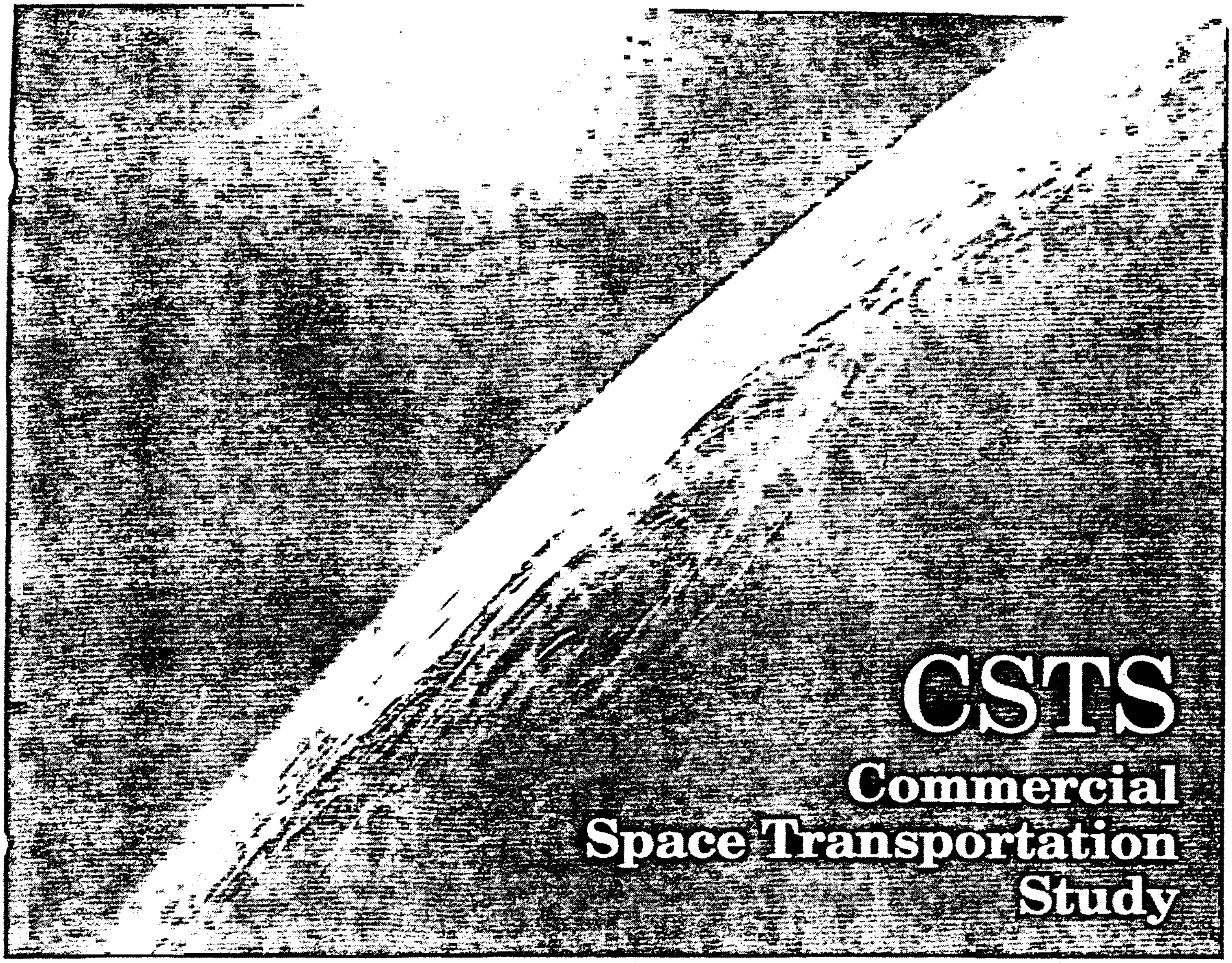

CSTS

Commercial Space Transportation Study

May 1994

Final Report

Boeing	General Dynamics	Lockheed
Martin Marietta	McDonnell Douglas	Rockwell

Commercial Space Transport Study Final Report

April 1994

BOEING
GENERAL DYNAMICS
Lockheed
MARTIN MARIETTA
MCDONNELL DOUGLAS
Rockwell

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Commercial Space Transport Study Final Report

CONTENTS

1.0 Introduction

Commercial Space Transport Study Final Report

1.0 INTRODUCTION

The U.S. commercial launch industry needs revitalization to recapture the market from subsidized foreign competition. The principal technology base for our launch industry is 30 years old. This study will change this situation by systematically identifying future launch opportunities and defining a next-generation launch system to optimally meet the users' requirements. The results of this study will benefit commercial, civil, and DOD users, as well as make the United States more competitive across the aerospace industry.

1.1 BACKGROUND

The basis for this study was the perception held worldwide by government and industry that (1) significant untapped markets exist or could be created if the costs for access to space could be reduced by an order of magnitude or more, (2) a new launch system can provide this order of magnitude reduction in launch costs, and (3) a reduction of that magnitude will cause the equivalent of a space industrial revolution with a tremendous increase in users and traffic. This conjecture is often stated but has never been proved. Phase I of the study identifies those new users and categorizes their prospective payloads. Once the business opportunity has been identified, the best prospective launch system can be determined and the required technologies put in place. This is the linkage between phase I and the proposed phases II and III.

1.2 GOALS AND OBJECTIVES

It is commonly recognized that the U.S. space launch industry needs revitalization to recapture commercial markets from foreign competition and to stimulate the development of new commercial ventures in space. To this end, representatives of six aerospace companies (Boeing, General Dynamics, Lockheed, Martin Marietta, McDonnell Douglas, and Rockwell) and NASA met in March 1993 at NASA's Langley Research Center (LaRC) to discuss means by which a new, commercial space transportation system might be developed.

A perception is held by government and industry that a new, state-of-the-art launch system can provide an order of magnitude reduction in launch costs and that a reduction of that magnitude will cause the equivalent of a space industrial revolution with a substantial increase in users and traffic. The group meeting at NASA LaRC concluded that to become economically viable, a new launch system must generate new commercial markets. This group, now known as the Commercial Space Transportation Study (CSTS) Alliance, established the need for a market exploration study to identify potential customers, determine price elasticity of demand, and assess the commercial business opportunities for such a future launch system. This plan was briefed to NASA Administrator Dan Goldin on April 30, 1994, and in May the partnership between NASA and the companies began.

The CSTS objectives, as illustrated in figure 1.2-1, were to assess market elasticity with the long-term goal of expanding the market for space products and services. Significant results of the phase 1 CSTS effort, performed between June 1993 and February 1994, are summarized in this document.

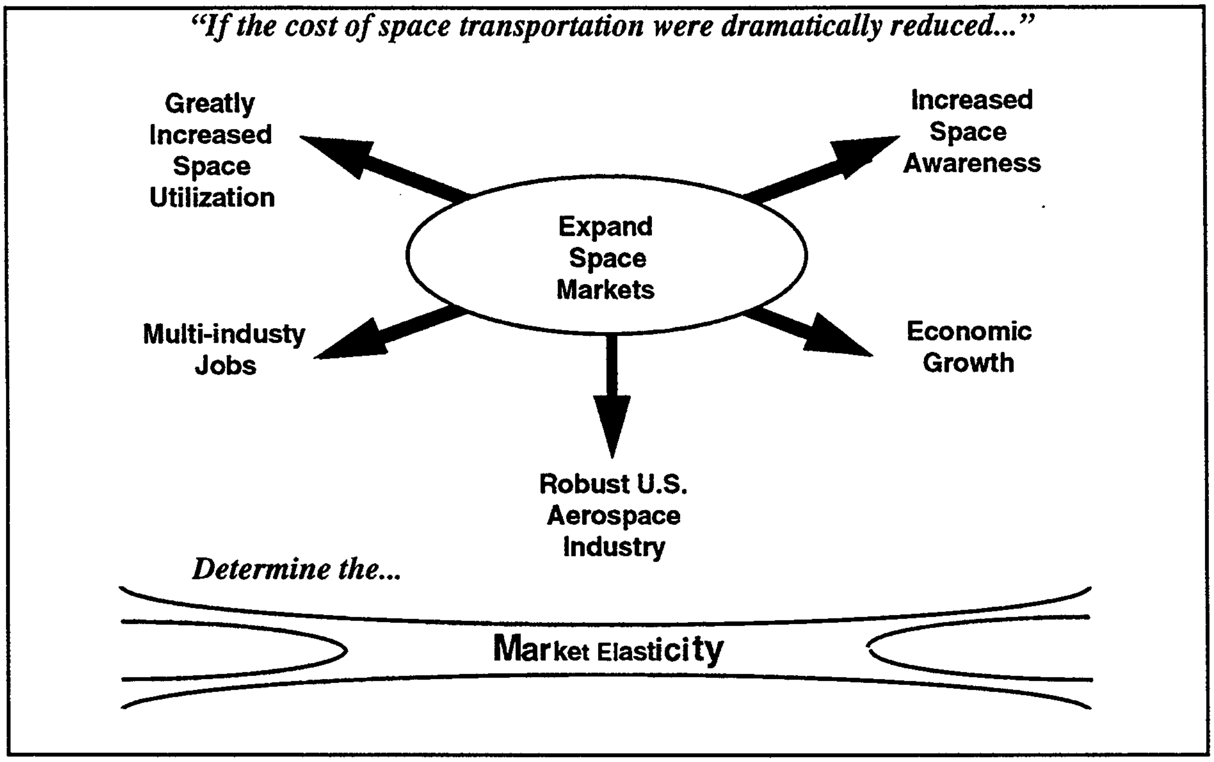

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Figure 1.2-1. CSTS Objectives Were ...

2.0 Study Methodology and Approach

2.0 STUDY METHODOLOGY AND APPROACH

The CSTS approach differed from traditional studies and is summarized in figure 2.0-1. First, six normally competitive aerospace companies worked together to accomplish the objectives of the study. Second, this study researched potential customer needs rather than starting with a preconceived solution of a transportation system and then trying to identify customers for it.

The CSTS market assessment followed two paths. Key decision makers within a broad range of industries who might have future business activities in space were contacted. These contacts spanned the spectrum of industry, including advertising, electronics, energy, entertainment, health care, manufacturing, telecommunications, tourism, and academia.

In parallel, a business analysis effort assessed the various opportunities using analytical business models to validate the data from the market surveys and to test assumptions about the new markets. Interview findings identified additional characteristics of the markets, new commercial space markets, key decision factors from an "insider's" perspective, and space transportation system attributes necessary to meet commercial user needs. Market area revenues and capture opportunities were then quantified. CSTS tasks, identified in figure 2.0-2, were augmented by additional efforts performed by the Alliance under discretionary resources (shaded boxes).

For each market area a range of demand was identified for high, medium, and low probability projections. High probability projections represented the lowest market risk and produced the lowest estimate of future transportation demand. Its business ventures included those that fall within current business operating conditions and meet market area financial projections. In contrast, the low probability demand projection allowed optimistic extrapolations and expansions of current business activities into space, with business activities still within current market area financial projections and acceptable market area rates of return. The medium probability demand model was a nominal extrapolation between the low and high probability markets.

CSTS Approach	Classical Approach
• Focus on market thresholds and market elasticity	• Focus on vehicle concepts
• Create the market addressing both traditional and nontraditional customers	• Survey the market
• Create opportunities	• Identify needs
• Contractors working together	• Contractors compete
• Government supported technology; commercially supported development and operation	• Government funded and operated
• Economic growth from government and commercial investment, and financial returns	• Economic growth from government investment
• Focus on economic return	• Vehicle performance driven

Figure 2.0-1. Why the CSTS Approach Is Different

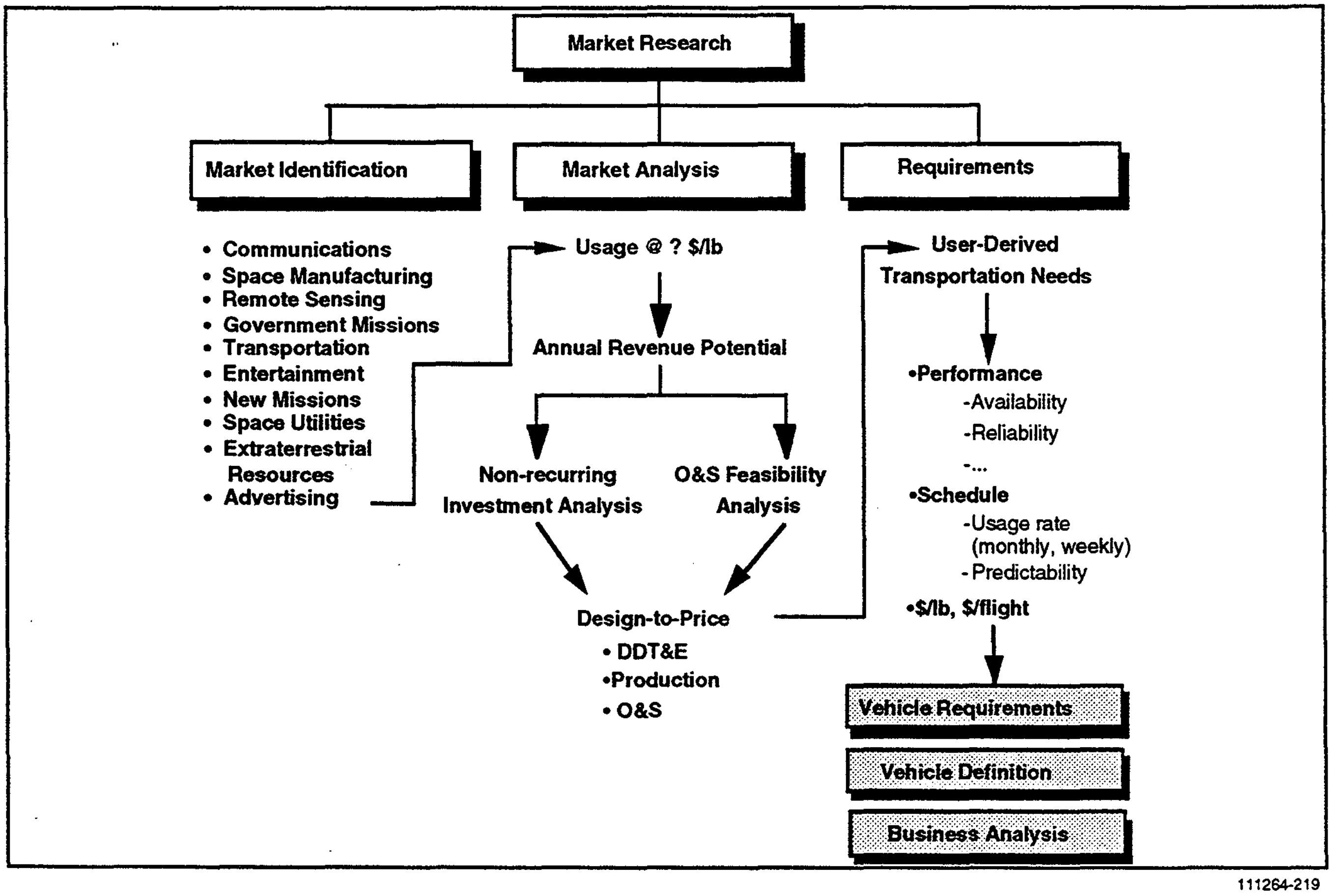

Figure 2.0-2. CSTS Approach and Methodology

3.0 Market Assessment/ Market Analysis

3.0 MARKET ASSESSMENT/MARKET ANALYSIS

3.1 COMMUNICATIONS MARKET

3.1.1 Introduction

3.1.1.1 History of Satellite Communications

In 1962 the world's first active relay telecommunication satellite was launched. Since that time the developed world has come to depend upon the services provided by these satellites. The advent of communications satellites has change the world. Because it is now possible for telephone and television companies to offer worldwide service, people over the entire globe are able to simultaneously share in historical and sporting events. This has been used to truly increase social understanding and provide a stronger bond between all the people of the world. Figure 3.1.1.1-1 highlights the history of satellite communications.

Year	Satellite	Technology Event
1958	SCORE	First satellite with broadcast capability
1958	Courier 1B	First teletype relay by satellite
1960	ECHO	First passive relay communications satellite
1962	Telstar	First fully functional active communications satellite
1962	Relay	First worldwide TV transmission satellite
1963	Syncom II	First geostationary communications satellite
1965	IDSCS	First operational military communications satellite
1965	Early Bird	First operational commercial communications satellite
1967	INTELSAT II	First communications satellite capable of multiple access transmissions
1968	TACSAT	First satellite to provide UHF mobile communications
1968	INTELSAT III	First satellite with a despun antenna
1971	INTELSAT IV	First satellite with high-power spot-beam antennas
1975	INTELSAT IVA	First communications satellite to achieve frequency reuse
1976	MARISAT	First communications satellite to provide commercial mobile satellite services
1980	INTELSAT V	First complex hybrid communications satellite capable of operating in multiple frequency bands with multiple frequency reuse

Figure 3.1.1.1-1. Communication Satellite Development Highlights

The earliest systems were sponsored to provide services for individual national governments and militaries. These earlier communications satellite systems were fitted into existing terrestrial networks utilizing existing end user hardware. As the consumer base has grown, the technology base has grown and expanded the product utility which has further expanded the consumer base. It is this expansion cycle that continues to fuel the development of telecommunications satellite systems. They have been sponsored by governments and corporations in member groups and individually. Most of the development and governments commercialization of each type of system was led by those in the United States.

Today there are approximately 150 geostationary satellites in orbit around the globe. Of that number around 125 are used for commercial communications. These satellites are shown in figure 3.1.1-2. Satellite communications are continuing to expand to new applications and technologies. The first quarter century of development in communications satellites has provided global coverage for telecommunications systems of numerous types. As the development continues other countries have taken increasing involvement and leads into various markets. The demand for additional features and expanded service areas has attracted new investors. Various user consortium-owned systems have been formed to spread the high initial cost for service. The continuing market expansion has given rise to entrepreneurial provider systems.

Symbol	Satellite Manufacturer		Symbol
▭	Hughes	Aerospatiale/Loral	▨
⬚	General Electric	Aerospatiale	○
⊟	Ford Aerospace	British Aerospace	◌
▨	Loral	Alenia	⊜
▦	TRW	Matra Marconi	⬯
◇	China (Peoples Republic)	Eurosatellite	▢
△	Soviet Union (Former)	Siemens, MBB	▢
◇	Japan	ISRO (Gov't of India)	⬭
▬	Direct Broadcasting Capability	Spar	⬭

Designator	Satellite Operators
Ab	Arab Satellite Comm.
Al	Asiacom
As	Asia Satellite Comm.
att	AT&T
Au	Optus Comm (Australia)
B	Brazilsat
Bd	British Sky Broadcasting
C	Telesat Canada
CC	Chinese Min. of Post
cc	Columbia Comm. TDRSS
Cm	COMSAT
D	Deutsche
Dt(TV)	Bundespost
F	France Telecom
ge	GE Americom
gte	GTE Spacenet
Em	European Met. Services
Eo	European Space Agency
Es	Hispasat
Et	Eutelsat European

Satellite Operators	Designator
Hughes	h
Indian Dept. of Space	Id
Inmarsat	IM
Intelsat	IN
P.T. Telekomnikasi (Indonesia)	Is
Italian Space Agency	It
Societe Europeene Des Satellites	Lx
Telecomunicaciones de Mexico	M
Marisat	Mr
Japan Comm Sat Co	N
Telecomm Satellite Corp Corp/Japan	Nt
Panamsat	Pn
Intersputnik	Rg
Russian Min. of Post	
Gorizont	Rg
Raduga	Rr
Ekran	Re
Cosmos	Rc
Swedish Space Corp.	Sw
Norwegian Telecom	V

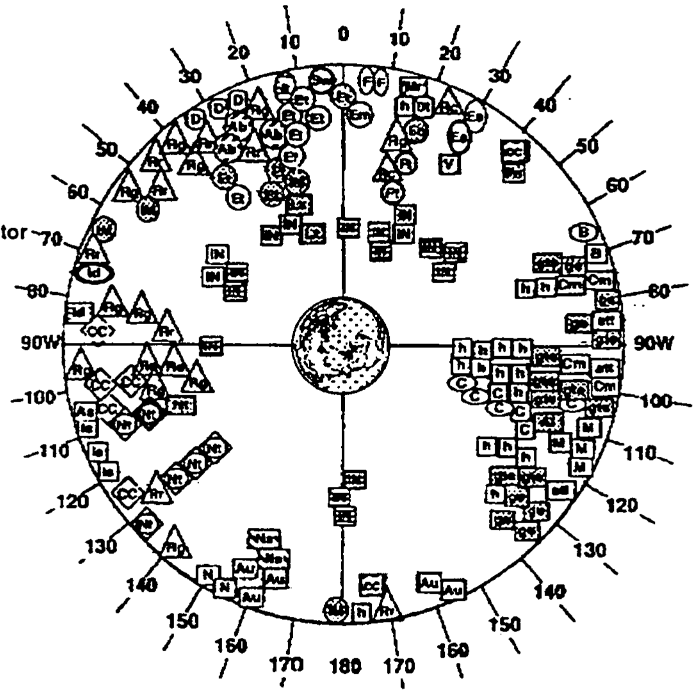

Figure 3.1.1.1-2. Current Commercial and Communication Satellites and Their Positions

3.1.1.2 Industry Overview

As satellite applications have grown the communications industry has grown at a fantastic rate. In the past 10 years all communications market areas increased in revenues. Domestic long distance calls, for example, grew exponentially from 4.7 billion calls in 1965, to 48.9 billions calls in 1989, to 66 billion in 1991, and a projected 260 billion in 2011(ref. NASA CR191145, "Potential Market for Advanced Satellite Communications"). Another example is cellular telephone usage, which has increased to 75 million subscribers. Like examples are possible for cable TV where TCI, a fledgling company 10 years ago is now earning $4 billion per year. Such performance results in high industrial growth, as shared by Pelton of the University of Colorado and cited by TCI in several references. The communications industry worldwide revenue in 1982 was $120 billion; today the industry is earning $460 billion. The same groups are predicting $3 trillion in revenue for the industry by the early 2000s. These growth projections are shown in figure 3.1.1.2-1.

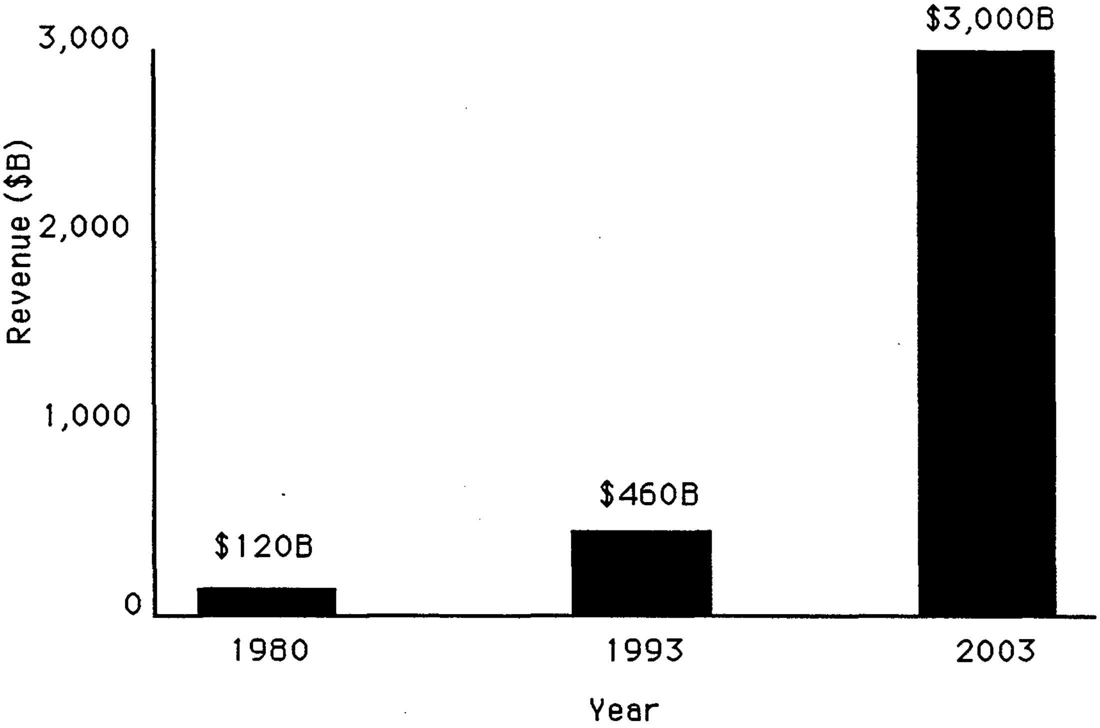

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Figure 3.1.1.2-1. Industry Revenue Projections

One reason for this high growth is an industry strategy of high dollar amount reinvestment into high technology. This also has a high amount of capital available for such reinvestment. For example, AT&T, in its 1992 annual reports, cites $65 billion in revenue with $39 billion coming from telecommunications. The margin from the telecommunications portion by itself was $14 billion.

3.1.2 Current and Evolving Communications Satellite Applications

3.1.2.1 Applications Roadmap

There are three spheres of technology included in each satellite communications system. They are the satellite, the distribution system/network interfacing to the end user, and the mechanism by which the end user accesses the communication system. Within each sphere, of course, are multiple designs and management solutions. It is common to each, however, that development within that sphere proceeds only to a point where it either drives or waits for development in another sphere. Figure 3.1.2.1-1 tracks the increases in each of these areas and illustrates the relationship between developments within one area and the resultant growth in another area. The development of smaller scale user apparatus, resulting in localized broadcast systems, from the ability for worldwide telecommunications satellite "feeds" by broadcast Networks can be viewed as a "top-down" evolution. Another evolution, if not revolution, is the development within the distribution system sphere of interactivity, combined with the development within the user sphere of individual-sized hardware driving the development of satellite networks.

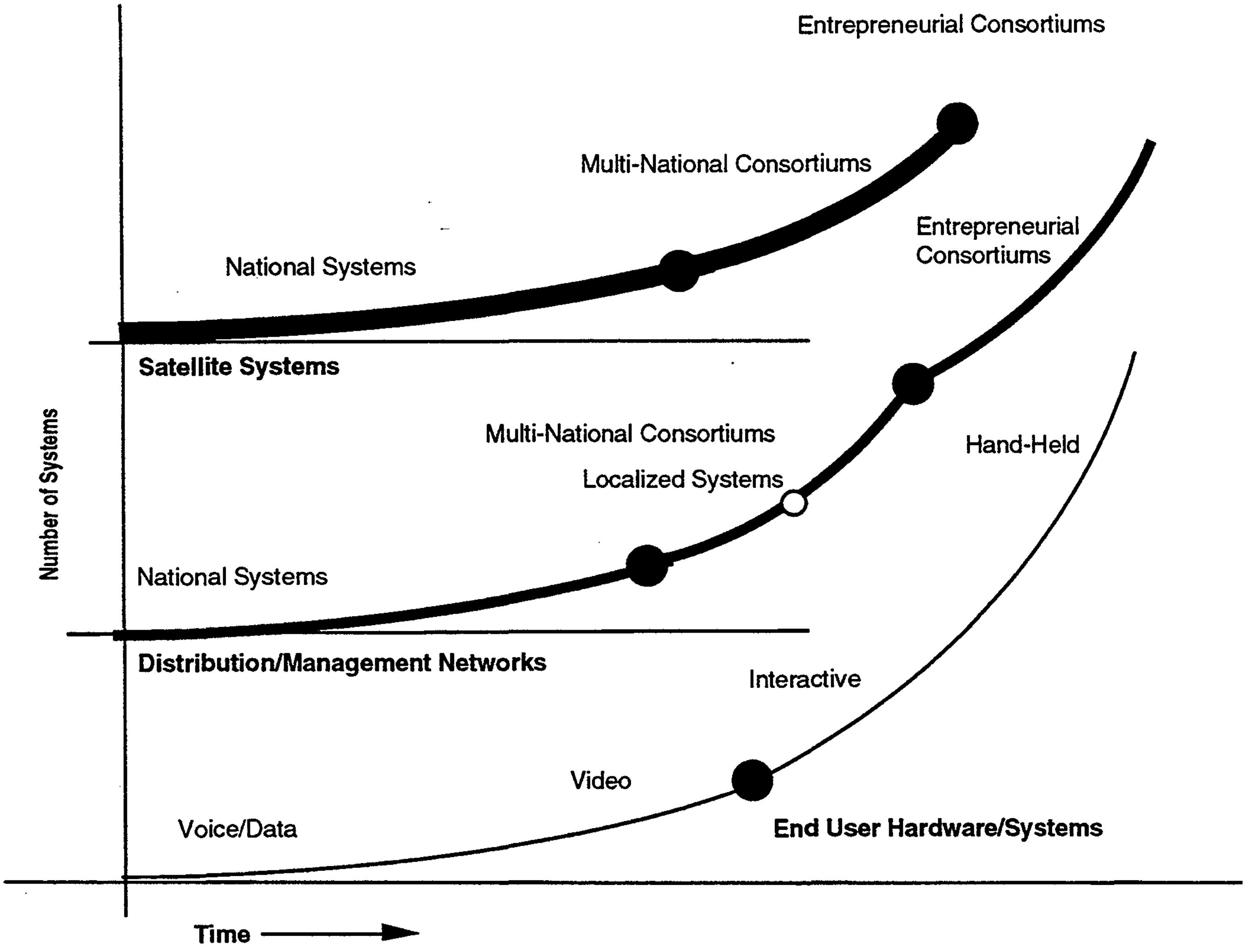

Figure 3.1.2.1-1. Growth Interdependence—Telecommunications Systems

Since the start of communications satellite usage nearly all satellites have been used placed in geostationary orbit for use in transmitting TV, radio, and telephone signals. These signals are transmitted from one point on the globe either to a single point (point to point) or from one transmitter to multiple receivers (point to multipoint). This type of service is denoted as fixed satellite service (FSS).

New services have recently entered the marketplace or are about to. These services can be grouped into three categories, discussed below. A logical extension of FSS systems is to directly broadcast TV and radio signals from geostationary satellites to the consumer on a mass basis. Two technical achievements have enabled this concept to become practical. These are higher power satellites and digital signal usage and compression. This has enable up to 150 channels to be delivered into the home equipped with a dish antenna between 14 to 18 inches in diameter.

With the advent of the cellular telephone, people have started to take for granted the ability to use the telephone anywhere. A satellite service that enhances this capability is called mobile satellite service (MSS). Up to a dozen potential competitors are considering entering this market.

Yet one other communication service is now being used. This service uses satellites such as the global positioning system (GPS) to determine precise locations anywhere in the world. This service, called positioning satellite service (PSS), is revolutionizing navigation and surveying. Figure 3.1.2.1-2 shows the application roadmap for the industry.

The ultimate in satellite communications is a concept called global grid, which would use satellites in low earth orbit (LEO) for high bandwidth communications between any two points in the world. This concept allows for easy and inexpensive establishment of communications to handle data and voice communications requiring gigahertz data rates. Such a system requires hundreds of satellites in LEO.

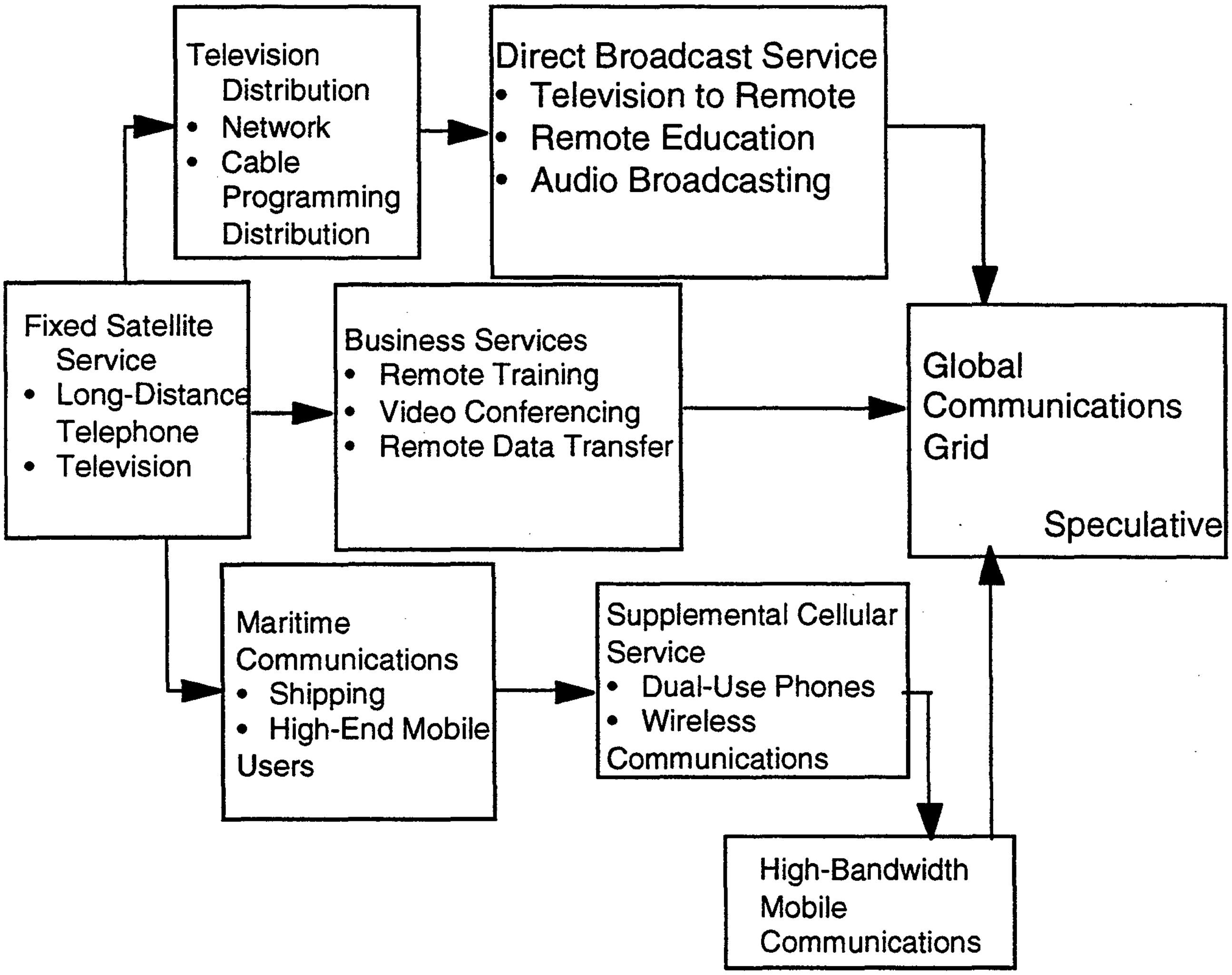

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Figure 3.1.2.1-2. Communication Satellite Applications Roadmap

3.1.2.2 Market Area Cross Reference

Figure 3.1.2.2-1 illustrates how applications are growing up around the communications industry. The table shows the market as originally envisioned by CSTS and how industries relate to the basic services provided by the satellite communications industry. Every industry uses information and communications. The transportation industry demonstrates the point. Industries—be they airline, railroad, trucking, rental cars or maritime—all have similar problems that can be helped by the communications industry. The industry must monitor and control the location of its assets, which, by their very nature, are constantly changing location. The industry can use PSS to locate a car, train, airliner, or ship, and then transmit its location back to a home office or control center. This has the highest priority for the airline industry's transoceanic traffic, where ground radar is ineffective. By the use of GPS the industry would be able to decrease the distance between aircraft when flying crowded routes, thereby increasing traffic flow.

Example Industry Application	Original CSTS Segment	Industry Service
Long distance telephone	Telecommunications	Fixed satellite service
Surveying	Survey and locate and global positioning	Positioning satellite service
Locating moving objects (trains, ships, cars, etc.)	Survey and locate	Positioning satellite service
Oceanic air traffic control	Global air traffic control	Positioning satellite service and Fixed satellite service or mobile service
Airline in flight radio	Direct broadcast service	Direct broadcast service
Remote education	Remote area education	Fixed satellite service going to direct broadcast service
	GEO platforms	Not a service or market

Figure 3.1.2.2-1. Cross-Reference Between Example Industry Applications, CSTS Original Market Segment, and Communication Service

Overall, the outlook for satellite communications is for continued rapid growth in most areas with the greatest expansion in the areas and mobile satellite systems (MSS), which will drive growth in LEO and medium earth orbit (MEO) satellite systems. FSS and maritime mobile satellite services (MMSS) will experience more moderate growth rates. It is predicted that the commercial satellite communications market will grow to $38.8 billion by the end of the decade (fig. 3.1.2.2-2). Satellites today provide approximately 60% of the world's intercontinental telecommunications in spite of, or in partnership with, fiber-optic cable facilities.

Satellite Service	1992	2002
	$billion	
Fixes Satellite Services		
INTELSAT	4.5	8.5
Regional and other international satellite systems	1.8	3.6
U.S./Canada national systems	2.3	4.5
Other national systems	1.4	3.4
Subtotal	10.0	20.0
Mobile/Low Orbit Services	0.8	10.0
Broadcast Satellite Services	0.5	8.0
Other (e.g., Data Relay, etc.)	0.1	0.3
Total	11.4	38.3

Figure 3.1.2.2-2. Satellite Revenue Projections

Commercial communications satellites occupy three orbital locations. The geostationary earth orbits (GEO) are positioned at points above the Earth's equator at a distance of 22,236 mi (35,786 km), where the relative motion is that the satellite remains at a fixed location rotating in unison with the Earth. With only small corrections, this allows the satellite to constantly cover an area of the Earth's surface. This also allows a fixed focal point for the uplink-downlink antenna and for the ground base. Additionally, it requires only three properly located satellites to cover the Earth's circumference. Satellites with orbits much closer to the Earth (LEO) have a much smaller viewing angle of the surface, and also follow various paths about the surface and thus multiple satellites are required for constant coverage. An intermediate class of orbit is the mid, or medium, Earth orbit. Satellites in these orbits have larger viewing angles but suffer other disadvantages of those in LEO. For those coverage areas that are far from the equator, such as Russia, and thus on the fringe of a GEO satellite view, a Molniya (the USSR satellite to first employ this orbit) orbit is used. This orbit is highly elliptical and polar. Satellites on this orbit spend about 6 hours at the apogee, which occurs over the desired coverage area, and thus four such satellites are required for continuous coverage.

3.1.3 Fixed Satellite Service

3.1.3.1 Market Description

Fixed satellite service (FSS) is the transmission of analog and digital data over long distances from fixed sites. For the purpose of this report, it is further defined to mean basic services used by the telephone and television industry using geostationary satellites (satellites in geostationary orbit communicating with fixed ground stations). The users of these services are telephone, television, and business doing business in multiple cities.

Early fixed services satellites were merely signal reflectors and had no electronic components. These reflectors (or passive satellites) radiated the signal in all directions, and thus only a fraction of the signal was directed toward the receiver. This required very high-power transmitters for adequate signal reception at the receiving ground station. Subsequent satellites are active satellites having many electronic components and function as repeater stations. These receive the uplink carrier, process, and then retransmit on the downlink to other Earth stations.

Current communications satellites have multichannel capability and use various schemes for modulating the actual information signal onto the carrier signal. Normal transmission frequencies are in the megahertz range, but the information (voice) requires only the range (bandwidth) of 30 to 20,000 cycles. The higher frequency "carrier" is then "modulated" in the lower information frequency range. The higher frequency, in the gigahertz (GHz) range, is thus said to be modulated by the information (signal), in the kilohertz (kHz) range. A receiver tuned to the carrier frequency picks up the transmission and then "demodulates" so that the signal is again audible. The actual carrier frequency is determined by several factors, physical and political. The physical factors are concerned with noise. This noise is from either atmospheric (Earth) or galactic (space) sources and is generally negligible above 1 GHz. Atmospheric absorption is less below about 12 GHz but water vapor and oxygen absorption increase noise above 10 GHz. Thus, an ideal carrier frequency range would be between 1 GHz and 10 GHz. Political factors (regulations) imposed by regulatory agencies such as the FCC (U.S. Federal Communications Commission), the ITU (U.N. International Telecommunications Union), and the WARC (World Administrative Radio Conference) allocate which frequencies are available. The S and C bands have been most predominant in telecommunications with the 4-GHz band used for downlink and the 6-GHz band used for uplink. Currently these are becoming crowded and expansion is taking place into the L and Ku bands, with audio signals in the L band and those signals containing video information into the Ku band. With these improvements, satellites accomplish some 60% of the intercontinental telecommunications today.

Applications

Telephone. Telephone companies have used FSS since the early 1960 with success. The satellite has allowed companies to establish or supplant long distance services between continents or into remote areas without laying telephone cables. This is factor is one of the driving forces keeping telecommunication usage alive today.

Since the first telecommunications satellites were put into service, transoceanic cable has been laid in increasing number. These cables are now being replaced with fiber-optic cable, resulting in greater capacity and service. With these occurrences, telephone use (analog) has decreased to 16% of satellite usage in the early to middle 1990s.

However, FSS still offers several features that will keep it in use for telephone service. These are (1) a single geostationary satellite has a constant view over continent-size areas of the globe and (2) satellites have the flexibility to shift capacity between ground stations. For example, if a cable breaks between two sites being serviced by fiber-optic cable, the satellite can add system capacity to help make up the loss cable.

Satellites offer the most efficient manner to establish telecommunications services for regional development. The satellite alternative is becoming more attractive as the cost of ground stations decreases. This is particularly true for the Pacific Basin area (ITU region 3), where there are over 2,000 islands requiring service. At the same time the increased wealth of the area has driven demand for telephone and data services. General agreement found in the industry was that this area would drive fixed satellite demand. In 1993 transponder demand was for 926 transponders (36 MHz equivalent). According to industry prediction, this demand will double by 1997. This increase in usage will occur before it becomes practical to lay fiber optics between all the islands.

Business. Businesses are having a greater interest in telecommunications as data generation and usage go up. Many businesses are now global in standing, with many having locations in remote locations. The oil industry is a case in point. The oil industry is exploring and recovering oil from Alaska, offshore locations, undeveloped regions of South America, and other remote locations. Readied and comprehensive communications with these locations are of vital interest to industry. The need for communication rates of over 5 megabytes/second with quantities of terabytes from a single location has been quoted in interviews with oil companies. The ability to transmit these data from/to remote sites is a major factor in the efficient exploration and exploitation of resources.

More classical business usage is for video conference and the transmission of business data. Very small aperture terminals (VSAT) have increased the business usage for videoconferencing between diverse locations. In less than 15 years 6,000 terminals have appeared; their increased demand now accounts for 8% of the total communication satellite usage. Increases of business usage by three to four times are predicted by the industry. As costs of ground systems and satellite systems decrease usage will be accelerated.

A second specific application is the satellite usage by financial houses. Global electronic transfers are done via satellite for the majority of the world (in 1992, according to JTEC Panel on Telecommunications, some $300 trillion). Other cited current applications are airline transport, international and national retailing, stock trading, and insurance.

Television

The television industry uses 60% of all FSS. Satellites offer the most appropriate means for networks and cable programmers to transmit video signals from remote locations to a central production facility and from the production facility to affiliates and cable operator head ends. The most attractive factors for television usage of satellites are (1) ability to transmit the same signal dependably with a single asset to an unlimited number of sites on the ground, (2) ability to rapidly set up transmission from a remote site to a central location for video service independently of the location of the remote site, and (3) ability to reliably maintain and control the quality of delivery of service to all distribution sites.

Several factors are affecting the future bandwidth requirements for the industry. These include increased television programming requirements (for more shows, and more channels), the introduction of high-definition TV (HDTV) and interactive TV, and digital compression technology. Each of these will be discussed in turn.

Television Programming. One only has to look at TV or program listings to witness firsthand the increased number of programs that the consumer has to choose from. The cable industry in particular has made available channels, such as HBO, ESPN, CSPAN, CNN, Showtime, and many others. The number of channels that a typical consumer has to choose from has increased from three or four in most areas 20 years ago to over 50 in most metropolitan areas. Cable operators such as TCI expect to introduce 500-channel service in the relative near term. This will mean additional pressure for more niche programming.

The niche programming area that is receiving most attention is in education. Cable programmers are currently offering services such as The Learning Channel, Mind Extension University, and The Discovery Channel. Programming is expanding to specific industries, companies, and disciplines. Candidate areas include medicine, engineering, law, and sales. Already the auto industry is using satellites to teach mechanics how to perform maintenance items and teach salesmen about the latest cars. Firehouses across the country receive specific programs on lessons learned from fires across the country. New companies are enjoying success producing such programming.

Elementary and high school education is also benefiting, New programs from historical sites or news scenes are now starting to appear in the classroom. The most spectacular example of this is where space shuttle crews televise simple experiments from space or where students participate with "live" operations of underwater exploration devices.

High-Definition TV and Interactive TV. These applications are nearing fulfillment and being prepared for the consumer. Both applications require greatly increased bandwidth. HDTV is receiving high attention by the NITA, FCC, WRAC, and the ITU. HDTV is designed to have twice the resolution of conventional TV, a wider screen, and compact disk-quality sound. Analog HDTV signals will not fit into current spectrum allocations. With the advent of digital signal compression, HDTV should fit into current allocations. HDTV will impact both the FSS and direct broadcasting service areas.

Interactive TV. This application, currently in the demonstration phase, offers consumers the ability to affect the video images they receive. For example, for sports telecasts, the viewer will be able to select which seats they watch the action from, get the latest statistics on specific players, and even select multiple windows at once. Such programming increases the bandwidth requirements by four times to an order of magnitude.

Digital Compression. To enable the television industry to deliver these products, video compression had to be developed. Using video data requires 1,000 times the bandwidth of voice and typical information data. With video data in the megahertz (MHz) range there are far fewer "channels" available per band. To mitigate some of this over demand a technique known as compressed digital video (CDV) has been developed. The typical (U.S.) video bandwidth is 4.2 MHz. This requires a sampling rate of 8.4 MHz, and with 8 digital bits per sample (byte) a bit rate of 67.2 Mb/s is created. With a three-color system the bit rate climbs to 201 Mb/s. In comparison, a current diskette holds about 1.44 MBytes or 11.5 Mbits. A 100-minute movie would then require over 100,000 diskettes. Furthermore, the higher resolution the video signal requires, the higher the bit rate. A typical VHS-quality signal requires about 1 to 2 Mbps for one-way transmission. With the advent of HDTV, this requirement may grow to 15 to 25 Mbps. This growth is being driven by demand for larger viewing formats (such as large screen or projection TV systems), and the increased demand for digital pictures and interactive TV.

Thus, some method of compression and decompression of the data is required. Combinations of techniques are used. Initially, preprocessing the data to remove what is most difficult to code but is relatively unimportant is employed. Then techniques are used to delete or simplify coding of the remaining data. One such method is to code only the changes from one frame to the next frame.

In 1992, General Instrument Corp. and Compression Labs Inc. began selling the commercial systems for digital compression in transmission of multiple, high-quality video channels on a single satellite channel. Scientific Atlantic also recently began shipping equipment for this market, and several other companies have announced digital equipment for similar applications.

These systems are moving toward adopting the new MPEG digital standard for high-definition television and developing interoperability between different pieces of equipment such as satellite receiver, computers, TVs, and VCRs. Consumers will be more likely to purchase standardized products, which will also increase the number of products and decrease unit cost

With compression, current planned systems can provide up to 32 video channels in the same bandwidth that would have previously provided less than 10.

Digital compression is not always appropriate for use. TV networks, and programmers require a full signal from a remote site (backhauling) for postproduction work in order to preserve the signal quality. Digital compression by its nature removes data from the signal. While in most circumstance consumers will not notice the difference in the signal sent to them, compressed video does degrade the quality sufficiently to be noticeable for postproduction. Therefore, backhauled information will likely not be compressed.

3.1.3.2 Study Approach

Three different methods were used to size the FSS satellite demand and required transportation attributes. Figure 3.1.3.2-1 shows the process for the method used. The first method was to interview and collect data industry leaders from Hughes, Martin Astro Space, AT&T, Americom, Intelsat TCI, Jones Intercable, The FCC, the University of Colorado, and others. Sources for the data were printed matter, recorded Congressional testimony, and direct interviews. Appendix B.1 lists all contacts used in this study.

The second method was to review all current and anticipated satellite orders. This information was divided up into current contract, pending, and proposed. The data provided information to establish the current traffic for FSS satellites.

Third, an analytical model was developed to forecast satellite requirements for the future. The model has three basic features. The first is the current transponders in service and their expected lives. Two curves were developed to provide an upper bound and lower bound estimate. The lower bound number represents the number of current in-service transponders remaining in any particular year, based on launch date and engineering design life. The upper bound is adjusted for historical lifetime of the satellites.

A set of transponder demand curves were then developed by taking data gathered from interviews and printed material. Specific demand curves were made from projections made for Martin Marietta proprietary use, space policy projections, industry projection of 6% per year annual increase, and from satellite order information.

Next, two different satellite models were developed, the first was an Intelsat class, which has 90 36 MHz equivalent transponders with a LEO equivalent weight of 27,000 lb and a life of 15 years. A single owner class of 27 transponders and 13,000 lb LEO equivalent weight and a 7-year life was developed. These two satellite models were developed by reviewing projected order information.

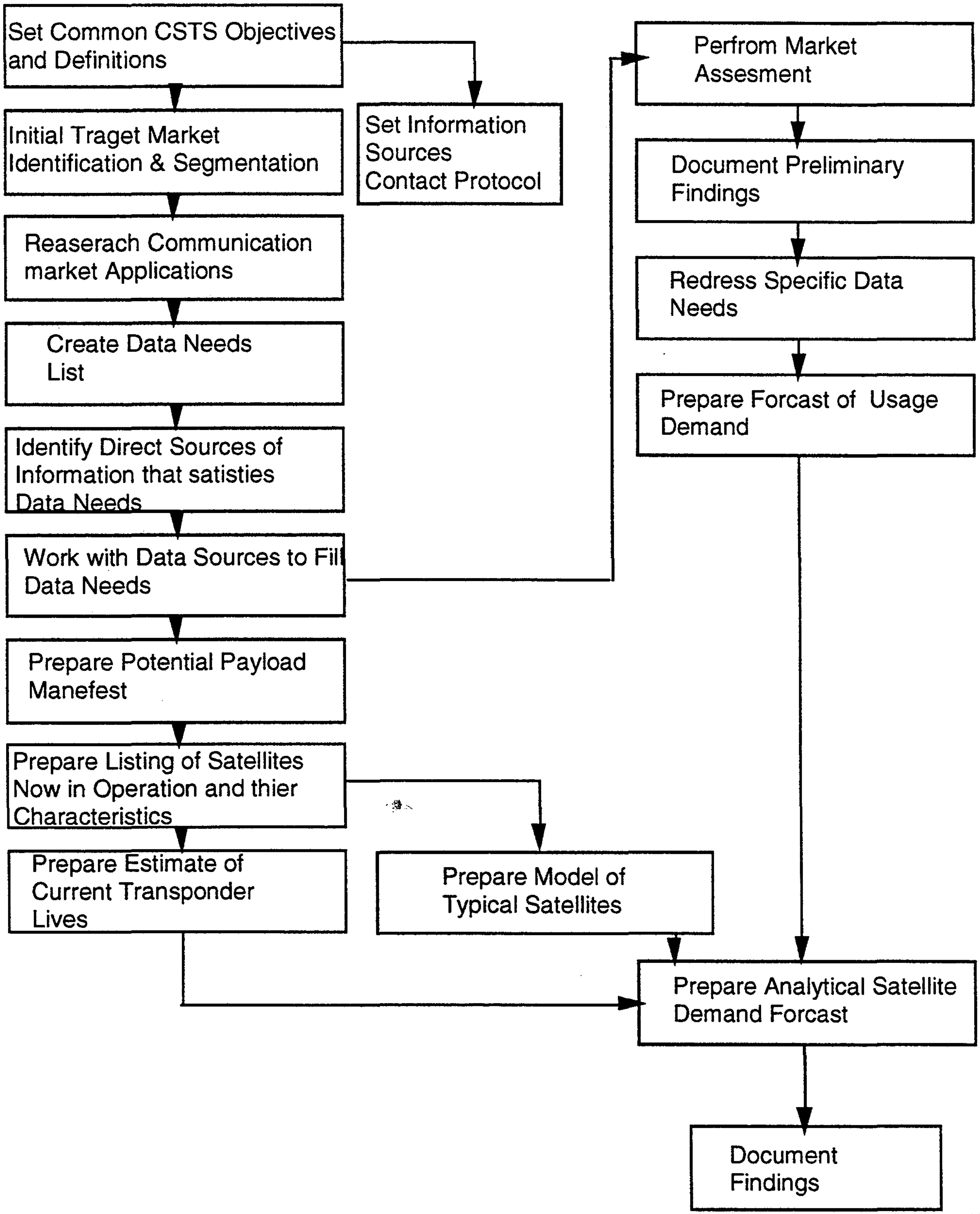

Figure 3.1.3.2-1. Study Methodology

The information was then combined to project demand for future satellites from the present to 2010. Information was then reconciled into high, medium and low probability and reported in both number of satellites and mass to LEO. The LEO orbit used was 100 nmi circular at 28.6 deg inclination launch from the Eastern Test Range in Florida. Price elasticity is based upon comments made on digital compression and the percentage of budget spent to launch and maintain a satellite system.

3.1.3.3 Market Assessment and Projection

The accepted lives of the transponders currently in service is seen in figure 3.1.3.3-1. As seen, there were currently just under 2,940 transponders in service at the end of 1993. The number of the transponders continuously decreases, with zero reached sometime around the year 2010 as satellites reach the end of their projected lives.

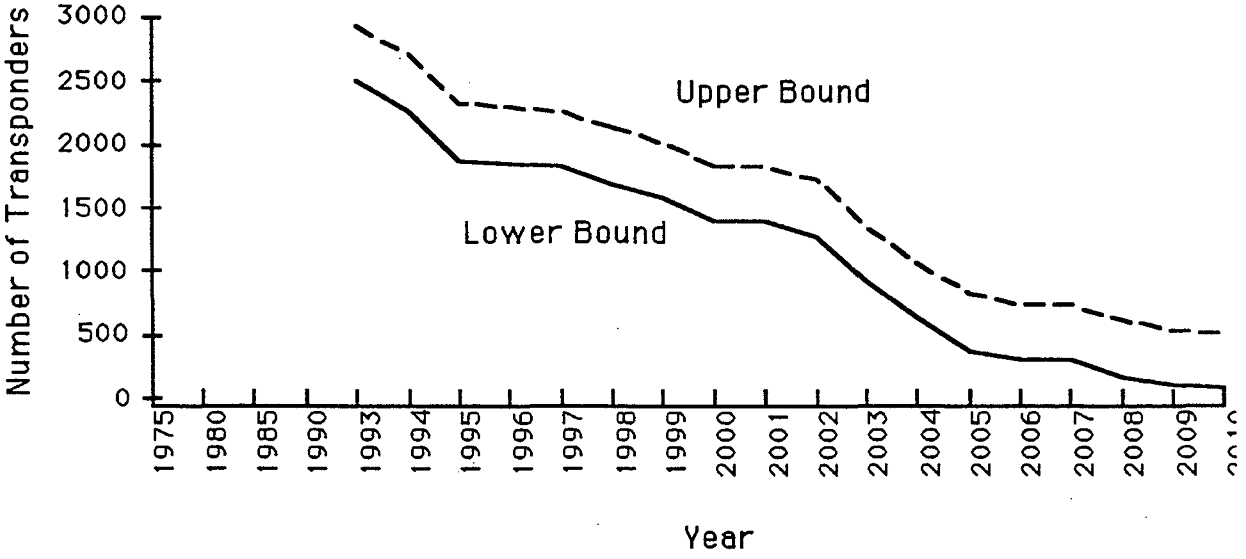

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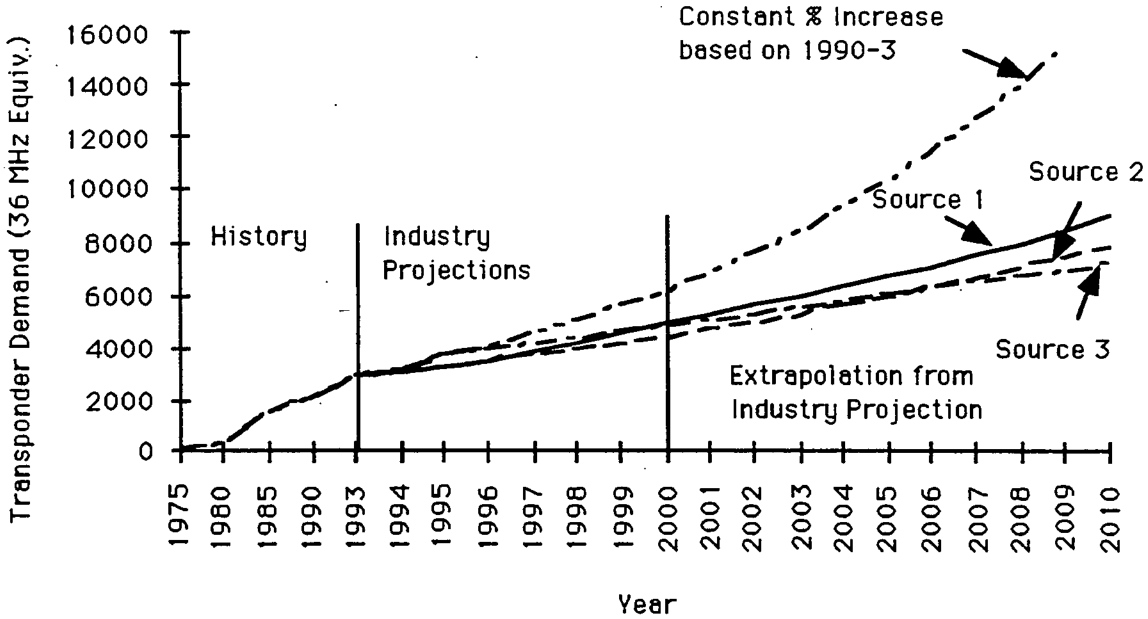
Figure 3.1.3.3-1. Projected Lives of Current Transponders on Orbit

Figure 3.1.3.3-2 shows transponder demand estimates. Four different estimates are shown. The highest demand curve is based on the trend established in the 1990s, where over 15,000 transponders would be forecast in the year 2010. The next highest curve is extrapolation of proprietary reports from consultants, which show demand for some 8,200 transponders . A projection from space policy shows some 3,900 transponders in use in the year 1996. Using a 6% per year increase to this number to the year 2010 results in demand of approximately 8,870 transponders. A lower bound conservative estimate curve of resulting in 7,200 transponders is the lower curve shown, which was created by roughly halving the current growth in transponder demand.



Source 1: Industry Projections with 6% Growth after year 2000
Source 2: Space Policy Projection wiht 6% Growth after year 1996
Source 3: Satellite Order Projection Estimate

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Figure 3.1.3.3-2. Transponder Demand Projection

The resulting satellite demand from satellite replacement and demand is shown in figure 3.1.3.3-3. This curve is the result of combining the information contained in figures 3.1.3.3-1 and -2 and using the satellite features of the two classes of satellites developed. A 40%/60% split between the Intelsat/Single Provider satellite transponders was used as developed from historic launch data. The lowest estimate derived for the time period between 2005 and 2010 is 24.3 satellites per year, found by combining the upper bound current transponder curve and the lower bound transponder demand curve. Combining the lower bound current transponder curve and the extrapolated consultants data results in an estimate of 31 satellites per year.

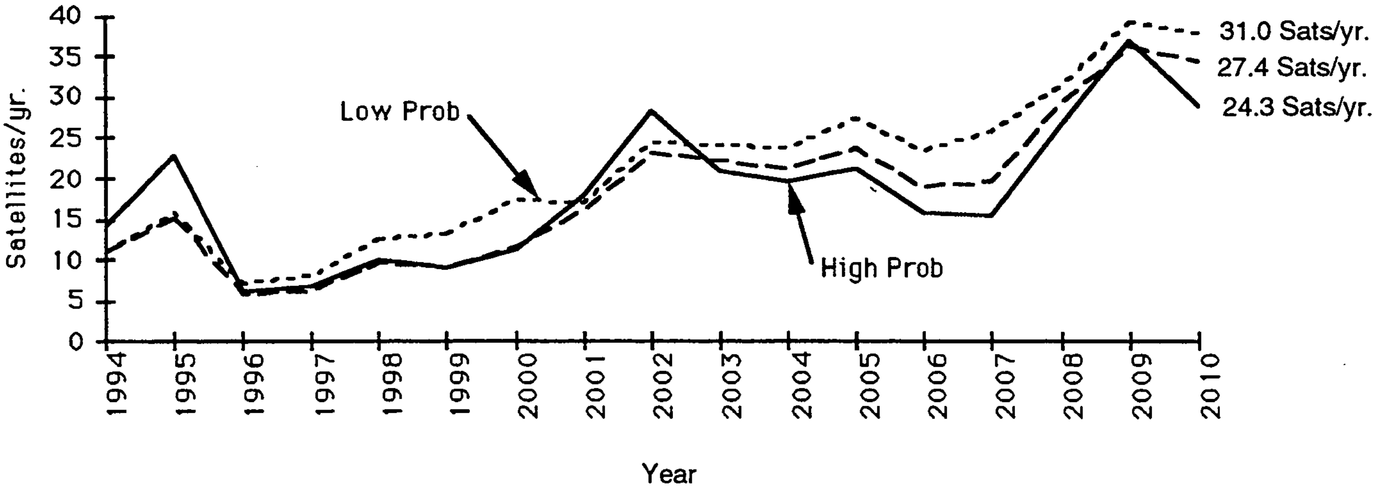

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Figure 3.1.3.3-3 Fixed Satellite Service Launch Demand by Year

Use of satellite orders information resulted in an estimate of 20 satellites per year estimate for a high-probability market. Another four satellites were added to that total for medium models based on consideration of proposed projects. The low probability number was derived by consideration of all reported proposed projects. This analysis assumes that the market remains stable throughout 2010.

Based upon the above analysis are the projections found in the figure 3.1.3.3-4 below.

	Market Probability		
	High	Medium	Low
Number (avg./yr.)	20	24	31
Mass (avg. klbs/yr.)	295	395	457

Figure 3.1.3.3-4. Market Projection With Current Prices

Price elasticity is based on comments made by cable programmers in conversations about digital compression. They commented that the additional capacity gained by digital compression was to be immediately consumed. Digital compression was to be used to provide additional capability while maintaining the current budget for satellite usage. In other words, a one-to-one correspondence is maintained between the cost of satellite usage and resulting demand. This ratio may be conservative based on the fact that the additional capacity is to be immediately consumed, leading to the conclusion that if made available the demand would increase faster than a 1:1 ratio. However, to be conservative in this analysis a 1:1 ratio was used. Since the cost of transportation is approximately half that cost of providing satellite service a simple formula is possible (e.g., a decrease of 50% in launch cost would drop the cost of satellite service by 25% and result in an increase of 25% in transponder and satellite demand. This treatment results in the following price elasticity curves, as shown in figure 3.1.3.3-5.

	Launch Cost		
High Probability	Current	$1,000/lb	$600/lb
Number (avg./yr.)	20	25	33.3
Mass (klbs/yr.)	295	369	493
Medium Probability			
Number (avg./yr.)	24	30	40
Mass (klbs/yr.)	354	443	591
Low Probability			
Number (avg./yr.)	31	39	51
Mass (klbs/yr.)	457	571	793

Figure 3.1.3.3-5. Demand Changes as a Result of Changing Price

3.1.3.4 Prospective Users

Prospective customers of the CSTS system for launching communications satellites are primarily the current customers of launch systems. The largest user by far is Intelsat, which currently has 20 satellites in operation, 14 satellites on order, and options for 14 others. Other users, such as AT&T, Americom, and individual countries and postal telegraph and telephone (PTT) organizations will continue to be primary customers. See appendix B.2 for a listing of users.

3.1.3.5 CSTS Needs and Attributes

Fixed satellite applications dominate the commercial uses for space transportation. As a result, they currently have a wide experience base. The industry infrastructure for processing and launch payloads is in existence worldwide. The infrastructure needs are unlikely to change to any appreciable amount. Satellites will maintain their current requirements for contamination, hazardous processing for propellant servicing and ordnance installation, and ground transportation.

Selection criteria used to select launch vehicles, in order of importance, are—

a. Payload capability (can the launch vehicle lift the payload to the correct orbit).
b. Availability (Can the launch vehicle be schedule to meet the need).
c. Reliability.
d. Cost.
e. User friendliness (documentation requirements, logistics, provider responsiveness).

3.1.3.5.1 Payload Capability

Two classes of satellites were found to exist, and they will continue to be produced for the foreseeable future. Both classes are ultimately delivered to geostationary orbits over the region where service is required. The heaviest class of satellites weighs around 27,000 lb at launch, including kick stages, and fits within a 14-ft diameter envelope. The second class weighs typically 13,000 lb and fits within a 10-ft diameter.

While there has been speculation that as launch costs decrease and launch vehicle capability goes up, the mass of all satellites would increase. This has not been sufficiently proved for GEO-based satellites. While LEO satellites will have an earlier time adapter to less restrictive launch requirements, GEO satellites may not enjoy the same benefits. This is due to two causes: first is the additional energy requirements to get to GEO, and second is insurance. Typically, a GEO satellite enters a park orbit of around 100 to 160 nmi. After reaching this orbit, the satellite must make two more "burns." The first burn places the satellite into a GEO transfer orbit and the second burn at apogee places the satellite into its service or operational orbit at geostationary location. Before GEO satellites can grow any significant amount, a low-cost upper stage must also be developed with significant payload capability.

Insurance availability is also a consideration on how large a commercial payload can become. The pool of insurance available for insuring communication satellites is about $400 to $500 million worldwide. This amount has failed to grow even in light of the recent losses of an Intelsat and the recent Ariane 4 failure and the current rates of 11% to 18%. These factors place a potential limit on the size of GEO-based communication satellites irrespective to the size of the launch vehicle.

3.1.3.5.2 Availability

Currently, booking times of 36 months are typical in the industry. In some cases books of 18 months before launch have been done. Typical satellite orders take 2 to 3 years to fill. In some cases an 18-month schedule has been accomplished. To meet a launch at the earliest opportunity an integration timeline of 12 to 16 months is needed. This allows the user 2 to 6 months to select a launch vehicle and perform contract actions before committing to a launch.

3.1.3.5.3 Reliability

This is a major issue with users and satellite providers. Insurance rates are between 11% to 18% of the total cost of placing a satellite system in orbit. While the current typical design reliability of 0.98 and demonstrated reliability of 0.96 are being used out of necessity, higher reliability would remove risk and lower insurance rates. Higher reliability will allow the insurance industry to recoup the losses they have encountered and should allow the industry to eventually reduce its rates. Moreover, a satellite lost is a satellite not earning revenue. A loss of a satellite system costing $100 to $200 million obviously is a hardship on both the owners and users of a satellite.

3.1.3.5.4 Cost

Current cost supports the use of space communications. However, launch service costs now are 50% of the cost of providing a satellite to the user. A decrease in cost will result in greater satellite usage and numbers.

3.1.3.5.5 User Friendliness

This category can be broken down into several components. These are type of service provided, logistics, provider responsiveness, and documentation requirements. Every user and satellite manufacture indicated that the launch provider is performing a service, and as a part of that service, the nearer the launcher places the payload to its final destination, the more attractive the service. If the launch places the payload into the transfer orbit rather than a park orbit, it reduces the burden on the satellite manufacturer and user by elimination of an additional organization (the upper stage provider) to deal with. Hence when an upper stage is provided, the burden and interfaces for the payloader are greatly reduced.

Logistics is another issue. Satellite manufacturers would like the launch provider to be located in an easily accessible and user-friendly environment. A U.S. launch site for example, offers a number of ways to receive payloads, roads, barges, or aircraft. Logistics for the employees of the satellite users and manufacturers was also cited. Access to TV, good hotels, easy communications, selection of restaurants and entertainment, and good medical care were noted as being important. While U.S. launch sites offer these features, most foreign sites do not have ready access to some or all of these amenities. This is improving, but several contacts expressed distinct preferences for U.S. launch sites.

The ability of the provider to give personalized attention to the user and manufacturer was noted by the interviewees as being important. Users like and want to be able to call in to a single point of contact and need to have confidence that their needs are being considered.

A major complaint was that launch providers think too much like government contractors, imposing extensive documentation requirements and failing to effectively challenge imposed requirements given by the government. Streamlining of documentation and providing classes of standard service with minimal unique requirements will help satisfy the complaint. Users noted that the U.S. launch industry is incapable of effectively dealing with range safety requirements. Sifting safety requirements imposed on both the launch vehicle and spacecraft is a major issue with commercial users. Stability in these requirements will improve the perception of the users.

3.1.3.5.6 Ground Handling

Existing ground facilities are proving to be adequate to service this market area. No new special provisions are envisioned to be needed. Typically the satellite manufacture supplies all unique aerospace ground equipment, including that required for handling. Satellites typically require facilities for hazardous processing such as loading of hydrazine. The launch provider typically transports the payload from the spacecraft processing facility to the launch vehicle.

3.1.4 Direct Broadcast Service

3.1.4.1 Market Description

A new market area is direct broadcast of TV and audio channels directly to homes, remote or business directly from satellites. Currently, Japan and Europe are successfully using and expanding direct broadcast services (DBS). Direct broadcast is extremely attractive for areas such as the Pacific Rim, where infrastructure has not been fully established and is difficult to establish. DBS is being reintroduced in the United States in 1994. Direct broadcasters in the United States are planning to provide up to 150 channels to the consumer from satellite pairs. The primary market was seen as the consumers who do not have access to cable TV. However, DBS may be a direct competitor to the cable TV provider. DBS providers are intending to provide high-definition TV service.

Another new market is direct broadcast digital radio from satellites. This offers the advantage over conventional radio by consistency of programming over large global areas or on a global basis. Estimates of several hundred channels of programming may be possible.

Digital compression technology is an enabler for this market area. This technology improves the effectiveness of tansponders from 4 to 12 times, thereby increasing transponder effectiveness for both conventional TV picture standards and for HDTV. Without digital signal compression BSS providers would not be able to provide the breadth of service demanded by the consumer.

3.1.4.2 Study Approach

The same methodology as the FSS assessment was conducted here. Interview results, current satellite inventory, and satellite orders data were used in the market assessment.

3.1.4.3 Market Assessment and Projection

The DBS market area is a direct outgrowth from the FSS area and, as a result, is very similar in many characteristics. Both systems operate at GEO, go through similar approval processes, and have like launch vehicle interface requirements. However, unlike the FSS area, which has both point-to-point, and point-to-multipoint communications, BSS is only point to multipoint. Therefore a greatly reduced number of satellites are required to service the market. For example, for the United States, if two competitors are successful, only six satellites would be required. Other regions require more satellites, due to language and cultural differences. To provide good quality services worldwide as few as two dozen satellites may be required. This conclusion is supported by the number of projected satellite projects (in the listing in app. B.2).

The traffic model (fig. 3.1.4.3-1) based on currently planned satellites and their replacements results in an average of 3.8 satellites per year for the period of 2005 to 2010. If HDTV increases bandwidth requirements by two times and the satellite to increase the services are introduced starting in the year 2000, then the satellite traffic increases to 5.4 satellites per year for the same time period. This estimate is used for the medium probability estimate. If we assume the world demand for DBS double from the projected high-probability market with HDTV, then a 6.8 satellite per year requirement for 2005 to 2010 results.

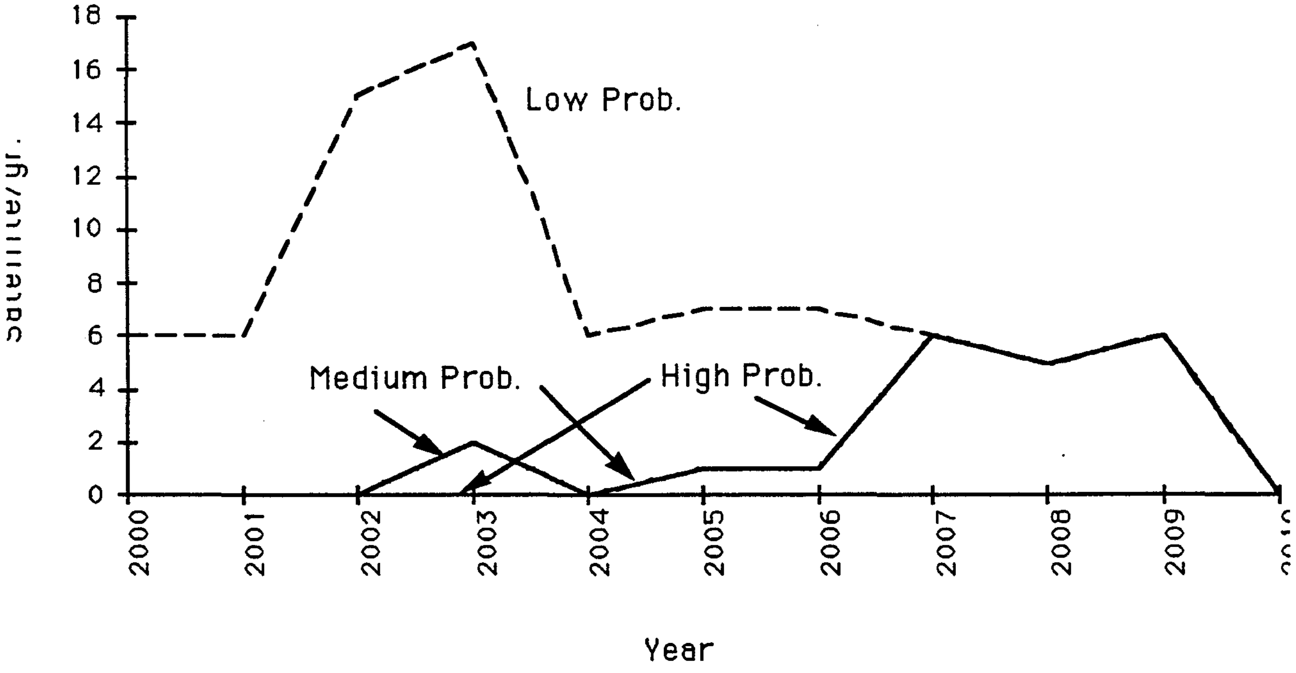

Figure 3.1.4.3-1. Direct Broadcast Satellite Demand by Year

Using the same method as used for the FSS market, figure 3.1.4.3-2 shows the resulting elasticity curves.

	Launch Cost		
High Probability	Current	$1,000/lb	$600/lb
Number (avg./yr.)	3.8	4.8	6.3
Mass (klbs/yr.)	91	144	152
Medium Probability			
Mass (klbs/yr.)	130	163	216
Number (avg./yr.)	5.4	6.8	9.0
Low Probability			
Number (avg./yr.)	6.8	8.5	11.4
Mass (klbs/yr.)	163	204	273

Figure 3.1.4.3-2. Demand Changes as a Result of Changing Price

3.1.4.4 Prospective Users

Prospective customers of the CSTS system for launching DBS satellites are current manufacturers and providers of DBS. Appendix B.2 contains a listing of current and planned users.

3.1.4.5 CSTS Needs and Attributes

DBS systems are very similar to those which provide FSS and hence, result in similar requirements. The industry infrastructure for processing and launch payloads are in existence worldwide. The infrastructure needs are unlikely to change to any appreciable amount. Satellites will maintain their current requirements for contamination, hazardous processing for propellant servicing and ordnance installation, and ground transportation.

Selection criteria used to select launch vehicles are, in order of importance are—

a. Payload capability (Can the launch vehicle lift the payload to the correct orbit),
b. Availability (Can the launch vehicle be scheduled to meet the need?).
c. Reliability.
d. Cost.
e. User friendliness (documentation requirements, logistics, provider responsiveness).

3.1.4.5.1 Payload Capability

Typical BSS satellites weigh around 24,000 lb at liftoff, including kick stages, and fit into a 14-ft diameter.

3.1.4.5.2 Availability

Currently, booking times of 36 months are typical in the industry. In some cases books of 18 months before launch have been done. Typical satellite orders take 2 to 3 years to fill. In some cases an 18-month schedule has been accomplished. To meet a launch at the earliest opportunity an integration timeline of 12 to 16 months is needed. This allows the user 2 to 6 months to select a launch vehicle and perform contract actions before committing to a launch.

3.1.4.5.3 Reliability

This is a major issue with users and satellite providers. Insurance rates are between 11% and 18% of the total cost of placing a satellite system in orbit. While the current typical design reliability of 0.98 and demonstrated reliability of 0.96 are being used out of necessity, higher reliability would remove risk and lower insurance rates.

3.1.4.5.4 Cost

Current cost supports the use of space communications. However, launch service costs now are 50% of the cost of providing a satellite to the user. A decrease in cost will result in greater satellite usage and numbers.

3.1.4.5.5 User Friendliness

This category can be broken down into several components. These are types of service provided: logistics, provider responsiveness, and documentation requirements. Every user and satellite manufacture indicated that the launch provider is performing a service, and as a part of that service, the nearer the launcher places the payload to its final destination, the more attractive the service. If the launch places the payload into the transfer orbit rather than a park orbit, it reduces the burden on the satellite manufacturer and user by elimination of an additional organization (the upper stage provider) to deal with. Hence, the paperwork is significantly reduced and interfaces for the payloader are greatly reduced.

Logistics is another issue. Satellite manufacturers would like the launch provider to be located in an easily accessable and friendly environment. A U.S. launch site, for example, offers a number of ways to receive payloads, roads, barges, or aircraft. Logistics for the employees of the satellite users and manufacturers was also cited. Access to TV, good hotels, easy communications, selection of restaurants and entertainment, and good medical care were noted as being important. While U.S. launch sites offer these features, most foreign sites do not have ready access to some or all of these amenities.

The ability of the provider to give personalized attention to the user and manufacturer was noted by the interviewees as being important. Users like and want to be able to call in to a single point of contact and need to have confidence that their needs are being considered.

A major complaint was that launch providers think too much like government contractors, imposing extensive documentation requirements and failing to effectively challenge imposed requirements given by the government. Streamlining of documentation and providing classes of standard service with minimal unique requirements will help satisfy the complaint. Users noted that the U.S. launch industry is incapable of effectively dealing with range safety requirements. Sifting safety requirements imposed on both the launch vehicle and spacecraft is a major issue with commercial users. Stability in these requirements will improve the perception of the users.

3.1.4.5.6 Ground Handling

Existing ground facilities are proving to be adequate to service this market area. No new special provisions are envisioned to be needed. Typically the satellite manufacture supplies all unique aerospace ground equipment, including that required for handling. Satellites typically require facilities for hazardous processing such as loading of hydrazine. The launch provider typically transports the payload from the spacecraft processing facility to the launch vehicle.

3.1.5 Mobile Satellite Service

3.1.5.1 Market Description

The areas of mobile communications are the most volatile of all the communications segments. The mobile services are intended to provide wireless communication to any point on the globe. At the current time there are only limited mobile services using geostationary satellites made available by InMarSat. The InMarSat network relies on a backbone of three satellites to give global coverage. The first use of the network was to provide communications with commercial shipping at any time, at any point. This function is still being successfully accomplished with the InMarSat system. Private companies are now entering the market. With the advent of lower cost satellite technology and the increasing expectation to be able to communicate with anyone a number of new systems are being investigated and proposed. By one count some 11 different systems were being proposed. The new entrants are proposing a wide variation in approach. For example, American Mobile Satellite Company plans to use geostationary satellites to supplement cellular networks over the United States, while Iridium proposed the use of a satellite constellation of 66 polar LEO satellites to give global coverage. As a result, prediction of what systems will be deployed and service is difficult.

The strategy that all the companies are using to promote the mobile satellite market is to allow easy access to the satellite system. With the current system a typical ground unit is approximately 50 lb in weight and incurs 1/2 second transmission delays due to the distance between the satellite and Earth. Most mobile satellite ventures are attacking both of these problems and attempting to make the service user friendly or even seamless with current cellular terrestrial based systems. The future of the segment is dependent upon the successful introduction of satellites with sufficient capability and capacity to allow the use of lightweight, inexpensive, hand-held telephones similar to cellular telephones.

Development Status and Architecture Comparison

There is a variety of architectures that have been and are being developed to address mobile satellite communications. They include satellites in geostationary orbit (GEO), mid-inclined orbits at altitudes of thousands of nautical miles (MEO) and polar orbiting systems in low earth orbit (LEO). As well, two different classes of services have also been or are being developed. The first, called Little LEO by the industry, are small satellites put into service to perform simple text messaging and paging operations. Voice, fax, and data services constitute the second class. Here, a wider diversity of systems and constellation is in play. One architecture, called Big LEO, is one such solution. The big LEO systems used mid- to high-inclined orbits in circular altitudes in orbits below 600 nmi. This market area is also being serviced by the other orbit types of MEO and GEO.

Mobile communications by satellite was established in 1976 by the ComSat in developing the MARISAT system. Since that time a consortium of countries or signatories have developed today's InMarSat system. The InMarSat system has found high usage in applications from news-gathering to communicating with and controlling commercial maritime shipping. The current InMarSat system is based on the use of four geostationary satellite and ground equipment with the lightest of units, weighing approximately 50 lb, providing voice, fax, and data service. The advantage of this type of architecture is that it requires only one satellite to provide regional service, and only three to provide worldwide coverage and simple technology for communications between the satellite and ground. The limitations are the 1/2 second transmission delay caused by the distance between the ground and satellite, and limited capacity.

InMarSat has recognized these limitations and has been studying how to access the untapped potential of the mobile cellular telephone market. Its response has been a program called Project 21. This project's architecture conclusions have not been published at the time of this writing but will undoubtedly address these problems and provide access to the cellular user by dual-use phones (phones that allow access to both cellular terrestrial networks and a satellite network).

The newcomer to the mobile satellite area that has received most notice is the Iridium system. This system is based on a constellation of 66 satellites (not counting replacements or spares) in a 90° inclined orbit in six different orbital planes. Iridium has contracted for the production of its satellites, and has entered into launch agreements for launches on Delta, Long March, and Proton. The initial operating capability of the systems is 1998.

All current systems in development envision small hand-held telephones for voice communications and limited data transmission. Iridium inc. has been working to develop and deploy the Iridium system, which is projected to cost subscribers approximately $6.00/ min. Competition has appeared for the Iridium market in systems from systems such as Globalstar, Aries, Odyssey, Ellipso, and other others. These systems are listed in figures 3.1.5.1-1 and -2.

	Loral/Qualcomm Globalstar	Constellation Communications Aries	Iridium Inc.	TRW Odessey	Ellipsat Ellispo	AMSC	Calling Communications
Number of Satellites	48	48	66	12	14 to 24	1	924
Satellite Life (years)	7.5	5	5	15	5	10 to 12	7.5
System Development Cost ($B)	1.7	0.4	3.4	1.3	0.6	0.6	N/A

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Figure 3.1.5.1-1. Example of MSS Big Leo Systems

System	Geographic Coverage	Modulaltion	Handset Cost	Service Cost	Market Estimate	Operational Date
Odyssey	North America	CDMA	1000	N/A	N/A	Mid 1996
Iridium	Global	TDMA/FDMA	$2,000 to $3,000	$3.00/min	6 million	1998
Ellipso	U. S. and TGerritories	CDMA	($300 (add-on) $1,000 (new unit	$0.60/min	18 million	N/A
Aries	Global	TDMA/CDMA/FDMA	1500	N/A	2.9 million	1996
Globalstar	U. S. (first generation) Global (second gerneration)	CDMA	$700 (dual-mode) $600 (single mode)	$0.30/min	3.4 million	1997 (U.S.) 1998 (Global)

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Figure 3.1.5.1-2. Technology and Service Characteristics of Big Leo Systems

Little LEO systems offer only limited services. They are design to provide one-way emergency alerting, one-way locating for cars, trucks, or ships, paging, and limited two-way text messaging and data communication. These systems are placed into LEO, typically at 400 to 450 nmi. The cost to users ranges between $5 to $45 a month plus a nominal usage charge. The ground terminal typically cost between $50 to $400. Typical Little Systems and their attributes are listed in figure 3.1.5.1-3.

	Orbital Communication Corp.	Starsys, Inc.	Volunteers in Technical Assistance (VITA), Inc.
Number of Satellites	24	24	2
Services	One Way Emergency Alerting, Location , Two-way Messaging	Emergency Alerting, Location, Data Messaging, Global Paging	Data Transfer
Development Cost ($ Millions)	100	200	$3.0 Satellites
Terminal Cost	$50 to $400	$75 to $250	$4,000 to $6,000
User Cost	$5 to $40 per mo.	$150/yr	N/A
Operation Date	1994-5	1995	1990 (experimental) 1996 (fully operational)

Figure 3.1.5.1-3. Little LEO System Characteristics

3.1.5.2 Study Approach

Study methodology for this section was to use the interview process similar to that employed for the Fix Satellite Study. The information obtained from individual interviews was compared to find a consensus potion. This information was compared to mission model information to time initial placement of individual satellite systems. The engineering lives were then used to calculate the replacement schedule for the systems. This information was then combined into a spreadsheet to determine launch rates. Typical mass for each of the satellite types was applied to the mission model to obtain the mass per year requirements for each system type. The results were then added to gather to find a composite number of satellites per year and mass per year. For more details see section 3.1.3.2.

Since the satellites used in LEO typically do not require an upper stage, mass adjustments were used to find the effects of lower cost launches. The mass increase adjustment was made according to the Boeing methodology developed for the ALS program.

3.1.5.3 Market Assessment and Projection

The MSS market address three different types of users. The first type are those that are in remote locations. Examples are Maritime shipping and oil exploration. Second is to supplement cellular use by dual-use phones, and the third is for worldwide or regional paging/messaging.

The interview process yielded a consistent result, that being that three MSS systems will survive. This is also evidenced by the status of contenting systems. A Little LEO system named Orbcom by OSC is currently scheduled for launching on Pegasus starting in 1994. InMarSat is the incumbent MSS provider, with four satellites in use at GEO. Iridium has secured enough financing to contract for the build of its satellites and has manifested its launches for initial deployment and constellation maintenance. The Globalstar system is now starting its launch vehicle procurement process. The two most likely systems will be one at medium earth orbit and two at low Earth orbit. The MEO satellite is assumed to weigh the typical case of 1,500 lb. The two in LEO will be one Little LEO system, weighing approximately 500 lb per satellite, and one Big LEO system, weighing approximately 1,500 lb each. These three systems were used as the high-probability case. Figure 3.1.5.3-1 shows the total number of satellites per year and figure 3.1.5.3-2 indicates the total mass to orbit by year.

The mid probability estimate was perform to add on Big LEO system to the manifest. This estimate is predicated on the potential market size. Iridium has estimated that worldwide there are some 150 million cellular telephones. Iridium is also using a minimum market projection of 1.05 million subscriber with a potential base of three million. If Globalstar achieves the 3.4 million subscribers as listed in the table, the total number of subscribers for both systems represents only 3% to 6.2% of all cellular telephones. The medium-probability case is shown in figures 3.1.5.3-1 and -2.

The low probability uses the above systems plus one more. This additional system is based on a concept similar to an ARPA study called Global Grid. Under this concept a constellation of LEO Polar satellites would be placed into orbit. One solution by Calling Communication would use 840 operational satellites with a number of on-orbit spares, bringing the total number to 924 satellites. Establishment and maintenance of such a system would take around 200 satellites per year. Calling Communications believes that such a system would offer service at 30 cents per minute. The low-probability case is shown in figure 3.1.5.3-1 and -2.

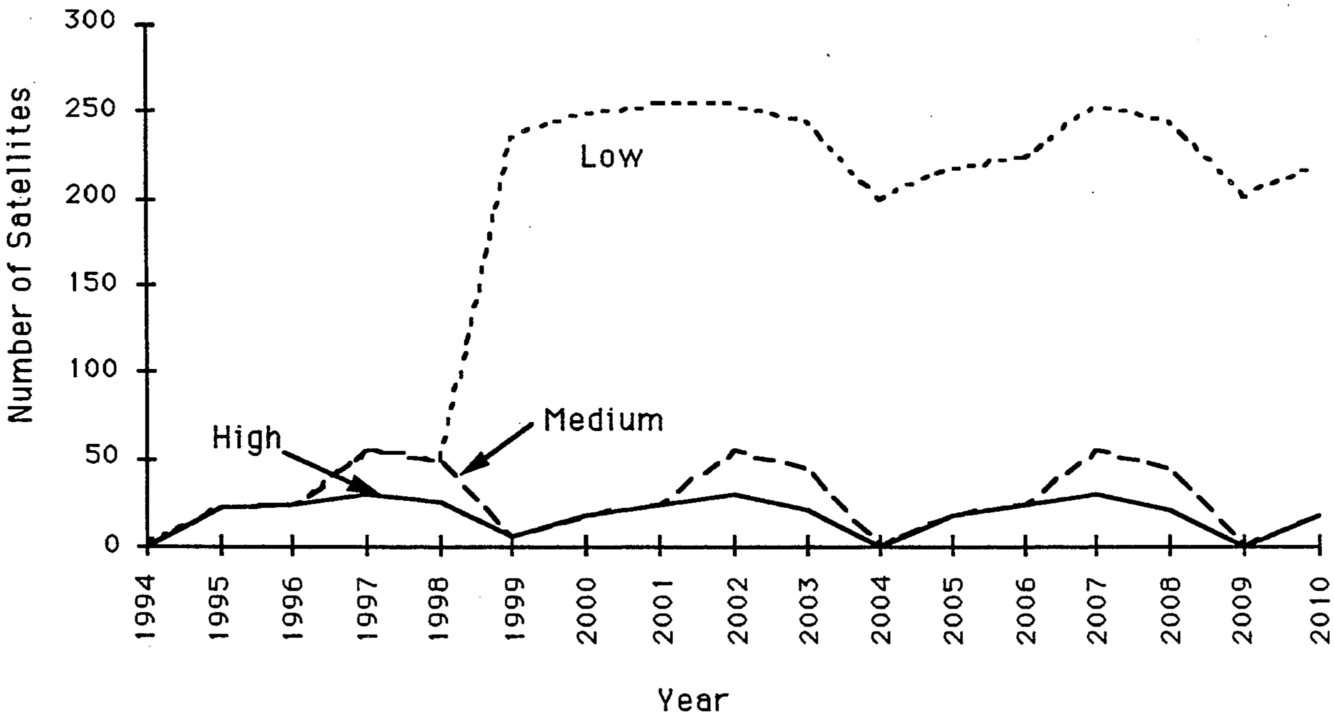

Figure 3.1.5.3-1. Total of MSS Satellites Demand by Year

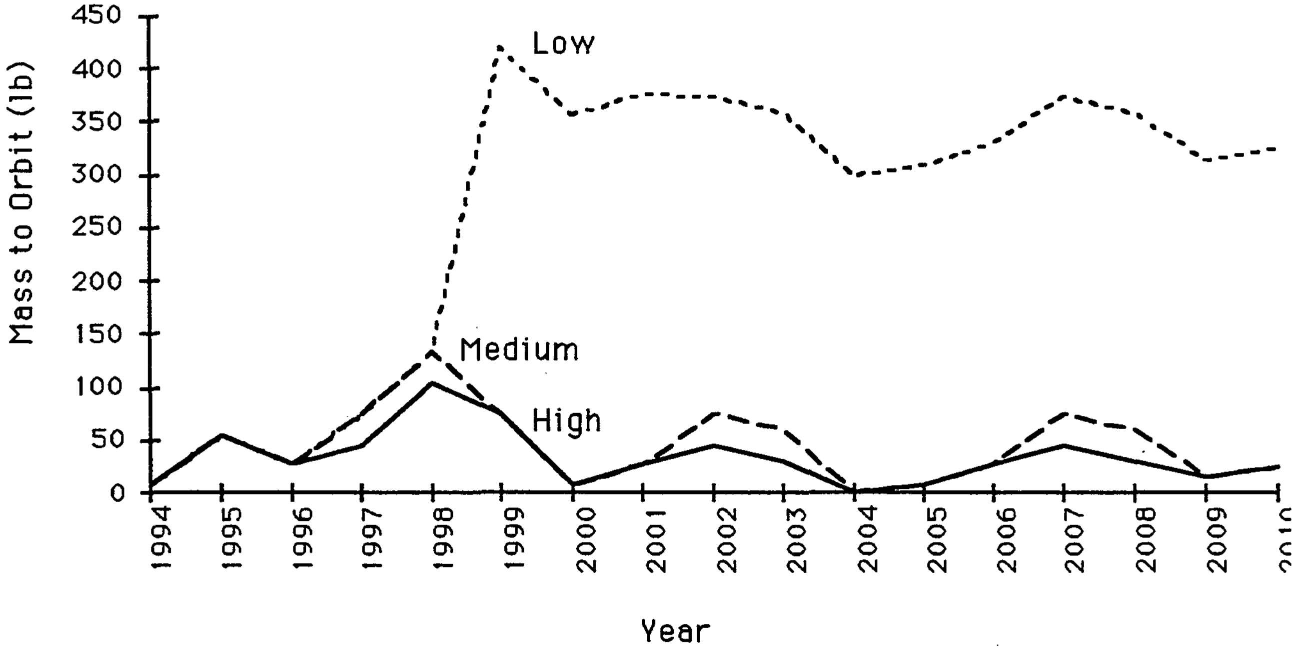

Figure 3.1.5.3-2. MSS Satellite Mass Demand by Year

The one compelling argument on the effects of lowering the cost of LEO systems is the increased mass per satellite. A Boeing study indicates that the system weight will double as the cost is reduced to 1/10 the current cost. The effects of this mass increase for the years 2005 to 2010 are seen in figure 3.1.5.3-3. This factor is responsible for all the mass increase seen. To be conservative, no additional systems were placed into the model.

	Launch Cost		
	Current	$1,000/lb.	$600/lb.
High Probability (klb/yr.)	29	50	58
Medium Probability (Klb/yr.)	41	69	81
Low Probability (klb/yr.)	392	666	784

Figure 3.1.5.3-3. Mass Demand Changes as a Result of Changing Launch Cost

3.1.5.4 Prospective Users

Prospective customers of the CSTS system for launching MSS satellites are primarily the current customers of launch systems and the current developers of the newer entries. These include such systems as being championed by InMarSat, Orbcom, VITA, Iridium, Globalstar. Appendix B.2 contains a listing of potential MSS satellites.

3.1.5.5 CSTS Needs and Attributes

3.1.5.5.1 Transportation System Characteristics

This category of communications satellites differs from its counterparts in both size and number. The vast majority of MSS satellites constellations are composed of 10 to 924 identical satellites. All the prospective systems need one-half to all of their satellites (minus spares) in orbit to earn revenue. This has caused launch strategies to be developed in which responsiveness and cost effectiveness are at a premium.

Launch strategies developed to date are to comanifest anywhere from two to seven satellites together. Reliability and responsiveness are deemed so important that satellite owners are selecting multiple launch vehicles.

The launch requirements for LEO MSS systems are among the least complex of all satellites. Mass requirements are between 500 to 2,000 lb into polar LEO orbit. However, due to the criticality of having a large number of satellites operating at all times, short callup times are required. Manufacturers have developed a hot ground satellite approach to satisfy this problem. Making a launch vehicle available on demand would greatly increase MSS system dependability and would help the launch vehicle capture all the market. Reliability of service is extremely important. A reliability of 0.98 would be appropriate.

3.1.5.5.2 Ground Handling

Existing ground facilities are proving to be adequate to service this market area. No new special provisions are envisioned to be needed. Typically the satellite manufacturer supplies all unique aerospace ground equipment, including that required for handling. Satellites typically require facilities for hazardous processing such as loading of hydrazine. The launch provider typically transports the payload from the spacecraft processing facility to the launch vehicle.

