AIAA Space 2000 Conference & Exposition
19-21 September 2000 Long Beach, CA

A00-42858

AIAA-2000-5228

COMMERCIAL SPACE STATION REQUIREMENTS

James H. Sloan*
Information Universe
(310) 515-0618
17701 S. Avalon Blvd. #407
Carson, CA 90746

ABSTRACT

Currently there is interest in developing commercial launch vehicles. It is therefore reasonable to believe that we will see the development of commercial space stations. This paper is intended to explore the requirements of commercial space stations. These requirements will include orbit selection, atmosphere selection, artificial gravity, radiation and micrometeorite protection, power requirements, thermal management, living quarters, life support, personnel, and market unique requirements. Until launch costs are reduced, commercial operations in space will be limited. Launch costs will be reduced when a high flight rate is achieved. This leads us to smaller launch vehicles and a return to the old concept of Earth Orbit Rendezvous at a space station. This will result in smaller, lighter weight space station modules than currently envisioned. A commercial space station will be developed around commercial markets. Four markets will be studied: the Geosynchronous Satellite Delivery Market; the Materials Processing and Manufacturing Market; the Lunar Base Market; and the Space Tourism Market. A two phase approach is proposed. The first phase utilizes an Expendable, pressure fed vehicle and a Single Stage To Orbit (SSTO) vehicle to prove the value of space commercialization. The second phase utilizes the SSTO in combination with a Hypersonic Skyhook. The Hypersonic Skyhook is a space based tether that drastically increases the performance of the SSTO.

PROBLEM

A commercial space station must be built based on the profits it can generate. Realistically, these profits must also provide for the development of low cost space transportation. Compared to developing a new launch vehicle, the development of a space station is a minor task.

A space station should not be dominated by its development costs but by its deployment and logistical costs. The development of space station technology must be based on cost trade analysis. The baseline for a space station is nothing more than an airtight compartment that is resupplied from the Earth. If new technology is to be introduced into this design then it must reduce the overall cost of the space station's life cycle cost. No single space station design will suffice. Instead it will be shaped by the purpose it is to meet.

The first question is "Why do we need a space station?" Launch costs are the greatest limiting factor in the development of space. We need a space station to reduce launch costs. To reduce costs we need to use our launch vehicles more efficiently. Increasing the number of flights reduces the operating cost per pound into orbit. The more flights the smaller the launch vehicle becomes which reduces the hardware cost and ultimately the development cost. Reducing development cost reduces the amount of money that must be borrowed and the debt that must be repaid. However, reducing the payload size requires integrating the payload at a space station

The space station maximizes the efficiency of our launch vehicles by permitting the full carrying capacity to be utilized. It also provides the opportunity to utilize unused propellants and to salvage spent upper stages for their equipment and metals.

There are four areas where I expect money to be made: The satellite transportation market, the material research and processing market, Lunar base support, and space tourism.

The satellite transportation market is estimated at $3 Billion dollars per year at $5,000/Lb., a total of 600,000 Lbs./yr. 450,000 lbs. of this mass is rocket propellant with an average price of less than a dollar a pound. The satellite hardware is only 150,000 lbs. for the geosynchronous and medium orbit markets. The $5,000/lb is not the cost to orbit but the price to orbit. It is what is currently paid. By reducing the cost to orbit to $1,000/Lb. then a profit of $4,000/lb would be realized, a total of $2.4 Billion/Yr. In turn, this profit would be reduced by the cost of building and deploying a space station.[1]

Rocket propellant would be carried to the space station for loading on an Orbit Transfer Vehicle (OTV). The OTV may in fact be an expended upperstage, reused for the second leg of the satellite's journey. The satellite itself would be integrated on orbit onto the OTV. This opens the door to many possibilities. The satellite could be shipped dry into orbit with attitude propellant added once it reached the space station. The satellite could be checked out before it is sent into its final orbit. Discovering a problem with the satellite, the bad unit might be removed and only a replacement unit shipped into space. Because satellites have become so modular, its conceivable that the satellite might be assembled on orbit raising questions as to the most efficient way to package the satellite. Liability at launch is reduced by shipping over several launches rather than one launch. This also leads to the idea of having the satellite size being independent from the payload size.

