Whither Mankind?

Louis Witten

Brought to the Literary Club May 23, 2005

"Is the surface of a planet really the best place for an expanding technological civilization?" This is the question that Professor Gerard O'Neill of Princeton University asked a group of his students in 1969. To his surprise, the answer he and the students arrived at was "Rather than remain confined to the earth, it is much more sensible for humanity to colonize space." They concluded that the major problems on earth — pollution, poverty, shortage of resources, global warming - were overwhelming. All are aggravated by the tremendous population growth; a doubling of the earth's population at the present rate of increase takes place every third of a century. O'Neill and the students argued that our technological civilization would do best, not on earth or on some other planetary surface, but in a space habitat, orbiting freely in space. One of the important disadvantages of a planet is the tremendous amount of mass necessary to create a gravity field to hold people as well as to maintain an atmosphere. A rather simple, rotating, pressurized vessel can achieve the same gravity effect. The asteroid belt contains sufficient resources to create rotating, thin-shelled, space habitats whose total surface area is three thousand times the land area of the earth. If all the asteroid material were gathered into a spherical mass, as it would be if gravity and not rotation where depended upon, its size would be smaller than the moon. It is the replacement of gravity by rotation that makes space colonization possible. O'Neill founded the Space Studies Institute whose primary activity is to study and support humanity's eventual migration from earth. Over the years NASA has provided the Institute with substantial support for its studies.

One of the most important problems facing us on earth in the near future is the shortage of a source of energy. Bringing the population of the earth to an acceptable standard of living and of luxury, even without considering the projected population increase, requires an enormous and increasing amount of energy. And energy is in short supply. The era of dependence on hydrocarbons will come to an end sometime during the twenty-first century, as the supply will be exhausted. Three replacement energy sources could prove suitable: fission reactors, fusion reactors, and solar energy. The other available energy sources, such as wind, ocean tides, and geothermal energy, could only be minor players. Fission reactors, particularly the fast-breeder reactors, could provide our energy needs for thousands of years. But the continual and persistent clamor of fear and of criticism, fed largely by the popular press, has made this choice today politically unacceptable. Fusion reactors are still in the laboratory research stage and are not yet ready for serious consideration. The best laboratory fusion reactors today produce a mere few watts output for every million watts input. If fusion reactors are ever successfully developed, they will introduce their own baggage of problems regarding radiation safety and other hazards.

Is the sun then the future energy source? And, if so, how will the solar power be generated. There is a sufficient supply of energy reaching the earth from the sun to supply the future needs. But the energy is very diffuse in space and variable in time and its utilization from ground-based equipment is very difficult. Power generating satellites built and kept in space may be the answer. They are always exposed to the sun and they show promise for being a clean, cheap, and plentiful source of energy. There is growing agreement that space solar power systems could deliver sufficient energy in the form of electricity to satisfy most of our energy needs.

The construction of a space solar power station may be a first step towards humanity's eventual migration from earth. The migration could be accelerated by a failure to reach a stable earthbound civilization in a reasonable time, if at all. It could come faster as a consequence of mankind's insatiable curiosity, his love of adventure and exploration, his quest of the exotic and of excitement. It might be accelerated by lack of enthusiasm for life on earth, which some may consider to have become too routine and bland and too overly constrained in population size. In any event, if the population on earth is not controlled in time or if, after it is controlled, there is a prevailing pioneering spirit, we will begin to see a migration to and a colonization of space.

Before seriously considering the structure and function of a space colony, one should quickly dispel the idea that this means colonizing Mars or Venus. These are unsuitable for human habitation. To reform their atmospheres to make human life possible would take centuries, if it could be done at all. At the very best, the colonization of Mars and Venus would only allow a tripling of the human population. If the population expansion is permitted to continue at its present rate, the land area needed to relieve the pressure on earth for the next few hundred years may require a several hundred or several thousand-fold increase.

What is meant by a space colony? A space colony is a large human community, orbiting in space, completely self-sustaining and replicating. Farming, manufacturing, gardening, sports, and all other human activities are carried out in the colony. A colony is replicating if it is growing in population and building new colonies without help from earth. The first reaction to the possibility of building such space colonies is disbelief - it is assumed to be far beyond our present day technology to achieve. Surprisingly this is not true. Already in 1969, Gerard O'Neill, outlined plans to build colonies in space. His studies showed that the migration could be successfully accomplished at manageable cost using only technology that existed at that time. As the plans developed it was decided to move towards the fully operational space colonies in three stages. The first stage would be the construction of small space stations orbiting the earth in the vicinity of the moon. These stations, housing about 10,000 inhabitants, are called Island One. The second stage, Island Two, would be larger stations and would have about 150,000 inhabitants. The final stage, Island Three, would be large enough to house about 10,000,000 permanent inhabitants.