3.1.6 Positioning Satellite Service

3.1.6.1 Market Description

The global positioning system (GPS) was originally designed to allows its users to located any position near the Earth, vertically and horizontally, to within 16m accuracy. This is accomplished by using the Navstar (Navigation System using Timing and Ranging) satellite network, consisting of a 24-satellite constellation with eight satellites positioned in three different planes parked in sun-synchronous 12-hr, 20,200 km orbits. Continual progress is being made that refines that location accuracy to levels down in the single meters. This system is in the process of transitioning over from a sole U.S. government DOD user to include in large part the commercial industry. Users range from foot solders in Desert Storm and aircraft pilots on the military side to mapping and excavating with heavy equipment on the commercial side. This market evaluation was focused on the impacts to this system that reduced launched cost would have. These impacts might possibly increase the number of launches per year and stimulate additional market growth from the user community that would increase demand for a larger network.

Application Description

The global positioning space market consists of multiple satellites that provide precision timing and ranging data signals that are globally distributed. This system, unlike others, does not have to make the transition from a current application to a space application. It's considered an existing space market at the present. This 24-satellite constellation allows any user to take advantage of the signals it generates at any location lower than 20,200 km in altitude.

Although the signal is encrypted and was originally designed for predominantly government use during war times and for nuclear surveillance, the commercial industry was originally allowed to use the signal in a de-rated from. The onset of Desert Storm changed the involvement of the private sector due to their earlier availability of receiver units over the government suppliers, who had to comply with additional specifications and procedures. The government's purchase of large numbers of receivers from the private sector sparked a supplier frenzy and stimulated the commercial industries' availability and innovative uses of the GPS signal for various applications.

The signal is currently free to the user community and the government has stated that they have no plans of changing that for the next 10 years. This adds additional momentum to the rapid development of new innovative applications of this timing and velocity signal. Without the added user fee, suppliers can realize larger profits while at the same time keeping unit costs to the user very low. The typical receiver unit cost is <$1000 and the number of suppliers has grown to >100.

The current market, in its unexpanded form, is not unfamiliar with this type of capability. LORAN is just one electronic navigation system that preceded the GPS network. Other space-based positioning systems such as Transit and Geostar have been used but are being phased out of the market.

Current market stimulus is being driven by cost and other benefits specific to navigation applications such as aircraft inflight positioning. Large availability of inexpensive receivers and the strong synergy of this system to other systems like vehicle tracking with local wireless communications and Geographic Information System (GIS) software aid in the development of this market.

Market growth is primarily in the ground systems applications of the GPS signal. The growth rate varies, dependent on forecaster, in excess of 20% annually, with projected future GPS-related markets in the tens of billions of dollars for mainly ground system applications.

3.1.6.2 Study Approach

The methodology used for this section is consistent with the process described in section 3.1.3.2 for the FSS market area.

3.1.6.3 Market Assessment and Projection

This market is expanding fast and is the middle of a transition from predominantly government applications to a more commercial centered user base. There has been concern expressed by domestic and foreign commercial industries alike over the U.S. government DOD controlled system and the future impacts of this to their particular industry. These concerns center around the political instability and policy evolutionary process related to a global network and their potentially adverse impact on the availability of this system.

International discussions of this market area focus on alternate solutions to the owner/user conflict. Alternate options include a piggyback system on the Iridium communication network, being developed by Motorola, utilization of the Russian communications satellites system already in existence, or even deploying a second GPS network owned by the private sector. At present no alternate decisions have been made and usage will continue on the current GPS system.

To give a better assessment of this market and its possible future growth three different probabilities were identified and evaluated, the three being a high, medium, and low probability of occurrence.

The high probability market consists of the basic 24-satellite constellation and the maintenance of this already existing network. Each satellite was assumed to have a life of 10 years for the block GPS satellites. This does not effect the block 2R system designated to start being launched in the 1996-97 time frame. No additional GPS satellites are planned for this system.

The medium probability market has growth over the high market in that six additional satellites were included to the total number in the constellation. The standard current operational mode for this system is to have a minimum of four Navstars in sight at any one time. With this medium market an additional satellite is included with the original four to make five in sight at any one time. This provides voting between the group and biasing of good data after voting. Once the constellation is increased to 30 satellites the network is maintained at this level.

The low probability market is defined as the one with the lowest probability of occurrence. It consists of increasing the network by 12 satellites to a total of 36. The additional 12 are used to guarantee the uninterrupted use of the network by the domestic and foreign commercial industries. This would only be a consideration when the U.S. government in time of need would require security or priority on the system in war time or any other national/international event.

For the purposes of this market assessment the demand rates for the different probabilities are calculated based on the average life of the satellites being 10 years factored into the total number of satellites in each case. Figure 3.1.6.3-1 shows the different probabilities and the descriptions of each, with a listing of the total satellites in each case and the calculated demand or need rate.

The actual estimated launch rate will differ somewhat from the averaged high probability market and will be discussed later in section 3.1.6.6.1.

Probability of Occurrence	Probability Description	Total # of Satellites	Average Life of Satellites	Average Launch Rate Per Year
HIGH	Maintain 24 Satellite Constellation	24	10	2.4
MEDIUM	Maintain 24 & Add 6 New Satellites	30	10	3.0
LOW	Maintain 24 & Add 12 New Satellites	36	10	3.6

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Figure 3.1.6.3-1. GPS Satellite Service Launch Rate

Market Infrastructure

Because this market is an existing market the infrastructure is already in place. The launch system was earlier defined as the Atlas E and F and the latter launch system has been defined as the Delta II system. Ground operations for the signal have been routed through the Space Command control center at Falcon AFS in Colorado. The utilization of the signal is controlled by the individual user.

This system has the potential to grow in user size and possibly satellite number but the market infrastructure will not vary a great deal. In the extreme case a new system might be deployed to better accommodate the civil sector but the use of a different infrastructure is highly unlikely. The only real change might be the control center location and signal operations.

3.1.6.4 Prospective Users

Aside from the original U.S. government DOD user community, who funded and developed the system, the other potential users are limited only by one's imagination. Applications range from civil engineering to farming and crop stabilization to commercial and military aircraft navigation. With the market growing at a rate of approximately 20% per year and the total number of receivers number over 100,000 with the network only having been put in full operating condition in 1993 (planned) this market will continue to branch out as a typical broadcast market. It should be noted that this market is not confined to the United States alone but has and will continue to branch out to foreign markets as well.

3.1.6.5 CSTS Needs and Attributes

3.1.6.5.1 Transportation System Characteristics

For a CSTS system the existing transportation system requirements and characteristics would be adopted. Slight changes would be made to accommodate the increase in weight of each new block satellite if additional capabilities were incorporated into the network. The current transportation system should be assessed and incorporated into the basic design of a new CSTS if this market is a strong driver for the development of such a vehicle.

The response time of the CSTS system for GPS satellite launches needs to be within a scheduled week (equivalent to the communications satellites). Reliability needs to be greater than 0.95.

3.1.6.5.2 Ground Handling

With the growth of this market being predominantly in the user community the ground handling considerations for the CSTS with respect to this market would take place in the additional ground transportation systems and dedicated processing facilities. Ground transportation systems might be needed to handle small satellite increases in yearly launch rate should the constellation grow from 24 satellites to 30 or 36. Additional dedicated processing facilities would also be needed should the number of satellites increase.

3.1.6.5.3 User/Space Transportation Interfaces

For this market area the user community is distanced from the space transportation interfaces in that the system is only used once on orbit. This requires no special transportation need or accommodations in order for the user community to take advantage of the network.

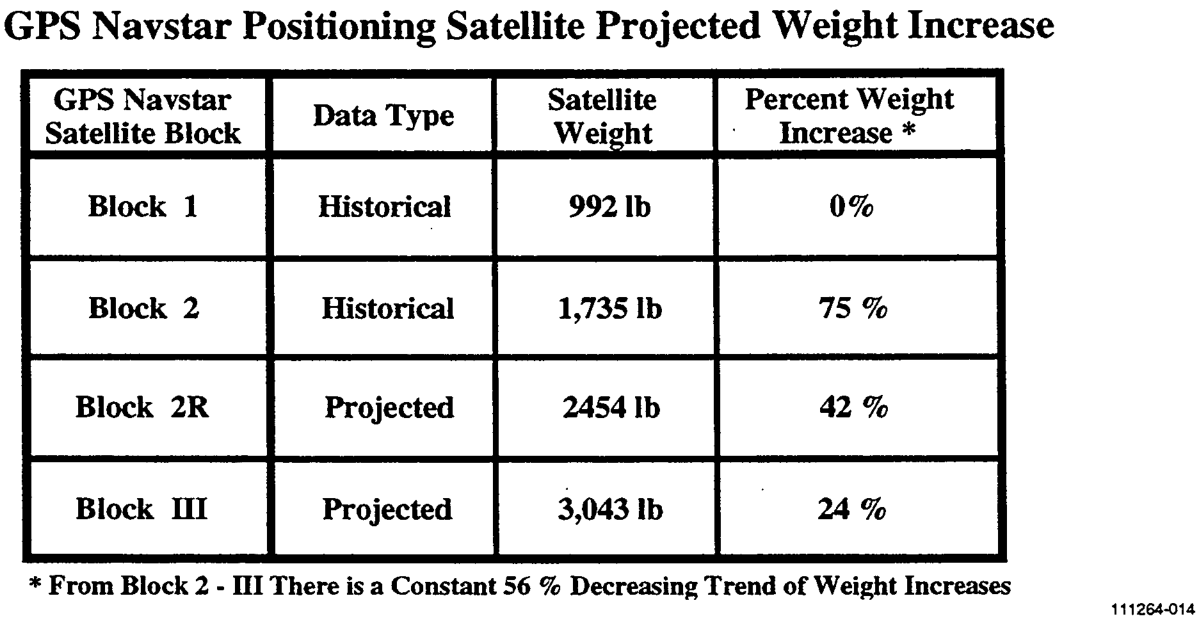
3.1.6.5.4 Improvements Over Current

No really strong transportation improvements are needed for the utilization of GPS or this market area. Any improvements over the current system would only affect the actual deployment of the system, which would provide no real benefit for the user community.

3.1.6.6 Business Opportunities

3.1.6.6.1 Cost Sensitivities

To evaluate the effects of reduced $/lb transportation cost, ROM estimates of the lb/yr for each of the different probability cases at the different launch cost break points were estimated. Figure 3.1.6.6-1 shows the historical data for the GPS Navstar satellite weights and the percentage of growth of each block change. A projected weight increase for the block III GPS satellites has been calculated based on the downward trend of weight increases from each previous block change.



GPS Navstar Positioning Satellite Projected Weight Increase

GPS Navstar Satellite Block	Data Type	Satellite Weight	Percent Weight Increase *
Block 1	Historical	992 lb	0%
Block 2	Historical	1,735 lb	75 %
Block 2R	Projected	2454 lb	42 %
Block III	Projected	3,043 lb	24 %

* From Block 2 - III There is a Constant 56 % Decreasing Trend of Weight Increases

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Figure 3.1.6.6-1. GPS Satellite Weight Projections

A top-level performance sizing of the system, based on the required Δ velocities needed for the delivery of the satellite using block 2R weights coupled with the trend in weight growth, was used to arrive at the 16,000 lb LEO equivalent weight of the block III system. For this system, assumptions needed to be made that defined the system and the number of stages used. Along with stage count, stage function was needed. The launch system delivered the payload, being the GPS Navstar satellite and the apogee kick motor (AKM), to LEO 28.5 deg inclination 150 nmi circular orbit. From this point the AKM would do a plane change as well as its apogee kick burn to get the satellite into the destination orbit of 55 deg inclination 11,000 nmi circular.

Although this is a non-optimum trajectory for the delivery of this satellite the approach was taken to maintain consistency across the CSTS study. The more optimum approach would be to launch directly into a 55-deg inclination orbit with the launch vehicle and minimize the plane changes required from the entire system. These changes require large Δ V hits to the system, which degrades the overall vehicle performance.

Having taken the different probabilities into account and evaluated this data against the Boeing satellite weight/cost vs launch cost data the projected delivery weights have been calculated for each probability case. The different transportation cost break points for this market analysis are shown in figure 3.1.6.6-2 as current cost, $1000/lb, $600/lb, and $400/lb. This figure summarizes the weight growth of the GPS satellite, based strictly on the Boeings data curve, as the launch cost/lb decreases. For a fixed constellation like the GPS system where there are no projected planes for additional satellites over and above the different probability cases, satellite weight increases translate into additional functionality of each satellite rather than an increased number of them. These additional functions could be in areas like the nuclear detection system as well as others.

GPS Navstar Block III	Probability	High	Medium	Low
	* of Satellites	24	30	36
	Satellite Life (yrs)	10	10	10
Launch Cost	Current Cost			
Relative Wgt Factor*	1.00			
Satellite Weight (lb)	16,000			
	Launch Wgt (lb)/Year	38,400	48,000	57,600
Launch Cost	$1000/lb			
Relative Wgt Factor*	1.45			
Satellite Weight (lb)	23,200			
	Launch Wgt (lb)/Year	55,680	69,600	83,520
Launch Cost	$600/lb			
Relative Wgt Factor*	1.55			
Satellite Weight (lb)	24,800			
	Launch Wgt (lb)/Year	59,520	74,400	89,280
Launch Cost	$400/lb			
Relative Wgt Factor*	1.65			
Satellite Weight (lb)	26,400			
	Launch Wgt (lb)/Year	63,360	79,200	95,040

* Factor Based on Boeing-ALS Data Curve - (Spacecraft Weight&Cost vs Transportation Cost)

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Figure 3.1.6.6-2. Estimated Equivalent LEO Payload Market vs Launch Costs

The analysis shows that the largest growth of 45% in weight is between the current market price and the $1000/lb market. After the first break point the growth is a consistent 10% over each subsequent break. 10% growth on a small fixed constellation is not really significant growth and would need further detailed analysis to determine if this would ever be a strong enough driver to warrant development monies.

3.1.6.6.2 Programmatics

Figure 3.1.6.6-3 shows the historical launch rate of the GPS Navstar constellation beginning with the first production launch in 1978. Block one ran from 1978 to 1985 with several gaps in the number of satellites launched each year. Block 2 began in 1989 and was to finish in 1993 with a full constellation of 24 satellites. Historical data for block 2 runs through 1990 with projected launch rates for 1991-1993 coming from the CNDB 90. Projected launch rates for the block 2R satellites is based on the extended average life of the Navstar from 5 years to 7.5 years in going from the block 1 to the block 2 system. The block III system, which is the main area of concern for this effort, is based on an extended average life of the block 2R system to 10 years. Based on the data available, the actual satellite's life of the block 2R has not yet been refined to anything more than >6 years life. For the purposes of this effort 10-year life was assumed.

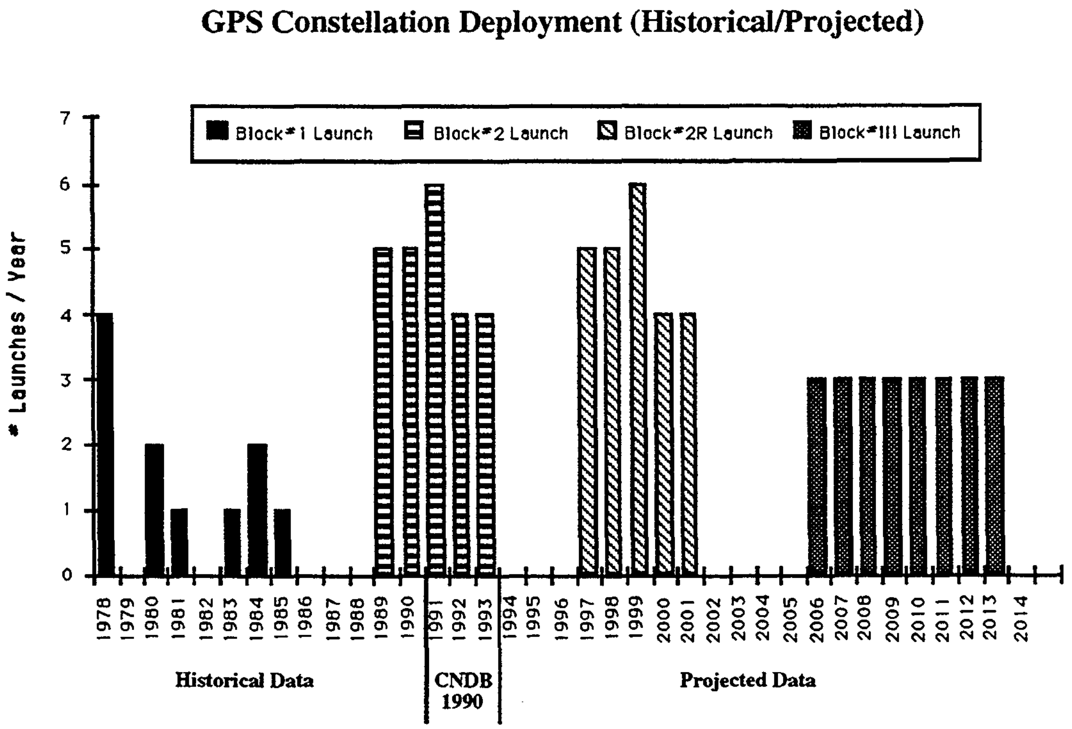

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Figure 3.1.6.6-3. GPS Satellite Projected Launch Schedule

The block III was also averaged out to a consistent launch rate of three satellites per year over an 8-year period. Because the average life of the Navstar is assumed to be 10 years there are 2 years shown with no launches at all. As was mentioned earlier the average launch rate over 10 years was calculated at 2.4 satellites per year for the high-probability case.

This system is assumed to be an ongoing consistent market with satellite maintenance occurring every 10 years on the network.

3.1.7 Summary

The communications satellite industry has managed to change the world: this industry has managed to link every continent together and has allowed the proliferation of telecommunications, which has allowed for people in diverse locations and cultures to achieve greater understanding of each other. The applications which allowed the communications industry to grow and these cultural benefits to occur are expanding.

Both the number of satellites and the mass on orbit for the communications satellite market segment will continue an overall increase. Two factors will control the number of satellites launched in any particular year. These are replacement requirements and new demand. Replacement satellite launches vary greatly following a predictable pattern. A composite model of all four market areas is found in figures 3.1.7-1 and -2. These figures show both the yearly variation by probability and cost of launch in satellite number and mass.

This market area was one of the first satellite industries developed and continues and is currently the most important and largest of the commercial space ventures.

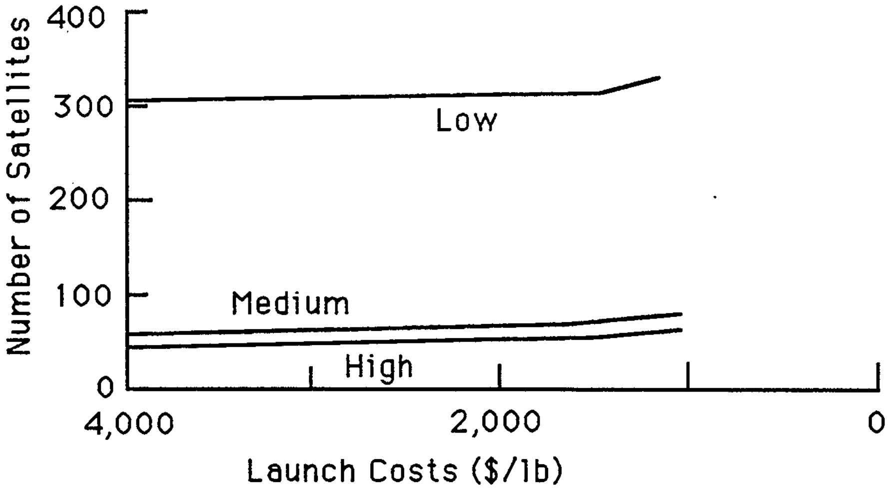

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Figure 3.1.7-1. Total Number of Communication Satellites as a Function of Launch Cost

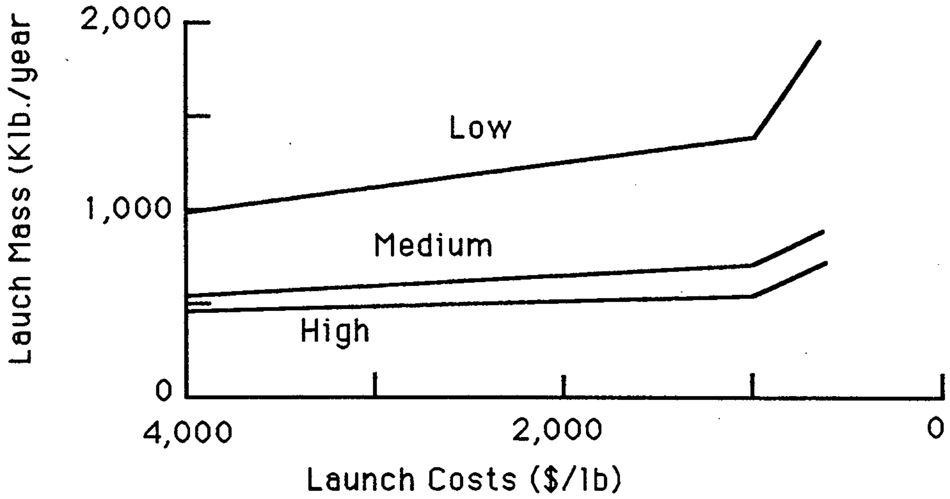

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Figure 3.1.7-2. Total Number of Communication Satellites as a Function of Launch Cost

3.2 SPACE MANUFACTURING

3.2.1 Introduction/Vision

In the years 2000 through 2010, commercially owned and operated space manufacturing and processing facilities are orbiting in sun-synchronous low Earth orbits (LEO). These facilities provide high-powered, ultrahigh-vacuum, microgravity environments to enable the automated production of unique materials used in ground-based biotechnological, pharmaceutical, electronic, and catalytic processing industries.

The orbital assets are routinely serviced by regularly scheduled launch vehicles with maneuverable upper stages that provide autonomous rendezvous and docking for orbital delivery of unprocessed samples and constituent supplies.

Return capsules, containing processed products, detach from the orbital asset and, following controlled reentry into the Earth's atmosphere, deliver these products to reception centers on the ground.

Dedicated ground-based facilities provide both prelaunch and postlaunch processing functions. Ground-based biotechnological and pharmaceutical industries have developed drugs and genetically engineered vaccines based on the processed materials provided by the space manufacturing and processing orbital assets. These drugs and vaccines have eliminated many of the major diseases prevalent in the 20th century.

Enhanced nutritional foods, also derived from base materials produced in space, have been combined for the elimination of disease. Human life spans are now extended to 100-plus years.

Genetically engineered substances based on materials produced in space have eliminated many of the chronic human conditions derived from genetic disorders such as multiple sclerosis, cystic fibrosis, and Alzheimer's. The effects of aging on the human body have been controlled by discovery of the means to stimulate cell replacement and regeneration of vital human-life-sustaining-and-controlling enzymes.

Electronic materials derived from space produced base materials have contributed to the existence of super-high-speed processing, ultralow-energy-consuming, super-enhanced data storage capability chips and devices. These items have enabled the information processing and automation industries to develop to an unprecedented scale to enhance the quality of life.

Environmental improvements have been enabled by bioremediative products developed from base materials produced in space such that major concerns of uncontrolled environmental degradation have now been eliminated.

The orbiting space manufacturing and processing asset also provides an automated research facility for the further development of new materials and processes and the advancement of knowledge of physical and biological processes subject to limitations imposed by Earth-based gravitational effects.

Many hundreds of thousands of personnel are employed by industries whose base materials and processes are supported by the space manufacturing/processing system facilities.

3.2.2 Space Manufacturing/Processing Market

3.2.2.1 Introduction/Statement of Problem

The space manufacturing/processing market area, as defined by the CSTS planning discussions of June 1993, encompasses microgravity processing, drug production, space epitaxy, catalyst/separation, biotechnology production and university/industrial research. The market areas do not correlate one for one with the U.S. Government Standard Industrial Classification (SIC) system as defined for 1,006 industries in 1987 and as annually reported in the *U.S. Industrial Outlook 1993* compiled by the U.S. Department of Commerce (DoC) from data derived from the Bureau of the Census and others.

To establish an estimate for the existing business base of the subject market areas, certain correlations were assumed wherein definitive DoC information in SIC categories of related business areas were correlated and collected as representative of the study areas.

The U.S. business base for materials processing was compiled from the SIC categories of semiconductors, instruments, and catalyst/separation and integrated to the area of electronic materials as derived from a report entitled *International Electronic Materials* (1991) conducted by Peat Marwick Inc. for the Center for Space Processing of Engineering Materials at Vanderbilt University.

The base estimate for university/industrial research, which also includes federal expenditure, was derived from a study conducted in 1992 by the Battelle Memorial Institute.

Manpower estimates associated with each category were derived either directly from DoC-published data or estimated based on average rates for appropriate labor categories.

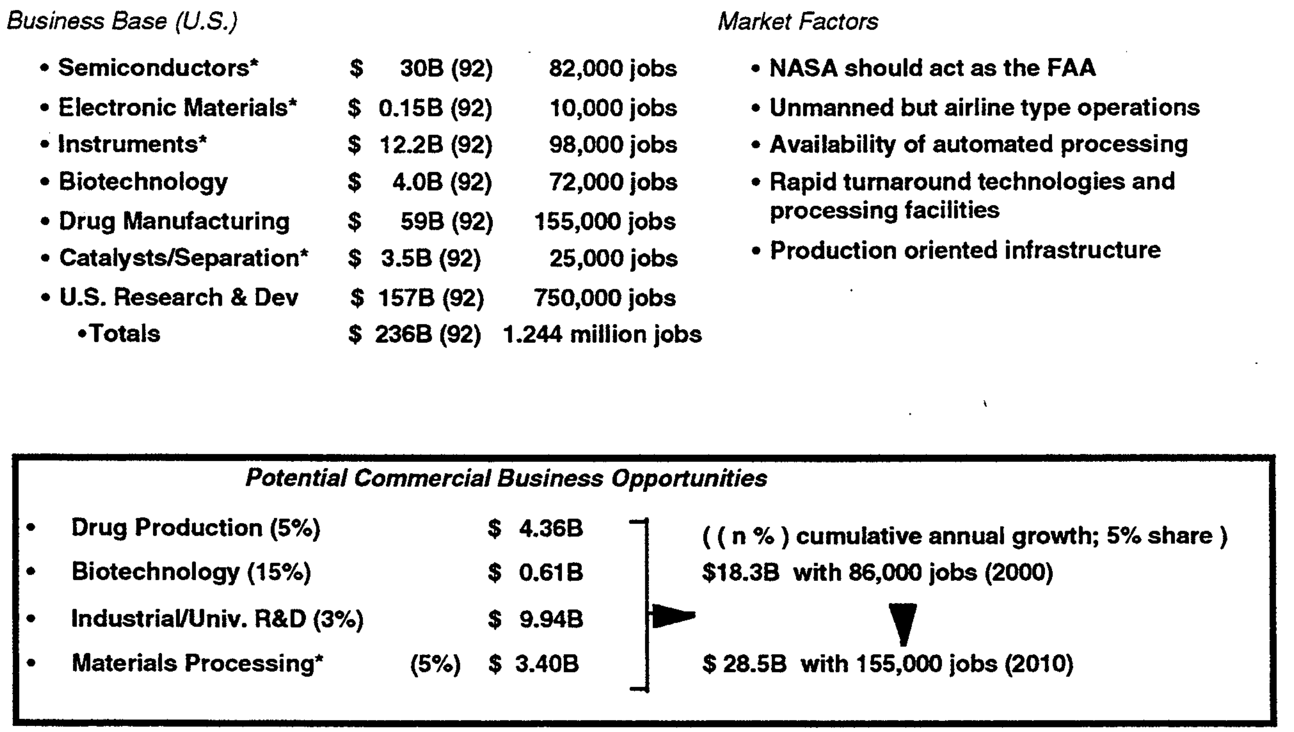
The total resultant U.S. business base for the industries associated with semiconductors, electronic materials, instruments, biotechnology, drug manufacturing, catalyst/separation, and U.S. research and development was estimated as $236 billion (1992) with 1.244 million jobs (fig. 3.2.2.1-1).

The projected potential commercial business opportunity associated with space manufacturing and processing was evaluated by correlating the above industrial areas into four SIC-related industrial categories and by assuming for each an individual cumulative annual growth rate based on DoC projections.

The four categories and individual growth rates are drug production (5%), biotechnology (15%), industrial/university R&D (3%) and materials processing (5%).

The final value of the business share associated with space manufacturing and processing was estimated at a conservative 5% of the total business base for each category. The overall total business base for these categories was estimated at $18.3 billion with 86,000 jobs in the year 2000 and $28.5 billion with 155,000 jobs in the year 2010.

This conservative estimate is, of course, based on the assumption that this new market will evolve provided that certain enabling factors are in place. The scenario for the development of these factors is contained in the body of this report.



Business Base (U.S.)

• Semiconductors*	$ 30B (92)	82,000 jobs
• Electronic Materials*	$ 0.15B (92)	10,000 jobs
• Instruments*	$ 12.2B (92)	98,000 jobs
• Biotechnology	$ 4.0B (92)	72,000 jobs
• Drug Manufacturing	$ 59B (92)	155,000 jobs
• Catalysts/Separation*	$ 3.5B (92)	25,000 jobs
• U.S. Research & Dev	$ 157B (92)	750,000 jobs
•Totals	$ 236B (92)	1.244 million jobs

Market Factors

- NASA should act as the FAA
- Unmanned but airline type operations
- Availability of automated processing
- Rapid turnaround technologies and processing facilities
- Production oriented infrastructure

Potential Commercial Business Opportunities

• Drug Production (5%)		$ 4.36B
• Biotechnology (15%)		$ 0.61B
• Industrial/Univ. R&D (3%)		$ 9.94B
• Materials Processing*	(5%)	$ 3.40B

((n %) cumulative annual growth; 5% share)

$18.3B with 86,000 jobs (2000)

$ 28.5B with 155,000 jobs (2010)

Figure 3.2.2.1-1. Space Manufacturing/Processing Business Base

The industry categories identified under the Space Manufacturing/Processing general heading have mostly not been associated with the actual space scenario. Exceptions are microgravity processing and university/industrial R&D, the former being unique to the space environment and the latter comprising a small portion of the activity base.

The term "space manufacturing" is somewhat misleading, since it suggests an industry whereby an orbital asset (with an inherent microgravity environment) is used to support the making of "production" quantities of items by controlled processing of raw materials. These items or products assumed to be characterized by structure and properties that cannot be duplicated in the unitary gravitational environment on Earth.

The misconception basically concerns the *quantity* of processed products considered to be of manufacturing production magnitude. For example, some pharmaceutical materials derived from space processing and intended for the treatment of critical human conditions have values up to $15 million per pound (i.e. tissue plasminogen activator—TPA).

It would be useful at this point to summarize a sample of the potential advantages and products that may be produced in a microgravity environment.

a. Immune response understanding leading to viral infection antibodies or vaccines.
b. Synthetic production of collagen for use in constructing replacement human organs (e.g., corneas).
c. Manipulated differentiation of plant cells to produce desired chemicals (e.g., Taxol).
d. Production of targetable pharmaceuticals (cancer cures).
e. Protein crystal formation for structure identification (structured biology).
f. Protein assembly.
g. Growth of large pure electronic, photonic and detector crystal materials (computer chips, quantum devices, infrared materials).

h. Ultrapure epitaxial thin film production in very high vacuum (e.g., Wake Shield Facility).
i. Production of perfect solid geometric structures.
j. Manufacture of pure zeolite crystal material for filtration applications (pollution control).
k. Manufacture of polymers with unique characteristics.
l. Electrophoresis for separation of microscopic components within fluids.

In the context of this report space "manufacturing" refers to the processes either of producing relatively small quantities of high-value materials in an orbital microgravity environment or of producing small quantities of pilot material with the intent of identification and analysis of the material's three-dimensional molecular structure. Both categories of product would be returned to Earth but the latter materials would be uniquely characterized by analysis. The resulting knowledge base would be used for the development of new drugs, themselves designed (via structured biology techniques) to *interface* with those molecular structures to produce beneficial therapeutic effects.

The unique characteristics associated with an orbital microgravity environment have been promoted by NASA for some years and have involved international cooperative efforts with Europe (ESA) and Japan.

Initial efforts in the late 1980s involved suborbital sounding rockets (Consort and Joust), which provided typically minutes of microgravity exposure.

A KC135 aircraft has also augmented this capability with manned minutes of microgravity exposure. More recently shuttle-based carriers such as Spacelab (a European Space Agency carrier) and the series of U.S. Microgravity Laboratories have provided access to space for experimental programs. These shuttle flights are, of course, manned and typically provide up to 12 days in orbit.

A further shuttle-based access capability is the so-called get-away special (GAS) payloads. These facilities effectively are small and self sustaining and occupy cargo bay capacity remaining after major payloads are installed.

Spacehab has been developed commercially as an annex to the shuttle and to date (January 1994) has flown once with a complement of 22 individual experiments. The above shuttle-based carriers that provide microgravity access are integrated within the parent vehicle and provide an orbital duration of 12 days.

The Europeans have flown an orbital asset known as EURECA, which provides a microgravity exposure of about 9 months. This satellite is equipped to support long-term experiments and is both launched and recovered by a U.S. shuttle.

A further NASA/HQ-sponsored proposed program, pioneered by the Universities Space Research Association (USRA), is the student explorer demonstration initiative (STEDI). This initiative is promoting new exploratory space science projects for science graduate students within academia.

The projects are individual experiments typically about 100 lbm mass, which will be combined to yield a launch payload of about 450 lbm. The experiments are designed to support space-related research in areas such as astrophysics, space, earth, life, biomedical, and microgravity sciences.

The payloads are planned to be placed in orbit using a multiservices launch vehicle (MSLV) such as a converted Minuteman II missile. Current STEDI plans are to conduct three payload launches in 1996, all to LEO polar orbit, for which NASA/HQ has allocated funding of $24 million. Future plans project an escalation to 25 launches per year from 2004 through 2020.

The USRA believes that if the STEDI program is successful it will be able to establish a steady stream of dedicated space flights for research and development at universities, government laboratories, and commercial research centers.

3.2.2.2 Study Approach

The study approach adopted for the general area of space manufacturing/processing is outlined as follows:

a. Conduct internal research to obtain an appreciation of the potential advantages available to the market areas in this category as afforded by space applications and potentially serviced by a commercial space transportation system (CSTS).
b. Conduct research to identify potential primary and secondary contacts.
c. Conduct a comprehensive telephone survey soliciting potential interest in a future CSTS that would enable commercial activities in space profitably relevant to each market area.
d. Follow up immediately by FAX with a written introductory letter explaining the purpose of the CST study and defining the cooperating informal alliance members.
e. Conduct further telephone solicitation of selected primary contacts with request for interviews to discuss responses to a list of CSTS-related questions. These questions designed to evaluate the potential of space-based applications for the individual market areas making use of a CSTS. The questions are as follows:
    1. What is the maturity of users' space application?
    2. What are payload form factors?
    3. What infrastructure and support to user must launch system company provide?
    4. What is end user market infrastructure?
    5. What changes or improvements are needed in the market infrastructure to reduce costs of space-produced products?
    6. If users are performing experiments now, when will they begin producing commercial products in space.
    7. What are current and near-term costs associated with using space?
    8. How sensitive is user demand to launch system cost. How many more times will they use space if launch costs are reduced?
    9. What decision-making process is used to decide on the use of space?
    10. What are titles and names of executive managers who are making business decisions to invest their companies' resources into producing products in space?
f. Follow up telephone solicitation for interviews by FAX with a summary of the CSTS survey, the list of pertinent questions, and a matrix of the market areas under evaluation.
g. Conduct face-to-face interviews with responsive primary contacts using the above questionnaire as the basis to guide detailed discussions.
h. Record the indepth responses obtained with field research reports and summarize the overall response.
i. Summarize and analyze the results of the market survey in appropriate reports and estimate the business potential for the space manufacturing/processing general area.

An alternative technique was tried with regard to soliciting responses from Bay Area, California, biotechnology companies. From a list of 360 such companies resident in this area, 107 were selected based on employee headcount of 60 or over. A CSTS letter was sent to the CEO of each company providing information on the study and requesting a response describing interest in face-to-face discussions.

The majority of these companies (98%) provided zero response. The remainder each sent a polite letter declining interest. We concluded that whatever advantages space may hold for the evolution of the biotechnology industry, none of the letter recipients were aware of it.

All primary and secondary contact listings, contact reports, communications, and field research reports have been stored in an accessible database with comprehensive search and locate facilities. This information is a valuable resource pertinent to the overall objectives of the CSTS and represents a current realistic record of the reactions of industry and selected NASA-sponsored agencies to the concept of a commercial space transportation system used in support of commercial space manufacturing and processing activities in space.

3.2.2.3. Market Assessment

The market for potential commercial utility of space manufacturing/processing currently consists only of experimental payloads wherein electronic, photonic and detector crystalline materials, protein crystal structures, and epitaxial devices are produced in small quantities. Most of these experiments are hosted by the shuttle with various annex facilities resident in the cargo bay.

The European Spacelab and the U.S. commercially developed Spacehab are both designed as an annex to the shuttle and provide facilities for similar experiments.

The 17 NASA-sponsored and partially commercially supported Centers for the Commercial development of Space (CCDS) are the primary means of access to space.

The following dialogue is an assessment of characteristics of the current access to system which have been advised to the CSTS researchers in direct interviews as being factors which *discourage* the near-term commercial involvement in microgravity-related space-based research and development.

These factors are summarized under market con drivers and the subsequent section reports on a potential launch services system that would stimulate the long-term development of commercial space activity.

Drivers Con:

a. Government (NASA) ownership and operation of the only access-to-space transportation system currently suitable for support of space manufacturing/processing is totally incompatible with commercial ways of doing business.

b. The NASA bureaucracy associated with flight certification of hardware/software and sample materials is a major impediment to commercial utilization of current access to space.

c. The extended time scale between decision of intent and the actual flight event of a shuttle experiment is unacceptable to potential commercial users.

d. High costs of commitment of staff/materials from experiment conception to actual flight even though the actual flight cost is zero by working through the CCDSs.

e. Shuttle touch-down location is subject to somewhat unpredictable local weather conditions, particularly at KSC. This leads to uncertainty and therefore redundant recovery team planning for the timely receipt of processed samples. This represents a risk for processed samples of limited lifetime and could introduce unpredictable sample degradation. This situation is unfavorable for a commercial operation.

f. The shuttle also has a history of experiencing delayed launch schedules. These delays represent a risk to sustained funding and the integrity of form for unprocessed sample materials, which could effectively negate the experimental objectives. This also is a significant risk to a commercial operation.

g. Shuttle manifests are subject to change at the discretion of NASA management. While we recognize that these manifest changes are managed with responsible integrity and due process with respect to priorities, the inherent uncertainty of flight date commitment is a cost and operational risk to a commercial customer.

h. Astronaut crew rotation for shuttle flights incurs a burden on retraining to ensure that appropriate expertise is available to conduct processing experiments, particularly if these are repetitive experiments. The benefits of manned versus autonomous experimental management has been quoted as worthy of a critical trade study. The retraining burden is certainly a cost disincentive to commercial involvement.

i. An inherent requirement within experimental programs is timely repetition subject to known variation of control factors. This requirement is difficult to implement due to uncertain manifests and change of associated onboard personnel. Recognizing that these random factors are perhaps inevitable with the shuttle-based program, they do, however, represent a further unfavorable factor regarding commercial involvement.

j. The nonavailability of regular routine flights committed to materials-processing experiments is a further disincentive to commercial and noncommercial involvement. This nonavailability is understandable due to the competition for access to space coupled with the limited number of annual shuttle flights.

k. Shuttle flights inherently involve human presence within the microgravity environment created by orbital precession. While this is an obvious advantage with respect to the presence of human intelligence, the microgravity environment is subject to unpredictable local disturbances due to crew motion. Some concern has been expressed by some respondents to the CSTS survey that these disturbances could affect the outcome of experiments. In addition, the possibility of undisciplined or accidental activities could also impact experimental processing, particularly in early phases of sample growth. The current necessity of human presence has been advised as a potentially unfavorable factor.

l. Limited time on orbit obtainable via shuttle-hosted experiments is a major problem. The maximum duration flight to date has been about 12 days, whereas potential experimental users have strongly advised that 30 to 90 days would be much preferred. Some experiments cannot tolerate 90 days; the selection is a function of the material being processed.

m. The issue of proprietary rights to experimental data derived from zero-cost access to space provided at public expense is a troubling concept (i.e., free rides if the experimenter is affiliated with any one of the 17 CCDSs).

There also seems to be a lack of published data reporting the benefits of microgravity processing. This is particularly surprising since many academic organizations (CCDSs) are associated with current experimental microgravity activities.

a. Even direct approaches to some selected CCDSs by CSTS researchers have failed to solicit specific information with reference to positive results of microgravity experimentation. *The author is of the opinion that resolution of the above issues and perplexities would considerably enhance progress towards greater involvement by commercial entities, with subsequent long-term beneficial results.*

b. The cost of access to space via the shuttle is perceived by commercial industry to be prohibitively high, particularly when the potential return on investment appears to be illusive. Even in the scenario of free rides, obtainable as an affiliate or member of one of the CCDSs, the *cost* of long-term involvement in preparation and certification of flight hardware and samples is a major factor.

Perhaps the Spacehab carrier situation is a good example. The rental cost of each locker is about $1.8 million and preparation and approval time duration is about 18 to 24 months. As noted previously, this time commitment is a significant additional cost to the user. The effective cost for orbital flight is between $6-7K per hour, which is almost two orders of magnitude above the cost of ground-based research.

The locker price is a function of return on private capital investment raised to design and develop this commercial shuttle annex carrier and also the cost charged by NASA for each flight.

As an example of manifest changes, the second flight of this carrier has been slipped due to the Hubble repair mission and delayed from late 1993 to early 1994.

c. The amount of electrical power available to support shuttle annex experiments is also limited. The result is that activities of a commercial scale cannot be accommodated, at least with reference to the growth of industrial-size electronic material crystals.

Any *manned* orbital facility must of necessity budget a proportion of available power to include life-support functions, which effectively reduces power available for experimental support. Some respondents to the CSTS survey also expressed similar concerns with reference to the Space Station experimental support facilities.

Drivers Pro:

The development of a future (2000-2010) market for space manufacturing/processing depends on a number of factors unrelated to the new development of a suitable low-cost launch system.

It is essential that NASA's commitment to the support of microgravity experimental projects be aggressively continued and, if possible, expanded regardless of the limitations relative to commercial applications that have been previously described.

The probability of achieving breakthrough enabling technologies will be enhanced only by sustaining or preferably increasing the number of flight opportunities.

An aggressive commitment to the publication of experience and results achieved through microgravity processing will stimulate more widespread interest within the general but relevant industrial base. A recurrent theme of feedback derived from contacts with commercial companies was a lack of knowledge as to what had been achieved to date.

NASA's support of the Spacehab and Comet programs is also an essential near-term stimulant to long-term commercial involvement.

Following are the essential characteristics of a potential launch services system that, if available, would fully support a significant commercial space manufacturing/processing-based industry.

a. Commercial ownership and operation of the access-to-space transportation system available to support space manufacturing/processing is essential to support commercial utilization and, therefore, development of the market.
b. Routine access to space, similar to flight travel opportunity offered by the commercial airline industries, is required.
c. Elimination of extended time scales between the decision of intent and the launch-to-orbit event would be more suitable for commercial users. This would effectively maximize the efficiency of staff commitment and reduce the overall cost of involvement in space-related activities.
d. The postflight delivery of processed samples or products to a fixed known location without deviations would be favorable to commercial utilization.
e. Launch on schedule must be an essential characteristic of the space transportation system.
f. The launch of a given payload to an agreed schedule with zero probability of manifest changes is an essential requirement for commercial business operations.

g. An unmanned, autonomous system for payload launch, on-orbit processing, and processed sample or product return is much preferred by respondents interviewed by the CSTS researchers. The astronaut corps would have no part in this system and requirements and cost for repetitive training would therefore be eliminated.
h. Routine airline-type operations would enable the timely repetition of space processing activities.
i. A commercial space transportation system would provide regular routine flights dedicated to materials processing requirements.
j. The potential degradation of the orbital microgravity environment by human presence would be eliminated with an autonomous system. This would require the development of automated sample-processing facilities within the orbital asset.
k. The commercial system must provide a minimum of 30 days and a maximum of 90 days access to the orbital microgravity environment. This effectively means a regular return of processed samples achieved by either an on-orbit resident return capsule (s) or a recovery capsule launched from the ground with rendezvous and offloading capabilities.
l. Proprietary ownership of data derived from space applications would be absolutely guaranteed with a commercially owned and operated access-to-space system wherein launch, orbital processing facilities, and product return capsule services are obtained under standard contract conditions.
m. A low-cost access-to-space system is an enabling essential characteristic for commercial market stimulation and support. Development of the acceptable cost is addressed elsewhere in this report.
n. An orbital asset designed specifically to maximize the electrical power available for microgravity processing is also essential. A sun synchronous, LEO dedicated, autonomous processing asset would provide the necessary facilities.

3.2.2.4 On-Orbit System Description

The commercial space manufacturing/processing system will comprise an orbiting service module (estimated as 4,000 lb mass) equipped with autonomous microgravity processing capabilities. These capabilities will be used to support the manufacture of electronic, photonic, and detector materials; ultrahigh vacuum processing; biological and organic materials processing; and the support of research subunits for microgravity activities. The capabilities will include monitor and control facilities for each processing activity.

The service module will be designed for at least 5-year on-orbit operations and will be configured with standard guidance, navigation and control functions; automated rendezvous and docking functions; command and communications functions; environmental control capability; high onboard continuous power systems; and an autonomous product module exchange facility for onload/offload of, respectively, unprocessed and processed product material subunits.

The service module will be placed in a polar sun-synchronous orbit to enable maximum onboard electrical power availability (estimated as 20kW) to support comprehensive product processing. A trade study has been conducted to compare the placement of the service module at a high-inclination orbit versus a low-inclination orbit (app. C.1) with the result that the polar orbit is preferred.

The orbital service module will be serviced at 30-day intervals via a launch system that will provide access to polar orbit for an approximately 1,500 lb recovery module that will carry a maximum of 3,000 lb of product and containment support modules.

The recovery module chase vehicle will be designed with autonomous rendezvous and docking capability (with ground support back up) such as to dock with the orbiting service module.

Following successful docking of the recovery module with the service module, the unprocessed product materials with support containment will be offloaded to the service module and the processed products will be onloaded to the recovery module. The latter module will then detach from the service module and deorbit to reentry for recovery at a fixed preplanned land-based site within the continental United States.

A recovery site team, equipped with helicopter services, and queued by a dedicated ground-based recovery module tracking system, will search or, locate, recover, and deliver the recovery module containing processed products to a dedicated recovery site facility (RSF). This RSF will be equipped with all necessary facilities to preserve the functional integrity of the returned processed products prior to pickup by the appropriate system customer.

Recovery modules will be refurbished on a routine basis and delivered to the launch vehicle site for integration and reuse.

The disposal of the orbital service module following completion of useful service life is an open issue.

Possibilities include a deorbit rescue mission using an unloaded recovery module or perhaps a shuttle rendezvous and recovery. The former is preferred because of its system-independent nature without reliance on government-controlled assets.

The orbital service module will be monitored and controlled during routine autonomous processing operations and possibly during rendezvous operations using a ground-based single program operations center (POC) positioned at a high geographic location (possibly Alaska).

In summary, the mass of the orbital service module is estimated as 4,000 lb, the recovery module as 1,500 lb, and the 30-day periodic product specific payloads as 3,000 lb. These estimated mass budgets are predicted as adequate to provide the necessary space manufacturing/processing facilities and service capabilities and effectively define the maximum payload weight for the commercial launch system as a maximum 4,500 lb to a 98-deg sun-synchronous polar orbit.

3.2.2.5 Business Assessment

A viable space transportation system for commercial space manufacturing/processing must provide a product and/or service that is specifically designed and operated with commercial use as the fundamental premise.

As discussed at length within this report, the current NASA-dominated system of providing access to a microgravity environment is not appropriate for this long-term commercial use. The current system does, however, (with some limitations) support the necessary preceding process of experimentation and demonstration of the potential benefits of microgravity processing.

To perform the business assessment of a future commercial space manufacturing/processing system, it has been assumed for convenience that the total system will be designed, built, owned, and operated by the space launch company or consortium of companies.

It has also been necessary to postulate an enabling system configuration that contains the essential subsystem elements and operating scenarios derived from discussions held with users of the current NASA-sponsored systems and also potential future users.

This enabling configuration as described in sections 3.2.2.4 and 3.2.4.1 has been evaluated in terms of development and subsequent operation.

Standard investment analysis techniques were used to evaluate the space manufacturing/processing system. The goal of the analyses was to determine the feasibility of the launch system from an investment/return perspective. Analyses were performed assuming varied flight profiles, R&D expenditure profiles, and government funding levels.

The criterion for an acceptable investment opportunity was a 20% internal rate of return (IRR). A 20% IRR is achievable on paper in any investment analysis since the analysis can assume enough revenue (either through volume or profit margin) to produce a 20% IRR. The discriminator is the market and its ability to support sufficient sales volume at the calculated price level to produce the subject IRR. The approach taken in this analysis was (given investment levels, recurring costs, and flight profiles) what unit price is necessary to achieve a 20% IRR. The unit price is examined to determine if the market will bear such a price.

Some basic assumptions were used for all the space manufacturing/processing investment analysis scenarios. R&D effort began 5 years before the first flight. Fixed asset investment began 3 years before first flight. Straight-line depreciation was used for the life of the asset (7 years). Additional replacement fixed assets were added with a 1-year leadtime. Tax rate was assumed at 35% and loss carry-forwards offset outyear tax liabilities. Working capital adjustments were not included. The ROI analysis was performed over a 15-year window, which encompassed 5 years of R&D and 10 years of operations.

Three scenarios were analyzed: D, D1, and D2. Scenario D straight-lined the R&D expenditures over 5 years and used an initial step function flight rate beginning at IOC and then a gradual-growth flight profile. Scenario D1 utilized the same flight profile, while distributing the R&D expenditures over the 5 years as follows: 10% in year 1, 20% in year 2, 30% in year 3, 30 % in year 4, and 10% in year 5. Scenario D2 used the distributed R&D profile and a 3-year flight ramp up at IOC.

Within each scenario were three subscenarios, representing different levels of government funding of R&D. The government was assumed to fund all R&D and initial fixed assets, 50% of R&D and initial fixed assets, and no R&D or initial fixed assets.

Figure 3.2.2.5-1 below presents the price per pound to orbit of the scenarios D, D1, and D2.

Analysis Scenario	Investment Strategy	Necessary Price for 20% IRR		
		Maximum $K/lb	Minimum $K/lb	Average $K/lb
D.	Zero Gov't	18.5	12.8	15
	50/50	12	10.3	11
	Total Gov't	6.9	6.3	6.6
D1.	Zero Gov't	16.8	12.7	15
	50/50	11.4	10.1	10.7
	Total Gov't	6.6	6.2	6.3
D2.	Zero Gov't	25.3	12.7	14.8
	50/50	14.7	10	10.7
	Total Gov't	6.6	6.2	6.3

Figure 3.2.2.5-1. Commercial Price Scenarios for Space Manufacturing/Processing

The rough order of magnitude estimate for R&D investment, the cost of replacement of limited life assets, refurbishment of recovery modules, and operation of the system are given in appendix C.2, together with detailed spreadsheets of the financial analysis for each scenario.

The business analysis performed as above was kept at a fairly simplistic level. Since the input data were speculative and business operations, which dictate cash flows, are not well defined, complex analysis techniques would not add value to the results.

The criteria for an acceptable investment opportunity was a 20% internal rate of return (IRR). A 20% hurdle rate is consistent with the level of investment and speculative nature of the programs. However, increases to the risk-free rate in the time frame of the analysis may warrant a higher hurdle rate.

R&D investments were separated into two parts, R&D and fixed asset-related R&D. R&D was treated as a sunk cost and recovered through future profits. Fixed-asset design was assigned to the asset value and depreciated over the useful life of the asset. Straight-line depreciation was used, although an accelerated method is normally used for tax and book purposes. The rationale behind straight-line is twofold, elimination of the need to classify assets and the ability to match the depreciation period to the true (assumed) useful life of the asset. The analysis assumed the businesses to be going concerns (i.e., no recoupment of residual fixed asset value at the end of the analysis period).

A significant factor in the analysis is whether the business entity is a standalone company or part of a larger firm. The tax implication is loss carry-forward. A standalone company will roll forward losses (investment) and offset future tax liabilities, whereas a division's or subsidiary's losses will offset its current year tax liability (assuming the parent shows sufficient profit). The effect of being a division is an alleviation of the cash burden during the R&D phase. The model used herein assumed a standalone entity and associated loss carry-forward.

Net working capital adjustments were excluded from the analyses. Details of the payment schedules were not clearly defined, so cash receipts were assumed to coincide with expenditures and profits were paid upon launch.

3.2.2.6 Market Infrastructure

The current infrastructure that supports experimental exploitation of microgravity processing has been previously discussed in section 3.2.2.3. Fundamentally the commercial access infrastructure is presently dominated by NASA through the use of the shuttle configured with various annex processing equipment and by the sponsorship of 17 previous CCDSs, the latter with some partial support from commercial sources.

A limited number of value-added companies are also involved and provide individual materials processing and containment equipment. The companies usually act as support agencies between the user and the CCDSs.

Other than long-exposure duration experiments and certain untended get-away special canisters, each of the microgravity processing experiments is human tended by the shuttle crew with associated repetitive training requirements.

An exception to the above space access logistics involving the CCDSs is the commercially developed Spacehab processing module. Herein the user negotiates with the commercial Spacehab company, which in turn deals directly with NASA for shuttle manifests. It is understood, however, that to date the majority of users for Spacehab locker facilities are in fact also NASA centers.

The COMET program managed by the University of Tennessee Center for Space Transportation and Applied Research (CSTAR) is currently in a development stage as a small-scale (~300 lb of experiments) freeflyer-based system. This is an unmanned alternative to the shuttle but is also sponsored and funded by NASA.

This overall current NASA-dominated infrastructure is perhaps the only currently available and sustainable U.S. system to support experimental exploitation of microgravity processing but for the reasons discussed in the Drivers Con paragraphs of the "Market Evaluation" above, this system is not appropriate for profitable large scale *commercial* exploitation.

Based on feedback from CSTS research interviews, an infrastructure necessary to support commercial utilization of the benefits of microgravity processing is believed to be that of commercial ownership and operation devoid of government involvement other than as a customer and a regulating agency using commercial standards.

The current infrastructure as depicted in figure 3.2.2.6-1 is more suitable for experimental exploitation of microgravity processing (an essential preliminary activity) and appears to be self-perpetuating with regard to government access control and operation. This self-perpetuation is due to a number of factors, including the concept of "free rides" offered to users by the shuttle-based systems, the sponsorship of CCDSs by NASA, the dominant purchase by NASA of facilities offered by the commercially developed Spacehab, the NASA funding of the COMET program through CCDSs and the proposed access to NASA-owned Alpha Space Station. None of these access routes are conducive to encourage routine *commercial* exploitation of space.

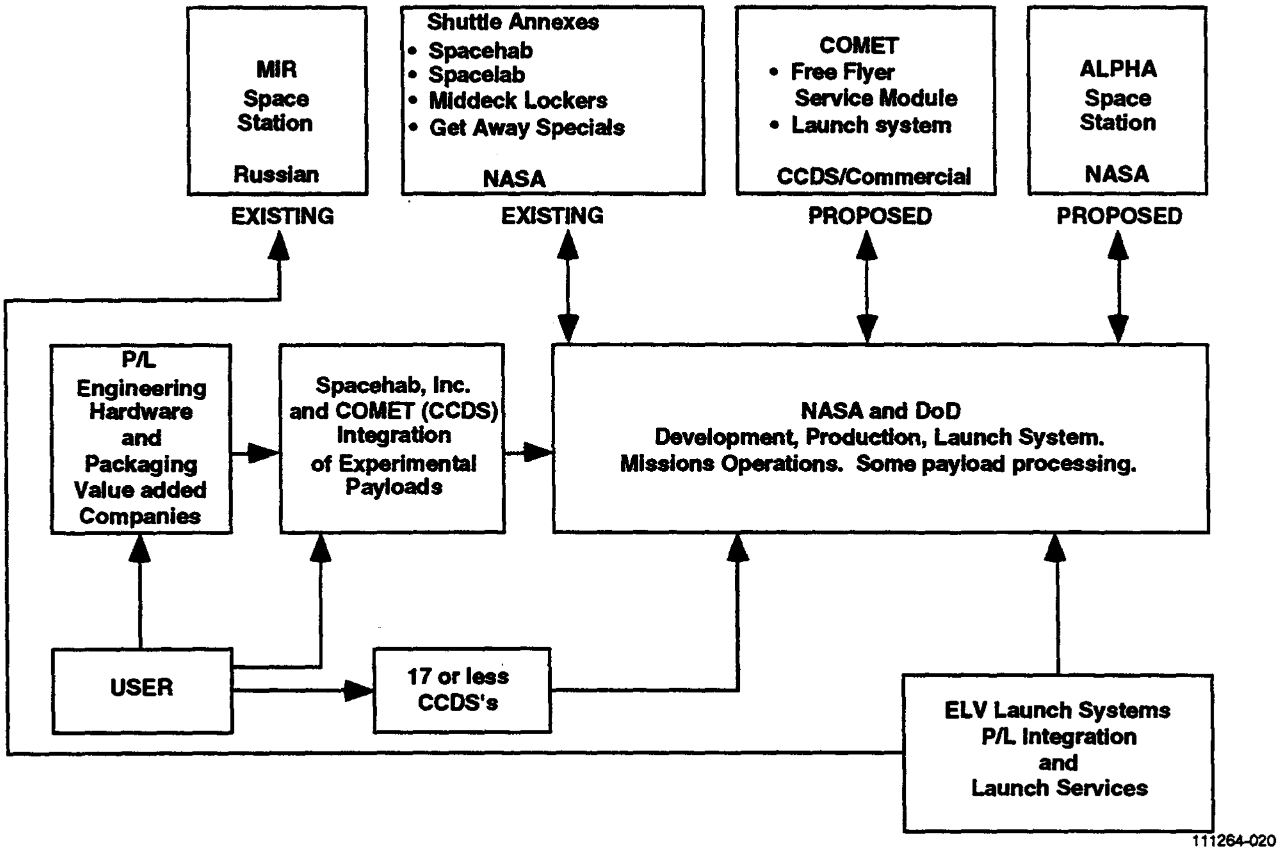


Figure 3.2.2.6-1. Space Manufacturing/Processing Infrastructure, Today

The existing small-scale but commercial access to the MIR Space Station is believed to be an independent attempt by commercial sources to gain access to a controlled microgravity orbital environment independent of NASA or U.S. government control.

The illustration of figure 3.2.2.6-2 outlines a future commercially compatible recommended infrastructure. Within the Drivers Pro paragraphs of section 3.2.2.3 and within the System Description of section 3.2.2.4, it has been assumed that the total system consisting of the large-scale orbital service module, the recovery modules, the launch system, and both the launch facilities and recovery site facilities are all maintained, owned, and operated by the commercial launch company.

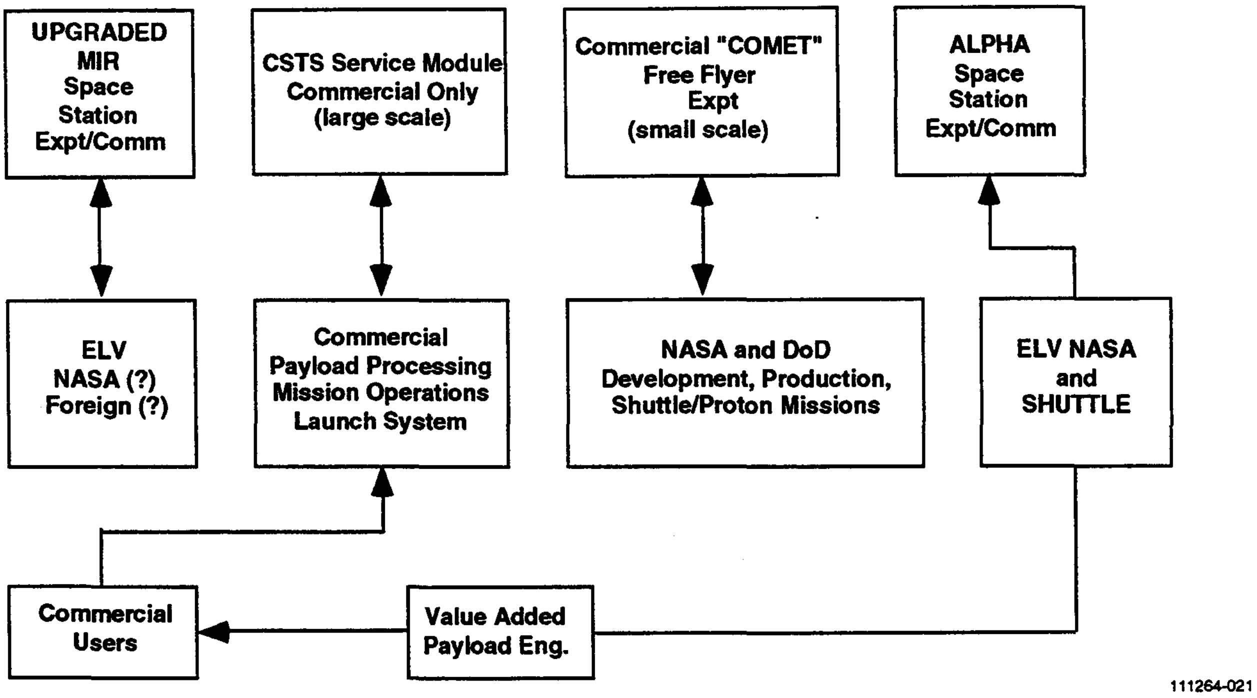


Figure 3.2.2.6-2. Space Manufacturing/Processing Infrastructure, Future

The future system an operational commercial large scale CSTS space manufacturing/processing system as defined in the previous sections of this report. The commercial version of the COMET freeflyer is predicted to be suitable for small-scale experimental activities, possibly as pilot projects for subsequent migration to the larger scale commercial CSTS system. The relevant competitive utility of these somewhat similar concept systems will eventually be defined by market forces.

An upgraded MIR station and the ALPHA station will be available as manned facilities assumed to be supportive of fundamental research-oriented activities but with access availability for microgravity processing shared with other life support and space science-related missions.

The users for the large-scale commercial space manufacturing/processing will interface with the CSTS commercial launch system either directly or through value-added commercial companies that provide individual customized materials processing and containment capsules.

3.2.3 Prospective Users

3.2.3.1 Contacts

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Dr. Hardy W. Chan, VP and Director of Biotechnology
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Dr. William Wilcox, Center Director
Mark Pasch, Dir., Technology Dev.
Prof. Liya Regel
Consortium for Commercial Crystal Growth, Clarkson University
Potsdam, NY 13699-5700

Dr. Javier de Luis, President
Dr. Anthony Arrott,
Payload Systems, Inc.
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Dr. Charles Bugg, Director
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3.2.3.2 Summary of User Inputs

Instrumentation Technology Associates (ITA) with John Cassanto

See Appendix C.3.1. The firm has been in business since 1982, providing technical space services and space hardware (instrumentation and materials processing in space (MPS) hardware and containment devices) to university researchers, and biotechnology and drug companies who want to perform experiments in space. They employ about five full-time personnel, with an additional 10 to 20 part-time personnel available, as required to support specific projects or space shuttle launches. Messrs. Cassanto and Alvarado and other personnel previously worked for GE Aerospace, Valley Forge, PA. Mr. Cassanto left GE/VF to start Instrumentation Technology Associates.

The firm provides their engineering services and hardware to drug (pharmaceutical, chemical, biotechnology, etc.) companies. They provide the technical understanding of space to drug company researchers who want to place their experiments on the shuttle, Spacehab, or the MIR.

ITA developed the Materials Dispersion Apparatus (MDA) minilab, which can accommodate as many as 150 sample data points during protein crystal growth, casting thin film membranes, cell research, encapsulation of drugs, and conducting biomedical and fluid science experiments. Four MDA units are accommodated in current shuttle flights, in mid-deck lockers, and provide 500 to 600 data points. Mr. Cassanto says other types of experiment holders that are available to researchers typically provide six sample points.

A major product area for ITA includes providing their services and equipment to researchers who are experimenting with space-grown protein crystals. Researchers have demonstrated they can grow larger, more uniform protein crystals faster in a microgravity environment than can be done on Earth. The three-dimensional molecular structure of the larger, space-grown crystals can be determined using X-ray diffraction. Determining the molecular structure is an essential step in several areas of medical research and rational drug design.

At the current cost and infrastructure, the experimenters will continue their current level of space research, primarily to exploit the two principal attributes of space: the diminution of gravity and the attendant virtual absence of convection. There have been no scientific breakthroughs that would indicate a high-growth space market. There is no certainty that a breakthrough will occur in the foreseeable future.

ITA personnel believe that the probability of a biomedical breakthrough could be enhanced by increasing the data yield per mid-deck locker. One approach to accomplish this is to use high-density space processing hardware devices that allow multiple techniques to process samples. This can be made available through the private sector. ITA has the technology and equipment on hand to increase the data yield by an order of magnitude, for example, from the present ~ 60 samples to 600 samples per mid-deck locker.

Consortium for Commercial Crystal Growth (CCCG) with Dr. William Wilcox

See Appendix C.3.2. The center, established in 1986 under NASA Code C funding, conducts technology development for commercial growth of electronic, photonic, and detector crystalline materials.

Crystal growth activities in space are experimental rather than commercial manufacturing, and the center was involved with five shuttle-based microgravity-related experiments in 1992.

Their experience indicates skepticism about immediate space applications from the commercial sector due to high costs. Their view is that a preferred facility for conducting microgravity experiments should be automated and unmanned and should provide extended duration orbital flights.

They believe that one of the greatest benefits achieved by the CCDSs is the development of ground-based capabilities in commercial crystal growth.

The launch system company should provide support to the user by affording on-schedule launches, return of samples to a predetermined location, and access to extended duration orbital flights in a simple straightforward way with an absence of bureaucratic procedures.

Commercial value-added companies should be encouraged to provide instrumented sample containment equipment for general application in ground- and space-related activities. There appears to be little short-term benefit in "manufacturing" crystalline material in the space environment, since to date there has been no statistically significant evidence of a higher performing infrared or semiconductor crystal material that has been produced using methods unique to the space environment.

With reference to space application activities, there appears to be currently near-zero sensitivity of user demand to launch system cost. This is due to the free rides currently offered by NASA and also the fact that few higher performing materials have been produced using methods unique to the space environment.

The lack of experience with regard to space applications, shown by nonspace commercial companies, is such that informed opinions on the investment potential of space-based business is difficult to obtain at this time.

Payload Systems Inc. with Dr. Javier de Luis

See Appendix C.3.3. The researchers met with Dr. Javier de Luis, president, Payload Systems Inc. (PSI), and with Dr. Anthony Arrott, formerly with PSI, on August 3, 1993, to discuss the commercial markets for space. For reference: Dr. Arrott can be reached at Arthur D. Little, Acorn Park, Cambridge, MA 02140-2390. Tel

617/498.5886 and FAX: 617/498.7007. The firm began business operations in 1984. They currently employ about 20 personnel. The 3-hour meeting focused on applications in commercial space research markets.

PSI provides space experiment containment devices or holders and instrumentation; the combination can be referred to as "minilabs." They also provide space engineering and payload integration services to drug companies (i.e., pharmaceutical, biotechnology, medical), universities, and government researchers who want to perform experiments in space. Recently, the firm received a contract from the Canadian Space Agency to develop a furnace and data management system that will support Canadian researchers' needs. The equipment will fly on Spacehab.

The company was flying three missions per year on NASA's C-135 parabolic, 0g flights. However, they have stopped these flights because NASA-HQs lawyers redefined the liability to the user to include the aircraft and crew. The insurance is now more than the flight costs.

Dr. de Luis commented, "...they are helping experimenters get into space." PSI has moved aggressively into providing innovative space services to the users. In 1988 they began contracting with the Russians to fly on MIR. This move has been successful for the company and they are seeing an increase in the frequency of biomedical research. Some key reasons why researchers want to fly on MIR are—

a. MIR provides the researchers with more than 2 weeks on orbit.
b. The experimenters do not have to disclose the specific research compounds.
c. The Russians can accommodate an increased frequency of space experiments.
d. There is less leadtime for reserving space on MIR.
e. There is much less preplanning, meeting, and reviewing than with NASA flights.

Dr. de Luis thinks protein crystal research in space is a growing market. The experimenters want to do much more research in space. The number of protein crystal space experiments is increasing significantly. The actual increase or growth, however, is confidential to the experimenters.

Payload Systems' customers include—

a. USA: BioServe Space Technologies, Kansas State, Penn State (CCR/CCDS), Bionetics, MIT, Instrumentation Technology Associates, Los Alamos National Laboratory.
b. Japan: Hitachi, Fujitsu Laboratories, Ishikawayima-Harima Heavy Industries.
c. Europe: Novaspace, Kayser-Threde, OHB System.
d. Canada: Alberta Research Council, National Research Council of Canada.

University of Alabama – Birmingham with Dr. Charles Bugg

See Appendix C.3.4. The CMC specializes in space-grown crystals of biological materials that are identified by participating firms in pharmaceutical, biotechnology, and chemical industries (i.e., drug companies). The goal is to work with companies to develop the technology and applications for space-based materials processing of biological crystals. The mission of the center focuses on—

a. Developing new techniques for protein crystal growth on Earth and in space. (This report summarizes the space-related activities.)
b. Structural studies of biological macromolecules using protein crystallography for drug design and protein engineering.
c. Definition and development of hardware and software for performing various macromolecular crystallography experiments.

Since 1988, the center has flown 17 protein crystal experiments on the space shuttle. The next shuttle flight (STS-51) will include another CMC experiment. The last shuttle flight had one CMC experiment in the Spacehab module. Other CMC experiments are scheduled on future shuttle flights.

There are also plans to perform CMC flights on free flyers in space. CMC experiments had been designated to fly on the Comet free flyer; however, the Comet project is on hold (see Comet Summary below) pending additional funding to complete the development. Another alternate is the LABS, a new free-flyer project discussed below.

Space Vacuum Epitaxy Centers with Dr. Alex Ignatiev

See Appendix C.3.5. The researchers met with Dr. Alex Ignatiev, director of the Space Vacuum Epitaxy Center (SVEC), at the University of Houston on July 29, 1993, to discuss the commercial markets for space, including space manufacturing. The SVEC is a NASA CCDS. Their primary technical area is applied engineering on thin film epitaxy using molecular beam epitaxy (MBE) processes for producing a new generation of semiconductor, magnetic, and superconductor thin-film materials.

The 1-1/2 hour meeting focused on the SVEC plan to produce higher quality thin films in space than can be produced in Earth-based, production vacuum chambers. Several years of work have led up to a space demonstration flight of the deposition of thin films of gallium arsenide (GaAs) wafers, layer-by-layer in a harder vacuum than can be achieved in a manufacturing environment on Earth.

SVEC researchers conceived a wake shield facility (WSF), with a 12-foot disc flying in LEO (fig. 3.2.3.2-1). The free-flying facility will be deployed from the shuttle. The stainless steel disc is estimated to provide a vacuum of 10 E-14 torr on the wake side. The first of four flights, a 2-day mission, will demonstrate thin-film growth of several GaAs 6- to 7-micron wafers, using MBE processes. Three additional flights will expand the thin-film processing capabilities and the autonomy of free-flight WSF operations.

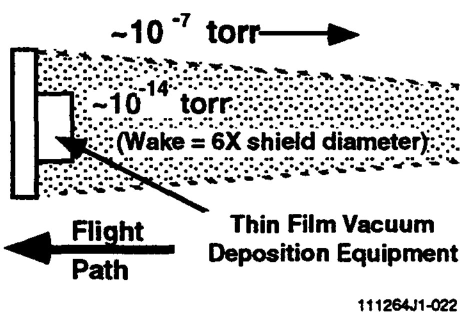

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Figure 3.2.3.2-1. Wake Shield Free Flyer Concept

The first flight is on STS-60, scheduled for early 1994. The second and third shuttle flights will increase the duration of processing operations and autonomy of free-flight operations. For the first flight, the WSF hardware is estimated to cost $12.5 million. Additional hardware through flight three will increase the facility costs to $22 million. The industrial partners are contributing an additional $3 million. Space Industries, Inc., is the principal industrial partner for developing the WSF flight hardware. A fourth flight would demonstrate pilot commercial operations, but will require additional industrial funding. The WSF is a proof-of-concept (Mark I) demonstration program. Dr. Ignatiev has plans for a follow-on program (Mark II), that will demonstrate commercial approaches to thin-film deposition process on GaAs wafers.

The University of Houston Business School estimated that a free-flyer Mark II facility with a 5-year operational life would be economically feasible. For commercial operations, approximately four resupply flights per year would be required. Each flight would deliver approximately 100 lb of materials for processing and return an equal weight of finished product to Earth. The facility would cost about $30 million to build.

University of Alabama—Huntsville with Dr. Charles Lundquist

See Appendix C.3.6. The writer contacted the Dr. Lundquist, director, UAH-HSV. They are a university organization working as part of the NASA Center for the Commercial Development of Space (CCDS) program. They are lead center for materials development in space.

Regarding CSTS, he commented that there have been many studies, several per year. The companies and his activity are getting tired of so many studies.

Dr. Lundquist has 8 to 10 ongoing, active materials development initiatives as part of the CCDS program. Some are with small companies, other with large business.

Small business examples are with ITA, John Casanto, in Pennsylvania. They are selling space on a facility that can go into LEO to other companies.

Another small business is SHOT (Space Hardware Optimization Technology), Floyd Knobs, Indiana. Contact is Mark Duser, president. Application is biological separation.

Dr. Lundquist promised to send complete contact information for these referrals. He also promised to provide recent reports on their accomplishments.

An agreement was made to follow up with meetings or telecons in the later part of July to discuss these applications, when the alliance begins the market research phase.

Grumman Corporation with Mr. Louis Hemmerdinger

See Appendix C.3.7. Grumman has considerable experience in research and development of crystalline group III-V materials. They have also been involved as a commercial member with the Center for Commercial Crystal Growth in Space at Clarkson University, Potsdam, NY.

This membership has been discontinued due to the perception that the center activities seem to emphasize university-based research rather than commercial-based research. The apparent trend of the CCDSs is to conduct growth experiments on smaller samples, requiring less on-orbit power than is required for commercial products. In addition, the quality and size capability of ground-based crystal growth furnaces is increasing rapidly, whereas the NASA trend is to smaller size equipment for space applications.

A past Grumman proposal to utilize a limited number of initial no-cost shuttle flights to demonstrate proof-of-concept for an in-space commercial crystal growth venture was mutually terminated by NASA and Grumman following the Challenger disaster, due to a 4 to 5 year delay to launch the furnace system.

Grumman has no current plan to participate in space applications of crystal growth or subsequent manufacturing. Prevailing NASA-sponsored flight-qualified equipment and power limitations are considered inappropriate for the crystal materials they would be interested in producing.

In addition, the limited on-orbit duration and extended turnaround time between experimental proposal request and actual flight for shuttle-based flights is not compatible with Grumman's commercial-scale requirements.

Grumman appears to favor a commercial access-to-space launch system that must provide reliable, launch-on-schedule, extended-duration orbital facilities, recovery capabilities, and appropriate contractual agreements with regard to payload accommodations and multiple launch commitments.

Grumman does not anticipate a significant space manufacturing market until the current experimental exploitation of space for crystal growth has demonstrated a conclusive advantage for material processing in a microgravity environment.

Given this successive demonstration and low-cost of access, Grumman may use the system about four times annually.

The decision criteria for space application depend also on the availability of equipment (furnaces) and adequate power to support large crystal growth.

Research and Development Facilities – Lockheed Missiles & Space Company with Mr. Chuck Rudiger

See Appendix C.3.8. Unique environmental conditions obtainable within an Earth orbital asset should be a stimulant to spaceborne research and development, particularly for materials and life sciences considerations. Payloads that feature research and development assets will be broad-based, and, therefore, no specific form factors were estimated at this time.

The launch system company must provide a go-and-return capability in support of an orbital R&D facility. In addition, human two-way transportation, stringent environmental and temporal constraints on access and return, and autonomous rendezvous and docking capability may need to be provided. Current infrastructure involves NASA and the government central to the whole process of access-to-space. The incumbent bureaucracies, uncertain STS flight schedules, and the potential for priority manifesting are not conducive to the concept of commercial use of space for R&D facilities.

The commercial user must be offered on-time, reliable, cost-effective, and efficient access-to-space and safe return of processed experimental assets to a guaranteed specific landing location. All these attributes must be available with absolutely minimum bureaucratic procedural processes.

The current costs burdened on the space experimenter user community are far too high, even though the actual ride is free. These costs include the use of an inflight protective container, resources and materials commitment to experiment planning, multiple sample preparation, recovery from landing sites, and final analysis of resultant materials. Some of these costs are significantly influenced by STS flight schedule uncertainties and priority manifesting.

Acquisition of independent company funding for space-based research is usually more difficult than for nonspace-based projects, is usually associated with business development opportunities for large programs, and incurs the risk of cancellation due to shuttle flight delays and NASA procurement decision fluctuations.

Spacehab Incorporated with Mr. Al Reeser

See Appendix C.3.9. Spacehab Incorporated is a commercial company that offers a pressurized habitant module that flies in the shuttle cargo bay. The SH-1 SPACEHAB module first flew on STS-57 on June 3, 1993. The module provides pressurized lockers, and single and double rack enclosures for commercial and government researchers to conduct experiments in the microgravity environment of space. During the initial flight, crew members operated and monitored 21 laboratory experiments during the 8-day mission.

The firm's headquarters are in Alexandria, VA, with business operations near Kennedy Space Center (KSC) and Johnson Space Center (JSC). They have a payload processing and launch operations facilities near KSC and mission operations offices near JSC.

Space Agriculture – Lockheed Missiles & Space Company with Dr. Steve Schwartzkopf

See Appendix C.3.10. Lockheed has participated in the STS-based Life Science Flight Experiments program.

Pertinent to space agriculture, the program seeks to identify the role of gravity in plant cellular processes, embryonic development, morphology, and physiology. An attempt is ongoing to identify mechanisms of gravity sensing and the transmission of gravity sensing perception information in plants. The interaction of light and stress stimuli is also being studied. Perhaps the main emphasis of understanding plant growth and metabolism is to provide for long-term survival and self-operation of bioregenerative systems for future space missions.

Lockheed has developed a number of flight-qualified common module-type life science laboratory equipment items, which have flown on the shuttle.

A general characterization for space agricultural payloads is that of similarity to those required for human transportation.

Experiments require a life-sustaining environment with nutrients, temperature, pressure, airflow, illumination, and contaminants carefully controlled.

This life-sustaining environment is required throughout the flight experiment including prelaunch, recovery, and delivery back to the original sample source, although the levels can be changed during launch and landing.

The enclosures must allow confident identification of the isolated effects of microgravity.

Flight durations of 12 days maximum as obtained via the shuttle are only of limited value in the study of plant physiology in microgravity; durations of 30 to 90 days would be more valuable to researchers.

No agricultural products are currently being manufactured in space. Companies involved in ground-based production of agricultural products are mostly inexperienced in space applications. The opinion was expressed that there is currently no predictable benefit to producing plants in space; in fact some plants have become sterile when exposed to microgravity. Effects observed to date are stochastic rather than deterministic.

The effects of microgravity on plant growth are not understood and there appears to be no reason to suppose that the environment of space "encourages" growth.

It appears that the primary reason for plant-based research experiments in space is in support of development of a bioregenerative environment to sustain human life in space vehicles or planetary colonies rather than the discovery of a new-generation plant species derived from growth in microgravity.

The interviewee felt that reduction in launch costs either direct or indirect would lead to an increased demand for experimental missions. This demand could be rapidly accumulative if a unique advantage of the space environment were demonstrated, particularly in the microbiology field rather than space agriculture.

The launch system must allow late access to samples (2 hours), have high launch reliability, launch on schedule, and guaranteed return to a postflight collection point.

Space Industries with Mr. Ole Smistad

See Appendix C.3.11. The writer contacted Space Industries to discuss their COMET program as part of the CSTS market research project. Smistad is the program manager for the COMET program.

The COMET is basically a service module, or space platform, that can be used to perform space manufacturing and processing. Space Industries views themselves as a service organization that provides the module to end users.

The end users buy space in the service module for performing processing and manufacturing in space. The service module weight is in the 1-ton range. Smistad says that the shuttle is too expensive for space manufacturing applications. An inexpensive ELV would be appropriate for the mission. The mission requires the payload to be recovered, and therefore, a recovery module is needed to return the payload to Earth. Space Industries has developed the overall approach for supporting potential manufacturers with a service module and recovery module.

Space Industries has evaluated and is familiar with Pegasus for launching the service module. Estimated launch costs for Pegasus are about $12 million.

Figure 3.2.3.2-2 shows the Smistad summary of the overall costs for a COMET flight as—

Product Element/Activity	Cost ($M)	
	Now	Future
Expendable launch vehicle, including ELV and ground ops, is about	$18	6
Service module	6	3
Recovery module	6	3
Mission operations, including ground stations	2	2
Total	$32	$14

Figure 3.2.3.2-2. Overall Costs for a COMET Flight

The key points of the discussion included—

a. Reducing the launch vehicle cost by a factor of three to $6 million will make it economically possible to sell space manufacturing to users.
b. The benefits would include increased launch rates.
c. Lower operating costs for space manufacturing will cause innovation.

Syntex Discovery Research with Dr. Hardy W. Chan

See Appendix C.3.12. Syntex has no direct experience of space applications and does not budget to track developments that may be occurring.

Syntex is a "small molecule" pharmaceutical company with ground-based annual manufacturing of thousands of metric tons of materials. Research budget is $300 million (~20% of profit) totally expended in nonspace activities.

Syntex's assessment of space applications is that they have seen no evidence of benefit to their particular industrial interests. If a smaller biomedical or biotechnology company were to discover some kind of enabling technology derived from space application experiments, then Syntex would simply buy equity in that company. This would provide the necessary production, distribution, and marketing support necessary to commercially capitalize on the enabling technology.

Subsequent to the demonstration of enabling technology, Syntex may well become involved in space experiments targeted to drug development with multiple flights annually at $200K per flight.

Payload samples probably would not exceed a few kilograms per year. Syntex would need appropriate sample containment enclosures and close support in the development of their inhouse space application experience base.

A reliable, launch-on-schedule, late-sample-access-and-early-retrieval, rapid-turnaround space transportation system would be required. Commercial business practices are perceived as incompatible with NASA's current methodologies associated with space access via the shuttle carrier. Syntex affirmed that they would never produce "small molecule" products in space. The company perceives that the overall cost of space application is high without specific reference to launch cost apportionment.

Pharmaceutical product pricing is a function of supply and demand rather than the recovery of specific investment in development of a particular product.

Syntex would only use space for product research and development if they become convinced that the space environment afforded a definite unique advantage.

They also are concerned that a good starting point for commercial space application be established by NASA funding.

Space Hardware Optimization Technology (SHOT) with Mr. John Vellinger

See Appendix C.3.13. The researchers met with Mr. John Vellinger, vice president, SHOT (Space Hardware Optimization Technology) on August 2, 1993, for 2 hours to discuss the commercial markets for space. The company is a small business with four full-time personnel, and several part-time personnel. The firm began business operations in 1989.

SHOT provides space equipment, payload integration, and engineering services to drug company (pharmaceutical, biotechnology, etc) researchers performing space experiments. The firm provides the following type products and services to end users:

a. Containment equipment for housing biological experiments in the mid-deck lockers on board the shuttle and Spacehab.
b. Technical services (integration of biological experiments with space hardware).
c. Launch integration services.

SHOT's space hardware is designed to contain living organisms for space experimentation. They have provided their equipment and services on several shuttle flights and concert 5 and 6 missions. The firm provided payload containment facilities for two successful shuttle missions: (1) chicken embryos experiment on STS-29 in March 1989, wherein Kentucky Fried Chicken, Inc. was involved and (2) organic separation experiment on STS-57 in June 1993. In the former mission they provided flight-certified hardware, that contained both a suspension system and an environmental control system for experimental sample protection and containment.

Typically, SHOT provides an enabling interface between the commercial end user (e.g., KFC, drug companies) and the NASA shuttle organization or Spacehab organization.

The firm has a new business thrust to develop new containment equipment for the drug companies to use for housing or packaging their experiments for the space environment.

Center for Cell Research, Penn State University with Dr. Wesley Hymer

See Appendix C.3.14. The Center for Cell Research (CCR) was established in 1987 as a part of NASA's Centers for the Commercial Development of Space program. CCR focuses on commercial product and process-oriented biotechnology projects in the areas of physiological testing, bioseparations and illumination.

Recently, as a spinoff from the CCR, Penn State has formed a private enterprise for the production and marketing of various automated systems for use in conducting both space-based and ground-based biological research.

The discussions essentially indicated that significant potential exists for biological product development in space, but currently no commercial market exists.

Currently, space-based biological production will be on the research and development level only. Any one user's needs would require only small payload weights to be placed in orbit on an intermittent basis. Dr. Hymer estimates that as many as ten bio payloads per year may be commercially sellable but would require some more work.

International government interest in space-based biotechnology is increasing; the Japanese have indicated keen interest in space biotechnology and several European consortia (university/industry/government) will be in place in 1994 to do space biotechnology as well.

Human interaction is not an absolute requirement for conducting space-based research. Ultimately space-based processing (e.g., electrophoresis) may require manned interaction for routine maintenance on on-orbit laboratories.

Allowable cost per flight is difficult to estimate since payload space on current STS flights is provided at no charge. It is evident that low-costs will be required ($50K to $100K per user) to develop the market.

In order for commercialization of biological products in space to occur, a concerted commercial venture must be undertaken to convince biological product firms of the potential profitability of space-based research and production and coalesce these firms into joint investment ventures to conduct research. CCR has this charter. Six biotechnological/pharmaceutical companies have already flown experiments in the last 3 years because of the CCR. Applications for the space research include the concept that space can be used as a testbed in the drug development process leading to new pharmaceuticals for use on Earth. There is a surprisingly large database that shows that rodents and astronauts experience bone loss, muscle atrophy, immune dysfunction, and so forth, all symptoms that mimic diseases on Earth.

Wisconsin Center for Space Automation and Robotics with Dr. Ray Bula

See Appendix C.3.15. The Wisconsin Center for Space Automation (WCSAR), formed in 1987, works in a variety of areas among that is space agriculture.

Commercial interest in space agriculture does not directly exist. Essentially, commercial industry is interested in controlled environment systems for plant growth on Earth. Development of systems for space research is applicable to terrestrial plant growth.

Ultimately, space-based agriculture may become a commercial market in the event of lunar colonization or manned orbiting factories, hotels, and so forth. Until such achievements are in place there appears to be no commercial interest in space agriculture.

Universities Space Research Association (USRA)-Washington, D.C., with Beth Ransom and Rick Zwirnbaum.

See Appendix C.3.16. The researcher met with Beth Ransom and Rick Zwirnbaum, representatives of the Student Explorer Demonstration Initiative (STEDI) program, at the USRA offices in Washington, D.C., to discuss the academia space research market. Dr. Paul Coleman, USRA president, and Kevin Schmadel, assistant executive director, were not available for the meeting.

The objective of the STEDI program is to demonstrate that significant space flight missions can be performed for science and technology development at very affordable costs. USRA believes that if the STEDI program is successful that it will be able to establish a steady stream of dedicated space flights for research and development at universities, government laboratories, and commercial research centers. Two important aspects of the program are (1) support limited duration projects (e.g., PhD research) and (2) significant hands-on participation by students and entry-level engineers and scientists. The program is sponsored by NASA. The USRA will select a range of university experiments in 1994 to be built, launched, and begin mission operations, flying three polar LEO space flights beginning in 1996.

The science objective is to select small payloads that are designed to conduct research in space-related scientific disciplines (e.g., astrophysics, earth sciences, life and biomedical sciences and applications, microgravity sciences, and space physics). Approximately $8 million per flight is planned for payload (up to 450 lb) and launch vehicle. The cost for each flight is split evenly between payload and small expendable launch vehicle (SELV), that is, $4 million for the payload and $4 million or less for the SELV. The cost per pound of payload is equivalent to approximately $9,000/lb, assuming 450 lb to 100 nmi orbit at a 90-degree inclination. The multiservice launch vehicle (MSLV) has been identified as the expendable launch vehicle.

Mr. Dan Goldin, NASA administrator, supports the program. USRA estimates that a total of $24 million is needed to complete the initial phase of the STEDI program. Launch dates for the three flights begin in 1996. If the initial phase of the program is successful, then NASA would continue to support the program, leading to a robust academic research program with a buildup of up to 25 space research flights per year. An estimate of the initial and follow-on phase launches is forecast in figure 3.2.3.2-3.

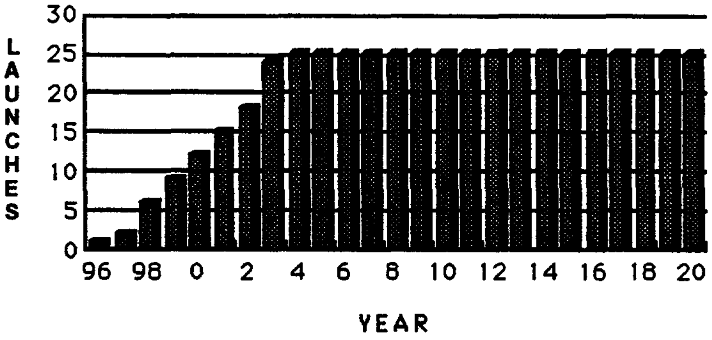

Figure 3.2.3.2-3. STEDI Program Launches

USRA is a nonprofit organization that consists of approximately 76 member universities. The association was established in 1969 by the National Academy of Sciences at the request of NASA. The objective of USRA is to provide a mechanism through which universities and other research institutions could cooperate with each other, with the U.S. government, and with public and private organizations to further space science and technology. The association operates a number of institutes, divisions, and programs throughout the U.S. that sponsor exploratory research and aerospace education.

3.2.4 CSTS Needs and Attributes

3.2.4.1 Transportation System Characteristics

In general, the potential users of the space manufacturing/processing system have expressed a strong preference for an airline-type operation with routine scheduled access-to-space operated as a commercial venture. Each payload must be precertified via adherence to predetermined commercial Federal space regulations, similar to the FAA regulations for aircraft, without individual government-controlled safety reviews.

The launch vehicle must provide a launch each 30 days, with late access of 12 hours for selected subunits of the total payload wherein inactive time delay would be critical to the integrity of the unprocessed products. The vehicle lift capability must be at least 4,500 lb to LEO at 98 degree inclination. This total payload mass to include 3,000 lb of product and containment support modules and also the 1,500 lb recovery module, which provides the controlled on-orbit maneuver and rendezvous functions for delivery to the orbiting service module.

The delivery of payload to the preferred sun-synchronous orbit at high inclination will require highly reliable launch operation timelines, highly accurate guidance, and staging and precision range-tracking instrumentation.

The customer base for the space manufacturing/processing system is envisioned to be from nonaerospace industry, such as semiconductor materials manufacturers, biotechnology, and pharmaceutical manufacturing/processing companies. The launch system company, therefore, must provide a full-service capability both before and after launch and will probably encourage the significant involvement of space-experienced value-added companies as primary interface agencies.

To accommodate the routine launch on a 30-day cycle of 3,000 lb of unprocessed payload comprising possibly 20 to 30 subunits of individual product/containment modules will require a significant scheduling, multimanifesting, and interface effort. A significant team of dedicated staff will be required to achieve this previously unprecedented tasking involving sustaining engineering, planning, and program management.

Prelaunch payload processing facilities will require careful planning to accommodate the necessary timely support to multiple subunits of the total payload. Commonality of product processing and containment modules will be an essential feature to support the relatively short preparation cycles for individual integrated payloads.

Preparation of the recovery module to be carried with each flight will commence following each return flight containing processed products. A refurbishment facility will be dedicated to this task and should probably be located at the actual launch site.

Postflight payload storage and holding facilities will be needed located at the fixed recovery landing site. This facility will enable the tasks of both dismantling the composite processed product and containment modules from the recovery module carrier and subsequently storing of each module within suitable environmentally controlled enclosures prior to customer pickup.

The entire emphasis of the space manufacturing/processing system will be to provide regularly scheduled, service-oriented access to microgravity space with minimum bureaucracy, maximum throughput efficiency, and minimum cost.

3.2.4.2 Elasticity of Demand

Commercial demand for space manufacturing/processing currently exists only as a supporting interest participating in shuttle-hosted flights committed to microgravity processing. A significant commercial demand for regular access-to-space to process raw materials for the creation of products to sustain a viable commercial market simply does not exist at the present time.

Commercial companies, with interest in the use of microgravity processing facilities, have for some time (8 years or so) obtained access at zero flight cost through the NASA sponsored and funded CCDSs. This zero cost transportation access as provided by NASA is, of course, impossible to match in price with any commercial access-to-space system.

Spacehab is the only operational commercially developed system currently available to support microgravity processing. The cost of such access equates to about $30,000/lb based on a 60-lb locker priced at about $1.8 million for a 10 to 12 day duration on orbit with a lead preparation time of about 18 to 24 months. Revisit periodicity had previously been planned for two Spacehab flights per year, but recent Congressional budget cuts have reduced this to only one flight per year.

It is believed that to date NASA has rented all available locker space for the second and third missions with no individual U.S. commercial reservations. This arrangement has been described as an "anchor tenancy," which ensures that the commercial developers of Spacehab (Spacehab Inc.) will be able to recover the construction costs of flight modules.

The issue of elasticity concerning price versus demand has therefore been estimated based on the assumption that the near-term experimental flights dedicated to microgravity processing will lead to technology breakthroughs. Furthermore, it has been assumed that these breakthroughs will receive appropriate publicity and therefore stimulate commercial interest in this activity. Products will be subsequently created that will have significant commercial potential and therefore will provide a commercial business incentive.

Current prices for access-to-space vary considerably depending on the approach used. The shuttle-based GASs intended as standalone, self-contained canisters cost about $10,000/canister. For a shuttle flight with about

40,000 lb capacity and price quoted as $400 million to $650 million per flight, the effective cost would be between $10,000/lb and $16,250/lb.

The Spacehab vehicle, operating as a shuttle annex, is priced at $30,000/lb. This price is understood to include markup intended to recover the commercial cost of vehicle development. The CCDSs managed COMET free-flyer program (currently in development) quotes a price of $32 million per flight, which involves about 300 lb of experiments and is therefore $100K/lb. This higher price, however, provides up to 30 days of microgravity environment exposure. As stated previously, the access cost to space is priced at zero cost for experimenters seeking access through the CCDSs.

The space manufacturing/processing system discussed within this report (sec. 3.2.2.5) has been evaluated on the basis of determining what price must be charged to users in order to recover the investment needed to develop, produce, and replace usable assets and operate a suitable system at a commercial profit.

These prices range from a maximum of about $25.3K/lb to a minimum of $6.2K/lb depending on annual flight rates and investment strategies, which include government/industry cost-sharing schemes (see summary fig. 3.2.2.5-1).

The actual stimulation of demand in the long term is perhaps more a function of service than of price. The space manufacturing/processing system as discussed herein is specifically designed to incorporate those elements of service and capability, advised to the CSTS researchers, as being essential to support commercial utilization. Discussions with potential users has established a guide to elasticity of demand, as shown in figure 3.2.4.2-1.