The second moneymaker is the material research and processing market. This market is estimated to be $3.6 Billion based on estimates of 36,000 Lbs. of products at $100,000/Lb. Again we have the cost of constructing a space station to support this effort. Launch price is assumed to be $5,000/Lb with launch cost at an average figure of $1,000/Lb.[1]

The third area is Lunar Base support. In this situation it's assumed that a commitment is received from the Federal Government to support flights to an U.S. Lunar Base. The market is estimated to be $1.4 Billion/Yr. based on a WAG (Wild Ass Guess) that the amount will not exceed ten percent of NASA's current budget. The Federal government is expected to want value for their money. The operating cost of a Lunar Base is driven by the rotation of the personnel. In today's launch dollars ($5,000/Lb) that amounts to $250 Million per person. The Federal Government is assumed not to be interested in the construction of the Lunar Base until the price for a round trip passage drops to $50 Million per person. In turn, industry will not be interested until its cost is half of this price.[4]

The fourth area is space tourism. This is estimated to be a $2 Billion industry based on transporting 200,000 passengers to orbit each year. However, this requires reaching a launch price of $10,000 per passenger. This is a price of $50/Lb. Assuming a fifty-week work year and a one-week stay requires supporting 4,000 tourists and another 1000 personnel on orbit at any one time.[1]

The space station must overfly the launch site. Other than the equator, this means that a single launch site and a single space station have only one flight opportunity per day. This would require an enormous launch vehicle or a series of Bed and Breakfast space stations to meet the space tourist market. More likely space tourism will launch from equatorial launch sites supporting a single large space hotel. The number of flights per day is limited only by the orbital period of the hotel. This period will be a whole fraction to permit a standard schedule.

Initially, we should see deployment of a commercial space station to support satellite transportation. This station would next be combined with the material processing facility. A second space station would be constructed to support the Lunar Base requirement. This would double the number of flights per day and increase ground operations efficiency. At this time we should see a transition to a more cost effective transportation system. This would pave the way for space tourism and expansion into equatorial orbit.

The launch architecture I use is based on a flight rate of 250 flights per year. This is based on a five-day work week, fifty week work year, The architecture consists of a pressure fed expendable, a Single Stage To Orbit (SSTO) launch vehicle, a Hypersonic Skyhook, and electric propulsion.[2,3]

The pressure fed expendable is the simplest and cheapest form of launch vehicle that can be developed. Estimated cost for a 4,000 Lb. payload class vehicle is $160 million. The vehicle is expected to be 90% reliable. This vehicle is limited to low cost, easily replaced payloads such as: Food, water, and air for manned operations; rocket propellant for orbit transfer and vehicle recovery, and the raw stock for space based manufacturing. It is expected to deliver payload at a cost of 1,000/Lb.[2,3]

The SSTO is a highly reliable vehicle used to transport personnel and extremely valuable cargo. Estimated development cost for a 1,000 Lb. payload class vehicle is one Billion dollars. The pressure fed expendable enables the SSTO. Upon reaching orbit the SSTO is serviced using fluids brought up by the pressure fed expendable. So a ten thousand-pound SSTO enters orbit, but a twelve thousand-pound SSTO leaves orbit. A transpiration heatshield uses a thousand pounds of water or Nitrogen to carry away the heat of reentry. Another thousand pounds of rocket propellant permits the SSTO to land like DC-X. Adding this weight after the SSTO has reached orbit permits the SSTO to be built without new engine or tank technology. This makes the SSTO more expensive to operate than the expendable but because it is easily justified because it carries only personnel and valuable cargo. It is estimated to deliver payload at a cost of $3,000/Lb. [2]

The Hypersonic Skyhook is a tether. The dynamics of orbiting a tether or cable have only been recently examined. As we move away from the Earth the Orbital velocity of a satellite diminishes. If we imagine a satellite in orbit constructed as a long tether or cable we would find that as we move along the cable towards the Earth that portion of the cable is moving at suborbital velocity. This causes the cable to pull downward. However, the portion of the cable that is above the center of mass is moving at above orbital velocity and provides a net pull upward. This places the cable in tension.

