SPACE COLONIZATION PROGRESS

Research And Technology For Space Utilization

November/December 1991 *Vol. 2 No. 6*

IN THIS ISSUE:

COMMERCIAL MARKETS FOR SPACE STATIONS

Predicting the future has never been easy. This is particularly true of the space industry which depends on the government for its initial development. To help facilitate investment from venture capitalists, space advocates try to estimate the demand for products produced by a space economy. The last article in this issue examines the space economy of the next century assuming there will be a demand for several products and services aloft. But how good is that assumption? This article introduces a tool to quantify these estimates to help determine when government financial assistance can be scaled back and free enterprise can take over.

In a paper published in the June 1991 issue of *The Journal of the British Interplanetary Society* D.M. Ashford, a Consulting Engineer in the United Kingdom, uses a "demand curve" to show how the market for a product increases as its cost diminishes. A demand curve shows the relationship between the cost of an item and the number of units sold. The driving factor for commercial uses in space is of course, the launch costs. Ashford's demand curves for each sector of a 21st century space economy plot the launch price against the annual payload delivered to low Earth orbit. The curves were derived from data in the astronautics literature and by analogy with similar existing commercial endeavors. This method can show which segment of the space economy will be profitable first as launch costs come down.

The first sector examined was a suborbital long range transport of the type that could deliver passengers halfway around the world in something like 75 minutes. Although this market segment is not a space station, it is expected to be available soon and can be compared with the supersonic Concorde for illustrative purposes. The Concorde offers a speedy savings in time for a premium, capturing 1.2% of the trans-atlantic air traffic or 100,000 passengers annually for about $3500 per ticket.

Long-range estimates of this market indicate that as much as 100 million passengers will fly yearly between Europe and the U.S. by 2010. Although the price of the suborbital flight would probably be closer to $5000, the savings in time (over 50%) could be expected to double the market penetration resulting in over

2 million passengers per year by the end of the first decade of the next century. If the price could be reduced to $1000, Ashford estimates that market penetration could go as high as 50% or 50 million passengers by the year 2010.

Space tourism was the next market examined. The essential prerequisite for this category was reliable spaceplanes with safety records on a par with the airline industry. Facilities on orbit would provide entertainment and a variety of experiences of "being there". These would include Earth and space observation decks, low gravity gymnasiums, and interactive exhibits of microgravity phenomenon.

Predictions of this market for space stations suggest that an initial fare of $100,000 would draw 1000 tourists annually while a ticket for $10,000 would attract 1,000,000 tourists per year. If the cost could ever be reduced to $1000 per ticket, it is possible that 50 million people per year would spring for a trip into space.

The market for solar power satellites (SPS) was analyzed next. Ashford looked at a 10 gigawatt baseline system that has been studied extensively in the past. He assumed a break-even payback in 4 years on revenues of $4.7 billion (6 ¢ per kilowatt hour). For an SPS weighing 57,000 tons, launch costs would have to be reduced to $10/lb to make the system profitable. That is three orders of magnitude improvement over today's prices! The weakness in this analysis is that it assumes everything would be launched from Earth. Obtaining building materials from the moon or asteroids was not considered, an approach that will reduce launch costs considerably and therefor increase demand. However, alternative propulsion systems such as laser propulsion (SCP; Nov./Dec. 1990) and electromagnetic launchers (see page 3) have the potential to bring launch costs significantly lower.

Space manufacturing is probably the most speculative market for the use of space stations. Current predictions forecast specialized high value products that can only be fabricated in space. The usual examples are pharmaceuticals and pure crystalline silicon for computer chips. There is currently no data on the demand for these products. Even so, it is safe to assume that the market for them will not materialize until launch costs drop to a point where they would be competitive with Earth based manufacturing. An interesting space product suggested by Ashford is distinctive costume jewelry, fabricated using the properties of microgravity, vacuum, and radiation on orbit to form unique shapes and surface finishes that cannot be made on Earth. Marketed as such, this "space age jewelry" might capture 10% of the world demand, says Ashford.