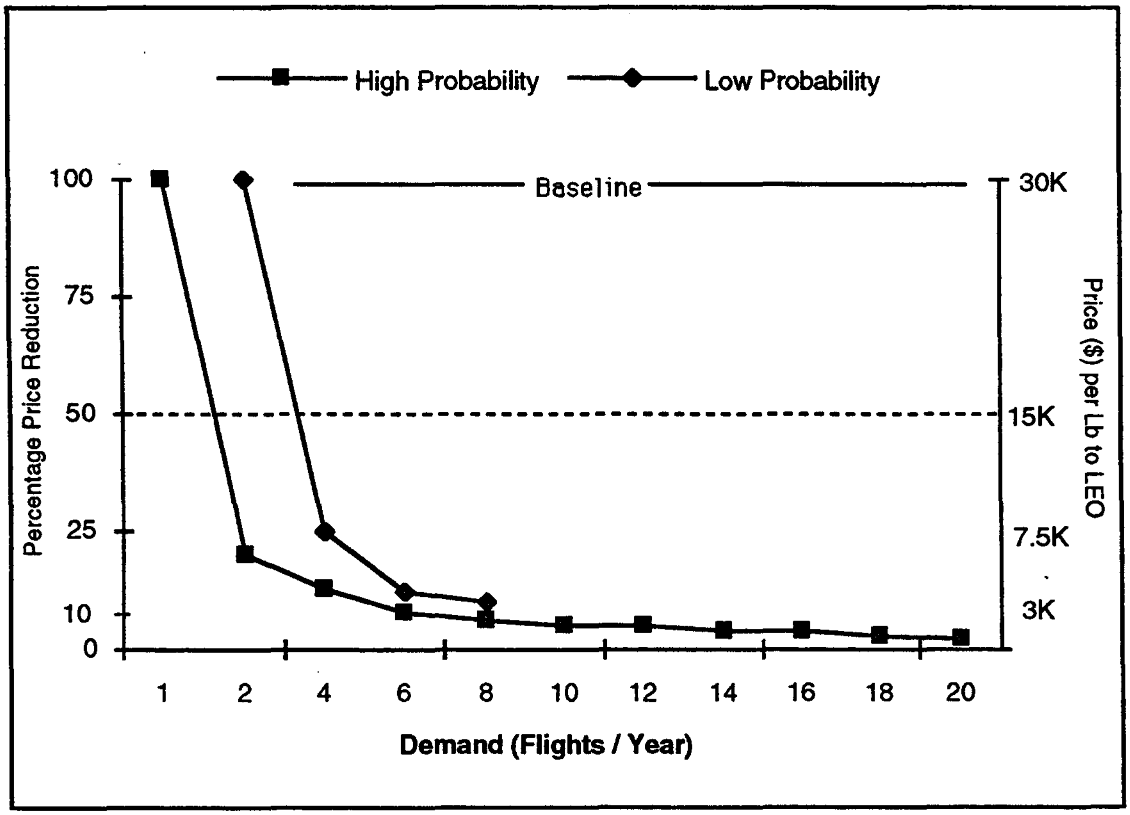

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Figure 3.2.4.2-1. Elasticity of Demand

The high probability curve demonstrates that for current price ($30,000/lb) as available from the Spacehab module commercial demand is practically zero to unity. Reduction to 25% range would stimulate perhaps a factor of 2 increase in demand.

Further reduction to 10% of current prices would yield a factor of between 5 and 6 increase in demand. A reduction in price in the range of two orders of magnitude (i.e., $300/lb) would increase demand by a factor of between 10 and 20. The net effect is therefore a nonelastic market. That is, the differential reduction in price exceeds the differential increase in demand, at reasonable economic prices (e.g., greater than $1,000/lb) which results in an elasticity of less than unity.

The projected flight rates for the space manufacturing/processing market have been estimated based on the assumption of continuing government-sponsored/funded experimental activities, technology breakthroughs, and the future availability of a service-oriented system with capabilities and operating characteristics as suggested by CSTS research contacts.

A highest probability baseline rate of 12 flights per year at about $1000/lb has been predicted to correspond to the requested minimum 30-day on-orbit duration. A slow growth has been assumed out to about 7 years following initial operating capability as being a conservative increase in utilization. This low-cost access is probably not achievable, even with government investment, if the launch company must assume replacement costs for the assets with limited lifetime, that is, the orbital service modules and the recovery modules.

The minimum projected cost for access that includes replacement of these assets has been evaluated as about $6000/lb. The high probability rate of 6 to 8 flights/year at current prices is a projection derived from commercial utilization stimulated by technology breakthroughs as potentially possible from the ensuring experimental programs but with demand bounded by relatively high-cost access.

Low probability rates are very unlikely to be realized in practice but have been estimated based on conservative upwards scaling of the higher probability cases.

The overall flight rates shown within the composite mission models demonstrate the potential impact on this specifically designed space manufacturing/processing system that a space business park may have, that is, certain users may prefer to utilize the latter manned facility perhaps for activities involving living organisms or animals or for activities that are less predictable than routine production processes.

It should be noted, however, that the threshold access cost to stimulate significant space business park activity is around $500/lb, which may well require application of leapfrog technology such as is predicted for a reusable transportation system. In that case, the same technology could be applied as the launch service element and the recovery carrier for the autonomous space manufacturing/processing system, thereby considerably modifying the effective access cost for this system also.

3.2.5 Confirmation of Market Opportunity

The field research reports that provided much of the database for this report were individually reviewed with the interviewed personnel from the organizations visited during the study. Amendments and corrections were incorporated such that the final versions of each report were confirmed as a faithful and true record of the responses obtained from the CSTS questions and subject discussions.

The primary sources contacted for the Space Manufacturing/Processing segment of the CSTS included the following list of organizations and individuals.

John Cassanto, President
Ulises (Al) Alvarado, Sys. Eng. Mgr.
Instrumentation Technology
Associates (ITA)
Exton, PA 19341

Louis Hemmerdinger, Dr. David Larson,
Grant Hedrick
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Dr. Hardy W. Chan, VP and Director
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Dr. Randolph M. Johnson
Syntex Discovery Research
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Dr. William Wilcox, Center Director
Mark Pasch, Dir., Technology Dev.
Prof. Liya Regel
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David Rossi, V.P. – Bus. Development
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Dr. Steve Schwartzkopf
Manager: Life Sciences &
Biotechnology
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3.2.6 Conclusions and Recommendations

The private sector has not yet endorsed space manufacturing and processing as a viable commercial business venture, at least not in the near term.

The potential advantages of processing materials and products in a microgravity environment are apparently not well publicized by the relatively few companies and university centers currently involved in experimental activities.

Practical demonstration of useful, real, space-produced products has not yet occurred on a scale of significant magnitude to attract commercial interest.

The current NASA virtual monopoly of providing shuttle-hosted zero cost access to an orbital microgravity environment, through the CCDSs, is commendable in principle for the support of limited experimental-based opportunities.

This shuttle-based approach, however, with government ownership and operation of the access-to-space transportation and microgravity processing system, is fundamentally incompatible with private sector commercial business practices.

The system is apparently excessively burdened with time-consuming bureaucratic procedures, provides less than desired on-orbit time duration and process-related electrical power, provides inconveniently long leadtimes between repeat flights and between planned intent and realization of a given flight, is subject to schedule delays and manifest priority changes, and provides a training burden and local microgravity disturbance potential due to the constant presence of crew.

The private sector development of the Spacehab equipment has been a commendable and promising first step towards commercialization of the provision of microgravity processing facilities., however,, the commercially acceptable price threshold for general use of this facility appears to be more than commercial industries are willing to pay. It seems reasonable to suppose, however, that the apparent reluctance of commercial customers to use the facility is also dependent on the current access system characteristics as described above, since Spacehab is flown as a shuttle annex.

The free-flyer COMET program concept for microgravity processing access appears to be a step in the right direction to address at least some of the concerns associated with the current STS-based system., however,, this new system still appears to continue the principle of government ownership and operation and appears to be designed and managed as a research asset rather than a commercial venture. In addition, this system also appears to offer a very high price for access at about a factor of 3 above Spacehab with therefore pessimistic prospects for stimulating commercial use.

The elasticity of demand for the space manufacturing/processing market has been estimated based on responses derived from direct interface with potential users and is shown in figure 3.2.4.2-1. Current access price for commercial customers is either zero (via CCDSs), $30,000/lb (Spacehab), or proposed as $100,000/lb (COMET).

A cost value corresponding to Spacehab was taken as a baseline for potential customer use discussions. It was found that commercial demand would probably become finite if the cost of access was reduced by 50%. Reduction to 25% of the baseline price would result in a factor of 4 increase in demand. Further reduction by an order of magnitude indicated an increase in demand of less than tenfold. A dramatic reduction in price by two orders of magnitude indicated an increase in demand by a factor of between 10 and 20. The net result indicated was that the differential reduction in price exceeded the corresponding differential increase in demand, therefore demonstrating an elasticity of demand of less than unity.

This finding indicates an unfavorable business proposition with respect to space manufacturing/processing, that is, although a decrease in access cost would stimulate increased demand, the revenue obtainable by the system provider from this demand would be insufficient to cover the cost of providing the means to satisfy the demand.

The business analysis of section 3.2.2.5, for a space manufacturing/processing system designed specifically to contain all the required attributes indicated by the CSTS research study, should also be noted. A rough order of magnitude evaluation was carried out with various funding profiles, investment cost-sharing schemes between government and industry, and also various flight profiles for 10 years of system operation following initial operational capability. This analysis is summarized in figure 3.2.2.5-1. Categories D, D1, and D2 are defined in appendix C.2.

This business analysis indicates that the estimated price for access, designed to achieve a reasonable rate of return for the required high-risk investment, in a dedicated "preferred concept" space manufacturing/processing system, is unlikely to attract commercial users.

Development and operation of such a system funded by the private sector alone is not sustainable.

With industry and government contributing an equal share in the upfront R&D investment, the business viability would still be highly uncertain, even though the price for access would reduce by about 40%. Consider the perhaps-unrealistic scenario of the government providing 100% of the upfront R&D costs, but with industry funding the replacement of limited life assets. In this case the minimum necessary access price needed to be charged to profitably operate in this service business is not less than $6,000/lb. This figure is < 60% of the STS cost and < 20% of the typical current commercial access cost.

To realize the earlier projection of stimulating a new industrial base, with inherent reliance on space manufacturing/processing, the government investment in the system will need to be more innovative.

It should be noted, however, that the user "value for price" projected for the dedicated "preferred" space manufacturing/processing system is considerably higher when compared with access systems in current use, that is, cost comparison should also be considered with schedule compliance, extended orbit duration, enhanced available processing electrical power, routine nonbureaucratic service, and so forth.

These additional benefits may stimulate more commercial interest even though the price charged for access still appears to be high.

The combination of these analyses indicates that in 1994 investment in a space manufacturing/processing system may not be a sound business proposition. The situation could change, however, pending dramatic results potentially achievable through the ongoing NASA-sponsored research experimental effort.

Recommendations

The government should maintain a vigorous support of providing access-to-space for microgravity research and development using the shuttle. A little less bureaucracy would also go a long way. Even though the STS system has certain limitations, it does provide a means of support to accelerate the possibility of technology breakthroughs. These breakthroughs are key to the stimulation of greater commercial interest.

The issues of *required* commercial proprietary control over experimental results balanced with the *needed* wider dissemination of knowledge gained from experimental work needs to be addressed. Simultaneous resolution of these issues is naturally difficult to achieve; however, denial of the former and absence of the latter are perhaps a further key to the current lack of commercial involvement on a significant scale.

Stimulation of commercial ownership and operation of the access-to-space system should be addressed. Numerous respondents to the CSTS research emphasized this point. Innovative investment options need to be considered, certainly with emphasis on the concept that government investment support in a potentially wide-ranging commercial enterprise could well be cost effective with reference to stimulation of the GNP and future employment.

Serious consideration should be given to the concept of an unmanned, automated space manufacturing/processing system. The characteristics of at least one possible system, as described in this report, were derived via direct feedback from potential users. In short, the optimum way to stimulate the interest and involvement of commercial users is to listen to their needs and, if feasible, provide them.

3.3 REMOTE SENSING

3.3.1 Introduction

The data in this chapter of the report are concerned primarily with assessing the launch vehicle market for deploying remote sensing satellites. Included is the market demand for commercial, U.S. government, and international launches, and the overall assessment of the launch market. Commercial launches are forecast to begin in 1995. The data on the commercial launch vehicle market are based upon several U.S. companies deploying a significant number of satellites in the latter half of this decade and then expanding and replenishing their satellite deployments in later years. The assessment also evaluates the remote sensing market to determine if there is a viable market for the commercial satellite operator and therefore provide a basis for validating launch vehicle demand.

Space remote sensing is a high-growth international market that is poised for rapid expansion in commercial applications over the next 5 to 7 years. Several U.S. companies are planning to deploy their own remote-sensing satellites and market their own space imagery.

The origin of the market can be traced to the U.S. government, which began promoting the civil uses of government satellite data by enacting the Landsat Remote-Sensing Commercialization Act of 1984. Earth images from Landsat satellites were being released by 1985 on a routine basis to the private sector. The French government, a consortium of European countries, and several prominent industrialized nations also pursued similar economic policies. By the late 1980s, several governments invested heavily in remote-sensing satellite programs in preparation for stimulating a new commercial market that would create jobs and exports for their domestic industries.

The civil sector has responded to governments' vision. Throughout the world today, the private sectors and government agencies of many nations have begun to rely on satellite imagery. The remote-sensing market has emerged from its embryonic state and is experiencing double-digit growth. It is a "high tech" industry with the potential to generate several billion dollars in sales annually within 10 years. Many commercial companies are poised to enter the market with better products than are currently being produced from government satellites.

Several initiatives and trends in the marketplace indicate significant growth in commercial remote-sensing satellite deployments in the next 10 years. There is substantial demand for more detailed images than can be provided by the current government satellites. Images are limited to 10- to 30-meter resolution. Current and future end-user applications are demanding better resolution. Governments are responding slowly with long-range programs to meet the demand. However, several U.S. companies announced plans in 1993 to independently launch their own constellations of remote-sensing satellites with 1- to 5-meter resolution that will be available in the mid-90s.

Independence from government-provided space imagery will stimulate the remote-sensing market over the next few years. Higher resolution (1- to 5-meter) imagery from commercial satellites will begin to compete with government data in the private sector. By the end of this decade, sales of space images from commercial satellites are expected to draw even with the share generated from government satellites and become the dominant supplier by the year 2005.

Combined launches of remote-sensing satellites from government, international, and commercial operators will rise from an average of 8 per year in the first half of this decade to 10 per year through the second half of this decade. Launches will remain relatively flat early next decade, maintaining an average of 10 per year through 2005.

Worldwide sales for the emerging space imaging market topped $190 million in 1992 and are expected to reach $332 million by 1995. The introduction of commercial satellite data in the mid-90s should cause the market to grow at a moderately higher rate and reach $823 million by the year 2000. As the market matures and diversifies in the 2001 to 2010 time frame substantial increases in private sector demand for space imagery will accelerate market growth. Annual revenues will top $2.7 billion in 2005 and surge to $6.8 billion in 2010.

Employment figures for the remote-sensing field are estimated at under 22,000 in 1991, including the aerial remote-sensing segment. The number is expected to jump to over 58,000 by the end of this decade, with most of the growth in high-tech jobs related to value-added imaging services, geographic information system (GIS) workstation engineering and equipment production, and satellite ground operations. Employment will nearly double to 100,000 by the year 2010.

3.3.2 Remote Sensing Market

Sales of Earth images produced by government satellites will continue to dominate the commercial remote-sensing market up to the end of this decade. The U.S. and French governments and the ESA consortium of European countries have ongoing long-range programs for replacement satellites with improved sensor performance in image resolution, spectral bands, swath, revisit times, data throughput, and other satellite parameters. These new satellites will come on line later in this decade and early in the next decade. Furthermore, Japan, India, Russia, China, Canada, and other countries also have the technical capability and resources to offer competitive remote-imaging data.

Commercial users, including universities, and state and local agencies, now depend on government satellite data for an expanding range of economic, environmental, analytical, surveillance, education, and regulatory uses. Earth images with 10- to 30-meter resolution are commonly available from an expanding commercial infrastructure.

There was substantial activity in 1993 to secure U.S. government approval for deployment of commercial satellites with a capability to provide 1- to 5-meter resolution data to the private sector. The remote-sensing industry believes there is substantial pent-up demand in a range of existing and creative new industrial uses for the more detailed images. If the industry estimates prove-in, they could earn several billion dollars annually and create tens of thousands of high-tech jobs in the process by the early part of the next decade.

The market value of worldwide sales of satellite and aerial remote-sensing data has been estimated by several sources[1] to exceed $2 billion in 1992, with satellite data and derived product sales estimated at $190 million (fig. 3.3.2-1)[2]. The estimates project that the space imagery market will expand by at least 15% annually through the first half of this decade. The market will grow from $190 million for 1992 to $332 million in 1995, as illustrated below. The entry of several commercial satellite operators by mid-decade should increase competition and industry sales of space imagery more rapidly in the latter half of this decade.

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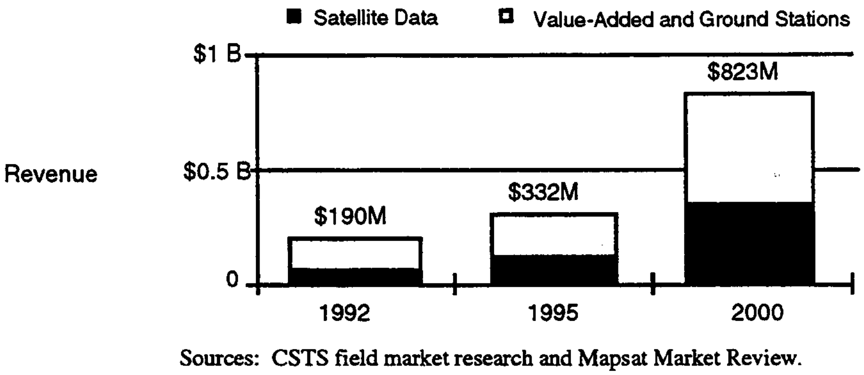
[1] Testimony before Congress, by J. N. McMahon, LMSC president, on June 10, 1993; Geographic Information Systems Survey, 8 April 1992, R. R. Jordan, LMSC.

[2] Mapsat Market Review, 1991, KPMG Peat Marwick.



Sources: CSTS field market research and Mapsat Market Review.

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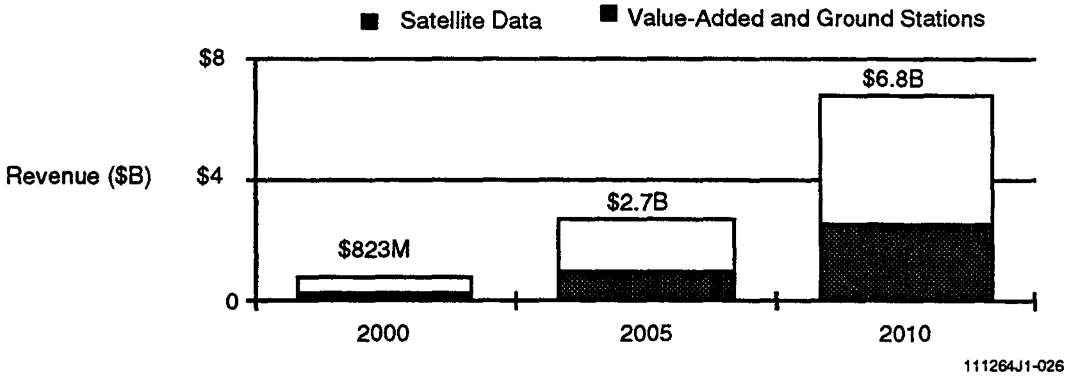
Figure 3.3.2-1. Projected Revenue From Satellite Space Images

By the 1995-96 timeframe, the private sector will reduce its dependence on government-provided low Earth orbit (LEO) imagery by deploying its own commercial remote-sensing satellites. These commercial satellites will provide better-resolution Earth images; more frequent coverage than government satellites currently provide; customized products to niche markets; and timely, responsive delivery of imagery to a growing number of users.

The entry of the commercial satellite operators and their concentrated efforts to expand the market will stimulate demand for space images. Worldwide sales have the potential to approach $823 million annually by the year 2000. The largest share of space imagery growth will come from the existing remote-sensing market serviced by aerial imaging products.

In the latter part of the decade new users, requiring specialized space imagery, will account for significant revenue gains. Sales of value added, or enhanced, images will therefore outpace the demand for more satellite data. Satellite operators will also provide Earth and Earth limb data directly to end users, as well as value-added resellers (and indirectly, through sales of ground station licenses). The growth should be large enough so that several commercial satellite operators can successfully compete for significant shares of a robust space imagery market.

In the longer term, revenue from space imagery is forecast to overtake the aerial market by the early part of the next decade. The combined total market revenues for satellite remote-sensing, including government, international, and commercial, indicate explosive growth in the range of 50% annually, in the 2001 through 2010 timeframe. The market has the potential to exceed $2.7 billion by 2005, and by the end of the decade to post $6.8 billion, as illustrated below. From discussions with industry providers and the companies planning to deploy commercial remote-sensing satellites, the researchers concluded that value-added operations that enhance space imagery will claim the largest share, as illustrated in figure 3.3.2-2.

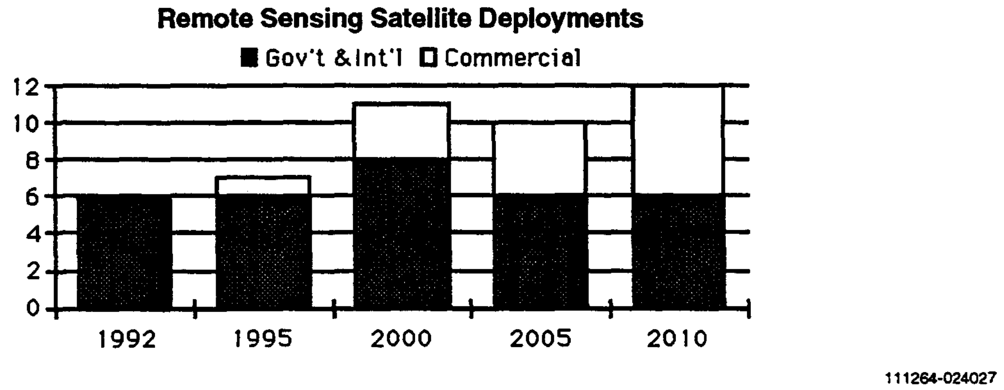


	Market Value ($M)			Growth (%)	
	2000	2005	2010	2005	2010
Satellite Data	$331	1,011	2,516	61	50
Value-added	455	1,688	4,201	57	50
Ground Stations	37	47	76	24	32
Total Market Value	823	2,747	6,793	53	49

Source: CSTS market research estimates.

Figure 3.3.2-2. Market for Satellite Remote Sensing

During 1995 through 2000 worldwide launches for all remote-sensing satellites will increase moderately from 7 to 11 per year, as illustrated in figure 3.3.2-3. This projection includes commercial operators who will begin deploying satellites in 1995 and ramp up to five deployments by 1997 and level off to three per year by 2000. The technology investments in low-cost satellite hardware during this decade will substantially lower commercial remote-sensing satellite costs and promote long-term growth.



Source of data: CSTS remote-sensing database.

Figure 3.3.2-3. Combined Deployment of Government, International, and Commercial Remote-Sensing Satellites

The overall market will have matured by 2001 and will be able to sustain and moderately increase the number of commercial satellites launched through 2010. Launches in the range of 10 to 12 per year will be based upon three fundamental factors. First, commercial operators who enter the market in the mid-90s will have recouped their investments and begun to expand their operations. The operators will begin replacing their first-generation satellites on the average of every 5 years. Second, the potential for substantial increases in sales, offset by lower operating margins, will fuel a surge in deployment of low-cost, specialized satellites for niche markets. Commercial satellite launches will increase to four in 2005 and six annually by the year 2010. Third, government and international launches will remain relatively constant, concentrating primarily on replacing aging satellites and initiating several new, multipurpose satellite projects.

The commercial demand for satellite remote images in the U.S. has been stimulated over the last decade as a result of the government's decision to allow satellite imagery to be marketed commercially. Data produced by U.S. government spacecraft are managed through the Earth Observation Satellite Company (EOSAT), Lanham, Maryland. The company was designated by the government in 1985 to market and distribute remote images to domestic and worldwide users. Multispectral Earth images using a thematic mapper on the Landsat-4 and -5 satellites provide 30-meter resolution in five electro-optic wavebands. The Landsat-6 satellite was to provide panchromatic data of 15-meter resolution, and 30-meter at multispectral (at bands 1 through 5, and 7) and 120-meter at band 6. Landsat-7 plans to provide 5-meter panchromatic images.

Other major providers in the international area are the French government and the ESA consortium of European countries. Japan, Russia, China, and India have also deployed satellites, and they provide remote data for commercial users. The French space organization, Centre National d'Etudes Spatial (CNES), offers satellite data to the worldwide market through a commercial company: Satellite Pour Observation de la Terre (SPOT) Image, Toulouse, France. Currently the SPOT-2 and -3 satellites acquire panchromatic data with 10-meter resolution, and 20-meter resolution in three electro-optic wavebands. The data are marketed and distributed worldwide through commercial affiliates and subsidiaries of SPOT Image.

EOSAT's and SPOT Image's combined worldwide sales revenue in the satellite remote sensor market for 1992 was $62 million. Both companies maintain they are profitable, however, their operating costs do not include payments for their governments' investments in acquiring and deploying the satellites that produce their sales.

Survey data provided by companies interviewed for this study indicate the cost for providing digital satellite imagery compares favorably with aerial imagery in an expanding commercial market. There is strong demand, both nationally and internationally, for topographic imaging of the Earth and the Earth limb from space using multispectral (electro-optic and microwave) sensors with 1- to 5-meter resolution to meet various commercial end user applications, including—

a. Commodity management, such as agriculture and forestry products.
b. Environmental monitoring and management.
c. Surveillance (real-time and non-real-time).
d. Mapping, charting, and geodesy.
e. Natural resource exploration.
f. Economic development, such as urban planning.
g. Crisis management, and others.

The increasing demand in the commercial sector provides significant economic momentum for producing more remote images. Aerial imagery has generated 10 times more commercial revenues than satellites due to the high demand for more detail resolution than the leading suppliers of satellite imagery (Landsat and SPOT) have been able to provide.

3.3.2.1 Market Evaluation

Overall, two key characteristics indicate moderate to high growth for satellite-based imagery over aerial imagery through the end of this decade. First, users will require medium resolution images in the 1- to 5-meter range over larger Earth viewing areas. The new commercial Earth-sensing satellites will provide this capability over broader area coverage more cost effectively than aerial platforms. Second, satellite data has the potential for reaching the customer much faster than aerial data. Satellite performance and costs in these regimes compete favorably with airborne platform costs.

In 1985, EOSAT was selected by NOAA to operate the Landsat satellites and to market and distribute the imagery for a 10-year period. NOAA, NASA, and DOD fund the acquisition of the satellites. EOSAT is required to provide the imagery at uniform prices to all commercial users. Because of this reliable and consistent source of imagery that is available on a long-term basis, industry has been able to build up a stable commercial infrastructure, which includes—

a. End users with inhouse capabilities to process and analyze satellite data,
b. Value-added firms, which enhance the images and resell to end users,
c. Entrepreneurial companies capitalizing on technology transfer from government-developed imaging capabilities,
d. Defense contractors transferring technology to commercial uses.

New government satellites (e.g., Landsat -7 and -8, the EOS family, and other international programs such as SPOT -4 and -5, and Helios) to be deployed over the next 10 years will improve the multispectral resolution of satellite sensors to the 1- to 5-meter range.

The remote-sensing market includes revenues generated from images produced by satellite operators, enhanced images provided by value-added resellers (VAR), and from fees paid by ground station operators to receive satellite imagery directly.

Significant growth in commercial demand for satellite imagery is expected in the future, primarily due to the existing and planned future government satellite programs. 1992 sales of satellite data and related products were estimated at $190 million, as detailed in figure 3.3.2.1-1 below. 1995 sales of satellite data alone should double, realizing an increase from $65 to $131 million.

Product / Year	**1991**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**2000**
Satellite Data	54.7	65.4	93.0	110.0	130.8	156.2	187.3	225.4	272.6	331.3
Value-added	80.5	97.9	117.6	141.2	170.3	206.1	250.3	304.3	371.0	454.7
Ground Stations	26.0	27.0	28.1	29.2	30.4	31.6	32.9	34.2	35.6	37.0
Total	161.2	190.3	238.7	280.4	331.5	393.9	470.5	563.9	679.2	823.0

Source: Mapsat Market Review, 1991, KPMG, Peat Marwick.

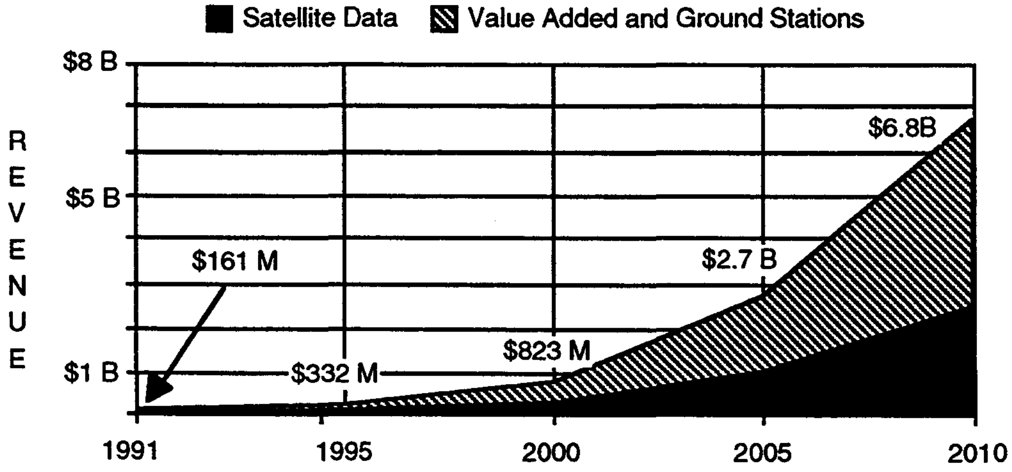
Figure 3.3.2.1-1. Satellite Segment of the Remote-Sensing Market

Several companies are targeting the higher resolution segment of the market where sales of aerial imaging produced an estimated $2 billion in sales in 1992. Typical aerial imaging resolutions are 1 meter. Earth coverage, however, is over relatively small land areas when compared to the broad area scenes that can be produced by satellite sensors.

U. S. companies believe they can offer panchromatic 1- to 5-meter resolution images that compete favorably with aerial sensors. Multispectral imaging and stereo capability that are not easily provided from aerial platforms will also have important market implications for competing successfully.

The satellite operators must also be able to supply timely imagery in a digital form that can be processed and analyzed quickly and accurately on geographic information system (GIS) equipment. The long-term rate of market growth depends heavily on how fast the industry can promulgate universal digital imagery standards for processing satellite, aerial, and terrestrial images and displaying the data on GIS and other desk-top terminals and workstations. The issue has been identified and standardization initiatives are underway.

The market for remote-sensing satellite data products is estimated to approach $823 million annually by the end of the century, as illustrated in figure 3.3.2.1-2. Commercial companies in the remote-sensing satellite market will realize the largest share of the double-digit growth forecast for the next 5-year period, and by the year 2010 will push the market to $2.7 billion.



Source: CSTS market research estimates.

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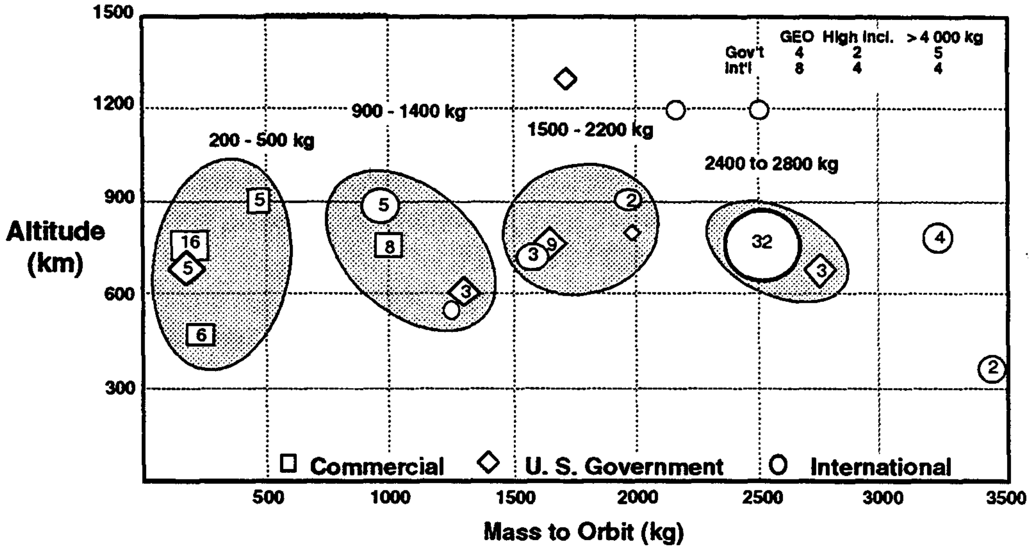
Figure 3.3.2.1-2. Market for Remote-Sensing Satellite Data

The satellite remote-sensing data market, in the 2005 to 2010 period, will experience 50% annual growth as standardized digital satellite imagery gains wide acceptance across an expanding list of commercial customers in the areas of environmental monitoring and assessment, geological mapping, commodity management, urban planning, and real-time surveillance.

3.3.2.2 Mission and System Requirements

The large majority of remote-sensing satellites operational since 1991 and most of those planned through 2005 are under 3500 kg and will be deployed to low Earth polar orbits, mostly at 400 to 900 km altitudes. Appendix D.2 summarizes the remote-sensing satellite deployments over this time period. The database indicates that a small quantity of satellites, however, will continue to be deployed to geostationary orbit, primarily for global weather forecasting. There will also be a few heavy government satellites to LEO, in the 5000 to 6000 kg range, that combine large suites of sensors for multiple missions.

The largest share of LEO satellites are clustered in four groups organized by mass to orbit, as illustrated in figure 3.3.2.2-1 below. Satellites to be deployed by commercial operators dominate the 200 to 500 kg group. Government, international, and commercial satellites in the 900 to 1400 kg category are relatively equal. Government and international satellites account for all deployed satellites in the bundles above 1500 kg, and international deployments outnumber U.S. deployments in the heaviest group.



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Note: Not included in the figure are small quantity of satellites in two groups — LEO satellites in the >4000 kg, medium Earth orbit and geostationary satellites. The former are multipurpose Earth observation platforms and the latter are weather satellites and remote sensors combined with communications satellites.

Source: CSTS Remote-sensing Satellite database, appendix D.2.

Figure 3.3.2.2-1 LEO Deployment of Remote-Sensing Satellites

Several U.S. companies are planning to develop commercial remote-sensing satellites, in the 200 through 1000 kg range, which incorporate visible and near infrared electro-optic (EO) sensors. There is also interest in radar images; however, adding this capability with EO sensors makes the payload package heavier, and more complex and expensive. The researchers concluded radar will not be combined with EO sensors on commercial remote-sensing satellites.

From low Earth polar orbits, remote sensors will look down to provide more Earth detail (e.g., 1 to 5 meter resolution) than can be obtained from operational satellites, such as Landsat-5 (30-meter multispectral), or from SPOT-2 and -3 (10-meter panchromatic, 20-meter multispectral).

The diversity of the private sector applications, as well as the larger government missions, require more than just satellites to respond to the demand. There are Earth stations operated by users that receive satellite imagery. There is also a growing number of third-party companies acquiring and enhancing Landsat and SPOT images and reselling their value-added products to the end users.

Operational life of remote-sensing satellites has been in the 3- to 5-year range. Advances in satellite technologies, such as lighter weight, more reliable buses, propulsion, solar array, avionics, recorders, multispectral sensors, computer processors, telecommunications, and others now make it possible to develop LEO satellites with 5-year lifetimes. Some commercial operators are estimating 7-year lifetimes.

Payload costs have also been reduced through miniaturization of electronics that provide more function per volume-mass and lighter weight materials that extrapolate into lower cost, smaller, less expensive launchers.

Low-cost processing of satellites at launch sites will be required to aid in the optimization of launch costs. Users will want to launch replacement satellites within 2 weeks in order to prevent loss of sales from a failed operational satellite.

The satellite owners will want to achieve accurate placement of their satellites in polar orbits. Onboard data storage in the hundreds of megabits will be required to reduce the number of ground stations required for downlinking of data.

3.3.2.3 Commercial Market Enablers

The market for commercial remote-sensing in the U.S. was precipitated by the government's decision to release Landsat data to commercial users through NOAA. The 1984 Landsat Act[3] modified the approach. Space imagery began to be released through EOSAT, a commercial company, which markets and distributes government satellite imagery to the private sector, under the auspices of NOAA. The most recent government policy changes, to the Landsat Act in 1992[4], reinforced the government's decision to make available comprehensive space remote-sensing data to the private sector. The government has planned several major investments in advanced technology to improve remote-sensing satellites over the next 15 years that are comparable with advances planned by governments of other countries.

A stable commercial infrastructure is required to ensure a viable and growing remote-sensing market. As a result of more than 10 years of government investment and support, the commercial infrastructure has been built up to the point where end users can rely and depend on gaining access to government-provided satellite imagery.

The marketplace must make adjustments in the products and services offered to the end users to ensure growth in the remote-sensing field. Companies perceive substantial demand for more detailed space imagery than is being provided from government satellites. Several firms have major projects to deploy their own remote-sensing satellites with 1- to 5-meter resolution in the mid-1990s.

From the research conducted for this report, a low-cost launch system that costs in the range of $3 to $5 million is required to expand the number of commercial satellites to be deployed to polar, LEOs. However, at today's launch system prices, commercial flight rates will build up to an average of three per year by the end of this decade. Replacement and growth satellites will push the average to four by the year 2005. In the longer term, growth in the remote-sensing market will require up to six launches by the year 2010 . Based upon discussions with the companies planning to deploy commercial satellites, if a $7 million per launch CSTS system were available in 2001, the estimated launch rate would increase from 6 to 12 annually by the 2010 timeframe. Also if the price were lowered to $4 million, the number would more than triple to over 18.

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[3] Land Remote-Sensing Commercialization Act of 1984.

[4] Land Remote Sensing Policy Act of 1992.

Small, inexpensive satellite buses capable of functioning as highly stable platforms for remote sensors will be required. Operational lifetimes in the 5- to 7-year range are also required.

A responsive launch system infrastructure that is capable of launching a replacement satellite within 15 days of a failed satellite will be needed by commercial operators in order to avoid major losses of sales revenue.

Data continuity between existing government satellite, aerial, and terrestrial sources with imagery from commercial satellites will be pivotal. Substantial growth in the market will depend on standardization of remote imagery in a universal digital format that can be accessed by a wide range of user workstations. The work on standardization of digital data has begun, however, it will take several years to secure international agreement. The explosive growth of commercial space imagery may not occur until after the widespread implementation and acceptance of standard format digital data.

Revisit time intervals between Earth scenes will be important to users in several applications. Currently, Landsat revisit times are every 16 days. As illustrated below in figure 3.3.2.3-1, there are many applications that require revisit images on a weekly basis, and others requiring as little as 2-day intervals between coverage.

Application	Bands	Resolution	Scene Size (Min)	Desired Coverage
Nonrenewable resources exploration	visible, near-IR, radar	2-30 m	40 km X 40 km	seasonally
Land use planning	visible, near-IR, radar	2-10 m	10 km x 10 km	weekly - monthly
Mapping	visible, near-IR, radar	1-5 m	30 km x 30 km	monthly
Resource Management	visible, near-IR, radar	5-30m	40 km x 40 km	weekly - monthly
Environmental Assessment	visible, near-IR, radar	2-10 m	40 km x 40 km	weekly
Agricultural / Forestry	visible, IR	5-30 m	40 km x 40 km	2 days - 2 weeks
Marine	IR, radar	20-1000 m	80 km x 80 km	2 - 7 days

Source: NASA, Office of Technology Assessment, 1993.

Figure 3.3.2.3-1. Sensor Requirements for the Remote-Sensing Market

The CSTS researchers found that commercial satellite operators are planning to deploy small constellations of remote sensors that will be capable of providing 2- to 3-day revisit times that are required by the commodity management applications in agriculture, forestry, and marine fisheries markets.

3.3.2.4 Business Assessment

To determine if it made good business sense for the CSTS Alliance to develop a launch system for this market, the study team concluded it was essential to evaluate the potential for the satellite owners to recover their investment from the revenues they earn from the remote-sensing market.

The analysis described below concluded that it was a feasible investment over a time horizon of 5 years. The investment costs were provided from field research data collected during discussions with analysts and from interviews with business leaders and technical authorities in the remote-sensing field. The several market reports referenced in this report provided data on the remote-sensing market and cost of operations for commercial enterprises.

The researchers concluded that there was adequate growth in the remote-sensing market during the 1995 to 2010 timeframe to support the entry of several commercial satellite operators. The size of the market is expected to grow from $332 million in 1995 to $823 million in the year 2000. In the longer term, the market would post annual sales of $2.7 billion in 2005 and surge to $6.8 billion by 2010.

To determine the near-term trends in satellite investments, data on the acquisition and deployment costs of remote-sensing satellites and their launch systems were assessed for the 1994 to 1998 timeframe, using the database in appendix D.2.

The researchers concluded the near-term investment in satellites and launch systems will remain relatively strong at an average of $1.6 billion annually over the 1994-98 timeframe, as illustrated in figure 3.3.2.4-1 below.

Element	1994	1995	1996	1997	1998	Total 1994-98	5-Year Average
P/L Costs ($M)	1,070	1,485	1,105	1,015	1,431	6,106	1,221
LV Costs ($M)	354	407	312	549	501	2,123	425
Total ($M)	**1,424**	**1,892**	**1,417**	**1,564**	**1,932**	**$8,229**	**$1,646**

Source: CSTS remote-sensing satellite database, appendixes D.2 and D.4.

Figure 3.3.2.4-1. Remote-Sensing Satellite and Launch Vehicle Investment

Beginning in 1995, the data above include investments by commercial operators that will augment government spending. Detailed inspection of the data (see app. D.4) revealed the commercial operators' investment will reach $1,195 million for the 1995-98 timeframe, with the launch costs accounting for more than one-third, or $450 million for 12 launches. This compares to $4,291 million and $1,319 million for government and international launch and satellite figures over the same period.

The operators expect to recover their investments through revenue earned on satellite imagery and related product sales to end users and value-added resellers. Individual commercial operators investments will be on the order of $135 million for a small constellation of three satellites, with 5-meter or better resolution, ground stations, mission operations, and end user workstations. Today's launch costs are approximately one-third of the total investment.

Satellite operators expect to recover their investment in 3 years. Their revenue projections appear to be very optimistic. Time horizons of up to 5 years with more moderate sales figures were used for this analysis.

The three revenue streams listed below (fig. 3.3.2.4-2) were evaluated for the assessment:

Revenue Projections
(Millions of 1994 constant $)

	1996	97	98	99	00	01	Total
Optimistic	10	50	125	200	300	400	1085
Nominal	5	35	70	140	250	350	850
Conservative	5	20	50	100	150	200	525

The revenue streams include sales of satellite data, enhanced imagery, and fees from ground stations.

Figure 3.3.2.4-2. Three Projected Investment Revenue Streams

From a business perspective, it may be reasonable for commercial operators to expect revenues from satellite imagery in the range of $100 million per year, after a 3-year startup period. Revenues should increase at a more moderate rate in later years in accordance with the figures above. A $525 million revenue projection over 5 years was baselined.

It is unlikely that 5-meter satellite data can be sold at a significantly higher price than that charged for Landsat or SPOT imagery. Previous market research[5] indicates the end users who purchase remote images have not shown a preference to purchase higher resolution images for a premium price. Therefore, commercial companies must provide comparably priced and just as reliable products as those available through EOSAT, or SPOT Image. The researchers decided that the higher resolution images would encourage users to consume the new operators data and that this would compensate for the lower pricing, therefore not seriously limiting the commercial operators revenue streams.

The data were used in an investment business model constructed to assess the viability of a satellite operator's investment and their ability to recover the investment over a reasonable timeframe.

A top-level parametric financial analysis was performed to assess the viability of commercial remote-sensing as a business. A rate of return of 20% was established as a floor for the investment. The baseline assumptions are listed in figure 3.3.2.4-3.

TY$Ms (4% infl)	1994	95	96	97	98	99	2000	01	02
Revenues			5.6	23.4	60.8	126.5	197.4	273.7	284.7
FA investment	11.4	37.0	42.2	24.9	0.0	9.8	14.5	23.6	37.7
Cost of goods sold	9.4	7.6	26.2	29.2	6.1	12.7	19.7	6.8	14.2
After-tax earnings	-16.2	-20.0	-51.9	-60.3	12.4	48.7	90.7	148.7	150.4

Figure 3.3.2.4-3. Commercial Remote-Sensing, ROI Assumptions

The above numbers assume that a spare satellite was built and used as a replacement satellite when one from the original constellation failed. Value-added expenses were assumed and the advertising/marketing expenditures included in the operating expenses (not shown) were at a $5 million per year level because of the relatively narrow target market. The full tax implications were used,

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[5] Mapsat Market Review, 1991, KPMG Peat Marwick.

assuming there was no other portion of the business that could benefit from the tax benefits associated with the initial losses. For simplicity, tax benefits were not carried forward.

The model treated the business as an ongoing entity, with replacement satellites produced and deployed at the end of life for the first-generation constellation. For terminal value, a book value of the assets at the end of 2008 (the assumed end of the program for the profitability calculations) plus the incremental net working capital was assumed.

The result of the analysis concluded that a company could successfully invest in a commercial space remote-sensing business and expect to recover its investment over a 5-year period using a 20% return rate. The data for this conclusion are illustrated in figure 3.3.2.4-4 below.

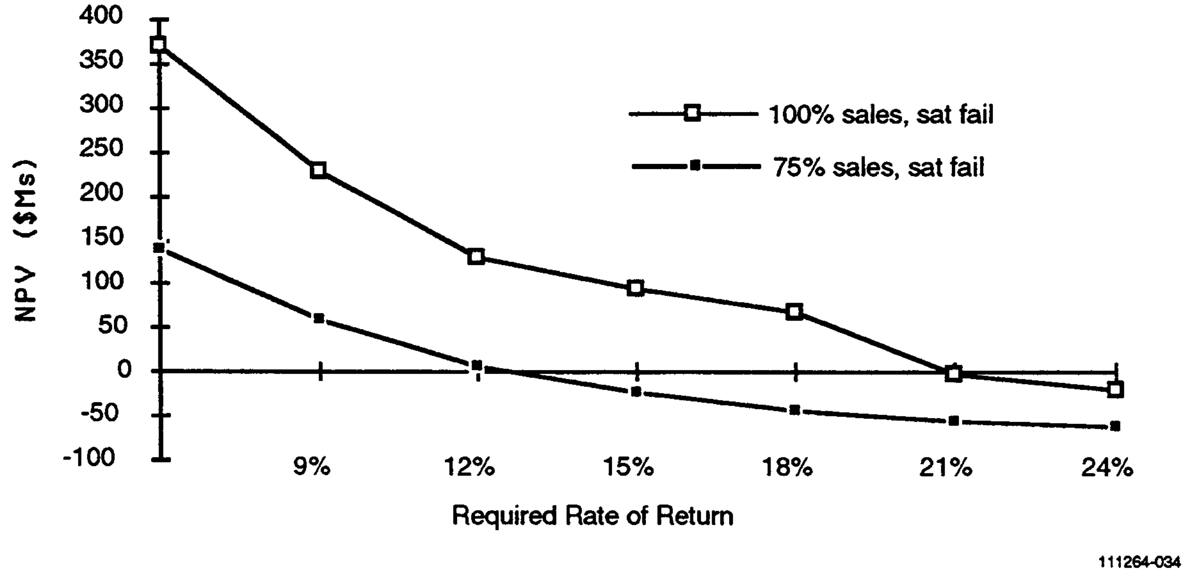

Figure 3.3.2.4-4 Parametric Analysis of 5-Year Investment

3.3.2.5 Satellite and Launch Vehicle Investments

The CSTS alliance market study was primarily interested in determining the launch systems needed to deploy remote-sensing satellites. The worldwide market[6] for the equipment (i.e., remote-sensing satellites) combined with their launch systems approached $1.8 billion for 1992, as detailed in figure 3.3.2.5-1 below. The 1993 market is estimated to be worth more than $1.8 billion.

	1991	92	93	94	95	96	97	98
Payload	1,635	1,160	1,387	1,070	1,485	1,105	1,015	1,431
Launch vehicle	410	598	455	354	407	312	549	501
Total ($M)	**2,045**	**1,758**	**1,842**	**1,424**	**1,892**	**1,417**	**1,564**	**1,932**

Sources: Space Directory, 1992-93; Civil Needs database, NASA, January 1993, and space industry periodicals.

Figure 3.3.2.5-1. Market for Remote-Sensing Satellites and Launch Systems

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[6] Remote-sensor satellites and delivery systems (i.e., space launch systems) are considered investments and not included as part of the remote-sensing market revenue.

Remote-sensing satellites will continue to be deployed at a rate of between 6 to 10 per year worldwide during the 1994 to 2000 timeframe. U.S. government and international users account for all remote-sensing satellite deployments in 1994. However, U.S. companies will begin deploying commercial satellites in 1995 and will reach six in 1999 before leveling off at three per year in 2000, as illustrated in figure 3.3.2.5-2 below.

Year of Deployment	**1991**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**00**
U.S. Government	3	3	2	3	3	1	1	4	1	4
International	6	3	8	4	3	2	5	4	3	3
Commercial	0	0	0	0	1	3	3	5	6	4
Total	**9**	**6**	**10**	**7**	**7**	**6**	**9**	**13**	**10**	**11**

Source: CSTS remote-sensing satellite database, appendixes D.2 and D.3.

Figure 3.3.2.5-2. Government, International, and Commercial Launches

Commercial satellite deployment will be more than two-thirds of the total in 1999 before dropping below half by the year 2000. In the longer term, commercial satellites will account for a larger share of deployments in the 2001 to 2010 timeframe, rising from four to six per year by the end of the decade.

3.3.2.6 Market Infrastructure

In 1985, the U.S. government made a 10-year agreement with the Earth Observation Satellite (EOSAT) Company to provide satellite images to nongovernment end users. The approach allows commercial users to purchase data directly or buy licenses to receive satellite data through their own ground stations, as illustrated in figure 3.3.2.6-1 below. VARs also purchase the satellite data, enhance the imagery, and resell it to the end users at a premium.

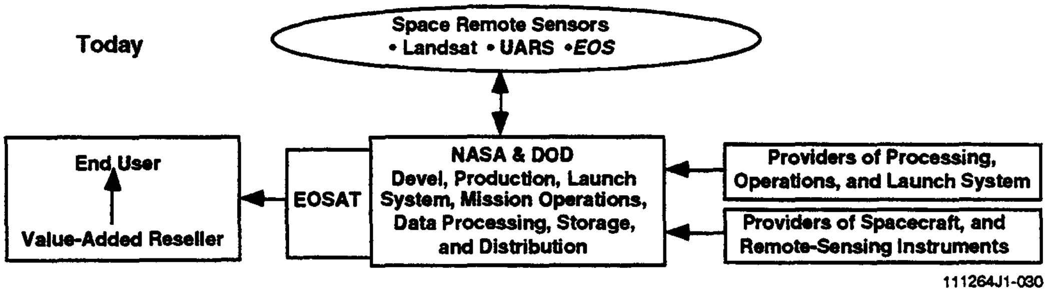

Figure 3.3.2.6-1. Remote-Sensor Satellite Industry Infrastructure, Today

The approach has been successful to the extent that EOSAT is able to operate profitably as long as it does not have to develop and produce its own remote-sensing satellites. SPOT Image has a similar situation with the CNES of the French government.

The high-growth commercial uses will change the infrastructure of the market. Commercial users are demanding better products and services, such as improvements in image resolution and shorter revisit times. Government-administered satellite programs have two difficulties in responding to commercial demand. First, they have difficulty justifying taxpayer development funds for commercial requirements.

Second, government administered programs cannot respond fast enough to the changing dynamics of the commercial market.

The remote-sensing satellite industry infrastructure must change to accommodate the high growth in the market. To capitalize on the market opportunities the commercial operators will build and operate their own satellites.

The remote-sensing market infrastructure will adjust over the next several years to incorporate the commercial operators. A notional approach to the change is illustrated in figure 3.3.2.6-2.

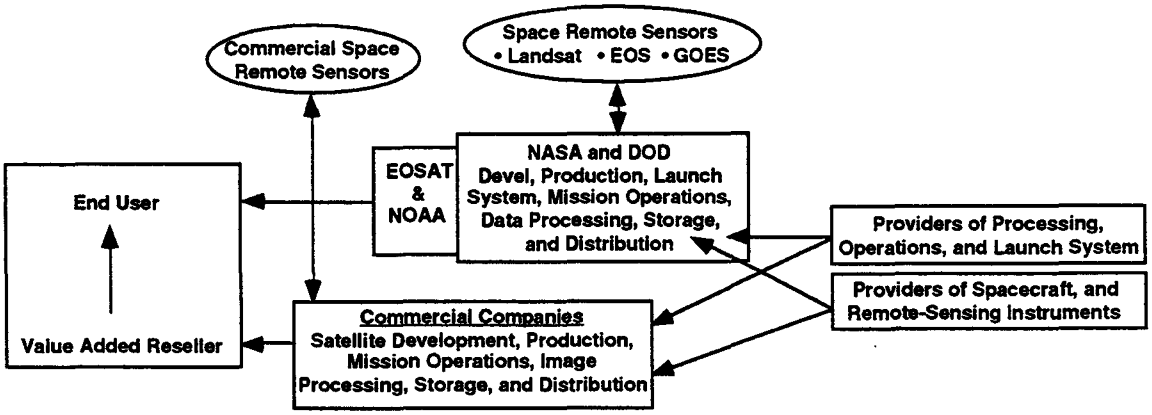

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Figure 3.3.2.6-2. Remote-Sensor Satellite Industry Infrastructure, Emerging.

During the next phase of the CSTS program, the launch system providers must begin working with the commercial satellite operators to develop the detailed satellite and operational requirements. The CSTS researchers concluded that a low-cost launch system for commercial remote-sensing satellites will be essential to ensuring the success of commercialization of the market.

3.3.3 Launch System Attributes

3.3.3.1 Launch System Characteristics

In general, the remote-sensing satellite operator wants the launch system provider to be responsible for all requirements related to delivering the satellite to its proper orbit, on time. Program leadtime of up to 2 years from selection of the launch system to the actual deployment has been acceptable in the past, however, being able to replace a failed operational satellite within days is also desirable. Competitive forces in the market may force operators to require shorter leadtimes, to as little as 6 to 3 months. High reliability of the launch system is important in order to reduce the insurance costs associated with deploying the satellite to its intended orbit.

Commercial satellite mass is 200 to 1,000 kg. Low Earth polar orbits of 400 to 900 km are required. Payload volume of between 2 to 4 meter^3 will accommodate the first generation of commercial space sensors.

Positioning a satellite to a specific point in space is important and requires a narrow time window for the launch. Operators want to pass over the same geographic point periodically at the same local time, that is, sun-synchronous orbits. This is a more demanding requirement for polar orbiting satellites and will require reliable launch operation timelines, highly accurate guidance and staging, and precision range-tracking instrumentation.

Some of the companies planning to commercialize space remote-sensing do not have the broad range of technical personnel, expertise, and equipment necessary to certify the integrity and operational readiness of their satellites before deployment. Furthermore, mission planning, especially for launch ballistics and orbit insertion, will require considerable expertise. The launch system company must provide the technical support and make available integration and test facilities to the satellites' operators.

In the short-term, launch system costs for the satellite operators are in the $12 million to $14 million per flight range. This will limit the buildup in commercial deployments from one in 1995 to an average of three per year by the end of this decade.

Small reductions in the prevailing price of a launch system do not appear to alter a company's business decision to deploy more satellites. The researchers found that companies began to increase the number of launches when the price was lowered by 50% as illustrated in figure 3.3.3.1-1.

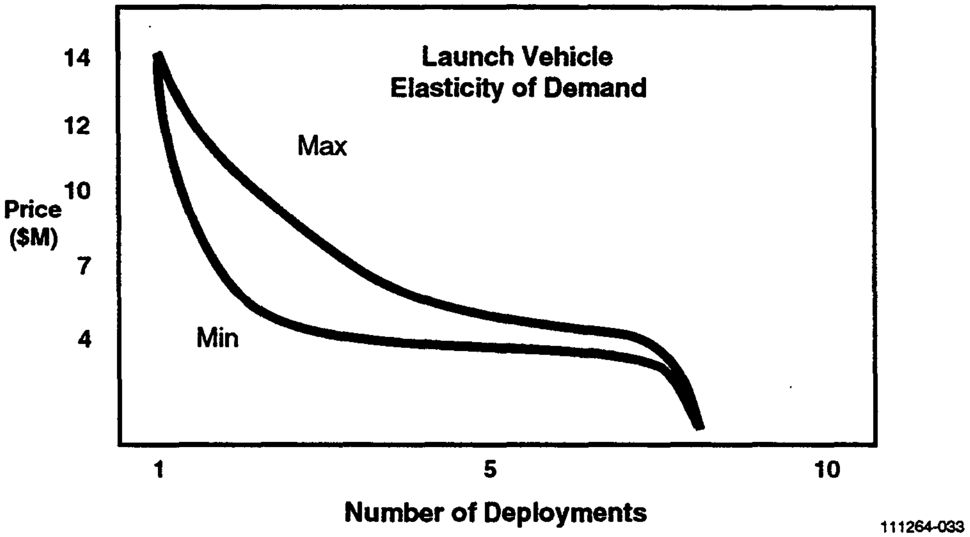

Figure 3.3.3.1-1. Remote-Sensing Launch System Elasticity

The satellite operators will maximize their deployments of satellites in the longer term if the launch price can be reduced. As illustrated in figure 3.3.3.1-1, the number of satellites increases much faster at the $4 million per flight level than at the $7 million; however, further price reductions did not urge operators to think about deploying more satellites. At this point, reductions in their internal costs for ground infrastructure (e.g., ground stations, imaging equipment, GIS hardware and software, and end user workstations) would have to be realized before more reductions in launch prices would wring out more demand.

Assuming that a CSTS launch system is available at a more attractive price in the early part of the next decade and that it can be used for noncommercial flights also, the number of deployments are forecast to increase sharply. By 2005, the number of satellites deployed on a CSTS launch system could reach 12 per year and climb to 18 or more per year by 2010.

3.3.3.2 Launch System Preliminary Capabilities

Commercial satellites can be lofted to orbit by small launch vehicles. The operators are evaluating air launched and ground-launched solid rocket and liquid fueled vehicles that are capable of throw weights of up to two metric tons to LEO.

Developers are designing satellites to the launch loads and environmental requirements of the air-launched, multistage Pegasus or ground-launched multistage vehicles based on solid rocket motors. Typically longitudinal stress of under 8 g's is suitable.

A standard interface between the payload (satellite bus and sensor instruments) and the launch vehicle is needed to provide commonality among the several types of launch vehicles. The separation interface between the boosters and payloads uses Marmon clamps.

Orbital injection requirements will require high-precision trajectories with final trim capabilities. Trade studies will probably be performed after launch vehicle selection to determine if the satellite bus or the upper stage of the launch vehicle will be used for the final orbit adjustments.

Launch reliability will be extremely important to commercial satellite operators. Insurance costs can amount to 7% to 15% of the launch price. Therefore, a CSTS launch system must provide a 99% ascent reliability, or probability of mission success. Achieving this requirement may require significant redundancy in the launch vehicle subsystems and equipments to ensure fail-safe operations.

The redundancy requirements for all flight vehicle subsystems, except primary structure and pressure vessels, should be established on an individual subsystem basis. Designs should emphasize fail-safe modes, which allow the vehicle to sustain a failure and successfully complete its mission.

3.3.3.3 Unique Ground Handling Requirements

Some satellite operators are small companies and will not have the facilities and equipment to verify the integrity of the payload prior to deployment. The space launch system should therefore include provisions to provide ground test facilities to assist the small company in space-qualifying their payloads.

Dynamic tests must be considered on commercial operators' satellites to ensure that mechanical interfaces between payloads (sensor instruments and spacecraft) and launch vehicles function properly.

3.3.3.4 User/Space Transportation System Interfaces

The launch system must incorporate standard interfaces across the payload to launch vehicle interfaces. The potential customers could not provide the researchers detailed information about the payload to booster interfaces. This type of data should be collected during the next phase of the CSTS program, however, some examples of interface requirements include mechanical payload attach fittings to the launch vehicle. Vehicle-payload electrical interfaces must also be standardized to ensure that test, checkout, and sustaining power to the payload are provided during integration and prelaunch operations.

3.3.3.5 Launch System Refinements

The CSTS researchers concluded from field research that a new-generation commercial launch system that is available in 10 years must incorporate these requirements:

a. Lower launch costs.
b. Improvements in launch system reliability.
c. Responsiveness and performance.

In the short term, however, existing launch systems must accommodate the commercial satellite operators' needs for lower costs. Single-satellite launch vehicles are estimated at $14 million per flight by the commercial operators. To respond to their concern for lower cost launches, the operators should consider manifesting more than one satellite on a single flight. This could be a feasible approach to lowering launch system costs.

The mass and volume of commercial remote-sensing satellites is relatively low as compared to those produced for government remote-imaging missions. These low-volume features allow accommodation of multiple satellites on a single launch. A typical commercial satellite mass is estimated at under 400 kg. Up to four payloads could be launched on one of several launch vehicles that are available today. For example, a Titan II could launch three to four satellites at once, with performance margin. To the first order approximation, each satellite could be placed in orbit for under $10 million each.

Since some of the satellite owners will be small companies with limited technical staff, equipment, and facilities, the launch system providers must provide support in a range of areas:

a. Space flight operations, including mission planning, spacecraft tracking, orbit planning and altitude determination, data acquisition and uplink services, and special orbital requirements such as time of month, of day, and phase of the moon to determine the constraints on the launch time.
b. Spacecraft and launch vehicle integration, including design of the spacecraft with the physical constraints.
c. Integration of instruments with spacecraft, including thermal, electrical, communications, data recording and downlink, and command and control.
d. Development of ground test program, including thermal vacuum, EMI, and vibration testing to ensure the integrity of the payload design and its implementation.

3.3.4 Confirmation of Market Opportunity

An interim version of this report was circulated to the prospective satellite operators, the companies that would use a potential new launch system to deploy remote-sensing satellites, and other organizations involved with the remote-sensing market. Their comments have been included in the report.

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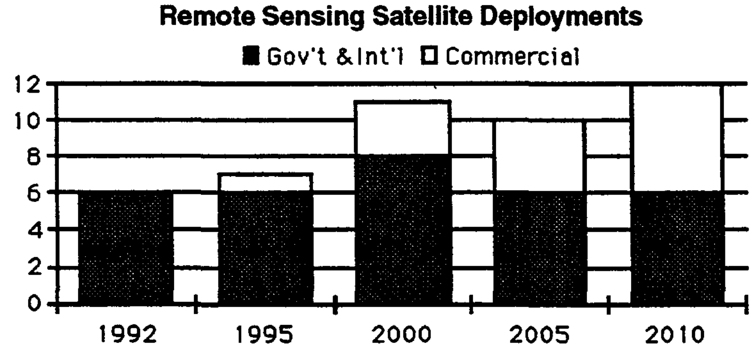
3.3.5 Conclusions and Recommendations

The private sector is planning to produce its own space imagery and sell the data to commercial users. Initial remote-sensing satellite deployments are scheduled to begin in 1995. The number of new satellites required through the late 1990s to accommodate commercial demand will be modest. Several companies are planning to operate small constellations of two, three, and even seven satellites. By the end of this decade, commercial operators will account for an average of 3 of the 11 estimated annual satellite deployments illustrated in figure 3.3.5-1.



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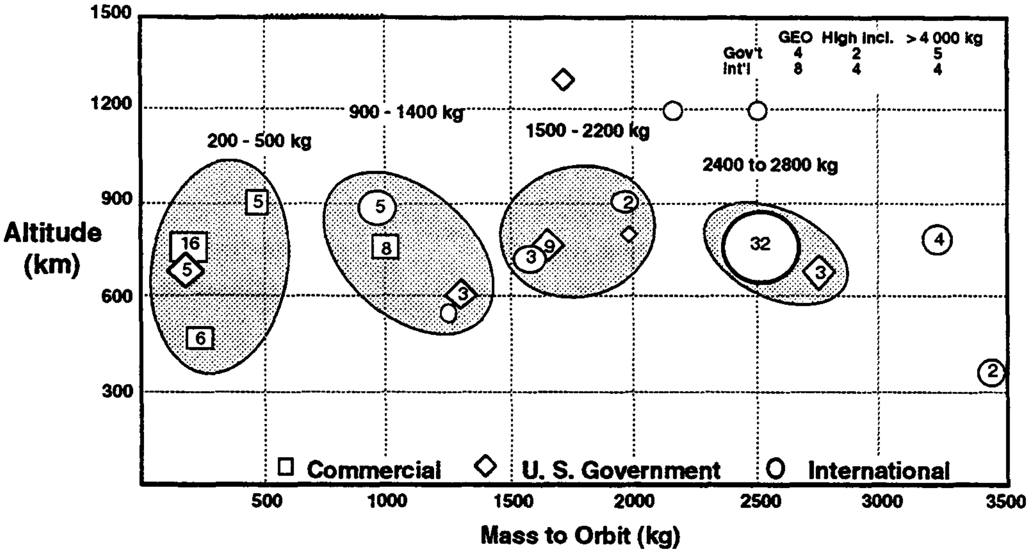
Source: CSTS remote-sensing database, appendixes D.2 and D.3.

Figure 3.3.5-1. Combined Deployment of Government, International, and Commercial Remote-Sensing Satellites

In the longer term, the explosive growth in the space remote-sensing market will require continued launches of commercial satellite deployments for replenishment and real growth. Four commercial satellites will be launched in 2005, and up to six per year by 2010.

Commercial satellites weights are in the 200 to 1000 kg range and are deployed to circular, low Earth polar orbits, in the 400 to 900 km range, as illustrated in figure 3.3.5-2.



Note: Not included in the figure are small quantity of satellites in two groups -- LEO satellites in the > 3500 kg, medium Earth orbit and geostationary satellites. The former are multipurpose Earth observation platforms, and the latter are weather satellites and remote sensors combined with communications satellites.

Source: CSTS Remote-Sensing Satellite database, appendixes D.2 and D.3.

111264-032

Figure 3.3.5-2. LEO Deployment Ranges of Commercial Satellites

In the short term, small launchers with the capability to place payloads up to one metric ton to LEO have been selected by commercial satellites companies for their initial launches in the 1995 to 2000 period. Using today's launch price of $14 million per launch for small launchers, the companies will require three to four launches annually.

The CSTS researchers' assessment of the remote-sensing market concluded that a relatively small number of satellites will be able to meet the end users demand for space imagery during the 1995 to 2000 period. From the launch provider's perspective, this means three to four launches per year, which is not high enough to warrant the development of a new CSTS transportation system.

Demand must be substantially higher in order to make the major investment needed to create and operate a new transportation system. The satellite companies would not significantly increase the number of satellites deployed until the price were cut by as much 50% as illustrated in figure 3.3.5-3.

Without cost savings in other parts of the commercial companies operations, a two-thirds reduction in today's launch system prices seems to be the threshold for substantially increasing the number of satellites deployed. Also, further price reductions, such as to 10% of prevailing prices, would not stimulate further launch demand, because the operating and investment costs of the satellite operator's ground infrastructure must also decrease proportionally.

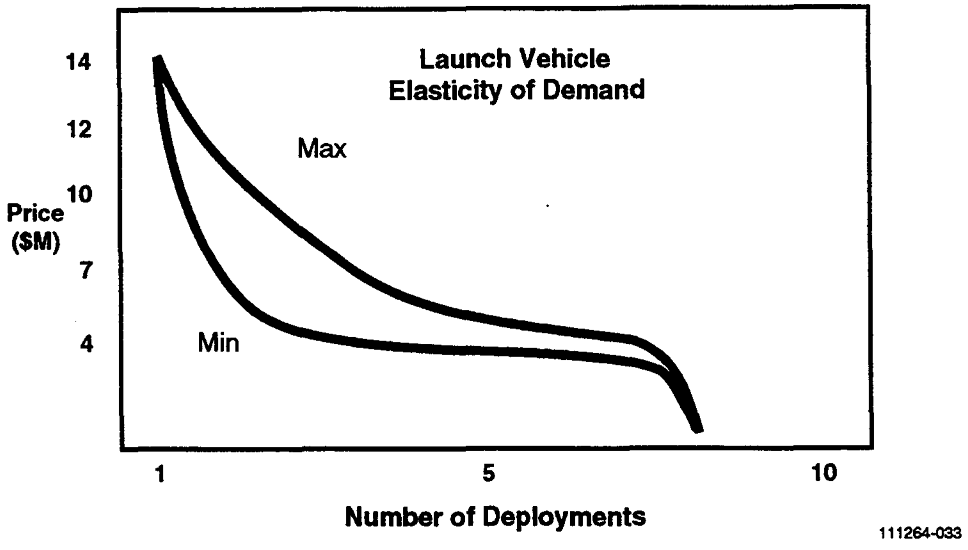


Figure 3.3.5-3. Launch Vehicle Elasticity of Demand

To achieve a 50% or more reduction in launch costs for the mid-1990s may require interim solutions, such as multiple manifesting of satellites on existing launch vehicles. Either multiple remote-sensing satellites or other types of payloads with similar deployment requirements, that is orbit altitude and inclination, may be able to be combined. Space research, LEO mobile communication, and microgravity processing are examples of complementary commercial applications that can be combined with remote-sensing.

The initial surge to populate small constellations will sustain three deployments of new remote-sensing satellites per year, building to four or five through the end of this decade. Most demand in the commercial sector by the year 2000 will be for replenishment satellites, accompanied by an increase in demand for expansion satellites. Substantial growth to 6 to 10 satellite deployments per year can be expected by the year 2005. After commercial satellite operators establish their positions in the user markets and satellite hardware costs come down, there will explosive growth in the use of space imagery, which should push commercial deployments to more than one launch per month by 2010.

3.4 GOVERNMENT MISSIONS

3.4.1 Introduction

The government missions market area consists of missions that are predominantly funded by the Federal government budgets. These include existing government missions (primarily DOD, space science, space station, space testbed, asteroid detection, emerging nations, law enforcement, and treaty verification. Most of these missions do not have a commercial customer (the most notable exception is space testbed), although space launch services may be acquired commercially.

3.4.2 Existing Government Missions

3.4.2.1 Introduction

The government missions market area was established to account for currently planned civil (NASA) and DOD missions. These payloads are not commercial revenue-generating; however, it is important to account for them because of the potential anchor tenancy arrangements that may contribute to the viability of a commercial space transportation system. These missions will be used in conjunction with commercial markets where payload form factors and attributes are compatible.

3.4.2.2 Study Approach

A significant amount of information is available for this group of missions. Since many projects have been conducted to study future system requirements, data are readily accessible for both NASA and DoD missions. Typically, future requirements are tabulated databases for near-term activities (present to about 2000) as well as far-term projection (beyond 2000 to 2010 or 2020). The DOD missions used here are an updated version of the NLS mission model. The civil missions are a combination of the mixed fleet manifest (present to 1998), midterm (1998 to 2010) captured in the Civil Needs Data Base (CNDB), and placeholders for 2010 through 2020 (also in the CNDB).

The combined total mission model includes all U.S. government missions. For CSTS a preliminary screening was performed to remove missions that were accounted for in other CSTS market areas. CSTS has defined the global space launch market in terms of market areas; those U.S. government missions falling into market areas other than "Government Missions" were transferred to the appropriate categories (discussed later in this paper). For example, deployment and resupply of space station missions were deleted from this market area since they have been assigned their own market area.

Many DOD missions remained intact under the government missions market area because most DOD requirements are unique and divorced from commercial and civil space. There is some recent (late 1993) evidence that the military space role may be changing, allowing both commercial and civil applications to benefit from DOD assets and technologies. This change in DOD philosophy may be incorporated in specific market assessments (e.g., remote sensing), however, our assessment of government missions is based upon the assumption that DOD requires separate assets and capabilities from the civil and commercial needs. We expect DOD to maintain a steady and sizable space presence.

After developing a representative market area of government missions, we performed several processing steps before actually quantifying the final market. As missions are destined for different places in orbit, we normalized all projected traffic mass to equivalent low Earth orbit (LEO) for consistency. Although this method is quick and simple, it has its own drawbacks, as will be discussed later in this paper. Normalizing the payload mass involved assuming a certain delivery/upper stage beyond the booster for delivery of the payloads to their operational destinations. When examining results, it is important to remember that the normalized mass also contains delivery stages, not just payloads.

3.4.2.3 Market Description

The resultant average *annual* LEO equivalent mass to orbit of the above-mentioned mission model is 240,000 lb. Figure 3.4.2.3-1 shows the flight rate, mass, and velocity requirements for the NASA portion of this mission model. Figure 3.4.2.3-2 shows the flight rate, mass and velocity requirements for the DOD portion of this mission model

Note: The names, destination, launch site, and launch vehicle have been withheld; however, the data are still useful to mission capture analyses and launch vehicle requirements definition.

	NASA MISSIONS 8/5/93 MODEL						NASA																						
Code	Name	LV Class	Lnch Site	Destination	Lnch Δ Vel	Mass	P/L #	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total
	NOAA	MC	W	LEO SYN	26702	2255	1	1			1			1			1												4
o	MESUR	MC	E	DS MAR SUR	34768	1316	2		2		2																		4
o	MDEX	MC	E	LEO OTH	26700	3000	3	1	1	1	1	1	1	1	1	1	1	1											11
o	PROBE (M)	MC	E	EAR OTH	26700	7000	4		1		1		1		1		1												5
	ALT	MC	E	LEO OTH	26700	6000	5			1					1														2
o	OSL	MC	W	LEO SYN	26104	3813	6			1																			1
	AIM	MC	E		26700	9000	7					1																	1
p	GENERIC DS-1	MC	E	DS Planetary	34768	1600	8														1				1			1	3
p	GENERIC EO-1	MC	E	EAR OTH	36259	2400	9												1		1		1		1		1		5
p	GENERIC LUN-1	MC	E	LUNAR	34768	2700	10															1					1		2
p	GENERIC LEO SYN	MC	W	LEO SYN	26700	3000	11												1	1	1	1	1	1	1	1	1	1	10
p	GENERIC LEO OTH-	MC	E	LEO OTH	24800	7500	12												1	1	1	1	1	1	1	1	1	1	10
	GOES	IC	E	GEO	38267	2160	13					1	1																2
o	ARTEMIS	IC	E	LUN SUR	34768	4000	14			1	1	1	1	1	1	1	1	1											9
o	EOS-AM	IC	W	LEO POL	26452	12000	15				1					1													2
	TDRS II	IC	E	GEO	38267	4905	16	1	1	1	1	1	1		1		1												8
o	EOS-PM	IC	W	LEO POL	26452	12300	17	1					1					1											3
	CHEM	IC	W	LEO POL	26452	12000	18			1					1														2
o	NAE	IC	E	LEO OTH	26472	2645	19					1																	1
o	MSR	IC	E	DS MAR SUR	34768	10221	20						2																2
p	GENERIC DS-2	IC	E	DS Planetary	34768	10000	21												1					1					2
p	GENERIC EO-2	IC	W	EAR OTH	36250	8300	22															1							1
p	GENERIC GEO	IC	E	GEO	38267	5000	23												1	1	1		1	1	1	1	1	1	9
p	GENERIC LEO POL	IC	W	LEO POL	26452	12300	24													1		1		1		1		1	5
p	GENERIC LUN-2	IC	E	LUNAR	34768	4000	25												1	1	1	1	1	1	1	1	1	1	10
	CNM	LC	E	DS C/A	34768	9934	26			1																			1
o	GEOPLAT	LC	E	GEO	38267	12700	27						1																1
	LTT	LC	E	LUN SUR	34768	2204	28						1																1
p	SOLAR PROBE	LC	E	DS SOL	34768	2205	29											1											1
p	GENERIC DS-3	LC	E	DS Planetary	34768	10000	30													1			1			1			3
a	MDO	LC	E	Mercury	34768	11025	31								1														1
	NOTES:	a: Added to NLS, Listed in NSIA and NASA				TOTALS		4	5	7	8	6	10	3	7	3	5	4	6	6	6	6	6	6	6	6	6	6	122
		o: P/L mass differ, NLS used as most recent					E	2	5	5	6	6	9	2	6	2	4	3	5	4	5	3	5	4	5	4	5	4	94
		p: Not listed in NSIA Mission Model					W	2		2	2		1	1	1	1	1	1	1	2	1	3	1	2	1	2	1	2	28

111264-037

Figure 3.4.2.3-1. NASA Mission Requirements (Excluding Space Station Missions)

	DOD MISSIONS 7/30/93 MODEL						DOD																						
Code	Name	LV Class	Lnch Site	Destination	Lnch Δ Vel	Mass	P/L #	0	1	2	3	4	5	6	7	8	9	1011		1213		1415		1617		1819		20	
	DOD 1HLV		E		36760	8500	6			1	1	1	1			1	1	1	1	1			1	1	1	1	1		14
	DOD 2	MLV	W		26462	2700	10w	1		1	1		1																4
	DOD 3	MLV	W		26462	2000	11w							1	1			1	1			1	1			1	1		8
	DOD 4HLV		E		38000	10500	12			1																			1
	DOD 5HLV		E		38000	10500	13					1	1	1	1		1	1	1	1		1	1	1	1		1	1	14
	DOD 6	MLV	E		24566	9000	16		1			1			1			1			1			1			1		7
	DOD 7HLV		E		36711	11500	22	1		1		1	1	1		1		1	1	1		1		1	1	1		1	14
p	DOD 8	ILV	W		26721	14000	24w		1		1		1		1		1		1		1		1		1		1		10
p	DOD 9	ILV	W		26721	14000	26w	1	1		1	1	1		1	1	1		1	1	1		1	1	1		1	1	16
	DOD 10	HLV	W		25846	31000	27w			1																			1
	DOD 11	HLV	W		25846	38000	28w			1	1		2	1		2	1		2	1		2	1		2	1		2	19
	DOD 12	MLV	W		26469	5500	30w	3	3	3	3	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	30
	DOD 13	MLV	E		32435	2922	42								2	2	2	3	1										10
	DOD 14	SLV	W			1000	SLVw	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	55
	NOTES:	a: Added to NLS, Listed in NSIA				TOTALS		9	9	2	11	10	128	11		11	11	12	139		7	9	109	18	109	203			
		p: Not listed in NSIA Mission Model					E	1	1	3	1	4	3	2	4	4	4	7	4	3	1	2	2	4	3	2	3	2	60
							W	8	8	9	106		9	6	7	7	7	5	9	6	6	7	8	5	8	6	7	7	143

111264-038

Figure 3.4.2.3-2. DOD Mission Requirements for the Period Between 2000 and 2020

To provide a common basis for comparison, and to accumulate missions requirements across all market areas, the mission model was converted to low Earth orbit/low inclination (28.5 deg) equivalent masses. The result is a 21-year (2000-20) annual average of 240,000 lb LEO equivalent mass. This result is clearly dependent on the launch vehicle type assumed, especially for missions requiring upper stages. This assessment used equivalence ratios from the National Launch System study, which are typical of two-stage launch vehicles.

CSTS's division of the entire space launch market into separate areas (53 initially) created overlap of some market areas. This is particularly true for NASA missions, most of which are covered by other markets areas (i.e., Increased Space Station, Space Science Outwards, Human Planetary Exploration, Space Manufacturing, and Remote Sensing). The only NASA mission in this area that has not been covered elsewhere is the communication system deployment (i.e., TDRS and TDRS follow-on). This assumes that NASA will continue to deploy its own comsats and will not be solely tied into an existing commercial system/network.

Conversely, few of the DOD missions are covered by other market areas. Those covered in other market areas include GPS, GPS follow-on, and Landsat missions. Defense Meteorological Satellite Program (DMSP) was thought to be different enough from its civil counterpart, NOAA (National Oceanic and Atmospheric Administration) satellites, to keep them separate. All of the other missions are unique to this market area, with the assumption that DOD continues to provide its own weather, surveillance, reconnaissance, communication, and space test assets.

The result (after elimination of the redundant missions) was the time-phased, LEO equivalent mass requirements seen in figure 3.4.2.3-3. An 11-year average for the period 2000-10 (which seems reasonable to use, since beyond 2010 is predominately placeholders) results in delivery requirements of 167,000 lb (LEO equivalent mass). The 21-year average for the period 2000-10 results in a yearly traffic mass of 176,000 lb, which is a 5% difference from the 11-year value.

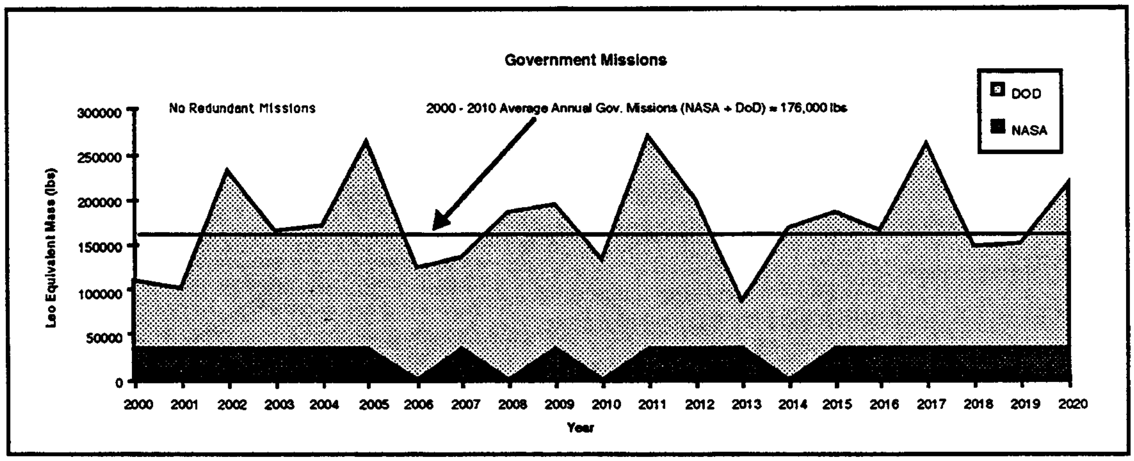


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Figure 3.4.2.3-3. Summary of the Government Missions (NASA and DOD) LEO Equivalent Masses

3.4.2.3.1 Market Evaluation

We focused on identification of top-level trends and driver missions, instead of using a bottom-up approach of examining each mission and then seeing how it impacted the whole market. In light of this, most government missions trends are driven by DOD requirements. NASA's TDRS will not have much effect on the total government outlook, although TDRS will always enjoy high priority (in terms of both satellite and launch service acquisition). Therefore, the following discussions concentrate mainly on the DOD requirements.

There are difficulties in discussing DOD missions, primarily due to their sensitive (and often classified) nature, which ultimately resulted in a lack of available information. Thus, for this analysis we cite general observations based on our previous experience with DOD missions, together with more current development gathered from public sources.

TDRS is expected to continue to operate at geostationary orbit (GSO) locations. Likewise, the DOD's missions are expected to continue at a full range of inclination orbits and altitudes. Figure 3.4.2.3-4 indicates that government annual launch rates will be in the range of eight per year from the East Coast and four from West Coast.

One major event that could change these launch trends is the size and capability of satellites in the future. Many factors can drive a change in satellite size, mass, and constellation. They include improved technology, reduced needs, reduced budget, higher demand for integrated satellite assets, and national policy. It is not necessarily true that satellite size will reduce over time. There are reasons they may reduce in size, and equally probable reasons they would increase in size. Reduction in satellite size could occur due to a reassessment of satellite needs, limited budgets, and/or introduction of microtechnologies to allow producing smaller satellites for flight on less costly launch systems. Growth in satellite size could occur due to combining capabilities from multiple satellites into a single system (this could also be triggered by reduced budgets). Also, growth could occur if a low-cost, heavy-lift launch system were available. This concept is known as "trading weight for dollars," where satellite costs go down because of reductions in tolerances and less costly manufacturing processes. Only continuous tracking of the market can tell the real trends.

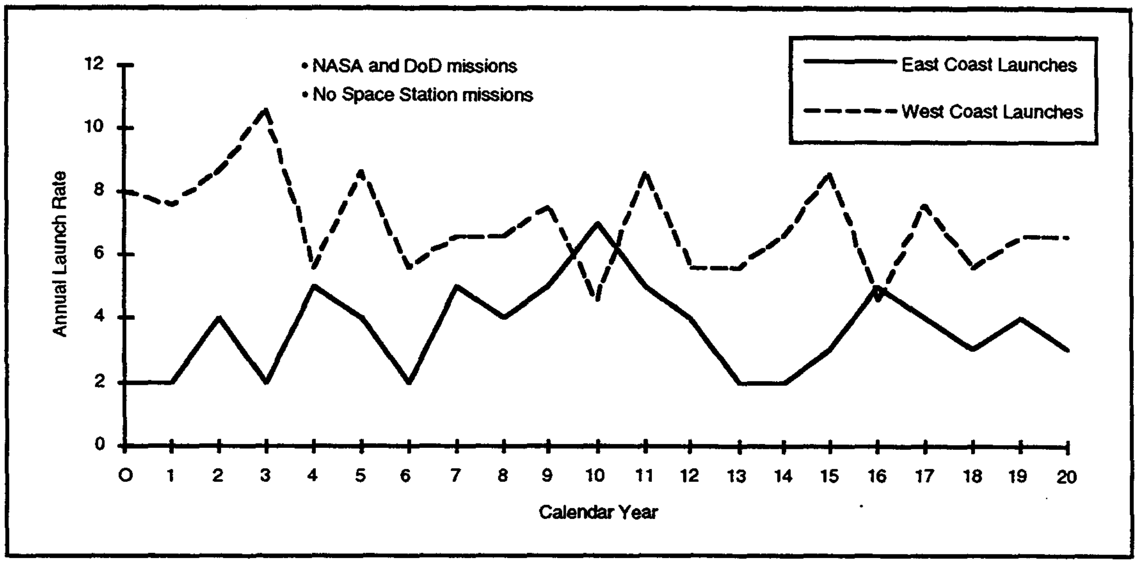

Figure 3.4.2.3-4. Projected Government Missions From 2000 to 2020

3.4.2.3.2 Space Application Description

It is expected that NASA and DOD will continue their given charters in space activities, with minor modifications due to shifts in policy or world situation. For the TDRS system, NASA will maintain and upgrade the constellation. TDRS serves two major roles: providing data relay services for the space shuttle missions and supporting a number of DOD requirements. TDRS receives significant support from Congress, NASA, DOD, and the users. It is also expected that TDRS use will increase as space missions around the world evolve.

Similar justification applies to DOD missions. Currently the DOD space missions encompass six main objectives: communications, early warning, global positioning, weather forecasting, intelligence-gathering, and testing. These are in existence with a single goal of providing support for the fighting forces. Because of this, it is projected that all DOD missions must continue in one form or another. It may be possible to consolidate some satellite functions in the future, but operationally the missions have conflicting requirements. Efforts are continuing to identify which satellite functions, if any, can be consolidated and in what form. The outcome may potentially include both larger (multipurpose) and smaller (more specialized) satellites. Continuous tracking of the market can help define these new requirements for government missions as they evolve.

3.4.2.3.3 Market Assessment

As discussed above, government missions are expected to continue in a business-as-usual mode in terms of mission goals and objectives. The projected sustained market size is as shown in figure 3.4.2.3-5 for the four main launch system weight classes. However, the market itself is transforming to cope with changes around the world and to take advantage of new technologies and meet fiscal realities. For near-term considerations, we see within the next 5 to 10 years changes in the industry in the following areas:

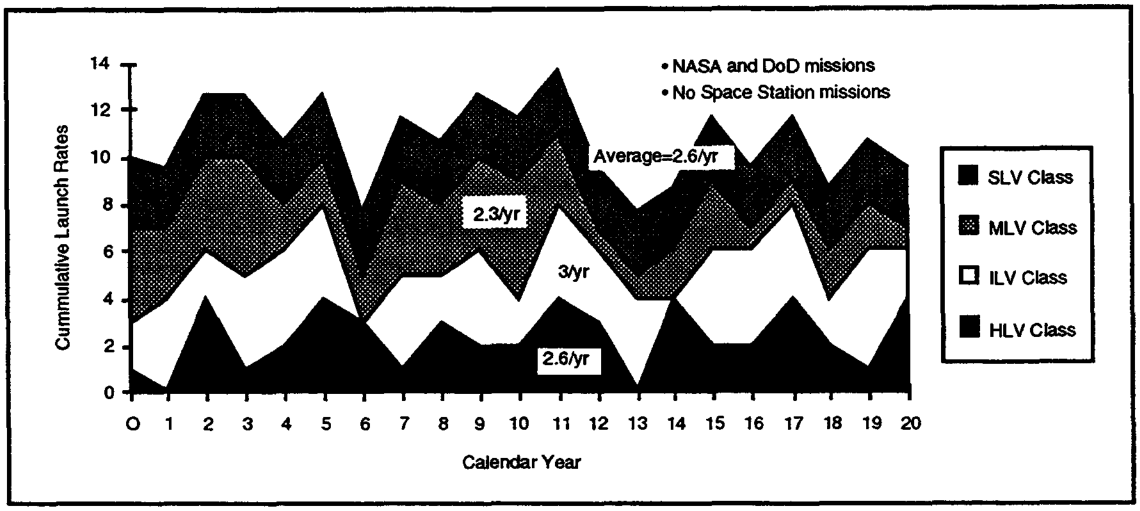

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Figure 3.4.2.3-5. Projected Market Size by Launch System Weight Class From 2000 to 2020

a. LEO small satellites may become the dominant concept of choice for the small users because of their low cost, quick availability, and affordable launch. New and existing space users can take advantage of small satellites when technology allows, but it is expected both NASA and DOD will maintain their fleet of large satellites for the major missions. For this reason, we see a continued need for launch services in the future, providing a consistent and justifiable basis for new launch systems or upgrades of existing launch systems.
b. On the other end of the technology spectrum are those technologies that will allow orders of magnitude improvement and/or addition of end user services. These may come with a price of more complex and larger satellite systems, but if returns can be proven, the users may be willing to pay for it and have a smaller constellation of satellites.
c. There currently are new and better satellite systems that can last longer due to better launch services, more efficient propulsion systems, and more accurate guidance and attitude control, among other things. The DOD has slipped some of its launch-on-demand satellites, possibly to take advantage of this trend. Launch schedules can be stretched out due to longer satellite life, resulting in an overall reduction in annual launch rate.

At this time we cannot predict which scenario (or combination of scenarios) will occur; thus we have not included any modifications to the mission model. Foremost with government missions is the ability to launch on schedule. This calls for a flexible support infrastructure (discussed in the next section). Within the government missions area itself, we see varying degrees of payload integration complexity, reducing our ability to satisfy the market with a single launch system. Rather, the existing launch availability format of small, medium, intermediate, and large classes of launch systems may continue to be practical. Finally, fixed budget projections over the next several years indicate a no-growth situation for this market area.

3.4.2.3.4 Infrastructure

The support infrastructure for government missions is in place. Ongoing modifications of this infrastructure have ensured its availability and operational status. The existing launch infrastructure can be considered satisfactory for the near-term needs.

Our observation indicates that the support infrastructure elements are being continuously improved for various programs, and this trend will continue for the foreseeable future.

3.4.2.4 Prospective Users

NASA and DOD differ in the way they establish mission requirements. In general, NASA's different code organizations originate mission requirements, which are screened through prioritization steps, then stored in the CNDB. The CNDB is continually scrutinized and continually updated. For DOD missions, specific users from the services generate their own requirements, which are then managed by the U.S. Space Command (USSPACECOM). USSPACECOM also has assistance from the Aerospace Corporation in compiling this classified mission model. These official sources were used to develop the market assessment.

3.4.2.5 CSTS Needs and Attributes

3.4.2.5.1 Transportation Systems Characteristics

Based on our analysis, future government missions requirements call for the following characteristics in new transportation systems:

a. The system is unmanned, at least within the definition of the CSTS government missions market area. All payloads identified in this section require only delivery to orbit without special human operations or human presence.

b. Launch capability exists to both low and high inclinations spanning LEO (90 to 100 NM) up to GSO (about 19,930 NM). As expected, both East and West Coast launch sites are required for these missions, with a launch rate of about eight per year from the East coast and four per year from the West Coast. A single site, or alternative locations are acceptable as long as performance and security requirements are met.

c. Government missions tend to require the following class of mass capability from the launch system:
   1. 8,000 to 10,000 lb to geostationary transfer orbit (GTO) and up to 12,500 lb to GSO,
   2. 18,000 to 20,000 lb and up to 40,000 lb to LEO due East,
   3. 14,000 to 16,000 lb and up to 32,000 lb to polar orbit.

d. The launch system must be able to launch on demand for national security payloads. The requirements come in terms of callup days, the number of days between callup authorization for the launch, and the actual launch date. The specific callup time varies with particular payloads, but for the GPS and DMSP the callups have been on the order of 30 to 45 days.

e. The launch system must be reliable but also affordable. Both of these parameters cannot be quantified presently, but future launch systems, old or new, must inherently provide better reliability than current systems at a lower cost. Considerations of reliability and affordability will be addressed as specific launch concepts are being designed.

f. Standardization of payload interfaces has progressed continuously, although slowly, as satellite users look for ways to reduce payload processing and integration costs.

3.4.2.5.2 Ground Segment

As discussed previously, the ground segment infrastructure currently exists for all current classes of launch vehicles. Upgrades to this ground facility network will satisfy many of future launch needs.

3.4.2.5.3 User/Transportation Interfaces

Other than the trend toward standardized payload interfaces, we anticipate little change in the interaction between users and the launch provider for this market area.

3.4.2.5.4 Improvements Over Current

Since the launch capabilities were found to be sufficient for the projected needs, improvements for the government missions fall mainly in the areas of cost reduction and improved reliability and operability.

3.4.2.5.5 Management and Policy

We find that both NASA and DOD have been improving and changing their organization and management policies that work in supporting this market area. Both have gone through major organizational, responsibility, and operational overhauls. Some resulted in immediate impacts, others resulted in slower changes. We expect that both agencies will share responsibilities of launch assets, drawing from the same stable of available launch systems. We project that NASA and DOD will continue to fund and manage spacecraft development and launch within their agencies, with other considerations secondary to the primary objective. How policies would change with the introduction of a new launch system is hard to predict, but it is unlikely to change policies significantly.

3.4.2.6 Business Opportunities

3.4.2.6.1 Cost Sensitivities

We found that government missions are not very sensitive to launch costs because the payload costs account for the major programs cost. On the other hand, for the same reason, they are very sensitive to launch system reliability, especially since government payloads are rarely insured.

3.4.2.6.2 Programmatics

It is expected that the launch schedule identified earlier will change over time. Since the mission functions must continue, the mission themselves will exist in one form or another. If a new system is brought on line, it will be phased in over a period of time much as was done for the space shuttle. Again there is no specific unclassified milestone that a new capability must be available.

3.4.2.7 Conclusion and Recommendations

Many of these missions reflect vehicle interface requirements for existing launch systems, and will fly long before a new launch system is available. A portion of this market could be available for capture by a new system if transition planning was in place early. The government programs identified in this section represent a current snapshot of planned government missions. As budgetary cycles pass, programs will enter and exit this manifest. Obviously, reduction in any, or all, of these areas would provide additional budget to potentially increase this or other market segments.

Because the government missions were created to be only a representative manifest of DOD and civil requirements, we will not be continually updated for minor program changes. If there is a substantive change it will be captured in our market area analysis.

3.4.3 Treaty Verification

3.4.3.1 Introduction

A treaty is defined as "a formal agreement between two or more states." In addition to this traditional definition of border disputes, we enlarged the market area to include agreements/commitments made by a government to its people and international oversight (e.g., human rights and pollution control). Treaty verification was partitioned into seven market segments, and then we assessed what satellite services were required for each of the market segments. It was determined that treaty verification required four fairly traditional types of services: communication, navigation, surveillance, and reconnaissance.