The advantage of the Hypersonic Skyhook is that it provides a suborbital harbor for the SSTO. Given that the Skyhook is far more massive than the SSTO, the capture of the SSTO by the Skyhook has little impact on the Skyhook's orbit. Using today's materials it is practical to build a Skyhook that can reduce the SSTO's Delta V by 3 Km/sec. This requires a tether 1751 Kilometers long from its center point. It must also be 26 times more massive than the SSTO to limit the change to the Skyhook's orbit. This translates into an increase in payload from 1,000 Lbs. to 12,000 Lbs. for the SSTO. Realistically, 2,000 Lbs. of this weight must be allocated to the return propellant for this system would replace the Expendable/SSTO combination. Another 2,000 Lbs. should be allocated to increasing the lifespan of the SSTO hardware. Typically SSTOs are planned with a lifetime of 100 launches. A thousand launches are more practical as we move to equatorial launches with a flight rate of 2,500 per year. A fleet of 25 vehicles would then serve for a ten-year period. This would provide us with a 13,000 Lb. SSTO derivative capable of carrying 8,000 Lbs. to the Skyhook.

This combination is ideal for the space tourism market. The Skyhook is a kinetic energy storage system. When the Skyhook captures the SSTO, the Skyhook falls into a lower orbit. When it releases the SSTO, the Skyhook climbs into a higher orbit. As long as the mass is kept in balance with the movement of tourists on and off of the space hotel there is no problem. There are two options for building the space hotel. The first option is that the space hotel is built at the lower end of the Skyhook. This requires strengthening the Skyhook and placing a comparable mass for the hotel at the opposite end of the Skyhook. The space hotel would have reduced Earth gravity. Access to Microgravity would involve climbing the Skyhook and free falling or moving all the way up to the Skyhook's center point.

If we want to move mass permanently into orbit, as in the case of building the hotel at the center of gravity of the Skyhook, we must then climb the Skyhook. This requires energy. An advantage is that this energy can be expended slowly. When mass is moved down the Skyhook some of this energy can be recaptured. This system will use an electric train to climb the Skyhook and regenerative braking to slow the train's descent. Given that the engine is an electric motor there are going to be inefficiencies in moving the train and even greater inefficiencies in recapturing the energy. Energy must be available from either a solar/regenerative fuel cell system or nuclear power. To climb the Skyhook will require about 1.5 Megawatt of power for every Million Kilograms of passenger mass delivered in the course of a year. This assumes an average power level of one Megawatt, 33% efficiency, a period of 2.4 hours for the climb, and one Kilogram of structure for every Kilogram of passenger.

The Skyhook may make use of the Air Scoop concept where atmospheric gases are captured and then a portion of these gases are ejected at high velocity through a Magneto Plasma Dynamic (MPD) thruster. In this case the mass is moved solely by electric energy. This is the most efficient way of transferring mass into orbit. This mass may then be used as a counterweight to balance mass that is climbing the Skyhook from the SSTO.[4]

If mass is brought up the Skyhook without returning then the Skyhook will enter a lower orbit until it is dragged from the sky. To compensate for this, electric propulsion must be used. An ion engine with an Isp of 5000 Sec will consume 36 Kilograms of propellant for every ton of payload delivered to the Skyhook's center.[3] An MPD thruster with an Isp of a 1000 Sec will consume 180 Kilograms of propellant for every ton delivered.

The strategy for occupancy of the International Space Station (ISS) assumes that the astronauts live aboard the space station for ninety days and return to Earth for 270 days.[5] Four crews are required for this strategy. This is based on limiting radiation exposure. Radiation damage is assumed to be cumulative. The annual exposure rate is based on a working lifetime of twenty years in the radiation environment. For individuals working less than the twenty-year period, a higher radiation level is permitted. For the commercial space station this raises the possibility of two distinct groups. One group being rotated every ninety days and a second group rotated on an annual basis.

The ninety-day rotation would be suitable for personnel doing routine tasks. The same task being performed equally well by each crew. The annual rotation could be used by those involved in more creative ventures such as research. This assumes the researcher needs the Microgravity environment to prove his research and that leaving the work for others to perform is simply not practical. The annual period for rotation is based on the military's rotation period for remote sites. This is a psychological rather than physiological requirement.

The radiation environment for the space station can be reduced through shielding. The amount of radiation shielding to meet the annual requirement for the ninety-day rotation cycle is two-grams/square centimeter. Ten grams/square centimeter is needed for an individual to live year round on the station for twenty years. [5] The standard rule for radiation exposure is keep it "As Low As Possible". A commercial space station will accumulate material on orbit. Expended upperstages and residual propellants will be gathered for future use. It is therefore reasonable to increase the amount of shielding of a Commercial Space Station over time. This could result in a single, staggered crew using three months on station and one month off. On the one hand it would keep the experience level high, but it could also have a high turn around of seasoned personnel.