Another proposed use for space stations is an outpost established for mining asteroids for valuable ores such as platinum and gold which could be sent back to Earth. Ashford suggests that the transportation costs of equipment to low Earth orbit would have to be 10% of the total value of the ore, assuming it was 100% pure (1% for 10% pure). Using data for current world production of several metals, a demand curve was constructed for this application.

The demand curves for each market segment were overlaid on the same graph for comparison. This analysis revealed that as launch cost diminish, the first market to emerge for space stations will be tourism. If high value pure ores are discovered in asteroids, mining will be the next use. If not, solar power satellites surface as the second application followed by manufacturing.

The demand curve is a useful tool for quantifying estimates of space markets. This analysis has shown that there is a clear demand for space tourism revealing the need for more detailed study of this application of space stations. Since high value ores have not yet been found in space, the SPS is the next highest priority. The demand for an SPS may go up if systems are designed to utilize extraterrestrial materials.

ELECTROMAGNETIC LAUNCHERS FOR SMALL PAYLOADS

The obvious disadvantage of living at the bottom of a gravity well is that it takes a lot of energy to get out. When self sufficient facilities have been established in space this will no longer be an issue. Until then, we who are interested in establishing those facilities, are continually looking for ways to reduce the cost of moving materials off the planet. Studies currently underway to reduce launch costs are focusing on optimizing chemical rockets or developing fully reusable heavy lift vehicles. The cost reductions expected from these programs will not be enough to establish large scale industrial facilities in space.

In addition to lower costs, the ideal payload delivery system for materials (not humans) should have continuous launch capability, reliability of launch and trajectory, the absence of any deleterious environmental pollution, and high mass throughput. These requirements can be met by electromagnetic launch systems. In this year's first quarter issue of *Space Technology*, Lucien Deschamps of Electricite de France and Peter Glaser of Arthur D. Little Inc. (inventor of the Solar Power Satellite) describe the possibilities offered by electromagnetic launchers.

Electromagnetic launchers (EL) are essentially big guns where the projectile is accelerated through electromagnetic forces. The two fundamental elements in the system are the same as those in a common electric motor: a stator which generates a powerful magnetic field and an armature in which current flow interacts with this field creating a propulsive force. The payload is carried within the armature which is accelerated to escape velocity. The higher the acceleration that can be attained, the shorter the required length of the system.

Because of the physics of ELs, high accelerations are needed to achieve the required velocities. For ground based systems, this means that the payload must be able to withstand tremendous g-forces (on the order of 10,000 gravities) and be streamlined to punch through the lower atmosphere with a minimum of friction. The best location for the accelerator would be on a steep mountainside or in a deep shaft. The authors suggest the possibility of winged high altitude launchers powered by microwave beams which could be stationed high above most of the atmosphere and therefor lessen atmospheric heating effects. Winged platforms powered via microwaves have been successfully demonstrated by the Canadians.

The system for "catching" the payload on orbit has to be considered when designing the launcher. The projectile can either be "smart" (equipped with a guidance system) and maneuver itself to the target or it can be dumb requiring an active acquiring system. This mass catcher would slow the payload with a magnetic field - essentially the same principal as the launcher with reversed polarity.

There are several different types of ELs that have been studied or proposed to date. There are two systems that show the most promise through demonstrated results. They differ by how the current is generated within the armature. The first system, called a rail gun, is composed of two parallel tracks carrying direct current. The armature is the projectile which holds sliding contacts that short between the rails. The current in the armature coupled to the magnetic field between the rails generates a force that accelerates the projectile. This system has been studied extensively through the Strategic Defense Initiative and is the most developed. Programs to date have achieved 317 gravities and 5 kilometers/second.

The second promising EL is the mass driver. This system utilizes a series of coaxial drive coils as the stator. The payload is contained within the armature which is composed of another set of coils that ride inside the drive coils. Current is generated in the armature by induction rather than through physical contact as is the case with the rail gun. Thus, the payload is "levitated" within the drive coils reducing friction. Mass Driver III built at Princeton University by the Space Studies

Institute achieved 1800 g - enough to launch small payloads off the moon with an accelerator length of 160 meters. The mass driver holds the most promise for general applicability to space projects.

