SPACE COLONIZATION PROGRESS

Research And Technology For Space Utilization

May/June 1991 *Vol. 2 No. 3*

IN THIS ISSUE:

ALTERNATIVE U.S. SPACE PROGRAM

Last year Gerard K. O'Neill, President of the Space Studies Institute, gave a presentation to the National Space Council on an alternative plan for the U.S. National Space Program. The plan is based on the realities of international competition in space markets emerging within this decade. We think the U.S should seriously consider adopting this plan to be a leader in the coming space based economy. It should be interesting to keep this issue and compare it with events as they unfold over the next few years.

O'Neill points out that the realities of the world today are shockingly clear. First, at least two major entities have technical capabilities in the space arena which equal or surpass our own: the Soviet Union and the European Space Agency. Japan and China are not far behind. Any space strategy cannot be evaluated in isolation of other nations.

Second, because of economic deterioration in the Soviet Union and the political changes in the Soviet Block, the conventional Cold War is essentially over. A space effort based primarily on boasting of technological superiority (like Apollo) makes no sense in the 1990s.

Finally, a significant economic threat is the aggressive penetration by Pacific Rim nations into U.S. and global markets. The economic unification of Europe in 1992 will likewise increase market pressures on the United States.

The sum of these realities suggests that in the next few decades the United States will have neither capital nor a military reason to fund a national space program unless it is market driven. Since space is a high technology field, the space effort should address the problem of U.S. competitiveness in high technology.

In light of the above realities, O'Neill introduces three premises that form the foundation of the alternative space program. The first premise is that the program should be cost effective, create export markets, and be planned in cooperation with other nations so that all will benefit.

The second premise is that the time allotted for return on investment should be a maximum of five years. We are no longer an isolated world leader with unlimited government funding and 20 to 30 years to burn. The pace of the program should be appropriate to outrun today's fierce global competition.

The third premise builds on the first two. Significant results can be achieved economically and relatively soon by utilizing resources that are already in space. These resources include abundant solar energy and the oxygen, silicon, and metals available on the Moon.

A space program plan designed consistently around the above three premises will enable the United States to be a competitor in tomorrow's space markets. O'Neill believes we could do better by developing general capabilities rather than locking into rigid plans that span many decades. The lesson to be learned from past experience is that much time and effort was wasted on the false premises of national prestige and the promise of a low cost reusable launch system.

There should be three components to the U.S space program. Space science, resource prospecting, and manufacturing of economically productive space structures. To be cost effective, modular systems should be developed whenever possible to allow mass production.

Space science has always been popular with the general public. Because of our inquisitive nature, it is important for humans to understand the universe around them. Thus, space science missions are an appropriate part of any national space plan.

Some fundamental changes are needed for this aspect of the space program. Institutional and policy barriers should be eliminated to allow more international cooperation. Very few foreign scientists are allowed to fly their experiments on U.S probes. Consequently, other nations are reluctant to allow U.S. sensor packages on their craft. Costs could be lowered and all nations would benefit from more international collaboration.

In addition, more missions should be flown more frequently. The current method of expensive, one shot probes crammed with many experiments is discouraging to young scientists who have to gamble on one chance and a ten to fifteen year turn around for their results. This method does not allow a second follow-up mission with improved instruments to zero in on unexpected results from the initial data.

A more logical strategy would be to standardize designs and mass produce spacecraft in order to offer flights more frequently, say every one or two years. Thus, data from the initial missions would arrive in time to affect later designs and scientists would not have to risk a substantial portion of their careers on missions without a back-up.

Resource prospecting should be the second component of the U.S. space program. To better characterize available resources for use in refueling spacecraft and building space structures, a survey of the inner solar system is urgently needed. Sadly, this is not on NASA's list of things to do. The vehicles required would cost far less than a typical space science mission, and would provide vital data on lunar raw materials and asteroids in orbits that approach the earth.

A lunar orbiter probe should be dispatched first* to determine if ice exists in the permanently shadowed craters of the moon's polar regions. Readers of this publication know by now that if water is found on the moon, it will hasten lunar colonization by providing a vital compound for life support and a source of rocket fuel (hydrogen), two valuable commodities that would otherwise have to be imported from Earth at extreme cost.

