SHOULD WE COLONIZE THE MOON BEFORE SPACE?   C. H. Holbrow   Colgate University *

A number of recent proposals for lunar utilization have suggested a small base on the Moon for mining raw materials with a large permanent community performing manufacturing somewhere in space (1), (2), (3). A major argument against a large, permanent colony on the Moon has been the cost and difficulty of lowering and raising people and supplies in and out of the Moon's gravitational potential well. This argument may still be valid, but viewed against the complex engineering problems of designing and shielding a rotating space colony, the issue is not clear cut. The purpose of this note is to point out some of the advantages of colonizing the Moon first; mention is also made of some of the difficulties.

Problems of Colonizing Space

The most recent and detailed study of the colonization of space is the Stanford-Ames study (SAS) made during the summer of 1975. (3) SAS proposes a colony of 10,000 people in a torus 1790 m in diameter and rotating at 1 rpm to simulate earth-normal gravity. To keep radiation exposure below the 0.5 rem/y dosage permissible by U. S. safety standards for individuals in a general population, the torus is to be surrounded with 10 million tonnes of non-rotating shield.

Such a large rotating structure is a source of formidable engineering problems. Access must be through non-rotating docking ports connected to the torus' rotating hub. Because the radiation shield also insulates the interior, heat must be removed from the rim of the torus by heat pipes through the six spokes to a large despun radiator attached to the rotating hub.

At 1 rpm the rotation of the torus will move the 2-cm thick aluminum walls of the habitat at 93.7 m/s (210 mph) through its tunnel of shielding. Clearly, maintaining proper alignment of the rotating torus and its surrounding shell of shielding will be a critical control problem. Moreover, the alignment and control of the system of mirrors which bring in sunlight will also demand a high level of engineering accomplishment. Despite the substantial problems there is considerable reason to believe that the aerospace engineering profession could successfully overcome these difficulties.

Shielding presents a less tractable problem. The very scale of an effort to place over 10 million tonnes in orbit at a large distance from the Moon requires technology not yet developed. Even at a rate of one million tonnes a year, the undertaking is impressive not to say daunting. The matter

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must be hurled from the Moon at high rates of launch by electromagnetic launchers whose engineering yet remains to be fully specified. The launch velocity must be controlled to an accuracy of about 4 parts in 10 million. The ways of collecting the launched material in space and delivering it to the colony are at best presently imagined only conceptually.

Moreover, before any manufacturing in space can begin we must have the raw materials; therefore, launching from the Moon must begin before manufacturing. Consequently, the initial materials and power for this launching can come only from Earth. To launch from the Moon the amount of material called for by SAS would require 200 MW of electrical power on the Moon. For reliability and availability of continuous power, SAS called for setting up a 200 MW nuclear power plant on the Moon. The very availability of this large amount of power on the Moon suggests other design possibilities.

Advantages of Colonizing the Moon

By placing the principal body of colonists on the Moon and rotating a work crew to factories in lunar orbit, most of the problems of a large rotating system and massive radiation shielding in space could be avoided. On the Moon shielding could be achieved by using underground residences in tunnels or simply under heaps of bulldozed lunar material. Five meters of regolith would probably be sufficient to bring radiation dosages below the .5 rem/y limit. Gravitation would be provided by the Moon's attraction although at only 1/6 of Earth normal.

To use the high vacuum, abundant sunshine and weightlessness available in space a factory of the size of the construction shacks proposed by Driggers (4) could be built in lunar orbit. Work crews of 2000 people would spend 120 days there each year and then return to the permanent colony on the Moon for the remainder of the year. Experience with Skylab indicates the workers could stand zero g for 120 days with no irreversible effects, so a non-rotating structure could be used.

Work crews are not "general public", (for example, they do not include children or pregnant women) and can be designated as "radiation workers". For this category U. S. standards limit radiation dosage to no more than 5 rem/y. In 120 days under normal circumstances they would not receive the annual dose in the absence of shielding or even from radiation due to secondary ionizing particles generated in the mass of the structures around or near the workers. Thus, extensive, massive radiation shielding would not be necessary.

One exception must be noted. Solar flares can produce bursts of radiation sufficient to kill unprotected humans. There would need to be available a shelter sufficient to protect the entire work crew against solar flares for a few days. Adequate protection against flares may be tricky because of difficulties in predicting them. If a permanently shielded

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factory were necessary the principal argument for basing the colony on the
Moon might be weakened. Nevertheless, a fully shielded sphere 100 m in
diameter (i.e. a typical construction shack) would still require only 1.4%
of the shielding required by the SAS colony, a substantial reduction of the
problem.