During the 1970's, while O'Neill was exploring the possibilities of colonizing space, Peter Glaser, an employee of the Arthur D. Little Company and a distinguished member of the International Astronautics Institute, was championing the feasibility of supplying the earth with energy produced by Solar Power Satellites. The possibility was also being explored by NASA and by the Department of Energy. Solar Power Satellites are satellites situated in relatively fixed positions above and close to the earth. They catch solar energy and convert the solar energy into microwave radiation, which is projected by laser beams to the earth's surface. The radiation is captured by giant receivers on earth and, after suitable modification, the energy is transmitted and distributed elsewhere on earth as needed. A network of such Space Power Satellites could provide much of the earth's energy needs. As an example, if energy is plentiful and inexpensive, hydrogen cells could readily be manufactured and replace existing automobile fuels. It was natural to examine the practicality of having the inhabitants of Island One build the Space Power Satellites. The conclusion was reached that such an industry on Island One was not only practical but would permit the whole enterprise to become profitable in three or four decades.

If the space colonization program were seriously started in the near future, there are people now living who might move into a space colony before they died. The conditions that we should like to have on a colony are normal gravity, normal day and night cycles, an earth like appearance, and natural sunlight. We also would like to have a fairly large colony. The most extensively studied geometry for a colony is one that is cylindrically shaped. Its length and circumference are determined largely by the strength and properties of materials. A feasible construction design would permit a cylinder about four miles in diameter and twenty miles in length. To provide a normal gravity environment for the inhabitants will require that the cylinder be rotating about its central axis. Residents dwelling inside the cylinder, on its outer surface, will experience a centrifugal force. This centrifugal force, sometimes called pseudo-gravity, is completely indistinguishable from a true gravity force. To achieve a comfortable force equivalent to earth's gravity will require a rotation period of two minutes. The centrifugal force acting on objects within the cylinder decreases as the object move towards the central axis and disappears on the axis. Thus there is a rapid decrease in pseudo-gravity from the surface to the central axis where it vanishes. This permits light manufacture as well as recreational activities to take place in a variety of gravitational strengths, from free fall at the axis to full gravity at the surface. For ease of maintaining the axis of the cylinder always oriented to the sun, the space colony will actually consist of two rigidly connected counter-rotating cylinders. This is a technical requirement to eliminate gyroscopic effects.

An earthlike appearance is readily achieved. On the surface, the interior of the colony shell, there is a layer of soil. The soil is the remnant or slag resulting from the mining of lunar material and of asteroids. After the ore is processed, the resultant slag is used as earth. The composition of this earth will be not unlike our own earth.

The circumference of each cylinder is divided into alternate bands of land or living area and of window area. Mirrors are placed outside the windows to reflect sunlight into the living area. The mirrors rotate with the cylinder. Opening and closing the mirrors control the length of day as well as the average temperature and the seasonal variations within the cylinder. In this way residents will have natural sunlight, normal day and night cycles, and whatever seasonal changes they wish.

The land area is devoted to living space for people, animal pets, and birds. It is made as attractive and earthlike as desired with gardens and parks, rivers and trees, lakes, mountains, and grass. Agriculture takes place elsewhere in agricultural cylinders external to and surrounding the residential quarters, perhaps twenty miles distant. Sterile seeds are used and resterilization performed as necessary. Insecticides and pesticides are not needed. For these agricultural units, the gravity, atmosphere, and sunshine are controlled but there is no attempt at an earthlike appearance. With proper planning there will always be a crop ready to be harvested and the food will always be fresh. As desired, some of the agricultural units may be devoted to animal husbandry.