Lunar landers will be required next to examine in detail the areas identified by the orbiters. These craft could be less complicated mechanically compared to those that would travel beyond the moon because they could be teleoperated (remotely controlled using television cameras) by operators on Earth. Teleoperation is not possible much farther away than the moon because of the round trip time delay of television signals. Spacecraft equipped with telescopes, much more effective than

* SSI in conjunction with Lunar Exploration Inc. has designed a Lunar Prospector Probe which could be launched next year. The Soviet Union has expressed interest in providing a launch vehicle.

ground based instruments, should be launched to search for earth approaching asteroids. These chunks of rock and metal could be retrieved at minimal cost in propellant. An asteroid 40 meters in diameter, would weigh 100,000 tons. This would cost over $100 billion dollars if the same material were launched from Earth at today's launch costs.

The third component of the alternative plan calls for manufacturing of economically productive structures in space. This aspect of the program takes advantage of resources available in space to build facilities that will pay for themselves (see SCP, March/April). A high priority is utilization of space shuttle external tanks, known resources of aluminum and residual propellants that could be put to use instead of burning them up in the atmosphere. Next, the moon is a virtual treasure chest of raw materials for manufacturing. In addition to Helium 3, an element in the lunar soil that could be exported to Earth-based nuclear power plants (see SCP, Nov./Dec. 1990), the moon has an abundance of natural resources such as oxygen, iron, and silicon that could provide feedstocks for space manufacturing projects. Studies indicate that there are significant potential markets for exports from the moon (An economic model for a lunar colony is discussed on page 4).

The space program plan outlined above will enable the U.S. to remain competitive while fostering cooperation and trade within the global space marketplace. All nations involved will benefit from space programs which are market driven instead of those based on premises of politics and posturing. The three essential components - space science, resource prospecting, and manufacturing of economically productive space structures - should be the foundation of any blueprint for a national space program in the 21st century. According to O'Neill, this strategy was well received by the NSC. Space Colonization Progress will report on developments of this plan as they unfold.

FARMING ON THE MOON

After the turn of the century the first colonies on the moon will need to be self-sufficient as soon as possible. High space transportation costs and excessive travel times dictate that lunar habitats will be on their own. They will need facilities to grow their own food and recycle air, water, and wastes. Like the Earth's biosphere, plants could be grown in a protective enclosure to provide oxygen and nourishment while human (and eventually animal) respiration would provide the carbon dioxide required for photosynthesis. But many questions need to be answered before homesteading the moon. For instance, how will the 14 day lunar night be dealt with? Can plants grow in lunar soil? Can crop yield be optimized to minimize growth space. Can plants be grown in zero gravity allowing crops to be grown on space ships that will travel to the outer reaches of the solar system?

These questions and many others regarding the growth of plants in space have been the subject of research over the last decade mainly in the Soviet Union and the United States. In the January issue of the journal *Acta Astronautica* Frank B. Salisbury of Utah State University's Plant Science Department discusses the results of some of these studies in a paper entitled "Biogenerative Life-Support System: Farming on the Moon".

Salisbury envisions a facility called a Controlled Ecological Life-Support System (CELSS) which would have four components: underground farms, food technology kitchens, waste processing/recycling facilities, and a control system. The report is written from the viewpoint of one of the 250 inhabitants of a colony called Luna City in the year 2019. The colonist is a farmer unlike any from the Midwest.

We are given an overview of the facilities starting with the subterranean farms. The crops are grown in tubular modules covered with lunar soil for protection against ionizing radiation. Sunlight is piped down with fiber optics during the lunar day and supplemented with lamps during the long night. Although studies in the 1980s proved that plants can be grown in lunar soil watered with nutrient solutions, bathing the roots in liquid nutrient media (hydroponics) allows better control and higher production outputs. Research at Utah State on wheat grown in hydroponic nutrient solutions indicated that photosynthesis could be increased and farm size could be reduced by raising light intensities. Based on these experiments and a safety factor of four, the lunar colony allows for 50 square meters of crop area per person.

Crops are selected by such criteria as energy concentration, nutritional composition, suitability to soilless culture, and continuous harvestability.

The food technology kitchens create different types of foods from the limited crops. They also utilize inedible parts such as cellulose in the stems of plants to synthesize sugar. As much nitrogen as possible is recovered before the wastes are recycled.

