by Aldrin [9] is considered as an example of permanent space-based infrastructure where inexpensive building materials are needed on a large scale. The Cycler travels continuously in an Earth-Mars obit, offering more interior space than a usual space mission craft, as well as long-term storage and radiation shielding sufficient to protect and provide for many traveler-years. In the literature, concepts for structures in space are limited to assembly of earth-built modules [10] or using extra-terrestrial resources with conventional construction techniques [11-13]. The latter is for habitats.

Infrastructure Test Case for Cost Estimation

The Mars Cycler [9] was chosen as a specific example to focus cost comparisons. Typical dimensions for such a vehicle might be a length of 50m, diameter of 20m, and shell/panel thickness equivalent to 0.05m of hollow aluminum spheres. Three cases were compared:

1. Modular construction on earth and assembly in space using human and robotic labor. Pre-built panels probably require large launchers.
2. Earth-based materials in particulate form shipped to construct panels using Acoustic Shaping in orbit. The launch costs come down because the compact material allow several shipping options.
3. Construction using extra-terrestrial resources and Acoustic Shaping Technology.

The cost in the first case was $ 2.6 billion, which reduced marginally to $ 2.53 billion in the second case (Fig.1). The third case uses lunar materials, shaped using Acoustic Shaping technology. The shapes required are obtained by modifying the sound field, and assembled by robotic arms. Here the estimation process runs into a roadblock because the very existence of commercial operations to extract lunar materials presupposes a market which makes such operations economically viable. The solution is argued below.

Delivered Cost Approach

The lowest projected launch cost today (Year 2000) is roughly $1000 per lb to Low Earth Orbit. This is the lowest price at which investors are likely to support any venture which delivers hollow aluminum spheres to the L-2 point from the Moon. Higher prices will open the competition to Earth-based launchers. Ref. [13] projects a far lower cost of such materials, lending confidence to our estimate. The precise cost of extracting and shipping the material is irrelevant to our estimate. Using this reasoning, the cost dropped sharply to $ 1.16 billion. An accelerated production schedule using multiple acoustic-shaping chambers, showed a negligible increase to $ 1.2 billion (Fig.1). Figure 2 considers the Net Present Value of a company started up using the Cycler shell construction project. Here the a partnership gives NASA a 50% stake in the corporation in exchange for funding the R&D through the various Technology Readiness Levels before flight, and for providing space at a NASA Center to develop the manufacturing facility, and boost the facility to the L-2 Lagrangian point.

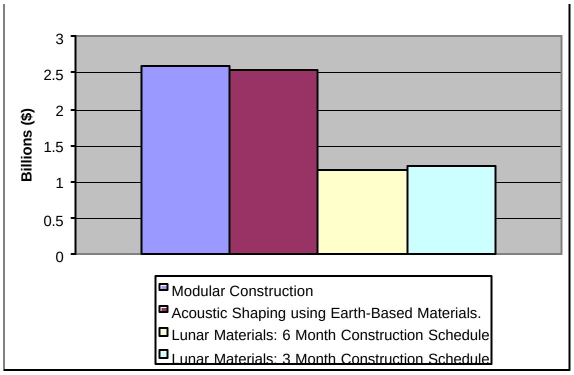

Figure 1: Cost Comparison

The presence of this facility provides the initial customers for the material collected on the lunar surface, and helps bring that entrepreneur into business. The NASA outlay is justified by the fact that the money goes into establishing a growing infrastructure, and cuts the per-unit cost of building craft such as the Cycler for NASA missions. This goes with our argument in Ref. [1] that a national-level investment in infrastructure is essential to developing a space-based economy.

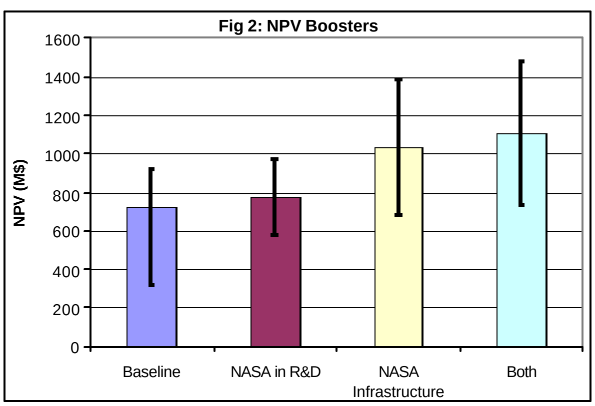

Figure 2: Net Present Value of an Acoustic Shaping company modified from [1], constructing a Mars Cycler vehicle shell at L-2 .

Assuming the same outlay and incomes in all the years of the development of the system (a simplifying assumption), initial calculations project a cost saving of $ 400 million in the 13th year of operation, compared to Earth-based competitors. Compared to the NPV projections for a startup company given in Ref. [1], the initial uncertainty period is now eliminated. Such a facility will operate with minimal recurring costs, because the product is something required over an extended period, with minimal design changes other than the custom-tailoring of shape which is done on Earth, and the operation is robotic. Barring disasters such as meteroid impact, the company shows promise of being profitable. The other side is that in the process of the Cycler project, it also helps the lunar-based material extractor and shipper make revenue as well. Further refinements of this model of cost estimation and space-based construction will be presented at the Roundtable.

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