The limiting factors for each type of EL were presented. The rail gun has two problems. First, the intense magnetic field generated between the rails induces a force that tends to push the rails apart and adequate bracing must be considered to hold the rails in place. Second, the longer the launcher the more energy is lost to the repulsive force between the rails and to heat. The problem with the mass driver is synchronization of the drive coil current pulses as the payload comes down the tube.

Given the above limitations, the authors estimated the upper limit to the payload capacity for the two types of ELs as they would be applied to launching building materials to geosynchronous orbit for construction of a Solar Power Satellite. A vertical oriented system or one inclined on a steep mountain side is the most efficient because the payload spends the least amount of time in the atmosphere. For a launcher of 5 kilometers in length at the equator, muzzle velocity of 10.4 kilometers/second, and an acceleration of 1100 gravities, the payload capabilities for the mass driver and rail gun are 244 kg and 441 kg respectively. Although the mass driver delivers less incremental mass to orbit, it is easier to operate and maintain making it the preferred long-term method.

The authors conclude that ELs are technically feasible for launching significant masses of commodities into space and could be competitive with chemical rockets. Payloads would have to be conditioned to endure the high accelerations, streamlined to reduce atmospheric drag, and would be constrained to the mass limitations of the system. Although the rail gun is the most mature technology, the mass driver is preferred for maintainability and ease of operation on earth and in space.

MAGNETIC SAIL FOR INTERPLANETARY TRAVEL

In near-Earth space, a robotic cargo ship begins deployment of a peculiar propulsion system. A drum shaped canister starts to play out a loop of superconducting cable. An electrical current is introduced into the circular web and maintained indefinitely in the superconductor without additional power. The magnetic field generated by the current induces a hoop stress in the cable facilitating deployment and forcing it into a circle 10 kilometers in diameter. Supported by struts like spokes on a bicycle wheel, the energized cable's magnetic field begins to interact with the solar wind. Deflected by the field, the charged particles impart momentum to the loop causing it to accelerate outward on a transfer orbit to Mars.

This magnetic sail or "magsail" could be used early in the next century to reduce or eliminate fuel requirements on interplanetary missions. Proposed by Robert M. Zubrin and Dana G. Andrews in *The Journal Of Spacecraft And Rockets* for March-April 1991, the magsail has the potential to accelerate large payloads to velocities comparable to that of the solar wind. In the vicinity of the Earth that turns out to be between 400 and 600 kilometers/second, which is sufficient for interplanetary travel. In addition, this system could be used on interstellar missions to slow starships down from relativistic velocities without having to carry extra fuel.

With its axis oriented parallel to the solar wind, the force induced causes the magsail to move radially away from the sun. If the axis is perpendicular to the wind, the forces are such that the loop accelerates tangentially to the wind effectively creating "lift" and significantly increasing the possible number of maneuvers. Although the acceleration is low and the travel time is slightly longer than the conventional transfer orbit, the magsail still out performs the solar lightsail and is appropriate for unmanned cargo missions.

Calculations indicate that the magsail could accelerate outward to the distance of Mars, circularize its orbit, and end up with a velocity somewhat less than Mars itself. Thus, it could loiter there until Mars caught up with it. This capability eliminates the need to wait for optimum launch windows so that Mars will be in the right place when the ship reaches its orbit.

Interstellar ships accelerated to large percentages of the speed of light with nuclear power, antimatter, or some other means, could use a magsail as a brake to slow the craft down on the last leg of its journey. In this case, the charged particles in the interstellar medium would create "wind" relative to the starship. This capability would greatly reduce fuel requirements enabling a larger payload.

Magnetic sails have the potential to transport large payloads anywhere in the solar system. They require no fuel enabling larger payloads and can be launched at anytime without the necessity to wait for a launch window. The magsail can also be used as an interstellar brake for starships without the need for extra propellant.

THE SPACE ECONOMY OF THE NEXT CENTURY

This article examines the economic possibilities offered by space industry over the next 50 to 60 years. This kind of prediction of the future is useful in highlighting technologies that need development and in refining economic models that predict future markets. The following analysis was presented by R.C. Parkinson of British Aerospace Space Systems Ltd. in the March 1991 issue of *The Journal of The British Interplanetary Society*.