Both biological and chemical systems are utilized to recycle wastes. Bacteria and fungi combine the wastes with oxygen releasing carbon dioxide, water, and minerals. This natural method is supplemented with physical processing such as incineration of plant wastes resulting in nitrogen rich ash used for fertilizer. The smoke is processed using filters and catalytic converters.

A sophisticated network of sensors throughout the colony sends atmospheric data to a central computer. This control system activates pumps which circulate air between the farms and the city if data indicates that a constituent in one area has been depleted. The network also activates other controls. For example, if carbon dioxide levels decrease in the farms, more wastes must be burned; conversely, if oxygen is depleted in the colony, photosynthesis is speeded up by increasing light levels in the farms.

The scenario postulated above is the best prediction possible with what we know today about the effects of extraterrestrial environmental factors on plant physiology. The CELSS on the moon will be the prototype for systems used on Mars and in deep space. Because of their remoteness, colonies and spacecraft in the outer solar system will face the same problems as the lunar facility in that they must be self sufficient. But each locale has special requirements. The Martian environment has plenty of carbon dioxide, a day equivalent to Earth's, and gravity a little more than 1/3 that of the Earth. But the light intensity at that distance is much lower requiring larger farm sizes or supplemental grow lamps.

The effect of zero gravity on plants is still not well understood. Research so far indicates that plants grow in a direction guided more by the light source than by gravity. But gravity appears to be more of a factor influencing the root systems than moisture or nutrient gradients. Just as long periods in weightlessness have a detrimental effect on human physiology, plants too may suffer a similar fate. It may turn out that CELSSs on deep space missions will have to be spun in a centrifuge to provide artificial gravity.

AN ECONOMIC MODEL FOR A LUNAR COLONY

A concept for an export driven lunar colony has been modelled by Kent L. Miller of the International Management Institute located in Geneva, Switzerland. Writing in the November/December 1990 issue of Acta Astronautica, Miller draws a parallel with the colonization of the New World half a millennium ago. Many of the same challenges were faced by Europe, yet the greatest shift in capital and human resources in history occurred with the colonization of the America. In the face of enormous transportation costs and the risks of sailing the Atlantic, investors funded these missions because there was a huge market in the Old World for gold, spices, furs, and tobacco.

For investors to fund the start of a colony, there must be a market for the colony's products and a method for determining return on investments. In an attempt to establish a basis for growth and posterity of a lunar colony, Miller has created a model which examines the patterns of trade with the Earth. The colony would be exporting goods such as aluminum, oxygen, and ceramics to space stations in low Earth orbit (LEO) allowing these facilities to expand, which would in turn stimulate more demand. The price of these commodities would be competitive with items launched from Earth because the lower gravity on the moon allows cheaper transportation costs.

Twelve key market sectors were identified that would be required in proper proportions to insure survival and promote growth in the colony. 21 goods and services were identified that form the inputs and outputs of the various sectors. The sectors and goods are shown in Table 1. The model provides a tool to estimate the possible scales and proportions of the activities within the economy.

Table 1. Sectors, Goods, and Services

Sectors	Goods & Services
1. Cis-lunar transportation	1. Development
2. Power	2. Production
3. Lunar LOX	3. Operation
4. Metals	4. LEO LH_2/LOX
5. Glass & ceramics	5. Earth-LEO trans.
6. Excavation	6. LEO-LB trans.
7. Surface transportation	7. LB-LEO trans.
8. Lunar labor	8. Power
9. Habitation	9. Lunar LOX
10. Workshop	10. Metals
11. Agriculture	11. Glass & ceramics
12. Science	12. Excavation
	13. Surface trans.
Accronyms	14. Labor
	15. Floor space
LB=Lunar Base	16. Food
LEO=Low Earth Orbit	17. Consumables
LH_2=Liquid Hydrogen	18. Construction Mtrls
LOX=Liquid Oxygen	19. Spare parts
	20. Equipment
	21. Research

(Adapted From A Table by Kent L. Miller
Acta Astonautica, 11/90)

A five year development phase was assumed followed by investments and operations scheduled over a 20 year period. The results of the scheduling efforts were entered into a matrix of the sectors which predicts all the inputs and outputs over the 25 year life of the project.

Prices were then estimated for the products in each year of the project. Some prices are known inputs to the model such as the cost of low Earth orbit transport. Prices of outputs were based on achieving production targets with industry assumed to have a 15 - 35% return on assets, and labor receiving wages of 15% over expenses. Cash flow, profit and loss, and balance sheets were then computed for each sector using the price estimates. This would allow an entrepreneur to predict the cost basis of a business on the moon and determine the return on investments in the colony. This exercise is a prerequisite for a sound business plan with any hope of attracting venture capital and potential settlers.