This market can be satisfied by space assets/constellations defined in the communications and remote-sensing market areas, and thus no independent requirements were defined in this market area. It is important to stress that in addition to the space assets, a significant ground infrastructure must be developed before a market for treaty verification emerges.

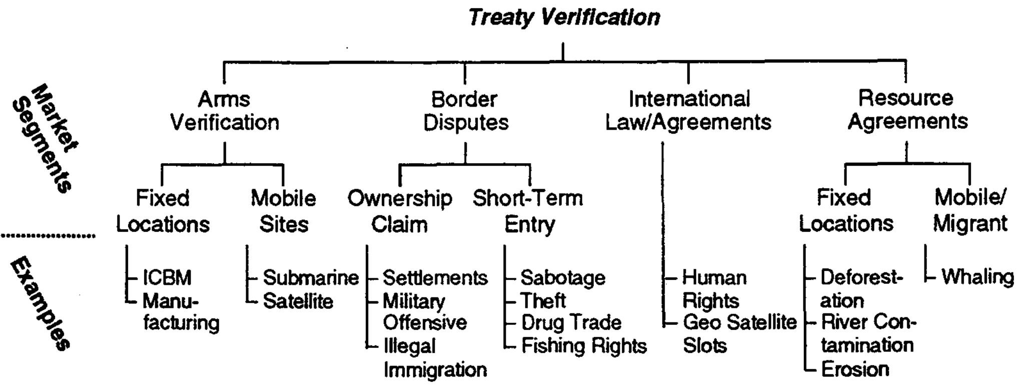
3.4.3.2 Study Approach

We defined the following eight step approach to defining the treaty verification market area:

a. Market Definition–Determine how broad a market area should be encompassed under treaty verification.
b. Satellite Service Requirements–Make a first-cut evaluation of potential satellite capabilities required to satisfy each market segment under the treaty verification market area.
c. Satellite Service Research–Develop an understanding of the technical aspects of the satellite services we want to discuss with potential customers.
d. Customer Contacts-Phone and visit customers with current or potential applications under treaty verification.
e. ROM Market Analysis–Quantify the potential treaty verification space launch market over time based on a continuum of launch costs.
f. Supplementary Markets–Discuss supplementary markets to the treaty verification space launch market (e.g., ground data processing centers for remote processing satellites) and their potential growth over time.
g. Corollary Markets Assessment–Examine other market areas being studied under CSTS and determine if they require identical and/or similar services. Examine the potential for satisfying multiple market areas with a single, combined satellite capability.
h. Review and Refine Results–Review with potential customers, satellite service providers, and CSTS alliance. Update as appropriate.

3.4.3.3 Market Description

The strict definition of "treaty" is "a formal agreement between two or more states." After brainstorming this area, we decided to open up the definition to include binding agreements. This allowed us to examine agreements/commitments made by a government to its people and international oversight (e.g., human rights and pollution control). The top half of figure 3.4.3.3-1 shows the breakdown of treaty verification into seven market segments, followed by examples within each segment.



Communication			X	X			X
Navigation			X	X			X
Remote Sensing							
• *Reconnaissance*	X	X	X		X	X	X
• *Surveillance*		X		X	X		X

X – *Satellite Capability Required*

111264-042

Figure 3.4.3.3-1. Treaty Verification Market Segments and a First Cut at Potential Satellite Services Required by Each Segment.

3.4.3.3.1 Market Evaluation

Once we had established our market segments we took a first cut at delineating potential satellite services for each segment. We split remote sensing into two categories, reconnaissance and surveillance. We differentiated between the two, since surveillance has the added requirement of tracking the subject, requiring rapid data processing, and the ability to adjust our view based on a subject's movements. The lower half of figure 3.4.3.3-1 shows the mapping of satellite services to market segments.

It is important that this market area decomposition for treaty verification be reviewed with the other market areas. There is definitely overlap with the law enforcement area (e.g., illegal immigration, drug trade, and maybe more), and there is a good chance some of these segments were addressed in the remote-sensing area.

3.4.3.3.2 Space Application Description

Treaty verification requires a fairly traditional set of space assets and supporting infrastructure. Communication, navigation, and remote-sensing reconnaissance are traditional space applications. Remote-sensing surveillance most likely is being performed by DOD, under classified programs. It is important to determine if this is the case, and what the likelihood is of sharing this technology for other applications, such as treaty verification.

3.4.3.3.3 Market Assessment

Remote sensing is required for each of the seven market segments in one form or another. Three of the segments require communication and navigation capabilities. The communication would clearly be mobile communication. Since communication and navigation are considered secondary capabilities for treaty verification, we assumed work being performed in other market areas would more than satisfy our requirements (corollary markets). Even though there is a market area dedicated to remote sensing, because the entire treaty verification market area would be predicated on a remote-sensing capability we performed additional research into this field.

Today, the remote-sensing market is approximately $200 million per year worldwide (split 50-50 between government and commercial customers) with a projected growth of 20% per year[1]. Commercial users are beginning to see significant benefits to remote sensing information (e.g., mineral and petroleum industry, agriculture, forestry[2], civil engineering, and others), but do not want the responsibility of processing raw data. They want to ask a question and get back an answer, not a pile of images/photos.

Europe is leading the way in remote sensing for commercial markets, and for the Envisat-I project, 30% of the total program budget is for the ground segment (information processing)[3]. This would imply that 70% is for spacecraft and launch services. Unfortunately, by the end of the decade over 20 terabytes per week (equivalent to 20 million books of data) will be returned to earth[4] , thus there will be few new satellite programs like Envisat-I. Clearly the focus will be on information processing. Those interested in using remote sensing for treaty verification, and they have limited available budgets, stated an unwillingness to procure their own satellite capability. Thus, this market would rely on data (hopefully, processed data) from other sources.

3.4.3.3.4 Infrastructure

As stated in section 3.4.3.3.2, no changes to satellites are required to satisfy the needs of this market area. To fully satisfy those looking to utilize space for treaty verification, a sophisticated ground segment would be required. This would require combining GPS data with a mobile communications network, and the ability to obtain near-real-time remote sensing information.

The cost of establishing the required ground infrastructure could be significant, and this market could not justify the required investment. Clearly, work is going on to make individual components happen. Motorola, Loral, Qualcomm, and a number of other companies are investing in a number of competing mobile communications systems. Lockheed, Worldview, and others are looking at true commercialized remote sensing. What is needed is to tie these efforts together into an integrated capability for treaty verification, law enforcement, and other applications.

3.4.3.4 Prospective Users

Working with the law enforcement (sec. 3.4.5) market area effort, we have contacted the Justice Department to discuss the border dispute market segment (illegal immigration, drug trafficking, etc.). The arms verification market segment has not been researched because of its classified nature and our belief that those space assets are in place. We had conversations with Greenpeace to discuss the resource agreements market segment.

3.4.3.5 CSTS Needs and Attributes

As stated in section 3.4.3.3, there are no immediate changes required to satellites, and thus no impacts to the current launch vehicles or the process of launching satellites. As satellite technology and constellation strategies change, launch systems must evolve to meet the new requirements. Launch system requirements for this new generation of satellites are covered in appropriate market areas (e.g., communications and remote sensing).

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[1] "Getting Down to Earth," SPACE, July/August 1993

[2] "New Sensors Eye the Rain Forest," National Geographic, September 1993

[3] "Getting Down to Earth," SPACE, July/August 1993

[4] "Getting Down to Earth," SPACE, July/August 1993

3.4.3.6 Business Opportunities

The amount of remote sensing data information returned to earth each year is staggering (see sec. 3.4.3.3.3 above). The near-term market to support treaty verification is clearly in information processing on earth. The requirements for satellite launches would primarily be for replacement satellites, which would be once *every couple of years.*

We are not completely without hope. Most remote-sensing satellites are in a polar or sun-synchronous orbit. In the best case, we are receiving information on a particular location every 90 minutes. For a number of the market segments under treaty verification we would like information more frequently. To satisfy these consumers, additional polar satellites (a constellation approach) or even new satellite constellations in a lower inclination orbit (providing a higher dwell time) may be required. In addition, some segments require active tracking (surveillance), which is a little tougher than just "taking pictures." Finally, if the entire remote-sensing commercial market expands rapidly through the entrepreneurial efforts of those focusing in on value-added remote-sensing information processing, we may see a trend away from large, multicapability satellites to single instrument, rapid-response monitoring satellites for a single user.

There would be the potential for a significant remote-sending market under a scenario in which a ground infrastructure is established to rapidly process remote sensing information allowing commercial users to obtain answers to their specific problems. It would use existing space assets, and would occur during the next 10 years. After seeing the power of this information, customers want more information, primarily in terms of shorter duration between samples and more specific data. Satellite manufacturers are able to provide low-cost, single-mission (single-instrument) satellites. A low-cost, dependable (launch ± a couple of days) launch service supports single-purpose satellite demand.

With the little work we have done, we would estimate this market anywhere from *6 to 20 launches per year.* Of these, *two to four would support treaty verification.* This information was supplied to the remote-sensing market analysis effort, and thus treaty verification requirements are covered in their total remote-sensing market.

3.4.3.7 Conclusion and Recommendations

Treaty verification does not require unique capabilities or space assets. It requires mobile communications tied in with GPS for location. In addition, it is desired to have both a reconnaissance and surveillance remote-sensing capability. The primary problem is establishing the immense ground infrastructure to obtain and distribute the required information to mobile locations in near real-time.

This market can be satisfied by space assets/constellations defined in the communications and remote-sensing market areas, and thus no independent requirement is defined in this market area. It is again important to stress that in addition to the space assets, the ground infrastructure must be developed before a market for treaty verification emerges.

3.4.4 Increased Space Station Missions

The Space Station program, now a joint US/Russia/International venture[5] , has tremendous potential as a growth transportation market. The additional resources of the combined Mir II and Alpha Station will speed the testing and development of new manufacturing and research processes. It is projected that reduced transportation costs will allow more frequent visits to the station as well as usher in the viability of free-flying platforms which will offload the matured processes and experiments from the station. The main, if not only, users for the space

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[5] Alpha Station Program and System Definition, Joint Program Directive, SSP-JPD-002, Oct. 27, 1993.

station will be governments and their agencies, each contributing its own share of investment. Although we expect the station to have a wide range of use, they would mostly fall under the areas of technology development, testing, and demonstration.

3.4.4.1 Introduction/Statement of Problem

The currently planned space station deployment and maintenance scenario requires more than $21.6 billion in launch cost on the space shuttle through 2006 (see fig. 3.4.4.1-1). This represents about 47% of the total station budget (program cost + launch cost) required in the same timeframe. Examination of the resupply phase reveals a more lopsided picture of station costs. Between 1994 and 2001, which is when the station is expected to achieve permanent human capability (PHC), transportation cost is about 31% of total station budget. Most of the money goes into developing and deploying the initial station elements.

Station Phase	Program Costs* Russian Alpha		Launch Costs # STS/yr	$ STS/yr
	Fiscal Year	$B		$B
DDT & E	1994	2.1		
DDT & E	1995	2.1		
DDT & E	1996	2.1		
Deploy	1997	2.1	2	0.8
Deploy	1998	2.1	5	2.0
Deploy	1999	2.1	4	1.6
Deploy	2000	2.1	4	1.6
Deploy	PMC - 2001	2.1	4	1.6
Resupply	2002	1.5	7	2.8
Resupply	2003	1.5	7	2.8
Resupply	2004	1.5	7	2.8
Resupply	2005	1.5	7	2.8
Resupply	2006	1.5	7	2.8
	Total All Years	24.3		21.6

* Based on NASA 1994 budget projections.

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Figure 3.4.4.1-1. Current Funding of Station DDT&E, Operations, and Transportation

Beginning in 2002 when resupply flights are required to replenish the station, transportation cost become 65% (or $2.8 billion) of the annual station budget. This is due to an increased in shuttle flights to support and maintain the station, and it is a major portion of the costs. It is therefore important to reduce shuttle cost to help the space station program in several ways:

a. Assure that transportation cost alone will not hinder effective long-term station operation.
b. Make station access affordable for ongoing users; at the same time, attract new users.
c. Free up funding for new payloads and experiments, or increased shuttle access to the station, or both.

3.4.4.2 Study Approach

Our approach is to assess the current estimate by the user community (NASA HQ Codes C and U, ESA, and the National Space Development Agency of Japan, or NASDA) to determine the types of resources required, the payload classes, and what would be desirable in a transportation system to increase/improve use of the station.

Since the deployment phase of the station will not likely be affected by transportation cost changes because it is in the near-term future, our main analysis emphasis will be on the post PHC resupply time frame.

3.4.4.3 Market Description

The Space Station Utilization Conference[6] in Huntsville, Alabama (Aug. 3, 1992), explored what the users envision the space station as being and what their dreams of the future would mean for station growth. Most of the applications fall within the area of experiments in various scientific fields and technology development for commercial and other uses. Although requiring specialized interface, handling, and operations, these provide for a steady demand on transportation access to the station. This demand is expected to increase with reduced transportation costs. Three scenarios emerged as the driving force for the market. They are—

a. Phased approach to build an orbiting facility for technology development, from shuttle-based experiments to space station-based activities to work performed on free flyers. For a particular technology, the following possible phased events might take place:
    1. Test a process/technique on an STS flight (Spacelab, Microgravity Lab).
    2. Develop and learn to automate the process on the station.
    3. Move it off to free flyers for actual production or long-term testing.
b. The entire laboratory is in space, so specimens and samples would not have to be returned to Earth for analysis, which sometimes compromises the integrity of the experiment. This option calls for a facility that can accommodate all necessary end-to-end functions for the experiments. This means data collection, storage, processing, and analysis capabilities must be available on board. As one can expect, transportation needs to support this version of the station would be much greater than in scenario 1, above.
c. A third possibility is driven by frequent access to the station to collect experiment data and to allow the lead scientists involved in the experiments to spend a couple of weeks at the station conducting their experiments. This scenario ensures high data quality and keeps the investigators close to their experiments.

These are seen as three potential scenarios for space station utility. For each scenario, the transportation market can be summarized as consisting of the initial buildup of the facility and resupply transportation to the station with both unpressurized payloads and pressurized payloads (including people). As mentioned before, for the purpose of this analysis, transportation requirements will be discussed with emphasis on the resupply missions. As time progresses one must revisit the station requirements because they are intimately tied to technological, socioeconomic, and political forces (including current funding/budget and operational trends). For now, the identified requirements provide a basis for how the space station might grow and what role transportation could play in this process.

3.4.4.3.1 Market Evaluation

There are several areas expected to drive the transportation market for the space station. These are all related to the fact that the station must be supported so it will function as designed. The following transportation drivers are seen as important considerations for a space station resupply launch system:

a. Regular access to the station. This general requirement is the major driver of transportation to the station. It is critical to maintain space station operations and ensure user access to what the station was built for in the first place, experiments and their data. The bottom line is that the launch system must be able to launch on

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[6] <u>Space Station Freedom Utilization Conference</u>, Aug 3-6, 1992, Huntsville, AL. Sponsored by SSFP, NASA HQ.

schedule and possibly on demand, as called for by the space station resupply plan. This leads to the next driver, resupply of the station.

b. Resupply of the station. Regular visits to the station, either manned or unmanned, are required to ensure station operations. This includes replenishing, checking out, and fixing all the different functions of the station. Propellants must be refueled, power system maintained, guidance and control system maintained and upgraded, EVA equipment checked out, and so forth. Maintaining the station alone is expected to be continuous throughout the life of its utility.

c. Delivery and return of people. Since this is envisioned to be a manned facility, delivery, return and maintenance of the integrity of the living environments are critical for the station's success. The launch system must provide support for human to live in space. Currently the space shuttle provides sufficient access capability to space. But it is not capable of increasing launch rate or launching on demand. As a result a new (or upgraded) system may have to be considered.

d. Delivery and return of experiments, their specimens, and data. At the heart of the station utilization are the multitude of experiments the users will be conducting either inside or outside of the pressurized station modules. These experiments must be delivered and in many cases returned to Earth for processing and analysis. Due to a variety of applications (to be discussed in the next section), each experiment is expected to require its own environmental support and interface. Vibration, temperature, cleanliness, and datalink are just some of the various interfaces required by a particular experiment. Most, if not all of these, will probably be provided by the launch system.

3.4.4.3.2 Space Application Description

Major applications for the space station fall in the areas of microgravity experiments, life science experiments, space physics, astrophysics, Earth science and applications, solar system exploration, and other technology research activities. Payload interfaces with the space station lab support equipment will be simple, and experiment packages will be highly contained. The research facilities will feature international standard payload racks (ISPR), arranged in various configurations and sizes throughout the different station modules.

Each experiment will have control of its own environment and activities. However, the station will provide a multitude of services to the experiments in terms of power, environmental control, data collection, storage and transfer, and even limited data processing and analysis. The transportation system that will deliver the experiment payloads to and from the station will have many of the services for the payloads in the quiescent mode. Actual experimentation is not expected to occur during transit, except for a limited few.

One unique requirements of the experiments is the need for early or late access. This calls for access to the payload as late as 10 hours before launch, and as early as 2 hours after landing. This is driven by the quality of data or experiment results, many of which become invalid after prolonged exposure to gravity after landing.

3.4.4.3.3 Market Assessment

The key to growth will be the ability to efficiently move experiments in and out of the station to maximize use of the resources. For the United States, the pressurized cargo will be delivered at 90-day intervals. Experiments must therefore be timed around these flights. For protein crystals, deterioration begins within hours after the crystal is removed from its solution. Ideally, the payloads would return when they were ready rather than based on the crew rotation schedule. The reduction of transportation costs (at one-tenth the current shuttle level of approximately $10,000/lb) will allow the flexibility to move payloads through the station at a greater efficiency and timeliness. These lower costs would allow individual organizations and agencies to plan and pay for their own missions and be in better control of the progress being made.

The reduction of launch costs to the one one-hundredth level would allow the delivery and servicing of free flyers and thus allow the natural evolution of the station payload process. Man-tended free flyers would allow industries to customize a facility for their own needs and provide the personnel to support and maintain it. Frequent access would be required for some processes, while others would require undisturbed periods measured in months.

Currently, the pricing policy concept is under development, but it is expected that shuttle and Spacelab policies will be adopted, or at least be used as the basis. There may be two standard service packages that the user can buy. One is for round-trip transportation and integration. The other is on-orbit operations. The former affect the launch market directly, the latter indirectly.

Round-trip transportation and integration price will be based on weight, volume and length of the payload, with standard interfaces provided for by the launch vehicle. On-orbit operations price will be based on space required (or volume), energy usage, crew time needs, and length of stay in orbit. All of these impact how often the transportation system must visit the station. Obviously optional services will be offered as well at additional costs. The key to a successful transportation in the station resupply market will be in providing timely launch services and on-orbit operations at an affordable price to the users.

3.4.4.3.4 Infrastructure

The infrastructure must be assessed from two points of view. From the users' standpoint, only minor infrastructure modification will be needed, if even that. The users normally operate their own laboratories (either government, private, or university) where many experiments will be built. The principal investigator and his/her project team usually reside at these same facilities; therefore preflight and postflight preparation and analysis will be done there too. At the launch site, these small payloads are expected to require simple integration operations, which can readily use existing payload processing facilities. Only minor payload specific hardware and equipment will be required, which will be supplied by the users.

From the launch provider's standpoint, the infrastructure will be whatever is inherently required to process, launch, and refurbish the vehicles, with the assumption that the system will be reusable. If the shuttle (or some upgraded version) will continue to fly, then it is foreseen that only minor infrastructure impact will occur, mostly in the areas of improved operations and reliability. If at some future date a new system will be brought on line, then the impact to the infrastructure will be high with major new infrastructure required.

3.4.4.4 Prospective Users

Prospective users of the space station market are expected to consist of only U.S. and foreign government entities, and research and educational establishments. In general, the partners in building and deploying the station will be its main users. These include the functions within NASA, other U.S. agencies such as NOAA and Department of Energy, the European Space Agency (ESA), the NASDA, and potentially as-yet unidentified Russian agencies. Our main contacts have been the following sources:

Code C:	James Fountain (MSFC), Kay Enman (MSFC)
Code U:	Betty Segal (HQ)

General: Vance Houston (MSFC), Jason Otashi (Ames), Carl Gustaferro (Ames), Stan Parkson (Ames), Rich Rodriquez (Crew Reqts, JSC), Doug Sander (MOD, JSC), ESA & NASDA requirements provided through Boeing Station Contract.

3.4.4.5 CSTS Needs and Attributes

3.4.4.5.1 Transportation System Characteristics

The station currently is built based on deployment and resupply capabilities of the space shuttle. As a result, by default, most shuttle capabilities become the required transportation system characteristics. In fact, in many cases the transportation system ends up driving what the payloads can and cannot do. If the shuttle is going to be replaced by some new system in the future, the latter should also have many of the shuttle's characteristics because it will fly shuttle payloads. Among the standard shuttle capabilities, the following are considered very important for improvements for space station support:

a. Increase payload weight to support high traffic, high inclination orbits.
b. Provide higher reliability for delivery and return of high valued cargoes and people.
c. Have more flexible schedule for launch-on-schedule and launch-on-demand.
d. Offer improved ground processing for quicker refurbishment and turn-around.
e. Maintain affordable per flight cost to the customers.

Another operational characteristic to be considered is the early and late payload access capabilities. Our research has shown that many users have late/early access requirements on the cargo (30% of crew, 30% of ESA, 54% of NASDA, 100% of Code C, and 50% of Code U). Additionally, much of the remaining cargo requires conditioning or thermal control of some sort. As it stands today, the shuttle at 28.8-deg inclination can only meet 30% of the user requirements[7]. At 51.6-deg, this is expected to be even less. Therefore, the critical characteristics for a transportation system to support increased station missions would also include extensive late/early access capability (<72 hours) and sufficient power and thermal capabilities (either in the vehicle or as kits) to meet the payload demands.

3.4.4.5.2 Ground Segment

Most of the ground segment issues were discussed in section 3.4.4.3.4, “Infrastructure.” Specific payload ground facilities and infrastructure needs will be closely related to payload access, on-orbit control, and postflight processing. Specific launch system ground segment components depend on the vehicle in operation at the time. For the shuttle it is not expected to require major ground facilities and infrastructure network. For the payload, the ground segment to support the significant amount of late/early access will require on-pad payload access. Also, close monitoring of power and payload temperatures prior to, during, and after launch will be critical. In general, we do not foresee major ground segment addition as the station design stands at present time.

3.4.4.5.3 User/Transportation Interfaces

Many of the user/transportation interfaces fall in the areas of mission planning and mission operation. Mission planning in this sense includes all activities leading up to the actual flight of the payloads. Negotiation of launch

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[7] Station Alpha Decision Package, Italian Pressurized Cargo Carrier versus Mid-deck Refrigerator/Freezer Implementation, Boeing, Nov 2, 1993.

price and services, and crew training for the mission, also fall within this area. This is important because it is inherently tied to the pricing policy and payload manifest of resupply to the station. In the mission operation area, interfaces between the payloads/experiments and the vehicle are expected to be driven not so much by payload mass but by services provided to the payloads. For example, power and thermal capabilities for refrigerators and freezers during all phases of flight must be provided by the vehicle. Also, animal transportation requires in-transit access for visual monitoring. These and other environmental, electrical, and data interfaces will determine whether the experiments are successful in providing quality results to the scientists.

3.4.4.5.4 Management and Policy

Since the station program and its resupply transportation are and will remain under the control of NASA and other government partners, it is expected that management and policy of this market will continue to follow government regulations. Just as in recent years, the station budget will need to be justified to the U.S. Congress for approval in the coming years. However, once the resupply phase begins in the early 2000s, we expect the program to receive stable support from the lawmakers. Even though Russia will become a major partner, we expect the station program will continue to be run under U.S. management and policy.

3.4.4.5.5 Improvements Over Current

As discussed above, the space station users will include mostly government and educational entities. To enable lower cost per flight for space station resupply, the U.S. government agencies (including NASA) will act as an anchor tenant, thereby providing a base transportation needs for the transportation system. With this anchor tenancy, other users such as foreign governments and private and educational users can take advantage of the low transportation cost to use the station's capabilities. An average of seven shuttle flights per year to the station is projected with the aforementioned main users. Depending on the launch rate capabilities of the launch vehicle, additional users may begin to conduct experiments in orbit while taking advantage of the lower launch cost. The cost sensitivities of the market will be discussed in section 3.4.4.6.1.

3.4.4.6 Business Opportunities

The following two sections present an overview of our assessment of the space station business opportunities. Emphasis will be placed on the transportation aspect of the market.

3.4.4.6.1 Cost Sensitivities

Figure 3.4.4.6-1 shows the cumulative cost of the station program, including deployment phase and the following 5 years of resupply. The impact of reducing transportation costs by one-tenth and one one-hundredth are included for comparison. One can see the large savings resulted from reducing launch costs to one-tenth of current values. However, the benefit of reducing below one-tenth of current launch costs provides little added value, but most likely would require significantly more development dollars. Figure 3.4.4.6-2 shows the annual cost difference for the same cases. Since the post-PHC resupply flights have the lowest operations cost segment and largest transportation costs, the benefit of reducing launch costs by an order of magnitude are greatest. The savings would be $2.5 billion per year for a reduction of one-tenth in launch costs. This would be sufficient to—

a. Develop 50 new integrated science racks.
b. Develop 250 new technology or commercial racks.

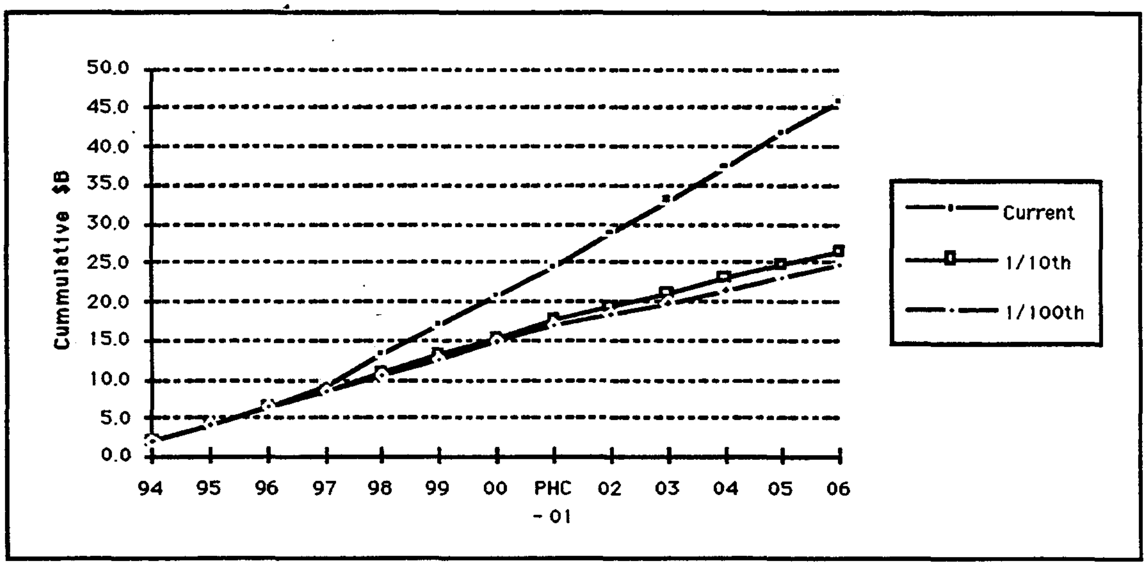

Figure 3.4.4.6-1. Projected Cumulative Station Costs (Deployment + Resupply)

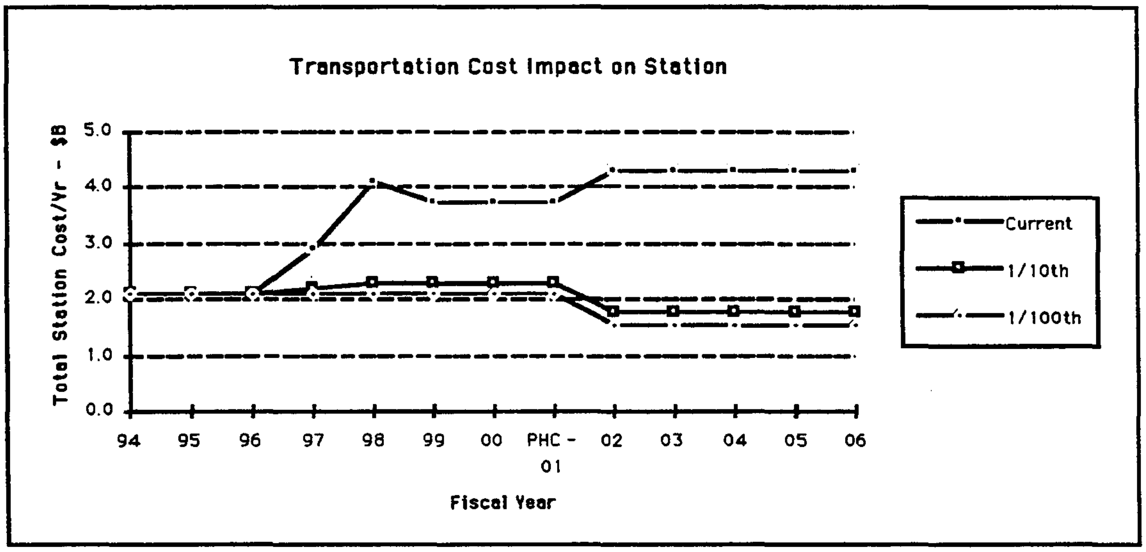

Figure 3.4.4.6-2. Projected Annual Savings of Reduced Launch Costs (Deployment + Resupply)

c. Fly 60 additional flights.

d. Some combination of the above.

The highest probability (and most austere) case for the savings would be to maintain the affordability of the station program and would result in little additional growth. A periodic additional flight to increase the user payload throughput could be easily justified.

A more optimistic case could assume that some percentage of the savings would be available for growth of the station. The addition of a Hab and Lab module would significantly increase the output of the station. Figure 3.4.4.6-3 parametrically assesses the growth in requirements with the addition of Hab and Lab modules, which directly reflect in crew size and additional experiment volume for the crew to work with. Since crew time is one of the most limiting factors, it is used here as the basis for growth. The impacts of the additional Russian hardware and crew are uncertain at this time. The PHC station configuration is now anticipated to have 110 kW of power, twice that of the previous U.S. only options. Power should therefore no longer be a limiting consideration, at least for early growth.

			Pressurized Requirements*				
* Habs & Labs**	* Crew	Crew Avail for Exper.	Crew Reqts (racks/yr)	User Reqts (racks/yr)	Station (racks/yr)	Power Reqd (kwatts)	Resupply Flts/Yr
1	4	2	17	17	15	30	7
2	8	5	34	43	23	75	11
3	12	8	51	68	30	120	15

* Due to limited external space, only pressurized requirements are assumed to grow.

** Assumes that Hab and Lab modules are both delivered before the benefits of either can be realized.

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Figure 3.4.4.6-3. Parametric Growth Estimates of the Hab and Lab Modules

A low-probability option would be that the major portion of monies saved by the reduced transportation costs would be available for station growth and evolution (i.e., addition of man-tended free flyers). The $2.5 billion annual savings is more than the DDT&E and nontransportation deployment costs planned for the space station. Significant growth in resources and capabilities would be possible.

Figure 3.4.4.6-4 shows reference station logistics missions that can be used to quantify the above growth options. We assumed that payload costs will average $10,000 per pound. While this is high for clothing and food, it is low for integrated science and user payloads; so is a good overall estimate. Based on the cargo capabilities of a shuttle mission with pressurized or unpressurized cargo only (due to performance limitations to 51.6 deg and overhead), the reference cost of a pressurized mission is $98 million, and an unpressurized mission is $93.2 million.

Reference Missions	Payload	Cost/Lb Pld	Total
Pressurized Cargo Carrier	9.4 klbs	$10K	$94.0 M
- ISPR & Stow Racks			
- Aisle Racks			
Refurb. Costs			$4.0 M
Total Press. Mission			**$98.0 M**
Reference Weight			**25 klbs**
2 Unpress. Cargo Carriers	9.3 klbs	$10K	$93.0 M
- ULC Carrier			
- Dry Cargo Carrier			
- Other Payload			
Refurb. Costs			$0.2 M
Total Unpress. Mission			**$93.2 M**
Reference Weight			**17.5 klbs**

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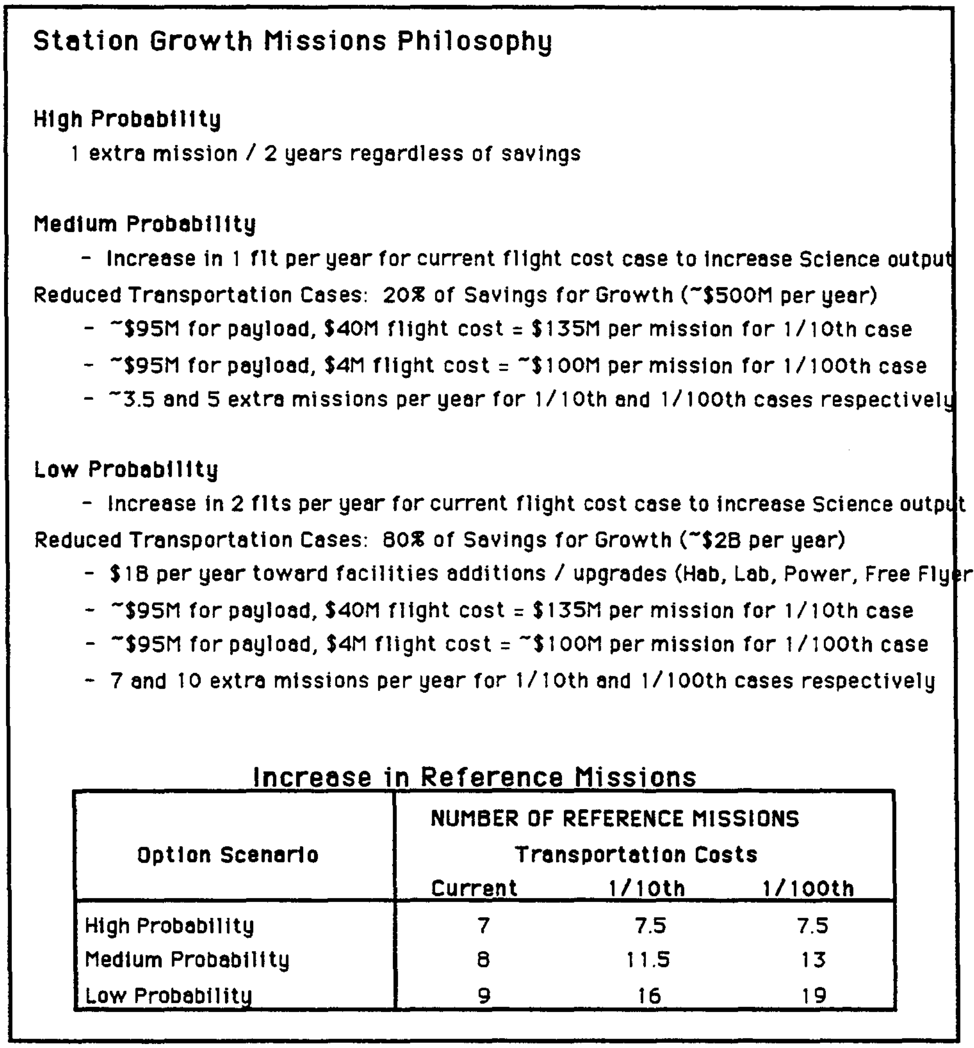
Figure 3.4.4.6-4. Reference Logistics Mission Payload and Costs

Figure 3.4.4.6-5 shows the rationale for high-, medium-, and low-probability funding/growth scenarios and potential results. Note for the low-probability scenario (large funding) that half the funds are going into facilities additions/upgrades. If launch cost can be reduced by an order of magnitude, the high- to medium-probability cases indicate that between 7.5 and 11.5 flights annually can be expected.



Station Growth Missions Philosophy

High Probability

1 extra mission / 2 years regardless of savings

Medium Probability

- Increase in 1 flt per year for current flight cost case to increase Science output

Reduced Transportation Cases: 20% of Savings for Growth (~$500M per year)

- ~$95M for payload, $40M flight cost = $135M per mission for 1/10th case
- ~$95M for payload, $4M flight cost = ~$100M per mission for 1/100th case
- ~3.5 and 5 extra missions per year for 1/10th and 1/100th cases respectively

Low Probability

- Increase in 2 flts per year for current flight cost case to increase Science output

Reduced Transportation Cases: 80% of Savings for Growth (~$2B per year)

- $1B per year toward facilities additions / upgrades (Hab, Lab, Power, Free Flyers)
- ~$95M for payload, $40M flight cost = $135M per mission for 1/10th case
- ~$95M for payload, $4M flight cost = ~$100M per mission for 1/100th case
- 7 and 10 extra missions per year for 1/10th and 1/100th cases respectively

Increase in Reference Missions

Option Scenario	NUMBER OF REFERENCE MISSIONS Transportation Costs Current	1/10th	1/100th
High Probability	7	7.5	7.5
Medium Probability	8	11.5	13
Low Probability	9	16	19

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Figure 3.4.4.6-5. High-, Medium-, and Low-Probability Funding Scenarios

3.4.4.6.2 Programmatics

The shuttle is the only existing launch system with space station support capabilities and is expected to continue operation at least through the mid-2000s. Following the development phase, the station elements will be deployed between 1997 and 2001, achieving permanent human capability (PHC) in 2001. The traffic to the station beginning in 2002 will consist mainly of resupply and crew rotation missions. As figure 3.4.4.6-6 shows, the deployment requires about four flights per year, while the baseline resupply missions will total seven shuttle flights per year.

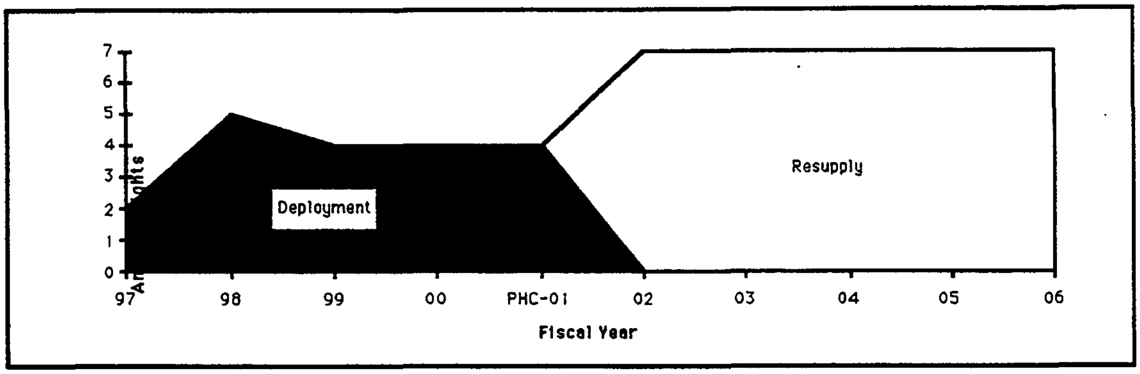

Figure 3.4.4.6-6. Space Station Deployment and Resupply Schedule

3.4.4.7 Conclusions and Recommendations

By design, transportation to the space station will be on a regular basis. The sponsoring governments will provide anchor tenancy for the transportation system, which will help stimulate other users to take advantage of the lower launch cost. We examined three possibilities of how the launch cost savings could be reinvested back into the program, ranging from no reinvestment to 80% reinvestment. For the conservative high- and medium-probability cases (no reinvestment and 20% reinvestment), we have projected that up to 12 launches per year to the station is a possibility.

Three aspects of the space station launch market are summarized as follows:

a. Space station utilization. The space station will be a major orbital facility built for the purpose of conducting high-technology experiments and development. A variety of applications are envisioned for the station to include life science, microgravity experiments, manufacturing techniques, material development, and space sciences just to name a few. These high-valued payloads require delivery to the station and return to Earth for analysis.

b. Launch vehicle requirements. A dependable and reliable launch system is required to deploy and resupply the station. It must provide delivery and return services for the experiment payloads, at the same time satisfying stringent payload interface requirements and late/early payload access requirements. Because of the criticality of resupplying the station, the launch system must launch reliably at up to 12 launches per year.

c. Launch cost reduction goals. Our assessment indicates large launch cost savings to reach the one-tenth cost goal. Additional work to reach the one one-hundredth would not result in much more cost savings, while potentially requiring very high launch system development dollars.

3.4.5 Law Enforcement

3.4.5.1 Introduction

This market area covers all needs associated with communications, navigation, reconnaissance, and surveillance dictated by local, state, Federal, and international law enforcement agencies. Currently this market area only utilizes GPS for location, and standard space- and ground-based communication networks.

U.S. plans included a dedicated capability for communication and position tracking (personnel and asset), but Justice Department studies describing this requirement are classified, and we were unable to examine them during this phase of CSTS.

As a standalone market, law enforcement is small, but combined with other markets (e.g., treaty verification), it provides substantiation for growth in the communications and remote-sensing market areas.

3.4.5.2 Study Approach

A literature search was performed to determine efforts to date in utilizing space assets for law enforcement, which agencies were at the forefront in utilizing space, and to characterize and categorize worldwide law enforcement. Based on this information, telephone interviews of key personnel in several agencies were performed.

3.4.5.3 Market Description

Law enforcement space market consists of the use of space platforms/satellites to provide real-time support to individuals for tracking, communications, and surveillance. This market area would service the following customers:

a. Foreign governments.
b. United Nations.
c. INTERPOL.
d. U.S. Government.
  1. Federal.
    (a) Justice Department (INS, DEA, ATF, FBI, CIA, Customs, and Forest Service).
    (b) DOD (Coast Guard, National Guard).
  2. State (highway patrol).
  3. Local (police departments, community patrols).
d. Commercial (insurance, security).

Most current capabilities are classified and were not discussed by potential customers. However, basic requirements can be derived and would be applicable to all potential customers.

The Justice Department conducted the classified Constellation Interoperability Working Group (CIWG) study to determine the feasibility of utilizing dedicated space assets for all Federal law enforcement requirements. Options investigated include one or two geostationary satellites to provide such a service. Launch costs were expected to be $100 million; satellites in the $150 million or more range; and real-time ground support $200 million per year.

Interestingly, the infrastructure costs for the extensive ground support network, not launch costs, were the tall pole in their study. Constrained budgets have put implementation on hold.

3.4.5.3.1 Market Evaluation

The commercial market (e.g., insurance and security) would be driven by the successful implementation of an equivalent government-sponsored system. Critical technologies would have to be proved before commercial markets could be developed. The primary driver for growth of this market for both government and commercial would be the decrease in ground infrastructure costs.

Law enforcement can be aided by the use of space-based tracking, surveillance, and communications, but it has been hampered on a national level by constrained budgets. The required technologies are in hand, with the exception of low-cost ground-based infrastructure. Launch costs were considered of minimal impact compared to the yearly investment in ground infrastructure required. Commercial exploitation of associated technologies is not expected to occur in the near term (5 to 10 years), due almost exclusively to limited ground infrastructure.

3.4.5.3.2 Space Application Description

Law enforcement requires a fairly traditional set of space assets and supporting infrastructure. Communication, navigation, and remote sensing are traditional space applications, and the procedures are in place to operate them. The ground infrastructure necessary to retrieve and distribute necessary data in near real-time is not currently in place. As mentioned above, this would require a yearly investment of $200 million to operate.

3.4.5.3.3 Market Assessment

A cursory market analysis (without examining the Justice Department's classified mission model) indicates a requirement for no more than two satellites every 10 years (assumes a 10-year satellite life). Growth would be based on the potential synergism between domestic and international needs; however near-term requirements dictate separate, secure systems. A lower probability growth market would include commercial applications, but it is currently cost-prohibitive.

3.4.5.3.4 Infrastructure

As stated in section 3.4.5.3, no changes to satellite technology are required to satisfy the needs of this market area. To fully satisfy those looking to utilize space for law enforcement, a sophisticated ground segment would be required. The cost in establishing the required ground infrastructure could be significant, and this market could not justify the required investment.

3.4.5.4 Prospective Users

A number of contacts were made with the Coast Guard, U.S. Customs, and the Drug Enforcement Agency. In the Coast Guard they are—

a. Cmd. Ben Thomason, Ellington Field.
b. Jack McCready, Research and Development Center.
c. Michael Lewis, Office of Law Enforcement and Defense Operations.
d. C.W. McMahon, Operations Security Manager.

In U.S. Customs they are—

a. Patricia McCauley, District Director, U.S. Customs Service.
b. John Hensley, Commission for Enforcement.
c. M. Bower, Enforcement Support.

In the Drug Enforcement Agency they are—

a. Louis Cegala, Office of National Drug Enforcement.
b. Jack Mayer, Director of Operations.
c. Mike Horn, Technical Operations.

3.4.5.5 CSTS Needs and Attributes

As stated in section 3.4.5.3.2, there are no immediate changes required to satellites, and thus no impacts to the current launch vehicles or the process of launching satellites. As satellite technology and constellation strategies change, launch systems must evolve to meet the new requirements. Launch system requirements for this new generation of satellites is covered in appropriate market areas (i.e., communications and remote sensing).

3.4.5.6 Business Opportunities

There is a sound business opportunity if an all-up combined mobile communication, navigation, and near real-time remote-sensing network were in place. These agencies do not have significant one-time development budgets, but could afford the yearly operating costs if a proven system were available on a subscription basis. A number of efforts are under way to provide necessary space assets, but there is not a large ongoing effort to develop the immense ground infrastructure required.

3.4.5.7 Conclusion and Recommendations

Law enforcement does not require unique capabilities or space assets. It requires mobile communications tied in with GPS for location. In addition, it is desired to have both a reconnaissance and a surveillance remote-sensing capability. The primary problem is establishing the immense ground infrastructure to obtain and distribute the required information to mobile locations in near real-time.

This market can be satisfied by space assets/constellations defined in the communications and remote-sensing market areas, and thus no independent requirements is defined in this market area. It is again important to stress that in addition to the space assets, the ground infrastructure must be developed.

3.4.6 Human Planetary Exploration

3.4.6.1 Introduction

Exploration of both near-Earth and more distant heavenly bodies has been one of mankind's most inspired dreams for many years. Recently, NASA and the U.S. government have led several studies to help pave the way for the next steps in space exploration by man and manmade machines. Almost all exploration scenarios studied concentrated on missions to the moon and Mars exclusively, with manned involvement at various levels of activities. Whether they will occur in the near- or far-term future, many believe exploration missions are man's destiny.

Within the context of CSTS, exploration missions to the Moon and Mars are not in the same class as other Earth missions. They command their own requirements with unique technology and capability needs from the transportation systems. These combine to make up two main characteristics that differentiate exploration missions apart from other missions.

Unlike other commercial or revenue-generating missions, exploration missions are conducted purely for scientific and technology development reasons. As such, the missions require a large amount of cash outlay with unknown returns. The associated amount of risk is also very high, which therefore means that only government agencies can afford this type of missions. Another characteristic is the tremendous mass that must be delivered to orbit to support lunar and Mars missions. It is not surprising to find, as a result of the mission requirements, a launch system on the order of 250 metric ton (MT) or 550 Klb payload to orbit. Taking into consideration the technology required to travel to these planetary bodies, living and working there for an extended period of time, and coming back to Earth safely, one can see the enormous investment exploration missions call for.

In this white paper we offer a general overview of the lunar and Mars exploration missions, discuss their top-level mission and system requirements, and provide a framework on how they can potentially benefit from a transportation system within the context of CSTS goals. We do not expect exploration missions to drive a particular vehicle design. Instead we think these missions provide a valuable backdrop for secondary considerations such as anchor tenancy or technology commonality between the eventual candidate systems.

3.4.6.2 Study Approach

Our approach was to review documented NASA studies performed in the recent past and extract appropriate information to create three baseline scenarios used in this study. The scenarios are the First Lunar Outpost (FLO), the Lunar Base, and the Lunar Base and Mars Exploration scenarios. Various NASA lunar and Mars mission alternatives were considered to create these scenarios. For each of these cases, we identified mass-to-orbit, number of flights, and other mission parameters. We also estimated the launch cost impact on each scenario if Earth-to-orbit (ETO) transportation could be reduced. Only the initial and steady-state missions are considered, because precursor missions are already treated in other market segments.

3.4.6.3 Market Description

The transportation market within space exploration is very much focused on satisfying the main goals of delivery of cargoes to the destinations (the Moon or Mars), and delivery of humans and their safe return to Earth. For each of these piloted and cargo missions, one can also break the transportation into two main segments for CSTS's purposes. One is the delivery of people and cargo from Earth to Earth orbit; the other is trans-lunar, trans-Earth, and near-Moon transportation. Although we discuss the latter to some extent, most of the analysis concentrated on ETO delivery. Figures 3.4.6.3-1, -2 and -3 present the annual mass to orbit for each of the three scenarios. Of this large annual mass to orbit, people account for a negligible amount and therefore do not appear in the figures. However, we stress that both manned and unmanned launch vehicles will be required to fully support exploration missions. As can be seen, exploration missions are not typical commercial, revenue-generating missions but are more suitable as national programs.

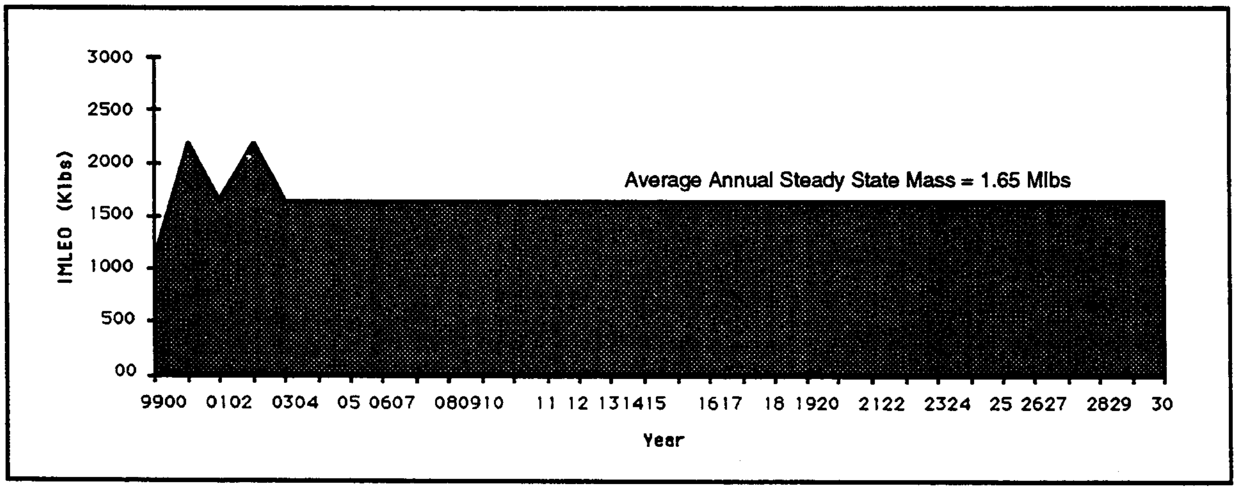

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Figure 3.4.6.3-1. First Lunar Outpost (FLO) Projected Annual Mass to LEO

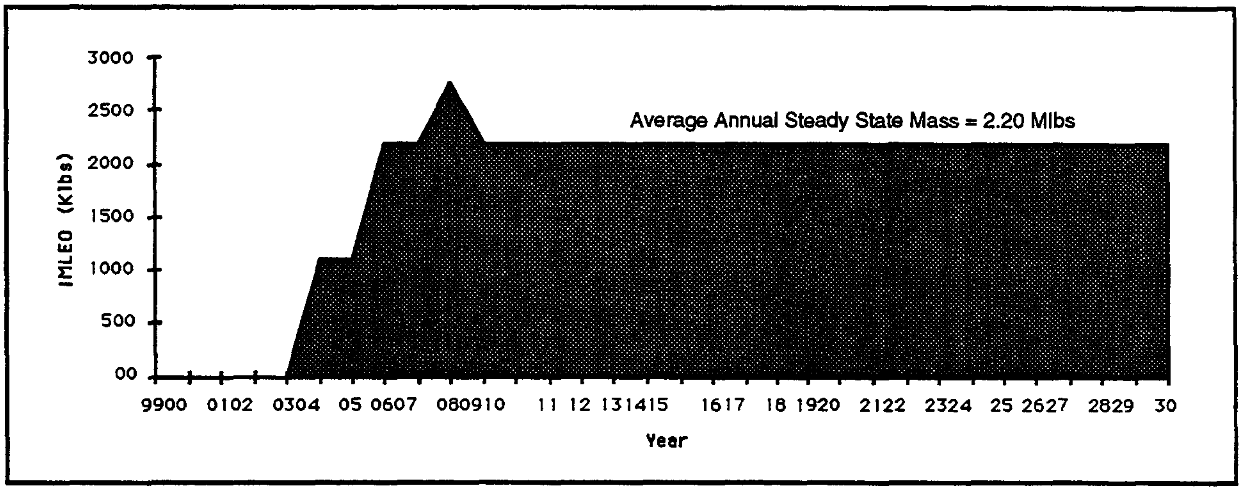

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Figure 3.4.6.3-2. Lunar Base (LB) Projected Annual Mass to LEO

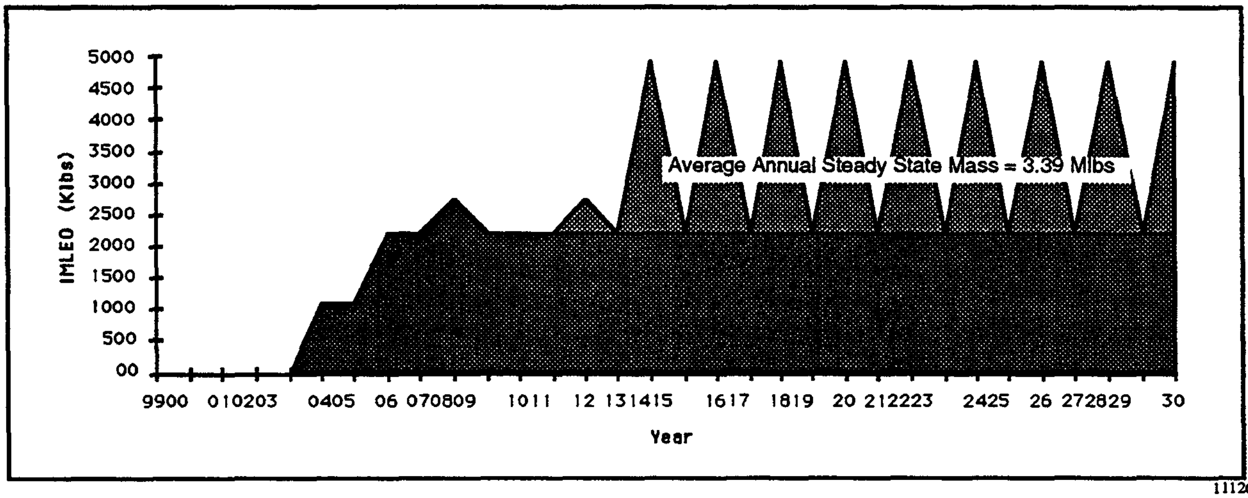

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Figure 3.4.6.3-3. Lunar Base and Mars Exploration (LBME) Projected Annual Mass to LEO

A brief description of the three scenarios is provided in section 3.4.6.3.2.

3.4.6.3.1 Market Evaluation

The three described scenarios represent levels of probability that exploration missions will occur. As shown in figure 3.4.6.3-4, relatively speaking, the FLO scenario at 1.65 Mlb annual mass to orbit is defined as high probability, the LB at 2.20 Mlb is medium, and the LBME at 3.39 Mlb is low.

Scenario	Average Annual Mass to Orbit, Mlb	Scenario Probability
First lunar outpost	1.65	High
Lunar base	2.20	Medium
Lunar base and Mars exploration	3.39	Low

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Figure 3.4.6.3-4. Level of Probability of Three Exploration Scenarios

Obviously the scenarios are intimately tied to level of funding available. However, for the purpose of this analysis, the scenarios are created not based on funding availability, but on the amount of science the end users requested. This results in three mission models, as shown in figures 3.4.6.3-5, -6, and -7. Note that for lunar piloted missions in all three scenarios, the crews are launched on the same expendable ETO system used to launch the cargoes. For the Mars missions in the LBME case, the crews must be taken to orbit by a manned ETO delivery system to meet the trans-Mars vehicle. This is appropriately shown as STS flights in figure 3.4.6.3-7.

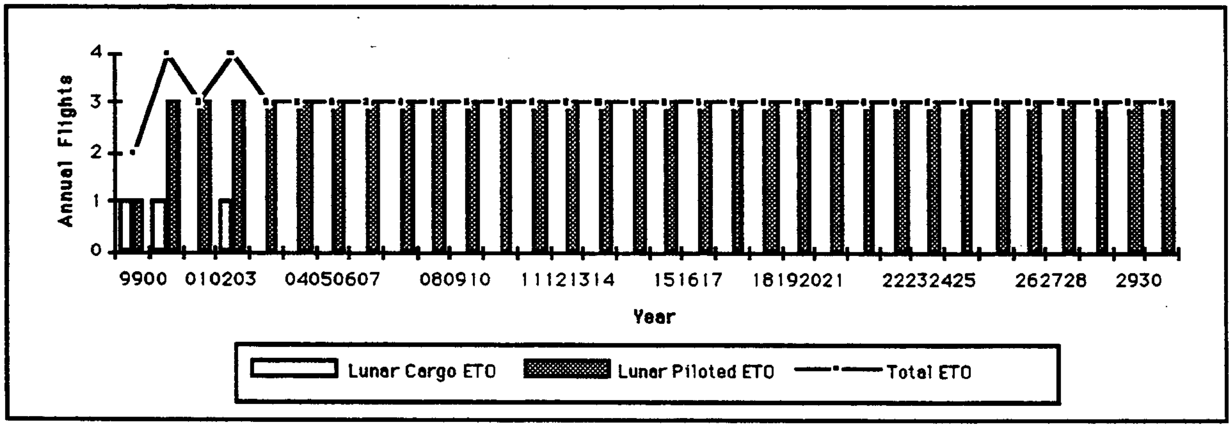

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Figure 3.4.6.3-5. FLO Annual Cargo and Crew ETO Flights

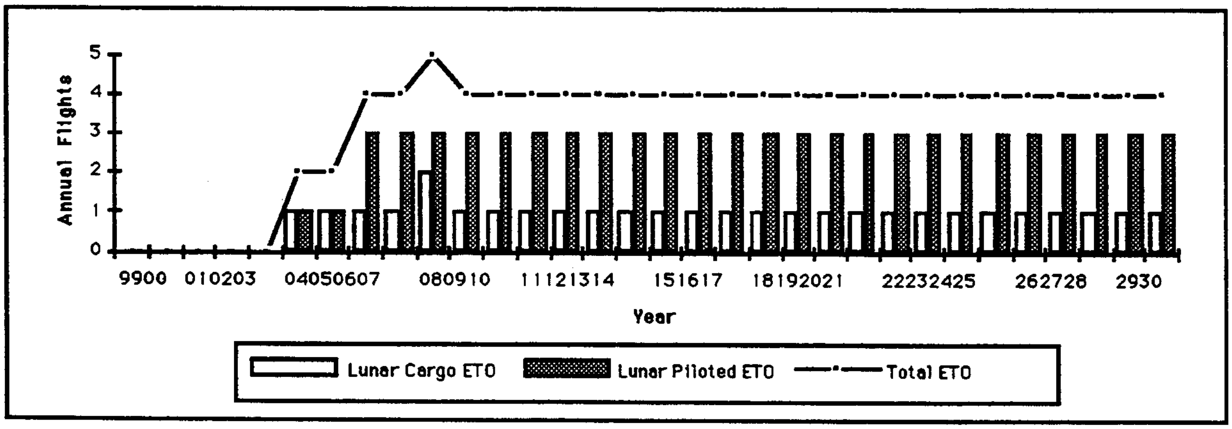

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Figure 3.4.6.3-6. Lunar Base Annual Cargo and Crew ETO Flights

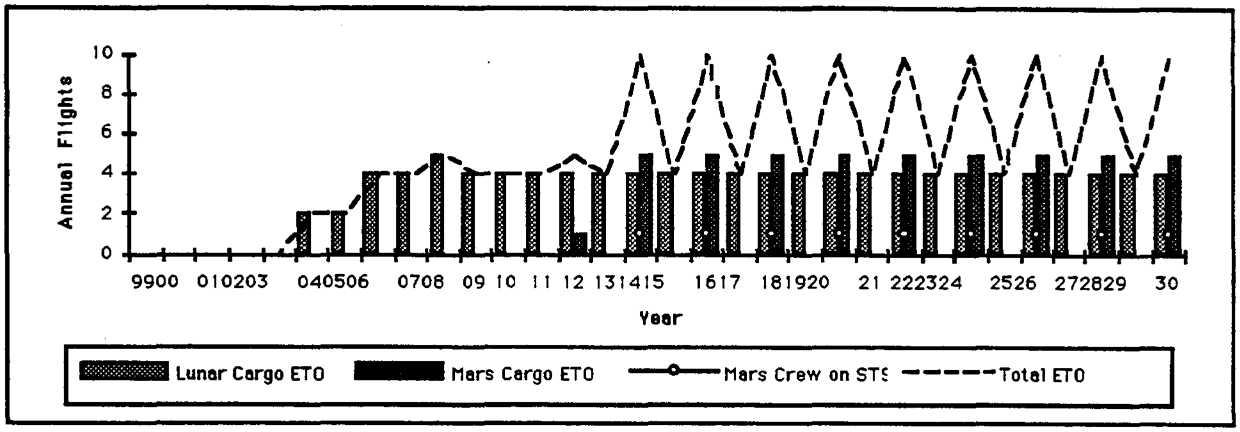

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Figure 3.4.6.3-7. Lunar Base and Mars Mission Annual Cargo and Crew ETO Flights

3.4.6.3.2 Space Application Description

The following paragraphs describe the three scenarios. Our goal is to examine various levels of exploration activity, ranging from relatively simple mission requirements such as in the First Lunar Outpost (FLO) to the all-up Lunar Base and Mars Exploration (LBME) scenario. It should be pointed out that these are generic cases for study purposes and do not represent approved NASA philosophy. All scenarios call for a launch vehicle capability of 250 mT or 550,000 lb to LEO.

First Lunar Outpost (FLO). The goal for FLO is to establish a continuing human presence on the lunar surface. Science and exploration activities will be conducted exceeding those of the Apollo programs. We expect significant return very early in the program with a limited investment strategy. Only three cargo-only flights to the Moon will be implemented to bring large payloads to the Moon's surface. The steady-state operations will each employ piloted missions with crews of four. Surface stay duration will be 45 days (lunar day-night-day), and revisit intervals will be every 5 to 6 months. The first cargo flight to the Moon is planned for 1999, followed by the first piloted mission in the same year. Typical mass to the surface will be 36 mT (about 79,400 lb) for either cargo and piloted mission.

Lunar Base (LB). The Lunar Base scenario represents the next level of activity beyond the FLO. Permanent facilities on the Moon surface will be established together with lunar transportation infrastructure to support frequent missions to the Moon. Major objectives will be to build the facilities towards life-support self-sufficiency capabilities. These include breathing gases and food production, waste management for extended human presence, sufficient and comfortable living space for routine activities with limited independence from Earth, and reliable communication and video link with Earth for science and education.

Permanent human presence on the Moon will give impressive scientific capability. Use of surface pressurized rovers and robotics assistants will extend human reach for great distances across the lunar surface. To achieve this extensive capability on the Moon, Lunar Base program will employ one cargo and one piloted flight beginning in 2004. Flight activities will step up in 2006 with one cargo and three piloted flights per year and continue at this steady-state mode throughout the time period considered in this analysis (1999 to 2030).

Figures 3.4.6.3-8 and -9 show generic piloted and cargo transfer vehicles with their payload configuration during trans-lunar injection (TLI). The cargo flight will be one-way, while the piloted flight includes the trans-Earth injection (TEI) stage to return the crew. The crew module will be designed to accommodate four to six people on each flight.

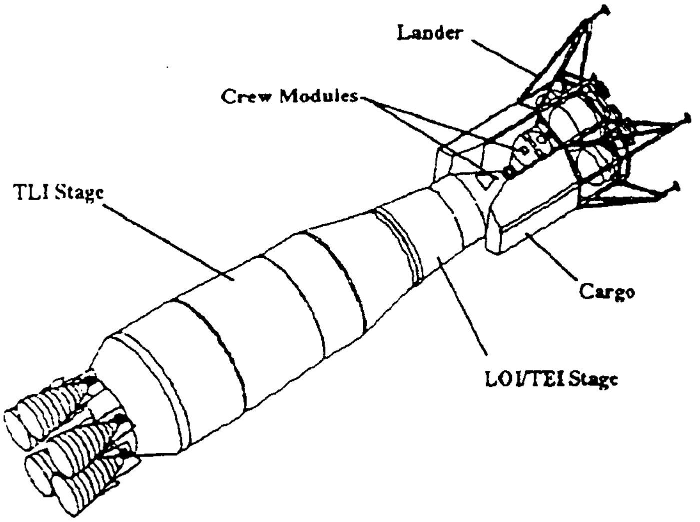

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Figure 3.4.6.3-8. Generic Lunar Piloted Transfer Vehicle

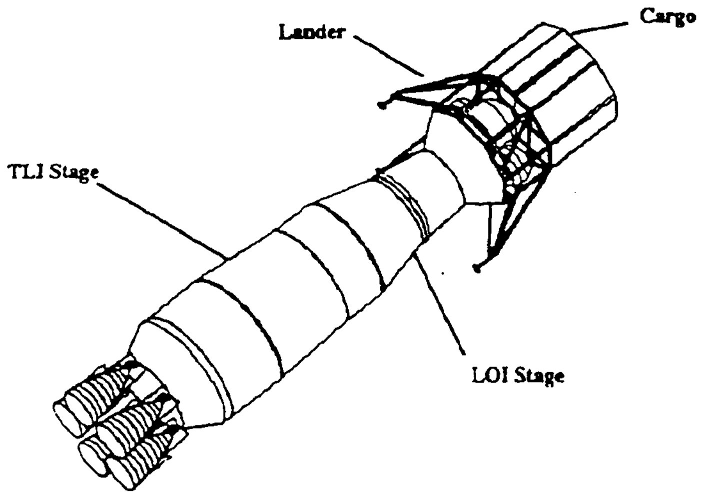

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Figure 3.4.6.3-9. Generic Lunar Cargo Transfer Vehicle

Lunar Base and Mars Exploration (LBME). This scenario is composed of the Lunar Base case described above, plus missions to Mars beginning in 2012 with a cargo flight on a one-way trip. Once the cargo mission success has been verified, a crew of four to six people will follow on a fast transfer opposition mission in 2014. This split-sprint mission concept will be used for the rest of the Mars missions when launch opportunities arrive about every 2 years. Nuclear thermal or other advanced propulsion concepts are required to enable Mars transits.

Figure 3.4.6.3-10 presents the Mars cargo and piloted mission configurations. Once at Mars, mission objectives will include extensive studies and exploration of the Martian system. Emphasis will be placed on returning the significant scientific data never before obtained. Surface stay for the first human visit will be up to 100 days, while subsequent stays of up to 600 days may be possible.

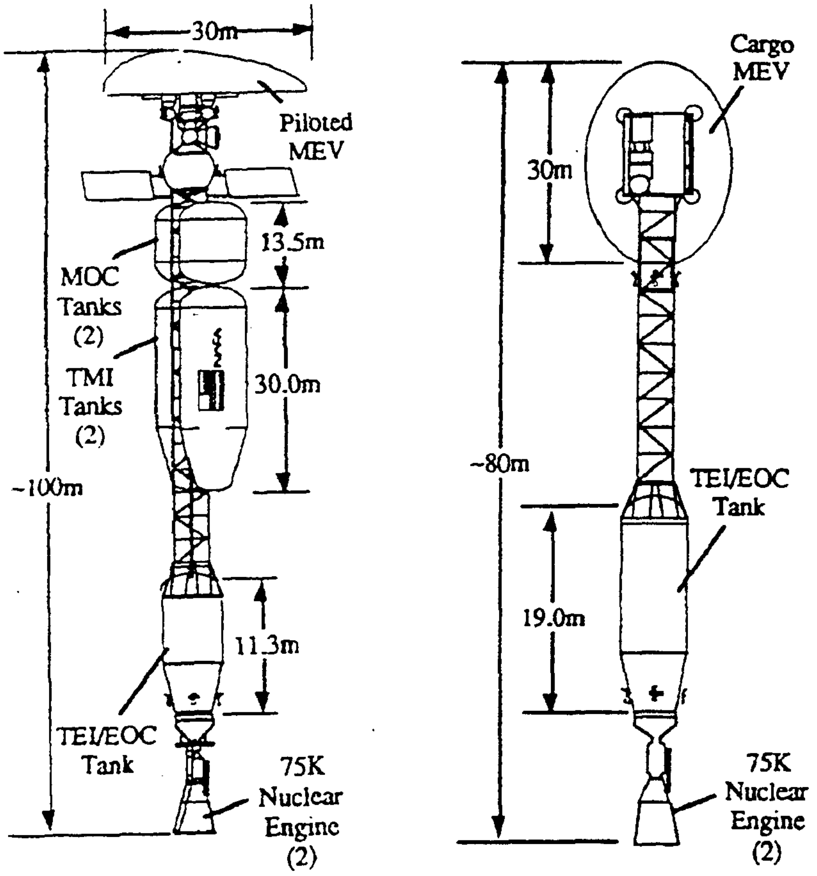

Figure 3.4.6.3-10. One Concept of Mars Piloted and Cargo Transfer System

3.4.6.3.3 Market Assessment

This market calls for an on-going capability to reliably launch cargo and people to low Earth orbit (LEO). This is critical in order to support and maintain existing activities on the Moon and Mars. As such the launch market should receive very high political and scientific priority if the exploration program is actually initiated. On the down side is, again, the noncommercial nature of the market, driven again mainly by political and scientific decisions. We do not expect commercialization of exploration missions to become viable in the time period considered, nor the launch market for these missions to be profit-driven.

The launch system requirements arrived at from this analysis will be examined within the context of commercial launch system compatibility. In other words, if it makes sense to build new launch systems that can provide economic transportation for both exploration missions and other commercial missions, then they will be identified as among the best concepts for further consideration in CSTS.

3.4.6.3.4 Infrastructure

For exploration missions, the total infrastructure would include telecommunication, navigation, and information management assets beside the "normal" infrastructure required by other missions, such as launch facilities, and mission control. Telecommunication assets include relay satellites, receiving stations, and other communications capabilities; navigation assets include navigation satellites and extraterrestrial control stations;

and information management assets include transmitting and receiving stations, data processing center, and relay satellites. However, for CSTS purposes, these are treated as part of the payloads delivered to LEO. This is because the mission for the ETO launch vehicle ends at LEO, so it is a valid assumption.

As a result, the Earth-based infrastructure would include only those facility assets that directly support the launch of exploration payload elements to LEO. The infrastructure to support a 550,000-lb payload would require many new facility assets. Among them are new transport capabilities (cargo planes, trucks, or barge), larger and more automated processing and checkout facilities (for larger cores, booster segments, propulsion systems and payload fairings), and larger payload processing and integration facilities (larger payload in terms of mass and volume). Furthermore, new launch facilities must be built for these launch systems to maintain a combined crew and cargo launch rate of 6 per year (FLO), 7 per year (LB) and up to 12 per year (LBME). Other more specialized facilities unique to exploration missions are crew training and mission simulation facilities, expanded mission control, communications, and data management centers.

3.4.6.4 Prospective Users

Our input came mainly from NASA documentation. There was not enough time available for specific user contact and interview. Again we expect that the U.S. government and its agencies, together with other nations' government agencies, to be the only users.

3.4.6.5 CSTS Needs and Attributes

3.4.6.5.1 Transportation Systems Characteristics

Our analysis shows the following as the most important characteristics for exploration missions ETO transportation systems. They are divided into manned and cargo system characteristics. An actual system design, when it is time to be considered, may include a mix of these characteristics for cost savings through system commonality.

Manned ETO delivery and return system. Crew delivery to orbit and return to Earth require highly reliable vehicles. Further studies have indicated additional features such as crew escape and abort capabilities to ensure crew safety at all segments of the ETO mission. The system must be available for scheduled launches, with contingent launch-on-demand for emergency situations. An upgraded space shuttle may provide for these capabilities in the near term. However, for steady-state exploration activities, a much more robust and dependable system must be built. Since most cargoes will be launched by the heavy lift booster (discussed below), the crew delivery and return system can have only small payload capability. Again the emphasis for this system should be on reliability, dependability, and availability. Crew launches range from three per year for the FLO scenario to three to four per year for the LBME scenario (see fig. 3.4.6.5-1).

Cargo ETO delivery system. As described in section 3.4.6.3.2, an ETO launch system of 250 MT or 550 Klb payload and a usable fairing size of 25 by 60 ft could satisfy all the three scenarios examined. The main differences are in the launch schedules, which range from three cargo ETO launches per year for FLO up to nine per year for the LBME case. It should be pointed out that this is based on the lunar and Mars vehicles shown in this report; any other vehicle design would require different launch booster. Figure 3.4.6.5-2 shows both lunar and Mars launch vehicles.

	FLO	LB	LBME
Lunar Mission			
Steady State Annual ETO Cargo Flights		1	1
Steady State Annual ETO Crew Flights	3	3	3
Mars Missions			
Steady State Annual ETO Cargo Flights			5
Steady State Annual ETO Crew Flights			0-1
Total Annual ETO Cargo Flights		1	6
Total Annual Crew Flights	3	3	3-4

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Figure 3.4.6.5-1. Summary of ETO Flights

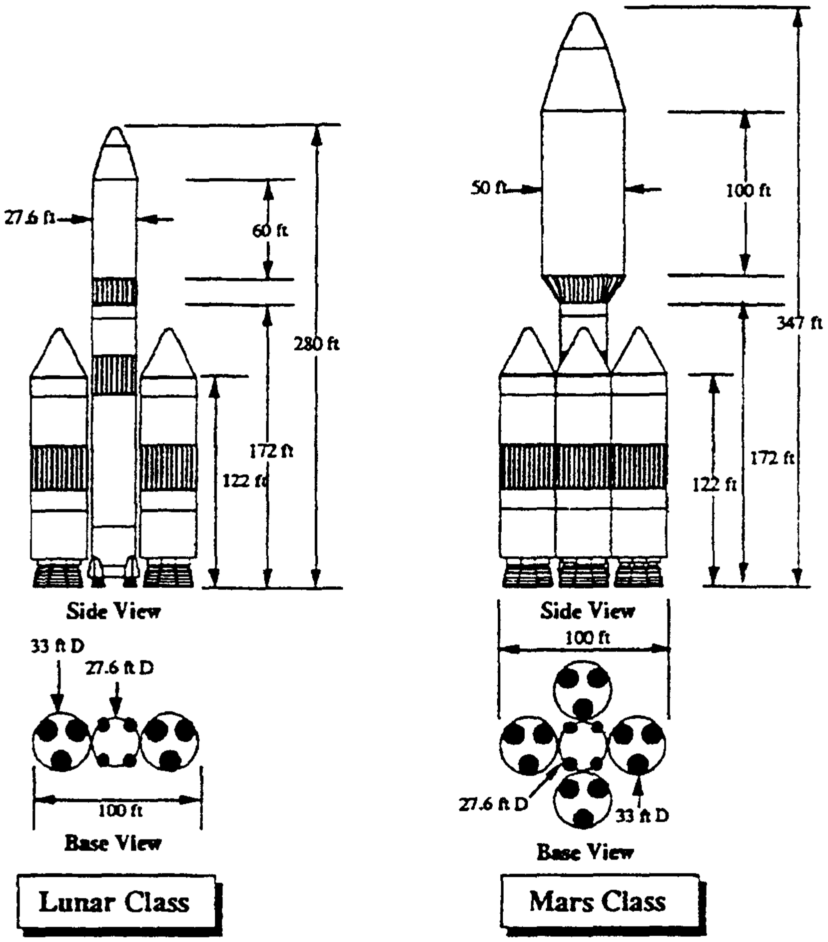

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Figure 3.4.6.5-2. Generic Lunar and Mars Class ETO Launch Systems

3.4.6.5.2 Ground Segment

All existing facilities (e.g., at Eastern Test Range) are expected to be fully utilized to support exploration missions. Many of the Shuttle facilities were actually upgraded Saturn facilities, so it should be no surprise that existing facilities will be modified for lunar and Mars mission support. However, since very large launch systems and payloads will have to be accommodated, we expect some major work to be done to the Vertical Assembly Building (VAB), the launch pad, the Payload Processing Facility (PPF), and so forth.

Other totally new facility elements may have to be built. These include integration facilities for the larger core and booster segments, integration facilities for the lunar and Mars payloads (including for the possible use of nuclear engine in the Mars Transfer Vehicle), and the Mobile Launch Transporter, which is necessary for transport the vehicle stack from the assembly building to the launch pad. Detailed analysis of the ground segment requirements and their cost has not been performed in this analysis. However, we expect them to take a major cost portion of the exploration program.

3.4.6.5.3 User/Transportation Interfaces

There are standard interfaces for both manned and unmanned cargoes. The lunar and Mars payloads are not expected to require any added services from the launch vehicles compared to existing scientific payloads. The standard fluid, data, power, and environmental services will all be provided by the launch system. Those payloads to be flown on the cargo or piloted flights leaving Earth are expected to be similar in physical characteristics. The astronauts are to be launched either with their cargoes (as in the FLO scenario) or separately to LEO by a manned launch vehicle.

3.4.6.5.4 Improvements Over Current

Because of the inherent requirements of manned exploration missions, the launch systems must be designed to have higher launch rate, more dependable and reliable performance, and higher mass to orbit capability. This alone makes the new system a great technological improvement over existing systems. It is a much different story when it comes to system costs, since there is nothing to compare the new system to, as existing systems are not in the same class as lunar and Mars launch systems; our largest existing booster (the Titan IV) is rated at 40,000 lb to LEO. This is not even 10% of the performance required for exploration missions (550,000 lb to LEO).

Our findings indicate that reducing launch cost does not necessarily impact the whole exploration program in any major way. This is because in a program as big, expensive, and high-risk as the exploration missions, the most important issues are those related to ETO, transfer and lander vehicle system performance, crew safety, amount of science returns, and total mission success. In this instance ETO launch costs are of secondary importance. Therefore we think, for exploration missions, cost improvements over current assets are not applicable.

3.4.6.5.5 Management and Policy

As mentioned previously, lunar and Mars missions are expected to be mainly a government program. There may be joint efforts between partnering governments, and it is very unlikely to become a commercial operation involving profit-driven missions and operators. We also think that such missions will very likely require top priority in government programs once the program reaches steady state. This is to ensure continued mission and crew support on the Moon and Mars. Technological challenges aside, the most important factor that will make exploration missions possible may be commitment for long-term and stable funding. Without this policy, technological breakthroughs alone won't take people off planet Earth.

3.4.6.6 Business Opportunities

3.4.6.6.1 Cost Sensitivities

As explained throughout this paper, we think exploration missions are somewhat insensitive to ETO launch costs. In other words, payloads delivered to the Moon and Mars serve specific scientific goals that are independent of ETO launch costs. For example, the FLO program is based on technological constraints that resulted in planned revisits every 6 months with a 45-day stay time per sortie. In addition, the surface payload is driven by the level of activities defined for the scenario, which is again independent of ETO launch costs.

For Mars missions we have similar mission definitions that govern the mass delivered to the Martian surface. On top of this there are only specific launch opportunities to launch to Mars. Large ETO launch cost reduction (as shown in fig. 3.4.6.6-1) does not directly improve launch opportunities. Rather it may enable larger ETO payloads (larger transfer vehicles, more propellant, etc.) which allows larger mass delivered to the destination, a consideration that has not been addressed in the present analysis.

LEO Performance = 550,000 lbs

Dollars per pound >>>	$10,000/lb	$1,000/lb	$100/lb
Cost per Flight >>>	$5,500 M	$550 M	$55 M

111264-062

Figure 3.4.6.6-1. Per-Launch Cost Goals for Lunar and Mars ETO Systems

3.4.6.6.2 Programmatics

Figure 3.4.6.6-2 shows the launch schedules for the three scenarios. Included are both the planetary mission schedules and their associated ETO support flights. Note that these schedules represent steady-state operations and do not include precursor missions, which will be necessary for establishing landing sites and other mission parameters.

We have identified three main issues that will make or break any one of these exploration programs. The problem is not in the lack of interests or goals. Rather, the issues are—

a. Political support. Political support is one of the biggest hurdles before an exploration program can take shape. With the high-cost, high-risk characteristics associated with lunar and Mars missions, decision-makers will not approve such programs.

b. Technology development. Advanced technologies such as in propulsion, environmental, and control systems must be developed. Many technology areas—too numerous to mention—here have been identified as providing both enabling and enhancing capabilities. Most of them must be available in the aggressive timeframe called for.

c. Funding. Both of the above-mentioned issues are related to the question of whether or not money is available for such project. In fact all issues come right back to this one issue, for with enough funding many technological and political problems can be overcome.

FIRST LUNAR OUTPOST

	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Lunar Cargo Flight	1	1		1																												
Lunar Piloted Flight	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
550Klb ETO Cargo	1	1		1																												
550Klb ETO Piloted	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
TOTAL ETO	2	4	3	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

LUNAR BASE

	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Lunar Cargo Flight						1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Lunar Piloted Flight						1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
550Klb ETO Cargo						1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
550Klb ETO Piloted						1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
TOTAL ETO						2	2	4	4	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

LUNAR BASE & MARS MISSION

	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Lunar Cargo Flight						1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Lunar Piloted Flight						1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Mars Cargo Flight														1		1		1		1		1		1		1		1		1		1
Mars Piloted Flight																1		1		1		1		1		1		1		1		1
550Klb ETO Lunar Cargo						1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
550Klb ETO Lunar Piloted						1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
550Klb ETO Mars Cargo														1		1		1		1		1		1		1		1		1		1
550Klb ETO Mars Piloted																4		4		4		4		4		4		4		4		4
Mars Crew on STS																1		1		1		1		1		1		1		1		1
TOTAL ETO						2	2	4	4	5	4	4	4	5	4	10	4	10	4	10	4	10	4	10	4	10	4	10	4	10	4	10

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Figure 3.4.6.6-2. Launch Schedules of the Three Scenarios

3.4.6.7 Conclusion and Recommendations

Exploration missions push the ETO launch requirements above and beyond any existing capability. It is expected that all new systems must be built to carry out these missions. Existing Earth ground facilities are expected to contribute to the infrastructure required to support exploration missions with appropriate modifications.

In summary, exploration missions are mainly government missions with heavy emphasis on science and technology development together with manned activities in space and on the moon and Mars. They do not lend themselves readily to commercial applications, nor do they provide for a viable commercial launch market. Findings on transportation requirements for this market segment should not be used as a standalone blueprint for a future launch system. Rather they should be considered as secondary design requirements after more realistic near-term missions.

3.4.7 Asteroid Detection/Negation

3.4.7.1 Introduction/Statement of Problem

Within the past few years, there has been a general increase in awareness (by astronomers and by the general public) of the potential threat to Earth from the impact of extraterrestrial bodies. There have been proposals for large efforts to detect and defend against "Dinosaur Killer Comet Impacts." A more probable scenario is a continuing effort for the ground detection of these objects, with some possible future space-based detection efforts. No short-term defense measures are likely to be undertaken, unless there is a specific hazard detected.

In the year 1800, the first of a new class of objects was discovered, Ceres, which was termed an "asteroid." There are now more than 30 asteroids known with diameters between 200 km and the 940-km diameter of Ceres; one of these, Chiron, was discovered as recently as 1977. There are more than 4,000 smaller asteroids we know enough about to justify assigning a number to them. At first, asteroids attracted little attention; they were small, and far away, between Mars and Jupiter, and they seemed to have little practical effect, except for occasionally streaking an astronomical plate. Though there has been only minimal effort at deliberately finding asteroids, not only is the number of discoveries increasing, but the rate of discovery is accelerating.

In 1976 an unusual asteroid (named Aten) was discovered that has a mean distance from the Sun less than that of the Earth. In ordinary scale illustrations, it is impossible to distinguish Aten's orbit from that of the Earth; fortunately, it has a somewhat different inclination from ours. In the intervening years, a total of a dozen Aten class (mean distance less than Earth) asteroids have been discovered, despite the difficulty of observing them (most asteroids are discovered when they are near opposition, the point directly away from the Sun as viewed from Earth).

As new discoveries of asteroids were made, not only did they come closer to Earth, but they expanded in other directions as well, further away from the sun. Chiron, for example, is always beyond the orbit of Saturn. It was further found that asteroids overlapped with a number of other previously known phenomena. It is now recognized that asteroids are merely another manifestation of the same class of objects as most meteors and meteorites, and that they also are not clearly distinguishable from comets, which are another class of "minor members" of the solar system. Comets are thought of as being "dirty snowballs" in very eccentric orbits, and being characterized by a tail. "Typical" asteroids are stony or metallic and are located between Mars and Jupiter. It is now known that there is considerable overlap, and some "asteroids" are comet cores, which have lost most of their volatiles, and both comets and asteroids can be in a much wider range of orbits than was previously recognized.

It has also become recognized that impact craters, far from being rare, are a distinctive and common feature of nearly every body in the solar system, including the Earth. Much publicity has been associated with the theory that a large event approximately 65 million years ago was responsible for widespread environmental change on the Earth and massive extinctions, including the dinosaurs. There are more than 100 features on Earth that are recognized as impact craters. This is a small number compared to the Moon, for example, due to atmospheric shielding, and weathering, but it is sufficient to make it reasonable to assume that the impact rates are similar for Earth as for other planets.

There are still many uncertainties in the hazard that impacts of the Earth by comets and asteroids represent, and even greater uncertainty with the specifics of mitigating such potential impacts, by deflection, for example. Though no one is definitely known to have been killed by the impact of any extraterrestrial object, it has been calculated that averaged over a long period of time, these objects could be responsible for more deaths than commercial airplane accidents. The hazard can be considered in two parts; local events (resulting in one to many fatalities in a relatively confined region), and global events (potentially killing most or all humans and resulting in the extinction of many species). There is considerable disagreement about the relative risks of events of various sizes. Everyone agrees that the effects of a global event are of great concern, the ultimate catastrophe. Estimates of the size of object which would cause such an event range from less than a kilometer to no more than 10 kilometers.

It is likely, based on a number of sources of data, that a 2-kilometer object (with an equivalent yield of about 1 million tons of TNT), should impact the Earth about once every million years. An impact of this size is roughly in the middle range of estimates of global extinction events. Since the number of known extinction events is much lower than that, we may be due for a run of bad luck. There are a number of known asteroids of considerably larger sizes than is required for global extinction events. It is known that while none of the very large asteroids are in orbits that can impact Earth in the space of a few centuries, some, such as Chiron, are in potentially unstable orbits that could have potential for Earth impact in relatively short time periods. In addition, there are many objects much farther out from the Sun than the known asteroids (e.g., long-period comets), and so far as the present state of knowledge is concerned, the size of these objects is not bounded. Very small-size impactors are very common, and do little or no damage. They are also difficult, if not impossible, to detect very much before impact, and therefore are essentially impossible to defend against.

The largest impact in this century, at Tungusha in 1908, is now believed to have been a very ordinary chunk of stony asteroid, probably about 50 meters in diameter with a yield of perhaps 10 megatons, sufficient to destroy all the buildings in a 25-km radius (large enough to destroy a city the size of Los Angeles). Note that this size is well below the threshold that experts think can be detected or defended against. However, the odds of the impact occurring in a heavily populated area are small (the actual Tungusha is not known to have resulted in any fatalities, and there is some evidence that the Earth is impacted by one "Hiroshima" size object every year, but few are noticed). The best estimate is that on the average an impact of that size would “only” kill 5,000 people (those in a 20-km radius). It is estimated that the recurrence interval for Tungusha-size events is about 300 years. Some estimates are that the odds of a major U.S. population center being hit by a Tungusha-size event are so low that all of them will be destroyed by a larger event, all at once, before any one of them is destroyed by an impact this size.

Currently the most infamous event is the "KT boundary impact" (dinosaur extinction theory) which is thought to have been approximately 10 kilometers in diameter, with a yield of around 10^8 megatons! Events of that size are predicted to occur about once every 10 million years, which could indicate that some have occurred and were not noticed, or that some are missing.

It is this size object, or a bit smaller, that would be most likely to be detected in time for defensive action, and for which a defense would be technologically possible, in the foreseeable future.

At the upper limit of impact size, there is a very small (but not zero) possibility, of a very large-sized long-period object, one that has never (or at least not in the last several millennia) entered the inner solar system, appearing "over the celestial horizon" at any moment; if it were on an collision trajectory, it would be only a few months from impact. Long-period comets can enter the solar system in such a way that they are always near the Sun, from an Earth perspective, and therefore may never be visible until very shortly before they impact Earth. Such an object might not be deflectable by nuclear devices, even ones that are many orders of magnitude greater in yield than any which have yet been constructed. This is true even if very large nuclear devices were instantly available for launch, and even if the launch vehicle had performance far in excess of any present system. In other words, the worst possible scenario is not preventable with present (or even presently foreseeable) technology.

In the mid sizes, around 1 kilometer, deflection might be possible with systems that could be available on notice of a few years (if the deflection can be made years in advance, very small velocity changes are sufficient to cause safe misses). The most probable class of impactor in the 1-km size range is a "near Earth" asteroid. It has been estimated, based on several approaches, including the size distribution of larger asteroids, that only 5% of the potentially species-threatening 1-km-diameter objects have been observed.

Another hazard posed by asteroid/comet impacts is the possibility of mistaking the airburst of a small object for a nuclear attack. On October 1, 1990, DOD sensors detected a 40-kiloton explosion over the southern Pacific Ocean. Had the object exploded not in the south Pacific but over the Middle East, it could have been mistaken for a nuclear attack. For this reason it is of interest to catalog even the smaller objects.

3.4.7.2 Study Approach

Options for detection and negation were discussed with experts in the field to ascertain the rough parameters and launch rates of probable space-based assets.

3.4.7.3 Market Description

3.4.7.3.1 Description Market Evaluation

One class of objects that are a potential major threat, and which are difficult to find by ground search are the Aten class asteroids. These are Earth-crossing asteroids that have mean orbits inside that of Earth. Since the most effective way of observing asteroids is by looking directly away from the Sun, and since the Atens are usually between the Earth and the Sun, they are very difficult to observe. The first was found in 1976 and there are only about a dozen known, but due to the bias in the observing techniques, there could be many more, any of which could be a potential impactor, very likely from "out of the Sun," a direction from which even a large object might not be observed before impact.

It has been proposed that a very suitable location for a space-based optical asteroid detection system would be in orbit around Venus. From that location, it would be in an ideal location to observe asteroids in the vicinity of Earth, and would also benefit from the shadow of Venus when observing "at opposition" (away from the Sun.)

Additional optical systems would possibly be advantageous at other points in space. The Earth-Sun system Lagrange point, L1 (the "interior" or "halo orbit point") has been suggested. L4 and/or L5 of the Earth Sun system or L3 of the Venus-Sun system (the "anti Venus" point) might also be candidates. Some of these locations might be especially valuable for detecting long-period comets on Earth-impacting trajectories that are too difficult to see from Earth because the viewing angle is always too close to the Sun.

Since advance warning is of the utmost importance with these objects, it will likely be considered worthwhile to investigate detection methods, other than optical. One such technique that has been proposed is that of radio waves ("Alfven Waves") caused by the flow of the solar wind over any impermeable object. These waves are of low frequency and do not penetrate the Earth's ionosphere.

Although suggestions have been made that the international community should immediately adopt a program that would include very ambitious programs in deflection devices, and very advanced "Orion" type propulsion systems to deliver them, others have expressed the concern that such a program, and the problems of control of devices that are very similar to weapons that could be used against more conventional terrestrial targets, would be a greater hazard than the extraterrestrial threat they are designed to meet.

At some point, possibly in 5 years to two decades, there may be sufficient interest to justify one to four space-based optical systems, which would possibly be of the Hubble (2.4-meter aperture) class, or slightly less (say 1 to 2 meters aperture). These would be placed in locations, probably at or inside the Earth's orbit, with large average circumferential displacements (to minimize "blind spots") being desirable. Venus orbit is probably the most likely location for a first deployment. These observatories would require probably no more than one equivalent shuttle launch each, and would likely be distributed over a span of a decade to put in place. Maintenance is unlikely, and some eventual replacement of failed systems would be expected to be required.

Subsequently, systems using other advanced detection techniques, such as radio waves, might be deployed. These would likely be deployed no sooner than 5 years after the first of the optical observatories, and probably at no higher launch rate (say one every other year for 10 years) .

It seems very unlikely that any pre-positioned, Earth-based, or space-based deflection devices or delivery systems would be deployed prior to the development and deployment of significant space-based detection systems. If a threat were to be detected by the detection systems, then the development of deflection devices, and deployment systems could be expected to proceed with high priority.

The most likely scenario for actually deflecting an incoming object is thought to be that we will have years or decades of warning. An object will be discovered to have an orbit that will evolve into a collision course only after several subsequent orbits. These objects will be able to be studied by precursor missions to determine the best way to deal with them. Most likely, they will be able to be diverted at their perihelion by ΔV's of only cm's/s. For a 1-km-sized object, this translates to only modest power requirements (dependent on the physical properties but likely no more than a few kilotons on the high side). These can be met by chemical rockets and conventional explosives, although the larger objects would require nuclear bursts.

Leadtimes on the order of only a year or two pose much greater difficulty. High-energy upper stages (well out of scope for other CSTS missions) and high-energy explosives would be required to divert such an object.

Leadtimes of only weeks or days would leave very few options. Only incredibly powerful space-based defenses could hope to avert disaster and such attempts are not given a very high probability of success. Although with sufficient radar data, the object's entry can be modeled and an impact point be estimated, contact binaries make the accuracy of such modeling even lower than it currently is. Therefore, evacuation may not be very efficient. The possibility may exist to divert the object to a less populated region, although the political implications are not very savory. Also, if a mistake were made, the new impact site could result in more damage than if the object's course not been altered. Newly available data from DOD sensors that record several airbursts per year may make modeling of the entry of impactors more accurate in the future.

If an object large enough to cause a global catastrophe is detected only days or weeks out, an attempt may be made to fracture the object, even if it meant there would now be several (albeit smaller) pieces. It would certainly seem desirable to reduce the threat from a global one that threatens civilization to a few regional ones.

Figure 3.4.7.3-1 is an example of the increasing difficulty of dealing with short warnings. This figure assumed a near-Earth object (NEO) 2 km across. The body is assumed to have been fractured in half. The energy shown is that required to impart sufficient ΔV to both halves so that they miss Earth, assuming interception occurs at the specified range. Although no estimate is made of the energy required to fracture the object in half, it should be noted that such energy may actually be quite small if the phenomenon of contact binaries turns out to be the rule rather than the exception, as newly discovered evidence seems to indicate.

Actual scenarios for diversion are also greatly varied. Concepts involving explosives include surface bursts, standoff bursts, and subsurface bursts. Surface bursts seem to be the best. The explosive vaporizes material in the formation of the crater and the ejecta provides the impulse to divert the offending object. A standoff burst would be used for an object like a comet that it was feared could fracture into several lethal pieces. Such a burst would use the neutrons to heat a surface region and blow off material for impulse. However, such an explosion would likely have to be two orders of magnitude greater than a surface burst imparting an equal impulse. Subsurface bursts would require penetrators that could be prohibitively large depending upon the desired depth and size of the explosive device. Also, some physical knowledge of the object would be required, depending upon if the desire was to simply deliver an explosive just deep enough to blow more material off than a surface burst or if the penetrator is aiming for the center of mass in an attempt to destroy as much of the object as possible.