The Microgravity environment presents the next limitation on occupancy. Microgravity is essential for the Material Processing and Manufacturing Research facility. Researchers in this facility will be exposed to the Microgravity. Microgravity has been found to be debilitating. Its effects can be partially mitigated through an intensive exercise program. Unless the researcher was already "body conscious", keeping the researcher on the exercise program will be a major problem. A mechanical solution to this problem is to produce Earth normal gravity living quarters. This has several advantages for normalizing the space environment. However this introduces another problem in the form of Space Adaptation Syndrome. Typically it takes a day or more for an individual to adapt to the Microgravity environment without feeling nauseous. What this may lead to is a one-day transition between the weekend and the workweek. This would leave us with a four-day workweek that would be compensated by a ten-hour workday. The two-day weekend would be spent in an Earth normal environment.

A similar problem exists with space suit work. Most of the work for satellite transfer will be carried out in space suits. Quarters maintained for these personnel will reflect the pressure and composition used in the suits. A two hour prebreathe would otherwise be needed to transition from an Earth Normal atmosphere (14.7 psi., 21% Oxygen, 79% Nitrogen to one based on a low pressure suit (5 psi, 80% Oxygen, 20% Nitrogen).[6] Space suit work is physically demanding. It is also anticipated that the personnel will be working in 1% gravity to provide for separation between the liquid and gas of the rocket propellant.

While an Earth normal environment habitat will certainly be valuable to a Commercial Space Station, it will not be critical in the initial operation. Whether it is built will probably become an issue between the workers and management, particularly if an accident occurs where a life could have been saved if an Earth normal infirmary was available.

Orbit selection for a Commercial Space Station is dictated by cost. A sunsynchronous orbit would be perfect for the energy needs of material processing. However, the lower cost launch vehicles I propose do not have the performance capability to reach this orbit. An equatorial orbit is excellent from the point of view of a launch site on the equator but this would need a supply line of expendable launch vehicles and storable propellant. An orbit with an inclination of 28.5 degrees is the best that can be done within the U.S. This limits us to one flight per day per space station The satellite processing and material processing would be combine under one space station. A second space station would be built to support the Lunar Base. This doubles the number of flights each day from the launch site and makes ground operations more efficient. The tremendous numbers involved in space tourism makes launch from the equator the only solution. Even so, multiple launch sites on the equator will be needed.

It's estimated that the minimum volume for a space station is 700 cubic feet per person.[6] This translates into a cylinder roughly ten feet in diameter and nine feet tall. This is small enough to be transported by truck or rail. We can even expand it slightly to four meters in diameter and three meters tall. Constructed of Aluminum and with an average thickness of four millimeters it would have a wall density of about one-gram per square centimeter. This amounts to each module being around 800 Kg with an internal airlock. Thermal control is one of the greatest problems in space. An estimated 2000 Watts of power is needed for life support per person.[7] This amounts to only about thirty watts per square meter. Placing the cylinder into a permanent shadow will reduce the impact of energy from the sun. It is more efficient to run the life support life support equipment directly from the sun, so we still run into the problem of thermal cycling. The heat absorbed by the mass of the cylinder and equipment will be released when the power is off. The issue is releasing this heat slowly, so that there is little temperature change. The most effective means is to surround the cylinder with a reflective screen. The thermal radiation would be reflected back onto the walls of the cylinder and keep the temperature steady. If the temperature rise is too great, then a pinwheel radiator on the roof of the cylinder can be adjusted to increase the level of heat escaping or an active radiator can be used to carry away the heat.

There exists the issue that space is too costly for private industry. A private company does not have the resources of the Federal Government. There cannot be the level of documentation or testing that has accompanied the International Space Station. A private company must make an educated guess based on engineering analysis. If we find that we guessed wrong then we try to make a quick fix to recover the program. If we can't recover, then the project is shelved. As launch costs are brought down, we need to normalize costs to the way we work on Earth.