The cash flow data was arranged to calculate inputs and outputs to another matrix composed of the original 12 lunar sectors plus a foreign and a lunar financial sector. The foreign sector would be LEO customers and the financial sector would be accumulated savings. This matrix was used to see how capital flowed in and out of the lunar industry over time and identify critical links in the economy. With this information, investment and growth rates were revealed leading to some interesting conclusions.

Return on investment does not begin until the 6th year of the colony but this is not unheard of in today's venture capital world. Exports exceed imports by a fair margin. Most of the imports are for liquid hydrogen and oxygen. The trade surplus might improve when lunar oxygen production becomes competitive or if a source of hydrogen is discovered on the Moon. This trade surplus is important to insure a good return on investments.

Within the limiting assumptions of the model, the results indicate that a lunar manufacturing colony would be a viable, lucrative business worthy of investment if a market can be identified that could absorb all the colonies exports. One LEO market identified by Miller is shielding for space platforms from space debris. As the number and size of satellites increase the probability of collision goes up creating a substantial demand for lunar materials that could fulfill this function. Of course, macro engineering projects such as solar power satellites would create a market larger than the model assumes. This would require scale up of the model which would actually make it more competitive on price.

Just as the Old World established colonies in America, lunar colonies will be justified on the basis of lucrative markets. Miller has developed a cookbook business plan which entrepreneurs will use to show investors and colonists that a lunar colony can prosper. The model is intended to be dynamic to allow for technological advances and changing market conditions.

MULTIPLE PROPULSION MODE STARSHIP

There are three general classes of starship engines which have been considered in research on interstellar travel. The conventional rocket, the photon sail, and the Bussard ramjet. In the conventional rocket, fuel on board is accelerated to as high an exhaust velocity as possible to propel the craft forward. The higher the exhaust velocity, the greater the speed of the rocket and hence the shorter the travel time. The fuel can be exhausted by heating it or by electromagnetic acceleration. The upper limit to the exhaust velocity, which results in the most efficient rocket, is the speed of light (the so called Photon Rocket). The only types of rocket engines powerful enough to achieve acceptable exhaust velocities are those utilizing antimatter or nuclear energy.

The photon sail captures electromagnetic energy beamed along its travel path converting it directly into momentum. This concept reduces or eliminates the mass of onboard fuel. The source of the radiation could be the solar wind, a high power microwave generator or a laser. This system has the potential of converting some of the energy to electricity which could be applied to the grid on an electromagnetic rocket.

The Bussard ramjet utilizes a magnetic scoop to channel interstellar hydrogen into a fusion rocket. First conceived by R. W. Bussard in the early 1960s, this system requires that the craft achieve a certain threshold velocity for a given density of hydrogen in the interstellar medium. Again, on board fuel requirements are reduced allowing more of the mass of the craft to be made up of the payload.

In all cases the mission consists of an acceleration stage, a cruise stage, and a deceleration stage. Antimatter rockets and photon sails can achieve travel times on the order of hundreds of years (SCP; July/Aug. 1990, Nov./Dec. 1990), a significant improvement over chemical rockets. Could a starship be designed which combines some or all of these elements to achieve better overall performance than any one of the concepts by themselves?

The answer to this question may be yes according to an Italian scientist named Giovanni Vulpetti. Writing in the December 1990 issue of the *Journal of The British Interplanetary Society*, Vulpetti has developed an interstellar flight optimization computer program called SMAC (Starship Mission Analysis Code).
The program analyzes starship designs with multiple propulsion modes and determines an equivalent pure rocket result. This result can be compared with each mode on its own. Optimum designs can then be determined which deliver the best performance.

A multiple propulsion mode starship might be composed of an antimatter-matter reaction rocket accelerating out of the solar system augmented by a microwave beam impinging on a collecting/reflecting sail. This rocket-sail mode would continue for 30 days until the craft had reached a velocity 43% of the speed of light and a distance of .018 light years from the solar system. At this point the craft would be moving fast enough to prime the ramjet mode. The microwave beam would be switched off and the ramjet would kick in while the rocket fuel consumption rate would be cut in half. This second rocket-ramjet phase would last for 90 days and achieve a velocity of 70% light speed.

