Space Manufacturing Facilities 1 Conference Introduction

By Gerard K. O'Neill

During 1969-72, calculations were made at Princeton relating to long-term development for our necessarily technology-based society. They were focused on energy and materials resources, and on the physical conditions for achieving high productivity and an expanding economy without damage to the environment.

Briefly, these calculations suggested the possibility of establishing a permanent beachhead in space, in the form of a manufacturing facility at L5, a gravitationally stable location in free space in the lunar orbit. At that location, where sunlight would be available 24 hours per day, the facility could use solar power for all its energy needs:

(1) after concentration by mirrors, for all industrial process heating;

(2) directly for the growing of crops under high-yield conditions; and

(3) as a heat source for electric turbogenerators for all electrical needs.

Its location was also chosen to allow obtaining nearly all the material for the construction of the facility itself, and all the raw material for its manufacturing operations, from the lunar surface. Because the energy required to move materials from the lunar surface to L5 would be about a factor of twenty lower than for moving materials from the Earth, and because the Moon has a vacuum environment, it appeared possible to obtain materials at a cost about 1/ 100 of that which would be required for transport from the Earth.

A facility of this kind was assumed to be a living and working habitat of large dimensions, Earth-like in environment and capable of supporting a population of the order of 10,000 people. The existence of this facility would then constitute the first step in a bootstrap process, in which habitat numbers could grow without the need to draw energy or materials from the Earth. It was not intended that these facilities would return material products to the planetary surface, but that they could, more economically than the Earth, build products whose end use would be at or near escape distance.

In these studies the condition was set that only 1970's technology was to be used. No rocket motor more advanced than the space shuttle main engine was to be required, and no nuclear-powered vehicle was to be considered. The transport of raw materials from the Moon to the habitat site was to be made by an electromagnetic accelerating device (mass-driver) running on solar power. it would accelerate compacted lunar payloads of a few kilograms each to the lunar escape velocity, provide precise guidance, and then release them to climb out of the lunar gravitational field; they would arrive at escape distance moving at near-zero speed. Such a device has never been built, but its performance is calculable and its construction would require only the technology of the present day; it could be constructed and tested on Earth.

With good direction and high priority, but not under "crash program" conditions, I estimate that the first space manufacturing facility could be in place with its productive capacity working by about 1988. Although the first habitat would accommodate a thousand times as many people as have now been to the Moon, the cost-saving techniques just described should permit its construction for a total cost comparable to that of Project Apollo. Even the highest estimate which I have so far heard, an estimate generated independently by a team within NASA and intended to be on the high side, is only a small fraction of the presently estimated cost of Project Independence.

Early Work

We have grown used to the fact that new technological developments, often heralded as beneficial, almost as often turn out to be absurd or counter-productive when all their implications are considered or when their natural growth is projected a moderate interval into the future. The first three years of the Princeton work were therefore devoted not only to finding solutions to the basic physics questions connected with the new development, but to establishing how large space habitats could eventually become within the limitations of presently available materials, and especially to examining how soon materials limits would be encountered. The conclusions were favorable: habitat sizes up to several hundred square miles in land area appeared possible, and asteroidal materials (not adding the resources of the Earth or of the Moon) appeared adequate for the eventual construction of total land areas many thousands of times as large as that of the Earth, should that ever prove to be desirable.

Beginning in late 1972 private lectures on this subject were given. and study of the economics was begun. In May 1974 a small, informal conference was held on the topic at Princeton. The Proceedings of that Conference are included as an Appendix to this document. As a result of a front-page article in the New York Times, reporting the 1974 Conference in favorable terms, a considerable wave of publicity was generated and is still growing.

The intensity of the public response seems to have three causes: the possibility of direct personal participation in a frontier activity; the sense, expressed by many correspondents, that this approach may be the most beneficial long-term solution to a number of problems of current urgency; and the realization that no new breakthroughs would be required for its attainment. In terms of mail, letters from individuals and organizations have been in favor of the new development by a factor of about 100 to 1. Many individuals with considerable technical qualifications have written to offer their services on an unpaid volunteer basis, and are now doing useful work to further these ideas. Environmentalist groups which have so far expressed an opinion have been uniformly in favor.