The moon and asteroids will supply the raw material. There will be a permanent mining station on the moon and "space freighters" will go to the asteroid belt to mine asteroids and bring them to the space colony. The moon and asteroids have all the elements necessary to sustain life, including water, metals, carbon, nitrogen, hydrogen, and silicon. By using this raw material, inhabitants of space colonies will be able to replenish their losses, which will be minimal, and to build other colonies. The need for replenishing will be minimal because everything they use will be recycled. It will either be purified or reconstructed. It takes energy to purify material or to break it into primary parts and build other material from it. Recycling everything used in the colony will require a large amount of energy. The power station for the colony is located outside the cylinder and always directed towards the sun. Assuming the solar power station uses present day methods, parabaloidal mirrors, boilers, and steam-turbine electric generators, it will fairly easily supply up to ten times the power per person used today in a highly industrialized society.

What of the dangers of life in a space habitat? One of the first issues that come to mind concerns meteoroids. These are rocks of various types and sizes that have been in the solar system since its origin. For the most part these resemble grains of dust, but they may be considerably larger and every few million years a huge meteoroid hits the earth causing major damage. It is estimated that a meteoroid the size of a tennis ball will hit the space colony every three years. The most sensitive parts of the habitat are the windows. They will be made of glass and will be vulnerable to breakage. The windows will necessarily be subdivided into small panels for structural support as well as to guard against catastrophic damage. Typically a panel may be twice the size of an airplane window. If a window panel were completely obliterated it would take the atmosphere about 300 years to leak out. A repair crew could patch the panel immediately and replace it soon after. A meteoroid of really large size, say a ton, would strike a colony once in about a million years. Such a strike would not necessarily destroy a space habitat but it would certainly cause a great deal of damage. Possibly evasive action may be taken to avoid such infrequent hits.

The inhabitants must be shielded from the incoming cosmic rays and from radiation emitted by the sun during a solar flare. This will require several meters of material to protect them from space. The shielding can consist of the earth and construction material, the mirrors and their supports, the outside agricultural cylinders and the manufacturing facilities. The design will be arranged to provide the necessary shielding. Because of the shielding there will be no direct view of space through the windows. Viewing stations or observation windows may be place at the ends of the cylinders where there are no residents and viewing mirrors can be placed outside all windows. Short time exposure to cosmic radiation is not dangerous.

To inhibit catastrophic fires, the structures in the habitat will be made of non-inflammatory material such as brick or cinder block. The pressure and constituency of the atmosphere will be controlled to minimize the danger of an explosive inflammation.

Precautions against terrorist attacks may be necessary. Precautions against war are hopefully not.

After the process of space colonization reaches an adolescent stage of development, space colonies start to reproduce and to proliferate. A mature space colony can build a second space colony using material mined from the moon and from the asteroids. It would take about ten years to build a new habitat. A space habitat consists largely of standardized structures. Once the structural elements of steel, aluminum, titanium, and glass are manufactured, assembly is quite rapid and may be largely automated.

Will life on a colony be pleasant? With plenty of energy, abundant fresh food, and controlled climate, the living conditions on the colonies are easy. Transportation from one part of the colony to another by bicycle or by electric vehicle produces no pollution and is physically undemanding. Light industry will be performed in the main body of the colony; heavier industry will be consigned to external cylinders or to space in the neighborhood of the colony. Travel between colonies requires unsophisticated spacecraft: shells to hold the atmospheric pressure and the passengers, an oxygen supply, kitchen and sleeping facilities, and simple guidance and propulsion systems. Visits to distant civilizations and cultures are easily possible. Sports and recreational activities in the colony are enjoyed just as they are on earth. Skiing, mountain climbing, sailing, all are available. Since the gravity decreases rapidly with altitude, man-powered flight may be possible. Noisy sports, such as auto racing, will be carried out in the external cylinders. A fully developed space colony could have a population of about ten to twenty million. There will be men, women, and children; playgrounds and parks; schools, universities, and hospitals. The size of living area per family will be equivalent to that of a middle class American family.

Of course the first colony, Island One, will be more modest in overall requirements than the mature ones already described. Perhaps it will be designed to maintain a population of about 10,000 in relative comfort. Its size, about V4 mile in diameter, its structural, and its radiation protection requirements are considerably different from those of the mature colonies. The shape is more likely to be spheroidal or toroidal rather than cylindrical as this minimizes the mass required for cosmic ray shielding.

The colonies will be located at about the same distance from the sun as is the earth. In particular. Island One will be located at a position in space called L5. L5 is a relatively stable region of space in which a space object will remain without wandering far away. It is a region close to the moon and rarely eclipsed by the earth or the moon so that Island One will almost always be in direct view of the sun.