With increasing leadtime come increasing options. Some more exotic proposals include laser deflection, solar sailing, mass drivers, rail guns, and mining. These all require considerable development.

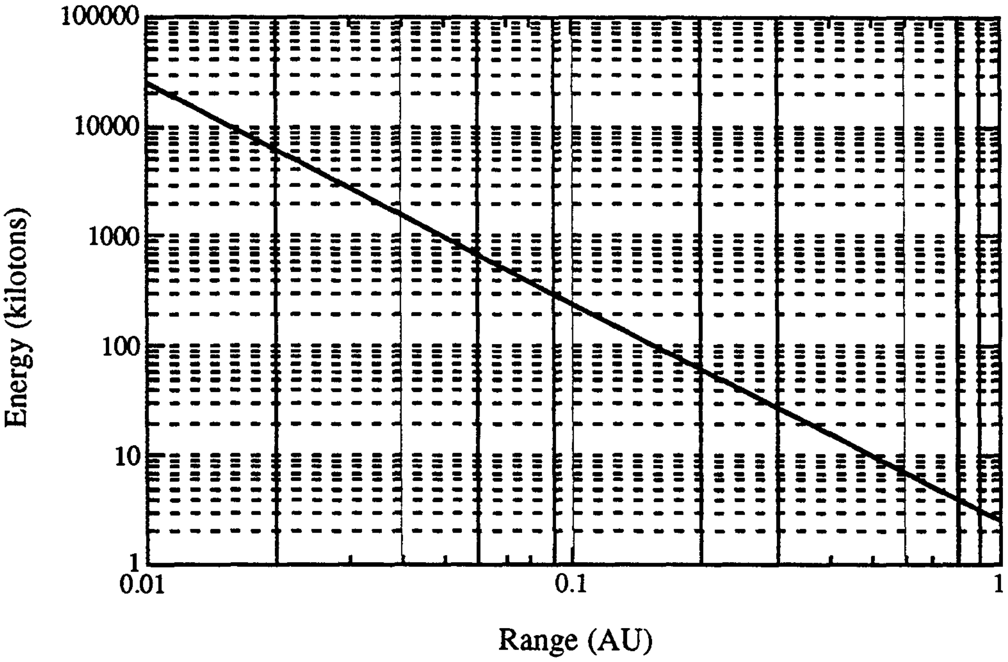

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Figure 3.4.7.3.-1. Interception Range Versus Explosive Energy

3.4.7.3.2 Market Evaluation

Before considering any defensive measures, potential threats must be detected. Various detection methods have been investigated, and a proposal made for an Earth-based system that would quickly detect most of the 1-km size, Earth-approaching objects. The full system would cost $50 million, a very small cost in terms of any possible near-term space-based system. This system would consist of six telescopes of 2- to 3-meter aperture with advanced charge-coupled device (CCD) detector arrays, and associated computers.

Technology advances in computers, electronic devices, and telescope construction will probably ensure that much of the proposed program for ground-based systems will be accomplished, regardless of the level of support by any particular government. This is an area in which many nations, and even nongovernmental organizations and individuals, can make contributions. It has been estimated that there are hundreds to thousands of objects in this class that are already recorded on existing telescopic survey plates and which require only scanning and computer analysis for discovery.

However, in 5 to 20 years, it is thought that a point of diminishing returns will have been reached for ground-based search techniques. At that point, space-based systems would be more cost effective at searching space without interference from our atmosphere.

3.4.7.3.3 Market Assessment

Initial market assessment can be based on the results of an NEO detection workshop The summary of the workshop presented a plan for increasing the detection of NEOs. The proposal called for the construction of six 2- to 3-meter aperture ground-based telescopes, three in each hemisphere. Within 25 years, the system (Spaceguard) should detect virtually all the near-Earth asteroids (NEA) 1 km and larger. This size was somewhat arbitrarily chosen as the threshold at which an impact had global repercussions. Hundreds of thousands of smaller size NEAs (these included short-period but not long-period comets) would also be detected.

The cost of such systems, deemed adequate for detecting virtually all threats except long-period comets, has been estimated at $50 million for capital and $10 to $15 million operating costs. Because of the international nature of the problem, the committee assumed a U.S. budget of $16 million for two of the six telescopes, $2 million for the operations center, and operating costs of $5 million per year.

The requirements for space-based telescopes were not defined in the workshop and are not really defined anywhere, but some inferences can be made from the recommendations for ground-based telescopes. Any space-based telescope that is more than a few (less than 10) light minutes (round-trip time) from Earth would need to have the computing capability to autonomously process all the data it collects. This is because a larger portion of the sky must be scanned, since fewer telescopes would probably be built. The onboard computers must have the capability to analyze the CCD images for moving images and identify nonstellar objects. After several scans, ephemeric data must be produced and compared to the database of known objects. Anything that may pose a threat to Earth must be instantly relayed to ground controllers. All data would ultimately be desirable, as they would augment existing databases.

A telescope near Venus or Mercury designed to spot Atens could have a relatively short design life if it were designed to detect most of the Atens in a short period of time. However, because long-period comets usually make only one appearance, the telescopes used to detect them must have long lives and be continually replaced. This is because the threat from new long-period comets is constant. Support and replacement missions would be necessary for such devices.

Despite the fact that long-period comets are estimated to be 25% of the threat, it is doubtful that extensive space-based detection systems will be advocated or funded in the near future. The currently proposed ground-based Spaceguard system should provide adequate detection for global-catastrophe- sized objects well into the next decade, and has an even chance of detecting the next "Tungusha" sized object as well.

For a rough estimate, it is assumed that one 30,000 lbm-LEO equivalent payload is launched every 5 years.

3.4.7.3.4 Market Infrastructure

There will be some interface with tracking and data collection sites, such as the Deep Space Network. In addition to scheduled launches of detection platforms, there may be the occasional unscheduled (short callup) launch to investigate and/or deflect a threatening object, requiring some flexibility at the launch site.

3.4.7.4 Prospective Users

Although the initial space-based system is not too expensive, the customers will still be a government or governments, perhaps in the form of the United Nations. Of course, asteroid impacts are a global concern, and perhaps all nations could contribute proportionally. It has been suggested that insurance companies may be interested, but the cost of a deflection/negation system would probably be so huge that only governments could afford it.

In preparation of the technical aspects of this market segment, contacts were made with Los Alamos National Laboratory and the Department of Planetary Sciences at the University of Arizona.

3.4.7.5 CSTS Needs and Attributes

3.4.7.5.1 Transportation System Characteristics

Emplacement of the space-based emplacement assets is within the technology and size of today's launch vehicles. Scheduling is somewhat flexible, although missing a window could degrade the integrity of the sensor constellation. Reusable upper stages are probably not realistic, given the location of the assets.

No estimate is made here for the size or capability of the transportation system associated with deflection/negation.

3.4.7.5.2 Transportation System Capabilities

For detection concepts, including optical platforms up to the Hubble Space Telescope class, the ΔVs to get to the anti-Venus point is approximately 11 km/s.

3.4.7.5.3 Ground Handling

For space-based sensor systems, no unique ground facilities are contemplated. If one considers active deflection/negation flights, there will be a considerable quantity of high explosives, propellants, or nuclear weaponry integrated at the launch site.

3.4.7.5.4 User/Space Transportation Interfaces

Interfaces would look like any other interplanetary payload with an expendable upper stage.

3.4.7.5.5 Improvements Over Current

For the initial detection phase, current performance, reliability, and cost would be acceptable. Negation missions would require very high reliability, as there would be only one "shot" to perform the mission.

3.4.7.6 Business Opportunities

3.4.7.6.1 Cost Sensitivities

No cost analysis was performed as relates to the cost of transportation. It is suspected that, if some governments undertake such a project, the market is inelastic to launch cost.

3.4.7.6.2 Programmatics

The timing of this market segment will be driven by the public's perceived need for such a system; it is not technology driven in the observation/detection phase. Negation missions are so variable in their size and complexity that there is no way to credibly estimate programmatic requirements.

3.4.7.7 Conclusions and Recommendations

A wide variety of opportunities exist for CSTS from asteroid detection/negation scenarios, although none are likely to be funded by the U.S. Government in the near term. They range from missions achievable with current or near-term technologies to those requiring years of development. The most likely customers are governments, although certainly not limited to the U.S. Government. Other countries have stakes in detection and deflection as well, since the threat is global in nature, although few countries are equipped to deal with them alone. In any event, asteroid detection/negation is not a driver mission for a new commercial vehicle.

3.4.8 Emerging Nations Missions

3.4.8.1 Introduction/Statement of Problem

This section describes the market for space launch services of emerging nations. Emerging nations include those countries that are rapidly moving away from undeveloped status towards industrialization, for example, South Africa, South Korea, India, Israel, and Pakistan. This market postulates that these nations will create a demand for space launch services as they reach industrialized status.

3.4.8.2 Study Approach

Our approach started with an identification of nations with a growing industrial base and space activities either in the formative stages, or in operation. However, many of these activities are redundant to other market areas like remote sensing, communications, and space science. After review of these redundant areas it was determined that there were no separate and distinguishable missions in this market. A few countries were assessed as having indpendent space transportation programs. These market areas were not addressable CSTS markets for a new, low-cost space transportation system, since these space transportation programs are not driven by economic factors. Space transportation developments in these nations appear to be driven by national pride and prestige, and military considerations more than economics. All of the potential missions from these countries are covered in the other market areas.

3.4.8.3 Conclusions and Recommendations

Since we could not find missions for this market area that were not covered by another market area it is recommended that this market be defocused. The reader should refer to the functional market area for a discussion on the contribution of emerging nation missions to the entire demand.

3.4.9 Space Science Outwards

3.4.9.1 Introduction/Statement of Problem

Scenario (Launch Control commentary):

. . . four . . , three . . , two . . , one . . , we have liftoff! ! ! We have liftoff of Erudition 1 with its payload, Parhelion I spacecraft!

This launch marks the maiden flight of the Erudition launch vehicle! A new era in space science research has dawned! Erudition, the new and astoundingly low-cost space launch vehicle for small-sat class payloads, is streaking heavenward with seeming indifference!

. . . At 25 seconds into the flight, Erudition's main engine is burning well.

Parhelion I is the first in a series of six University of Academia/General American Astronautics (UA/GAA) contracted research science missions that will fly graduate student projects aboard Erudition launch vehicles over the next 2 years. The objectives of the Parhelion missions are to increase man's knowledge of our nearest stellar neighbor and to increase awareness of our dependence upon the Sun, whose strong gravity pull maintains the orbit of Planet Earth and whose radiation energy flux maintains all chemical reactions, including life itself.

. . . At 1 minute 15 seconds into the flight, Erudition is approaching maximum dynamic pressure, or Max. Q. UA students, responsible for development and operation of the spacecraft, report that the telemetry data indicate that all flight parameters are nominal. Erudition 1 continues to burn well.

Erudition is lifting the Parhelion I spacecraft into a low Earth orbit, where the spacecraft's upper stage will take over and inject the satellite into a heliocentric orbit. Parhelion I will employ a new guidance and navigation software package developed by graduate student John.

. . . At 5 minutes and 30 seconds into the flight, everything still looks very good! All planned events to this point in the flight have happened right on time!

Erudition's low cost and service-oriented philosophy have universities and contractors scrambling to convert their newfound launch cost and schedule savings into additional missions.

For the purposes of this research we have defined space science outwards (SSO) as any mission with a scientific focus on celestial bodies (other than Earth) and on space physics. This includes missions whose goal it is to advance knowledge in the areas of—

a. Astronomy.
b. Solar/space physics.
c. Unmanned planetary exploration.
d. Celestial/orbital mechanics.
e. Near Earth objects.

Other space science areas such as remote sensing, space technology demonstrations, space manufacturing/processing, microgravity research, and life sciences are covered under other market segments.

The purpose of SSO missions is to conduct pure scientific research to increase mankind's understanding of the universe in which we live. In principle, the opportunities for SSO missions are unlimited because the science content of the universe is unbounded (at least from mankind's current perspective). However, these missions are not commercial in nature and as such do not produce immediate sources of revenue for companies to exploit for profit. Funding for SSO missions is normally dependent upon federal governments and, to a much smaller extent, local governments (for example, states) and personal grants. Our analysis approach will account for the budget limitations imposed by the finite nature of tax revenues and competition for those funds.

3.4.9.2 Study Approach

Our approach to understanding the SSO demand elasticity as a function of launch vehicle costs is presented in figure 3.4.9.2-1. The methodology was composed of five primary steps. They are described below.

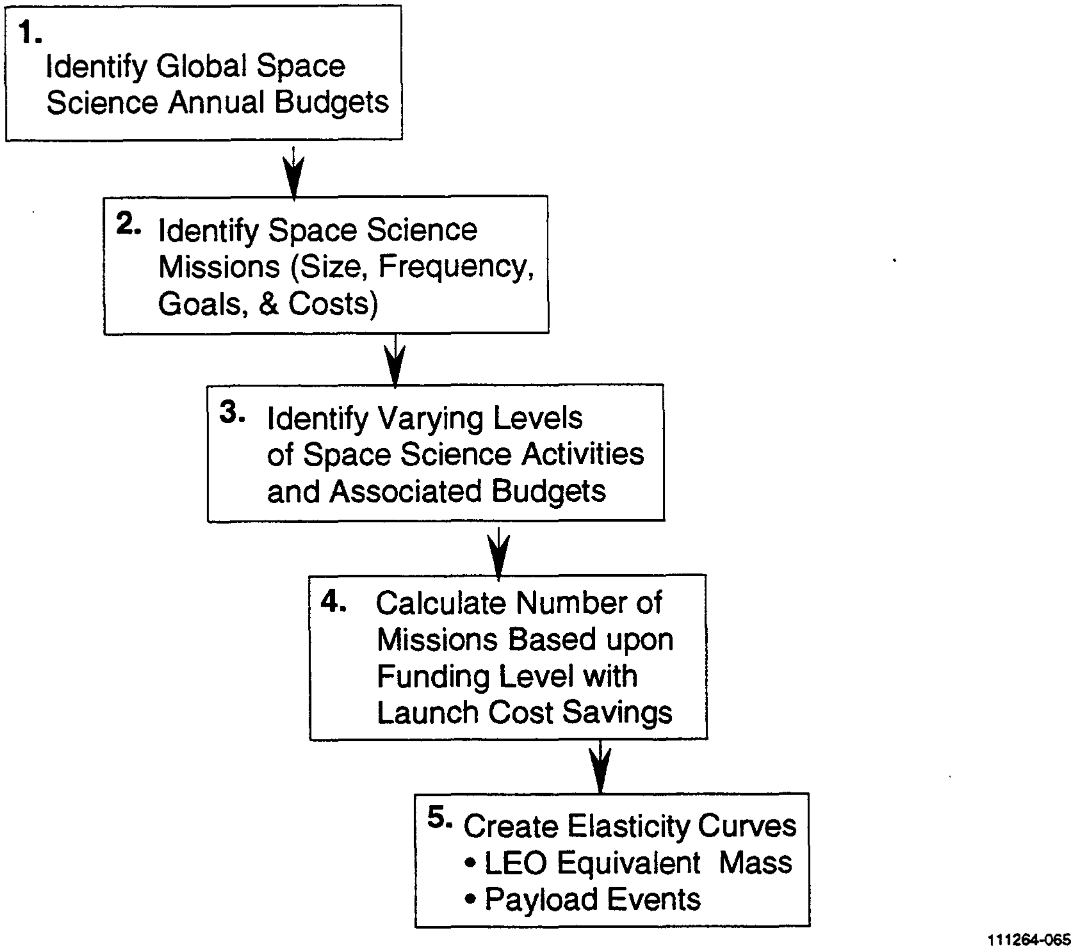

Figure 3.4.9.2-1. Space Science Outwards (SSO) Study Methodology

Step 1 - Identify Global Space Science Annual Budgets. Understanding the current expenditures in this area will establish the bounds from which we may extrapolate, based upon existing trends, to provide future projections.

Step 2 - Identify Space Science Missions. This step produces a database of historic space science payloads. Included in the database will be the programmatic name, destination, payload size/mass, and flight dates. From this database we can construct general classes of missions and we can incorporate more recent trends to define the market payloads and launch vehicle requirements.

Step 3 - Identify Varying Levels of Space Activities and Associated Budgets. Since these missions are dependent upon federal government sources of funding, we need to establish budget allocation estimates for the varying probabilities of space science activities.

Step 4 - Calculate Number of Missions Based Upon Funding Levels With Launch Cost Savings. The number of missions demanded for each class of space science payload are based upon the amount of available funding minus the cost to develop, launch, and operate the payloads (see fig. 3.4.9.2-2). If the cost of launches were to be reduced then more missions could be flown for the same amount of money (contingent upon budget availability for more development and operations).

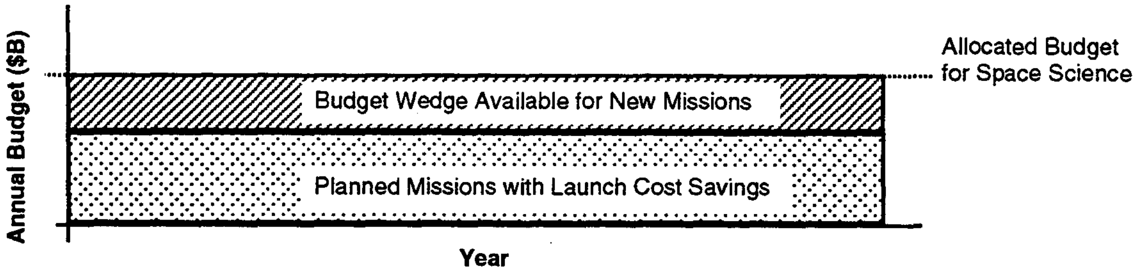

Figure 3.4.9.2-2. Budget wedges resulting from launch cost reductions can be applied toward additional space science missions.

Step 5 - Create Elasticity Curves. Based upon the knowledge of the budgetary limitations, the space science payload costs (development, operations, and launch), and an assumed reduction in launch costs, we can calculate the affordability of new missions and hence the increase in demand for launch services.

3.4.9.3 Market Description

The Market Description section is separated into four subsections: Market Description, Market Evaluation, Market Assessment, and Market Infrastructure. The Market Description subsection will identify the SSO budget environment and the types of payloads flown. The Market Evaluation subsection will formulate scenarios of varying probability to which the budget projections and payload classes will be applied, in the Market Assessment subsection, to generate elasticity of demand curves. The Market Infrastructure will discuss the operational and organizational relationships characteristic of this market.

3.4.9.3.1 Market Description

Space Science Budgets. Given the current economic environment, any increase in space science mission activity can be realized only by using existing funds in a more productive manner. Ways to increase the scientific return given fixed or shrinking budgets include—

a. Encouraging more cooperative or joint programs (i.e., between universities, industry, and countries).
b. Reducing spacecraft costs.
c. Reducing launch costs.
d. Reducing spacecraft operations costs.

This study will examine the potential for increasing mission activity for the space science outwards market segment through launch cost reductions. Thus, given that current budgets will not likely expand, the savings derived from launch cost reductions could be reinvested into additional missions. Therefore, it is necessary to understand what is being spent on space science missions today.

Utilizing various sources (shown), we have compiled a list of global space agency expenditures and the portion of that budget spent on space science (see fig. 3.4.9.3-1). This table shows that the global space expenditures exceed $26 billion per year. Approximately 12% of that is allocated to space science efforts ($3 billion). The primary driver for this analysis is, of course the United States, which accounts for more than 56% of the total space expenditures (excluding military efforts) and 60% of space science.

Nation	Annual Space Agency Expenditures ($M93)	Annual Space Science Expenditures ($M93)	Space Science Relative to Annual Expenditures (%)
Argentina	$10	$0.1 ****	1.0%
Australia	$13	$1.3 ***	10.0%
Austria	$29 *	$0.3 ****	1.0%
Belgium	$135 *	$1.4 ****	1.0%
Brazil	$10	$0.1 ****	1.0%
Canada	$340 *	$16.0	4.7%
China	$1,200	$12.0 ****	1.0%
Denmark	$40 *	$0.4 ****	1.0%
ESA	$3,144	$306.0	9.7%
Finland	$46	$0.5 ****	1.0%
France	$1,996 *	$133.0	6.7%
Germany	$1,204 *	$83.0	6.9%
India	$170	$5.0	2.9%
Ireland	$6 *	$0.1 ****	1.0%
Italy	$815 *	$198.0	24.3%
Japan	$1,477	$365.0 ****	24.7%
Netherlands	$87 *	$0.9 ****	1.0%
Norway	$29 *	$0.3 ****	1.0%
Pakistan	$8	$0.1 ****	1.0%
Russia/CIS	$68 **	$15.0	22.1%
South Korea	$50	$0.5 ****	1.0%
Spain	$140 *	$1.4 ****	1.0%
Sweden	$82 *	$8.2 ***	10.0%
Switzerland	$61 *	$0.6 ****	1.0%
Taiwan	$75	$7.5 ***	10.0%
United Kingdom	$256 *	$2.6 ****	1.0%
United States	$14,700	$2,000.0	13.6%
Total	$26,191	$3,159.1	

* Contributor to European Space Agency (some or all may go to ESA).

** Based upon an exchange rate of $0.00085/ruble.

*** Countries with significant independent and recognizable space science efforts.
Space science programs assumed to be 10% of annual expenditures.

**** Countries without significant independent space science efforts.
Space science programs assumed to be 1% of annual expenditures.

Sources: Interavia Space Directory, 1992-1993 (Global Space Exenditures)
Space News, August 31- September 6, 1993 (Global Space Exenditures)
Space News, October 18-24, 1993 (U.S. Space Expenditures)
Space News, November 15-28, 1993 (CIS Space Expenditures)
Aerospace America, September 1993 (Global Space Exenditures)

111264-067

Figure 3.4.9.3-1. Global Space Budget and Space Science Expenditures by Nation

The following ground rules and assumptions were used to develop the global space agency and space science expenditures:

a. Only civil programs were accounted for (i.e., no military space programs).

b. An attempt was made to separate out ESA contributions from independent operations; however, many sources conflicted or were confusing on this subject. As will be explained in the next section (Market Evaluation) this does not impact the low- or medium-probability cases.

c. CIS activities were based upon a published exchange rate of $0.00085/ruble (Space News, November 15-28, 1993). The level of activity (i.e., payloads, launches, mass to orbit) in CIS does not compare to other countries with the same level of expenditures.

d. Some sources did not provide programmatic breakdowns for all countries. Where information was available, it was noted. When confronted with no further information one of two groundrules was selected: (1) For countries with significant and recognizable independent space science efforts, 10% of the annual space agency expenditures were used for the space science, or (2) for countries without significant independent space science efforts, 1% of the annual space agency expenditures were used for the space science.

Space Science Missions. The research into current and historic space science payloads has resulted in the identification of three generalized classes of spacecraft (based upon development cost and payload mass). These three classes are Flagship, Discovery, and Small-Sat. Figure 3.4.9.3-2 shows the approximate grouping of these payloads into their respective classes. Figure 3.4.9.3-3 shows the same data in a more readable format.

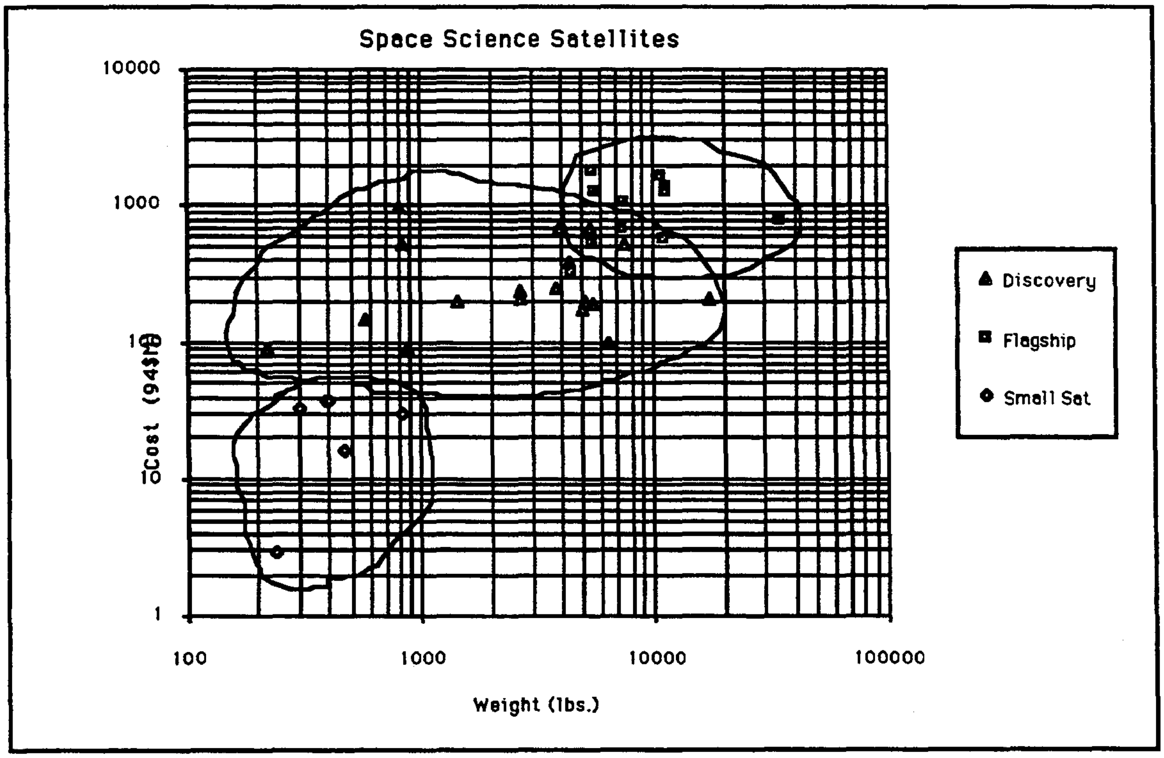

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Figure 3.4.9.3-2. Space Science Satellite Groupings

Category	Satellite	Weight (lbs)	Dev. Cost (94$M)
Discovery	ACE	1430	200
Discovery	ASTRO	17239	209
Discovery	COBE	5020	198
Discovery	CRRES	3793	248
Discovery	FUSE	6350	101
Discovery	GAMES	572	145
Discovery	GP-B	5500	188
Discovery	HELIOS	814	962
Discovery	MESUR-Path	220	92
Discovery	NEAR	880	92
Discovery	OAO-1	3907	698
Discovery	OSL	7500	516
Discovery	POLAR	2640	242
Discovery	ROSAT	5337	676
Discovery	SMM	4990	174
Discovery	SOHO	4400	393
Discovery	ULYSSES	816	527
Discovery	WIND	2640	205
Flagship	AXAF-I	11440	1400
Flagship	CASSINI	5504	1770
Flagship	CO	34364	776
Flagship	GALILEO	5634	1244
Flagship	HST	10843	1657
Flagship	MAGELLAN	7377	682
Flagship	MDO	11000	563
Flagship	MO	5447	537
Flagship	SIRTF	11242	1258
Flagship	VIKING	7462	1056
Flagship	VOYAGER	4435	332
Small Sat	ALEXIS	240	3
Small-Sat	CRRES-1	466	16
Small-Sat	FAST	298	33
Small-Sat	SAMPEX	388	37
Small-Sat	SWAS	400	37
Small-Sat	TOMS	836	30

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Figure 3.4.9.3-3. Satellite Weight and Cost Data

The data in figures 3.4.9.3-2 and -3 are a small subset of the data gathered and analyzed. These items were selected because they most closely correlated with the current or planned programmatic trends. An output of the raw data spreadsheet has been appended to into section 3.4.9.8 for reference. This database has over 90 entries. While concentrating primarily on space science satellites, data were also included for a few communications and Earth-observation satellites for comparison purposes. The original intent was to be able to develop a weight-based cost estimating relationship (CER) from the satellite data that could be used to predict costs for future payloads in the various mission scenarios. However, the regression analysis indicated that there is little correlation between weight and cost on the selected satellites, or in other words, weight is not a very good parameter to use in creating estimates of the cost for space science spacecraft. This may not be surprising due to the unique nature of these missions (infrequent missions, nonstandard instruments, inhospitable environments, long duration, etc.) and since past programs have always had "meeting the science objectives" as their number one goal. A greater correlation may exist between the type of mission (e.g., astronomy, planetary orbiter, planetary lander); however, it would be more difficult to project the flight frequency and mission capture with that type of a characterization.

Flagship Class. This class of space science program includes large LEO observatories or large interplanetary type missions. They usually require a Titan IV or shuttle launch (approximately 40,000 lb LEO equivalent). The interplanetary missions require the use of an upper stage, which has to be included in the LEO equivalent performance and the spacecraft cost assumption. Based upon the space science payload database we have assumed the following:

a. Development cost	$1,500 million
b. Launch cost	$500 million
c. Operations cost	$100 million

A few examples of these Flagship class missions are the Hubble Space Telescope, Magellan, and Mars Observer. Recent history has shown that the flight rate for such missions is approximately one every 3 years.

Discovery Class- Discovery class missions are a new philosophy to space science research. The programmatic ground rules for such missions are 3-year developments and costs of no more than $150 million including launch costs. The current Discovery missions are MESUR and NEAR, although there have been similar classes of missions in the past (without the new programmatic ground rules). These missions can be launched on a Delta or Atlas vehicle. These payloads typically fall within the 10,000- to 15,000-lb range, LEO equivalent. Using the new programmatic ground rules we have assumed the following:

a. Development cost	$80 million
b. Launch cost	$50 million
c. Operations cost	$20 million

Currently, two flights every 3 years are planned.

Smallsat Class. These missions are launched on a Pegasus class launch vehicles. These payloads are in the range of 1,000 lb or less, LEO equivalent. Based upon the space science payload database we have assumed the following:

a. Development cost	$20 million
b. Launch cost	$20 million
c. Operations cost	$5 million

Examples of Smallsat class missions are Fast Auroral Snapshot Explorer (FAST) and Small Explorer (SMEX). Currently, the planned flight rate for Smallsat missions is three or four per year.

3.4.9.3.2 Market Evaluation

Our desire to understand the universe and our place in it will ensure a constant flow of ideas for potential space science missions. However, because there is no immediate gain in terms of commercial revenues, this market segment is constrained to operate within a government-allocated budget. As was shown previously in figure 3.4.9.3-1, of its nearly $15 billion budget, the United States currently spends approximately $2 billion (excludes $1 billion for shuttle-based spacelabs and general overhead expenses) in the space science area. In addition, international space agencies spend approximately $1 billion on SSO missions.

Based on our research and discussions with potential space science users of a new commercial space transportation system, we have projected three possible future budget scenarios. They have also been rated as to their probability of occurrence using the standard CSTS approach (high, medium, or low). The economic forecasts for the SSO market with their associated probabilities of occurrence are—

Scenario	U.S. Activity Level	Probability	Budget
1	Low	High	$1B
2	Current	Medium	$2B
3	High	Low	$3B

Scenario 1 - The projection for this scenario assumes a decrease in science emphasis over current U.S. SSO levels of activity, from $2 billion to $1 billion. This is considered a low U.S. capture scenario and may be realistic considering budget constraints and a seemingly greater emphasis on technologies that have a dual use (government and commercial). This scenario was purposely developed to be extremely conservative and is therefore deemed to have a very high probability of occurrence (90% or more).

Scenario 2 - This scenario assumes the U.S. will maintain its current level of space science activity, approximately $2 billion per year. This is considered to be medium probability of occurrence (approximately 50%).

Scenario 3 - The most optimistic forecast calls for a $3 billion annual budget for space science missions. This can be considered full capture of U.S. plus international missions or an increased U.S. space science level of activity.

3.4.9.3.3 Market Assessment

The scenarios developed in the previous section will be used to scope the level of demand for space science mission flights. All savings from launch cost reductions will be transformed into new missions. The costing assumptions listed in section 3.4.9.3.2 will be used to identify the number of new missions made possible while constraining the total budget to stay within the scenario assumptions. When selecting which class of mission to fly with the freed-up budget the emphasis will move away from Flagship class missions toward more Smallsat missions. For this assessment we examined launch cost reductions of one and two orders of magnitude (one-tenth and one one-hundredth launch costs).

The results of this assessment are presented in figures 3.4.9.3-4 and -5. These figures show the number of payload events and LEO equivalent mass delivered per year for each class and each probability (budget scenario). These results are described on a probability basis.

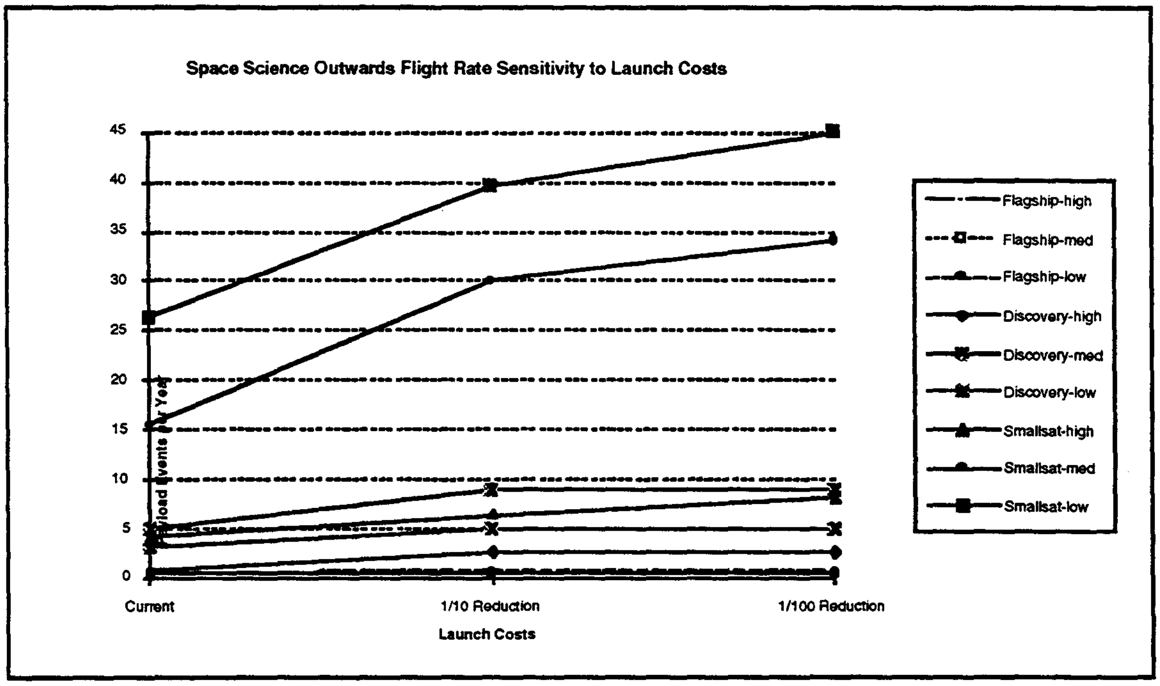

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Figure 3.4.9.3-4. Space Science Payload Events Elasticity of Demand by Payload Class

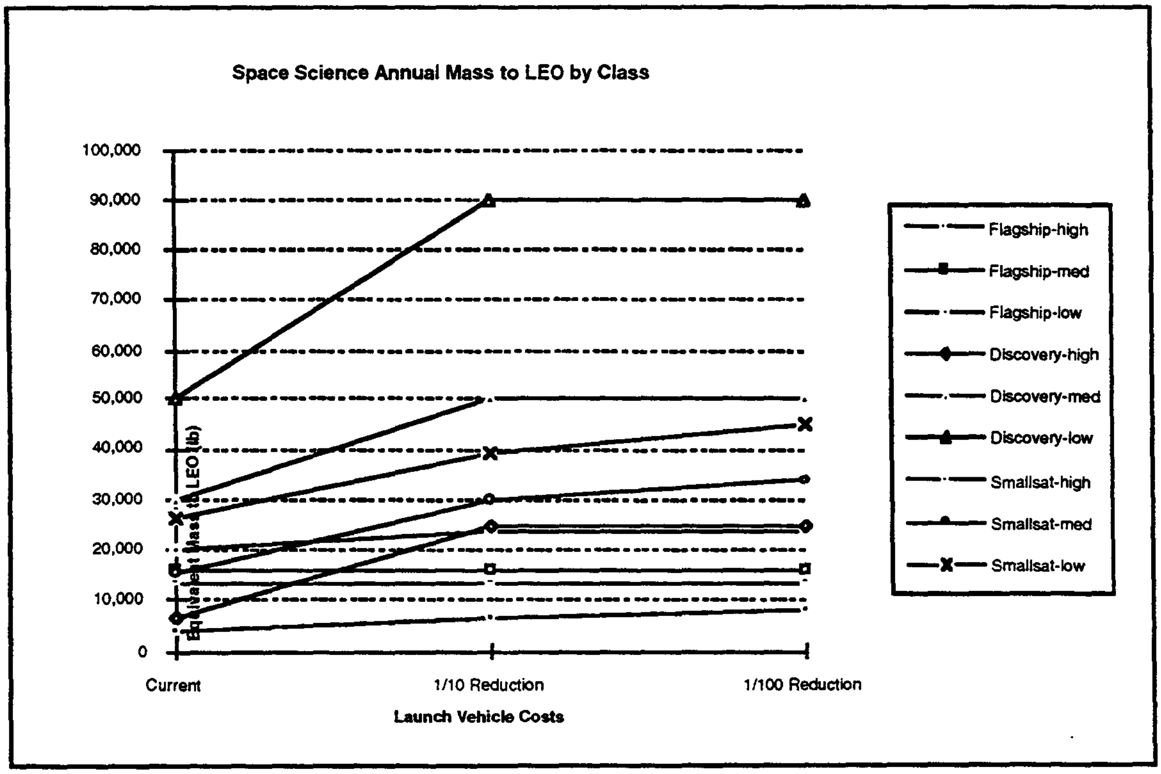

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Figure 3.4.9.3-5. Space Science LEO Equivalent Mass Elasticity of Demand by Payload Class

High Probability (Scenario 1). In this scenario, there are no new Flagship class missions. The budget savings are not large enough to allow an additional Flagship mission (nor even one-tenth of a new mission). There is a small increase in the number of Discovery missions (from 2.3 years to 2.5 per year). Ironically, this small increase in missions would be a big boon for scientists and graduate students. The Smallsat missions have the greatest increase, from four per year to eight. However, since the Smallsats are very lightweight, the greatest mass increase comes from the Discovery payloads (see fig. 3.4.9.3-5).

Medium Probability (Scenario 2). In this scenario, there are still no new Flagship class missions. With the additional budget provided by scenario 2, approximately three more Discovery missions are possible over scenario 1. However, only two more missions are enabled by reductions in launch costs. Smallsats show a significant increase, 11 over scenario 1 and a doubling of payload events, as launch costs are reduced. The same trends exist for this scenario as in scenario 1.

Low Probability (Scenario 3). In this scenario, Flagship class missions increase to approximately one mission every other year. With the additional budget over scenario 1 there is nearly an order of magnitude increase in missions (5 per year instead of 2.3 years). As launch costs are reduced, Discovery mission nearly double (from five to nine per year). Nine Discovery missions per year would bring back a wealth of science knowledge equivalent to a decades worth of data currently gathered by similar missions. Once again the Smallsat class missions show the greatest growth potential. These missions could climb as high as 45 per year if launch costs were reduced by two orders of magnitude.

The cumulative impact, in terms of LEO mass delivered per year, is displayed in figure 3.4.9.3-6. This figure shows that with a single order of magnitude decrease in launch costs, the amount of mass delivered to LEO on an annual basis would grow from 20K lb to nearly 160K lb. More important, and more difficult to quantify, is the resultant increase in knowledge of our universe and the potential stimulation of the world's educational systems from these programs. Note again that the LEO equivalent mass includes the spacecraft and the appropriate upper stage for the particular mission application.

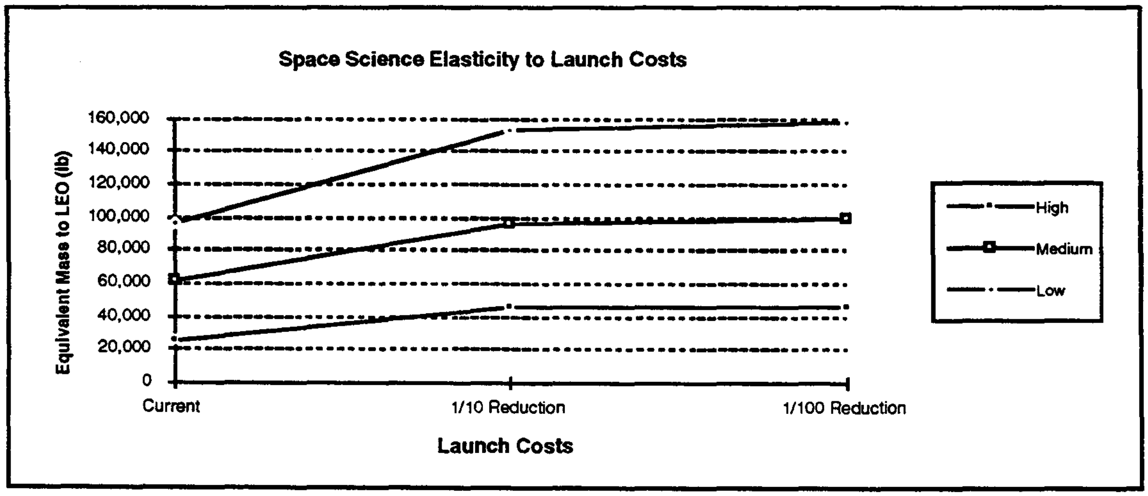

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Figure 3.4.9.3-6. Space Science LEO Equivalent Mass Elasticity of Demand, Cumulative Market Segment

To evaluate the effect of launch cost reductions at points other than one and two orders of magnitudes, interpolation may be used to determine the desired value.

As is evidenced by the data, the Smallsat mission classification would stand to benefit the most from launch cost reductions given any economic scenario. This is not completely surprising when one compares the launch cost percentage of total budget for each mission classification, as shown in figure 3.4.9.3-7.

Space Science Outwards
Programmatic Costs ($M) and Percentages (%)
Breakdown by Mission Class

Cost Component		Flagship	Discovery	Smallsat
Spacecraft	$	$1,500	$80	$20
	%	71%	53%	44%
Launch	$	$500	$50	$20
	%	24%	33%	44%
Operations	$	$100	$20	$5
	%	5%	13%	11%
Total Program		$2,100	$150	$45

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Figure 3.4.9.3-7. Percentage Breakdown of Cost by Mission Classification

3.4.9.3.4 Market Infrastructure

This section will describe two components of the space science market infrastructure, technical and organizational. Technical infrastructure deals with the infrastructure necessary for the mission to perform its technical function. Organizational infrastructure covers the management, organization, and working relationships established to enable the mission. Responsibilities for SSO missions (both technical and organizational) are generally divided among NASA (or other space agency), universities, and contractors. Figure 3.4.9.3-8 shows how these responsibilities are traditionally delegated. Differences between the mission classification (Flagship, Discovery, and Smallsat) exist but are not highlighted here.

NASA	University	Contractor
• Strategic planning • Budget allocation • Program selection • Overall program mgmt • Program integration • Technology development • Mission requirements	• Science research • Knowledge reservoir • Experimental approach • Experimental instruments • Student labor pool • Data analysis	• Spacecraft • Subsystem components • Launch vehicle • Mission integration • Launch operations

111264-074

Figure 3.4.9.3-8. Traditional Space Science Working Relationships and Functions

Technical Infrastructure

Command and Control. SSO missions require ground-based, human interactive control. This function is exercised through small mission control centers (relative to launch vehicle control centers) located at NASA centers (predominantly JPL or Goddard) or, to a lesser degree, at universities (e.g., Cal Tech or University of Colorado).

Tracking and Data Acquisition. Tracking and telemetry, although they usually use the same node as the control center, may require the support of an orbital asset (e.g., TDRS) or a remote location (e.g., Deep Space Network). NASA normally provides these services as part of its support or charges a nominal fee for non-NASA missions. Some futuristic planetary lander missions may require the use of an in situ orbital relay satellite. This would be accounted for in the programmatic costs or separated as its own mission.

Organizational Infrastructure

Organizational relationships for SSO vary significantly from mission to mission. Although there are no standards for these organizational relationships this section will characterize the types of relationships that have been demonstrated in the past or proposed for some missions. Figures 3.4.9.3-9 through -11 depict the general organizational relationships for Flagship, Discovery, and Smallsat mission classes, respectively.

Because of the complex integration and high costs of Flagship class missions, NASA usually takes on a much more active role in the program. Figure 3.4.9.3-9 shows NASA interfacing directly with all participants within the program.

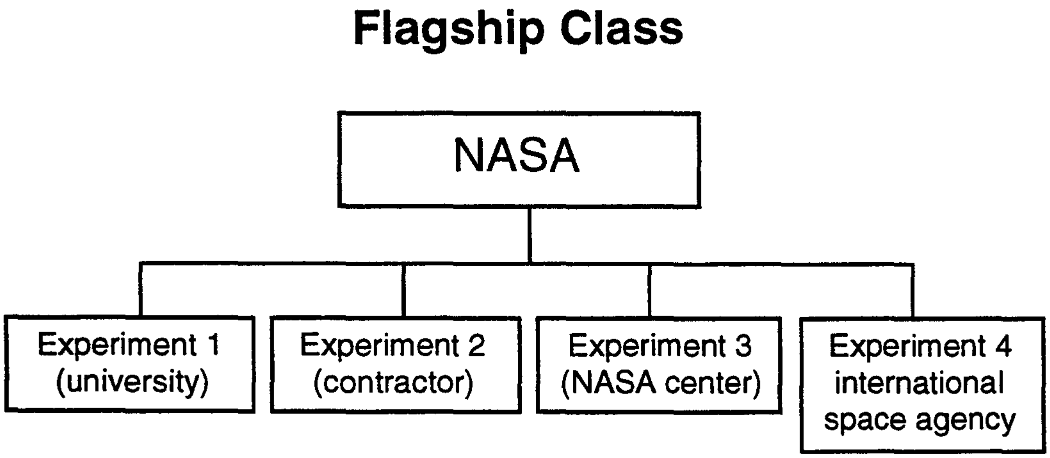

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Figure 3.4.9.3-9. Flagship Program Organization

Discovery class missions usually have a secondary program manager who interfaces with the NASA equivalent and leads the subcontractors in performance of their separate tasks. Figure 3.4.9.3-10 shows this generalized relationship.

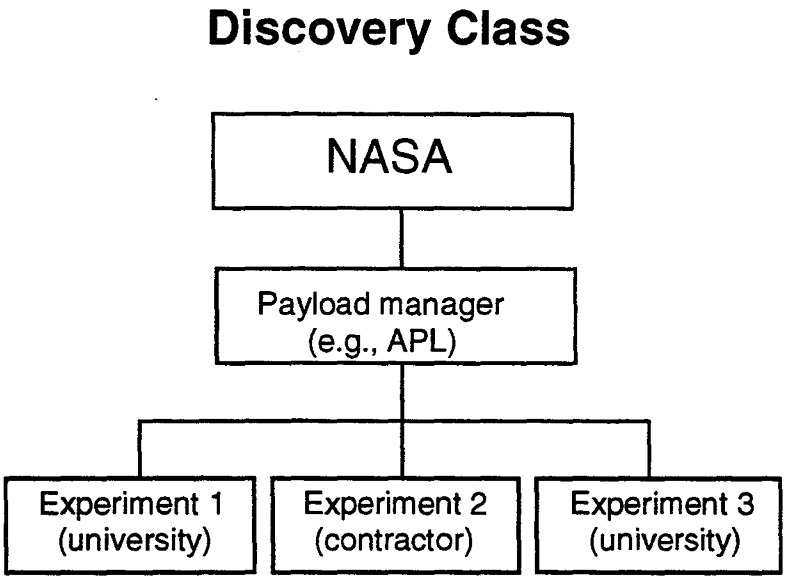

Figure 3.4.9.3-10. Discovery Program Organization

Smallsat class missions have a unique opportunity to involve students in the day-to-day process of payload conception, development, design, production, integration, launch, and operation. Figure 3.4.9.3-11 shows how this arrangement might be structured.

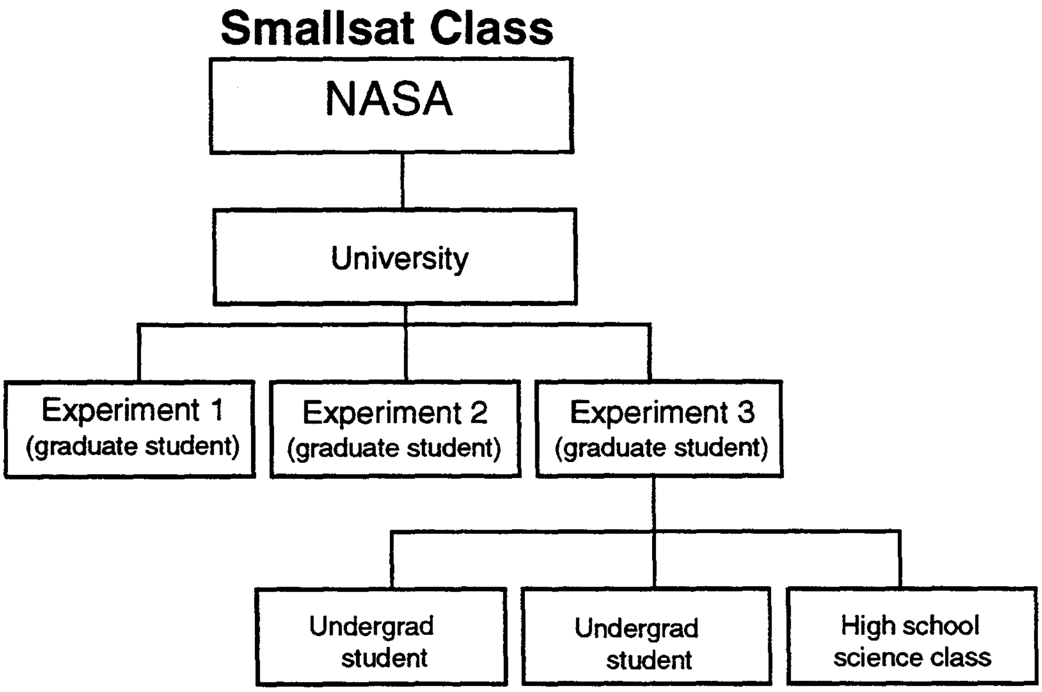

Figure 3.4.9.3-11. Smallsat Program Organization

3.4.9.4 Prospective Users

As mentioned in the introduction, in contrast to space technology development, there is no commercial interest in SSO missions. The cost is too great and the payoffs are indeterminate and too long term. Governments, and to a small extent academia (through government funding and private grants), are the sole sponsors of space science research. In other words taxpayers are the principal investors in space science research.

In the SSO area, the sponsors and the users turn out to be the same people. Governments and universities are the principal participants in the space science area. It is solely up to the government and to the universities to keep pushing the space science frontier back.

When it comes to mission classifications, governments are the primary player in the Flagship and Discovery class arena. The government also is a key player in the Smallsat arena, but universities are also potential users.

3.4.9.5 CSTS Needs and Attributes

This section defines the space science mission requirements that would be imposed upon a new commercial space transportation system.

3.4.9.5.1 Transportation System Characteristics

Upper Stage. Many SSO missions require the payload to be delivered beyond LEO; therefore, they require an upper stage. For the purposes of this study it was assumed that if an upper stage was required its cost was included in the cost of the spacecraft.

Unmanned. SSO payloads are generally unpressurized, unmanned, and have no return-to-Earth needs (with a few shuttle-related exceptions). As with the Hubble Space Telescope, some SSO missions may be upgraded during orbit to extend their capabilities and life expectancies. The majority of SSO payloads, however, are one-time-up experiments that have the capability to transmit their acquired data back to Earth.

Reliability. Although improved reliability is desirable, these missions would still fly (and are flying) at current system reliabilities.

Flight Environment. Although a more benign flight environment (e.g., vibration, heating, acceleration loads) would be desirable, conditions at least as good as current ELVs would be sufficient.

3.4.9.5.2 Transportation System Capabilities

The SSO mission launch requirements range in equivalent mass to LEO capabilities from less than 1,000 lb up to 40,000 lb. Performance capability needs, in terms of ΔV, are highly dependent upon payload size and mission destination. Generally, most SSO missions have destinations beyond LEO and require upper stages.

Class	LEO Equivalent Mass
Flagship	40,000 lb
Discovery	10,000 lb
Smallsat	<1,000 lb

Figure 3.4.9.5-1. Class and LEO Equivalent Mass

3.4.9.5.3 Ground Handling

Transportation and Integration. Many SSO payloads have sensitive instruments/optics on board requiring delicate transportation and handling. Current procedures and equipment can satisfy these requirements.

On-Pad Services. Standard thermal conditioning and power support of SSO payloads while on the pad should provide an adequate environment.

Special Facilities. Many SSO payloads require a cleanroom facility while final processing, checkout, and payload integration into the fairing are completed. In addition, most Flagship class payloads require the processing and launch facilities to be capable of processing/checkout of a radioisotope thermionic generator (RTG) or other nuclear power source.

3.4.9.5.4 User/Space Transportation Interfaces

Many of the interface requirements will be dictated by the launch vehicle configuration. For example, shuttle payload services while on the ground, during ascent, and on orbit differ dramatically from an expendable launch vehicle like Atlas. Therefore, the following interface requirements are generalized for the space science mission market but could vary depending upon the launch vehicle solution.

Mechanical. The spacecraft will require some standardized mechanical attach-points with a separation capability for the time of deployment.

Power. Most spacecraft transition from ground power to internal power prior to launch. There are no indications that a change is needed unless the configuration of the launch system would dictate a change (e.g., no umbilical access to payload prior to launch).

Telemetry/Communication. The spacecraft will require two-way communications, through the launch vehicles telemetry system, to the ground control facilities. Transmission of data to the ground control regarding the payloads condition and readiness is required. It is also necessary to provide for commands to the payload from the launch vehicle for sequencing of events and in the event of a need to destruct the payload.

Fluids. Most SSO do not need fluids loading after encapsulation.

3.4.9.5.5 Improvements Over Current

Reduced Launch Costs. Although spacecraft costs are the single biggest cost contribution, reduced launch costs would enable a higher frequency of SSO launches. This would result in greater standardization of spacecraft buses or components and allow the manufacturers to come further down their rate and learning curves.

Shorter Mission Planning. One of the more critical technical goals is the ability to get a launch opportunity within a reasonable amount of time. Providing quick access to space will allow graduate students and researchers to get necessary data returned from a SSO mission to complete their studies. This will maintain a high level of interest, build confidence in the national science programs, and generate return business.

Availability to More Users. This requires that a system have sufficient flight opportunities to let customers know that they have a good chance of getting a flight when they need one, so they will proceed with their preliminary planning and design efforts.

3.4.9.6 Business Opportunities

3.4.9.6.1 Cost Sensitivities

As we have seen, launch costs, although important, are not always the predominant cost component. In addition, this market is budget limited and does not have commercial forces driving it. Therefore the space science market has not demonstrated a high degree of demand elasticity. There is an opportunity to significantly increase the efficiency of national space science expenditures and return a greater wealth of knowledge to humankind with a significant decrease in launch costs. A majority of these new missions reside in the Smallsat class (in terms of payload events).

3.4.9.6.2 Programmatics

There exists a unique opportunity within the space science market that could result from a reduction in space launch costs. That is the delegation of responsibility down to extremely low levels, to students. There are several universities that have active student participation in space science activities; however, a reduction in launch costs will enable more universities to sponsor their own programs. The experience of managing design and hardware programs will introduce more capable engineers/scientists into the workforce.

3.4.9.7 Conclusions and Recommendations

Launch cost reductions will free up room for significant growth for Smallsat class missions, moderate room for growth for Discovery class missions, and little room for growth for Flagship class missions. This growth will allow for an increased investigation of the universe and eventually return significant benefits to humankind. However, these missions will still be budget limited, since there is no immediate commercial application for these sciences. In the long term, new technologies (with terrestrial commercial applications) will be spawned from the science investigations made today. Predicting these new technologies is difficult; however, they may include fusion and other energy sources, antigravity, better weather prediction and control, and so forth.

It is important to continue to understand the impact on space science missions because it impacts the future workforce capabilities and is the building block for future technologies. Getting greater participation from universities across the country and around the world into the analysis would enhance the credibility and quality of the analysis. In addition, the University of Colorado has recommended the establishment of a computer bulletin board to enable a national discussion on this topic.

3.4.9.8 Space Science Payloads Database

Figure 3.4.9.8-1 and -2 document the space science outwards payload database used in the Commercial Space Transportation Study.

Name	Dry Weight (lbs)	total Weight (lbs)	Year$	Dev. Cost (Raw)	Curr	Currency Conver Factors	Inflation Factor	Dev. Cost (94$M)	Prod. Cost (94$M)	Ops Cost (1 year) (94$M)	Type	Category	Customer	Launch Date	Launch Vehicle	#	Comments
Advanced Composition Explorer	1430		1994	200			1.000	$200M			Discovery	Physics	NASA	1996	Delta II		Charged particle detector in interplanetary space.
Astronomical Observatory	17239		1984	150			0.718	$209M			Discovery	Astronomy	NASA	1990	STS		Series of UV, X-Ray telescopes
Solar Terrestrial Science Program		8800	1992				0.937		$43M		Discovery	Physics	NASA/ESA	1995	Ariane V	4	Conduct microphysics studies in magnetosphere
Cosmic Background Explorer	5020		1988	160			0.807	$198M			Discovery	Astronomy	NASA	1989	Delta		Measure cosmic background radiation
Combined Release and Radiation Effects Sat	3793		1988	200			0.807	$248M			Discovery	Physics	NASA/USAF	1990	A/C I		Solar Terrestrial physics and rad. effects research
Extreme Ultraviolet Explorer		7216	1990				0.875		$213M		Discovery	Astronomy	NASA	1991	Delta II		Astronomical Survey
Far Ultraviolet Spectroscopic Explorer	6350		1997	74.7	£	1.49	1.100	$101M			Discovery	Astronomy	NASA	2000	Delta II		Untraviolet spectrograph
Gravity & Magnetic Experiment Sat	572		1995	150			1.033	$145M			Discovery	Physics	NASA/ESA	1998	Pegasus		Gravity Experiments
GEOSPACE Science mission	1408	2134	1990				0.875		$63M		Discovery	Physics	NASA/Japan	1992	Delta II		Earth's magnetosphere
Gravity Probe-B	5500		1996	200			1.066	$188M			Discovery	Physics	NASA	1999	Delta II		Test Einstein's general theory of relativity
Helios	814		1970	260			0.270	$962M			Discovery	Astronomy	NASA/German	1974	T-IV/C	2	Solar Studies
Life Sciences Sat.	900	3050	1993				0.968		$103M		Discovery	Biology	NASA	1994	Delta II	4	Recoverable space radiation biology experiments
Mariner 6 & 7	909		1966				0.236		$628M		Discovery	Planetary	NASA	1969	A/C	2	Mars fly-by
Mariner 8 & 9	1298	2268	1968				0.252		$541M		Discovery	Planetary	NASA	1971	A/C	2	Mars orbiter
Mariner 10	1107		1970				0.270		$370M		Discovery	Planetary	NASA	1973	A/C		Mercury/Venus Flyby
Mars Environmental Survey	220		1985	95			1.033	$92M			Discovery	Planetary	NASA	1996	Delta II		Mars Lander
Nuclear Astrophysics Explorer	11000						1.000				Discovery	Physics	NASA	1999	Delta II		Cooled Germanium Detectors.
Near Earth Asteroid Rendezvous	880	1496	1995	95			1.033	$92M			Discovery	Planetary	NASA	1998	Delta II		Asteroid flyby - 4660 Nereus
Orbiting Astronomical Observatroy	3907		1966	164			0.236	$698M	$212M		Discovery	Astronomy	NASA	1966	Atlas Agena		Deep Space Observation
Orbiting Astronomical Observatroy	4435		1966				0.236		$212M		Discovery	Astronomy	NASA	1968	A/C		Deep Space Observation
Orbiting Astronomical Observatroy	4884		1966				0.236		$212M		Discovery	Astronomy	NASA	1972	A/C		Copernicus - Deep Space Observation
Orbiting Astronomical Observatroy			1966				0.236		$212M		Discovery	Astronomy	NASA	1970	A/C		Failed on launch
Orbiting Solar Laboratory	7500		1996	550			1.066	$516M			Discovery	Astronomy	NASA	1998	Delta II		1M optical telescope
Global Geospace Science	2640		1991	220			0.909	$242M			Discovery	Physics	NASA	1993	Delta II		Plasma physics fields and particles of ionosphere
Roentgen Sat.	5337		1987	530			0.784	$676M	$66M		Discovery	Astronomy	NASA/German	1990	Delta II		X-Ray telescope
Solar Maximum Mission	4990		1978	79			0.455	$174M			Discovery	Astronomy	NASA	1980	Delta		Solar Obs., gamma ray obs., comet obs.
Solar and Heliospheric Observatory	4400		1993	380			0.968	$393M			Discovery	Astronomy	NASA/ESA	1995	A/C IIAS		Coronal physics, helioseismology
Int'l Solar Polar Mission	816		1990	461			0.875	$527M		$23M	Discovery	Astronomy	NASA/ESA	1990	STS		Polar orbit around sun for observation
Global Geospace Science	2640		1990	179			0.875	$205M			Discovery	Physics	NASA	1992	Delta II		Plasma Physics fields and particles, in solar wind
Advanced X-Ray Astrophysics Facility - Imaging	11440		1994	1400			1.000	$1,400M			Flagship	Astronomy	NASA	1998	STS/T-IV	2	Space-based X-Ray observatory
AXAF - Spectroscopy	11440		1994				1.000		$320M		Flagship	Astronomy	NASA	1999	STS/T-IV		Space-based X-Ray observatory
Saturn Orbiter/Titan Probe	5504	12395	1993	1714			0.968	$1,770M		$77M	Flagship	Planetary	NASA/ESA	1997	T-IV/C	1	Saturn explorer, combined with CRAF
Compton Observatory	34364		1984	557			0.718	$776M			Flagship	Astronomy	NASA	1991	STS		High energy extra-galactic study
Jupiter Orbiter	5634		1984	893			0.718	$1,244M		$99M	Flagship	Planetary	NASA	1989	STS		Jupiter observations
Hubble Space Telescope	10843		1990	1450			0.875	$1,657M		$149M	Flagship	Astronomy	NASA	1990	STS		Deep Space Observation
Intl. Very Long Baseline Interferometer Sat.							1.000				Flagship	Astronomy	Intl.				Major space telescope
Venus Mapper		7377	1988	550			0.807	$682M		$57M	Flagship	Planetary	NASA	1989	STS		Venus observations
Mercury Dual Orbiter	11000		1996	600			1.066	$563M			Flagship	Planetary	NASA	2001	T-IV		Mercury explorer/fields and particles sensors
Mars Observer	5447		1990	470			0.875	$537M	$171M		Flagship	Planetary	NASA	1992	T-IV		Study Mars Surface
Mars Sample Return	13420						1.000				Flagship	Planetary	NASA	2001	T-IV	4	Return samples of Mars to Earth
Mars Site Reconnaissance Orbiter	15114						1.000				Flagship	Planetary	NASA	2003	T-IV		Site Recon and ComSat orbiter
Space Infrared Telescope Facility	11242		1995	1300			1.033	$1,258M			Flagship	Astronomy	NASA	1999	T-IV/C		Space-based infrared observatory
Mars Lander	7462		1972	310			0.293	$1,056M	$1,056M		Flagship	Planetary	NASA	1975	T-III	2	Mars orbiter, detachable Mars lander
Outer planet explorer	4435		1974	108			0.326	$332M	$325M	$109M	Flagship	Planetary	NASA	1977	T-III	2	Exploration of outer planets
Array of Low Energy X-Ray Imaging Sensors	240		1989	2.5			0.841	$3M			Small Sat	Astronomy	NASA	1992	Pegasus		All-sky soft X-Ray survey
Combined Release and Radiation Effects Sat	466		1992	15			0.937	$16M			Small-Sat	Physics	NASA	1993	Small ELV		Experiments offloaded from CRRES

Figure 3.4.9.8-1. Space Science Payload Database, Part I

Name	Dry Weight (lbs)	total Weight (lbs)	Year$	Dev. Cost (Raw)	Currency	Currency Conversion Factors	Inflation Factor	Dev. Cost (94$M)	Prod. Cost (94$M)	Ops Cost (1 year) (94$M)	Type	Category	Customer	Launch Date	Launch Vehicle	#	Comments
Fast Auroral Snapshot Explorer	298		1991	30			0.909	$33M			Small-Sat	Physics	NASA	1993	Scout		Examination of auroral region
Solar, Anomalous, and Magneto. Particle Explorer	388		1988	30			0.807	$37M			Small-Sat	Physics	NASA	1992	Scout		Solar energetic particles, cosmic rays, etc.
Small Explorer			1988				0.807		$37M		Small-Sat		NASA	1994	Small ELV		Astronomy, space physics payloads
Submillimeter Wave Astronomy Sat.	400		1988	30			0.807	$37M			Small-Sat	Astronomy	NASA	1994	Small ELV		Deep Space Astronomy
Small sats		594	1990				0.875		$37M		Small-Sat	Physics	NASA		Pegasus		Surveillance, nav, weather, comm, R&D platforms
Total Ozone Monitoring Spectrometer	836		1993	29.3			0.968	$30M			Small-Sat	Physics	NASA	1993	Scout	2	Study stratospheric ozone
Experimental Communications	3243	5588	1990	499			0.875	$570M				Comm.	NASA	1993	STS		Experimental communications sat.
American Mobile Sat. Comm	2530	5610	1991	100			0.909	$110M				Comm	AMSC/TMI	1994	A/CIIA		Mobile communications, paired with MSAT
Astronomical Sat. D	924		1990	40			0.875	$46M				Astronomy	Japan	1993	M-3SII		X-Ray Satellite
Advanced Tracking and Data Relay	4840		1995	500			1.033	$484M	$484M			Comm	NASA	1997	IELV	9	Communications Relay
Planetary explorer	484	968	1992	6			0.937	$6M				Planetary	NRL	1994	T II		Moon fly-by and then asteroid Geographos
Cryogenic On Orbit Liquid Depot Storage and Transfer	7600		1995	251			1.033	$243M				Physics	NASA	1997	Delta II		Cryogenic fluid storage & transfer
Earth Observing System/Polar Orbiting Platform		29500					1.000					EOS	NASA/ESA/Japan		T-IV	6	Remote Earth sensing
Earth Observing System/Synthetic Aperture Radar	2860						1.000					EOS	NASA	1998	Delta II		Radar
European X-Ray Observation Sat	1122		1980	164	AU	1.12	0.540	$340M				Astronomy	ESA	1983	Delta		Deep Space X-Ray Observation
Fleet Sat. Communications	2696		1986				0.763		$164M			Comm	USN	1989	A/C 68		
Freja	603		1987	15	AU	1.12	0.784	$21M				Physics	Sweden	1992	CZ2C		Magnetosphere, aurora studies
Geostationary Platform	11000						1.000					EOS	NASA	2002	T-IV	5	Earth Observation
Magnetosphere observer	1263		1974	54			0.326	$156M				Physics	ESA	1977	Delta		Study of Earth's magnetosphere
Comet Observer	1263	2112	1983	150	AU	1.12	0.692	$243M	$121M			Planetary	ESA	1985	Ariane 1		Halley's Commet fly-by
Geostationary Operational Environmental Satellite	2161	4545	1989	574			0.841	$683M	$238M			EOS	NOAA	1991	Atlas I	5	Earth Observation
Geopotential Research Mission	4840		1996	400			1.066	$375M				Physics	NASA/ESA	1999	Delta II		Study Earth's gravity field
High Precision Parallax Collecting Sat	1269	2515	1990	364	AU	1.12	0.875	$466M				Astronomy	ESA	1989	Ariane 4		Triangulation of Stars out to 400 LY
SS-13	434		1987	3180	Y	0.01	0.784	$37M				Physics	Japan	1990	M-3SII-5		Geotail, L4, LF, Lunar research
Infrared Space Observatory	5280		1990	450	AU	1.12	0.875	$576M				Astronomy	ESA	1994	Ariane 44P		All-sky survey
LANDSAT 6	6050		1989				0.841		$276M			EOS	NOAA	1991	T-II		Earth resources
Lunar Observer							1.000					Planetary		1996	IELV		Lunar resources mapping mission
Lunar Explorer (SS-17)	1210		1993	100			0.968	$103M				Planetary	Japan	1996	M-5		Lunar ovserver
Multiple Access Comm. Sat.	150						1.000					Comm	NRL	1990	Scout	2	Navy Satellite
Mars Network							1.000					Planetary	NASA	1996	Delta II		Precursor Mars msn(surface/subsurface/met. conditions)
Mesosphere and Lower Thermosphere Explorer	2483		1992	55			0.937	$59M				Physics	NASA	1994	MELV		Remote sensing of mesophere and thermosphere
Minisat	1012		1992	1500	Pts	0.01	0.937	$11M				Astronomy	Spain	1994	Pegasus		Hign Energy telescopy
Mars Orbiter	~6600		1997	400			1.100	$364M				Planetary	Japan	1999	H II		Visual, IR, X-Ray mapping of Mars
Mobile Satellite		2500	1991	263			0.909	$269M	$110M			Comm	NASA/Can.	1994	IELV		Advanced Mobile communications paired with AMS
Polar Orbit Earth Observation Mission			1990	929	AU	1.12	0.875	$1,190M				EOS	ESA	1998			Earth Observation
METSAT	2268						1.000					EOS	NOAA	1991	A/C I(3),T-II(2)		Meteorological data
Radarsat	6050		1991	313			0.909	$345M		$46M		EOS	NASA/Can.	1994	Delta II		Monitor Sea Ice
Special Purpose Inexpensive Sat. Tech. Altimeter	359						1.000					EOS	NRL	1991	Scout		Navy radar altimeter sat.
Satellite Astronomia raggi-X		2970	1988	2E+05	L	0	0.807	$161M				Astronomy	Ital./Dutch	1994	A/C 1		X-Ray astronomy
Space Flyer Unit	8800		1991	430			0.909	$473M				Astronomy	Japan	1994	H II		IR telescope, solar furnaces, micrograv research
Solar Probe	2640						1.000					Physics	NASA	2000	T-IV/C		Plasma physics
Spacelab (Shuttle Cargo Bay Module)	31900		1982	565	DM	0.57	0.659	$492M				Physics	Germany	1985	STS		Materials Processing
Spacelab (Shuttle Cargo Bay Module)	31900		1986	830	DM	0.57	0.763	$624M				Physics	Germany	1993	STS		Materials Processing
Tropical Rainfall Measuring Mission	5720		1995	150			1.033	$145M				EOS	NASA/Japan	1997	H II		Observe rainfall in tropics
Viking	618	1186	1983	30	AU	1.12	0.692	$49M	$20M			Physics	Sweden	1986	Ariane V16		Magnetosphere, aurora studies
Waves In Space Plasma	5000		1991	26			0.909	$29M				Physics	NASA	1993	STS		Measure of space plasma to RF perterbations

Figure 3.4.9.8-2. Space Science Payload Database, Part II

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3.4.10 Space Testbed Market Segment

3.4.10.1 Introduction

Spacecraft and their components are subjected to an exhaustive series of tests to determine if they will perform as required in a space environment. Environmental testing is used to space qualify subsystem components prior to being exposed to on-orbit effects of zero gravity, hard vacuum, cyclic heating, radiation, or atomic oxygen. Technology validation testing is used to verify new technologies intended for use on future spacecraft. Most environmental testing currently takes place preflight on the ground, whereas technology validation testing is conducted both on orbit and on the ground. Ground testing typically uses a facility that simulates the space environment. These facilities can only approximate the actual environment that the spacecraft will experience, thus degrading the accuracy of the results. This white paper addresses the following issues associated with space based testing: (1) what current ground tests can be done more accurately in space? (2) among those tests, at what launch cost is it economically viable to use space testing? and (3) what is the space testbed market sensitivity to launch costs?

3.4.10.2 Study Approach

Previous studies identified several potential markets for space testing. The space testbed missions were divided into four submarket areas: (1) all-up stages and spacecraft; (2) large space structures, (3) component testing; and (4) materials qualification. These four submarket areas include examples of current and potential future uses of both environmental and technology validation testing.

3.4.10.2.1 All-Up Stages and Spacecraft—R&D Flights

Because the complexity of the subsystems required to validate an all-up stage or spacecraft, including main engines, any new testbed would require complexity approaching that of the element to be validated. It makes more sense to fly the actual design and avoid developing a new testbed. In this case, the term "space testbed" should be replaced with the traditional term, "R&D flight." Return of the stage is probably not required, but a full telemetry downlink is required. Most of these missions could be carried on Delta class or smaller launch vehicles if tested in LEO.

3.4.10.2.2 Large Space Structures

Gravity environments of 1g present several testing problems for the makers of spacecraft that have large trusses, antennas, or solar arrays. Analytic structural models that are used to predict on-orbit shape of antennas can not be verified easily with ground testing due to static deformation of the structure in 1g gravity. Instead, considerable time and effort is spent constructing and testing a test article that is modified to compensate for 1g effects. The analytical models are then updated with the test data. Missions to LEO would provide the environment needed to test the actual configuration in zero gravity. No payload return, and only limited telemetry, would be required.

Control structure interaction technology validation is a current research activity that many makers of large space structures are pursuing. Among the technologies being studied are vibration suppression, active shape control, beam pointing, and structural identification. Both ground and on-orbit testing are currently being used; however, the ground test results are subject to inaccuracies due to 1g gravity effects.

3.4.10.2.3 Component Testing

The following environmental testing is conducted on spacecraft components and subsystem elements prior to being space qualified: (1) thermal, (2) pressure, (3) radiation, (4) electromagnetic, and (5) vibration.

These tests could be carried out on orbit, probably bundled together similar to materials testing. Component technology validation testing is currently used to test new sensor, communications, and other hardware-dependent technologies. Examples of this kind of mission are SDI programs validating components and sensors. Depending on the payload, telemetry or full recovery may be required.

3.4.10.2.4 Materials Qualification

LDEF (Long Duration Exposure Facility) is a good example of a space testbed to validate materials. LDEF also bundled together large numbers of small materials experiments in a given flight, which should be true of future space testbeds aimed at materials tests. (There is no reason that future space testbeds would be packaged as large as LDEF). Sample return is probably required, but significant telemetry is not.

The space testbed is distinctive from space materials manufacturing in that testbed components are intended for use in space, and are probably manufactured on the ground, and space manufactured goods are manufactured in space, and are probably intended for use on the Earth's surface. R&D missions to validate space manufacturing processes prior to actual production (which might be considered as testbed missions) have not been included in this analysis.

3.4.10.3 Market Description

Our ability to undercut ground testing costs may be limited, even with an order of magnitude decrease in delivery cost. To determine when the benefits of space testing are economically feasible, one must consider all of the elements involved with the current test environment. In some cases, a significant amount of telemetry may be required to replace the data collection techniques used on the ground. Some testing currently requires human work. To conduct this testing in space would, at some point, require a manned launch vehicle or a robotic assembly at substantially higher costs. In some cases the cost of the test article is orders of magnitude higher than current launch costs, making launch costs insignificant at any rate.

The key to the space testbed is in providing a test capability that cannot be provided on the ground. Programs constantly must make hard decisions about how much reliability they are willing to risk versus how much validation testing they are willing to pay for. The reliability benefits of added testing are unfortunately hard to quantify compared to on-orbit testing that would replace ground testing on a one-for-one basis. Reduced launch vehicle cost will open the door for greater high-fidelity on-orbit testing and improved system reliability, though it should not represent an explosive growth market. Increased Earth-to-orbit activity in general (based on other new markets identified under CSTS) should have a multiplier effect on the number of systems needing space qualification, and in turn, should further increase the demand for on-orbit testbeds.

Figure 3.4.10.3-1 summarizes recent missions that can be classified as space testbed. The majority of the missions are in the component testing submarket area and have been sponsored by the SDIO program or flown as mid-deck experiments aboard the shuttle. With the recent cutbacks in the SDIO budget, continued demand for testbeds or the sensitivity of this market to launch costs is uncertain; however, the funding may be used for testing in other market areas.

Program/ Sponsor	Name	Mass (lb)	Orbit(nmi)	Date	Vehicle	Cost ($)	Market Area	Comments
SDIO	Delta 180	?	120,28	9/86	Delta	150M	Comp	Total pgm cost
SDIO	Delta 181	3600	?	2/88	Delta	250M	Comp	Total pgm cost
SDIO	Delta Star	5984	270, 47	3/89	Delta	140M	Comp	Total pgm cost
SDIO	RME/LACE	3487	297,43	2/90	Delta	38M	Comp	Launch costs
SDIO	Losat-X	166	197,40	7/91	Delta	?	Comp	Launch costs
SDIO	MSTI 1-2	330	239.97	11/92	Scout	15M	Comp	Launch costs (ea)
SDIO	MSTI 3-6	330	239,97	3/94	Conestoga	15M	Comp	Launch costs (ea)
SDIO	MSX	6490	480 Sun	3/94	Delta	400M	Comp	Tot pgm cost
AF	Clementine	968	Lunar	1/94	Titan 2G	?	Comp	
NASA	SPAS-1	?	195,28	6/83	STS-7	?	Comp	Remote sense, alloy
NASA	LDEF	21351	313,28.5	4/84	STS-41C	?	Materials	
NASA	WING	?	184,28	8/84	STS-41D	?	Comp/LSS	Lt wt solar arrays
NASA	IRCFE	?	203,28	9/88	STS-26	?	Comp	IR comm eqpmt
NASA	SHARE	?	184,28	3/89	STS-27	?	Comp	Heat pipe/radiator
NASA	SPAS2/STP	?	161,57	4/91	STS-39	?	Comp	Optical disk
NASA	MODE	200	184,28	6/91	STS-40	?	LSS	0g dynamics
NASA	SHARE-2	?	184,28	8/91	STS-43	?	Comp	
NASA	MODE	200	355,57	9/91	STS-48	?	LSS	
NASA	TSS-1	?	271,28	7/92	STS-46	?	Comp	Tethered satellite
NASA	ACTS	3243	GSO	9/93	STS/TOS	?	Comp	Adv comm tech sat
NASA	LITE	~30K	?	9/94	STS-64	400M	Comp	Lidar In-space Tech
NASA	Comet	450	300,40	3/94	Conestoga	45M	Materials	
NASA	MACE	200	LEO	6/94	STS	?	LSS	Mid-deck active control

Figure 3.4.10.3-1. Recent Space Testbed Missions

The data in figure 3.4.10.3-1 give some indication of the current market for testbed missions, but no insight to the cost sensitivity. To assist in determining overall sensitivity, an effort was made to identify which CSTS market segments would benefit from space testing, and to categorize that testing into the four market areas. Shown in figure 3.4.10.3-2, this information is used to determine the multiplier used for growth of other CSTS markets. The multiplier effect is determined by estimating what contribution, in terms of flights/year and lb/year at a given launch cost, each market segment would contribute to a space testbed submarket area.

R&D Flights	Large Space Structures	Component Testing	Material Qualification
Telecommunications Mobile communications Humanplanetary exploration	Academic Research Telecommunications Humanplanetary exploration Space Solar Power Orbiting Billboards Direct Broadcast TV	Telecommunications Survey & Locate Global Digital Data Geo. Platforms Space Manufacturing Academic Research R&D Facilities Remote Sensing Govt. Missions Space Debris Managmt	Academic Research Geo. Platforms

Figure 3.4.10.3-2. CSTS Market Segments That Benefit From Space Testbed

3.4.10.4 Prospective Users

The following individuals were contacted to determine the potential uses of space testing. These contacts are representative of the four submarket areas in both technology validation testing and environmental testing. A summary of their inputs is contained in section 3.4.10.6.

Area	Organization	Contact
Space Qual. Testing	Wyle Labs	Ron Bollo
	NASA/Goddard	Bill Cas
Satellite Primes/ Users	Hughes Space &Com	Dave Robinson
	MMC-Astrospace	Carl Marchetto
Large Space Structures	NASA LaRC	Bill Grantham
	CSI Program Office	
Component/Subsystem Quakification	Honeywell-Sat Syst. Ops	Jackie Crobuck
	Allied Signal Aerospace	Dick Smise
	Hughes Space&Comm	Steve Sylvester

3.4.10.5 CSTS Needs and Attributes

There are significant impacts on current launch vehicles for the R&D flights and large space structures submarket areas. Based on discussions with the satellite makers, a less than 1-1/2-year leadtime requirement for a satellite test may be a greater impediment to R&D tests than current launch vehicle prices. Similarly, deployment testing of large antennas requires a 6- to 9-month leadtime. A reduction in the operations turnaround time of current launch systems would be required to capture these markets. Some technology validation testing requires human effort. If a robotic system is not substituted, then a man-rated launch system like the shuttle is required.

3.4.10.6 Business Opportunities

3.4.10.6.1 All-Up Stages and Spacecraft—R&D Flights

Hughes and MMC-Astrospace each tell us that they develop new classes of satellite about every three years. If we assume that the other satellite makers combined do the same, this represents a maximum of one satellite R&D flight/year at the current utilization of space. A key factor is the multiplier effect in space utilization (and space qualification) if other CSTS market segments grow. A summary of this market is shown in figures 3.4.10.6-1a and -1b. Makers of telecommunications satellites typically have production runs that do not provide large profit margins. The costs of constructing a prototype that would return any valuable data for these manufacturers could be substantially higher than the launch costs, and not be feasible. Manufacturers of smaller satellites designed to operate in large constellations such as for mobile communications could probably afford one R&D flight per production run.

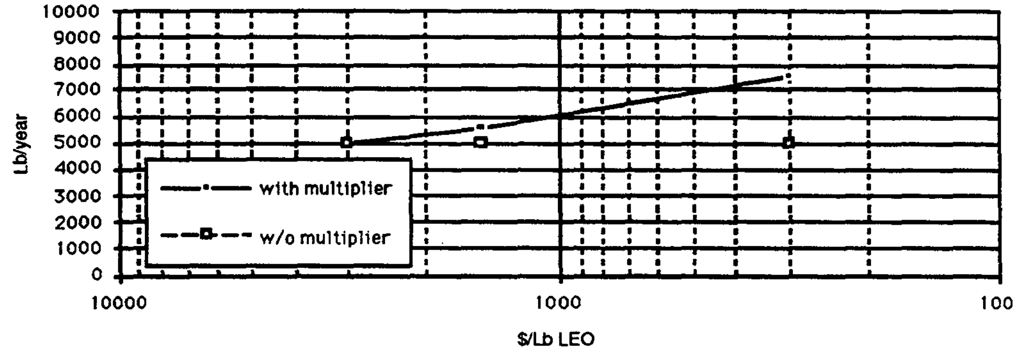

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Figure 3.4.10.6-1a. R&D LEO Equivalent Mass Demand

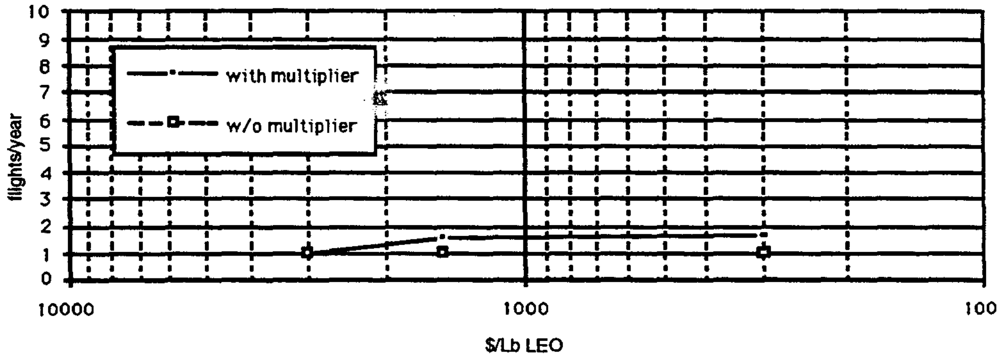

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Figure 3.4.10.6-1b. R&D Flight Demand

Pratt & Whitney, the maker of the RL-10 engine, does not see the likely use of a separate space testbed for main rocket engines. However, R&D flights of new stages and launch vehicles could again take place with reduced launch cost. Historically, R&D flights with no actual payload were common. But in recent years first flights of new launch vehicles and variants have carried payloads, but they may be discounted. If we assume new U.S. stage development at one every 2 years, this is the potential capture of R&D flights. (It is likely that there would be no multiplier effect for stages since CSTS economics partly depend on higher flight rates for fewer launch vehicles.) Capture of 100% would likely occur when prices dropped to approximately the amount that first flights might be discounted .

3.4.10.6.2 Large Space Structures

Three types of large deployable space structures represent a special market for a space testbed: large antennas, truss structures, and large solar arrays. Hughes gave a recent example of a large antenna with a cost overrun of >$50 million and a 6- to 8-month schedule slip primarily due to ground testing challenges of the large antenna. (Hughes said large antennas will become even more common with the emergence of the direct broadcast TV market.) Martin Marietta Astrospace also indicated a potential market in this arena. Even at current launch costs testing of the example Hughes antenna would make sense. The key limitation is leadtime, not cost. Hughes and MMC indicated leadtime requirements of 6 and 9 months respectively, something that the current launch vehicle fleet cannot provide.

Validation of LSS technologies such as vibration suppression and active control represents another testing challenge. Comparison of ground and on-orbit test results indicate that the ground test structural mode frequency estimates are off by 10% to 20% due to the 1g testing environment. From an accuracy point of view, it would be more desirable to conduct these experiments in a 0g environment. Ground testing will always be used, however, due to the relative ease in changing the structural configurations and collecting the data. A manned launch or a robotically conducted experiment could perform some of the ground test functions, but at significant additional cost. For some programs the launch costs are insignificant when compared with the total program costs. There is not much sensitivity to launch costs for these programs. In addition, many testbed missions are NASA programs that are given free rides aboard the shuttle. The launch costs are transparent to the program, although the taxpayer eventually foots the bill.

At lower launch costs some of the market would grow. As overall space activity increased in other key market segments, the multiplier effect would increase the number of large structures to be space tested, as shown in figures 3.4.10.6-2a and -2b.

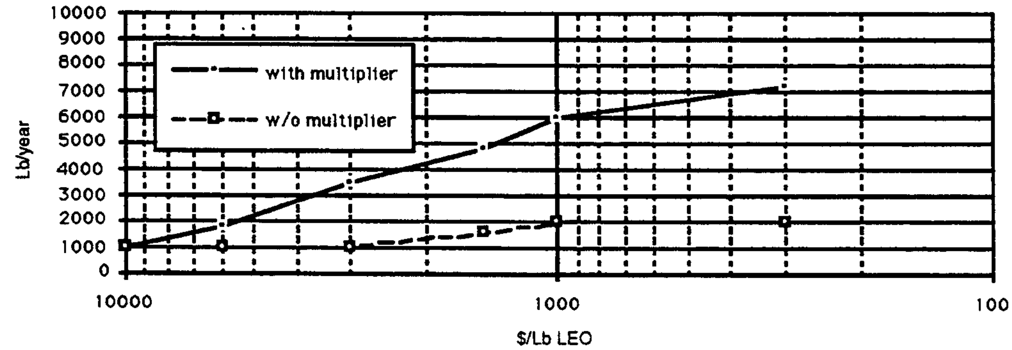

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Figure 3.4.10.6-2a. Large Space Structures LEO Equivalent Mass Demand

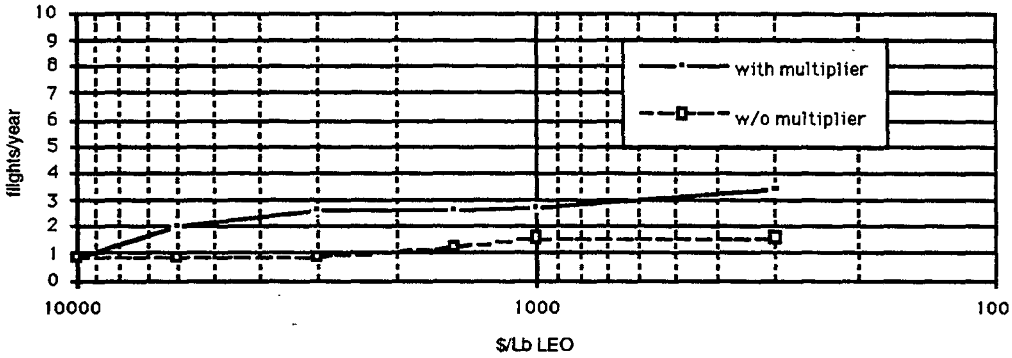

Figure 3.4.10.6-2b. Large Space Structures Flight Demand

3.4.10.6.3 Component Testing

A current example of this kind of mission is the NASA Advanced Communication Technology Satellite (ACTS) program to validate new communication technology. Also in this category are the numerous similar SDI programs validating components and sensors from suborbital sounding rockets.

In general, ground testing of components for space qualification is relatively inexpensive. Spacecraft thermal testing, typically conducted in vacuum chambers or by filling the shroud with LN2, and takes 2 to 3 weeks. Spacecraft EOL thermal environments that can be easily simulated in the chamber cannot be replicated in space. If the testing were conducted in space, extensive additional instrumentation would be required for telemetry. Test article recovery would be required in order to effect a thermal system redesign or repair. The advantage of space-based testing is that heat pipe configurations would not have to be designed for test in a 1g environment. This would allow for more design options, but is not a big cost driver.

Radiation/EM testing in space would require long (5 to 10 years) exposure times. This length of time is prohibitive to obtaining any useful data for spacecraft design/manufacture, and therefore does not represent a promising market. The space testbed market should remain limited until a substantial reduction in launch costs is realized. As overall space activity increased in other key market segments, the multiplier effect would further increase the number of components to be space qualified, as seen in figures 3.4.10.6-3a and -3b.

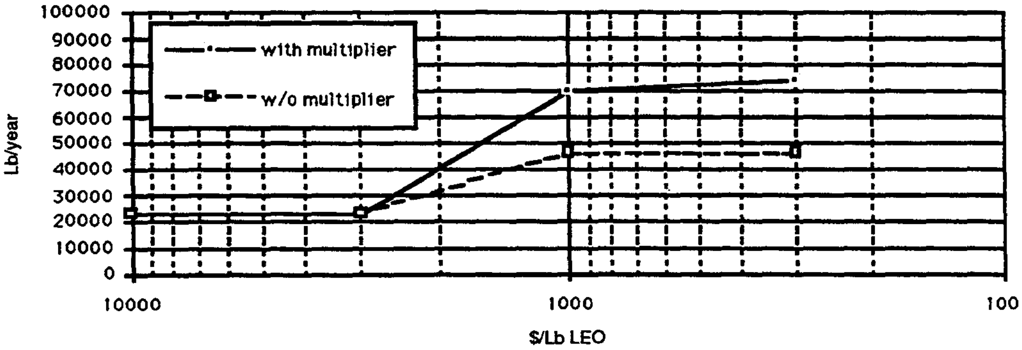

Figure 3.4.10.6-3a. Component LEO Equivalent Mass Demand

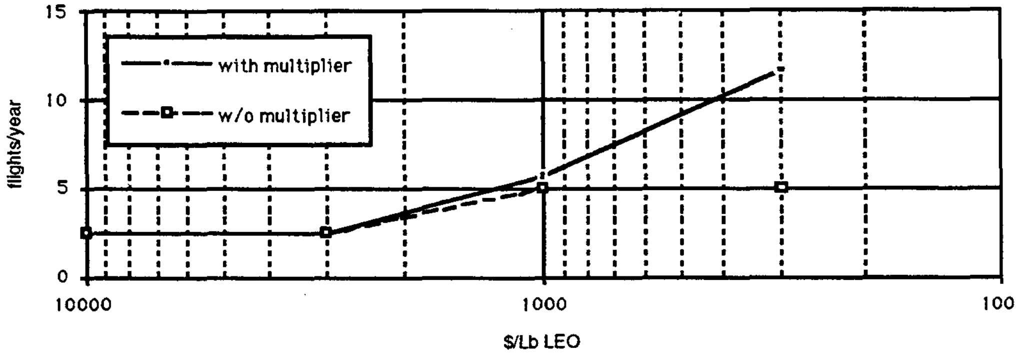

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Figure 3.4.10.6-3b. Large Space Structures Flight Demand

3.4.10.6.4 Material Qualification

A series of CMSE (Extended Duration Space Environment Candidate Materials Exposure) experiments are manifested to fly at a rate of one per year through the late 90s. This follows the LDEF, delivered in 1984 and returned in 1990, and Limited Duration Exposure Facilities (LDCE), which flew in 1992. At a flight rate of once per year for these secondary payloads, even the inclusion of a multiplier effect due to increased space activity will lead to a fairly modest potential market, as shown in figures 3.4.10.6-4a and -4b.

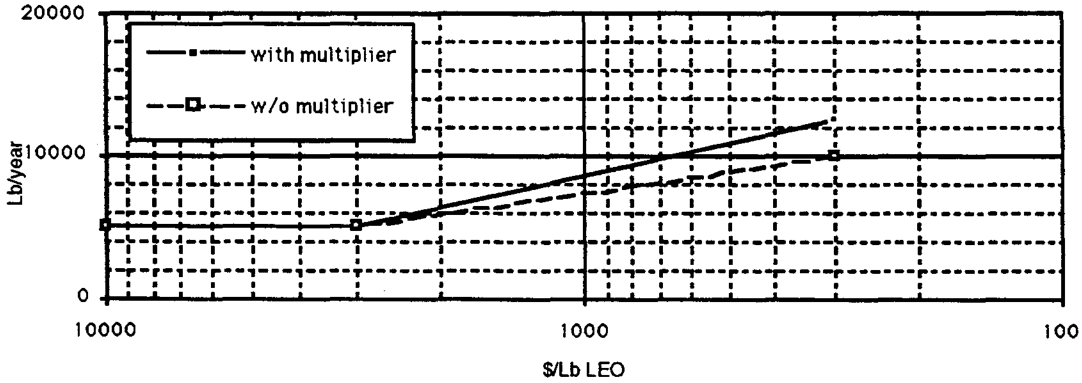

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Figure 3.4.10.6-4a. Material Qualification LEO Equivalent Mass Demand

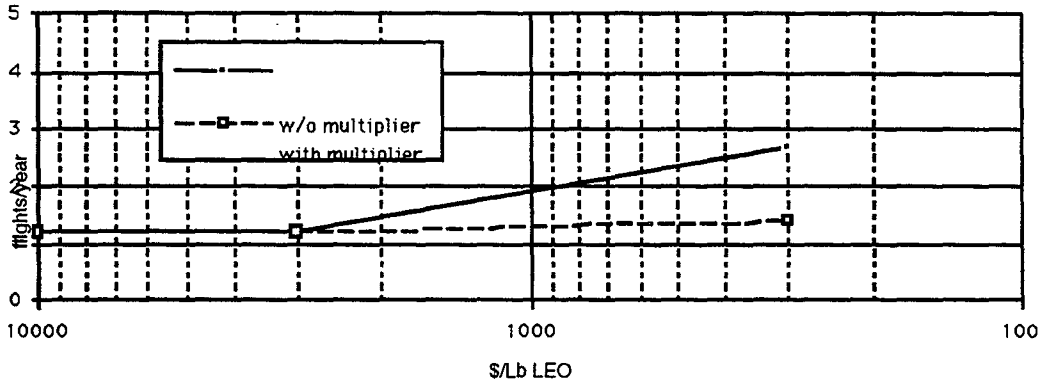

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Figure 3.4.10.6-4b. Material Qualification Flight Demand

3.4.10.7 Conclusions and Recommendations

The space testbed market segment has some potential for growth; however, the current market is not very sensitive to launch costs. The amount of new hardware requiring space testing is proportional to the size of the overall market growth identified in the other CSTS market segments. It is recommended that an additional iteration of estimating the multiplier effect on the space testbed market be carried out when more detailed estimates of the overall CSTS effort are available.