Recent Developments.

The first technical publications on this topic were a letter to Nature and an article in Physics Today (September 1974). A significant consequence of the Physics Today article has been the acceptance of the basic physics calculations; the article has been widely read and reprint requests for it are still arriving from many parts of the world; yet in spite of intensive review and exposure to a large technically trained readership, no significant disagreement with any of the numbers or calculations has so far appeared

The reaction from NASA has been favorable.

Although these ideas were unknown to the agency until May 1974, by January of 1975 NASA headquarters and one of its research laboratories had jointly given to Princeton a small grant for further research; I consider this to the credit of some far-sighted individuals within the agency. Interest, particularly among the younger people of the NASA laboratories, is also strong.

Energy Needs at the Earth's Surface

Until the autumn of 1974 I had considered the development of space habitats or colonies as a desirable longterm goal, but did not see any possibility for immediate payback to the Earth. I still regard it as impractical to think of the habitats sending back manufactured products to the Earth, except for very small, specialized high-value items. Clearly, though, even the earliest such habitat would be in a favorable location for producing (from lunar material) and assembling (at its zero-gravity industrial site) large objects whose end use would be at or near escape distance from the Earth.

One such product could be satellite solar power stations, for relocation in geosynchronous orbit to supply electric power to the Earth's surface by a low-intensity microwave link. The satellite power station concept has been under discussion since 1968, and research on it is supported at a modest level. It appears to have considerable advantages from an environmental viewpoint over liquid-metal fast-breeder reactors or other fission power sources. It has not been taken very seriously so far, though, mainly because its achievement of economic feasibility appeared to depend on reducing by large factors (10 to 20) solar cell mass and cost and lift costs to geosynchronous orbit.

It appears that a more conventional kind of satellite solar power station, using turbogenerators rather than solar cells, could be built at L5 for about one tenth the price required for construction and launch from the Earth. Relocation from L5 to geosynchronous orbit, included in the estimates, would be a small fraction of the total cost. If these numbers are correct, once a space manufacturing facility is established satellite solar power could become competitive even without any technology beyond that of the 1970's. Maintenance costs of such a system should be low, so after amortization the power costs of satellite solar energy should decrease. An article on this subject was written and published by Science (December 1975).

Interaction with NASA

The agency supported the Princeton work initially on a temporary basis at a low level: $25,000 per year. That support continues, and has been expanded somewhat. NASA has also conducted a year-long study of its own on the question of its role during the years 1980-2000: the "Outlook for Space" report, published in January 1976. The report included some discussion of the space manufacturing facilities concept. Major events related to this work are NASA Ames Laboratory/Stanford University Summer Studies, one scheduled for June 16-August 22, 1975, with a probable follow-on in 1976 and subsequent years. Twenty full-time participants for the 1975 study have been selected from about 100 applicants.

The Future

Up to the present time the technical work has developed on a rapid time scale, and every indication is that public interest is growing at a similar rate; in addition several more popular articles based on interviews are already scheduled for publication.

If the potential payoff from the new development is in fact as great and as near as many of us now estimate, a loss of time now, in the early research phase, would be as serious as a corresponding loss occurring later on. Much time could be saved if a substantial effort were put into each of the following points: small-scale closed-environment agricultural growth tests; minimum-cost atmospheric mixes based mainly on chemical sources identical to lunar materials; detailed design of the mass-driver; design of a simplified lift-vehicle.and a simple space-tug, both to be derived from existing hardware and to require a minimum of new development effort; thorough and responsible cost estimation with participation from a number of independent sources of expertise both inside and outside the government; and detailed time estimates with alternate routes explored.

Altogether, if carried out in parallel, these studies would probably cost from $600 to $900 thousand, about 1/3,000 of NASA's annual budget. With such an input, for example, it should be possible in about a year to answer positively any remaining questions about basic feasibility, to block out a minimum-cost, minimum-time program leading to a first space manufacturing facility, and to design and cost out a satellite solar power station in considerable detail. If the necessary money were available and I had some degree of control over how it were to be spent, I would put most of it into studies within existing governmental, university and industrial laboratories, reserving very little for Princeton; most of the necessary expertise is located in other places.

Publishing History

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