Launch costs have been blamed for the difficulty of building on orbit, but if we step back we find that Government's R, D, T, &E costs greatly exceed launch costs. We need to bring R, D, T, &E inline with expected profits. A project that is expected to make a Billion dollars a year cannot expect more than a two to three Billion dollars investment. A commercial venture must be completed within three years or be overcomed by debt. We must simplify our designs and make use of off the shelf items.

The following point design is to help us step out of the box. A low orbit space station has very different requirements than a low orbit satellite. With humans in the loop changes can be made. If Skylab had been an unmanned project it would have been lost. We must rely on our people in space. Though, initially we will need unmanned systems.

The first step would be to launch a docking platform into space. The docking platform would consist of a radar unit, work platform, and docking site for the unmanned payloads. The docking site would be nothing more than a net that the unmanned payloads could attach to. The docking device would be little different than an automatic umbrella. It would slip through the links of the net and upon opening would tie the payload to the net. The net itself would act as a scaffold for the astronauts.

A work area needs to be assembled. This work area will be determined by the amount of continuous power the space station requires. It is assumed here that 100,000 Kilowatts is needed, the same as ISS. I propose that the platform be constructed out of two by fours and sheet metal. Two by fours are a common building material. So are the screws, nails, and braces that would make up a wooden truss structure. On one side of the truss would be placed the sheet metal. This is to provide the astronauts with a place to stand. This is a return to the fifty's concept of magnetic boots. Use of mundane materials such as two by fours and sheet metal breaks down the barriers of high cost.

We do not equate such a structure with high cost. For so long, we have thought in terms of reducing space systems weight that we spend thousands to save a pound. We think in terms that once launched, that the system is untouchable, so we test and document our systems to extraordinary levels to assure their success. As launch costs are brought down we must alter our thinking. This platform would measure thirty meters by thirty meters. Three such platforms would be assembled. Each has a mass of 11,200 Kg. At a $1,000/Lb into orbit this amounts to a total of $74 Million.

The three platforms would be tied together with four cables over a distance of fifty Kilometers (8,000 Kg). The center platform would be in a weightless condition. The other two platforms would experience one percent of gravity. A 100-Kilowatt tracking solar array would be placed on top of the first and second platform for a total of 200 Kilowatts. If we were to use terrestrial rather than space qualified solar cells the cost on the ground would be $8 per watt.[8] The light weight panels though are about six watts per pound.[8] A launch cost of $170/watt. To compete, space qualified solar arrays must be lower than $178/watt. A regenerative fuel cell system would be used to supply power during periods of darkness. This system is selected because it makes use of salvaged items. Each trip of the SSTO brings 675 pounds of residual Hydrogen/Oxygen propellant. The expended upperstages are used for gas storage for the regenerative fuel cycle. This power system is estimated at 22,000 Kg. compared to a space qualified system of 10,000 Kg.[9] The third platform is the one nearest the Earth.

The first platform is the habitat platform. Thirty-six cylinders are placed on the shadow side of this platform. Thirty of the cylinders house one person. Twenty personnel are on quarterly rotation while ten are on an annual rotation cycle. One cylinder is set up for an elevator. Five are used as latrines and radiation storm shelters. The mass of a cylinder is 800 Kg. One thousand Kilograms of a Closed Environmental Life Support System (CELSS) is contained in each cylinder, consuming two Kilowatt of power. As a method of energy conservation, the CELSS consumes power only during "daylight" and then only if the habitat is occupied. The regenerative fuel cell provides power for lights, cooking, heating, and other household requirements as well as serving as a back up power source for emergencies. A fence four meters tall is provided along the edge of the shadow side. The fence is initially hollow, providing one gram/square centimeter of radiation shielding. Estimated mass is 4,800 Kg. As the station matures this area will be filled with water from residual propellant to provide an additional ten grams of shielding per square centimeter. The latrines have 40 gm/square centimeter of water facing the sun to provide shielding against solar storms. This mass of water is integrated into the waste management system. This mass is equal to 5,000 Kg per latrine cylinder.

The second platform is used as the research laboratory for material processing. Nine cylinders are set up for the laboratory workspace. A smaller fence surrounds these cylinders. Each cylinder has its own independent life support. An elevator system carries them between the laboratory and the habitat platform.

The third platform is used as the landing field for the SSTO. It is the work area for gathering and processing the expended upper stages. Residual propellant is also processed from the SSTO and is used in a fuel cell as needed for power. Test stands are set up for checking out the satellites.