3.5 TRANSPORTATION

3.5.1 Introduction

The items grouped under "transportation" reflect a loose collection of market segments. The "value added" in these markets is primarily in the transportation of people and goods. The transportation elements do not exploit the features/advantages of space per se as is the case in other market areas explored in the CSTS. Many of these transportation scenarios involve high flight rate and price-sensitive operations; beyond that fact, the reader is cautioned not to place too much emphasis on the grouping of market segments under the transportation heading.

The following sections describe the following transportation market segments: Space Rescue, Fast Package Delivery, Space Servicing/Transfer, Hazardous Waste Disposal, Space Tourism Transportation, and Ultra High Speed Civil Transport.

3.5.1.1 Results Summary

The transportation market segments are truly driven by the availability of low cost, reliable systems. In the case of the transportation market segments, there is essentially *no significant profit to be made* until the transportation costs are reduced to a few hundred dollars per pound. Huge transportation revenues are envisioned, as the volume of traffic should increase more than proportionally to the price as compared to the higher cost markets.

Assuming the large traffic predictions for the transportation markets are realized, the required fleet size will be substantially larger than for other CSTS market groups. If the fast package delivery concept is realized, this market will set the fleet size for all the CSTS missions; likewise, the hazardous waste disposal market represents the largest market as measured by its mass-to-orbit requirements. Given the low net revenue per flight, it is imperative that the unit cost of the vehicles be as low as possible, assuming commercial amortization rates. This requirement should feed back into the design process instead of attempting to minimize the production costs after development.

Most of the CSTS markets will have as a requirement vastly improved service. In the transportation area, high flight rates dictate flight schedules (availability) must be maintained to a high degree of confidence. This can be achieved through very high reliability systems, fault tolerance, and spares/extra flight vehicles.

It appears that, in many ways, the requirements for transportation markets may be the most difficult to satisfy. One strategy is to exclude these markets from inclusion in a total aggregate until a second-generation commercial space transportation system is likely. Another view is that by addressing the stringent requirements for the transportation segments, other commercial markets will be able to use the same vehicles or technology without bearing the development costs and risks.

3.5.1.2 Associated Market Segments

The market segments grouped within this category have little association with other non "Transportation" markets due primarily to our definition of what is included in this category. Space tourism transportation is however, related to the entertainment and space business park concepts. Considerable effort was spent ensuring consistency in the treatment of these market segments.

Transportation markets provide leveraged growth for many other market areas. Beyond the jobs associated with developing, manufacturing, and operating the system, other terrestrial analogs would suggest there are several times as many jobs associated with the transportation markets.

3.5.2 Space Rescue

3.5.2.1 Introduction/Statement of Problem

Vision statement: *Bad news from the unmanned industrial materials processing platform Matsat IV- a failed solar array connection. In 3 days the batteries will be exhausted and the furnaces will shut down. The samples and the furnace will be ruined! A space rescue vehicle is called up and launched. Using the onboard intelligent algorithms, stereo vision, versatile toolkit, and multiple dexterous "armsÆ, a repair is effected with minimal telepresence support from the ground. The experiments and the facility continue on their mission . . .*

Timely rescue of humans and/or valuable space assets has heretofore not been possible. In the unforgiving environment of space, minor system failures or natural disasters (such as micrometeor strikes), can result in loss of life or the degradation of expensive assets.

In order to mitigate these potentially disastrous results, conceptually an industry would be created to rapidly and flexibly respond to crisis situations. Figure 3.5.2.1-1 lists some of the terrestrial services that are analogous.

Fire Department Rescue Teams
Emergency Medical Technicians
Hazardous Material Spill Teams
Forest Fire Smoke Jumpers
Oil Well Fire Specialists
Coast Guard Search and Rescue (SAR)
U.S. Navy Submarine Rescue Team
Commercial Aircraft Airplane-on-Ground Teams

Figure 3.5.2.1-1. Terrestrial Analogs for Space Rescue Service

3.5.2.2 Study Approach

Since there is no such capability (or company) existing today, it is not possible to directly interview any users. Assuming that it will be a part of a large, thriving commercial space scenario, we agreed to postpone further market analysis of this market segment, representing it as a small multiplier applied to the sum total mission model. This approach is insufficient to quantify the economics of the space rescuer's business or transportation system and is left for future study to refine.

3.5.2.3 Market Description

3.5.2.3.1 Description Market Evaluation

Rescue of personnel and assets has economic and societal value if the cost of the rescue is less than or equal to the cost of inaction. For purposes of this report, the term "rescue" is taken to imply that time is an important, distinguishing feature of this market segment.

Many terrestrial rescue services are not for profit, operating from municipal, tax-based revenues. The *cost* of rescue services is based on a cultural perception of the *value* of such services, rather than an economic analysis. Similarly, the assured crew return vehicle (ACRV), a planned rescue capability for NASA's space station, is not economically justified by any reasonable value assessed to the life of astronauts.

Other rescue services are based on economics. Terrestrially, even paying a high premium for a specialty company to extinguish and cap a burning oil well is justified by the revenue-earning oil that is preserved. In space, there have been several high-profile satellite repair missions. As there was not the element of time urgency associated with the term rescue, these examples will be discussed in section 3.5.4, Space Servicing/Transfer. It is possible in the future that a situation such as was described in the previous vision statement would result in the requirement for rapid response. The failure to act in a timely manner could result in tremendous costs for some space ventures when one considers loss of revenue, customers migrating to functioning alternatives, and replacement costs.

The market then, is for a service that could rapidly respond to any number of possible emergencies in space and perform a successful rescue (meaning extract, stabilize, rapidly repair, or retrieve) at an acceptable cost.

In the past, space rescue was all but technologically impossible. Pre-positioned rescue assets such as the ACRV have been studied for manned missions. Ground-based rescue concepts are attractive when one considers the advantages of checking the hardware immediately before use and making any modifications to accommodate unique rescue situations. Rapid response of launch vehicles was possible (witness the ICBMs in their silos) but not with a nonstandard payload and certainly not to any random orbital destination.

3.5.2.3.2 Market Evaluation

To credibly evaluate the market for space rescue services, one needs to examine the aggregate traffic model for what will be in space at any given time. Furthermore, one needs to know what the orbital parameters are for all potential "customers" and some basics about how a rescue could be performed physically on a given spacecraft.

When all this basic information is known, one would have to probabilistically assess likely failure rates and modes. This does not require a failure modes and effects analysis (FMEA) for all possible spacecraft. It would be important to acknowledge that some spacecraft are more likely to need rescue and some are more likely to be able to be rescued.

The value of rescue must also be considered. Insurance actuarials could be used to understand the monetary compensation that could be expected: if the price of the space rescue mission is lower than the amount paid out by insurance, law suits, and so forth, someone will pay for the service.

As much of the information required to do this market evaluation awaits the completion of this phase of the CSTS, no results can be presented yet.

3.5.2.3.3 Market Assessment

No business assessment for a space rescue enterprise was conducted within the time and resources of this study.

3.5.2.3.4 Market Infrastructure

A space rescue venture, like many terrestrial analogs, involves specialized equipment and operations. The degree of overlap with other commercial space infrastructure will be minimal. The costs of this unique infrastructure represents a negative factor on realizing space rescue.

3.5.2.4 Prospective Users

As space rescue is a new market with no existing customers and was not a focus area, we did not have time to discuss this concept with others outside of the alliance. Within the alliance, discussions were held with personnel who have worked on the ACRV program. Future studies may explore discussions with commercial, premium-priced terrestrial rescue services, government rescue agencies, and insurance community representatives.

3.5.2.5 CSTS Needs and Attributes

3.5.2.5.1 Transportation System Characteristics

In general, without specifically knowing the spacecraft to be rescued, one can only discuss transportation system characteristics in general terms. If pre-positioned, space-based rescue assets are required, there is some latitude as to the scheduling of launches. For a ground-based rescue concept, the transportation system is "called up" quickly; that is, all elements from the decision to rescue to launch of a rescue package will be effected within hours. The system will have adaptive guidance and large reserves of propellant to permit flexible, off-optimum rendezvous. Control and physical attachment with the rescued object will need to be largely autonomous with telepresence as a backup. Finally the rescue vehicle must be able to reenter and land with a large, minimally restrained payload (rescued items) with a wide range of possible centers of gravity.

3.5.2.5.2 Transportation System Capabilities

When a full accounting is made of the possible spacecraft to be rescued, the required capability of the transportation system will become apparent. The most difficult transportation capability to fulfill will be to remain dormant for an indefinite period and then reliably launch to a variable destination. Alternatively, the system could require a planned payload to be demated and a rescue payload to be mated and launched within a short time period.

3.5.2.5.3 Ground Handling

Minimal ground handling is required to ensure that a rescue mission could be called up and flown as quickly as possible.

3.5.2.5.4 User/Space Transportation Interfaces

In order for a successful rescue to occur, the rescuer must know as much as possible about the object to be rescued as early as possible. Online databases could provide instantaneous access to critical information. If the space hardware is developed to accepted standards, the toolkit of the rescuer would be more likely to be useful in the rescue.

If available in an unclassified format, the U.S. Navy submarine rescue experience could provide an excellent data source for interfacing in hostile environments.

In general, a successful space rescue concept would have to be very versatile in its ability to interface with any number of spacecraft.

3.5.2.5.5 Improvements Over Current

Most of the transportation characteristics described in the previous sections require improvements over current systems. Rapid transition from dormancy to operational status will be a challenge unlikely to be required of other CSTS missions.

3.5.2.6 Business Opportunities

Analysis of business opportunity was limited at this point. After summing the other CSTS missions, a 1% "tax" was applied to the manifest as a gross estimate of the likely level of rescue activity. For example, if there were 259 active orbiting spacecraft in the year 2013, there would be 2 rescue missions that year.

3.5.2.7 Conclusions and Recommendations

Space rescue constitutes a probable element of a healthy commercial space scenario. In the absence of specific spacecraft data, it is difficult to credibly assess even a preliminary business opportunity. Similarly, there are insufficient data at this time to determine how space rescue should be effected (ground and/or pre-positioned space assets options). A small multiplier, or tax, on the overall CSTS model was considered prudent.

3.5.3 Fast Package Delivery

3.5.3.1 Introduction/Statement of Problem

Vision statement: . . . *Tuesday, 9:32 am, on the outskirts of Singapore . . . . The sequence control computer has just burned up, bringing the Lumpur Enterprises, Limited, assembly line to a grinding halt. The replacement board is made at TechnoWorld Industries in Palo Alto, California, where it is 5:32 p.m. locally. If a night flight heading west could be found, the board would still not get to Singapore until, at best, Thursday morning - 2 days of expensive downtime at about $135,000 a day! Instead, the plant manager remembers reading about the new Global Express service called UltraDelivery™. After Global Express and TechnoWorld are called, a replacement board is whisked to evening express flight out of L.A. (San Francisco is still constructing its own express port). The cost in shipping charges paid to Global Express is $9,842. At 10:52 p.m., PST, the delivery rocket to the space port in Singapore, landing 48 minutes later at 3:40 p.m. local time. By 5:15, the board is delivered to the factory, enabling resumption of operations by Wednesday morning . . . .*

The concept of fast package delivery via a form of commercial space transportation is a logical extrapolation in the history of commerce. Rapid transport of physical goods is desirable for several reasons. Getting the product to market first can be the difference between success and failure. Competitive markets are driven to offer enhanced service (which includes responsive delivery and/or repairs) when the difference between the price or product quality of competing products is indistinguishable. For some industries, the higher costs associated with a more rapid transport of products is still preferable to the even higher cost of warehousing extensive inventories. Some products are too perishable to be viable unless the time in transit is very low.

{The fast package delivery mission does not go to a stable orbit, and one may validly ask why this market area is included in a study of commercial space transportation. As will be discussed in later subsections, the system solution will embody almost all of the attributes that an orbital system would have. The total energy required can be up to ~85% of an orbital mission, apogees can approach 800 nmi, and reentry profiles are as severe as a return from orbit. Operationally, the requirements for a fast package delivery vehicle include rapid turnaround, a high degree of reusability, low unit costs, and high reliability—all the same as (or better than) orbital missions. Furthermore, the market is near-term, which means some operations could conceivably begin today, at nearly today's costs, with the availability of a system. Finally, as the vehicles for fast package delivery tend to be smaller and technically less demanding than for other CST markets, fast package delivery offers the potential to serve as a bridging mission: investors, operators, and governments will learn and gain confidence in routine space transportation. Lower development risks and cost, lower valued payloads (liability), and evolutionary technology implementation will enable the hardware manufacturer some latitude to learn how to make a commercial space vehicle.}

3.5.3.2 Study Approach

Although the fast package delivery concept represents a "new" market, it was instructive to work with air freight companies, particularly those offering premium services, such as overnight delivery. Furthermore, it is likely that some of these existing carriers would offer fast package delivery as one of several specialized services. This business vision would exploit the experience and shared infrastructure efficiencies of these companies vis-a-vis some new company trying to start up offering only premium, low-volume (as compared to air freight) transportation.

Therefore, the study approach for this market began with an examination of current and predicted facets of air freight, and in particular, the fast package services that use aircraft transportation. The thesis is that by understanding the lessons learned and business models of this service/transportation industry, a reasonable and traceable extrapolation to a new fast package delivery market could be made.

3.5.3.3 Market Description

3.5.3.3.1 Description Market Evaluation

Rapid transport of products over long distances, currently in the form of air freight and express mail, continues to expand. Despite the current global economic slump, this transportation sector is healthy. Various sources predict that the global air freight and express market will grow at something like 7% per annum through at least 2010.

In the express delivery services market, even more optimistic predictions are claimed. The United States market, where the concept first was implemented, is the largest, worth approximately $16 billion and will continue to grow at some modest rate. In Europe and eastern Asia, companies are still learning to exploit the advantages of overnight and/or same day delivery services in their businesses. One could expect significant growth in these markets. True transoceanic fast package delivery appears mainly in limited markets and is mostly based upon charter-type operations. As the global economy becomes more and more interdependent, regular fast package delivery services will become a necessity, not a luxury (in the same way U.S. businesses have come to depend on Federal Express, DHL, Emery Worldwide, etc.).

There are some foreseeable factors that may limit the demand for fast package delivery. A significant percentage of current fast package users transport original documentation or currency to execute business transactions. With time, electronic signatures and money transfers are increasingly viewed as legal and acceptable, reducing the demand for physical transport of packages. Another factor relates to the capabilities of air transport: for small items, the trend in airplane design has created a glut of "free" cargo capacity in the belly holds that will attract some products that find that their time criticality is not worth the higher price of fast package delivery services.

Figure 3.5.3.3-1 depicts the forces and constraints at work in the development of a fast package delivery service.

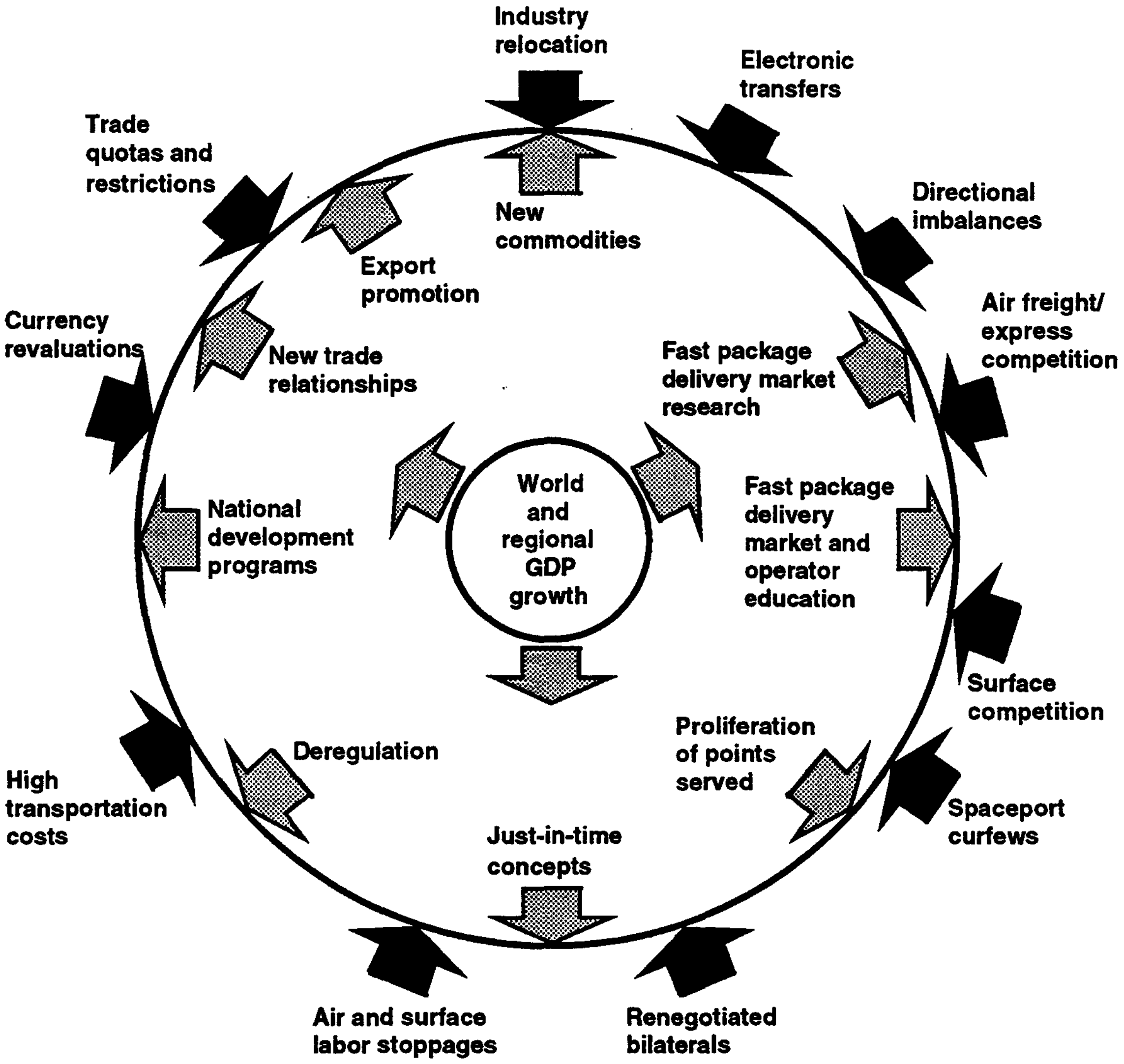

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Figure 3.5.3.3-1. Issues Related to the Development of Fast Package Delivery

3.5.3.3.2 Market Evaluation

The question that is invariably asked about the fast package delivery concept is: *What are the things that would use such a service?* <Anecdotally, and notably, interviewed personnel within the express package industry did not seem as skeptical or concerned as those in aerospace manufacturing with the makeup of the payload and the likelihood of a market materializing. . . .> There are two product classes that would use a fast package delivery system: (1) commodities/services for which customers are willing to pay a premium for speed of delivery and (2) commodities/services in created markets that were previously impossible due to the perishable nature of the product. The first category is typified by the difference between fees charged for overnight letters vis-a-vis conventional postal rates. An analogous example in air freight for the second class of product would be the inception of transoceanic flights of fresh cut flowers.

Data gleaned from current air freight practices may prove instructive on predicting why customers would use fast delivery services. Figure 3.5.3.3-2 lists the top five United States imports and exports commodity groups via air transport in 1992. The items are not intuitively obvious! Note, too, that the intrinsic value of the items being shipped represent a wide range- from 1 to 10,000 $/lb. Each of these industry groups has made a trade between the higher cost of air shipment and the costs of warehousing, "buying more time" for production, customer responsiveness, and service, and beating the competition to market. Similarly, our inability to precisely define the users of fast package delivery does not imply users will not exist.

Imports		Exports	
Commodity	lbm	Commodity	lbm
I/O units for computers	330,000,000	Aircraft Parts	38,000,000
Sound recording equipment	300,000,000	I/O units for computers	28,000,000
Footwear	206,000,000	Photo film	28,000,000
Photocopying apparatus	112,000,000	Specialized industrial machinery	24,000,000
Shirts, men's and boy's	110,000,000	Tractor parts	22,000,000

Figure 3.5.3.3-2. Top Air Freight Commodities for 1992

In the category of commodities that would find tangible benefit of rapid delivery, one could speculate that original documentation, currency, precious metals, and jewels may utilize such a service. These items have to have a very high value per unit weight; assuming shipping prices reflect the size and/or mass of the package, the fee would be tolerably low for such items.

Another potentially lucrative area of time-value delivery would be in the form of specialty machines or electronic parts and assemblies. As in the fictitious example given in the introduction to this market segment, the value of such items should be calculated to include more than the basic price of the item. The cost of downtime and inconvenience to many enterprises is potentially huge. A premium fast package delivery service would be part of just-in-time manufacturing principles, critical repair service, and supply-line disruption recovery. It is likely that a "package" of this type will represent the payload that will size the transportation system. Note that the cost of the delivery service must meet or beat the sum costs of transporting, storing, and depreciating comparable commodities.

The commodities and markets that would be created by a fast package delivery service may include items such as human organs for transplantation, fresh food delicacies, or biologic specimens for research.

Providing human organs for transplantation is a good example of a service enabled by a fast package delivery. As seen in figure 3.5.3.3-3, the demand for transplant organs is growing at a fast pace, as medical technology improves techniques to minimize rejection. Opinions in interviews with the medical community were diverse as to the appropriateness of an expanded transplant network. Some believe that artificial or cloned organs will obviate the need for the current donor/recipient matching systems. Currently, potential recipients typically relocate to an urban area that has a facility specializing in a certain type of operation and wait agonizing months until a donor is matched (assuming one is found at all, before death occurs). When a donor is found, the salvageable organs are carefully removed and packaged and whisked to the recipients' facility (typically by a chartered Learjet). Transplant availability is limited by the lifetime of the organ outside of the body (as little as 4 hours in the case of a heart). Faster transit time would significantly expand the range of potential donors. Some ethicists have expressed concern over the possibility of "harvesting" third world organs; there will be many aspects of this fast package delivery market that will have to be resolved before implementation. The fact is that if properly done, an expanded pool of donors would save many lives.

Organ	1989	1990	1991 (awaiting transplant)
Heart	1,700	2,085	2,045
Heart-lung	68	50	586
Kidney	8,706	9,560	18,464
Liver	2,164	2,656	1,466
Lung	119	265	450
Pancreas	419	549	170
Total	13,176	15,165	23,181

Figure 3.5.3.3-3. Organ Transplant Demand

One can explore the likelihood of finding products that would be justified in accepting the high cost of a commercial space transportation system by several techniques.

Market user surveys have been useful in identifying the issues and thresholds of a number of commodities. Quantitative data, however, are virtually impossible to gather: the initial operating capability of such a system in well beyond the long-range planning horizon of most prospective users. Additionally, it would appear that traffic estimates are highly elastic to transportation cost—at a sufficiently low cost, the mature relationship between air freight and other transportation modes would disruptively shift, making credible prediction difficult.

Another approach is to back into an estimate of economic validity. The cargo industry generally considers that products can bear about 3% to 6% of their value, in the aggregate, for transportation. Although there are examples of individual commodities varying from this range, this rule of thumb has a fairly good correlation to any number of transportation systems (including air freight). If one assumes that an operational fast package delivery system will meet with customer acceptance by falling in a similar range, one could assess the parametric value of typical products versus the anticipated range of CST system transportation costs. Figure 3.5.3.3-4 illustrates the range of likely product values as transportation cost is varied. At the right of the graph are some notional products and what their "value" is (remember, as in the introduction example, value includes a time component). From this exercise, it would appear that there are products for which fast package delivery is economically sound.

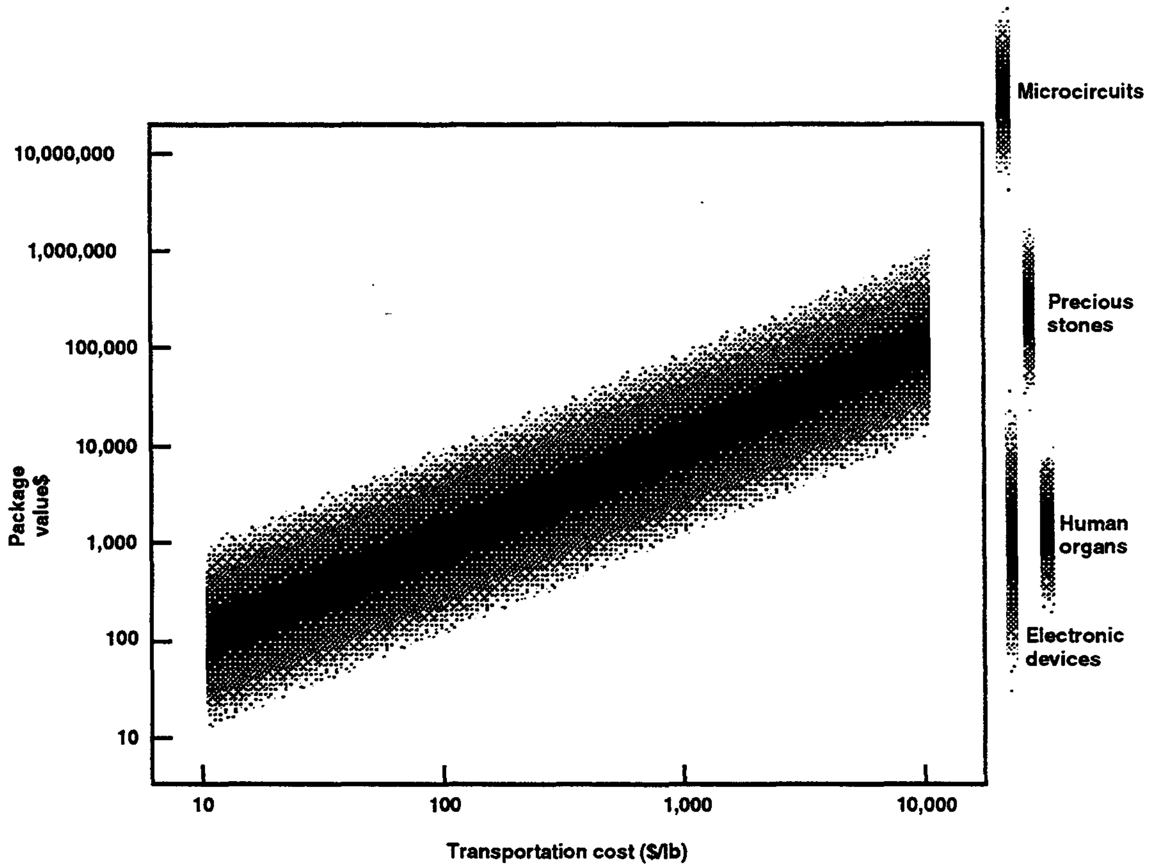

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Figure 3.5.3.3-4. Relationship Between Package Value and Transportation Cost

Other aspects of a long distance (primarily international) transport of goods would be those of customs, taxes, labor disruptions, and landing fees. These are very real facets of international trade and must be accounted for in a market assessment. For example, it is easy to visualize how a local customs inspector could hold up a shipment (having gone to lunch, misplacing a form, or even perhaps, exercising a work slowdown as a labor contract is in dispute) and rapidly erode any time advantage fast package delivery may have over a competing mode of transport. Proper planning and flexible response are keys to overcoming these obstacles.

International air transport is legally possible because issues such as liability have been resolved in treaties. The fast package delivery concept involves more launch and landing sites and more overflight of population centers than any other commercial space mission. Space transportation does not, as of yet, enjoy the same degree of understanding or precedent as atmospheric flight activities. The treaty "Convention on Liability for Damage Caused by Space Objects" (in force October 9, 1973) would seem to need some amendment. Basically liability is assessed to the country where the launch physically occurred. As written, this could be a strong disincentive to some nations to engage in fast package commerce.

Other issues would include interface with regional, national, and local air traffic control networks to ensure safety of atmospheric flight operations. Regulations concerning noise abatement, curfews, and environmental impact are real concerns for a system that must fly often and in proximity to population centers. Range safety, as currently defined, will be too cumbersome to implement at so many launch sites, and will probably be eliminated in favor of strict certification requirements.

3.5.3.3.3 Market Assessment

The number and city pairs serviced and the frequency/availability of flights requires careful consideration. Assuming the initial operators to be a commercial venture (governments may encourage or promote activity, but route decisions are not regulated), the selection of initial operations will determine how quickly the fast package delivery industry will mature. The following are several paths a fast package delivery business could take:

a. Limited scheduled service between major city pairs, maximizing traffic while minimizing the number of vehicles in the fleet.
b. Charter operations between major city pairs, maximizing revenue while minimizing the number of vehicles and the cycles on the hardware.
c. Charter operations between major embarkation points and many destinations, with deadhead return.
d. Scheduled service between many city pairs, maximizing market penetration.
e. Hybrid approaches of above options.

Discussion of the pros and cons of each option, and the implications for a transportation system follow.

Limiting service to major destinations would enable startup of operations with the least number of vehicles and would simplify maintenance logistics. Figure 3.5.3.3-5 depicts the current top air freight traffic city pairs in terms of mass. One could presume that fast package delivery would best be suited to these markets, where the collection/distribution systems are in place and demand is high. Selecting the top "n" markets would then determine the vehicle/fleet requirements. It should be noted that these city pairs do not necessarily correspond to the largest population or industrial base. In some cases, a particular industry has found that air freight is important to its operations and uses the service heavily. {For example, Columbus, Ohio, has a private airfield that supports the arrival of 747s loaded with imported clothing for The Limited™.}

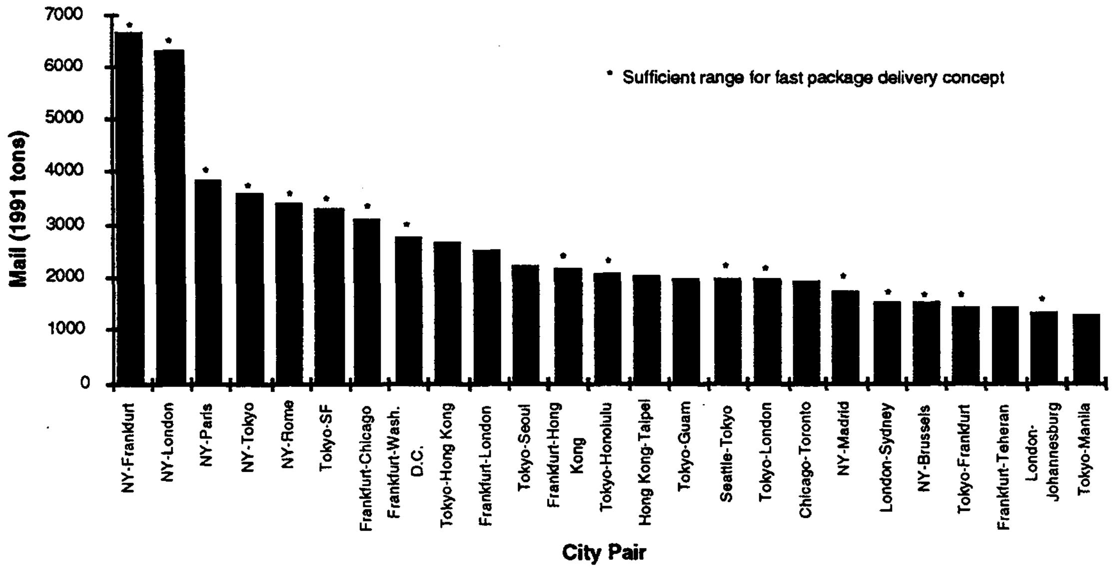

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Figure 3.5.3.3-5. Top Air Freight City Pairs

Charter operations would seem better suited to the nature of many fast package commodities; the arguments for reducing flight times are equally valid in the need to reduce the stem time prior to a scheduled flight. Vehicle life will be increased due to the infrequent use of the hardware elements. On the down side, predicting utilization in a new system is difficult, and the uncertainty in the estimates may scare off investors. The higher the cost of the hardware, the less desirable it becomes to establish an extensive network of destinations.

Designing a system to land in many locations, while staging in only a few could dramatically enhance utility of the system. Returning the vehicle to a launching site (assuming reusability) is potentially a major cost, and reduces the availability of the system.

Scheduled service in many city pairs will create a large and stable demand for fast package delivery. If the experience of the express mail market has any relevance to commercial space fast package delivery, the key lesson is this: there is a number, a critical mass, of networked nodes (cities) that cause the number of users to explode. The theory is the subject of doctoral dissertations, but the practical experience is worth examining. Federal Express began with a limited route structure flying small biz-jets, and lost money. When larger capacity airplanes and a nationwide network was established, an era of tremendous profitability was sustained. On the down side, there is a large upfront investment required to establish this capability (note that express mail service companies had the fortuitous timing to expand when a glut of used, convertible aircraft were available; no such used launch vehicle market exists).

The answer may lie, as it does with express mail/air freight, in a hybrid mix of operations. Currently charter operations account for about 10% of the revenues of the express delivery industry. If service really is of paramount importance to the users, the expense of the extra vehicles may be justified.

Estimating the size of the fast package delivery market, and the operating cost requirements ($/lb) was attempted via several methods. For a new market, none of these methods is rigorous to provide a precise estimate, but it was hoped some patterns would emerge.

In the first method, an extrapolation of Federal Express international operations was made. Federal Express was chosen because it is an industry leader and some financial data were available. Approximately one-quarter of its revenue is attributable to international operations. Applying this ratio to the ~$16 billion express market would indicate the current international express market is worth ~$4 billion annually. One could parametrically vary the percentage of that market that may be captured by a fast package delivery service as well as the rate of growth in international package services. Figure 3.5.3.3-6 portrays the range of annual mass estimates that result.

It is instructive to look at some 1991 data for mail, priority mail, and express mail (fig. 3.5.3.3-7). One could extrapolate to a fast package delivery market from these data (recognizing that mail data are not all-inclusive and other services such as charter operations are unrepresented). For example, if five million items were transported at $100 each, the market would be $500 million annually.

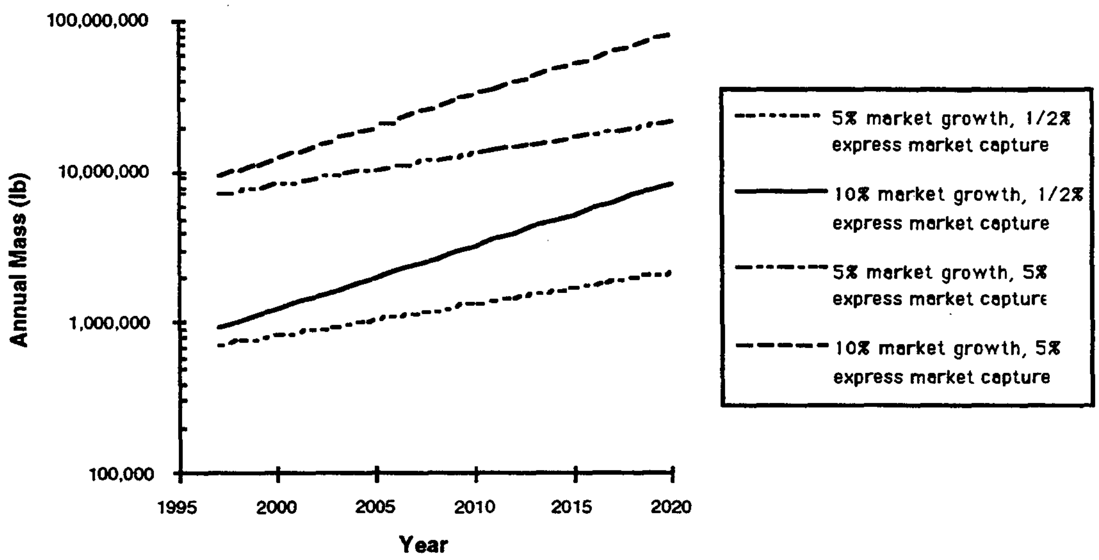

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Figure 3.5.3.3-6. Estimate of Annual Fast Package Delivery Mass

Parameter	First Class	Priority Mail	Express Mail
Per piece revenue	$0.30	$3.33	$11.52
Per piece attributable cost	$0.18	$1.91	$8.72
Per piece revenue less attributable cost	$0.12	$1.42	$2.81
Per pound revenue	$7.84	$1.74	$6.23
Per pound attributable cost	$4.64	$1.00	$4.72
Per pound revenue less attributable cost	$3.21	$0.74	$1.52
Pieces	~90,000M	~530M	~58M
Average weight/piece	0.0375 lb	1.919 lb	1.85 lb
Average density	14.4 lb/ft^3	11.3 lb/ft^3	7.0 lb/ft^3
Total weight	3,398Mlb	1,017Mlb	107Mlb
Total volume	236Mft^3	90Mft^3	15Mft^3

Figure 3.5.3.3-7. Cost/Revenue Comparison for Mail (1991)

Given the discussions held with express delivery industry representatives, charging users hundreds of dollars per pound is quite consistent with a specialty service philosophy. Even thousands of dollars per pound would still be acceptable to some users. Another order of magnitude was viewed as "iffy." Figure 3.5.3.3-8 depicts a rough order of magnitude model of what the price elasticity/demand may look like. Note that this corresponds to 1991 data and should be escalated at 7%, compounded annually depending on the anticipated date of introduction of service.

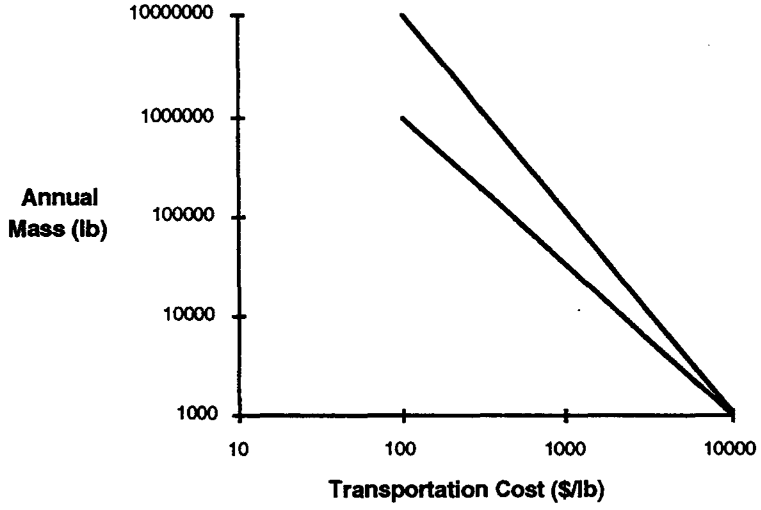

Figure 3.5.3.3-8. Fast Package Delivery Market Size

3.5.3.3.4 Market Infrastructure

It is expected that a fast package delivery system will begin as an adjunct to the existing express mail/air freight infrastructure. Package collection, sorting, loading/unloading, and distribution will probably not require extensive new infrastructure elements.

3.5.3.4 Prospective Users

Direct contact was established with several prospective users of a fast package delivery service. The responses received were all viewed as positive to enthusiastic. Representatives of Emery Worldwide, Federal Express, and the Boeing Commercial Airplane Group/Cargo Research organizations were interviewed and provided much of the information in this report. The concept of fast package delivery has in fact been discussed before: the CEO of Federal Express, Fred Smith, had even previously spoken on using the Orient Express for such a purpose (ref. 1).

3.5.3.5 CSTS Needs and Attributes

3.5.3.5.1 Transportation System Characteristics

The fast package delivery system is a hybrid between cargo aircraft and rocket transportation in that there are multiple takeoff and landing sites, but large amounts of energy are required to reach the destination. Typical payload sizes would not be anticipated to be very large. At this point, an educated guess would indicate a capacity of 3,000 lbm is sufficient. The performance capability, measured in terms of ΔV, is determined by the maximum range route one would anticipate flying. In the absence of a complete analysis of likely city pairs for service, it can be shown that the longest range of interest is about 10,000 nmi, with most major routes somewhat below this range. Figure 3.5.3.5-1 depicts a typical boost/glide trajectory between New York and Sydney—about the maximum range one would anticipate.

There are two classes of transportation systems that can achieve the fast package mission. The first, as represented in the previous example, is a boost/glide system. The system performs an initial accelerating burn that lofts the vehicle/payload in an elliptical, suborbital trajectory. The propulsion system (rockets) operates for only a small fraction of the flight time. As the vehicle reenters the atmosphere, it is aligned in such a way to cause it to skip along the highest fringes of the atmosphere. This technique maximizes the range for a minimum amount of propulsive energy and limits the aerodynamic and thermodynamic loads on the reentering vehicle.

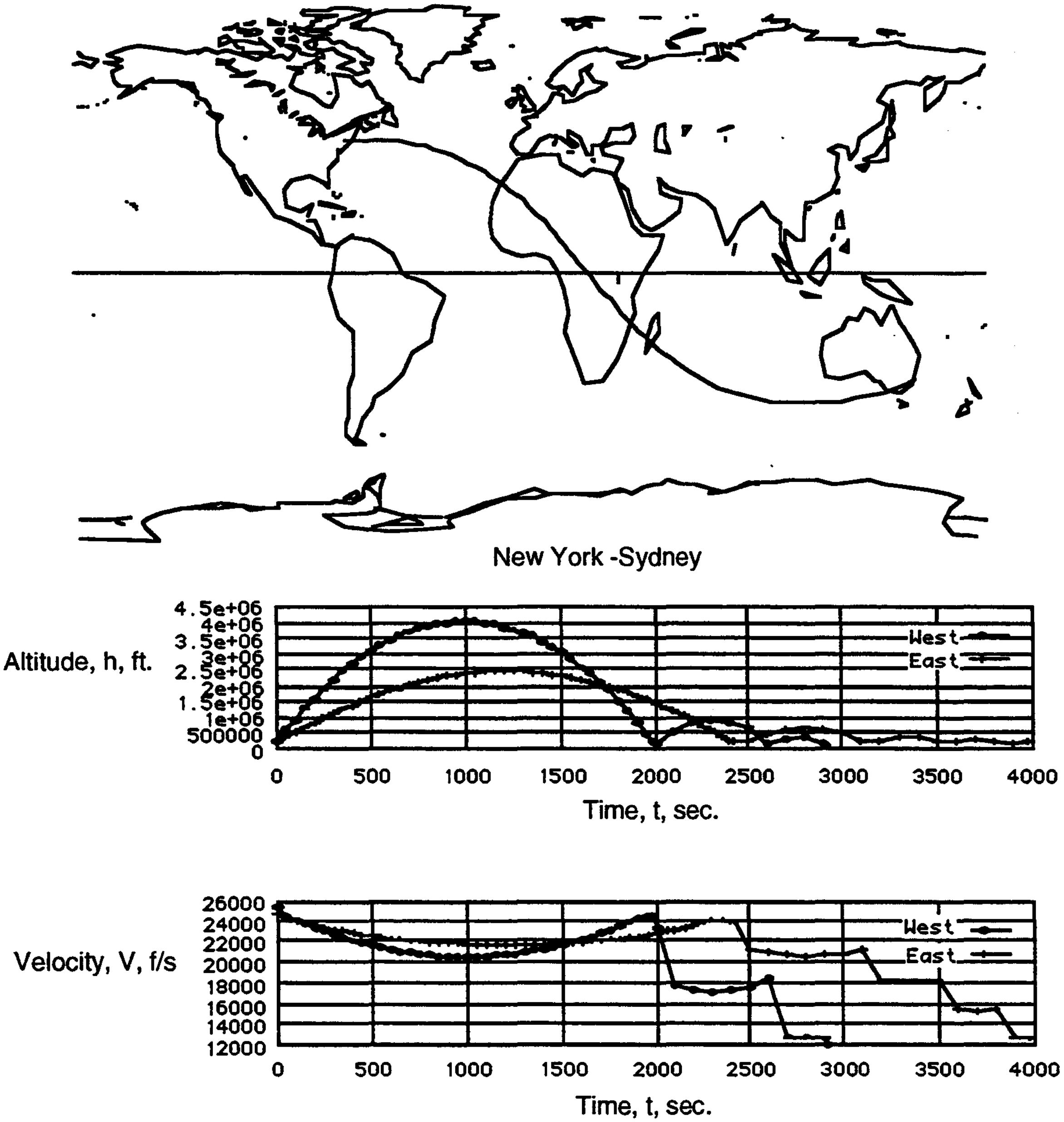

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Figure 3.5.3.5-1. Example Trajectory for Boost/Glide-Type Fast Package Delivery Mission

The second type of concept flies within the atmosphere using a continuously thrusting, air-breathing propulsion system, like an airplane. The National Aerospace Plane program was similar in concept. While the vehicle would be smaller (and theoretically less expensive) to move a given payload, the technology risk is substantial and has yet to be proven.

Other transportation system requirements would probably include a minimization of vibration and environmental extremes given the diversity and unknown fragility of the packages.

Reliability is a key requirement for a fast package service operator. What the operator defines as reliability is *not* the same as what the transportation hardware industry thinks of as reliability. The typical user of current express services only approaches such companies when all their other, slower, less expensive options have been explored. CST fast package delivery users could be expected to fit the same profile. Businesses do not usually plan to get into situations where premium express delivery is the difference between success and failure. When their services are employed, the express companies are *expected* to deliver as advertised. Failure to do so virtually guarantees there will be no repeat customers. What the fast package delivery operator defines as reliable will be the ability to deliver a given package at its intended destination and time with a very high degree of confidence.

If, as is the experience of current express package services, fast package delivery customers implicitly demand this form of reliable delivery 99.999% of the time, there are some major implications to a commercial space transportation venture. The space transportation developers may immediately translate this into a required vehicle reliability of 0.99999, a major development challenge. Realizing that subsonic aircraft have high "reliabilities," but only "dispatch reliabilities" of 0.93-0.99, should provide a clue to an alternative solution. Air freight companies maintain high schedule confidence by using extra aircraft, extensive spares (~5-10% of fleet cost), and standardized payload interfaces (rapid changeout to alternative vehicle). If the cost of developing a commercial space transportation vehicle to ultrahigh reliabilities is prohibitive, one could instead cost extra airframes and/or spares. A small fleet of vehicles for fast package delivery will be less efficient in major assets, such as rocket engines, would likely have to be pre-positioned at every destination to minimize downtime. Either way, the service demanded by fast package operators represents a significant input to the costs of a future system.

3.5.3.5.2 Transportation System Capabilities

The payload size of the fast package delivery transportation system is small compared to that required for other market segments, and the propellant tanks would not be sized to achieve orbital velocities. As was seen in figure 3.5.3.5-1, the longest fast package delivery routes (around 10,000 nmi) require the system to have a ΔV capability of around 24,000 feet per second (fps). Orbital capability requires about 30,000 fps and would necessitate the tankage (and the vehicle) be that much proportionally larger.

It is possible to use the fast package system to orbit small payloads, however. Conceptually, a fast package vehicle flight would be chartered on occasion to boost small satellites. {The cost of the flight should be much lower than for developing and operating a dedicated, small satellite launcher. In addition, the dependability, flexible scheduling, and operating infrastructure of such system should be attractive to customers.} Near apogee, the payload bay would open and a small payload/kickstage assembly would be ejected. The size of the payload will be limited by the ΔV of the fast package vehicle and the performance of the kickstage. In figure 3.5.3.5-2, the orbital altitude of a payload is plotted for the initial velocity capability of a fast package system for various kickstage ΔVs.

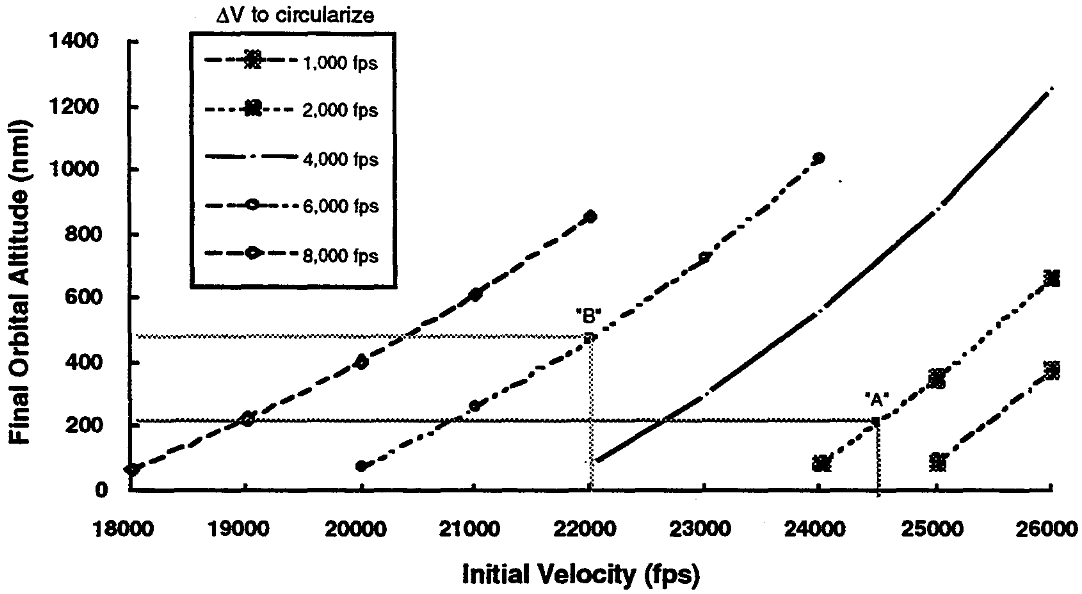

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Figure 3.5.3.5-2. Fast Package Delivery Vehicle Capability To Place Payloads in Orbit

Two example points are shown in the figure. The kickstage is assumed to be a conventional, solid-propellant expendable vehicle. For this example, the fast package payload capability is 3,000 lbm. Point "A" corresponds to a case where the fast package vehicle has a capability of ~24,800 fps (the same as a New York to Sydney route), with a kickstage sized to provide an additional 2,000 fps. Such a system could put a 1,850-lbm satellite in a 200-nmi circular orbit. In the Point "B" example, a 22,000 fps fast package system, combined with a kickstage of 6,000 fps capability could place a 911-lbm payload in a 483-nmi circular orbit.

The boost/glide trajectories offer another use for the fast package delivery transportation system. After the initial boost phase, the vehicle is lofted to very high altitudes in a 0g parabola before skipping back in the atmosphere. Again, it is conceptually feasible that occasional flights could be chartered for microgravity research, manufacturing, engineering equipment development, or astronomy. Many microgravity processes, such as crystal formation, could be performed during the 0g period of the flight, with near-immediate access to the payload upon landing. The New York to Paris route, for example, offers some 15.5 minutes of microgravity; a New York to Sydney route provides over 40 minutes of microgravity. Comparable to NASA's KC-135 research aircraft, such a system could provide multiple flights to microgravity researchers or even light commercial manufacturing at sizes well in excess of traditional-sounding rockets.

3.5.3.5.3 Ground Handling

It is reasonable to assume that the vehicle takeoff and landing facilities are collocated. This spaceport will look more like an airport than Kennedy Space Center; in fact, depending on the design solution, an airport is an excellent choice for a facility, as it represents a large, secure area that is near commerce centers. Access to the spaceport via other transportation modes is essential, particularly air and road transport.

There will be no time for payload checkout or inspection. Users must conform to some basic safety regulations, such as flammability. Packages will arrive or be picked up by the delivery operator, encased by the user to withstand the expected transportation environment. After sorting, packages will be placed in standard payload containers (such as sacks or airline type LD containers) with no interfaces external to the package. Conformity to standard containers is important as the package may have to be transferred one or more times to other forms of transit to get to its final destination. Reloading packages into other containers adds time and cost to a delivery.

3.5.3.5.4 User/Space Transportation Interfaces

The customer will interface with the operator of the fast package delivery service. That operator will be responsible for educating the customers as to the constraints (size, safety, pickup times) for shipment. The operator, having jointly agreed to the physical interfaces with the transportation vehicle developer, will know the limits of the hardware.

3.5.3.5.5 Improvements Over Current

Like many other CSTS missions, significant improvements in reliability and cost per flight represent the most obvious required improvements over current systems.

In addition to the transit time associated with the primary vehicle, the transport of cargo typically includes a significant time for collection (also called stem time) and distribution of individual items. In fact, the airborne portion of intercontinental shipping is only a small fraction of the total door-to-door transit time. The real benefit of a fast package system may be to exploit the time zone differences that currently influence east-west transport. As illustrated in following figures, a comparison of total timelines for several forms of "rapid" package/freight services shows the advantage of a fast package delivery system.

For a westbound example, figure 3.5.3.5-3 compares Frankfurt to New York traffic (currently the world's busiest international air cargo city pair). From all over Europe, air cargo is gathered, typically in the afternoon, to be export-processed in the early evening. Dedicated freighters have an advantage over cargo destined to fly in the belly holds of passenger flights: the freighter can leave in the night, whereas there are few passenger flights that are scheduled to leave so late in the evening. This is more than just a consideration of the inconvenience to the traveling public. As passenger airplanes function at a high operating cost to revenue ratio compared to freight (more crew, amenities, etc.), the airframe is optimally utilized through positioning of the airframe to maximize load factor and time in the air. For westbound European departures this translates into morning departures. Note that flying a passenger airplane faster than mach 0.9 does not significantly impact delivery time. A fast package delivery system would more closely resemble a freighter.

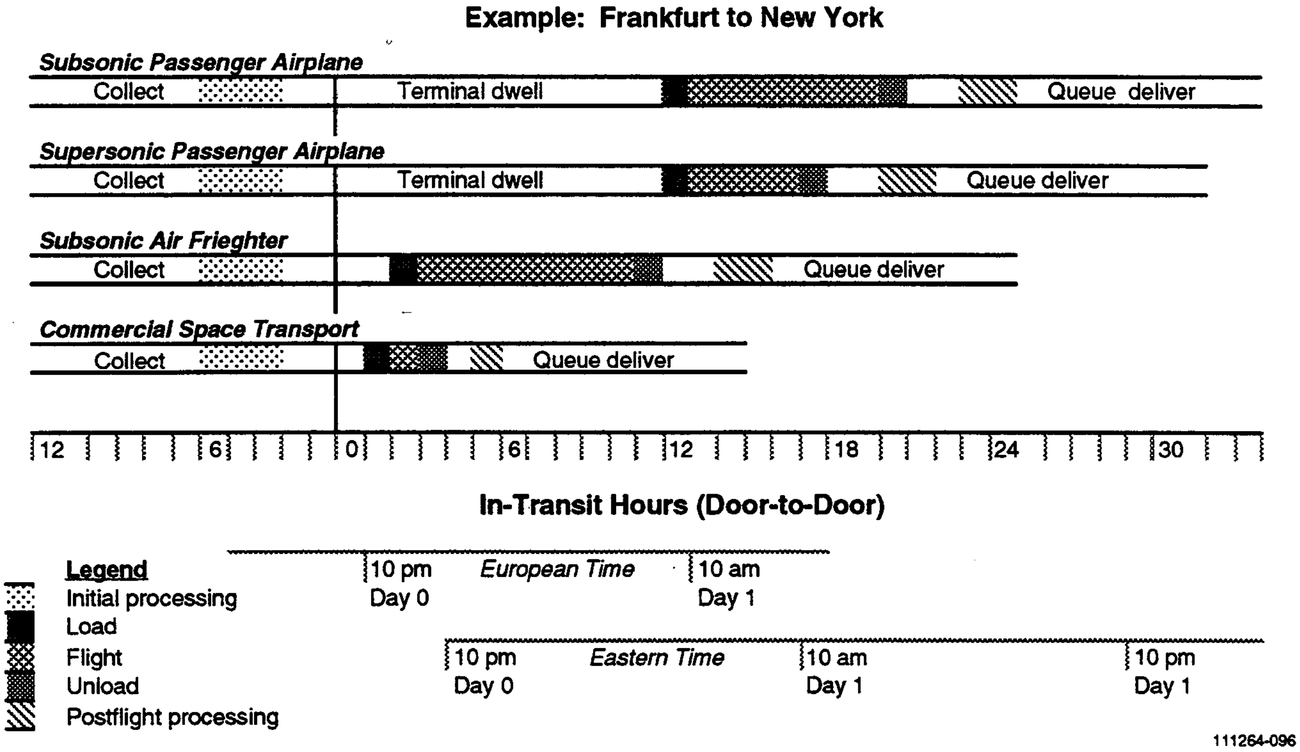

Figure 3.5.3.5-3. Westbound Transit Time Comparison

Similarly, figure 3.5.3.5-4 depicts a typical eastbound example, Tokyo to San Francisco, comparable to existing air freight markets. North-south markets would be represented by similar timelines, but with limited time zone advantages. One should also conclude from these timelines that the real routes for fast package delivery are in the very long distance markets where an appreciable (and therefore salable) improvement in door-to-door time can be realized. For example, coast-to-coast service within the continental United States may reduce total time by about 4 hours; conceptually, it is difficult to envision this reduction as a general enabler of new inter-U.S. markets.

As mentioned previously, there are some trends in subsonic air transport design that do have bearing on the market elasticity discussion for a fast package delivery service. The market for transported goods between two destinations (which are primarily produced and consumed by people) tends to be proportional to the size of the populations of those two destinations. While this may seem trivial, if one thinks of the number of people (flights) who travel between those population centers, one realizes that the onboard cargo capacity that a plane has in its belly hold is extremely synergistic with the needs of cargo services. Note that the new, twin-aisle aircraft (which require wider bodies for a given number of seats) that will replace existing fleets have higher cargo capacity. Passenger ticket pricing does not relate to cargo; this freight revenue is essentially all profit for the operator. The message from this discussion is this: the increase in availability in air cargo volume will drive freight prices down. This will certainly have a positive effect on the size of the air cargo market, but a widening of the price differential between air freight and fast package delivery may cause some customers to opt for a slower, less expensive system.

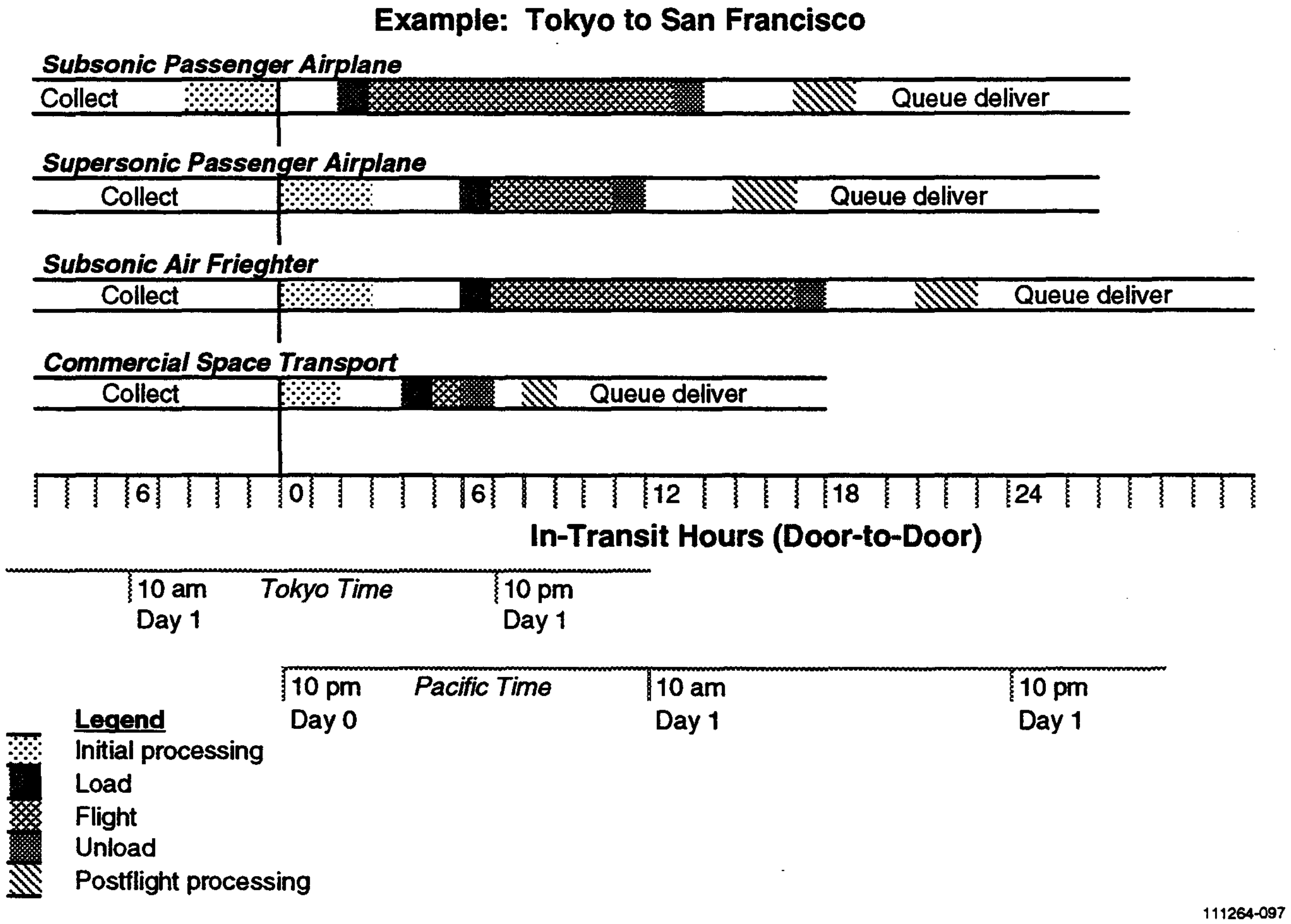

Figure 3.5.3.5-4. Eastbound Transit Time Comparison

3.5.3.6 Business Opportunities

3.5.3.6.1 Cost Sensitivities

Initial attempts at modeling the economics of this market revealed some amazing sensitivities.

First of all, a small, reusable vehicle is outside the bounds of current cost-estimating relationships. Fast package delivery will require more vehicles than any other market segment. As such, understanding the unit cost becomes important in determining the upfront expenditure required to begin service. Relatively small variations in estimated unit cost translate into success or failure of a venture seeking a 20% IRR.

Second, the number of vehicles in the fleet varies significantly with assumptions regarding the number and location of routes serviced and the turnaround times on the ground. Even if one assumes only a small handful of destinations, these variables lead to a wide range of possible fleet sizes. Again, price per flight can only be determined when one knows the size of the nonrecurring debt that has to be amortized.

Within the time and resource constraints of this study, it was determined that a credible model was impractical to create. Such a model would need to be detailed enough to account for "real world" constraints such as curfews, interface with air traffic control, relationship to local transport infrastructure, and spares placement strategy. It was decided, then, at the time of this writing, to defer any cost analysis and consequently to defer inclusion of fast package delivery in the aggregate CSTS economic model.

3.5.3.6.2 Programmatics

No programmatic analysis was performed for this market area.

3.5.3.7 Conclusions and Recommendations

The fast package delivery concept is a promising market segment. Although it is not an orbital transportation system, the technological and operational synergism with other CSTS market segments is significant.

Potential users would be available as soon as a system became available; the concept is a natural extension of world economic expansion and could be easily incorporated into the global trade infrastructure.

3.5.4 Space Servicing and Transfer

3.5.4.1 Introduction/Statement of Problem

Vision statement: *Commercial communications satellite operator ViaSpaceComm has been operating its LEO constellation for 6 years now. Some of its satellites have suffered minor failures and many are low on maneuvering propellant. They could replace the constellation, but the market doesn't require any more technology, not for another 7 or 8 years. Space Repair Inc. is asked to propose a servicing mission to the constellation. When ViaSpaceComm finds it is cheaper to repair than replace, they give the go ahead . . . .*

The idea of on-orbit repair is not a new one. Several space shuttle missions have been dedicated to satellite repair, including the spectacularly successful Hubble Space Telescope repair. While these missions may not have been economically justified if performed in a truly commercial environment, nevertheless, there are a number of postulated commercial spacecraft that would pay to repair rather than replace the asset, especially as regards large platforms.

3.5.4.2 Study Approach

There exists no true commercial capability to perform space servicing and transfer (the space shuttle servicing missions represent a government-funded special case). No commercial venture could be interviewed for this market segment. As it was the consensus of the CSTS alliance that such missions would not be a major market, only limited exploration of the specific business opportunities were conducted.

In the absence of specific spacecraft data, one cannot model with certainty the type or frequency of servicing and/or transfer missions. The *function* of space repair and transfer, however, can be predicted to be required in a thriving commercial space environment. Therefore, to include this mission without specifics, we agreed on a small multiplier on the total aggregate of spacecraft to quantify the number of missions for space servicing and transfer. (This is similar to the approach taken in sec. 3.5.2, Space Rescue.)

3.5.4.3 Market Description

3.5.4.3.1 Description Market Evaluation

Figure 3.5.4.3-1 describes the drivers for and against the introduction of a space servicing industry.

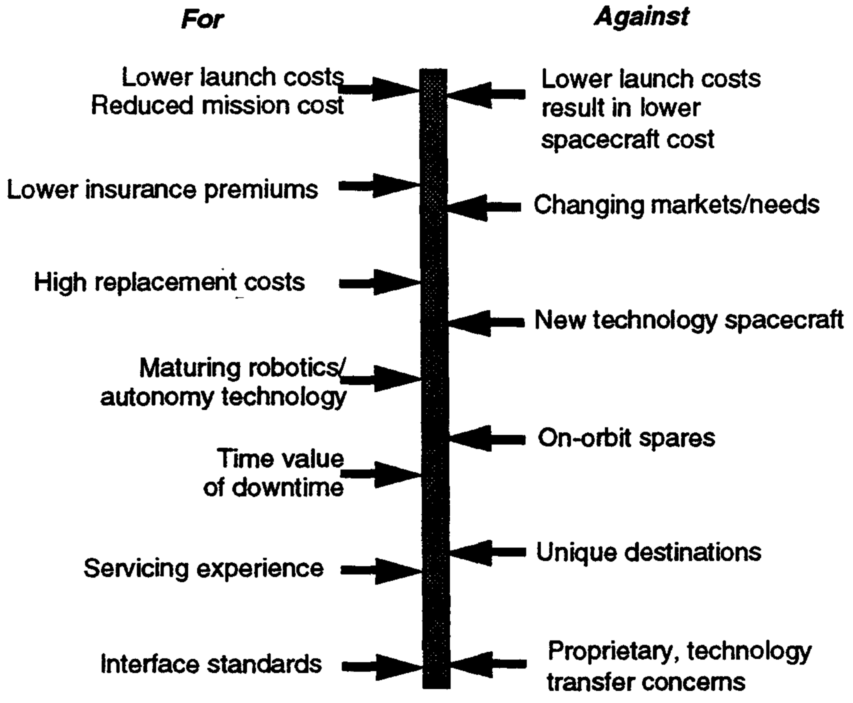

Figure 3.5.4.3-1. Forces Acting For and Against the Development of a Space Servicing and Transfer Business Opportunity

Note that lowering launch costs has both a positive and negative effect on creating a space servicing venture. While the cost of performing a servicing/transfer mission would be reduced, there is reason to believe lower transportation costs also results in less expensive spacecraft. This trend, described in more detail in section 3.1, basically projects opting for heavier (less complex and hence less expensive) platforms as launch costs drop; at some point, the spacecraft operator would find it economically justifiable to replace rather repair or service an asset.

On the positive side, there are valid reasons to consider space servicing and transfer that are insensitive to launch costs. Underwriters would rather pay for a lower cost repair mission than replace the entire spacecraft. Designing a spacecraft with the ability to be repaired on orbit would translate directly into lower insurance premiums, resulting ultimately in a lower price for customers. Similarly, the high replacement cost of a new spacecraft could be deferred with the availability of servicing/transfer, improving the operators' cash flow. Replacing orbital assets before the expected lifetime of the spacecraft can also result in a significant downtime that could be very detrimental to business. Lost revenues and customer migration to alternative services must be factored into the cost/benefit of a repair mission. Last, as experience is gained in autonomous and robotic servicing operations, such as those missions conducted on the space shuttle, the technology and interface standards associated with on-orbit servicing, repair, and transfer will have matured to a point at which a servicing venture is technically feasible.

It should be realized that there are also significant forces at work against the demand for on-orbit services. Obsolescence is a key driver in much of the world's high technology infrastructure. Markets and needs change constantly; looking back a couple of decades ago, for example, U.S. live black-and-white television satellites were state of the art; today even small countries own far more sophisticated assets. Combined with improved reliability in many subsystems, the usefulness of future spacecraft will be limited to the time between new generations of consumer-driven technology. There may be no real reason to plan for servicing a spacecraft due to be phased out within a few months or years. Other factors include the diverse locations and types of spacecraft, which would require a very versatile (probably expensive) servicing system. A trend towards on-orbit spares, driven in part by the need to minimize downtime when a satellite fails, is economically attractive to the operator, especially if launches can be comanifested to reduce costs. Finally, there could be an issue relating to transfer of national or company-sensitive data to a servicing company that would prevent some users from availing themselves of these services.

3.5.4.3.2 Market Evaluation

To credibly evaluate the market for space servicing and transfer services, one needs to examine the aggregate traffic model for what will be in space at any given time. Furthermore, one needs to know what the orbital parameters are for all potential "customers" and some basics about what types of repairs and/or refueling could be performed physically on a given spacecraft.

When all this basic information is known, one would have to probabilistically assess likely failure rates and modes. This does not require a failure modes and effects analysis (FMEA) for all possible spacecraft. It would be important to acknowledge that some spacecraft are more likely to need service and some are more likely to be able to be serviced. In addition, the very availability of space repair and transfer services is likely to influence the design and deployment strategy of new commercial spacecraft, creating a larger market for such services.

The value of repair/transfer/reboost must also be considered. As in terrestrial ventures, companies are continually trading off replacement and repair. Insurance actuarials could be used to understand the monetary compensation that could be expected: if the price of the space servicing mission is lower than the amount paid out by insurance, lawsuits, and so forth, someone will pay for the service.

Another probable aspect of the servicing business would be a sideline in salvage operations. For a fee, owners of a “dead” spacecraft would sell that asset to the servicing company. That company could then return and refurbish or cannibalize space-qualified hardware for resale. Insurance companies may also be interested in contributing to removal of excess space debris reducing collision hazards and lowering claims.

As much information required to do this market evaluation awaits the completion of this phase of the CSTS, no results can be presented yet.

3.5.4.3.3 Market Assessment

No business assessment for a space repair and transfer enterprise was conducted within the time and resources of this study.

3.5.4.4 Prospective Users

Space servicing and transfer is not performed by any one company, and not at all as a private commercial venture. While some potential existing companies, such as Oceaneering and TRW, were thought to be likely candidates to expand into this business, it is more probable that a new venture would be established to provide a flexible response to a diverse customer base. Other than discussion with alliance members, no formal contacts were established during this phase of the CSTS.

3.5.4.5 CSTS Needs and Attributes

When a full accounting is made of the possible spacecraft to be serviced, the required capability and characteristics of the transportation system will become apparent.

In order for successful servicing to occur, the space servicing company must know as much as possible about the object to be serviced as early as possible. Online databases could provide instantaneous access to critical information. If the space hardware is developed to accepted standards, the toolkit of the service provider would be more likely to be useful in the mission.

3.5.4.6 Business Opportunities

Analysis of a business opportunity was limited at this point. When a more complete portrayal of the total space based market is available, we can begin to model a venture (including the effect of transportation cost).

3.5.4.7 Conclusions and Recommendations

Space servicing and transfer is a likely mission as part of a thriving commercial space infrastructure. The size of the business opportunity is speculative until a more detailed portrait emerges of the specific spacecraft that could use this service. For purposes of modeling the launch traffic associated with this market, we have assigned a multiplier of 0.02 to the aggregate traffic. That is, as a gross assumption, 2% of the functioning spacecraft would employ servicing or transfer services per year.

3.5.5 Hazardous Waste Disposal

3.5.5.1 Introduction/Statement of Problem

Vision statement: *In or around 2010, nuclear power plants will be operating in large numbers across the planet without the threat of nuclear proliferation or contamination from leaking nuclear waste containers. This is accomplished by collecting the used fuel rods and shipping them all to a central location, where they are chemically separated under United Nations supervision and the portion containing radioactive wastes is immediately loaded into safe-reentry casks for shipment to a transfer facility in low earth orbit (LEO). In LEO these canisters are loaded onto a lunar lander, which is in turn the payload of a space tug. Every 9 to 10 days a reusable space tug leaves for the Moon and three days later a load of waste canisters is soft landed into a crater on the Moon's far side. Once on the surface, they are picked up by a remotely controlled tractor and placed in a position to radiate to free space, essentially forever. This system was put in place and operated continuously using the disposal surcharge assessed to nuclear power generation facilities. In addition, the steady traffic to LEO and the Moon has created a commercial transportation capability that has opened other profitable ventures . . . .*

The problems associated with hazardous waste are an ugly reminder of the downside of mankind's technological progress. Industrial processes and weapons production often result in wastes too toxic to simply put in a landfill. At a gross level, there are three categories of hazardous waste: chemical, biological, and nuclear. Both chemical and biological waste can generally be cracked through some form of incineration: chemical bonds break down with the addition of a sufficient amount of heat. There are still some compounds and heavy metals that will require extra processing steps. Radioactive waste is harder to process: humans can be harmed even without physical contact and accelerating the natural slow decay can only be accomplished by bombarding the materials with neutrons of just the right energy levels.

For the purposes of the CSTS analysis, hazardous waste disposal in space is limited to a discussion of nuclear waste disposal. The decision to do this was based on the following factors:

a. Longevity of the hazard represents a lasting problem for humankind.
b. Known budgets for terrestrial disposal from which to compare to.
c. Concern for international proliferation of weapons-grade nuclear material.

Resolving the nuclear waste disposal problem is critical to the future of nuclear power, but political, legal, and technical delays have put off the opening date for a permanent, government-operated high-level waste depository until at least 2010. Yucca Mountain in the state of Nevada is proposed as a temporary site for nuclear waste storage and is expected to become a permanent repository after 50 years. A second repository will also be necessary (probably on the East Coast), and the DOE plans to spend $43 billion for the two permanent waste repositories. Besides the high cost, public opinion is against having nuclear waste permanently stored underground because safety is difficult to guarantee for tens of thousands of years. Locals especially fear degradation of safe storage from seismic activity or contamination by running water. This issue has become a lightning rod for environmental concerns, and permanent ground storage of nuclear waste might already be a lost cause in the United States. Bear in mind also that the United States owns only 40% of the world's estimated nuclear wastes. Other nations (primarily Russia, Ukraine, and France) possess huge amounts of waste. The world's citizens are increasingly aware that nuclear waste is a global problem and will demand safe disposal by all nations with nuclear capability.

How extensive is the nuclear waste problem? Predictions state there will be 41,000 metric tons of high-level nuclear waste in the U.S. from nuclear power plants by the year 2000 and another 10,000 tons from government nuclear weapons programs. Spent reactor fuel will be accumulating at the rate of 1,000 tons per year in this country by the year 2000 and storage pools at the power plants are already full (ref. 2). On the other hand, electrical consumers in this country have paid a one-tenth of a cent fee on every nuclear-generated kilowatt hour since 1982 for eventual waste disposal, and the payments and interest currently total nearly $5 billion. What is needed is an environmentally acceptable *permanent* solution at an affordable price.

The world, especially the Third World, requires abundant, environmentally acceptable, low-cost power to raise the standard of living and avoid widespread starvation. Modern nuclear power plants can provide this low-cost power, but dissemination of the knowledge and hardware necessary to build these plants has been thwarted by the threat of the proliferation of nuclear weapons. However, nuclear proliferation is a political issue with a possible technical solution. If used nuclear fuel rods can only be removed (and permanently disposed of) by an international body like the United Nations, then surreptitious processing to obtain plutonium would be nearly impossible. The threat of global warming through emissions from burning fossil fuels, the dropping standard of living in the third world, and the decreasing cost of enriched uranium dictate that nuclear power must be seriously considered for developing nations; and safe, effective disposal of used nuclear fuel rods could make this practical.

3.5.5.2 Study Approach

Nuclear waste disposal in space has been studied for many years (ref. 3). Rarely have these studies considered that such a venture could be conducted commercially; most of the study effort was devoted to the technical aspects of the solution. Rather than duplicate these studies (many of which represent more labor-hours of work than the entire CSTS effort), the results were compared and the solution judged most promising was selected as a baseline for economic analysis.

Disposing of the waste outside the Earth's biosphere would be the ideal permanent disposal of nuclear generated wastes and byproducts. Various ideas for space disposal have been considered: Earth orbit, Earth-Moon libration points, 1.1 or 0.85 AU, Venus impact, Jupiter entry, solar impact, and solar system escape. Figure 3.5.5.2-1 lists a summary of pros and cons of the various space waste disposal concepts.

Repository Location	Transport System ΔV (km/s)	Transit Time (Fays)	Stability/ Security of Location	Future Recovery of Isotopes	Astronomical Interference
Earth orbit	10.6	0.12	<1,000 years	Yes	Yes
Libration point(s)	11.5	3	Perturbations can cause Earth impact	Yes	Yes
Solar orbit	10.9	5	Perturbations can cause Earth impact	Maybe	Some
Lunar repository	11.5	3	∞	Yes	Yes near side, no far side
Solar impact (direct)	38.0	65	∞	No	No
Venus impact	13.4	146	∞	No	No

Figure 3.5.5.2-1. Comparison of Nuclear Waste Space Storage/Disposal Options

The lunar surface repository was selected as the baseline option for CSTS analysis, based on this comparison and consideration of the following qualitative benefits:

a. The waste is stored in the gravity well of the Moon, so it cannot be deflected by passing asteroids or comets. (Aten asteroids where unknown at the time of the 1982 studies.)

b. The lunar transfer process is over in 3 days while the heliocentric transfer takes 165 days. If the control systems fail during transfer the waste directed to the Moon impacts the lunar surface with no possibility of Earth contamination. If a similar failure occurs during the longer heliocentric transfer, the waste is left in an orbit that could impact Earth at a future date.

c. The waste is stored in a controlled manner on the lunar surface and can be located and retrieved relatively quickly if a use is found for it in the future. Considerable effort was expended to create some exotic isotopes, which could be very valuable.

d. Nuclear waste packages are gamma ray emitters, and gamma ray spectroscopy, while unheard of in 1982, is now an important astronomy tool. Storage on the far side of the Moon would not affect astronomers.

e. The lunar surface is free of an atmosphere and running water, and the deposit site is localized and would present no threat to future lunar colonists.

f. A vehicle designed for disposal of nuclear waste on the Moon can have further applications such as lunar exploration, lunar mining, and lunar colonization.

g. It is conceivable that, at some future time, a low-efficiency power/thermal source could be made for local use on the Moon from the waste.

With a lunar repository as a baseline, several different scenarios for hazardous waste disposal were examined. All upper stages and lunar landers are based on a study done by Boeing in 1991 (ref. 3), which was considered representative (but by no means the only solution). From the estimates of the mass of spent nuclear fuel to be disposed of by 2000, the number of trips necessary for its disposal on the Moon was determined, assuming some or no ground-processing of the waste before launch is allowed. Once the number of trips is determined, a cost estimate, not including Earth to LEO launch, is made for each case. The cost of each is compared to the budget for the disposal of nuclear waste; the remainder determined the threshold transportation cost for feasibility.

3.5.5.3 Market Description

3.5.5.3.1 Description Market Evaluation

The amount of nuclear waste (U.S.) to be disposed of as of the year 2000 is estimated to be 40,000 metric tons of spent nuclear fuel and 10,000 metric tons of defense wastes. To be launched from Earth, the nuclear waste must be shielded to protect it during a possible launch failure, so the effective total mass to be launched is significantly higher.

3.5.5.3.2 Market Evaluation

Nuclear waste disposal is an expensive business. The DOE waste operations budget for 1990—1996 is $22.3 billion with an additional $2.2 billion for technology development. The Utility Waste Fund in 1993 is valued at greater than $6 billion. The waste fund is paid from a $0.001-kW/h nuclear waste disposal tax on nuclear power plants. At a current power production level of 100 gigawatts, the tax adds about $500 million a year. By the year 2030, nuclear power is expected to grow to 190-250 gigawatts, adding over $1 billion per year to the waste fund. Currently the first permanent repository is expected to cost $28 billion and the second to cost $17 billion. Therefore, the operating budget for this study is taken to be $43 billion, although more money may be available if space disposal is perceived to be more palatable to the public than currently proposed methods.

In fact, the issue of public acceptance is arguably the most important driver in the development of a commercial space disposal venture. Any economic benefit of space disposal is moot if regulation and protest prevent operations. The effort that will be required in convincing people of the safety of this concept cannot be overstated.

3.5.5.3.3 Market Assessment

There is a tremendous stockpile of high-level nuclear waste in this country left over from 50 years of bomb-building and 35 years of nuclear power generation. With the ending of the Cold War there is additional plutonium to dispose of in the safest way possible. In addition, the rest of the world, especially the former Soviet Union, has an abundance of high-level waste. Worldwide high-level waste will approach 100,000 metric tons by the year 2000 based on nuclear power generation data. Some of that waste is currently being processed (glassified) for above-ground storage (e.g., in France), but most will be sitting in temporary storage tanks in the year 2000.

Buried sites like Yucca Mountain offer long-term storage at moderate cost, but it is very difficult to prove no leakage over geological times because our database is not sufficient. This point is used by environmentalists to raise local opposition to proposed permanent depositories. As a result, the agreement defining the Yucca Mountain site states that after 50 years of operation the overall performance will be reviewed and a majority vote of Congress can close the facility and have all the waste removed. The agreement also states the second disposal site will be on the U.S. East Coast. That will be a very difficult sell.

An alternative to space disposal is transmutation of the long half-life radioactives to short-lived radioactives that decay away in 20 to 30 years While physically possible, this may be technically and economically unfeasible. This approach is discussed in depth in section 3.5.5.6.

Hence, our assessment is that the market for permanent disposal of high-level nuclear waste is huge, easily enough to justify major investments in infrastructure, and that space disposal provides a very valid alternative to ground disposal.

3.5.5.3.4 Market Infrastructure

The principal infrastructure required in addition to the space transportation system is a ground-processing facility to load the shipping canisters. We are planning only simple mechanical and chemical separation, but the Federal moratorium on processing has prevented any processing of spent fuel rods for the last 20 years. That moratorium is supposed to have been withdrawn, but if not, it will have to be rescinded before launch operations can begin. As will be discussed later, nuclear waste is best "aged" for about 10 years prior to processing to reduce the thermal loads from radioactive decay. Ground depositories such as Yucca Mountain would serve as excellent sites to temporarily store spent fuel prior to processing and launch.

3.5.5.4 Prospective Users

The U.S. customers for this service are the U.S. Government (in particular the Department of Energy) and the utility companies. It is possible that disposal of hazardous wastes could someday be an international concern and be controlled by the United Nations, but that is pure speculation at this time.

CSTS members held discussions with DOE, with informal exchanges conducted with members of Electrical Power Research Institute (EPRI), a number of West Coast utilities, and Greenpeace.

3.5.5.5 CSTS Needs and Attributes

Nuclear waste canisters do not care when or how they get to the LEO transfer station. They can fly on regularly scheduled launches that are undersubscribed or they can fly on dedicated launches that fill in holes in the launch schedule. They are small and dense, so they are easy to integrate. However, they are going to be radioactive and thermally active. How radioactive and how much heat is radiated was determined by quantifying various sample waste products. This data show the thermal radiation of concentrated nuclear waste 2 years after removal from the reactor to be about 180 kw/ton. After 10 years heat production has dropped by roughly an order of magnitude, and it decays very slowly after that. Hence, we recommend the spent fuel rods be aged for 10 years at a temporary repository prior to processing and packaging in the GPHS canisters. The canisters are designed to withstand the thermal flux from $^{238}PuO_2$, which is 0.4 kw_{th}/gm, or twice the worst flux expected from the concentrated spent fuel waste. On the other hand, the spent fuel waste radiates a large fraction of its energy as gamma particles unlike $^{238}PuO_2$, which is an alpha emitter. This further reduces the thermal load on the canisters but causes problems with ground handling and sharing a payload bay with live animals. The extent of the problem with gamma radiation will depend on the age and specific mix of nuclear waste and has not been fully quantified at this time.

3.5.5.5.1 Transportation System Characteristics

Two scenarios for placing the waste canisters of the lunar surface were examined: a reusable spacecraft that travels round-trip from LEO to the surface of the Moon, and a partially reusable spacecraft that positions a dumb solid rocket lander on a precise lunar intercept trajectory and then returns to LEO.

The first LEO-to-lunar transportation scenario involves a space-based reusable spacecraft. In this scenario, nuclear waste is brought to LEO as secondary- or low-priority payload on a LEO launch vehicle. The waste is accumulated at a LEO node and transferred to the lunar transfer vehicle (LTV). The LTV takes its cargo to the Moon, expending its translunar injection tanks and lunar descent tanks. The LTV returns to the LEO node where it picks up its cargo and full tanks for its next mission. A mission timeline and ΔVs are given in figure 3.5.5.5-1. The mission time from LEO to LEO is 187 hours, or almost 8 days. Adding 1 day at LEO for refueling and loading gives a total mission time of 9 days.

Event	ΔV (m/s)	ΔT (hrs)
ACS* separation/coast	6	0.8
MPS** TLI† burn	3300	0.3
ACS coast/corrections	10	84.0
MPS LOI†† burn	1075	0.1
ACS brake/tanks separation	12	0
MPS deorbit	60	0.1
MPS lunar descent/landing	1920	2.1
Cargo offload	0	12.0
MPS ascent	1822	2.0
MPS TEI††† burn	1075	0.1
ACS coast/corrections	18	84.0
Aeroassist maneuver	0	0.1
MPS orbit circularization	310	0.1
Rendezvous with LEO node	12	1.0
Total	9620	186.7

*ACS - attitude control system
**MPS - main propulsion system
†TLI - trans lunar injection
††LOI - lunar orbit insertion
†††TEI - trans-Earth injection

Figure 3.5.5.5-1. Mission Timeline for Reusable Lander Vehicle

The second LEO-to-lunar transportation scenario involves a space-based reusable propulsion module (fig. 3.5.5.5-2). In this scenario, nuclear waste is brought to LEO attached to small solid-rocket landers. Full tanksets are also launched to orbit, and the assembled vehicle delivers the landers to a lunar impact trajectory and expends its translunar injection tankset . The propulsion module returns to the LEO node where it picks up its cargo and full tanks for its next mission. The mission time from LEO to LEO is 170 hours or about 7 days. Adding 1 day at LEO for refueling and loading gives a total mission time of 8 days.

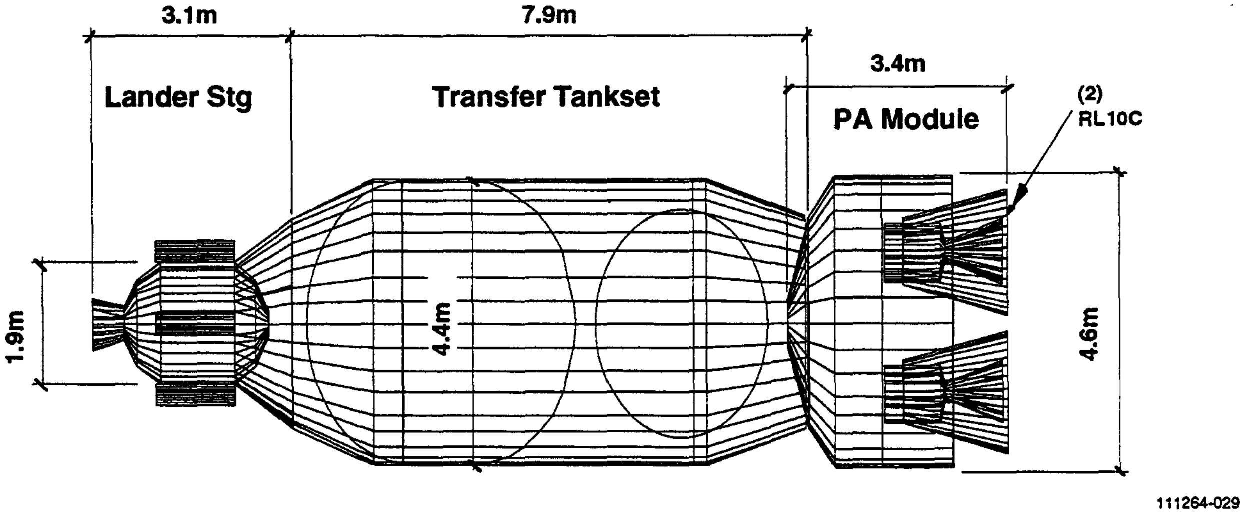

Figure 3.5.5.5-2. Conceptual Partially Reusable Transfer Stage

3.5.5.5.2 Transportation System Capabilities

It is obvious that the transportation system, perceived as the weak link in the disposal concept, will need to pay special attention to the safe delivery of its cargo. As scheduling the launches with certainty is not as important a capability as for other CSTS markets, the operator has some flexibility in launching when it is most prudent, Ideally, the launch system must be at least as safe and reliable as terrestrial delivery systems, such as rail transport. This level of reliability is arguably still for in the future, even if a commercial system embodied redundancy, health monitoring, engine-out, and so forth, in its design.

It is more likely that the payload can be encapsulated in a way that ensures that zero waste is released, even in worst case launch vehicle failure. There is a precedent for this in the launching of thermoisotope generators on interplanetary probes. In fact, for this baseline analysis, our concept for shielding is to use the already-space-qualified general purpose heat source (GPHS) containers. Each GPHS container holds 32.8 lbm of ^{238}Pu fuel and 27.1 lbm of shielding, giving a 0.83 shield-to-fuel ratio. The container has a 3D graphite aeroshell designed to withstand reentry and an impact of 165 ft/s.

In order to size the transport system to the Moon, the following assumptions are made:

• Mass of high level waste	50,000 metric tons
• Shield to fuel ratio	0.83
• Mass of shielding	41,000 metric tons
• Total mass to lunar surface	91,000 metric tons

With a payload to the moon of 91,000,000 kg, either vehicle must make several thousand trips (fig. 3.5.5.5-3). For this reason, preprocessing of the waste at the launch site is very attractive. If three vehicles are used on a 9-day cycle, 100 missions can be accomplished in 300 days, leaving 65 days a year for maintenance and repair. Given a lifetime of 10 years for the spacecraft, only 12 transfer vehicles need to be built for the large round-trip lander, compared to 50 for the small one-way lander.

Parameter	Round-Trip Lander Concept	One-Way Lander Concept
ΔV	9,620 m/s	6,432 m/s
Cargo to lunar surface	25,000 kg	3,222 kg
Total dry mass in LEO	48,000 kg	4,170 kg
Total flights	3,000	28,260
Years to complete with 100 flights per year	30	283
Number of core stages	10	94

Figure 3.5.5.5-3. Vehicle Comparison (No Preprocessing)

With preprocessing at the launch site, the number of missions and costs fall roughly by a factor of 30. This allows waste disposal over a reasonable time period using LEO delivery masses of interests to other users (fig. 3.5.5.5-4).

Parameter	Round-Trip Lander Concept	One-Way Lander Concept
ΔV	9,620 m/s	6,432 m/s
Cargo to lunar surface	25,000 kg	3,220 kg
Total dry mass in LEO	48,000 kg	4,170 kg
Total flights	100	942
Years to complete with 25 flights per year	4	38
Number of core stages	2	19

Figure 3.5.5.5-4. Vehicle Comparison (With Launch Site Preprocessing)

3.5.5.5.3 Ground Handling

Disposing of hazardous waste in space isolates it from our biosphere, removing the threat to future generations. However, to be economically practical we need to eliminate most of the nonhazardous material from the waste and only pay to launch the truly hazardous material. To accomplish, this we propose to move the spent fuel rods to the launch site and then (1) cut open the spent fuel rods, separate the fuel from the cladding, compress the cladding and bury it in low-level waste repositories, (2) chemically separate the uranium oxides from the spent fuel and recycle them as reactor fuel, and (3) put the remaining material into GPHS canisters designed for space launch and launch them promptly to a transfer station in LEO. By not separating isotopes, we believe we can keep the ground processing cheap (<$100/lb), relatively free from public/political controversy, and environmentally safe. Figure 3.5.5.5-5 presents preliminary cost estimates for ground processing from a DOE Environmental Impact Statement on Management of Commercially Generated Radioactive Waste, October 1980.

Ground Processes	Cost (1978$/kg)
Reactor to interim storage	3
Short-term interim storage	8
Removal of HLW and packaging in GPHS	60
Compaction of Zr clad	14
Storage of Zr/U as LLW	1
Noncombustible and failed equipment	20
Incineration of combustibles	6
Removal of gaseous products	13
Atmospheric protection system	2
Total	$127/kg

Figure 3.5.5.5-5. Ground Processing Cost Buildup

To quantify the type and mass of the remaining material after the two-step processing discussed above, we will provide an example based on a series of ORIGEN computer runs provided by Sandia National Laboratory (ref. 4). This example includes the ORIGEN2.1 output for Sequoyah Unit 2, with the model based on a reactor power of 3411 MW_{th} for 2 years. The fuel loading assumed was 88,563 kg of Uranium @ 2.535 enrichment. The basis point was 1.5 years after removal. After 1.5 years in cooling pool, the rods have 83.09 metric tons of actinides, 5.4 tons of fission products, and 30.3 tons of activation products. Removal of the cladding and unreacted uranium oxide reduces this to 2.74 tons of material to be loaded into GPHS containers and launched. With a typical GPHS ratio of container mass to fuel of 0.83, we estimate a total mass for this example of 5.01 metric tons. If we assume the Sequoyah Unit 2 produced 1100 MW_e of power at a 65% online factor, this would equate to $12.53X10^9$ kW/h of electricity over the 2 years. At the $0.001-kW/h millage, if we were to operate with just the money set aside, we must dispose of 5.01 tons of loaded containers for $12.53 million, or $2500/kg delivered to the Moon. Note that the current DOE disposal plan will require the equivalent of three times this cost. This example is thought to be representative of spent nuclear reactor fuel, but many more cases are necessary to quantify possible separation scenarios and disposal of the many types of nuclear waste.

3.5.5.5.4 User/Space Transportation Interfaces

a. Autonomous access to pad, mechanical only interface.
b. Cryogenic propellant transfer to payload bay.
c. Thermal heat rejection capability of up to 10 kW.

3.5.5.5.5 Improvements Over Current

a. Reliability such that vehicle loss rate ≤1/1000.
b. Launch costs < $600/lb.

3.5.5.6 Business Opportunities

The majority of nuclear waste is in the form of spent fuel rods, and they current belong to the electric utility companies. The government, in the form of the DOE, has committed to accept legal liability and responsiblity for this waste in 1998 and begin storing it in a semipermanent depository in 2010. That effort is not on schedule and becomes less likely all the time. Hence, there is a valid business opportunity to offer an alternative permanent solution that is cost competitive and more salable to Congress and the environmental movement. According to the cost assessments shown below space disposal has a lower life cycle cost than ground disposal and could be available in the same timeframe with moderate investments in new hardware (other than a new launch system). Hence, there is a legitimate opportunity to negotiate an anchor tenant agreement with either the electric utility companies or the DOE to permanently dispose of the U.S. and overseas nuclear waste. Right now space disposal is the moderate technical risk option but there is a higher risk major competitor, as discussed below.

The major competitor for removing nuclear waste from the biosphere (other than ground storage, which does not remove the waste, but only stores it) is nuclear transmutation. The Grumman Corporation and Los Alamos National Energy Lab are looking at the feasibility of accelerated transmutation of waste using a high-energy particle beam system. Conceptually, such a system would be capable of transforming the atomic nuclei of the waste into other radioactive elements with a shorter half-life.

The device to be used in the accelerator transmutation of waste (ATW) is a product of past Strategic Defense Initiative Organization (SDIO) research into directed-energy weapons and would use a derivative of the neutral particle-beam-based Continuous Waste Deuterium Demonstration (CWDD) program. The concept involves scaling up a charged particle accelerator beam until it produces a very dense and energetic beam of protons. These protons are then directed onto a lead or tungsten target. The protons interact with the target and produce highly energetic neutrons. Beyond the target a heavy-water or graphite "blanket" slows down the neutrons into an energy range such that they can interact with the nuclei of radioactive materials loaded into a target zone, and changes them into less-radioactive or inert materials. Meanwhile a continuous slipstream processor collects and separates the processed materials from the unprocessed materials in a continuous flow separation system.