The methodology used was a cost analysis called an input-output model. This is essentially a matrix of balance sheets showing cash flow among each segment of the space economy in the year 2050 AD. The idea here is to investigate if the projected income of each component in the economy equals the expenditures and if the results make sense. This technique is used to analyze terrestrial micro-economies and has appeared before in SCP to analyze a postulated lunar colony (SCP: May/June 1991)

Several assumptions were made about the economy. All prices were normalized to 1984 dollars. A growth rate of 2% per annum was assumed - conservative compared to the 2.75% preferred by most Western economies. Space products would be considered competitive over terrestrial sources if they could be delivered to the point of use at 80% of their cost. Interest on capital investment was set at 10% annually. Maintenance was fixed at 8% per year. The model neglects the affects of military spending and population growth. The former may speed the development of some of the infrastructure. The latter is related to the amount of wealth in the society and hence available financing. For these reasons Parkinson admitted that the model was conservative.

The market sectors of the economy are shown in the accompanying table. Each segment was analyzed for the flow of capital into and out of the sector and adjusted to balance income against expenditures. Highlights of the study are summarized below in a broad brush prediction of the year 2050:

1. Space Transportation
2. Near-Earth Infrastructure
3. Orbital Industry
4. Lunar Colony
5. Space Colony
6. Asteroid Mining
7. Mars Colony
8. Callisto Base

Space Economy Market Sectors

Space Transportation

The cost of space transportation will be a key factor in the economy. Transport to low

Earth orbit (LEO) is the most important cost element. It was assumed that a post shuttle launch vehicle like the National Aerospace Plane or the British Aerospace HOTOL (horizontal take-off and landing) would be developed and payload processing and launch operations approach the commercial airline industry. The launch vehicle payload would be 35 tons with the mission costs running at $3 million per flight. Costs will include vehicle amortization, maintenance, insurance, and interest on investment. Activity was predicted at a level of 450 launches/year with 11 vehicles in inventory.

Alternate launch systems such as the Phoenix single-stage-to-orbit vehicle or laser propulsion and mass drivers were not considered.

For transport between LEO and the moon (cis-lunar space) an orbital transfer vehicle (OTV) would be required. It would be powered by liquid hydrogen liquid oxygen engines and have a payload capacity of 25 tons. A fleet of these craft would embark on 1000 missions per year at a cost of half a million dollars per flight. Assuming a lifetime of 300 flights over 10 years will require 34 vehicles.

The fuel that will power the space economy of 2050 AD was assumed to be hydrogen. The closest known sources that are not at the bottom of a deep gravity well are the ices on Jupiter's moons. Thus, an interplanetary class rocket was needed to shuttle tankers as well as for other long distance missions. The vessel would have to be swift and have a large capacity because of the great distances involved. Drive power for this transport was assumed to be a gas core nuclear reactor utilizing hydrogen as propellant. High performance dictated a heavy reactor mass of 50 tons. Operations throughout the solar system would require 17 ships costing $300 million and averaging $40 million per mission.

Near-Earth Infrastructure

A network of communication, navigation, and earth observation satellites was predicted to provide a variety of services. Weather satellites, space based radars, position finders, television transponders, and mobile communications networks were the applications suggested to have growing markets. In addition, environmental monitoring and resource scanning segments would be expected to increase. Investment in geosynchronous satellites for these applications would be about the same as in today's satellite market - primarily because the launch costs would be a lower percentage of the capital outlay. Today, 50% of the cost of these systems are allocated to launch vehicles. That figure was expected to drop to 7% in the model.

Orbital Industry

The goods and services provided on orbit was hard to predict. Space tourism was predicted as well as servicing and launch operations for OTVs. A 700 guest orbiting hotel was assumed with 18,000 visitors a year. A room on orbit for 14 days would run a little over $66,000 dollars. This would be equivalent to $19,000 today - about the same as some up-scale round-the-world cruises at current prices.

OTV operations would generate revenues of $246 million annually with a turnover of $257 million of imported LOX from Moon and $86 million of hydrogen from Callisto. This would support a total of 500 outbound OTV flights.