To see how circumstances might favor colonization of the Moon, let us
consider an example. SAS calls for 192 MW on the Moon just for launching
lunar material. In space another 191 MW are to be used to extract annually
$\sim$ 50 kt of Al and $\sim$ 44 kt of O_2 from the material. Some glass would also be
manufactured, but the bulk of the material would be used as shielding. A
simple calculation shows that if on the Moon the aluminum bearing anorthosite
minerals were refined to alumina at a cost of 76 MW then it would be necessary
to launch each year only $\sim$ 100 kt of alumina in order to extract the desired
amounts of Al and O_2. The power required for launching this amount would be
19 MW. Thus the total expenditure on the Moon for refining and launch would
be 95 MW rather than 192 MW. This calculation does not take into account that
if construction shacks were built in space instead of full scale colonies
the demand for Al might be reduced by as much as 50%. The main demand for Al
in space would be for the manufacture of satellite solar power stations as
in all the other designs. (2) There would, of course, now be a substantial
demand for refined aluminum on the Moon which would counterbalance savings
due to reduced demand for aluminum in space.

Eight thousand people living on the Moon will need more power than 150.
In space they would have used 131 MW, 101 MW of direct sunshine for heating,
lighting, and growing plants plus 3 kW/capita of electric power. Because of
the periodic variations of insolation, direct sunshine would not be as
convenient to use on the Moon as in space although some could be used,
especially if its energy could be stored for the two-week-long nights. The
total power needs of 8000 people on the Moon, including refining and launching,
come to roughly 220 MW, only 10% more than was planned in SAS for 150 people
on the Moon. Thus the Moon base proposed in SAS could support a colony
rather than a mining camp if the requirement of launching enormous amounts
of matter were eliminated.

The energy requirements in space would drop from 131 MW for life
support and 191 MW for industrial purposes to 6 and 110 MW respectively. Not
only would there be some savings of capital equipment necessary to collect
and use the energy in space, there would be a large decrease in complexity
because the complex of mirrors would no longer be needed.

The energy savings would be offset because the use of the Moon as the
colony and the rotation of crews to and from the factory in space imply a
substantial investment in transportation. Two thousand people and the
supplies for them and their industry must be lifted off and soft-landed on
the Moon every four months. Transporting about 720 t of passengers and 4400 t
of supplies each year would be a large and expensive undertaking. Would it

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be as expensive or as complex as setting up the colony in space? Further study is needed to tell. The main point is that taking into account the complexity of design of large rotating systems plus the magnitude of the task of launching one million tonnes of lunar regolith each year, the answer is not obvious.

Problems of Lunar Colonization

Two problems with the foregoing arguments must be noted. It has been assumed that people can live without ill effects indefinitely on the Moon at 1/6 earth gravity. We have no evidence for this. If the assumption is false, then providing earth-normal gravity for large numbers of people on the Moon would probably be much more difficult than in space. If the assumption is true, then it is fair to imagine rotating systems that supply 1/6 g instead of 1 g. The engineering problems of these would be more tractable and a wider range of options would be available than in 1-g systems. However, the telling argument still remains the enormous mass of material to be launched from the Moon.

A second problem is pollution of the Moon. A growing colony of thousands of people with frequent launches and landings would eventually begin to build a tenuous lunar atmosphere. (5) It might well be that the Moon should be only lightly settled as a staging point for subsequent exploration and use of the asteroids. Only then would the real colonization of space begin.

References

1) O'Neill, G. K., Physics Today, September, 1974, p. 32

2) O'Neill, G. K., Science, December 5, 1975, p. 943.

3) NASA/Ames-ASEE-Stanford 1975 Summer Design Study, (in press, Moffett Field, California)

4) Driggers, G., 1975 Proc. Princeton Conf. on Space Manuf. Facil.(in press)

5) Vondrak, R. R., Nature, April 19, 1974, 248, p. 657

DISCUSSION (C. H. Holbrow)

SPEAKER 1:   That is a very interesting idea, but how about doing one little
variant on it and put the workers on Earth, and the station do the final
processing in geosynchronous orbit. Then you don't have the worries about
polluting the Moon; you don't have the dependents of those workers being
supported all the way out on the Moon colony. You have all the dependents
on the Earth. And you have a bigger work force to choose from.

HOLBROW: It depends where they're going to get their materials. Are they
going to get them from the Moon? If so, you are going to have a base and you
are still going to the Moon. If not, you pay an enormous price in transport
up from Earth plus a price in environmental damage to Earth.

HOLBROW: I guess I'm not going to argue that alternative with you, Ralph.
I would certainly consider it. I have an open mind on the subject. I just
wanted to make sure that this one got a hearing.

SPEAKER 2:   Can I ask one question? Are you assuming protection against
solar flares? Presumably that's the major source of radiation hazard.

HOLBROW: Yes, but there are two sources. There are also the cosmic rays -
particularly the high Z, very ultraenergetic heavy ions component of cosmic
rays creates a serious problem. And they will, with a modest amount of mass
around the person, say about 100 grams per square centimeter, produce perhaps
20 rems per year of radiation exposure from the secondaries. And the solar -
if you finally get enough shielding against the cosmic rays, you're also
protected against solar flares.