Using this system, the ATW process is projected to result in very low-level, short-lived waste products, and short-lived species byproducts. The goal of this program is to get everything of significant activity to a 30-year half-life.

The status of the program is currently at conceptual stage. The ATW program currently is looking for at $30 to 50 million in government funding from the DOE for a conceptual study of an accelerator to produce a neutron beam that would be used to irradiate samples of nuclear waste. After this conceptual study, then a demonstration and test program is expected before this can be committed to for reprocessing of nuclear fuel or waste. There is an industry working group of Grumman, Westinghouse Electric, TRW Space & Defense, Lockheed Missiles & Space, Rockwell, Thomson, General Atomics, Litton Electron Devices, BDM Engineering Services, and Babcock & Wilcox, which is working to understand this technology. It was hoped that this project would receive TRP (Technology Reinvestment Program) funding for defense conversion work, but at this time no funding has been received. This information was provided by Grumman senior program engineer Timothy Myers and Anthony Favale, Grumman's deputy director of energy systems.

CSTS Comment - There are technical, political, and financial issues to be resolved with this system. The technical issues involved in this concept involve the beam system and the slipstream processor. The charged particle beam will have to achieve orders of magnitude of greater beam flux than current systems and orders of magnitude greater beam duration of operating time. (The current beam is a pulsed beam, and for effective transmutation the beam must be continuous.) The slipstream processor itself will be a technical challenge. The processor must work continuously separating out the transmuted materials from the nontransmuted products. This will involve continuous flow chemistry and separation, working with highly radioactive and rather nasty chemical substances, while the beam is running. And the separation system may have to separate between substances with different isotopes, but almost identical chemistry.

The political barrier is that there is currently an executive order prohibiting reprocessing of nuclear waste. This executive order was put into force primarily to recognize issues with waste reprocessing and the separation of controlled substances such as plutonium from existing nuclear waste stocks, including spent nuclear fuel. To demonstrate the slipstream processor needed to demonstrate the continuous flow reprocessing, this executive order will have to be changed. (It should be noted that the space disposal of nuclear waste will also have this problem, although the levels and complexity of the reprocessing are much simpler in the space disposal option.)

The final barrier for this system is cost. The final cost of developing a transmutation system for nuclear waste is unknown, but estimates for the cost of adding such a system to handle the disposal of commercial nuclear electric power wastes project the addition of costs to the generation costs of nuclear power, increasing the average price of electricity from 3% to 10% This represents a recurring cost from $5 billion per year to $17.5 billion per year. This compares to a cost of $1.2 billion per year for space disposal at $600/lb.

The time scale for this project potentially places it in the same time period as a new launch system. The current expectation is that an ATW system would require a conceptual study, then a demonstration system (including the nuclear chemistry demonstration, the continuous flow/separation system, and the beam power and duration scaleup), and then commitment to an operational system. From the market contract, the time to proceed to the first unit of an operational system ranges from 8 to 15 years, depending upon funding and the results of each stage of the program. The time scale to the operation of a small-scale fully operational demonstration system may be as little as 8 years, with the longer time period assuming 2 years for the conceptual study, 8 years in development of the demonstration system, and another 5 years to put the first operational unit into operation.

3.5.5.6.1 Cost Sensitivities

First-order cost estimates for the lunar transfer hardware were made using cost estimating relationships (CER) provided by General Dynamics (fig. 3.5.5.6-1). The complexity factor is taken to be less for the expendable spacecraft than the reusable spacecraft. The costs of the expendable tanks are estimated separately for the reusable spacecraft because they will need to be replaced each flight. For units after the first, the cost is estimated using a learning curve. The cost is estimated for both cases using the dry mass of the vehicle.

	DDT&E	First Article Cost
CER (cost =)	16.175*(WT^0.5)	0.4266*(WT^0.693)
Complexity factor		
expendable lander	0.7	0.5
reusable spacecraft	1	1
expendable tanks	0.23	0.065

Figure 3.5.5.6-1. Cost Estimating Relationships

This cost estimate does not include the ground processing facility that would need to be developed, nor the LEO node where the space-based propulsion/avionics module is stored. In this estimate, we will assume $2 billion for developing the necessary ground and LEO facilities. The expendable lander option can be accomplished with payload sizes of interest to many users, and has a large DDT&E savings and lower life cycle costs relative to the reusable lander (figs. 3.5.5.6-2 and -3). However, it does require more years to complete disposal.

If no ground processing is done then the entire 51,000 metric tons of waste must be loaded into GPHS containers and the total cost estimates including launch to LEO are $210 billion for the round trip to the surface system and $149 billion for the reusable TLI stage with expendable lander. This assumes a launch cost of $100/lb to LEO, which is the lower limit used in the CSTS discussions. Obviously, hauling the entire undifferentiated nuclear waste package to the Moon is not economically feasible.

If the nuclear waste is treated with the simple mechanical and chemical separation described above, and only 3% of the remaining material containing the most hazardous portion of the fuel rods is shipped to space, then the total cost of disposal falls to $35.8 billion for the round-trip system and $27.8 billion for the expendable lander system. This is at a launch cost of $500/lb ($1100/kg), so if the fuel can be partially processed at the launch site, space disposal presents an economically attractive alternative.

Total Nuclear Waste, mT	50000	MPS Isp, sec	470
Waste fraction from grd process	0.03	Dry mass in LEO, mT	12.6
Waste fraction from LEO process	1	Mass in LLO, mT	17.13
Drop tank mass fraction	0.06	MPS ascent DV, m/s	1822
Total flights	109.8	Mass after unload, mT	25.44
Total drop tanks	659	LTS payload, mT	25
Drop tanks learning curve	0.85	MPS descent DV, m/s	1920
Drop tank TFU, $M	8.18	Mass in LLO, mT	78.08
Ave drop tank cost, $M	2.32	MPS LOI burn, m/s	1075
Grd processing costs. $/kg	100	Coast mass, mT	99.84
Launch costs, $kg	1100	MPS TLI burn, m/s	3300
Launch costs waste to LEO, $B	3.02	LEO start burn Mass, mT	210.63
Launch-lunar prop and tanks, $B	20.90	Prop + tank mass/flight	173.03
Total launch costs, $B	23.92	Drop tank mass, mT	1.66
Total grd process costs, $B	5		
DDT&E costs, $B	5.2		
Hardware costs, $B	1.68		
Total disposal cost, $B	35.80	Delivery costs, $/kg	8713.15

Figure 3.5.5.6-2. Total Nuclear Waste Disposal Costs Using Reusable Lunar Lander Scenario

Total nuclear waste, mT	50,000	MPS isp, sec	470
Waste fraction from grd process	0.03	Dry mass in LEO, mT	12.6
Waste fraction from LEO process	1	Mass in transfer orbit, mT	3.30
Drop tank mass fraction	0.06	LTS payload, mT	8
Total flights	343.125	Lander mass fraction	0.2
Total No. of DT and landers	343	Lander Isp, sec	300
Lander and DT learning curve	0.85	Lander descent DV, m/s	2520
Lander TFU, $M	11.17	Lander mass, mT	21.02
Ave lander cost, $M	3.69		
Drop tank TFU, $M	8.38	Trans-lunar coast mass, mT	24.32
Ave drop tank cost, $M	2.77	MPS TLI burn, m/s	3300
Ground processing costs $/kg	100	LEO startburn mass, mT	53.02
Launch costs, $/kg	1100	Stage mass/Flt deliv to LEO	42.52
Launch costs waste to LEO, $B	3.02	Drop tank mass, mT	1.66
Launch-lunar prop and tanks, $B	15.06	Flights/year	17
Total launch costs, $B	19.07	Mass to LEO/year, MT	866.702
DDT&E costs, $B	1.5		
Ground processing, $B	5.00		
Hardware costs, $B	2.22		
Total disposal cost, $B	27.78	Delivery costs, $/kg	6946.24

Figure 3.5.5.6-3. Total Nuclear Waste Disposal Costs Using Expendable Lunar Lander Scenario

Note that within these spreadsheets, assumptions were made as to the ground processing costs. The sensitivity of the total disposal cost to variations in average launch cost and ground processing costs is shown in figure 3.5.5.6-4.

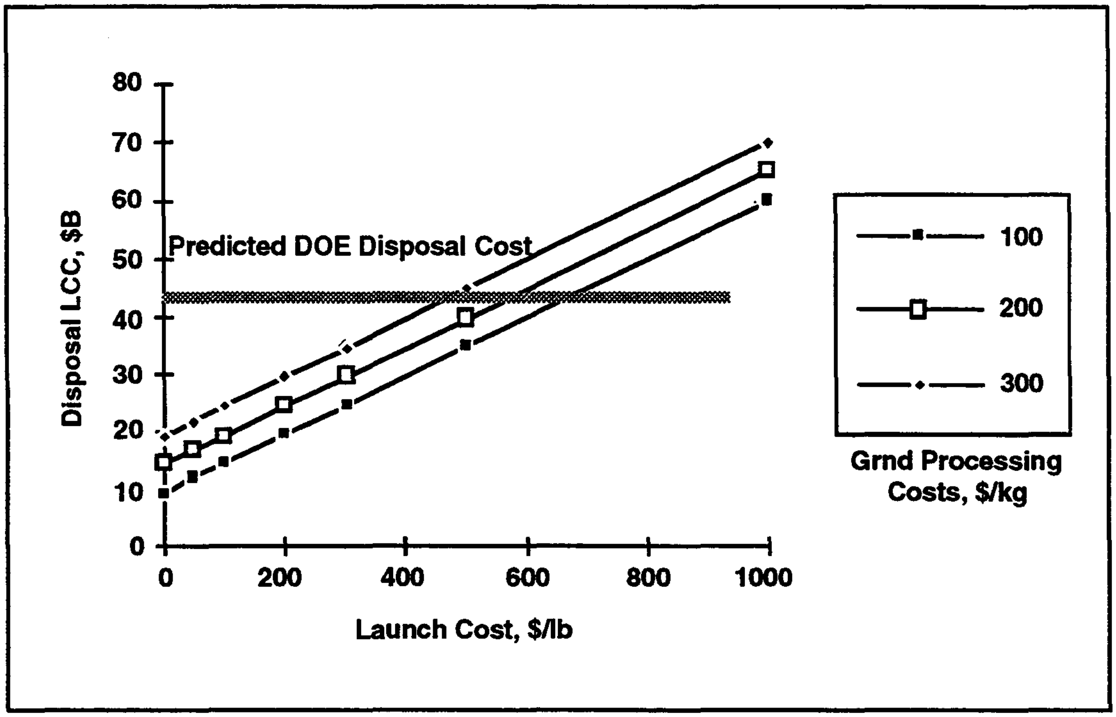

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Figure 3.5.5.6-4. Nuclear Waste Disposal Costs Versus Ground Processing and Launch Costs

3.5.5.7 Conclusions and Recommendations

Disposal of hazardous waste could represent a huge market attainable with launch costs achievable using near term technologies. The political and public perception issues to overcome are enormous and should be addressed continuously, beginning now. This market can be captured with launch costs as high as $500/lb to $600/lb and will average approximately 2,000,000 lb per year over 30 years of operation. The following recommendations are made for follow-on studies:

a. For disposal of hazardous waste on the moon to be viable, it must be shown to be less risky than burying it underground. A risk assessment, including public perception of risk, is necessary.

b. Because the shielding of the waste containers is designed to withstand Earth reentry and impact, a hard landing on the Moon may be possible. Using a high-acceleration rocket fired just before impact to almost stop the lander and then letting it fall the rest of the way to the surface has been examined. A cost trade of lander ΔV versus impact velocity and probability of burying the canister should be completed.

c. The cost of a dedicated unmanned LEO node to transfer the waste to the lunar spacecraft may be significant and should be estimated.

d. The development of ground infrastructure should be considered, such as the transport of waste to the launch pad, storage of waste while waiting for launch, and possible waste processing.

e. Decide if hazardous waste other than high-level nuclear waste could also be disposed of on the Moon profitably.

3.5.6 Space Tourism

The topic of space tourism is covered in several sections of this report. The intent of this section's discussion is to focus on the commercial viability of the transportation elements associated with space tourism. Tourism is a multibillion dollar business annually with a continuing annual growth increase. Space tourism is an extension of the current tourism market activity. Currently, people pay large sums of money for unique Earthbound adventures to satisfy their natural need for experiencing the unusual.

Space tourism to low Earth orbit (LEO) can become an economically viable industry if the proper conditions exist. The tourism market is primed and ready for the introduction of space travel as a means of recreation. The Cruise Line International Association of New York City reported that over three million Americans took oceangoing cruises in 1989 and that the average cost expended by each traveler was in excess of $7,000. The journalist William Buckley organizes a trip once a year to fly around the world with a few stopping-off points for the passengers. The cost for this trip —$60,000 to $80,000 per person.

From information taken from *Space Tourism, The Unbelievable Market* by G. Harry Stine, regular service would be provided with one space plane flight to LEO and return every day. This requires a fleet of at least four vehicles. Service could be provided from existing airports or from newly constructed launch/recovery pads. The only new ground servicing facilities required would be a fuel storage facility and a fueling facility. A turnaround time of 24 hours with no more than 200 maintenance labor hours would be expected. The reliability would have to be at least comparable to existing air transportation systems. The ultimate goal would be to provide a system that could operate on a per-flight budget of around $2 million. If a space plane could carry 110 passengers, the required price would be $18,181. This represents less than 25% of the William Buckley around-the-world tours. With these statistics, it is not hard to conceive of the tourist market being able support space travel.

A space transportation system must have the same economic and operational factors as other successful transportation systems. The system must be available to customers on short demand; costs and pricing structures must allow a reasonable profit margin; the system must be capable of operating without a standing army of support personnel; and, operating facilities must offer multiuser capabilities so that they can be more cost effective.

3.5.6.1 Introduction/Statement of Problem

Recreational space travel for the average person has been a dream for decades. Technologically, we possess the knowledge to design and build a transportation system capable of routine and somewhat safe carriage of human passengers to and from Earth orbit. Many previous studies[5-14] have extolled the attractions of space tourism as one element of the huge tourism industry that exists in the world of today and in the projected future. Indeed, the sum financial total of man's activities in space to date pale by comparison to the potential space tourism market. As many of these studies have pointed out, the key to financial success (assuming governments are uninterested in a long-term subsidy) lies in significant reduction of the cost of operating the transportation elements.

While there are many useful analogies to other segments of the tourism industry (e.g., cruise ship operations) that have been used to suggest traffic models and available income, a significant idiosyncrasy of space tourism is the relatively high cost of the transportation hardware. The ability to amortize the development and manufacture of new vehicles with even a substantial portion of the annual revenues may not be possible. The objective of the analysis presented in this report is to formulate economic requirements for any new space transportation system and to answer the fundamental question concerning the feasibility of developing the space tourism market: *Can* *the vehicle be developed and a fleet built and operated for the magnitude of money that can be reasonably expected to be generated from passenger revenue?*

3.5.6.2 Study Approach

There are several ways to estimate the elasticity, or price/demand curve, for tourism. One method is to conduct a market survey, or opinion poll. There have been several surveys performed that included space tourism questionnaires. The most often cited study was performed by Society Expeditions in the mid 1980's[4]. The drawbacks of this method include the limited sample size and a questionable correlation between survey results and actual ticket purchases. Questions must be phrased to address the specific information that investors would need to know before proceeding with a tourism venture. To date, our understanding of the breadth and depth of this information is too limited to credibly create a useful survey. We have contacted the U.S. Travel Data Center, in Washington, D.C., which has agreed to perform a nationwide space tourism survey. Sponsored by the travel industry, it is experienced in developing and phrasing the proper questions to correlate responses with actual sales.

Another approach to determining the space tourism market is to explore analogous terrestrial travel ventures. Oceangoing cruise lines operate ships worth hundreds of millions of dollars and offer a glimpse of the financial decisions involved when developing, financing, and profitably operating expensive assets. Exploring the growing market for exotic travel and/or ecotourism services sheds some light on the high-end tourist. We have contacted both cruise line companies and "adventure" travel groups. While we found some interest in both groups, quantitative data were very limited. (A summary of contacts is found in app. E.1-1.)

The third method to determining elasticity is to model the space tourism market parametrically by varying the economic factors that are likely to determine demand. An objective tool for examining the development of a space tourism vehicle was created for this purpose. For the purposes of this analysis, multiple uses for the transportation system (as well as the accompanying sources of development funding) were excluded.

Prior efforts to characterize the economics of space tourism were based on a top-down approach, depicted in figure 3.5.6.2-1. Typically, a concept for tourism is proposed first: either a vehicle design, an orbiting hotel concept, or a marketing approach, such as the "adventure travel" extrapolation from exotic terrestrial travel to spaceflight. A cost analysis of the concept is performed next, leading to a form of market analysis to determine the ticket price that results in a profit for the operator. Finally, one can speculate on whether people will buy a ticket at that price. While this approach is fundamentally sound, it is easy to create an optimistic view of the space tourism market by assumptions or ground rules that are based on sketchy projections and cost estimating.

An alternative approach to defining the space tourism market, a "bottoms-up" technique, was developed. Also shown in figure 3.5.6.2-1, the first step here was to define the pool of monies available by modeling the world's population in terms of annual income. From this, the percentage of people with the financial means to travel and the interest in traveling to space is defined, resulting in an estimate of the annual cash flow available for the space tourism operator/developer, as well as an idea of what the fleet size and vehicle passenger capacity would have to be. Then one can conceptualize concepts to fit the size and turnaround guidelines suggested from the previous steps. The costs of the concepts are estimated, and an assessment is made of whether or not the vehicle can be developed, built, and operated at a profit.

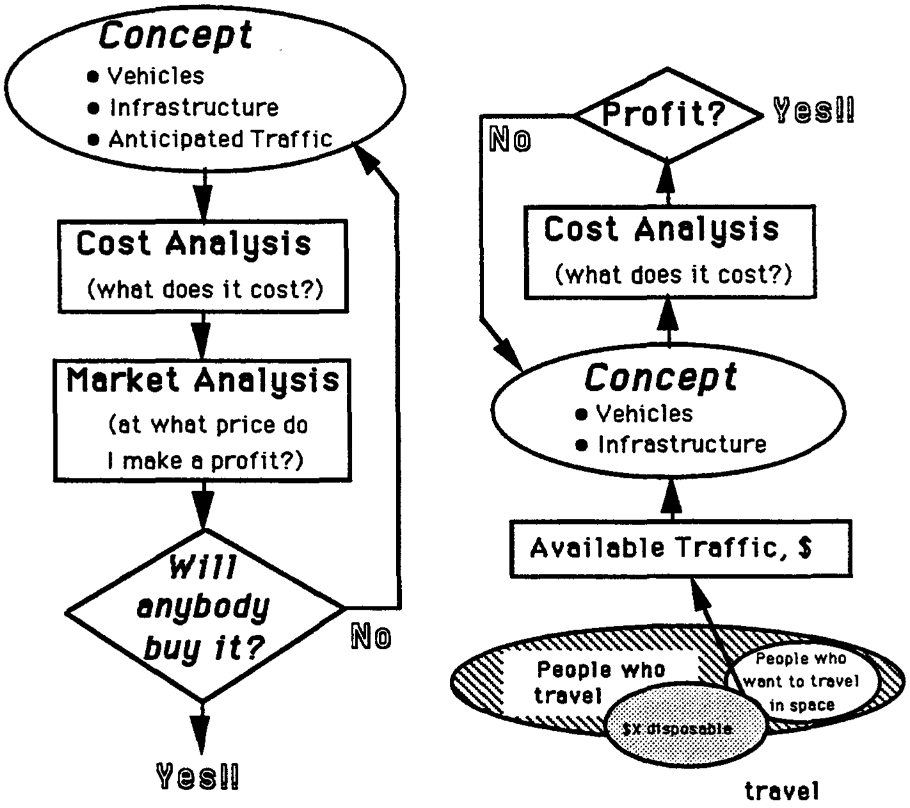

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Figure 3.5.6.2-1. The "Top-Down" Versus the "Bottoms-Up" Approaches To Analyze Demand

As a "sanity check," an independent but similar parametric model was developed based on the distribution of household income. This second model was based on an assumption that, for an expensive vacation, households were more likely to travel together than as individuals. These two models turned out to agree in the magnitude of the estimates of traffic and the resultant conclusions regarding the commercial viability of space tourism.

3.5.6.3 Market Description

Before proceeding, it is helpful to postulate likely aspects of the space tourism industry. First, some general categories of likely tourism scenarios are outlined, followed by some discussions of broad groupings of requirements. These categories are technical, regulatory/legal, and risk control. Later on, when the model produces a cost value, for example, one should scrutinize that number with these other "requirements/ desirements" in mind.

3.5.6.3.1 Description Market Evaluation

There are several potential paths for space tourism; which path is most likely to occur may be influenced less by pure technical considerations than by the desires of the investors in a space tourism enterprise. Categorizing alternative approaches here is intended to highlight some operational differences that have direct bearing on development cost and fleet size. The following list is approximately in order of complexity but may or may not be evolutionary: potential operators would conduct their own market analyses to ascertain what "niches" to pursue.

a. "Joyride"—Passengers would board a high-speed vehicle and experience an exhilarating, relatively short (in hours) ride suborbitally or up to a few orbits in duration. This scenario implies most of the cost of operation is related to the transportation elements and would probably feature rapid turnaround of reusable hardware.
b. Orbital Visit—Tourists visit a fairly simple orbital facility (such as Space Station Freedom or MIR) for durations of 3 to 10 days. Amenities are few and the transportation elements would probably be small (few passengers) to be consistent with the orbital facility. The percentage of the revenues that can be applied to the transportation vehicles is smaller than in the "joyride" scenario.
c. Space Hotel—Large numbers of tourists would stay at a multifeatured orbital facility. Both 0g and positive g zones would be available for living, playing, and looking out numerous windows. The percentage of the revenues that can be applied to the transportation vehicles is much smaller than in the "joyride" scenario.
d. Lunar Flyby—An Apollo 8-type mission where passengers experience 0g, the starry blackness of space, and views of the Moon and distant Earth. Vehicle development costs are significant.
e. Lunar "Hilton" and Beyond—Space resorts and more ambitious ventures are in a financial realm that is unlikely to occur if at least one of the previously listed space tourism ventures has not proved successful.

Over time the makeup of the tourism market will change. Initially, joyrides could justify a venture (in fact, the Society Expedition survey results show a healthy demand for joyrides); in later years, a destination will be required to sustain a space tourism industry.

3.5.6.3.2 Market Evaluation

The world's appetite for tourism continues to grow at a rate higher than the average gross domestic product of the nations' economies. By the time a manned commercial space transport would become available early in the next century, humans will spend about a *trillion* dollars a year on tourism. Of course, there are many choices that the traveling public has in vacations. Given the response to previous opinion polls on space, it is safe to assume some reasonable percentage of that huge market would migrate to space tourism if it were available.

One of the fastest growing areas in recent years in the tourism business is high-end, exotic tours. By combining exotic destinations with a learning experience, travelers find significant value added to their leisure time. This trend fits well with space tourism.

3.5.6.3.3 Market Assessment

For space tourism to be a financially viable enterprise, not only must there be a sizable potential market of interested individuals from which to draw the passengers, but the price must also be affordable to these people. (For most, this will be a once-in-a-lifetime experience.) The challenge of space tourism is to provide a service that has sufficient attraction to a large number of people and to provide this service at a cost that is affordable to a large enough share of the potential market so that they will avail themselves of the opportunity.

To establish the economic feasibility of this market, the CSTS team performed two "bottoms up" analyses to define the global market based upon annual income. (See app. E.1.2 for details.) Within that reduced market we further decreased the size by introducing age considerations and a "likelihood factor" to reflect the percentage that will make the trip.

Our starting point is the development of a worldwide income distribution by aggregating the populations of countries with per capita incomes similar to that of the United States. For the remaining, less wealthy, world population, 5% was assumed to have upper income levels similar to the United States. These statistics were obtained from the World Almanac with populations adjusted to the year 2020. From this information, the number of households worldwide with income levels comparable to U.S. standards is four to five times greater than just U.S. statistics alone. Specifically, the U.S. income distribution statistics was multiplied by a factor of 4.62 to arrive at the worldwide households with equivalent income levels. The number of worldwide households with incomes above a specified level is shown in figure 3.5.6.3-1 below. World wealth is growing at an uninflated rate of roughly 2% a year compounded. Thus, by the 2020, these population statistics could grow by another 67% (but not applied in this paper). The distinction between households and people is that for each household in the United Stated in 1991 there was an average of 2.63 people.

Income distributions have been collected by households from the three sources shown in figure 3.5.6.3-1, below: (1) 1990 census data, (2) the 1989 Adjusted Gross Income Tax Statistics, and (3) the 1992 Statistical Abstract of the United States. The income statistics used in this study were for households with adults aged 25 to 55. Below this age band, it is assumed that there is insufficient household income, and above the age band, physiological restrictions will prevail.

Household Income Level	1990 Census Data (Millions)	1992 USA Statistical Handbook (Millions)	USA 1989 Income Tax Statistics - Returns not Households (Millions)	US Household 25-55 Age Group (Millions)	Worldwide Household 25-55 Age Group (Millions)
$50K+	22.52	24.6	15.83	16.73	77.29
$75K+	8.74	9.7	5.92	6.67	30.81
$100K+	4.04		2.87	3.75	17.33
$150K+	1.44		1.50	1.67	7.72
$200K+	0.52		0.78	0.94	4.34
$300K+			0.47	0.56	2.59
$500K+			0.17	0.194	0.896
$750K+			0.10	0.0667	0.308
$1,000K+			0.06	0.0375	1.73
$1,500K+			0.0189	0.0167	0.0772
The numbers in italics are curve-fit estimates or interpolations.					

Figure 3.5.6.3-1. The Number of U.S. Households in the Different Economic Strata

Having defined the worldwide potential market, we next considered affordability. Our rule of thumb was that only households with an annual income equal to the ticket price, or greater, were financially able to afford the trip. Additionally, the more the annual income exceeds the ticket price, the more affordable the travel would be and the less likely the individual/family would be deterred from taking the trip. To account for this we defined the following rules:

a. If the annual income is less than the ticket price, the affordability factor is zero.

b. If the annual income is less than three times the ticket price, the affordability factor is the square of the ratio of the annual income divided by three times the ticket price.

c. If the annual income is greater than three times the ticket price, the affordability factor is the ratio of the annual income to three times the ticket price.

Within the set of households that can afford the trip, there is likelihood factor, defined as the percentage of households that will make the trip into space sometime during the 30-year window of opportunity, ages 25 to 55. The resulting number of passengers for different ticket prices and likelihood factors is computed using the worksheet in figure 3.5.6.3-2.

Household Income Level	This Income or Higher (US)	This Income or Higher (Global)	Number in This Stratum	Affordability Factor			
					Annual likelihood		
			Ticket price >>	$135,000	200	3,500	60,000
			Weight/person >>	225			
			$/lb >>	$600			
$50,000	16.73	77,292,600	46,477,200	0.00	0	0	0
$75,000	6.67	30,815,400	13,490,400	0.00	0	0	0
$100,000	3.75	17,325,000	9,609,600	0.00	0	0	0
$150,000	1.67	7,715,400	3,372,600	0.14	2,313	132	8
$200,000	0.94	4,342,800	1,755,600	0.24	2,141	122	7
$300,000	0.56	2,587,200	1,690,920	0.55	4,639	265	15
$500,000	0.194	896,280	588,126	1.23	3,630	207	12
$750,000	0.0667	308,154	134,904	1.85	1,249	71	4
$1,000,000	0.0375	173,250	96,096	2.47	1,186	68	4
$1,500,000	0.0167	77,154	77,154	3.70	1,429	82	5
				Households >>	**16,587**	**948**	**55**
				People >>	**43,625**	**2,493**	**145**
				Pounds into orbit (M lbs) >>	**9.82**	**0.56**	**0.03**

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Figure 3.5.6.3-2. Annual Passengers Worldwide for Three Different Likelihood Factors

We varied the likelihood factor over the range of 200 to 60,000 and developed relationships between the annual number of passsengers and the ticket price in constant year dollars ($CY92). In figure 3.5.6.3-3, the upper curve represents the most optimistic case and is referred to as the "low" probability curve. The lowest curve is the most conservative and is the "high" probability curve. The following figure depicts the upper and lower bounds of annual passengers to ticket price.

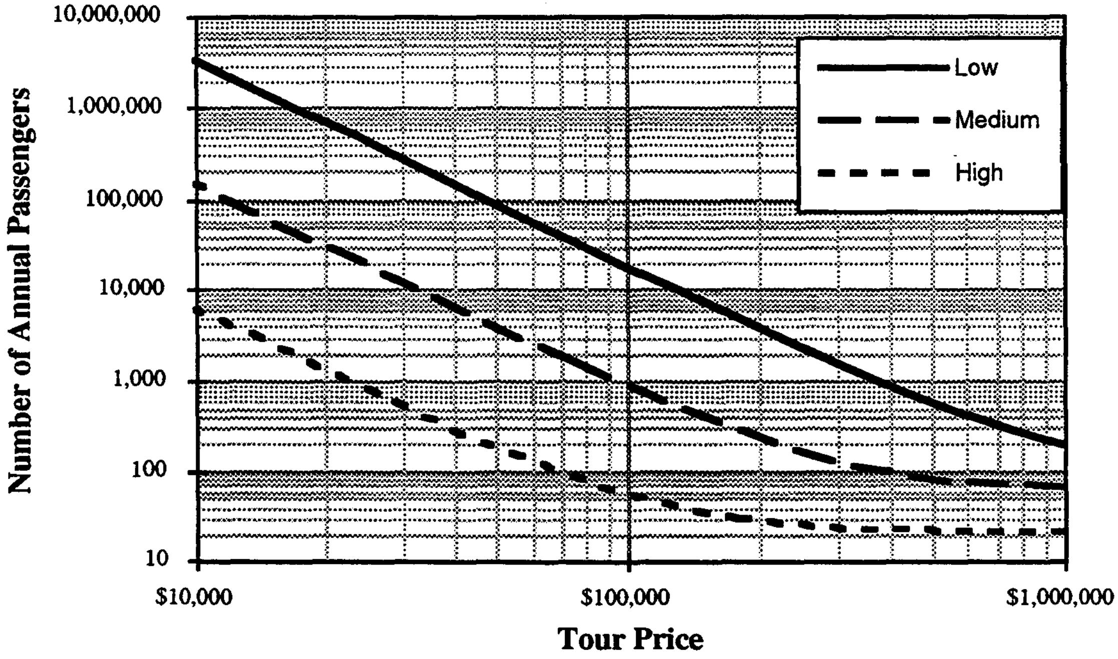

Figure 3.5.6.3-3. The Annual Passenger Demand for Different Ticket Prices

The "medium" probability curve is defined as the "visual" medium between the high and low curves when plotted on a log-log scale. (The "medium" probability curve is defined as our most likely curve.)

A firstorder approximation to the underlying equation for the predicted number of annual passengers at a given ticket price is an offset inverse exponential as given below:

$$Y = c + \frac{b}{\left(\frac{X}{s}\right)^{a}}$$

The above relationship is used in the subsequent market and business models, where Y is the annual number of passengers and X is the expected ticket price in CY92 dollars. The three sets of coefficients corresponding to low (maximum market size), medium, and high (lowest market size) probability curves are given in figure 3.5.6.3-4 below:

	High	Medium	Low
a	2.27	2.27	2.27
b	6,233	148,700	18,000
c	21	61	100
s	10,000	10,000	100,000

Figure 3.5.6.3-4. The Low, Medium, and High Probability Curve Coefficients

3.5.6.3.4 Market Infrastructure

As one more aspect of the tourism industry, a commercial space transportation system would likely interface with much of the terrestrial tourism infrastructure. Reservations, advertising, and financing will probably be handled by existing or spinoff travel companies. The point of embarkation (i.e., the launch pad) will need to be reasonably accessible to a major transportation hub, such as an international airport.

One specialized aspect of the space tourism infrastructure will be a passenger familiarization/orientation facility. While formal crew training is probably impractical (and expensive), there will be some procedures and physical preparation that would be more extensive than the typical safety lecture presented on an airline flight.

Tourism is the largest industry in the world, and equates to between 5% and 6% of the world's gross domestic product. According to the Madrid-based World Tourism Organization (per information extracted from the 4 January 1994 Orange County Register), international tourism receipts for 1993 were slightly more than $324 billion, which is 9% above the 1992 figure. Americans, on an average, spend $991 million per day on travel (data source is from the American Hotel and Motel Association as printed in a recent addition of USA TODAY). People are constantly seeking new adventures and are willing to pay premium dollars for these opportunities. Examples of this growing trend toward "exotic" travel are as follows:

a. Individual suites on round-the-world cruise ships, per Kloster Cruise Lines, run $300,000 per month,and are booked solid.
b. A permit to climb Mount Everest now costs $50,000 and there is a long waiting list.
c. The Russians are chartering one of their icebreakers at $19,000 per person for trips into the Arctic Circle, and they are completely sold out.
d. NASA offered rides in a flight simulator in the Denver area at $1,500 per hour and couldn't keep up with the demand.

Accordingly, the infrastructure associated with the largest industry in the world is extremely wide and diverse. Businesses that support the tourism industry range from the large, well-organized vacation/travel agencies all the way to the individual entrepreneur who serves as a travel guide in the swamps of New Guinea. In the same manner that it exhibits such a wide and diverse scope of support, the existing infrastructure is highly flexible and adaptable to new and developing markets. For the most part, the machinery to accommodate the needs of an evolving space tourism industry is in place. Passengers would enjoy the same comforts and assistance as provided by the travel industry today.

The primary impact to the current infrastructure would most likely be in the direct support aspects of the space vehicle itself. This would encompass areas such as new/modified launch and recovery sites, maintenance facilities, propellant generation, and storage facilities. Support requirements for a new spaceport would include the following:

a. Proximity to existing transportation nodes (highway, rail, air).
b. Access to a high-capacity fuel-generation facility/depot (for example, if liquid hydrogen fuel is required, then availability of natural gas pipelines and a major electric power grid would be needed to convert the gas into the liquid fuel).
c. Availability of large hangers and maintenance equipment for performing the regularly scheduled preventive maintenance procedures.
d. A buffer zone surrounding the spaceport, which would protect the general populace from excessive noise levels associated with takeoff and landing operations, as well as providing a physical security perimeter to support access control operations.

e. Designated air corridors for departures and arrivals.
f. Connectivity to global communication networks to ensure constant ground-to-air coordination (similar to that used by NASA for controlling the shuttle operations).

3.5.6.4 Prospective Users

Although the primary thrust of this report is based on a "bottoms-up" financial analysis of the world population's annual income and the expected cash flow available for space tourism (sec. 3.5.6.3), contacts were also made with various people in the tourism industry to get their views on the viability of a future space tourism market. The actual process of contacting people who could provide us with meaningful data (i.e., the CEOs, presidents, and high-level corporate officers) was a very time-consuming and frustrating task. These people have very effective screening procedures to eliminate what are perceived as prank calls and/or inquiries that do not appear to have any impact on their bottom line. We recognized "going in" that this would be a difficult obstacle to overcome, and so we prefaced each verbal contact with a special delivery Fed-X package that contained an introductory letter and a copy of the CSTS brochure that asks for the recipient to “Talk with us” . . . . We're contacting you to understand your needs and your vision of the future." With persistence, we managed to talk to several people who we believe have credible inputs to this study. The detailed results of these contacts are provided in appendix E.1.1 and are summarized as follows:

a. There is a tremendous demand for new and unusual touring experiences, and the level of this demand is increasing at a rate that is outpacing the supply (i.e., there are long waiting lists for these types of opportunities).
b. Initially, trips into space will be viewed as "fringe" type events that only the most adventuresome would ever consider. However, as spacelines develop with attributes similar to the present airlines, these journeys will be included as "standard fare" for the majority of people in the developing nations.
c. As this market segment matures, there will be opportunities for a wide variety of new businesses to develop on the "coattails" of space tourism. This vision includes destination facilities that cater to the public's interests in the same way as do resorts, health spas, and hotels, as well as medical facilities that provide unique services as enabled by a 0g environment.
d. There is a perceived need by many in our society to do that which their acquaintances have not yet done, which always feeds upon itself as new options to old things are enabled. In this perspective, there will always be a market for new and exotic vacations, and the revenue that can be captured is clearly dependent upon the number of people who will have the discretionary income to avail themselves of these opportunities.

3.5.6.5 CSTS Needs and Attributes

3.5.6.5.1 Transportation System Characteristics

Technical Requirements. Space travel is inherently risky to humans, whether they are trained astronauts or paying tourists. Therefore, the primary set of technical requirements for space tourism should be related to the maximization of personnel safety. This is not merely a moral concern, but rather it represents essential business practice to minimize life cycle cost and maximize future markets. These requirements would generally include maximum reliability (including engine-out performance).

Other technical requirements focus on personnel comfort. Optimizing performance (as has been the trend to date in rocket travel) is secondary to providing the least stressful environment on the amateur space traveler. Robust environmental control and life support systems, g-constrained trajectories, and numerous windows are requirements for tourists.

Human tolerance to sustained acceleration depends on many factors. Some of the factors include—

a. Magnitude of the acceleration.
b. Duration of the acceleration.
c. Rate of onset and decline.
d. Physical condition/age.
e. Training.
f. Direction of the acceleration vector with respect to body position.
g. Type of g protection/couch.
h. Miscellaneous - motivation, lighting, temperature, etc.

Centrifuge tests have established approximate boundaries for acceleration limits, as shown in figure 3.5.6.5-1. These tests may not be consistent with the "limits" that would be desired for a paying, unconditioned, non-professional astronaut passenger. It may seem fanciful, but a better resource for determining acceptable levels of acceleration may come from amusement park rides. Surveys at these facilities as well as "tests" could ascertain the point at which the majority of paying customers would find the experience too uncomfortable to tolerate.

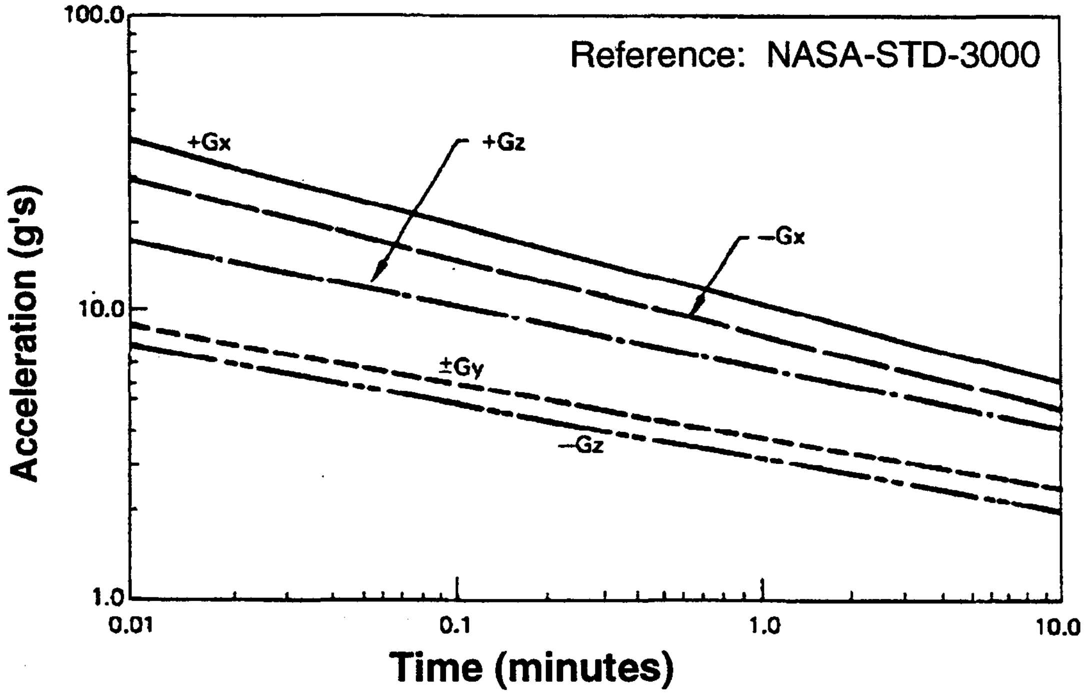

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Figure 3.5.6.5-1. Linear Acceleration Limits for Unconditioned and Suitably Restrained Passengers

The majority of concepts that are studied for new launch vehicles, and indeed all human experience in space to date, involve a vertical ascent rocket to get to orbit. Flight trajectories are essentially all of the gravity-turn type; that is, the effect of lift is essentially negligible. Rapid ascents reduce the gravity losses and hence minimize the total ideal ΔV (which implies a minimum propellant load). This performance optimization is particularly useful when one relates vehicle size to the cost of expendable hardware. For reusable hardware, the significance of minimum vehicle size is not as great when evaluating life cycle costs.

Historically, the vibration and g loads on the crew members have certainly been higher than those one would hope to see in a routine passenger-carrying vehicle. Trajectories are rarely optimized to minimize g's: this tends to result in larger vehicles (more propellants for longer burntimes) and can only reduce the peak acceleration so much before physics dictates that the ascent can only be achieved through extremely light materials (high λ') or rocket engines with extremely high throttle ranges (as high as 10:1 for an SSTO vehicle). In reality, the latter problem can be addressed by using several engines that are sequentially shut down. This assumes the total number of engines does not (a) affect overall reliability too adversely, (b) introduce unacceptable correlated failure modes, and (c) reduce overall thrust-to-weight performance significantly with the addition of extra plumbing, controls, and structure.

Several trajectory optimizations were conducted for typical future space transportation concepts where the thrust-to-weight ratio (essentially the g's experienced less the effect of gravity) is held to some limit, the nonlifting trajectory compensates by burning longer, and the resultant propellant weight required is calculated. Since the vehicle gross liftoff mass was fixed, the weight injected on orbit (which includes the inert mass and the payload mass) is simply the gross mass less the propellant mass. By parametrically varying the mass fraction, λ', one can determine the payload level (number of passengers). Conversely, for a given desired payload, one can find the resultant minimum mass fraction for an acceleration limit that the vehicle must meet in order to make orbit. Figure 3.5.6.5-2 depicts one example case. For the design point "X" shown, a postulated upper acceleration limit of 2 g's is desired. For this concept, the CSTS team believes a λ' of 0.91 is possible; the resultant maximum payload is 20,000 lbm. Design point "Y" depicts a case where the maximum g level is thought to be 2.6 for a passenger load equivalent to 36,000 lbm; this implies the vehicle will not make orbit unless the designer can meet a minimum λ' of 0.925. Analysis of several other nonlifting vehicle concepts resulted in similar trends of λ', acceleration, and payload masses.

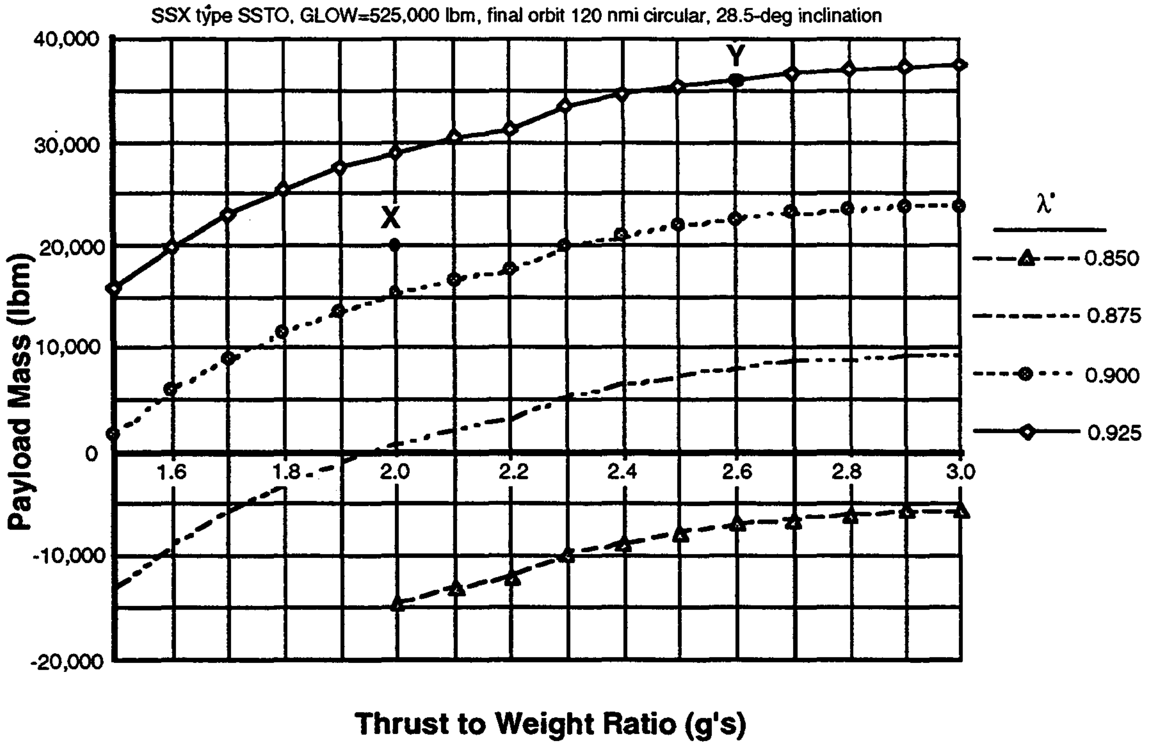

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Figure 3.5.6.5-2. Example Relationship Between Mass Fraction and Payload Mass for Acceleration Constrained Nonlifting Trajectories

Note that there is break point at a thrust to weight ratio of 2.2 where the optimized trajectories change from a direct-injection type to one characterized as a boost/coast type ascent. In figure 3.5.6.5-3 one can see the profound impact on time of flight (time of exposure to acceleration) with this shift in trajectory type. In figure 3.5.6.5-4, this acceleration/time curve is superimposed on the (extrapolated) +G_X curve from figure 3.5.6.5-1; note that the g-constrained trajectories fall well within the NASA physiological limits. There is also some evidence to suggest that minimizing the time when liquid rocket engines are firing results in improved overall reliability, although this effect may be secondary.

If the physiological and/or psychological demands of these minimized g levels is still too high, then a significant requirement can be inferred: passenger vehicles for space tourism must use a lifting ascent. The technology for winged ascent vehicles has been studied extensively in the form of single and two-stage-to-orbit rocket-powered vehicles, and air-breathing vehicles such as the NASP. While some could claim such concepts are within reach, the fact remains that a full-size system has yet to fly and this, in turn, will be a factor in determining the likelihood of financial backing for a new venture.

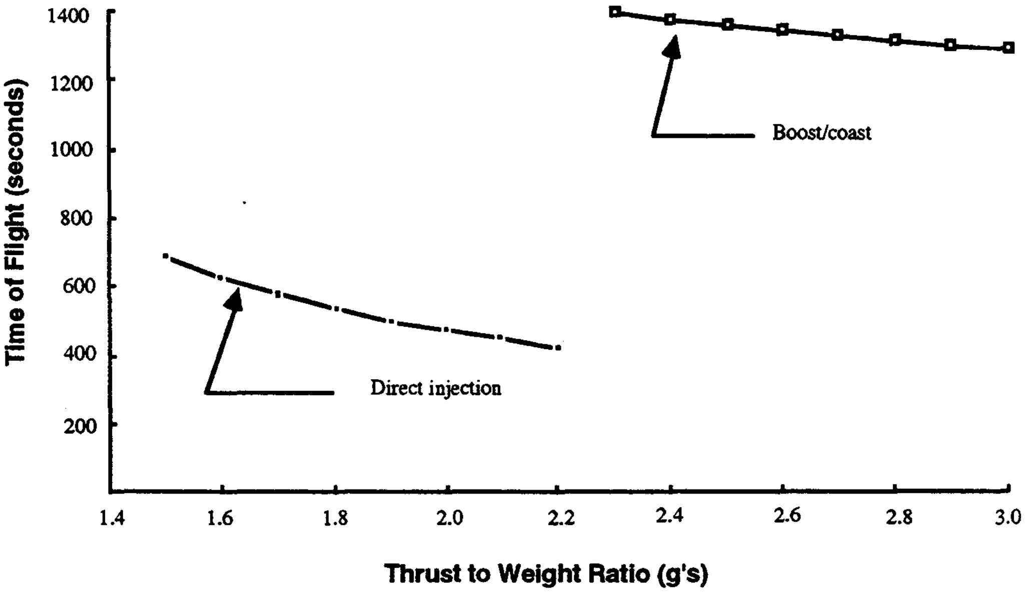

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Figure 3.5.6-5-3. Example Relationship Between Time of Flight and Thrust-to-Weight Ratio for Acceleration Constrained Nonlifting Trajectories

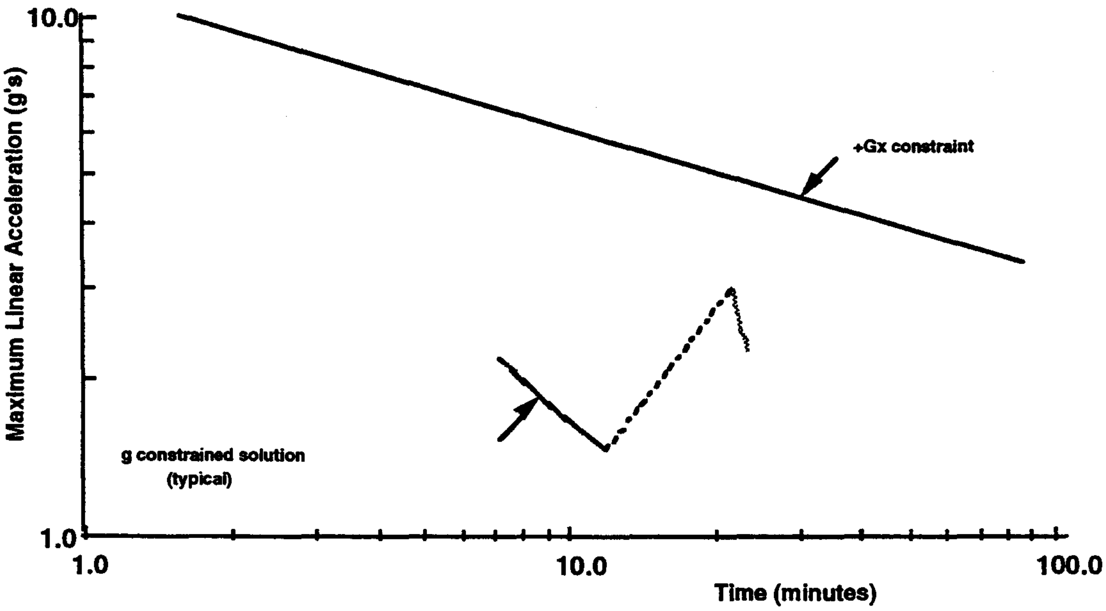

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Figure 3.5.6.5-4. Linear Acceleration of g-Constrained Trajectories Is Within NASA Limits

Regulatory/Legal Requirements. In the past, where orbital assets were financed, launched, and operated by a single government, property rights and jurisdiction issues fell under the law of the controlling government.

There are several international space policy agreements in force that serve to guide the general framework of a private tourism venture. Additional regulation is certain to occur as commercial operations become routine so as to resolve questions of product liability, civil torts, and criminal law. A possible model for space tourism legal affairs may come from international cruise ship lines or from Antarctica tourist travel.

In addition, space travel will always contain a degree of risk much higher than most nonrecreational terrestrial activities. A commercial venture must be able to limit financial liability through legislation, insurance standards, or some form of binding waiver. An interesting data point on what may be acceptable risk comes from a recent study of product liability cases (in 1992, some 12,000 cases were filed in federal courts). The study, conducted jointly by *Design News* and the Chicago law firm of Rooks, Pitts, and Poust, explored, among other things, jury perceptions. Nearly half the jurors believe that a product should be taken off the market if only one person in a million is seriously injured while using it. In the case of a commercial personnel transport of say, 100-person capacity, this translates to at best a single serious injury once every 10,000 flights.

Safety regulations and international regulatory authorities will also have economic impacts on operations costs, and "taxes" as part of the ticket price.

Risk Control Requirements. Managing technical risk is always an area that deserves attention. In a case where lenders are asked to support a new industry with new hardware and/or operations, considerable effort will be required (e.g., in the form of test programs) to ensure financiers of a favorable return on investment.

Any successful terrestrial tourism venture is either controlled from end to end by one company, or multiple sources of supply/services are available for cost competitiveness and/or failure (physical or business) recovery. Likewise, space tourism must not be based on a single "thread" unless one entity is financially in control of the entire operation and is legally allowed to operate in that manner (i.e., antitrust issues are addressed). For example, it is ill advised to have an orbital hotel run by company X that can only be reached by company Y's rocket unless X and Y are in a consortium where risk and profit are related.

3.5.6.5.2 Transportation System Capabilities

The space transportation system capabilities required for capturing the tourism market are similar to those provided by the airlines (for the near-term market) and by the cruise lines (for the far-term market). Passenger safety and comfort are paramount considerations, with secondary aspects being related to the economic and business aspects. In the near-term market, the transportation system would need to handle the adult joyride crowd, whereas for the far-term market, families with children would need to be accommodated as well as incorporating provisions for on-orbit docking operations.

As noted in the previous section, the vehicle dynamics associated with planned ascent and descent operations must fit within the boundaries of acceptable g loads for tourists (probably not more than 2 to 3 g's over a 10-minute period). Adjustable seat configurations, tailored to the contours of the individual passengers, will be needed in addition to either having the individual seats or the entire cabin capable of being rotated following passenger embarking to align their ±X body axis to the vehicle's major force vector (X axis being front-to-back, Y axis being side-to-side, and Z axis being up-and-down).

Passengers will also want to have direct visual access for viewing the Earth during flight, and to use cameras through these viewports for recording their journey. In addition, passenger viewing screens, coupled via fiber optics to selectable on-board optics, will enable the crew to point out items of interest, communicate instructions, and provide information on the flight's progress. An interactive system would also enable the flight attendants to handle questions and/or problems during periods when the passengers and crew are confined to their stations.

Passenger safety must be ensured to an even larger degree than is currently achieved by the airlines. Catastrophic events associated with space travel would undergo extreme public scrutiny (as did the Challenger accident), and have a major impact on the industry. Therefore, reliability of the transportation system must be ensured by employing conservative margins of safety in the design and using redundant systems for critical functions, as well as incorporating special features to ensure passenger protection during high-risk periods.

In addition to having reliable performance from the space vehicle itself, the transportation system as a whole will need to have the capability of meeting predetermined operational schedules for departures as well as arrivals. Tourists will expect to travel on the advertised dates and times that were set when they purchased their tickets. Moreover, as on-orbit travel destination points are utilized, the ability to meet the exact launch windows will become more and more important as people will also be waiting in space for the arrival of their return flight.

Finally, in looking at the economic viability of developing a transportation system exclusively for the tourist market (ref. sec. 3.5.6.6), we find that tourism will most likely take the form of being comanifested with other payloads on a "universal" type of vehicle. With this in mind, the transportation segment will need to be modular, expandable, self-contained, adaptable to the vehicle's physical mounting/attachments, and compatible with the on-board utilities (air, power, cooling, etc.). This may well be the driving function that shapes the final configuration more than any other consideration.

3.5.6.5.3 Ground Handling

Ground operations at a spaceport are envisioned to be similar to those at a major airline terminal. In order to sustain economic viability of a fleet of space vehicles, it will be necessary to achieve a very short turnaround time capability that is essentially comprised of replenishing the on-board consumables, changeout of any life-limited items, conducting scheduled maintenance tasks, and performing a systems verification test. For purposes of comparison, turnaround operations should be in the neighborhood of 72 hours with an inspection time of several hundred hours, as contrasted to the shuttle, which requires months of turnaround operations and nearly one million hours of inspection.

3.5.6.5.4 User/Space Transportation Interfaces

Since space travel presents many new and unique situations to the passengers, it is anticipated that pretravel education will be an essential part of the user/space transportation interface. Information would be made available via the “data superhighway,” which is expected to link all households together within the next several years. Video programs would provide detailed instructions on how to operate onboard life support systems and how to handle contingency situations. Passengers would be certified, similar to requirements for participating in sports such as scuba diving, through interactive video training courses that are tailored to the specific vehicle configurations, passenger accommodations, and the specific travel plan selected.

Standard passenger clothing would likely be required to meet flight safety requirements as well as to facilitate activities in the 0g environment. These "space suits" would provide control over material flammability, static buildup, outgassing, particle generation, and so forth, as well as provide features for assisting the travelers in performing on-orbit functions (such as having Velcro fasteners for attaching loose items).

Baggage would have to conform to a specified shape, volume, and weight limit. Personal items such as toiletries would of necessity be restricted to an approved list of products that are compatible with 0g usage.

For trips of long duration, certification of passenger health would be necessary to ensure compatibility with the flight environment and to preclude viral and bacterial contamination of the destination facility's air supply. Of equal importance is the fact that access to medical treatment facilities is virtually nonexistent for long periods of time, so the state of passenger health at time of departure becomes a very important consideration.

Passenger accommodations will need to be configurable to the ergonomics of the individual tourists. For example, seats for children will need to be sized to meet their body profiles, as contrasted to the "one seat for everyone" approach now used in the airline industry.

3.5.6.5.5 Improvements Over Current

The current systems providing manned access to space are not suitable for most commercial space applications. In order for space tourism and its related enterprises (hotels/casinos in space, theme parks, etc.) to be economically viable, significant improvements over the existing systems are necessary. These improvements include—

a. The operations and maintenance (O&M) costs, including launch costs, must be in the order of tens of dollars per pound to a few hundred dollars, not thousands.
b. Predictable (reliable) launch schedule.
c. Regular service.
d. Safety equal to or greater than commercial airlines.

3.5.6.6 Business Opportunities

Whether or not space tourism makes good business sense depends upon the financial aspects of developing, building, and operating a transportation system that can capture the potential market and provide a suitable return on the investment. This is a fairly complex question to answer since space tourism is envisioned as including a wide variety of travel scenarios (from short joyrides to long-term stays at orbital destinations), and the revenue resulting from ticket sales (i.e., the price of the tour) is shared between the transportation segment and other profit centers (e.g., on-orbit hotel, theme park). Therefore, in order to properly assess the overall viability of space tourism, a business model was constructed to tie all of the interdependent variables together into one composite picture.

3.5.6.6.1 Cost Sensitivities

The following sequence of steps was followed in constructing a comprehensive model for the space tourism business assessment.

Number of Annual Passengers. Sensitivity of the tourism market was evaluated over a tour price range of $10,000 to $1,000,000. As previously described in section 3.5.6.3.3, the number of people worldwide who would be financially able to afford a space trip and who would also have the desire to do so is depicted in figure 3.5.6.6-1. The high and low probability curves bound the data spread encountered during the market evaluation process. The medium probability curve is then derived from the high and low curves, and is set equal to the square root of their products. As these curves show, there is no appreciable market that would sustain a space tourism industry until the tour price falls below $100,000. Keep in mind that the term “tour price” includes everything; it covers the transportation to and from space as well as the cost associated with on-orbit destination activities at a hotel or theme park.

To determine the market sensitivity to transportation costs, several relationships need to be established: specifically, the composition of the passengers (adults, children, consumables, etc.), the length of their stay in space, the weight of the support systems (habitable module), seat occupancy, desired operating profit, and the revenue split between transportation and other profit centers.

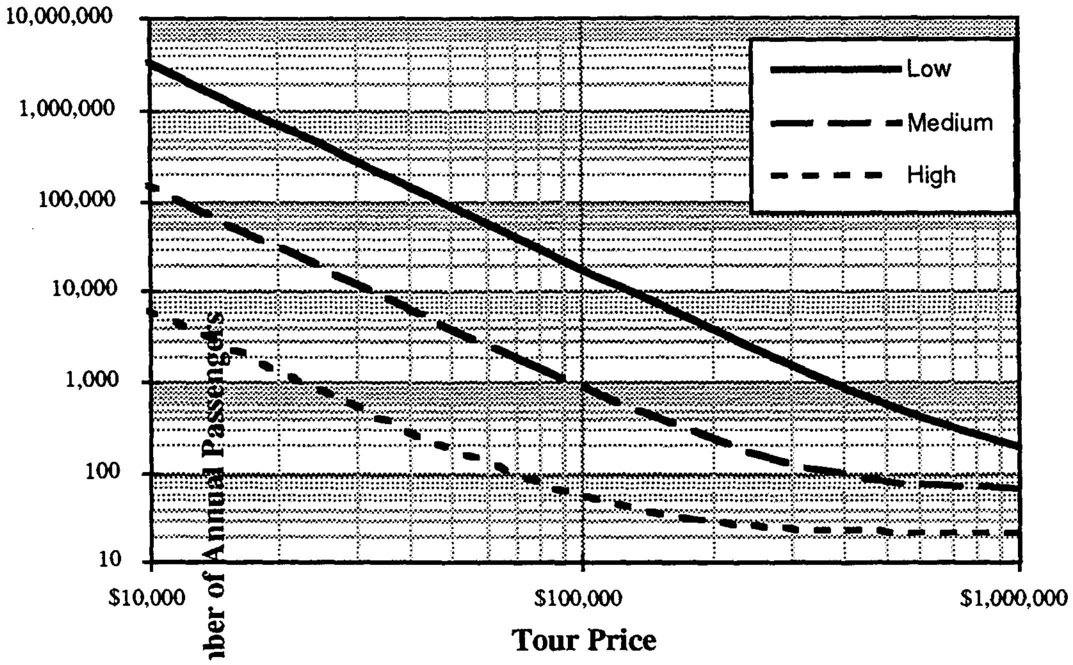

Figure 3.5.6.6-1. Space Tourist Market

Mass Characteristics of the Tourist Market. The average mass compositions for adults and children are estimated as shown in figure 3.5.6.6-2. The first line shows the current tourist mix of men, women, and children from an existing tourist database. The average body mass data also comes from this database. The other values shown for consumables, clothing, and ancillary items are purely estimates.

			Adult Male	Adult Female	12-yr old child	6-yr old child	Average
Percentage of Tourist Population			40%	35%	15%	10%	100%
Body Mass			184.0	140.0	90.0	50.0	141.1
Body mass	fixed		184.0	140.0	90.0	50.0	141.1
Consumables			19.1	16.7	13.4	10.0	16.5
Food (dry)	lb/day		1.4	1.2	1.0	0.7	1.2
Water - drink	lb/day		3.6	3.1	2.5	1.9	3.1
Water - food	lb/day		4.3	3.8	3.0	2.2	3.7
Oxygen	lb/day		1.8	1.6	1.3	0.9	1.6
Hand/body wash	lb/day	ext.	8.0	7.0	5.6	4.2	6.9
Clothing			4.5	3.9	3.1	2.3	3.9
Travel clothing	fixed		2.0	1.7	1.4	1.0	1.7
Recreational clothing	lb/day	ext	2.0	1.7	1.4	1.0	1.7
Nightwear	lb/day	ext	0.5	0.4	0.3	0.3	0.4
Ancillary			12.5	13.5	8.3	7.3	11.7
Toiletries - short stay	fixed		2.0	3.0	1.0	1.0	2.1
Toiletries - extended stay	lb/day	ext	0.5	0.5	0.3	0.3	0.5
Flashlight, watch, etc.	fixed		2.0	2.0	1.0	1.0	1.8
Writing materials	fixed		1.0	1.0	1.0	1.0	1.0
Camera, recorder	fixed		5.0	5.0	3.0	2.0	4.4
Entertainment devices	fixed	ext	2.0	2.0	2.0	2.0	2.0
Miscellaneous	fixed		1.3	1.4	0.8	0.7	1.2
Fixed mass - <1 day			**197.0**	**153.8**	**98.0**	**56.5**	**153.0**
Additional fixed mass - >1 day			**2.2**	**2.2**	**2.2**	**2.2**	**2.2**
Variable (lb/day) - <1 day			**11.1**	**9.7**	**7.8**	**5.8**	**9.6**
Additional variable (lb/day) - > 1 day			**11.1**	**9.7**	**7.7**	**5.8**	**9.5**

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Figure 3.5.6.6-2. Estimated Mass Characteristics - Space Tourists

Composition of the Tourist Market Based on Price. In order to properly use the mass data shown in figure 3.5.6.6-2, it was also necessary to look at how the mix of passengers by gender might be affected by price. As shown in figure 3.5.6.6-3, it is assumed that, at high $/lb prices, only adventure-tourists would be traveling into space. As on-orbit assets become available, which is not expected to occur until much lower rates are established, then families with children would be expected to participate. The curves shown in figure 3.5.6.6-3 are set to match the percentages for males, females, and children from figure 3.5.6.6-2 when the tour price equals $10 per pound.

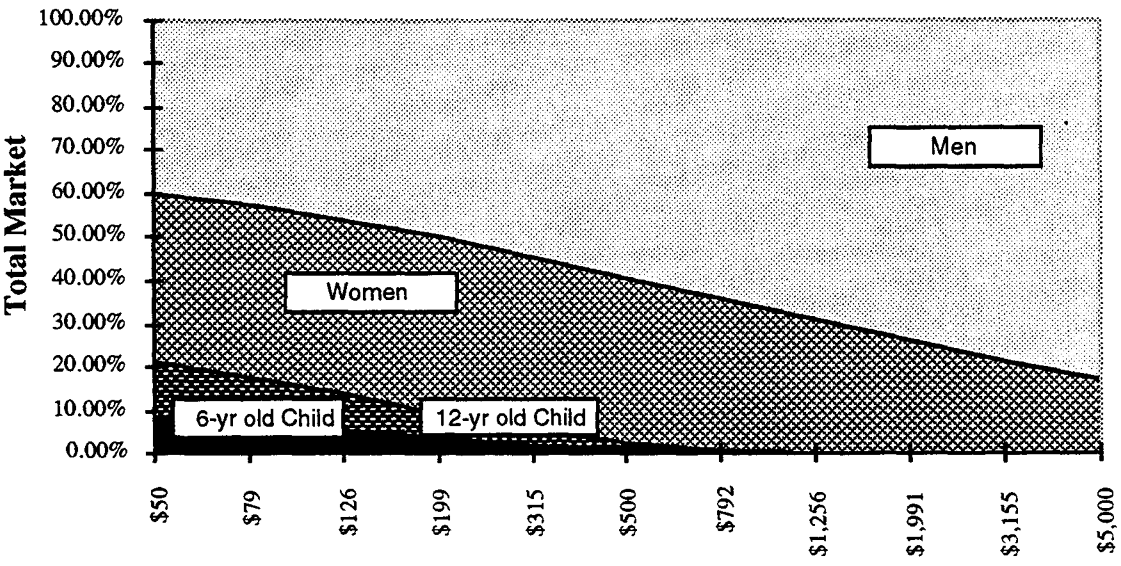

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Figure 3.5.6.6-3. Tourism Mix by Tour Price per Pound

Trip Duration. Another factor that had to be considered to properly use the mass data is the anticipated length of stay in orbit (to account for the weight of the consumables). At high $/lb prices, the market is predominately adventure-travelers who would only be staying for 1 day or less. As the $/lb price decreases, it is envisioned that travelers would be able to stay at on-orbit destination points, with an average time of 14 days set at the $10/lb point as shown in figure 3.5.6.6-4. (A tour of 14 days was selected based on the feeling that a family could reasonably allocate 2 weeks to a trip of a lifetime and could generally not afford to be away from their business for longer periods.)

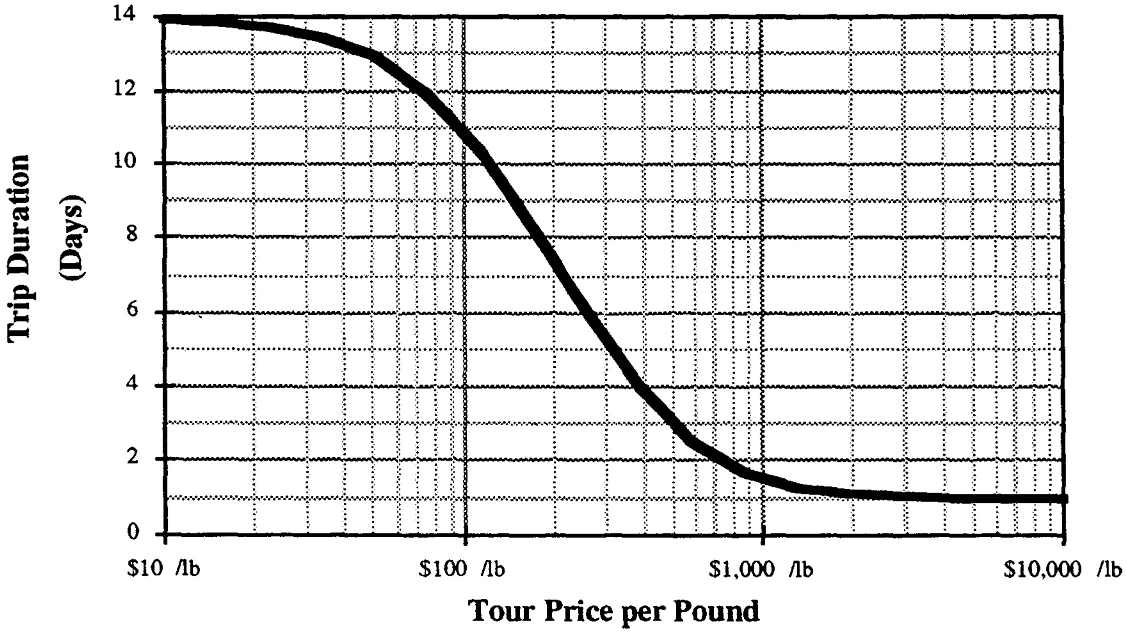

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Figure 3.5.6.6-4. Average Length of Stay by Tour Price per Pound

Allocated Passenger Weight. Using the data shown in figures 3.5.6.6-2 through -4, a graph showing the average weight per ticketed passenger as a function of tour price was constructed (fig. 3.5.6.6-5, Average Weight per Ticket). As depicted on this graph, the total allocated weight varies from 210 lb to 300 lb. This variable is then used in subsequent calculations for assessing the effects of weight (passengers + consumables + clothing + ancillary items) on the tourism model. An additional weight penalty is considered in subparagraph I to account for the habitable module in which the passengers ride.

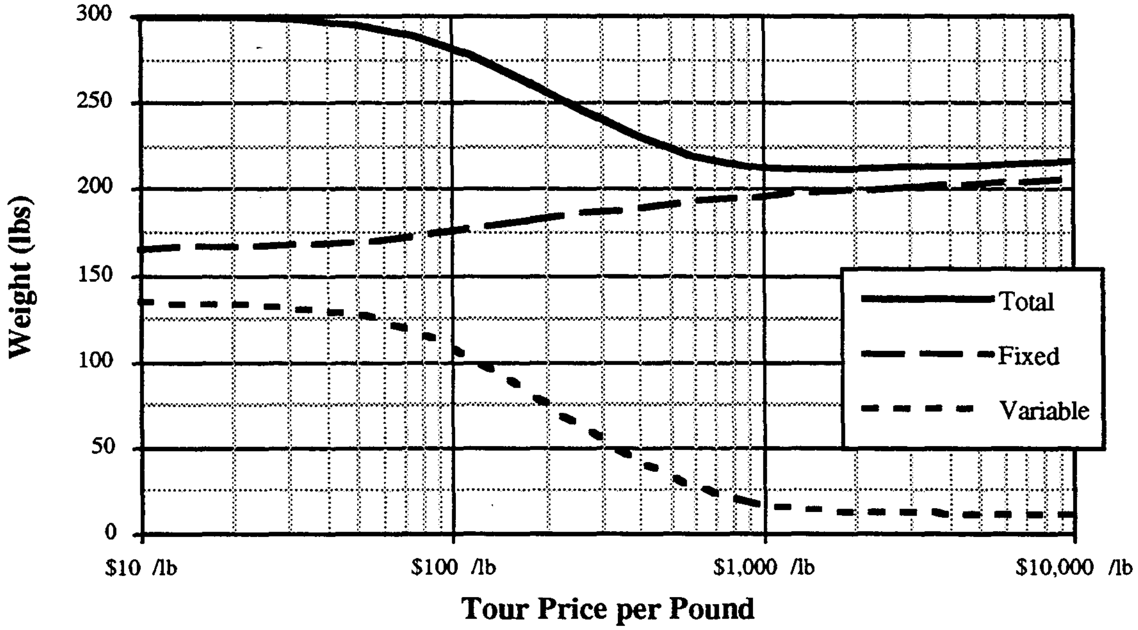

Figure 3.5.6.6-5. Expected Composition of Passenger Weight Versus Tour Price per Pound

Revenue as a Function of the Tour Price per Pound. Figure 3.5.6.6-6 shows the relationship between the average weight per ticketed passenger (from fig. 3.5.6.6-5) and tourism revenue (from fig. 3.5.6.6-1). As this figure indicates, for a nominal case (medium probability), annual tourism revenues above $100 million can only be expected when the tour price per pound gets below $400 (around $100,000 per ticket). Note that the medium and high probability curves, in the high price per pound region of the graph, show a dip in revenue as the price decreases. This reflects the situation as shown in figure 3.5.6.6-1 that, for the high-end tour prices, the number of passengers does not significantly increase as the price drops, and thus the revenue also goes down as price goes down.

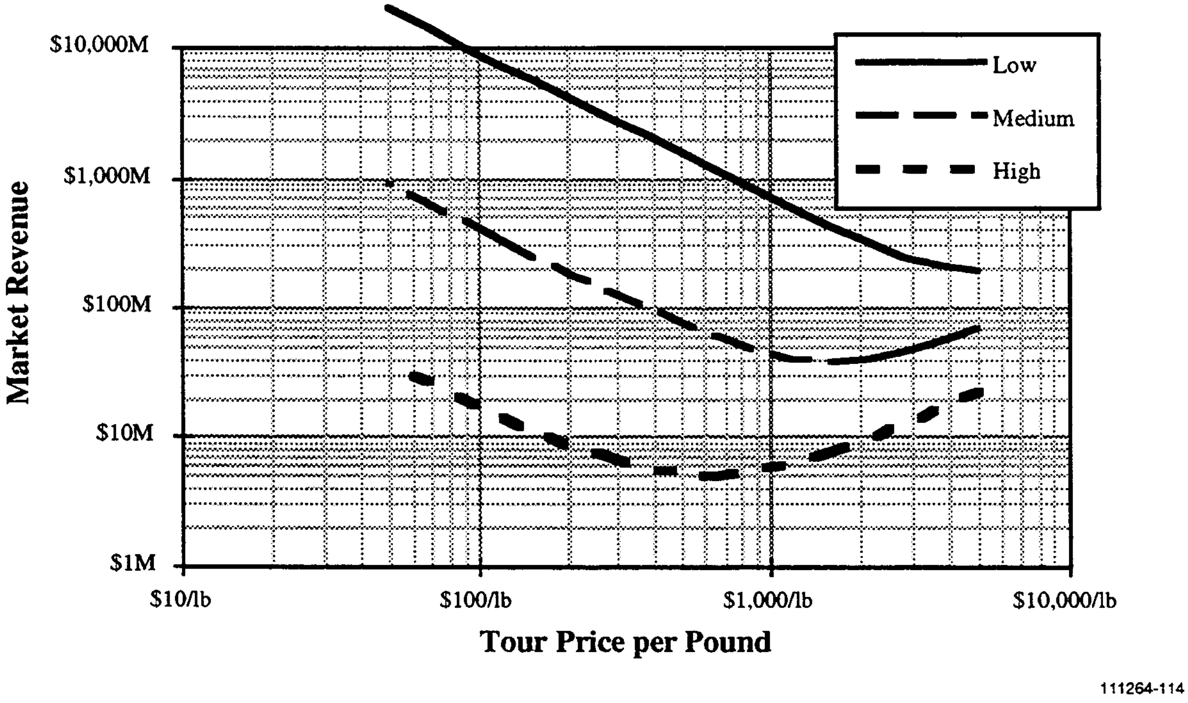

Figure 3.5.6.6-6. Tourism Revenue Versus Tour Price per Pound

Revenue Split Between Profit Centers. To determine how much revenue would be made available for the transportation system from the overall tour price, a revenue-sharing factor (fig. 3.5.6.6-7) was established. It was assumed that for short trips the entire revenue would go to the transport segment, but as the trip duration increased, revenue would become available for the other profit centers (e.g., space theme park, hotel). The curve was constructed to give a 50-50 split in revenue at the 14-day point, and it asymptotically approaches 0% for much longer trips.

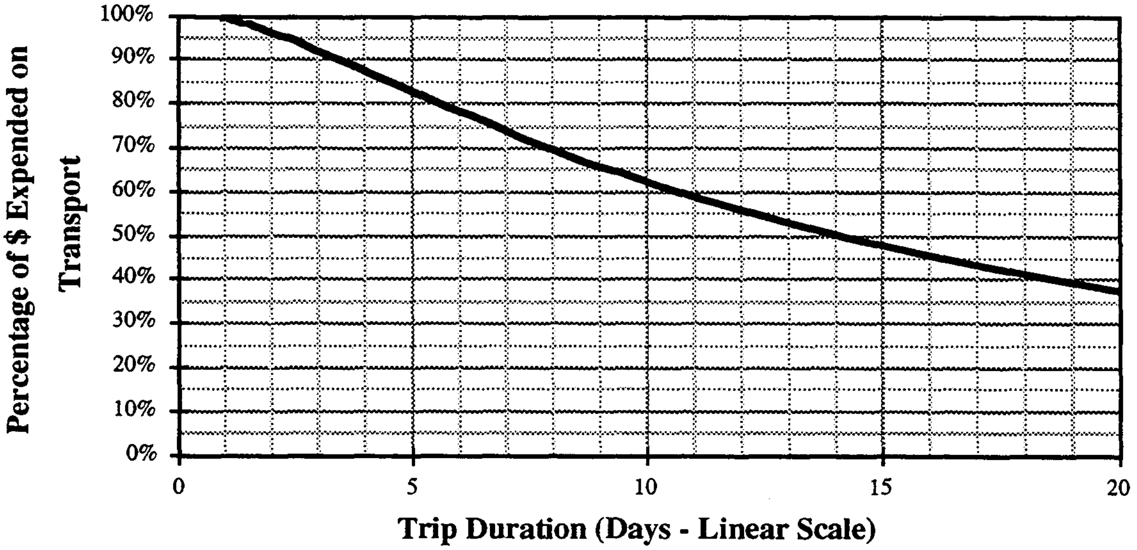

Figure 3.5.6.6-7. Tourism Revenue Sharing Versus Trip Duration

Passengers as a Function of Transport Price per Pound. Using the revenue-sharing factor just as described, the number of annual passengers as a function of transport price per pound can be calculated as shown in figure 3.5.6.6-8. This curve reflects the relationships established in figures 3.5.6.6-1, -4, -5, and -8. This curve establishes the market as a function of the price charged per pound for transportation.

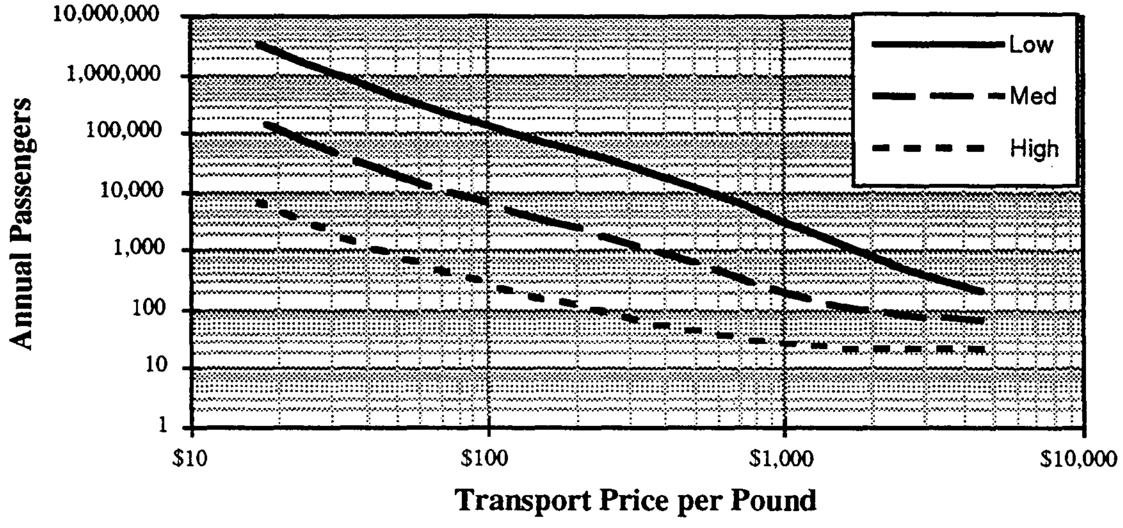

Figure 3.5.6.6-8. Space Tourists as a Function of Transport Price

Support System Weight as a Function of Number of Passengers. To establish a price-to-cost relationship for the transport segment, it is necessary to account for the weight penalty associated with the habitable module in which the passengers ride. For purposes of accountability, the weight associated with a self-contained cabin (which includes the module's structure, seats, thermal control, air supply, waste management, food center, lighting system, and other required support items) is shown in figure 3.5.6.6-9. This curve basically changes as a function of the square root of the number of passengers. There is a heavier penalty assessed when the number of passengers is small, because the economies of scale cannot be achieved.

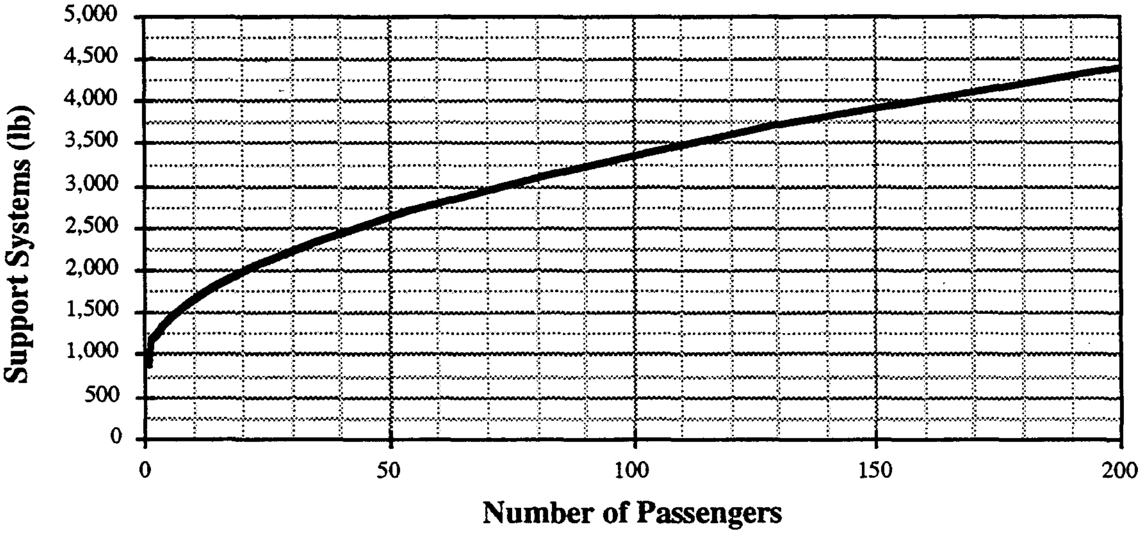

Figure 3.5.6.6-9. Habitable Module Weight as a Function of Passengers

Passengers as a Function of Transport Cost. Here we change from a "price" based model to a "cost" based model. In making this change, we have made two assumptions: (1) we assumed an annualized profit factor of 15% for the transportation segment (i.e., PRICE = COST + 15%) and (2) we assumed that each habitable module would be only 85% occupied, similar to an airline. Based on these assumptions, in conjunction with the data from figures 3.5.6.6-8 and -9, the number of annual passengers as a function of transportation cost per pound is shown in figure 3.5.6.6-10. All of the subsequent charts generated by the tourism model from this point on are in terms of transportation cost per pound.

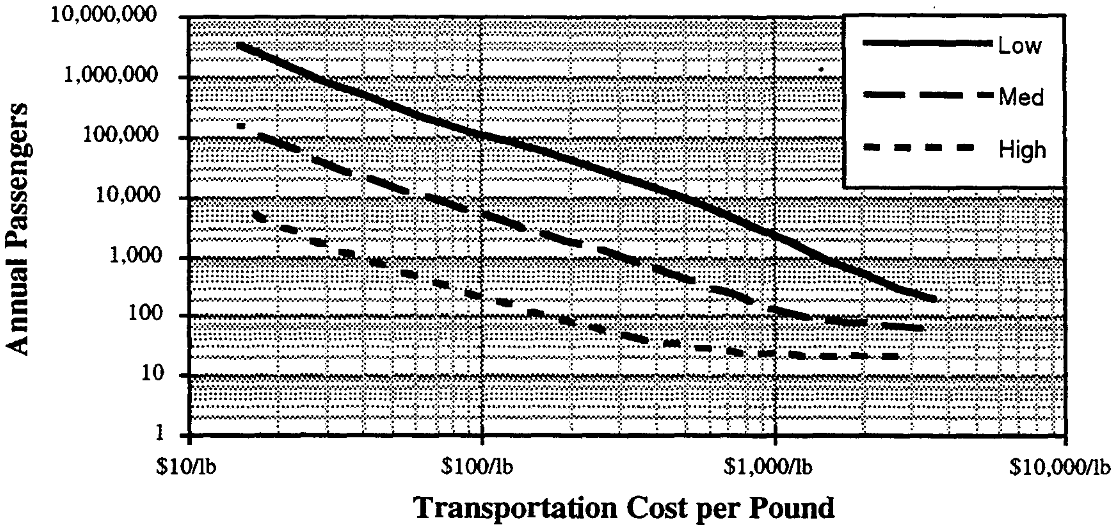

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Figure 3.5.6.6-10. Space Tourists as a Function of Transport Cost

Weight to LEO as a Function of Transport Cost. With the use of the average weight per ticket of figure 3.5.6.6-5, converted to transportation cost per pound, in conjunction with the habitable module weight of figure 3.5.6.6-9 and the number of passengers of figure 3.5.6.6-10, the overall tourism weight to LEO can be calculated as shown in figure 3.5.6.6-11. This information is useful in performing vehicle/fleet sizing analyses as well as looking at comanifesting opportunities with other LEO payloads.

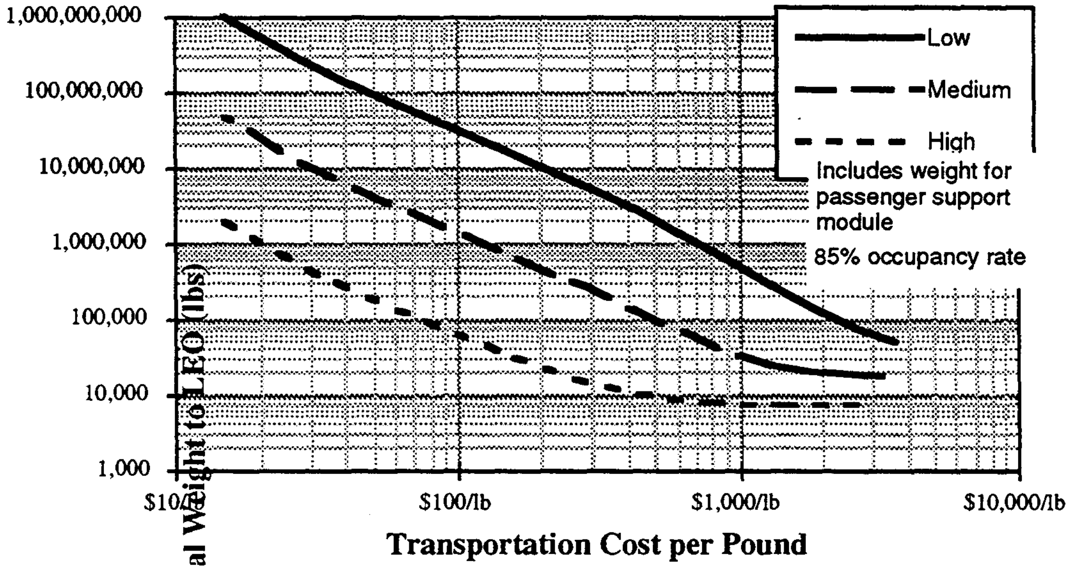

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Figure 3.5.6.6-11. Space Tourism Launch Weight to LEO

Revenue as a Function of Transport Cost. With the use of the information from figures 3.5.6.6-1 and -10, the total tourism market revenue as a function of transport cost per pound is calculated (fig. 3.5.6.6-12). The market revenue shown is for transportation as well as any on-orbit facilities. The next three charts break out the transportation-related portion of this revenue, the associated transportation costs, and the resultant profits.

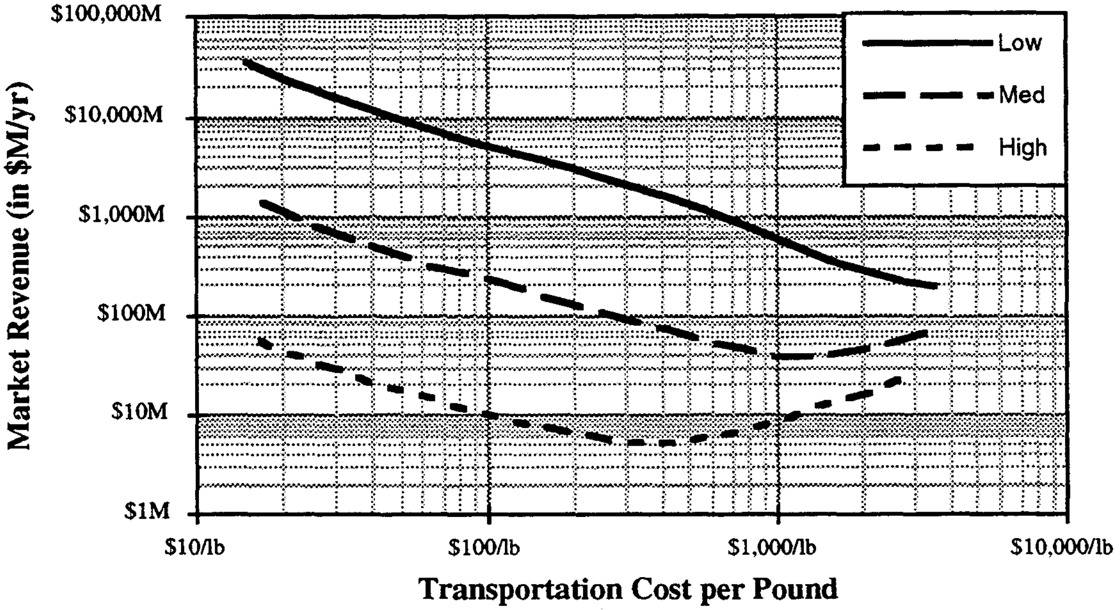

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Figure 3.5.6.6-12. Tourism Revenue as a Function of Transport Cost

Transport Revenue, Costs, and Profits. With the relationships established between price and cost (Passengers as a Function of Transport Cost, above) and also revenue sharing (Revenue Split Between Profit Centers, above), the portion of the total tourism revenue applicable to the transportation segment as well as the corresponding costs and resulting profits can be calculated as shown in figures 3.5.6.6-13, -14, and -15. In looking at the curves for transportation profits, especially in the region of low cost per pound, there is an extremely wide range of answers between the low and high probability cases (e.g., at $100/lb, the profit ranges from $450 million down to $1.5 million). This is reflective of the projected annual passengers which, as shown in figure 3.5.6.6-9 for $100/lb, varies from 100,000 down to 200.

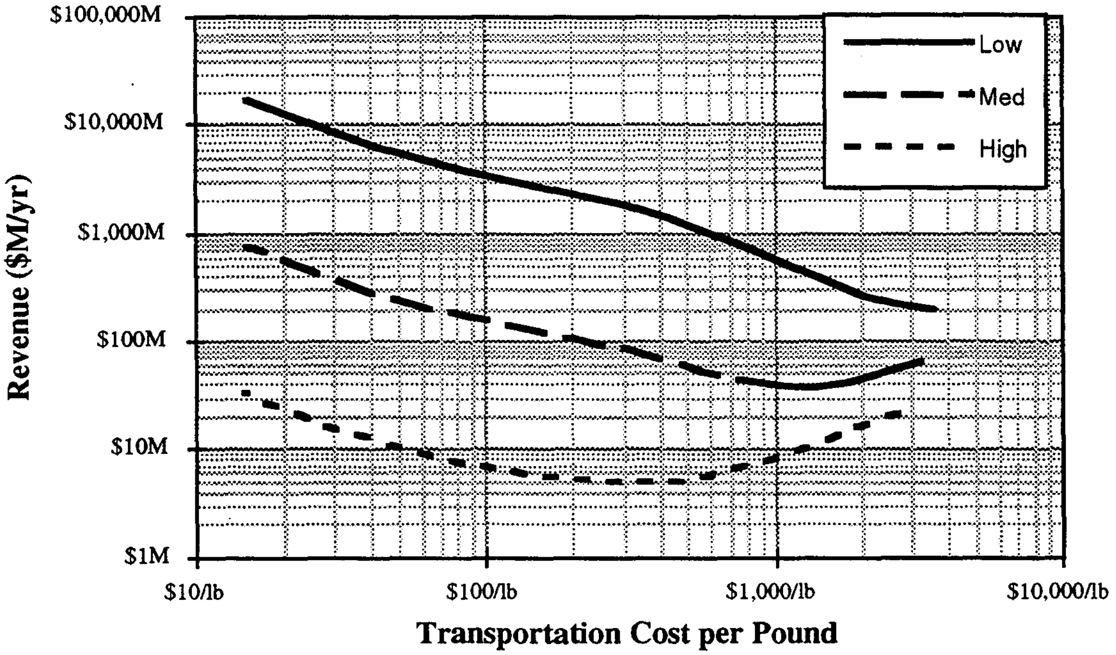

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Figure 3.5.6.6-13. Transport Revenue as a Function of Transport Cost

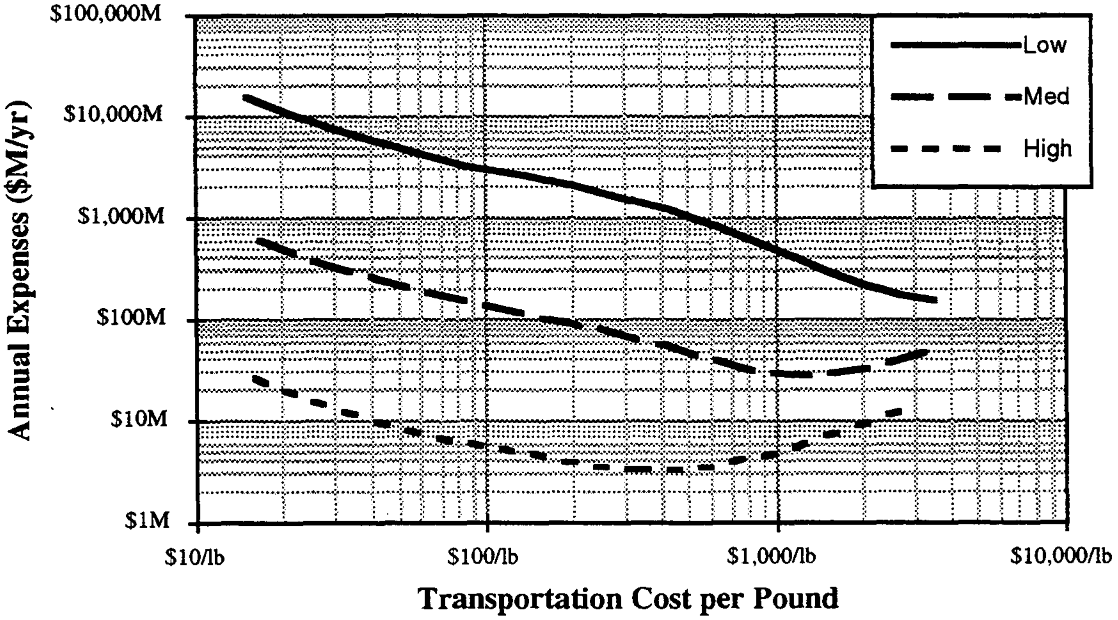

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Figure 3.5.6.6-14. Transport Cost as a Function of Cost per Pound

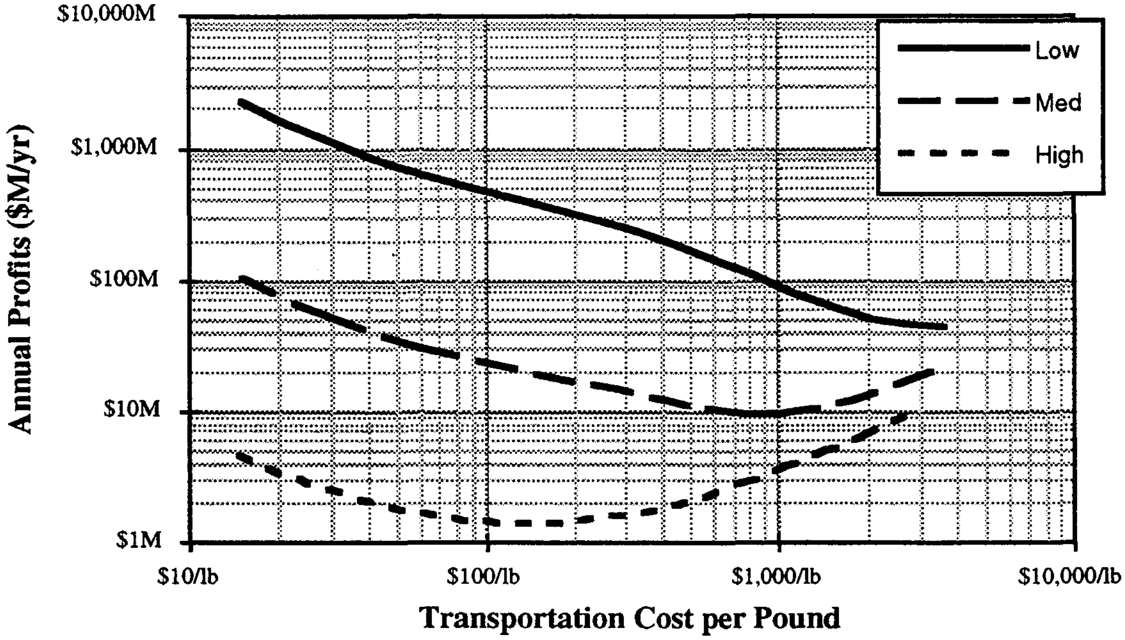

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Figure 3.5.6.6-15. Transport Profits as a Function of Transport Cost

Other Available Revenues. With the use of the revenue sharing of figure 3.5.6.6-7 in conjunction with the total tourism revenue of figure 3.5.6.6-12, the revenue available to other on-orbit profit centers (e.g., hotel, theme park) can be calculated as shown in figures 3.5.6.6-16 and -17. This information is provided as an aggregate annual revenue as well as by dollars per individual tourist per day.