The Lunar Support Space Station would be the same except for not having a middle platform. A second SSTO would be used for transport between the Earth and the Moon on a monthly trip to the Lunar Base. Development of a liquid Oxygen source on the Moon would mean that most of the return propellant would not have to be carried. This would reduce the overall mass to Earth orbit and reduce the cost of transporting personnel to the Moon. It is also here that experiments might begin with the use of tethers to reduce space transportation costs and to introduce space tourism.

Ultimately, space tourism must move to launch sites on the equator. It's estimated that there would be 200,000 passengers per year at a price of $10, 000 per passenger for a one week stay on orbit (50-week year). This requires a price to orbit of $50/Lb. assuming a 200-lb. passenger. A system capable of meeting this price is a tether placed into a 2.4-hour orbit with a tip speed of 5 Kilometers per second. A SSTO arriving at the tip, docks, and exchanges passengers. This system would have to bootstrap. The initial system would have to be launched into orbit at a thousand dollars a pound. Once in place, the system would build itself up until it reached an average cost of $15/Lb to orbit for cargo and $6,000/Passenger.

The SSTO is a relatively small launch vehicle at 100,000 Lbs. Gross Lift Off Weight. It's estimated that operating costs per launch site on the Equator will be $75 Million/yr-site. Each launch site will support 2,500 Flights per year. Four launch sites are required. At a payload of 8,000 Lbs. per flight this works out to $3.75/Lb of payload. Operating costs. Fuel cost is $2.50 /Lb. of Payload. Based on a fuel cost of $1/Lb for Liquid Hydrogen and ten cents per pound for liquid Oxygen. Manufacturing cost for the SSTO is estimated to be $5,000/Lb. of dry weight. The dry weight of the SSTO is 11,000 Lbs. plus another 2,000 Lbs. in consumable fluids. With engine and frame structure at a reusable level of 1,000 flights this cost amounts to $6.88/ Lb. of payload. Development cost is allocated to previous projects for the development of the SSTO. The tether is launched at $1,000/lb and must be 26 times more massive than the payload it captures. In this case that is the total weight of the SSTO at the tether, 21,000 Lbs. A total of 546,000 Lbs. for the tether. The tether though would have a lifespan of ten years, 100.000 captures resulting in an amortized cost of only $0.68/Lb of payload. Assuming a ratio of one to one between the passenger and his compartment doubles the cost to orbit to $28/Lb.

To move 200,000 passengers per year, 20 Million Kilograms, up the tether requires a solar/ fuel cell regenerative power plant of 30 Megawatts. Estimated cost of this plant is $40/watt, $1.2 Billion. Mass is estimated at 6.6 Million Kilograms. Again this plant is estimated to have a ten-year life and so contributes only $6/Kg of payload.

Construction materials at the Skyhook's center would require 180 Kilograms of propellant for every ton of material delivered. Delivery of building materials though is estimated to be $31/Kg.

Assuming that the cost of on orbit construction is equal to the cost of lifting the raw materials from the Earth we have a hotel fabrication costs of $62/Kg. Typical space station costs have run to about 4,500 Kg./person. Given 4,000 tourists on orbit plus another 1,000 support personnel provides us with a hotel mass of 22.5 Million Kilograms and a cost of $1.4 Billion dollars.

Movement of the construction materials for the power plant, 6.6 Million Kg, and the Space Hotel, 22.5 Million Kg, will require an expenditure of 5.24 Million Kilograms of Orbit keeping propellant at a cost of $162 Million.

With only a 4,500 Kg. per person budget the space hotel must still be smart in its design. . Pressure is a major driver on the outer shell so we can expect that the 5 psi pressure will probably be standard for the hotel. Some gravity is needed to avoid space adaptation syndrome and to simplify life support requirements. Minimizing gravity also reduces the internal structure. I believe that Lunar normal gravity will be selected. This also provides the hotel with a secondary market of a Lunar Simulation Laboratory, which can also serve as a tourist attraction. The hotel must provide multi-levels for efficient living space yet at the same time provide sufficient open space for activities. Human flight is a unique experience that is likely to be a major attraction. [10,11]

The space hotel is assumed to be a torus with a major radii of 500 Meters and a minor radii of 26 Meters. On Earth, such a structure would be constructed out of welded plates. This would bust the fabrication cost. I believe the more practical method is to build the torus as a filament wound structure using steel or aluminum wire and vapor deposition to bind the wire.