The inhabitants of Island One will be engaged primarily in manufacturing activities and only secondarily in agricultural. They will not be permanent inhabitants but will be commissioned for a fixed term of duty, perhaps two years. Their chief activity will be to process material from the moon and to help construct another Island One, or a more advanced version. Island Two. They will also construct the Solar Power Satellites using primarily material mined from the moon. Since the construction of these solar energy-producing devices uses many of the techniques necessary for reaching the long-range goal of building self-sustaining space colonies, a short description of the manufacturing activity is appropriate. All operations are possible using today's technology.

Among the important space ships to be developed will be the space freighters. These will be huge tanks that will ferry material from one location in space to another. The acceleration needed will be modest so the rocket engines need to produce very little thrust. Basically the engines will use solar energy, which will be processed to eject pellets of waste material from the rocket engine. The propellant energy is provided by free solar power and the fuel is basically waste junk material. Space is sufficiently vast that the junk waste propelled from the rockets will cause no hazards to other operations. These freighters will carry material from the asteroid belts to the Islands, from low earth orbit to Island One, and between other space locations as necessary. The crew of a space freighter can be quite small, perhaps five people or so, and many may be robotically controlled.

The most expensive and difficult operation in space construction involves overcoming gravity. This will always be carried out in stages. If material from earth is to be transported to space, it will first be launched into a low earth orbit, then offloaded into a space freighter to be carried to its final destination in space. Similarly, material mined on the moon will be flung into space by a sling shot type of launcher and caught by a catching ship in low moon orbit. The material will be carried to the Islands in space freighters.

The project may well begin with the construction of a permanent lunar base. This can readily expand into a lunar mining operation. All mining 'on the moon will be relatively easy surface mining on the moon's far side and its effects will be unobservable from earth. The construction, maintenance, and utility of the lunar base carry their own complexities and will not be explored further here. NASA is now in the midst of a study to learn how to establish a base on the moon.

The first Island One will be constructed from material coming primarily from the earth. After the project is operational, space liners will be ferrying workers up to the Islands and others on vacation back down to earth. The Islands themselves will be comfortable for living and for recreation. The actual manufacturing operations will be carried out in space outside the Islands

The four elements involved in the construction of the Solar Power Satellites may be summarized. One is the mining and processing of lunar material. The ore (all lunar soil is considered ore) is mined on the moon, flung to a catching station, ferried to Island One, and processed there. This requires a lunar station with about 100 persons, a catching station with about 5 persons, freighters with crews of about 5, and Island One with 10,000 inhabitants. A second stage is the transport of material from the earth. The material is first carried to a station (about 10 persons) in low earth orbit, transferred to freighters and carried to Island One or to the moon as needed. The third stage includes the processing and manufacturing operations carried out on Island One. Other Islands One are being built and Solar Power Satellites are being produced. The final operation carried out in space is to use the space freighters to transport the Solar Power Satellites to their fixed positions above the earth.

The plans for the construction of Island One and the solar power satellites suggest that they could begin production of power satellites within a decade after the start of the project. Eight years later, with a sustained effort. Island One could have the capacity to process 600,000 tons of lunar material per year. A work force of 3,000 could produce 2.5 solar power satellites per year, each with a capacity of 10 billion watts. In two years from the start of processing the lunar material it could produce enough solar power satellites to provide Cincinnati with all its electrical requirements.

One reason why development of large space stations and eventually space colonies is slow is the cost of launching material from the earth. Using the Space Shuttle or other available rocket launchers, the cost is approximately ten thousand dollars a pound. A great advance in lowering the costs could be achieved if the payloads could be launched without the need to carry their own fuel into space. Concepts are being developed that may make this possible. One may hope that the successful development of these concepts will bring the launch cost down to $100 a pound. Thus a 200-pound man could be launched into space for $20,000. At this cost, one would anticipate the existence of a lively tourist industry on Island One and a much faster movement towards space colonization. There are already plans to establish a space traveling industry with a ride into near space costing $100,000.

The cost to establish the various facilities and to construct the first satellite Power

Station is estimated to be between $60 billion and $120 billion, equivalent to two or three times the cost of the Apollo Project. If the idea of building Solar Power Stations in space proves feasible, building such stations at a reasonable rate would allow energy costs on

Earth to begin falling within a few years after the construction of the first Island One. All the power needs of the United States could be supplied in about twenty years; the total cost of the project would be paid for in less than four decades and would then start to earn a profit.