Looking at various combinations and different types of propulsion systems, a robotic mission to Proxima Centauri was analyzed which optimized each mode to deliver the highest mass payload at the destination. The results indicated that the Bussard ramjet was not needed and that the job could be done with an antimatter-photon sail acceleration stage and an antimatter deceleration mode. This combination yielded an equivalent rocket exhaust velocity of 95% the speed of light and a travel time of 15 years!

Vulpetti has found that with multiple modes of propulsion properly tuned for optimum performance, a robotic probe with foreseeable technology could return data from Proxima Centauri within twenty years after the launch. With improvements in technology travel times could be reduced. If planets capable of supporting life are found, it is safe to assume that manned missions could be close behind.

High Frontier News Briefs

NASA Centers Study Regenerable Life Support

(From *Space News*, March 4, 1991)

Funding has more than doubled over the last three years for research at three NASA centers on life-support systems based on growing plants to provide food and oxygen. Controlled Ecological Life Support Systems (CELSS) that recycle air and water could reduce the need for resupply ships.

Ames Research Center in Mountain View, CA is looking for ways to increase crop yields on a variety of grains, fruits, and vegetables. The Center is also planning a experiment to test plant growth in zero gravity aboard Space Station Freedom.

Kennedy Space Center in Cape Canaveral, Florida is using a two story sealed terrarium to prove that a plant-based system can provide enough food, air, and water to support one person. Scientists at the Johnson Space Center in Houston, Texas are planning to send a person into a CELSS for 90 to 100 days sometime in 1996.

Total funding for CELSS research in NASA's 1992 budget is expected to reach $7.5 million.

Commercial Space Development Plan For The 90s

(From *Space News*, March 18, 1991)

NASA's Office Of Commercial Programs envisions a three phased plan for commercial development of space. The first phase would development a technology base and test hardware. NASA already allocates $16 million a year to 16 Centers for Commercial Development of Space.

During the second phase commercial applications would be developed and more sophisticated equipment built leading to automated factories in orbit.

The final stage would require a NASA-sponsored corporation to foster private investment in the commercial ventures. This entity would help finance high-risk enterprises that would otherwise not get funded such as a Solar Power Satellite.

The proposal for this program has been submitted to NASA administrator Richard Truly for review but no decision has been made.

Nuclear Rockets Gain Support

(From *Aviation Week & Space Tech.*, March 18, 1991)

Based on recommendations from The Synthesis Group, nuclear rockets are being seriously considered for manned missions to Mars. The Synthesis Group was assembled last summer by the White House to consider options for lunar bases and Mars missions.

NASA's Lewis Research Center in Cleveland has started a nuclear propulsion program aimed at developing and ground testing a nuclear rocket engine by 2006. The Bush Administration is expected to request 21 million in F.Y. '92 for nuclear propulsion studies. Nuclear rockets could cut travel times significantly which would lessen astronauts exposure to weightlessness and cosmic radiation.

IN THE NEXT ISSUE:

Proposal For A Space Engineering Facility
Lunar Construction Techniques
Innovation And Space Exploration
Solar Power Satellite: The Strategy

BACK ISSUES:

Vol. 1 No. 1 ($5.00)
- Lunar Manufacturing
- Space Infrastructure
- Interstellar Solar Sail
- Negative Matter Propulsion

Vol. 1 No. 2 ($4.00)
- Space Station: Teacher's Aid
- Biosphere 2
- Lunar Helium Power Source
- Nuclear Rockets

Vol. 1 No. 3 ($4.00)
- Laser Propulsion
- NASA's Lunar Outpost
- Solar Power Satellites
- Antimatter Electric Rockets

Vol. 2 No. 1 ($4.00)
- Rocket For Space Tourism
- Space Industry And SDI
- Lunar Power System
- Solar Photon Thruster

Vol. 2 No. 2 ($4.00)
- Two-Launch Mars Mission
- First Colony On Mars
- SPS From Space Materials
- Rationale For Colonization

SPACE COLONIZATION PROGRESS is published 6 times a year by:

STAR PUBLISHING COMPANY
754 Glenview Drive #308
San Bruno, California 94066
Subscription Rates: Regular: $18.00; Student: $12.00
Editor-in-Chief: John A. Jossy