For a ten-year life we would need a $1.2 Billion dollar power plant, a fleet of 100 SSTOs at $5.5 Billion. A tether at $0.5 Billion. A space hotel at $1.5 Billion. Propellant expenditure of $0.16 Billion. This is a total of $8.9 Billion. If this money were borrowed at 30% then $2.67 Billion would have to be repaid on an annual basis. This exceeds the estimated revenue of $2 Billion dollars annually. If we assume that SSTOs are bought on an as needed basis then the total changes to $3.4 Billion. This amounts to $1.02 Billion dollars annually in debt repayment. A figure that is reasonable based on paying $0.55 Billion for a fleet of ten SSTO each year. If we assume that the $3.4 Billion is borrowed over a three year period at 30% for a debt of $4.3 Billion and then refinanced on a ten year note at 10%. This requires a debt repayment of $0.86 Billion, an annual SSTO cost of $0.55 Billion, which leaves a profit of $0.59 Billion/Yr. However added to this must be the annual operating costs of the launch sites of $0.3 Billion and fuel costs of $0.1 Billion. This leaves a profit of $190 Million/yr until the loan is repaid. To be practical we cannot expect to borrow more than three dollars on an annual return of one dollar.

We should have income after one year and be fully operational within three years. With two Billion dollars in revenue the maximum investment for space tourism is six Billion dollars.

In conclusion, We can expect our launch vehicles to become significantly smaller by a factor of ten. Launch vehicles will be operated more frequently. On the equator we can expect a launch rate of 2,500 flights per year with a figure of 250 to 500 flight at other longitudes. This will require smaller packaging of space station components and greater reliance on space suit operations. Commercial space stations are labor intensive and will require twenty to thirty personnel on orbit. Space based manufacturing and life support is energy intensive. A continuos power level of 100 Kilowatts was estimated in this paper based on a mixture of solar power, a regenerative fuel cell, and residual Hydrogen/Oxygen propellant. This is not enough. Space tourism is expected to require 30 Megawatts of continuous power. Roughly three watts of solar power is needed for every watt of continuous power. We must normalize our operations in space. We can expect no more than a three-dollar investment for every dollar earned annually. Minimizing this investment maximizes the profit the company receives.

REFERENCES

1. NASA. Commercial Space Transportation Study, June 1993- April 1994, Langly Research Center, Hampton, VA.

2. Sloan, J.H. "A Two Launch Vehicle Architecture to Reduce Space Transportation Costs", AIAA 95-3089, 31st Joint Propulsion Conference, July 10-12, 1995, American Institute of Aeronautics and Astronautics, Washington, D.C.

3. Zubrin, Robert, "Hypersonic Skyhook", Islands In the Sky, Pgs 27-39, 1996 John Wiley & Son, New York, N.Y.

4. Sloan J.H. "Cost Analysis and the Future of Spaceflight", AIAA 99-2693, 35th Joint Propulsion Conference, June 20-24,1999, American Institute of Aeronautics and Astronautics,, Washington , D.C.

5. McCormack, Percival D. "Radiation Hazards in Low Earth Orbit, Polar Orbit, Geosynchronous Orbit, And Deep Space", AAS 87-158, Science and Technology Series #72, American Astronautical Society, Univelt, San Diego, CA.

6. Woodcock, Gordon Space Stations and Platforms, Orbit Book Company, 1986.

7. Miller, Craig and Licia Kovach "Environmental Control Life Support for the Space Station", 16th Intersociety Conference on Environmental Systems, Society of Automotive Engineers, 1988.

8. Sunelco, Product Catalog, 11th edition pg 36.

9. Erickson, Albert and Hoyt McBryar " Development Status of a Regenerative Fuel Cell System for Orbital Operations." 16th Intersociety Energy Conversion Engineering Conference, Vol 1, pgs. 67-73.

10. Bock, Edward; Fred Lanbrow Jr.; and Michael Simon, "Effect of Environmental Parameters on Habitat Structural Weight and Cost", Pgs 33-83, Space Resources and Space Settlements., NASA SP-428, NASA, Government Printing Office, 1979.

11. Johnson, Richard D. and Charles Holbrow, Space Settlements: A Design Study, Pgs. 143-167, NASA SP-413, NASA, Government Printing Office. 1977.