Only about one half the work force of Island One will be devoted to manufacturing the Satellite Power Station. The other half will be devoted to constructing another Island One. After about fifteen or twenty Island Ones are in operation. Island Two will be built. Whereas Island One is spheroidal with a diameter of ^*A* mile and a population of 10,000, Island Two is a twin cylinder, each cylinder being about 1 mile in diameter and 4 miles long. Island two is designed to house 140,000 persons and will have sunlight entering through three windows running the length of the cylinder. The final scaled up version, Island Three, is a twin cylinder, each about 4 miles in diameter and about 20 miles long. Four miles of atmosphere is enough to produce a blue sky overhead with cloud levels forming at the same level as they do on earth (about 3000 ft.). Island Three will have about 250 square miles of living space to accommodate its 10,000,000 inhabitants. The size of a typical family dwelling unit will be about the same as that of a modest suburban house today. It is estimated that, after the project matures, about 15% of the work force on Island Three could build another Island Three in approximately eight to ten years, using lunar and asteroid material only.

It is perhaps surprising that the concept seems economically viable. It could not work if we had to lift all the material from the Earth, this would be completely unaffordable. It is mining the moon and the use of lunar and asteroid material that permits the scheme to be possible.

The question may be raised whether the lack of genetic diversity in a space habitat poses long-range health problems for the inhabitants. Or, a related question, might the inhabitants go "stir crazy" by being confined within their colonies. After the project matures there will be many Islands Three and additional habitats are constantly being built by nearby residents. The number of self-reproducing space habitats will grow exponentially. One may emphasize that travel from one habitat to another will be easy, safe, and cheap. The appropriate space vehicles need have essentially zero escape velocity to leave the Mother Colony. During the travel, there will be no inclement weather nor will there be air turbulence. There is every reason to expect that routine travel among many different habitats will be established. Thus the residents will see many different ecologies, lifestyles, and climates. If the colonies are established at distances approximately 150 miles apart, there will be about four billion people living within 18,000 miles of each other. Any colonist could visit any other after a journey of ten to fifteen hours.

Who actually will choose to be a space colonist? There, is today no difficulty getting candidates, both men and women, who are eager to become astronauts. This may involve living in an orbital vehicle for a month or more and many volunteers for such duty come forward. A tour of duty on Island One may be two years. Specialists in engineering and construction of all types will be needed, including electrical, mechanical, ceramics, and structural, as well as persons skilled in agriculture and plant science. Probably the work force will consist mostly of young people, less than thirty-five years of age. It is very important that life be as comfortable and as close to the familiar as possible. An attempt should be made to have almost an equal number of men and women in the work force. The colonists will meet and fall in love and establish homes as they do on earth.

It is anticipated that life on the first Island One will be sufficiently attractive, compared to life on earth for many people, that expansion to the other Islands One will proceed smoothly. Thereafter the attractions of Island Two and the final space colonies will be evident and powerful enough to encourage many to live in space.

An interesting question is what kind of government and economic system will be needed in a space colony. Of course each colony will establish its own. Probably every system imaginable will be tried in one colony or another. If a system does not work, its failure is almost surely within the system: one could not blame an energy crisis, resource depletion, population pressure, crop failure, or an unfortunate location.

The most difficult question of all is to ask why space colonization is not more in the mainstream of our thinking regarding our future in space. This is probably because we have been completely conditioned to consider life as being on the surface of a planet. Humanity has only existed on the surface of the Earth. In our imaginations, guided by science fiction writers, concepts of extraterrestrial life have involved the settlement of the surface of other planets or have involved creatures living on other planets. If we visualize extraterrestrial or extra solar civilizations we imagine them on the surface of a planet. Living on a planet is all we have ever known or ever imagined. When we struggle to visualize a future in space, we always imagine leaving earth and settling on another planet. Space colonization is an ideal Utopian scheme to "improve" humanity. Most such schemes involve tight central control over people in rigid, highly disciplined, communities. In contrast space settlement makes no such demands. It makes no promises other than to improve one's standard of living.

So, whither mankind?

In Heaven as He is on Earth!

Suggestion for Further Reading:

The High Frontier, Human Colonies in Space, 3d edition, by Gerard K. O'Neill, published by Apogee Books, Collector's Guide Publishing, Inc., Box 62034, Burlington, Ontario, Canada, L7R 4K2.