Lunar Colony

The earnings of the lunar colony would be from export of materials for LEO industry and space colonies as well as liquid oxygen for OTV propulsion in cis-lunar space and life support for the colonies. The mass driver break-even point would be 700 tons per year which would be exceeded by an order of magnitude in this thriving economy. The population on the moon by the middle of the next century was predicted to be close to 9000 with a growth rate of 12 % per annum.

Space Colony

The space colony postulated in the model was derived from the 1975 Stanford Summer Study featuring a population of 10,000 people with the SPS as the main product. The colony would produce one SPS per year generating an income of $4.5 billion. The SPS would then sell power to Earth with a generating capacity of 10 gigawatts. After a total of 12 SPS's had been produced the main product would be maintenance on the existing SPS's. Average stay in the colony was assumed at 10 years.

Initial investment to build the colony was estimated to be $21 billion of which $1.4 billion would be contributed by the colonists. This figure seems low because estimates in the past have assumed that the total cost would include development of the infrastructure which is already assumed to be present in the model.

Apollo Asteroid Mining

Another market considered in the model was mining a class of asteroids called carbonaceous-chondrites for hydrocarbons. Some of these bodies, rich in volatiles left over from the formation of the solar system, have orbits which approach the Earth's. Known as the Apollo asteroids, they could be a source of hydrocarbon materials not available on the moon for use by the colonies.

The model predicted that the venture would be profitable if more than 240 tons of hydrocarbons could be extracted per asteroid. Processed one at a time, a mission would last two years and include a crew of 25 with 50 tons of equipment.

Mars Colony

Perhaps the greatest unknown in the model due to lack of information, the Mars colony was assumed to generate most of its revenues from scientific exploration. There may be heavy element ores exposed by the severe weathering present on the planet, but more reconnaissance needs to be done to support this assertion.

The population of the colony would be 1200 with an average stay of six years. Four transport ships would visit the colony a year carrying 50 passengers per trip.

Hydrogen from Callisto

The suggested source of hydrogen for spacecraft fuel in the economy was Jupiter's icy moon Callisto. Picked for its prime location, the moon is located outside most of Jupiter's radiation belts. About 400 tons of equipment and a crew of 150 would be needed to provide enough power and production capacity to supply 7000 tons of liquid hydrogen (LH) annually, mostly for use in cis-lunar transportation. Another 3600 tons would be required for tanker operations to and from the Jovian system.

The mass of the five LH tanks in Callisto operations would amount to 4800 tons since they will have to be large and have sophisticated active cooling systems.

The Callisto production plant would prosper because of the assumption that fast, high performance nuclear powered spacecraft would be the primary mode of transport.

Parkinson concluded his study with an analysis of all the balance sheets to arrive at a "Gross Space Product" equivalent to a GNP used to measure terrestrial economies. This figure was $16 billion - a figure that the author thought was unreasonably low and indicates that the model may have been too conservative in its assumptions. However, given the initial conditions of a developed infrastructure and the feasibility of the SPS, the economy was found to be relatively stable. The model predicted that there would be some 34,000 people living in space and vast utilization of space resources to benefit all of humanity.

IN THE NEXT ISSUE:

Modular Moonbase Assembled On Orbit
Civil Engineering Applications In Space
Conference On New Field: Bioastronomy
Pulsed Fusion Rockets For Star Flight

BACK ISSUES:

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

Vol. 1 No. 2 ($5.00)
- Space Station: Teacher's Aid
- Biosphere 2
- Lunar Helium Power Source
- Nuclear Rockets

Vol. 1 No. 3 ($5.00)
- 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

Vol. 2 No. 3 ($4.00)
- Alternate Space Program
- Farming On The Moon
- Model Of Lunar Colony
- Multiple Propulsion Starship

Vol. 2 No. 4 ($4.00)
- Space Engineering Facility
- Lunar Construction Methods
- Innovation In Space Tech.
- SPS - The Strategy

Vol. 2 No. 5 ($4.00)
- Aluminum Mine In Orbit
- Waverider Shortens Mars Trip
- Accelerated Terraforming
- Culture Changes In Space

SPACE COLONIZATION PROGRESS is published 6 times a year by:

STAR PUBLISHING COMPANY
754 Glenview Drive #308
San Bruno, California 94066
Subscription Rates Regular: $25.00. Student: $18.00
Editor-in-Chief: John A. Jossy