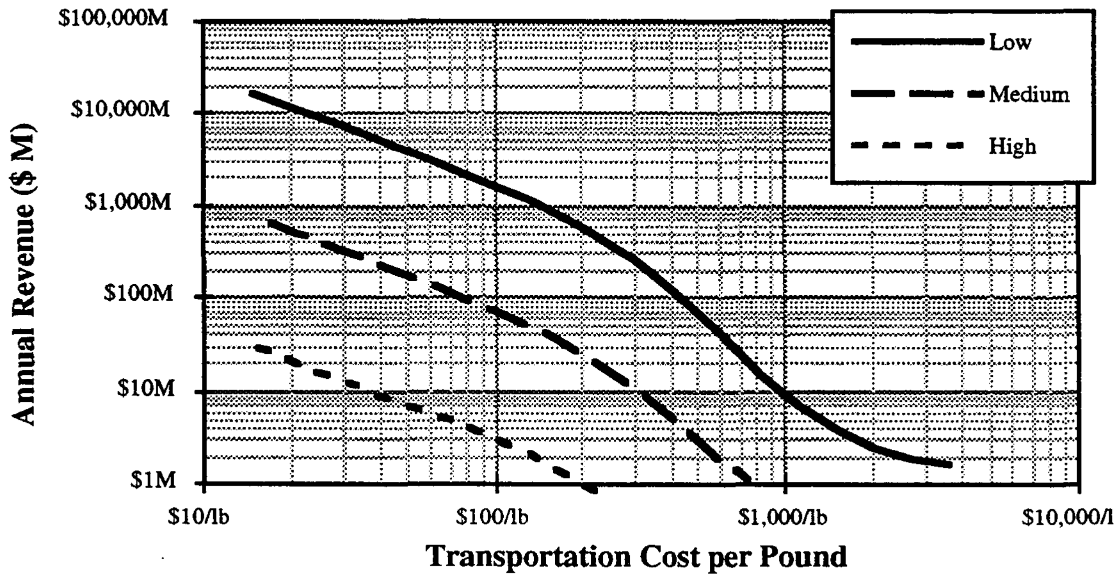

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Figure 3.5.6.6-16. Other Profit Center Revenue as a Function of Transport Cost

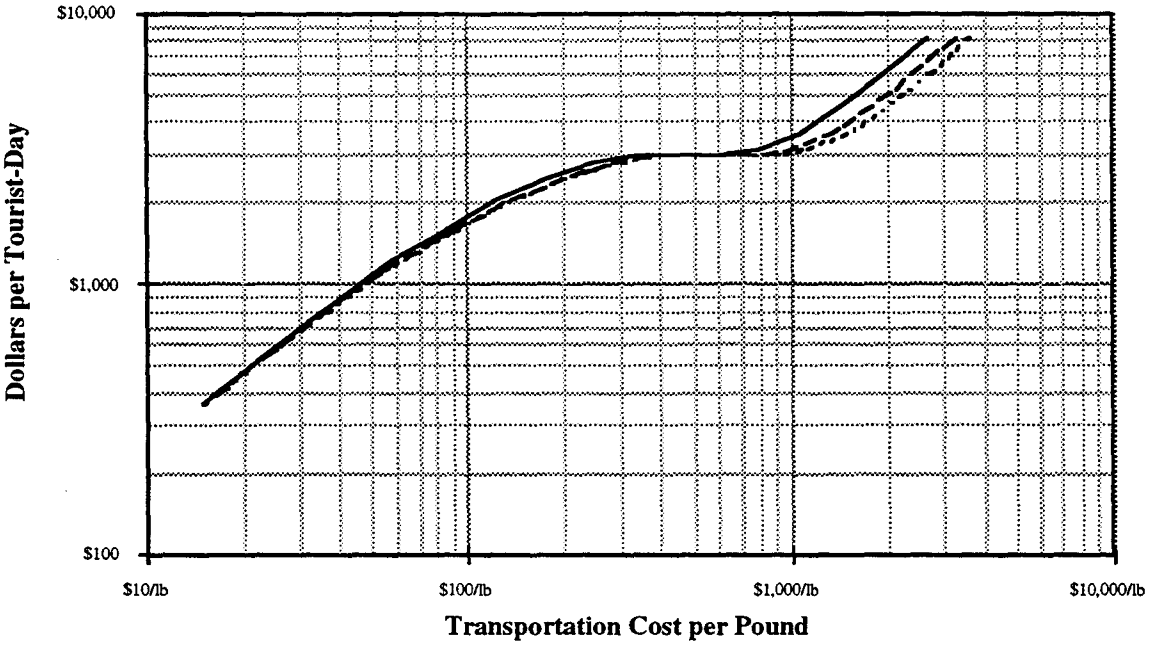

Figure 3.5.6.6-17. Per Diem Available for Other Than Transportation

Launch Rate. With the use of the tourism weight to LEO (fig. 3.5.6.6-11) and four launch vehicle capacities (10-, 30-, 55-, and 100-thousand lb), the number of launches per year can be calculated as shown in figures 3.5.6.6-18 and -19. Figure -18 assumes that 50% of vehicle capacity is dedicated to cargo and the remainder is used for passengers and their support module, whereas figure -19 dedicates the entire capacity to the tourists. These curves reflect an 85% seat occupancy.

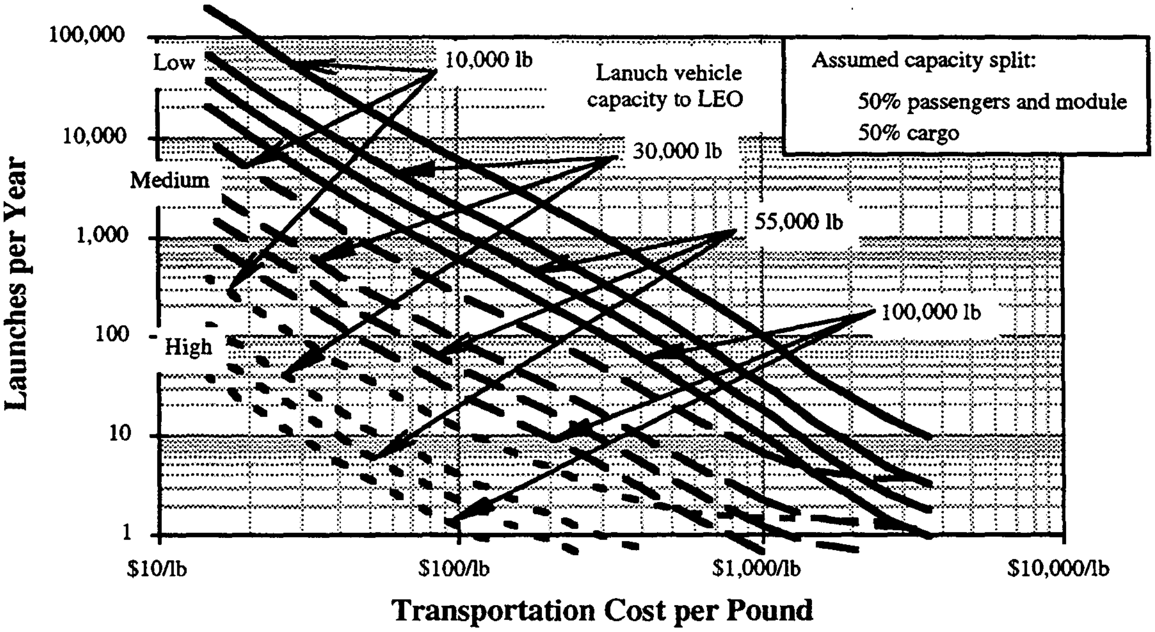

Figure 3.5.6.6-18. Annual Launch Rate for a 50% Comanifested Cargo

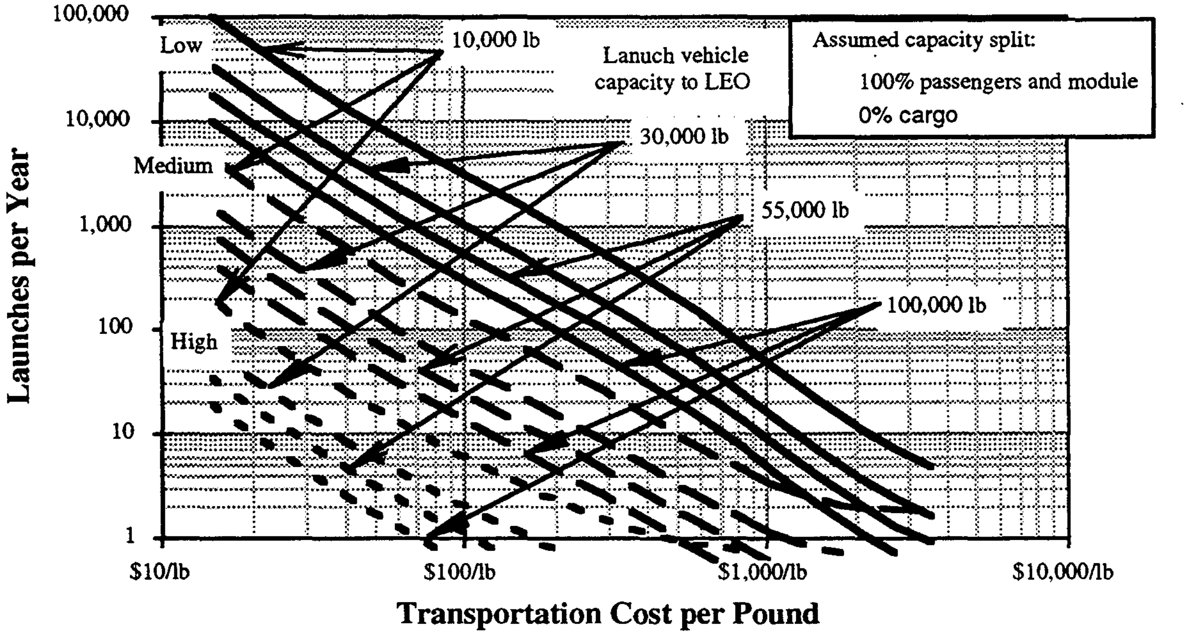

Figure 3.5.6.6-19. Annual Launch Rate for 100% Passengers

3.5.6.6.2 Programmatics

Now that the space tourism market has been analyzed from the demand side, and resulting projections made as to launch rates for several vehicle sizes that would be required to meet the demand, what remains to be done is to assess whether or not it would make sense from a business viewpoint to invest money in the development of a new launch system to capture this market. To assist in making this determination, a business model, using a "top down" approach, was constructed, based on the assumptions discussed below.

R&D Costs. The engineering design and development costs for a new launch vehicle are included. This cost is amoritized over the initial 13 vehicles.

R&D Period. It is assumed that there is a 5-year development period. The expenditures per year are 10%, 20%, 30%, 30%, and 10%.

Vehicle Fabrication. The manufacturing operations commence during the last year of the R&D activities (allowing for procurement of long-lead materials) and continue for 4 years. Over this 4-year period, it is assumed that 25% of the vehicles are built and delivered by the end of the second year, an additional 25% by the end of the third year, and the remaining 50% by the end of the fourth year. It is also assumed that vehicle fabrication continues after these 4 years to expand the fleet. In addition, a 95% learning curve was employed.

Vehicle Useful Life. Vehicles will operate reliably for 400 flights (approximately 15 years), at which time they are considered excess and retired from the fleet.

Operating and Maintenance Costs. The O&M costs include not only the operating and maintenance costs, but the ancillary costs (ticketing, advertising, etc.), as well. O&M costs will start accruing as the vehicles enter service. It is further assumed that O&M costs remain flat over the entire fleet operating period.

Effects of Inflation. All calculations are done in base year dollars.

Profits. A 15% profit margin is used.

With the use of these assumptions, a business model as shown in figure 3.5.6.6-20 was constructed to interrelate all of the financial aspects. For this analysis, the input variables were set as follows: (1) the R&D costs were set at $5 billion, (2) the cost of building the initial vehicle was set at $500 million and a 95% learning curve was employed, (3) the O&M costs were set at $10 million per flight, (4) the vehicle was sized at 30,000 lb of payload, which was set to equal 100 passengers, (5) the number of flights per vehicle per year was set at 26, (6) the initial fleet size was set at 13 vehicles, with additional vehicles continuing to be built at a rate of 5 per year, giving a fleet size of around 88 vehicles after 25 years, and (7) the amount of revenue allocated to nontransportation items was set at $0.01 million. As shown in figure 3.5.6.6.-21, which depicts the dollar value relationships after 25 years, the real driver turns out to be the O&M costs. Factors such as the $5 billion upfront R&D costs could be off by almost an order of magnitude and still not appreciably affect the results obtained from the model.

Value	Parameter	Value	Parameter
5,000	R&D cost ($M)	**26**	Vehicle flights per year per vehicle
500	Production cost ($M)	**100**	Passengers/vehicle
10	O&M cost/flight ($M)	2,155,400	Total required passengers (business)
15%	Fee	124,211	Total predicted passengers (low)
400	Vehicle life (flights)	5	Sustaining production
13	Vehicles to amortize R&D	30,000	Payload (lbs)
0.01	Other tour stuff/passenger ($M)	300	Average passenger weight
15	Vehicle life	444	Steady-state $/lb
0.95	Learning curve (production)		

Figure 3.5.6.6-20. Business Model Parameters

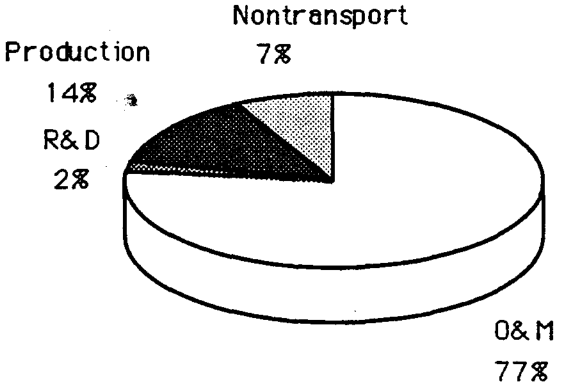

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Figure 3.5.6.6-21. Life Cycle Cost Over 25 Years

As shown in figure 3.5.6.6-22 it would require, as an example, around 40,000 passengers paying $200,000 per ticket to make this a viable business. However, this demand *is far greater* than the most optimistic (i.e., low probability) market that could be captured at that ticket price. Similar runs were conducted while incrementally varying the input values to assess their overall influence on the model and to see if there was an optimum point at which a viable business venture could be postulated.

As shown in figure 3.5.6.6-23, if we eliminate all R&D costs, decrease first unit production cost to $200 million, reduce the O&M costs per flight down to $1 million, and increase the sustaining production to nine vehicles per year we end up below the low probability market demand curve. The switch back in the business demand curve is caused by incurring vehicle production costs before the vehicle is online and generating revenue.

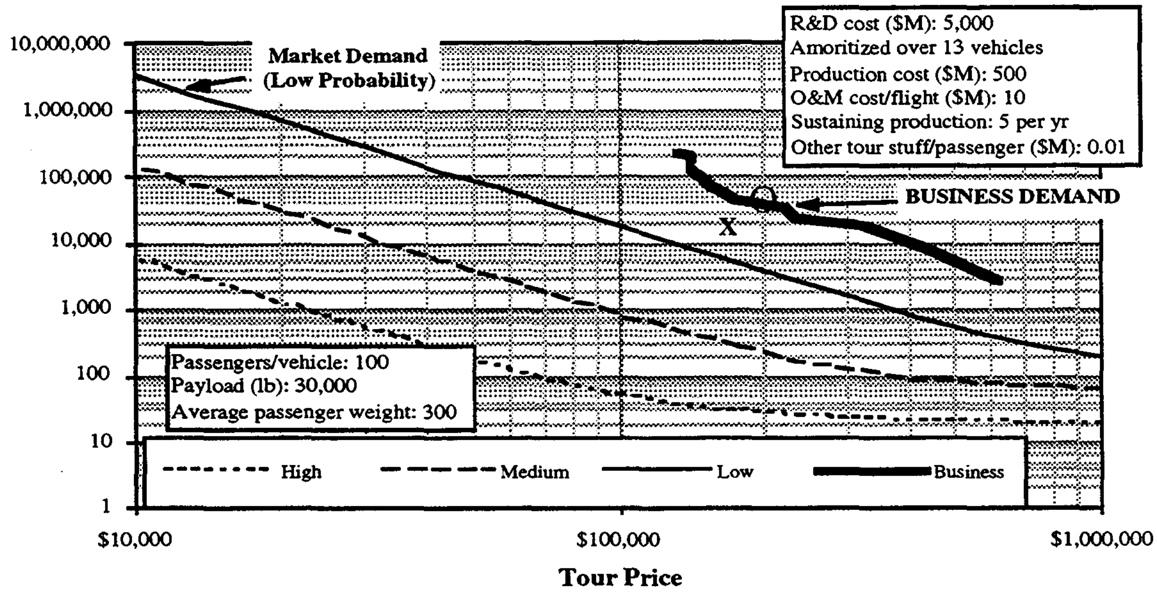

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Figure 3.5.6.-22. Annual Passengers Versus Tour Price

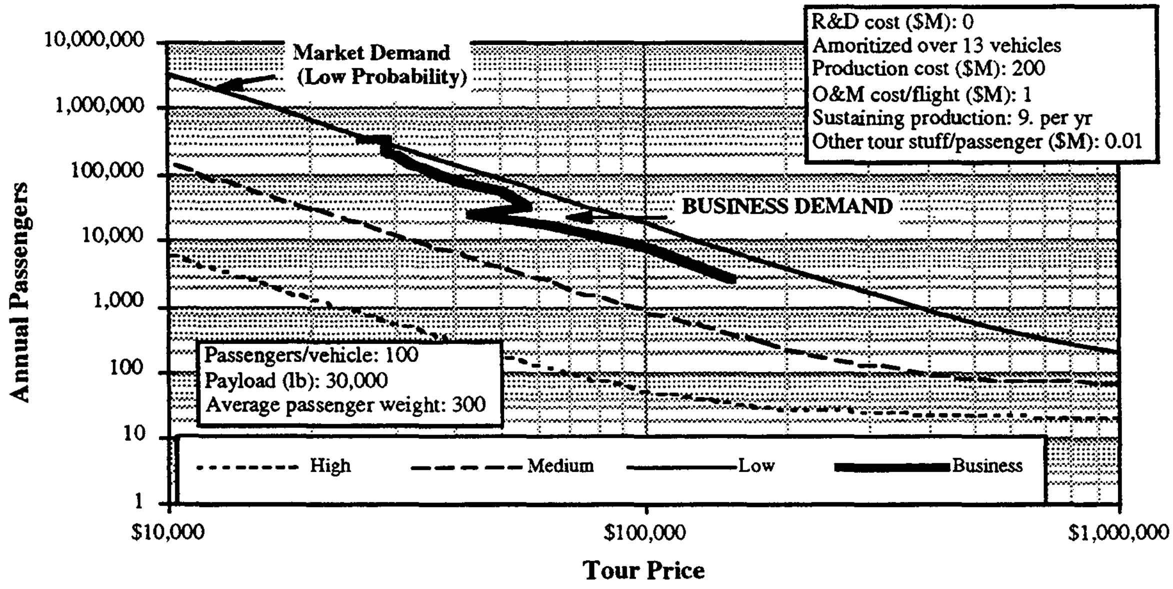

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Figure 3.5.6.6-23. Annual Passengers Versus Tour Price —Reduced Costs

3.5.6.7 Conclusions and Recommendations

An approach to defining the market for space tourism was developed based on the assumption that some percentage of personal income would form the basis for revenue.

New technologies and design philosophies can be judiciously applied to a vehicle specifically intended for routine, safe, manned transportation that will result in low operations costs. It appears plausible that appropriately sized vehicle designs can be operated profitably for the revenue available. Regulations that develop in the future could have a significant impact on the system's profitability and need to be addressed from the outset.

However, it would also appear that there is insufficient revenue in all cases to amortize the full cost of developing and building a space transportation fleet as a capitalistic venture. This impasse leads to several alternative solutions, assuming someone would still wish to develop the space tourism industry.

One could envision buying an existing launch vehicle (with the idea that the development costs are already sunk) and modifying it as required. The difficulty of rationalizing this approach is depicted in figure 3.5.6.7-1. The "cost" per flight comes from a variety of public sources (realizing also that different vehicles account fixed infrastructure costs differently against a quoted cost/flight); the exact number is not important. Most of these vehicles were not meant to fly passengers, and the range in number of passengers (called pax) is purely based on engineering judgment, not specific designs. While this quick comparison is not quite accurate, it does point out the magnitude of the problem. Even if tourism used the Energia, (with a price likely to change significantly as companies such as NPO Energiamash adjust to a market economy), the best one could hope for was a vehicle cost of about $1 million per passenger.

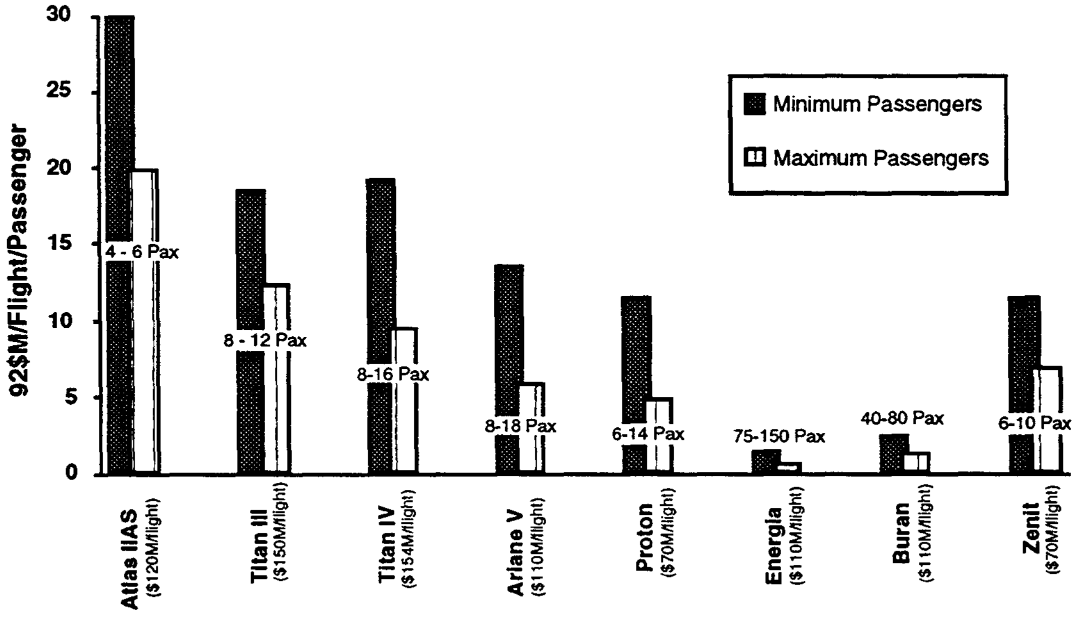

Figure 3.5.6.7-1. Comparison of Existing Launch Vehicle Flight Costs for Space Tourism Applications

Another possible solution involves the role of government, which could choose to develop and build the system at a "loss." History is rife with examples of this approach (the building of the U.S. Interstate Highway

System, Airbus, commercial nuclear power plants, etc.). Governments often have military requirements that can be satisfied by vehicles of similar capability; part of the government's rationalization for developing a new system could be related to these military needs. If the case can be made that a larger societal goal is achieved by this investment of tax revenue, such as jobs, prestige, technological superiority, "spinoffs," altruistic science, then the tourism industry could be a reality.

The word "subsidy" is often held in contempt by those promoting capitalistic economics. New, large ventures with enormous potential for payoff (such as space tourism) can be started only with the financial and legal assistance of government. By thoughtfully developing systems that provide short-term societal benefits, such as scientific or military transportation, such a concept should be easily justifiable.

Finally, it is apparent that there remains much work to be done in the area of market research. Defining the requirements of the paying public cannot be accomplished by systems engineering analysis alone. Experienced market research organizations should become involved to pulse the customers, financiers, and potential operators. Specifically, such surveys should establish—

a. Ticket price/number of interested travelers.
b. Optimum locale for spaceport operations.
c. Type of tourism flight/destination of most interest.
d. Tolerable acceleration/vibration environment.
e. Level of acceptable risk to personal safety.
f. Level of cost/schedule risk acceptable to financiers.
g. Profitability/ROI requirements of operators.

3.5.7 Ultra High Speed Civil Transport

3.5.7.1 Introduction/Statement of Problem

Vision statement: *Ms. Jones has a problem: her job as marketing executive vice president of TransWorldCo requires her to be in the New York office Monday afternoon, Bangkok Tuesday, and Buenos Aires Wednesday morning, and she's holding tickets for that premier back in New York Wednesday night. Twenty years ago, she couldn't have pulled it off with those day-long, grueling 747 flights. Today, traveling many times the speed of sound, the trip is possible . . .*

Commercial air travel for the business person and the tourist has had a profound impact on our world. As the speed of the aircraft has increased from the DC-3 era to the jet age to the advent of the Concorde Supersonic Transport (SST), the convenience of traveling has improved remarkably. Currently, the U.S. government and major commercial airframe and propulsion companies are investigating a high-speed civil transport (HSCT). Operating at two or three times the speed of sound, the HSCT is the next logical step in terrestrial transport.

It is proposed here that perhaps a derivative or element of a commercial space transportation system could be used to codevelop an ultrahigh-speed civil transport (UHSCT). The system would operate at some to-be-determined very high mach number and provide the time-constrained traveler with an even shorter method of travel.

3.5.7.2 Study Approach

It was decided that the UHSCT concept should be viewed as an evolutionary step in conventional transportation. This means that diverse passengers would approach the system and physically ride it as one of several choices to reach a destination. Therefore, special training, physical aptitude, or protective clothing is deemed inconsistent with the UHSCT concept. Those select persons for whom these are not factors, could be considered part of the fast package delivery market segment.

In the initial HSCT contracts in the mid 1980s, Boeing and McDonnell Douglas were asked to explore concepts covering the speed range from mach 2 to 25. As this spectrum covers a UHSCT, these early studies were reexamined to see if anything has changed in the last ~7 years.

3.5.7.3 Market Description

3.5.7.3.1 Description Market Evaluation

Air travel has become an indispensable part of world commerce and tourism. There are some markets for which the limiting factor to growth is the long transit time for people. For example, for North Americans or Europeans to vacation in Australia, individuals must be prepared to spend upwards of a day in the confines of a subsonic airliner. If the trip time was markedly less, more tourists would go to Australia.

The limited duration and resources of the CSTS could not hope to perform a fraction of the analysis performed by the HSCT program. It is encouraging to note that effort continues to grow for suggesting that the developers and operators of such a system see a path to commercial success for supersonic transport.

3.5.7.3.2 Market Evaluation

The concept of a UHSCT hinges on the premise that there are many individuals willing to place a premium on speed and that a UHSCT could appreciably reduce the trip time between desirable transit locales. Other considerations, such as noise, and environmental impact are secondary.

The time value of human transit is continually being evaluated by many transportation specialists. In general, history tells us that ever greater transportation speed has a tangible benefit at an acceptable cost. Witness the success of the superhighway, Bullet trains, and commercial jet transport. Yet there are limits to what the masses will pay for: the Concorde supersonic transport is an example of a marginal product. The HSCT program is proceeding cautiously in developing a system to operate at mach 2.3 to 2.7.

It turns out that the physics of a UHSCT may kill the concept before one has to answer the question of time value for human travel. Fundamentally, the planet Earth is not large enough to exploit the advantages of an UHSCT.

The maximum range for a UHSCT would be an antipodal flight of around 12,000 nmi. In reality, since the majority of the world's population lives in the Northern Hemisphere, the typical long-range city pair routes are in the 3,000 to 7,000-nmi spectrum. Figure 3.5.7.3-1 illustrates, for a 5,000-nmi route the effect that increasing the vehicle's maximum speed (cruise mach number) has on the time of flight. Several interesting features are immediately apparent. First, it is obvious that an SST or HSCT operating in the mach 2 to 3 range significantly reduces the trip time when compared to a conventional mach 0.8 transport. Second, the time advantage of going faster is much less: to save a hour of trip time off that offered by an HSCT, the cruise mach would need to increase several times. The carefully considered design points for HSCTs reflect the increased technology (read: cost and risk) required to increase this maximum cruise capability.

Next, note the effect associated with varying the maximum acceleration/deceleration rate. These numbers may seem small compared to rocket flight, but remember we are dealing with untrained, unconditioned, relatively unrestrained passengers. An acceleration rate of about 0.25g is about what one experiences during moderate to hard braking on a commercial airplane. Imagine the discomfort in sustaining that g level for *minutes* during takeoff and climb, followed by a brief cruise, and then an equally long period of deceleration during descent. Finally, note that by limiting this acceleration, the vehicle never comes close to reaching orbital-like (~mach 25) velocities. For example, a 0.1g-limited trajectory gets to about mach 9.5 before the deceleration and descent phase begins.

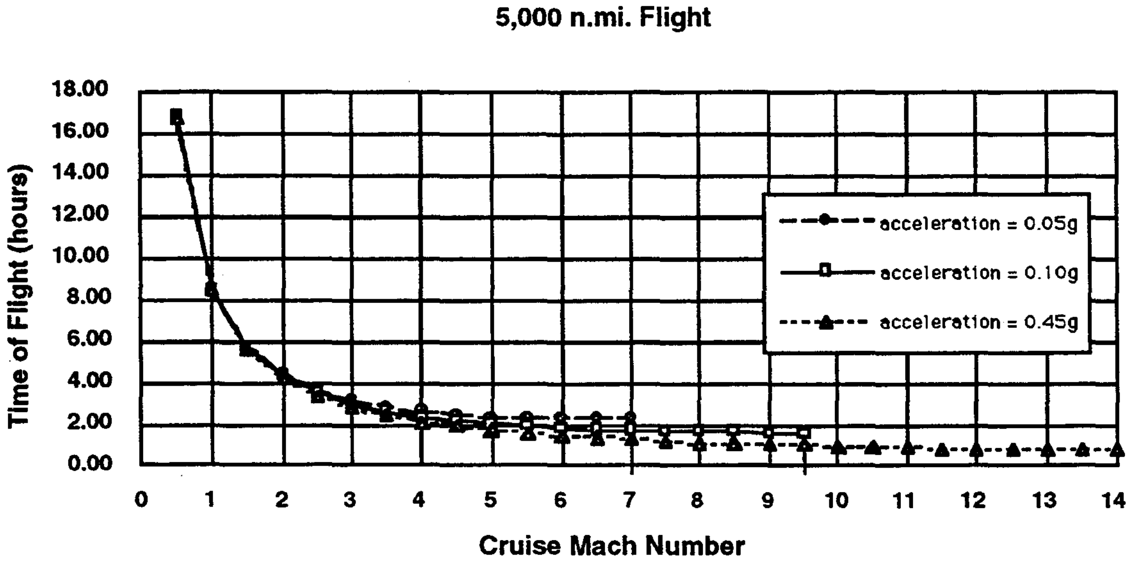

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Figure 3.5.7.3-1. UHSCT Flight Time (5,000-nmi route) Versus Cruise Mach Number for Acceleration-Constrained Flights

In the next figure, 3.5.7.3-2, one can see the same trending for several route ranges. Again the time value of increasing cruise speed beyond a certain point is probably insignificant compared to the technology and complexity issues associated with a higher cruise mach number.

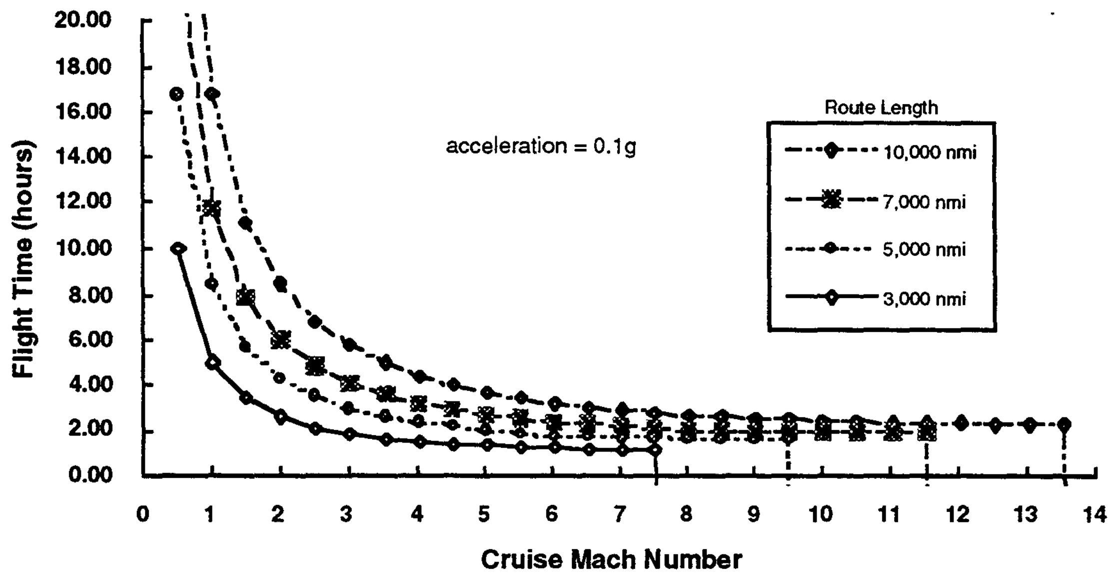

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Figure 3.5.7.3-2. Effect of Route Length on Flight Time Versus Cruise Mach Number for Acceleration-Constrained Flights

In figure 3.5.7.3-3, the data are plotted another way. The implication of these data is single-stage concepts claiming commonality between the UHSCT and other orbital missions are unrealistic. Of course, two stage-to-orbit concepts can claim commonality between the first, booster stage, and an HSCT. There is a trap here too, however. A commercially successful personnel transport is a highly cost-optimized vehicle. Scarring the vehicle to carry extra structure, landing gear, control surfaces, propulsion, and soon, makes it unlikely the economics of the transport will be favorable.

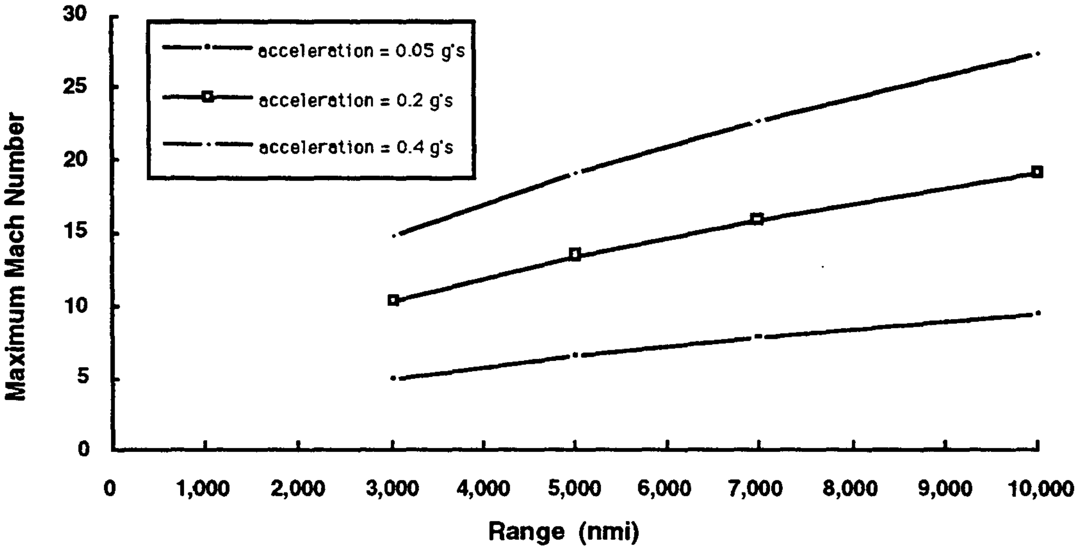

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Figure 3.5.7.3-3. Maximum Mach Number Versus Range for Acceleration-Constrained Flights

3.5.7.3.3 Market Assessment

No further market assessment was performed based on the conclusions of the previous section.

3.5.7.3.4 Market Infrastructure

It is expected that an UHSCT would operate within the general infrastructure of the world commercial airline system. No attempt was made within the CST study to refine this definition as regards an UHSCT.

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3.6 ENTERTAINMENT

Entertainment is an exciting and continually evolving industry. Film, theater, broadcasting, and theme parks represent a triumph of U.S. creativity and innovation recognized throughout the world. Technology and techniques used in the U.S. entertainment industry are recognized as the state of the art. The importance of the entertainment industry to the U.S. economy and its importance in international trade were recognized in the 1993 GATT talks. Commercial access to space for entertainment has been discussed as part of the generation of entertainment industries, and it can create new opportunities for industry pioneers. The current entertainment industry infrastructure is ready for a mechanism (transportation system) to move aggressively toward exploiting this new market area for viable economic return.

The U.S. entertainment industry represents a multibillion dollar market. U.S. movie box office receipts for 1993 are estimated to be $4.7 billion, with another $12.8 billion in home video sales, and $13.9 billion in cable services. Worldwide theme park revenues are greater than $4 billion annually. Over 150,000 persons are directly employed in film production, with hundreds of thousands of others involved in the retailing, servicing, and delivery infrastructure of this market. While the current economic climate has slowed the U.S. growth rate of these markets, they have grown from an aggregate of $21.7 billion in 1988 to an estimated sum of over $31.4 billion in 1993, for an average annual growth rate of about 7.5%. If this rate continues, these industries could comprise a U.S. industry of over $70 billion per year by 2005.

Furthermore, this is an industry that has been at the cutting edge of applying emerging technologies to consumer use. The new technologies of direct broadcast-to-home television, interactive cable, new electronic entertainment systems, increased infrastructure for entertainment distribution, and new methods for personal entertainment are opening up substantial new markets. Emerging technologies and worldwide expansion are expected to stimulate the industry.

These industries represent a major source of international trade, and the U.S. entertainment industry has been very successful abroad. The Motion Picture Association of America (MPAA) estimates foreign revenues from the U.S. motion picture industry at over $6.5 billion in 1990, with another $2.8 billion in revenues from video distribution. These markets are also growing rapidly, as worldwide consumers increase the purchases of home VCRs and other avenues for these entertainment products. For example, about 63% of U.S. households have access to cable TV, and about 77% own at least 1 VCR. In France, for example, only 40% own VCRs, and 5% have access to cable TV.

Technology improvement is a mechanism that supports continuing evolution of the entertainment industry. This industry often pushes the state-of-the-art capability in such areas as computer-generated special effects, animation, and interactive media (e.g., virtual reality). The addition of a space component will invigorate already-expanding markets and accelerate technology development/transfer. The benefit of this new form of entertainment will cascade to existing market segments such as feature productions and stimulate the growth of new entertainment forms.

3.6.1 Introduction

3.6.1.1 Results Summary

Using initial brainstorming, five entertainment market areas were identified for candidate development and feasibility assessment: digital movie satellites, orbiting movie studio, artificial space phenomena, space athletic events, and space theme parks. Market analysis has shown the entertainment market segment is very diverse.

Investigation into current entertainment markets identified several additional potential opportunities involving space-based movie distribution and production for use on Earth. Further investigation of human interactive and participatory entertainment has invited discussions on such topics as space theme parks, both ground- and space-based.

Discussions with key members in the entertainment industry and detailed market assessments indicate none of these individual commercial ventures would be viable as a standalone venture (which would have to fund all the development and installation of a complex in-space facility). However, very promising results were found when a central entertainment location is coupled with an in-space general-purpose facility that provides additional infrastructure necessary to support several of the market areas. Status of the five market areas originally investigated is as follows. A transportation impact summary is presented in figure 3.6.1.1-1.

	Annual Klb @ $5,000/lb	Annual Klb @ $500/lb	Annual Klb @ $100/lb
Digital movie satellite	0	0	0
Orbiting movie studio	1	2	633
Space athletic event	0	20	520
Artificial space phenomena	0	0	0
Space theme park			
Earth-based	15	60	180
Space-based	0	440	3,600
Entertainment demand (lb (K) per year)	**16**	**522**	**4,933**
Entertainment revenues ($M)	**80**	**261**	**493**

Figure 3.6.1.1-1. Nominal Annual Transportation System Demand Grows With Reduced Price to LEO.

Digital Movie Satellite. This concept entails digitally downlinking movies directly from an orbital satellite to individual residences with on-demand capability. The idea was dropped from further consideration, because technical problems in delivering the potentially large number of downlinked compressed signals were assessed, and because there are ground-based fiber-optic cable solutions being demonstrated that could offer a simpler, lower cost solution.

Orbiting Movie Studio. This concept—production of scenes for movies or other media using an on-orbit facility—is continuing to be defined and analyzed in conjunction with a total entertainment venue. It requires low transportation cost, based upon current industry production costs, but generates a potential 650K lb/year transportation market at $100/lb LEO transportation price.

Artificial Space Phenomena. For this market area, the presentation of large-scale public entertainment spectacles such as "light shows" or fireworks from space-based systems, no separable, identifiable market could be determined different from that for large outdoor displays. The concept was defocused as a separate entity, with the concept to be folded into the space advertising market segment.

Space Athletic Event. This concept is for athletic events performed in an on-orbit facility, and broadcasts (beamed) to terrestrial audiences. The analysis and contacts on this market area indicated positive results, if it was included in a multiuse facility—with revenue-generating options identified for single and multiple events with launch costs reduced at least an order of magnitude from today's price.

Space Theme Parks. The concept of using the space environment as a unique platform for space theme attractions continues as an area of interest within a multiuse commercial facility associated with space tourism. Moreover, contacts within the industry have indicated there is the potential for near-term demand for high-quality real-time data for interactive "space rides" using virtual reality systems. A 15 Klb/year transportation market was identified at current launch costs, including piggyback and smallsat systems. The larger space-based theme park/resort market requires substantially lower launch costs, under $400/lb.

3.6.1.2 Associated Market Segments

A breakdown of the five areas and the initial ideas related to each are presented in figure 3.6.1.2-1. The market areas described within the entertainment segment are closely related to the communications market segment (broadcasting), space tourism (within the transportation segment), and space business park (being developed in the new missions segment).

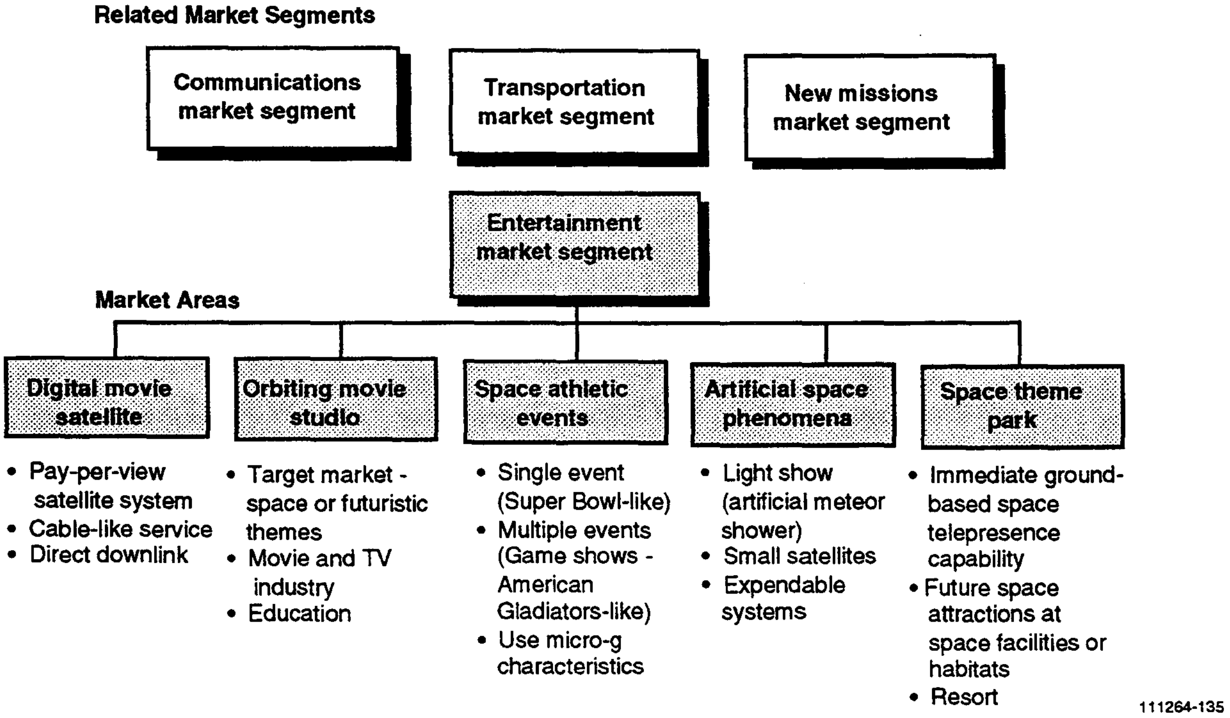

Figure 3.6.1.2-1. Entertainment Segment and Identified Market Areas

3.6.1.3 Assessment Approach

The assessment approach followed two tracks. The first track was to contact players in the pertinent sectors of the entertainment industry. Potential contacts for the CSTS market survey were identified after extensive literature search of the entertainment industry, which included newspapers, entertainment publications, corporate financial statements, and the like. The market survey approach used was to—

a. Identify industry/corporate leaders in various entertainment markets.
b. Make initial contact for introduction as well as to identify the appropriate executives within each organization.
c. Follow up through printed materials for familiarity.
d. Schedule a meeting or telephone conference, with the appropriate individuals.
    1. An attempt was made to meet with decision-makers (e.g., Vice President, Corporate Development).
    2. The meeting format included brainstorming sessions to identify a company's possible use and need for space, based on their existing business as well as new ventures.
    3. We never focused on $/lbs, but on existing infrastructure cost of doing business in this industry.

e. Generate a rough order of magnitude market assessment, based on the current cost of doing business (terrestrial equivalent).
f. Define the generic outlook and vision for the industry and the particular organization.
g. Review and compare individual interview results with information gathered from peers in the market area.
h. Followup on any referrals and recommendations.

Parallel to the direct market contacts, a business analysis effort tried to formulate a top-level ROM business model for the opportunities identified, so that the data from the market surveys could be validated, and assumptions for new markets tested. Interview findings were used to validate assumptions and market data about the general business area; identify potential commercial space transportation markets; quantify the commercial market area revenues; identify key decision factors from an "insider's" perspective; determine market capture opportunities; and identify commercial space transportation system attributes necessary to meet user needs. Products from the market survey task, identified in figure 3.6.1.3-1, augment additional CSTS tasks being performed by the alliance with discretionary resources (shaded boxes).

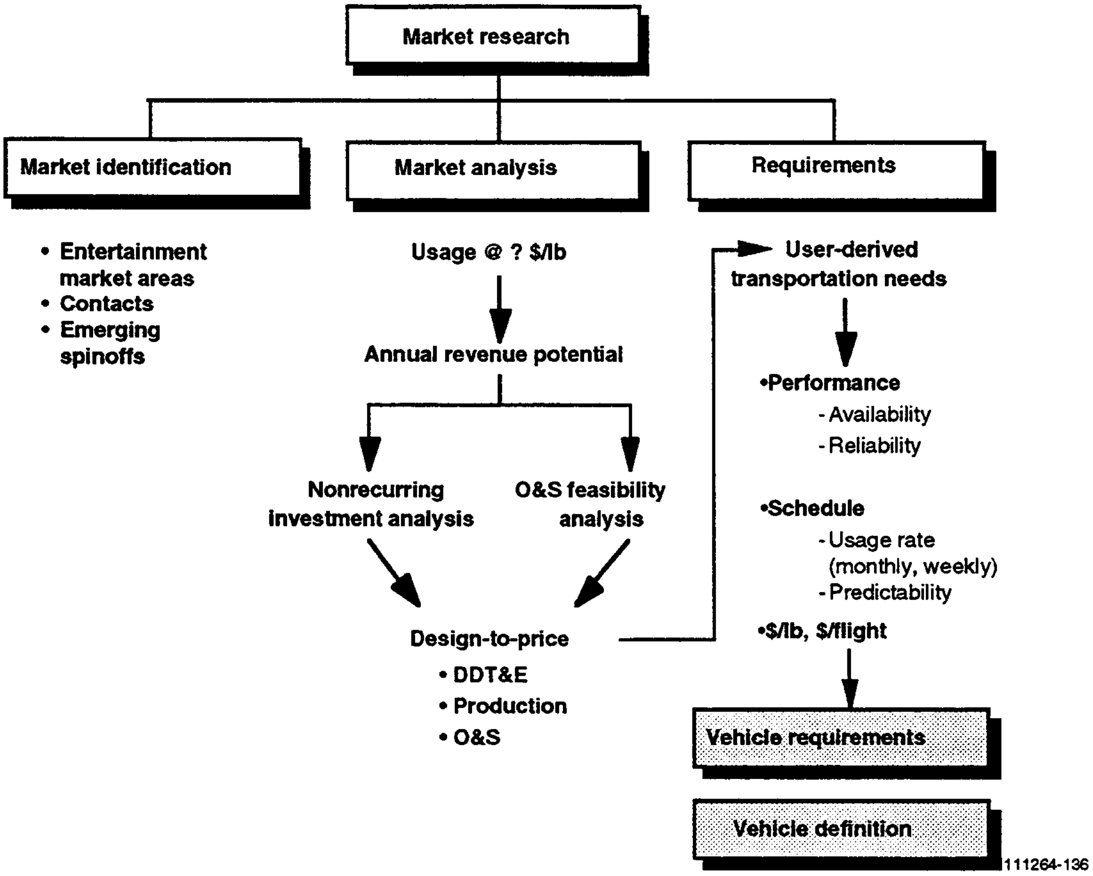

Figure 3.6.1.3-1. CSTS Market Survey Product Flow

3.6.2 Digital Movie Satellites

3.6.2.1 Introduction

Worldwide growth in the home entertainment industry prompted CSTS investigation into satellite downlink possibilities, and the expansion of proposed broadcast satellite markets. As developed in initial brainstorming sessions, a concept was proposed of a satellite constellation infrastructure established to downlink movies directly to residences, at users' convenience, by bringing the video store to the home.

3.6.2.2 Study Approach

The digital movie satellite survey investigated the relative market share of existing competing home video-related industries and qualitatively assessed the amount of change in the current market conditions. This information was used to assess the likelihood of a new competing option surviving. The following steps were taken to assess the market area:

a. We defined total market revenues and growth rate.
b. We established limits on prices to consumers, defined by current cost of home entertainment equipment (VCRs, laser disc players, cable services).
c. We identified market enables and potential showstoppers.
d. We analyzed transportation market potential.

3.6.2.3 Market Description

3.6.2.3.1 Space Application Description

Digital movie satellites are envisioned to fill an entertainment niche not unlike that of current pay-per-view satellite systems for home viewing. The big difference is that the digital movie satellite would downlink an entire movie to the viewer's set at one time. This would enable the viewer to specify any of a large number of films to be screened on demand. In effect, it would combine the attributes of video rental and pay-per-view.

Replacement or augmentation of current movie distribution systems could take advantage of lower satellite transportation costs while providing for on-demand access to a large digitally stored movie database. This would allow for increased worldwide distribution without the need to make and distribute actual prints of films, and also avoid the added costs from the wired infrastructure needed for competing services such as cable systems.

3.6.2.3.2 Market Evaluation

Most of the attributes needed to make digital movie satellites profitable have very little to do with the cost or availability of space transportation services. What really is needed is for the cost of digital data transmission and storage to decrease drastically, as well as the ability to downlink substantially more data from space assets.

The current state of the art in satellite digital data transmission allows the compression and transmission of approximately five to ten real-time television signals over a typical satellite transponder. VHS quality movies require 1 to 2 Mbps (millions of bits per data per second), whereas entertainment/sports events require 3 to 8 Mpbs. Thus a single satellite transponder is capable of sending around 20 to 30 real-time movie signals with advanced compression techniques. A single satellite is capable of sending perhaps several hundred simultaneous digital movie signals, again using compression techniques. If time-compression techniques are used in addition to the digital compression of the real-time signal (compressing a 2-hour recorded movie into a 12-minute "blip") to be received and played back by a home receiver, each transponder might be able to handle perhaps a hundred users per hour, on an individualized basis. To be competitive in the marketplace, the system would have to be price competitive with home video rentals ($1 to $3/movie), and pay-per-view television services ($2 to $5/movie).

For a major metropolitan region, such as the Los Angeles area, with several million households, a small market penetration of 1% would require the system to provide several hundred to several thousand transponder beams during peak usage periods. This requires a very wide bandwidth available to the system—with a potential need for over 100,000 MHz to serve this one metropolitan area. If equivalent services were provided to other major metropolitan areas around the United States, it is possible the downlink bandwidth could be reused with spot beams. But to provide the digital data for downlink, the system must have either a very large on-orbit digital data store, or extremely capable uplink from a central storage site. In the first case, a very large storage system on-orbit is required (which subsequent greatly increases the satellite cost), or a huge uplink bandwidth to upload the digital movies on demand for rebroadcast. Furthermore, since the satellite is assumed to be distributing these movies geographically, there would be little reuse of the uplink compressed bandwidth.

There is approximately 6,000 MHz available for satellite communications in the Ka-band (the least used). The requirement for one metropolitan market area alone exceeds this total available bandwidth by an order of magnitude. Considering the other uses for this bandwidth, allocation of this bandwidth will be difficult.

The problem of available bandwidth will increase as the next generation of high-definition and interactive television systems comes into the market. For full HDTV, from 15 to 25 Mpbs of data are required, which will increase the bandwidth required by about an order of magnitude compared to VHS quality pictures.

At VHS quality, each transponder, using the most advanced digital data transmission capabilities, could provide a maximum revenue stream of about $1,000/hour in peak periods. Since much of this demand is bunched into the prime viewing hours of 6 to 10 PM, the average revenue stream will be substantially less, probably in the vicinity of $200 to $300/hr.

The home entertainment system designed to receive the transmissions will require an added cost to the user (or investment by the operator). Current costs for a real-time satellite receiver, including decyprion system for compressed real-time video, run about $700 retail (Hughes DirecTV system). To this cost must be added costs for the digital storage and payback of the compressed signal, for an estimated per home cost of $1,000 to $1,500 dollars.

These problems are not technically unsolvable -- going to higher frequencies (such as laser/optical data links) would resolve the technical issue of bandwidth availability, and very large-scale mass production of the digital storage and payback systems will reduce their cost as well.

On the other hand, competing terrestrial technologies are currently being developed to address this market. Ground-based fiber-optic data networks, such as those being installed by cable TV and telephone companies, are just one way of solving the transmission bandwidth problem. Installation of an additional cable subscriber is estimated in the trade press at $1000 to 1500 per new subscriber, with substantially lower cost if the system is replacing existing copper cabling. Experimental on-demand data and pay-per-view cable systems are being tested in several cities around the United States.

Terrestrial solutions are viewed by industry to be less expensive and to offer more capability than space-based systems while taking advantage of an existing infrastructure. The timeliness and responsiveness of the terrestrial solution are important. By the time a digital movie satellite is operational (designed, developed, tested, launched, and activated), the bandwidth for operations allocated and approved, and the user ground equipment produced, marketed, sold and installed, the target user population will have had access to much more enhanced terrestrial capability for several years (e.g., interactive TV).

3.6.2.3.3 Market Assessment

About 18 million households have access to current pay-per-view television services, and this number is expected to rise by 2 to 3 million per year over the next several years.

In 1994, satellite direct broadcast to home systems will move into the market, with the institution of the initial 75 channels of the Hughes DirecTV broadcast system expected in April 1994. Fifty of DirecTV's 150 channels are expected to be set aside for pay-per-view offerings. DirecTV is targeting capturing a market of 10 million subscribing households by 2000. There are several other DBS satellite systems also in preparation.

Since the market addressed by the digital movie satellites is the on-demand pay-per-view market segment, its primary competitor is the video rental market. In 1992, the movie industry grossed $12.2 billion through home video rentals and sales. This represents a market share for video rental that did not exist 15 years ago, when home videotape equipment costs were in the thousands of dollars.

During that same time period, the average time between the release of a first-run picture from one of the major studios and the release of the same film on video decreased to 4 to 6 months. Some low-budget features are even directly targeting the video market. This suggests that home videotape rental is here to stay.

This market is also addressed by the cable pay-per-view system and the satellite DBS market discussed previously. This change has been brought about by a wholesale shift in home electronics, which includes the presence of at least one VCR in 77% of US. households (January 1992). This can be directly traced to the availability of progressively less expensive home VCRs.

The market advantage of pay-per-view is the greater convenience afforded viewers, who have only to phone in their program request rather than travel to a video store. On-demand viewing capability removes any barriers from a time lag until the movie is scheduled on a pay-per-view system.

However, it is unlikely that on-demand movie pay-per-view will displace home video's popularity as an entertainment vehicle. Live events, such as superstar rock concerts and high-visibility boxing matches have been the most profitable pay-per-view events to date. Movie purchases on a pay-per-view basis are highly cost sensitive, unless the film offered is on an "exclusive" basis.

This market is very cost sensitive. Significant increase in the market for on-demand movies will require a drastic decrease in the cost to deliver the movie. This appears unlikely, even with a greatly decreased space transportation cost (which allows a greatly decreased satellite cost), since significant user costs will also have to be amortized for this system. There are also potential technical issues in allocating the bandwidth available, and lower cost (although not on-demand) competing services that will soon be available.

3.6.2.3.4 Market Infrastructure

Since the digital movie satellite concept was not viewed as commercially viable, no transition to buy into the market area was established. At a minimum the market infrastructure needed would mirror that for the DBS systems—a distributed set of home receivers and playback systems, a satellite to store or relay the digital movies, and a ground station to uplink the transmission data and control the system. The most expensive part of this infrastructure is the user equipment, needed for each customer.

3.6.2.4 Prospective Users

The prospective users for this service include those persons not served by on-demand pay-per-view movies. This market is broad, since it extends past current television cable pay-per-view users, and encompasses those not covered by cable (about 30% of the U.S. households). However, there is no easily separable market between the digital movie satellite customer and those using a cable on-demand pay-per-view system. Additionally, the distinction between DBS and digital movie satellites in the non-cable-covered market places a premium upon price sensitivity of the consumer.

3.6.2.5 CSTS Needs and Attributes

The digital movie satellite market analysis indicated that the concept was not commercially independent of space transportation system cost due to satellite transmission technology limitations (bandwidth and data transfer rates), and due to market price pressures. Therefore, CSTS needs and attributes were not defined.

3.6.2.6 Business Opportunities

No business opportunities were defined at this point.

3.6.2.7 Conclusions and Recommendations

The digital movie satellite market area has been defocused at this time because it is not competitive when compared to ground-based systems.

3.6.3 Orbiting Movie Studio

3.6.3.1 Introduction

The space environment offers unique characteristics, such as microgravity, that can be exploited by the film industry. These conditions, difficult to simulate through digital and optical effects in terrestrial special-effects studios, offer some unique artistic and dramatic potentials. This market evaluation explored the concept of using an in-space facility for production of scenes for feature films or other venues. A transition of initial commercial methods of producing in-space footage (of space, Moon, or Earth) into more speculative options for actual space-based movie studios was examined. Actual space footage can be used in movies and television shows as background scenery or as a platform for generating special effects.

3.6.3.2 Study Approach

The market survey targeted several different segments of the film industry. A movie set and location company was contacted to determine its rate of usage and desirable characteristics for a location. Discussions with executives at major production houses provided insight into the potential industry interest in an orbiting facility. Statistical data on the film industry and costs of production from the California State Film Commission were used to establish comparative terrestrial and in-space business models, and these models were used to determine price thresholds where the in-space option for location shooting could be economically considered. Market analysis was conducted on both immediate need and future options.

3.6.3.3 Market Description

3.6.3.3.1 Space Application Description

The primary driver for the film production industry is the nature of the script, and the story presented in it. Consequently, having an orbiting production studio is useful only when a studio or a network has a project that could require this type of environment.

The current approach for any major production that requires a space environment scene (such as weightlessness) is to use very specialized digital and optical effects to simulate the visual image that could be obtained in a space environment. While this approach is expensive and time consuming, since a 3D definition in any computer package requires significant modeling and rendering effort, the quality and content of the image produced by these effects is exactly what the director wants to see in a particular scene in the script.

On the other hand, the fidelity of these images is not seamless, and there are significant unknowns in how to effectively model effects called for in the scripts. Furthermore, the thought of being physically able to send a crew to an orbiting facility sparked discussion of the possibility for special effects and artistic treatments not possible with current state-of-the-art methodologies or envisioned by current technicians and directors.

The majority of the filming and television activities in the U.S. entertainment industry consist of work performed by approximately 15 companies. They are the major film studios (e.g., Columbia, Warner, Disney), and major networks and cable companies (e.g., ABC, CBS, NBC, PBS, HBO). For any one of these organizations, there are roughly 30 to 40 projects in the production cycle and as many as 150 projects in the concept development phases. Besides these major companies, there are numerous independent production houses operating on a lesser scale, and additional companies that address the advertising, television, and feature film production segments of this market.

Internationally, there are a larger number of production houses and companies involved in this field. Three of the major U.S. production studios are foreign owned, and it is not unusual for foreign capital to be used to back a U.S. film project. India, for example, produces a larger number of feature films than the U.S., but with a much lower budget per picture. Other major production centers can be found in Europe and East Asia.

The orbiting studio, by itself, can capture the following needs of these projects:

a. Microgravity-based special effects.
b. Actual outer space footage.
c. Remote host station.
d. Remote location-studio hookup.

The best analogy for the orbiting studio is that of the terrestrial sound stage. These stages are equipped with standard utilities and interfaces, and used for many different types of productions over a year's time. Movies, artistic performances, commercials, or news broadcasts and interviews can be performed in the studio.

3.6.3.3.2 Market Evaluation

Two drivers were expressed for use of the space environment for production activities. The first was uniqueness, the ability to offer a product that would be distinguished by others in the market. The use of an in-space facility was seen as a potential selling point for a production. But this market advantage is transitory, as the goal of this overall project was to make space a regular part of business activity, and the "uniqueness" advantage can only be used on a few initial productions. Nevertheless, the image of "space activities" and its very cutting-edge impact prompted comments from industry contacts emphasizing the need to launch a public awareness program focusing on education, research, and entertainment to bolster space interest and enthusiasm.

The primary market need for in-space production is a function of a particular script and its scene requirements. For any given scene in a story, there are usually three or four different options that are given to the director (dependent upon the overall theme of the story and budgetary constraints). Based on our interviews, and on industry statistical data, the primary cost driver for any production is the labor cost (not just union—which there are over 130 separate unions—but the time involved to build and film scenes). To assess the market, we compared the cost for producing a movie scene in a remote location to producing it in an in-space facility.

3.6.3.3.3 Market Assessment

Since the scripts drive the market need, the cost of production is also a function of script scenes. The typical method is to use the bottoms-up approach to costing, based on scenes required to complete any project. Hence, the shooting location and set selections are directly related to scene requirements. On one hand this makes the cost drivers somewhat easy to identify, but on the other hand it is very inconsistent from project to project to attain any meaningful trends. For example, a people-oriented drama that relies on dialogue to tell its story and a special-effects filled science fiction theme may require the same number of scenes for both movies, but the cost of each scene may be drastically different.

The typical large production, however, spends a significant portion of its production costs on special effects or sets that exemplify the theme of the project. To date, the best estimate based on interviews have been that for a large production, anywhere from 20% to 35% of the total budget is spent on location-set and/or special-effects cost. For smaller budget productions we could not determine a meaningful trend for similar cost breakdowns. Within each major production house, as expected, some productions are given the lion's share of publicity and resources, as they are anticipated to earn a higher market return. As one might expect, for any given year, each studio has one or two (but most typically only one) "flagship" major project.

Based upon industry statistical data prepared for the California State Film Commission[1] in 1987 a typical on-location production shooting costs about $32,500 per day in the Los Angeles area (but outside of a studio lot). In 1987, the last year for which there are good statistical data, an average of 40.3 companies were filming on the streets of the Los Angeles area during any day; about $1.3 million per day was spent. Note that this number does not include personnel transportation, or lodging costs, since these costs are not incurred by workers within a few miles of their home operating site.

Outside the Los Angeles area costs increase. Based upon the available statistical data and from industry contacts, we estimated that transportation costs for these remote locations can add up to over $15,000 per day to support remote location filming, or over $105,000/week. This is, of course, a statistical average number. Some films will have a higher budget, and some films will have a lower budget.

To account for the differences in budget in the market evaluation, a ROM market utility demand curve was generated, based upon the data points from available statistical data and on information from contacts within the film industry. The utility demand function models the market such that at $/day production costs equivalent to local location shots, the demand is 40 users per day. As the $/day production cost increases, the demand decreases, still matching the California Film Board data for outside of Los Angeles but within the state of California. This model also accounts for the few productions that are willing to pay a high price for shooting in a unique location.

The costs of film production also seem to be increasing with time. While the numbers are highly variable, it appears that costs per production are increasing at about a 4% annual rate (in constant dollars). The trend appears to be that budgets for the few "flagship" productions from each major production house are being allowed to draw increasing amounts of production cost, in the expectation that they will return significantly higher sales. Since no space-based production facility is expected until the mid-2000s (if then), the available budget for unique location production shooting has been increased to account for this.

Besides feature films, television and commercial work are also performed on location. Estimates of the size of this market vary, with most estimates around twice that of the feature film market. Statistical data on these markets are more difficult to find, but common characteristics seem to be that television productions are more numerous, but have a much lower budget for location shooting, whereas commercial production typically has a higher percentage budget for location shooting, and is willing to spend a higher amount of money per day, but spends a shorter period of time on location. In this market evaluation television and commercial production is treated identically to feature film production, except that the total market population is increased threefold.

The key variable is the number of scripts are available that could use such a facility. Even if the facility was very inexpensive to use, if no scripts required use of such an extraordinary environment, the facility would not be used. To allow for this, industry contacts were asked to estimate the number of productions in house that could use such a facility. The answers ranged from 2% to 10%, with the caveat that the number of scripts that could use such a "space-related" facility was highly dependent upon what the current wave of interest in type of production.

For example, in the early 1980s there was a wave of science-fiction-related movies that drove the 10% estimate. Current estimates ranged from 2% to 5%, with scripts on hand or projects currently in production. One contact stated, "If you get this expanded use of space, this will probably drive up public interest and awareness of space activities. Then we might expect a higher percentage." Other contacts suggested an increased focus on space and science education may potentially drive up this percentage. For this estimate, however, we used 2% as the low estimate of script suitability, 5% as the nominal, and 10% as the highest (lowest probability) estimate.

It must be noted that initial production of in-space footage is already under way. Shuttle missions often carry IMAX cameras to capture footage of shuttle operations and the space environment to be used in revenue-generating venues. Several persons contacted in the entertainment industry identified expansion of this existing market as a viable market option in the near term (considering timeframe and current launch costs), and recommended options that would permit studios to acquire actual footage of space, the solar system, Earth, the Moon, the Sun, and so forth. Cameras could be placed onto such locations as the shuttle manipulator arm and commercial or government satellites and space probes, and the taped or live transmissions sold. Several firms already sell such space-related films and videos, although this business has not been highly profitable. Broadcasting could be done from the space shuttle or a space station and transmitted to the studio for editing. Later, as the infrastructure is established, movie footage could be downlinked to the studio for near-real-time use. Real-time satellite connections present another option if the transmission resolution can be improved (e.g., high-definition TV).

3.6.3.3.4 Market Infrastructure

In the near term, this market can be entered to capture and expand the small market of in-space production that exists today. To capture the immediate need opportunities, a policy must be established to permit small (camera size, <50 lb) payloads to piggyback on primary space shuttle and satellite missions. Several comments were made that flying payloads on current manned systems, even as an experiment, was very expensive and difficult due to the strong requirements to "manned space rate" hardware. The requirements to space-qualify hardware must be relaxed enough so that the cost to manufacture and qualify filming equipment is not excessive while still ensuring the integrity of the primary payload. For example, the space station program might consider the addition of an external camera mounting to be controlled on a for-fee basis, or the resale of footage to commercial production houses.

Small experiments should be examined for the shuttle and other vehicles, during which the production companies could "experiment" to determine what optical effects or artistic effects would be feasible and desirable for future productions. These could be as simple as filming free-floating objects in the shuttle mid-deck with crew interactions, or having the astronauts perform gymnastic maneuvers in front of a blue-screen cloth for later editing into a different background. For the orbiting movie studio to develop into a space-based location, the key is that the business environment must be developed to permit civilian access to space with minimal to no training requirements, and to develop the interest and expertise to use the space environment in new ways on a routine basis.

In the longer term, if an on-orbit move facility is to be accomplished, there must be a supporting infrastructure to provide key location services. This market evaluation indicates there is not sufficient market revenue to justify a standalone facility, due to the added costs of supporting the facility as a free-flying entity. The required infrastructure is essentially identical to the space business park, which provides users of the space facility living quarters, and provides utility support services to the production facility itself.

It should be noted that high-quality digital data links between the orbital production facility and the ground were assumed. Rather than shooting film and editing it on the ground, or sending "rushes" of scenes shot during the previous day back to the studio on a daily basis, it is assumed that by the time this facility is operational (2005+), high-definition digital equipment will be available. This does place a requirement for two-way transmission of a large quantity of digital data, potentially up to several hundred million bits/second (depending on the cameras used and the number of scenes to be shot).

3.6.3.4 Prospective Users

The primary users of an orbiting movie studio were identified as (1) feature film production companies/studios, (2) television show production companies and major networks interested in "on-location" series (multiple shows), educational programming, or special shows, and (3) commercial producers.

CSTS contacts included—

a. California State Film Commission, Patti S. Archuletta, Director.
b. CBS Television, John Kruer, Director - Advanced Technologies.
c. Columbia Pictures, John Butkovitch, Director - Marketing.
d. Real to Reel Incorporated (Location services brokerage), Scott Osberg, Chief Operation Officer.
e. Walt Disney Imagineering, Inc., Bran Ferren, Senior Vice President - Creative Technologies.
f. Warner Brothers, Ben Cowitt, Director - Future Productions .

3.6.3.5 CSTS Needs and Attributes

3.6.3.5.1 Transportation Characteristics

The primary transportation system function, after the market is established and an operational facility in place, is to accommodate the weekly traffic of passengers and production supplies. This annual traffic flow estimate assumes that the orbiting movie studio is occupied 52 weeks per year, yielding an estimate of about 650 Klb per year, in weekly flights. The transportation system must provide regular flights on a weekly basis, although some production crews may stay longer on orbit if the shooting schedules require it.

For customer acceptability, prospective customers must be able to reserve transportation services similar to a common or charter carrier. Reservation leadtime is estimated to be less than 3 months (driven by the need to produce footage in a typical production schedule). Schedule reliability of the transportation system must provide service within scheduled launches (and returns) within 1 day of the scheduled date. Production schedules, particularly with scheduled release or broadcast time, will not allow major slippage in the scheduled availability of the transportation system. Similarly, the system must be accessible by persons with little or no training (preferably none - they are "passengers," not "crew").

The system must be capable of carrying a mixed load of passengers and cargo (since the crew and cast must have their production equipment to be productive), and must be capable of rendezvousing, docking, and transferring these supplies to the orbital destination. Return payloads will also consist of a mixed load of passengers and cargo.

The initial launch of the studio may also impose a unique requirement on the launch infrastructure. The required facility is a large empty volume. If this is desired to be launched as a single unit, it may be a unique requirement on the transportation system. Further analysis should be done to establish the specific minimal requirements for this facility. For the purposes of this initial survey, it was assumed the 80,000 lb initial launch mass would accommodate such a facility, either assembled on orbit from modular sections, or as an inflatable system. The use of a surplus shuttle external fuel tank has also been suggested as this facility, although this would require some on-orbit construction to adapt and outfit the volume.

3.6.3.5.2 Transportation System Capabilities

Capabilities needed are for mixed cargoes of passengers and hardware in chunks of approximately 12,500 lb, launched at weekly intervals. Launch price to the user must be <$400 /lb to LEO. Transportation system must be capable of supporting weekly launches, with high schedule reliability. System safety must approach commercial air transportation reliability. System must be capable of delivering these mixed cargoes to an orbital destination in LEO, and transfer the passengers and their hardware to the orbital facility.

3.6.3.5.3 Ground Handling

The users of the space transportation system will not require special ground handling provisions. The space system will be booked and boarded in a manner as close to a commercial aircraft as possible. Standard cargo containers for pressurized cargo will be used for props, production equipment, and luggage.

3.6.3.5.4 User/Space Transportation Interfaces

The users of the space transportation system are passengers only. The space system will be chartered and boarded just as if it were a commercial aircraft.

3.6.3.5.5 Improvements Over Current

Significant improvements over current space transportation systems are required to support the future goal of an orbiting movie studio:

a. Launch costs at $400/lb or lower.
b. Launch on schedule (or on demand for charter flights), with high schedule reliability to ensure launch within the scheduled day.
c. Routine scheduled service, on at least a weekly basis for scheduled assess to the orbital facility.
d. Airline-like cargo and passenger handling.

3.6.3.6 Business Opportunities

3.6.3.6.1 Cost Sensitivities

To evaluate this market's potential, a ROM business venture model was created for a simple on-orbit "production studio." By analogy to terrestrial sound stages, the facility would be an empty volume, equipped with common utilities (power, ECLSS, communications), and capable of accepting "sets" to be outfitted for differing production needs. Such a common-usage facility could be used for movie production, from-space broadcast, artistic performances, or small-scale broadcast sporting events. This facility was assumed attached to an existing space facility, which would provide common housekeeping functions, such as power generation, thermal control, and attitude control, in exchange for a housekeeping fee. This would include living quarters and accommodations for those persons working in the orbital movie production facility. These infrastructure needs will be discussed in a later section.

To examine the feasibility of this concept it was necessary to construct a ROM business model. While this model is preliminary, it indicates some of the sensitivities involved in such a venture.

For initial ROM estimates, it was assumed this facility could be economically viable at a 20% IRR, after 15 years from start of the program. A 3-year build cycle was assumed. For a conservative assumption, about 80,000 lb for initial launch mass was included (about that of a shuttle external fuel tank), and a variable cost of production was assumed. (Baseline was $150 million, based upon ROM parametric data for large simple on-orbit pressure vessels).

It was assumed the operator of the on-orbit facility would construct and launch the facility, selling off time at the facility in 1-week intervals. The operator would charge a flat $/week operating cost, which would be the cost to the user.

Operating cost on orbit had three major components: transportation cost of the user to the facility (including people and cargo), support costs charged by the attached facility (assumed to be the "space business park" described elsewhere), and recurring maintenance costs of the facility (estimated as an annual percentage of the initial facility cost, per year).

It was assumed that a crew of eight persons (including performers) would use the facility. Each person was estimated at 250 lb each, with an additional allowance of 100 lb/person per day (for costumes, luggage, and other needs). Production equipment was estimated at 1000 lb, with another 4000 lb of props. This yields a ROM estimate of about 12,500 lb per usage of 1 week. Logistics support (food, water, ECLSS needs) are included in the support facility costs (the "space business park") and are included in its cost estimates. To account for these, a weekly support charge is assessed upon the production facility, as stated previously.

Financing costs were assumed at 8%, taxes at 35%, and a 7-year depreciation was assumed for the on-orbit facility. The facility was assumed 100% debt-financed. Initial launch was assumed at the start of year 4, with operations commencing very shortly thereafter.

Figure 3.6.3.6-1 indicates the threshold costs at which this venture reached 20% IRR, assuming a low-nominal-high annual percentage of movie scripts with space or futuristic themes, or special-effects requirements that could use such a facility.

Low Market Estimate	**Nominal (Medium) Market Estimate**	**High Market Estimate**
2% script suitability	5% script suitability	10% script suitability
$1/lb transportation cost	$ 36/lb transportation cost	$ 60/lb transportation cost

Figure 3.6.3.6-1. Space Movie Production Facility Threshold Costs

Using the medium model as illustrated, figure 3.6.3.6-2 shows the sensitivity of these results to the initial facility cost. This assumed that a 20% IRR was maintained on the ventures, in the nominal (medium-probability) case.

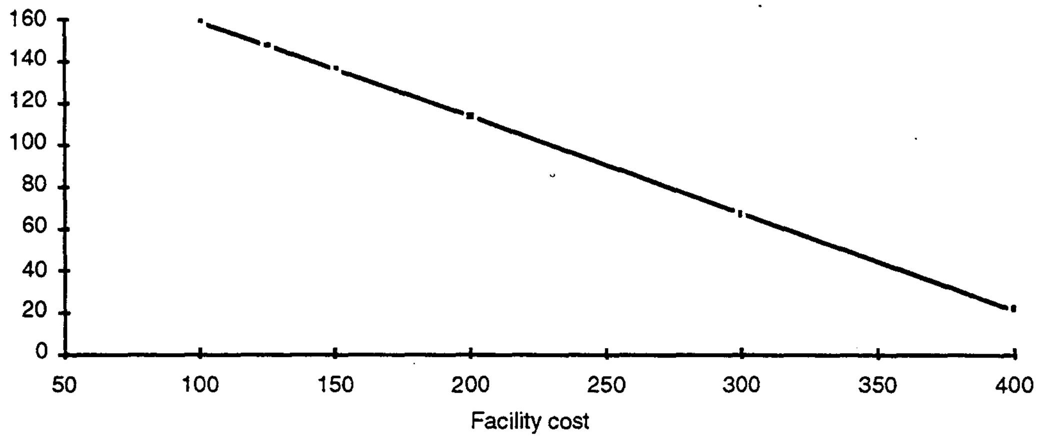

Figure 3.6.3.6-2. Transportation Cost Sensitivity to Initial Facility Cost

Figure 3.6.3.6-3 below indicates the sensitivity of these results to the required support costs to the orbital facility (the "space business park") to which this facility is attached. Again, a 20% IRR was assumed maintained, in the nominal probability case.

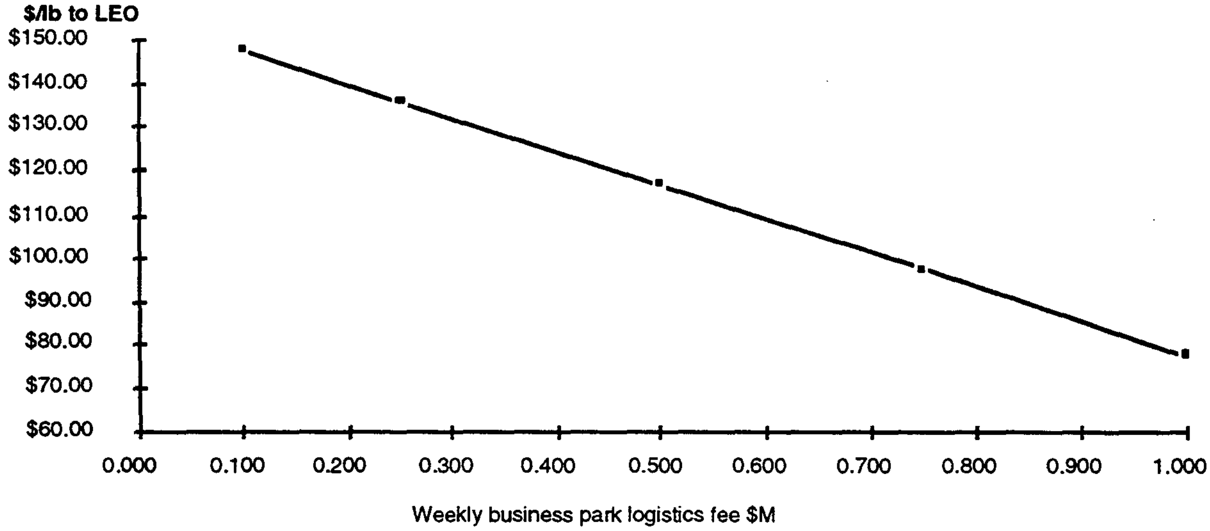

Figure 3.6.3.6-3. Transportation Cost Sensitivity to Weekly Orbital Support Fee

Competing technologies for the area may challenge this business opportunity if transportation and production costs are not reduced to the lowest feasible level. The limitation of current digital and optical effects is primarily driven by the high costs for near-realistic special effects. While special-effect generation is labor intensive it is not impossible with today's computer rendering and animation technologies. At current space transportation prices, the market will continue unchanged (with IMAX-type productions from shuttle cameras). With price reduced to $600/lb, we do not anticipate major expansion but continued growth of the space filming from satellites, shuttle, or space stations.

Growth in the current markets will be driven by increased need for production footage in current type of productions. At the high-probability assessment (fig. 3.6.3.6-4), this will not increase from the current level of about 1,000 lb per year at current costs. At low probability (highest market estimate), this demand will increase at least as the underlying industry production dollars increase for purchase of footage (4% per year). For a nominal growth rate, a 2% annual growth rate is assumed.

	High Probability	Medium Probability	Low Probability
Klb/yr @ $5,000/lb	<1	1.2	1
Klb/yr @ $600/lb	1	1.2	1.5
Klb/yr @ $400/lb	1	650	650
Klb/yr @ $100/lb	1	650	650

Figure 3.6.3.6-4. Orbiting Movie Studio Annual Klb/orbit Demand per Cost Option

3.6.3.6.2 Programmatics

Annual revenue generation is possible based on two to four 250-lb payloads per year at current transportation prices. Growth in the market is limited until transportation prices drop to $400/lb and under, and the orbiting movie studio is operational within the multifunctional facility. That timeframe is assumed to be 2008 to 2010, at the earliest. Figure 3.6.3.6-5 illustrated the revenue jump associated with this threshold transportation cost. Revenues will remain steady until the facility demand necessitates another studio.

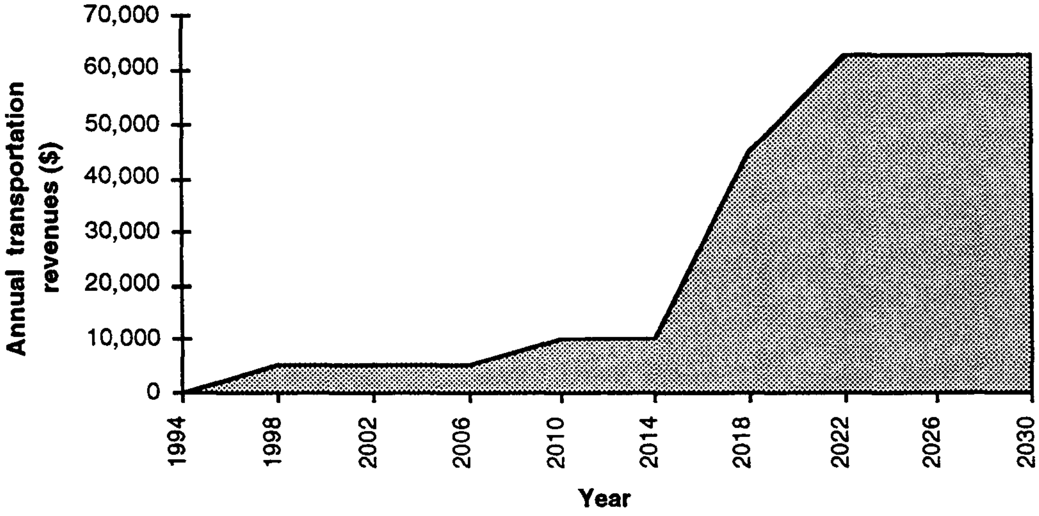

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Figure 3.6.3.6-5. Orbiting Movie Studio Market Area Time-Phased Revenue-Generation Assessment

3.6.3.7 Conclusions and Recommendations

Market demand for in-space production of movie and video footage is a very small market at current transportation costs. The market for a standalone facility is not feasible at current costs of equipment and transportation. However, if transportation costs can be reduced to well less than $400/lb, and probably into the $100/lb range, such a facility might be considered in conjunction with other orbital business activities. In that range of costs, it appears from ROM estimates that a facility could provide a sufficient return to be justified as an additional module as part of a commercial space facility. Such a facility however, is highly dependent upon the market demand from suitable scripts and production needs, which will be dependent upon specific future market conditions.

3.6.4 Space Athletic Events

3.6.4.1 Introduction

In initial brainstorming sessions, use of the space environment as the venues for a major broadcast sporting event was identified. Taking off on the big sporting event markets—Super Bowl, pay-for-view boxing, wrestling championships, and so forth—the space athletic event market area was conceived. This concept involves space-based sporting competitions with revenues generated primarily from selling advertising time for such an event.

3.6.4.2 Study Approach

This analysis is primarily driven by the costs and revenues associated with the broadcast of a major spectator sport market. A market capture (worldwide interest was determined to be the needed "target audience") and return on investment study was performed to establish a threshold price that would stimulate commercial interest and ensure competition for broadcast rights. Two different types of events were examined: a single annual "championship" event, and a periodic "series" event.

3.6.4.3 Market Description

3.6.4.3.1 Space Application Description

A space athletic event facility would support a wide variety of athletic events that incorporate the unique characteristics of microgravity. Sports and games could be devised and competitions would be held on a periodic basis. These events could become household words on Earth very quickly. This phenomenon has already been amply demonstrated by television shows such as *American Gladiators* and certain Japanese game shows. Athletic events can attract significant market interest, as represented by high corporate sponsorship of broadcast sporting events and by the ability of sporting events to maintain steady ratings in the broadcast markets.

It should be noted that the high ratings of these events are also driven by a large amount of nonevent advertising and consistent image development. For example, many athletic events have a strong local advertising presence (such as through local sports bars, store displays, and related promotional items). These support advertising campaigns would presumably be used in conjunction with an in-space event, but their costs (as with terrestrial events) are not included in the cost projections for the event producer. For conservatism, revenues from corporate sponsorship fees, subsidiary rights, rebroadcast rights, and spinoff merchandise rights are not included in revenue projections. It should be noted that the sales of these rights may be substantial, and in the millions of dollars per year. For example, professional baseball, the most successful league in selling merchandise licenses, generated $1.5 billion in licensed merchandise sales in 1990, and the NHL achieved $800 million in 1993 in licensed merchandise sales (Source: *Wall Street Journal*, 14 January 1994).

In the single annual "championship event," the market area concept is similar to the game show format; participation in the space athletic event would be determined by a periodic nationwide (or even worldwide) competition. Those aspiring to participate in microgravity games would have to prevail in their respective regional meets. The promotional aspects of this ongoing competition would represent significant value to event sponsors and advertisers.

High-visibility professional teams can be organized into regional leagues that participate in space-based competitions (alone or to augment ground-based competitions). The potential market share for such championship events can be quite large.

In the recurring series event, a weekly or periodic set of in-space competitions is broadcast, building up to the annual championship. This has the advantage of increasing public awareness through exposure, but the revenues per show average out to a lower value.

3.6.4.3.2 Market Evaluation

As in any spectator sporting event, the promotional aspects of the "microgravity games" competition would probably eclipse the actual nature or relevancy of the competition. The implication of this is that the revenue derived from advertising and promotions would represent a reliable revenue stream, *as long as public attention and interest could be maintained.* This is what makes the ongoing televised competitions to determine the contestants so important.

On the other hand, by having the games on an infrequent basis, their mystique could be maintained indefinitely, similarly to the Olympic Games. This would also enable the space used to conduct the games to serve other purposes at other times. In this way the same facility could be used for athletic events, theme park uses, and short-term medical uses, such as rehabilitation and therapy (multifunctional venue).

For the purposes of market evaluation, the U.S. market only is examined, with potential expansion into international markets.

For the single championship event as a ROM estimate, a market draw equivalent to the Super Bowl is assumed. The Super Bowl share of the U.S. television audience has ranged from 42.4% (1975) to 49.1% (1982), with the 1993 Super Bowl attaining a 45.1% market share. The advertising revenues for this large-draw spectator event are sold in 30-second units of advertising time, with a unit for the 1994 Super Bowl selling for $900,000 (Source: *Wall Street Journal*, 11 Jan 1994). Past Super Bowls have sold equivalent units for $750,000 to $800,000. For this market evaluation a market share of 40% is assumed, with advertising revenues at $800,000 to $900,000 per unit.

For a weekly series broadcast event, the rating and revenues are much less. The best 1993 periodic sporting event was NFL Monday Night Football, which achieved a 16.7% market share in 1993 (Source: Neilsen Media Research). Other weekly scheduled networks series events, such as prime-time series have typical market ratings of 10% to 20% of TV households. Syndicated shows are lower, typically in the 6% to 13% range. The revenues for these shows varied, depending upon the market penetration addressed. National advertising rates can run $100,000 to $250,000 per 30-second advertising time unit. For this market evaluation, a market share of 6% to 8% is assumed achievable, with national advertising rates of $100,000 to $150,000 per unit.

3.6.4.3.3 Market Assessment

To evaluate this market's potential, a ROM business venture model was created . By analogy to terrestrial events, a facility is needed on orbit. The required in-space sporting facility would consist primarily of an empty volume, sized to allow movement of persons through it, and equipped with common utilities (power, ECLSS, communications). It is most likely that this "sporting arena" would be capable of accepting "sets" to be outfitted for differing sporting needs, such that the challenges could be varied over the course of a competition, or to allow the use for different event production needs.

This facility has much similarity to production, from-space broadcast, artistic performances, or small-scale broadcast sporting events. This facility was assumed attached to an existing space facility, which would provide common housekeeping functions, such as power generation, thermal control, and attitude control in exchange for a housekeeping fee. This would include living quarters and accommodations for those persons working in the orbital movie production facility. These infrastructure needs will be discussed in a later section.

To examine the feasibility of this concept, it was necessary to construct a ROM business model. While this model is preliminary, it indicates some of the sensitivities involved in such a venture.

For initial ROM estimates, it was assumed this facility could be economically viable at a 20% IRR, after 10 years of operations. A 3-year build cycle was assumed. For a conservative assumption, about 80,000 lb for initial launch mass was included (about that of a shuttle external fuel tank), and a variable cost of production was assumed. (Baseline was $ 150 million, based upon ROM parametric data for large simple on-orbit pressure vessels).

It was assumed the operator of the on-orbit facility would construct and launch the facility, selling off time at the facility in 1-week intervals. The operator would charge a flat $/week operating cost, which would be the cost to the user.

Operating cost on orbit had three major components: transportation cost of the user to the facility (including people and cargo), support costs charged by the attached facility (assumed to be the "space business park" described elsewhere), and recurring maintenance costs of the facility (estimated as an annual percentage of the initial facility cost, per year).

It was assumed that a crew of 12 persons would be transported to the facility for this event (2 production crew—camera and audio), plus 10 competitors (two teams of 5, or two teams of 4 plus 2 referees/prop handlers). Tradeoffs between participants and crew can be performed, with 1 week on orbit. Each person was estimated at 250 lb with an additional allowance of 100 lb per person per day. Production equipment was estimated at 1,000 lb, with another 4,000 lb of props. This yields a ROM estimate of about 16,400 lb per usage of 1 week. Logistics support (food, water, ECLSS needs) is included in the support facility costs (the "space business park") and is included in its cost estimates. To account for these, a weekly support charge is assessed upon the production facility, as stated previously.

Financing costs were assumed at 8% and taxes at 35%, and a 7-year depreciation was assumed for the on-orbit facility. The facility was assumed 100% debt-financed. Initial launch was assumed at the start of year 4, with operations commencing very shortly thereafter.

Revenue estimates assumed 12 minutes of advertising time to be sold per hour, during a 2-hour broadcast. Additional advertising time could be sold as a pregame or postgame show, but these revenues were not included. Basic revenues were assumed to approximate Super Bowl market revenues, at the 1994 Super Bowl unit rates. This is a conservative assumption, since these unit rates have been rising more than 10% per year in real dollars. For a facility in the 2005+ time period, this would indicate a potential revenue rate of greater than $2,000,000 per unit.

To establish a range of probability on these market estimates, it was assumed that one event could be obtained per year in the highest probability/low market estimate. Two events (e.g., the United States and either Europe or the Far East) for the nominal market estimate, and four events in the low-probability/high-market estimate (e.g., the United States, Japan, Europe, and one other event). Since the total addressed populations are still significant market areas, the advertising unit revenues were kept constant, although the sensitivities of the results were tested to this assumption. Figure 3.6.4.3-1 indicates the threshold costs at which this venture reached 20% IRR.

Low Market Estimate	Nominal (Medium) Market Estimate	High Market Estimate
1 event/year	2 events/year	4 events/year
$0/lb (it was not possible to obtain 20% IRR, with a maximum of 18% at $0/lb)	$806/lb transportation cost	$1536/lb transportation cost

Figure 3.6.4.3-1. Space Athletic Event Facility Threshold Costs for "Championship" Type Event

A similar estimate was made for a recurring series-type sporting event. For this venture, it was assumed that the same number of persons would be required, except that the produced event would only be 1 hour in length. The revenue rate for this show was assessed as substantially less, assumed at $125,000 per unit, for a 13-week series.

To establish a range of probability on these market estimates, it was assumed that one series could be established in the highest probability/low-market estimate. Two 13-week events were assessed in the medium-probability/nominal-market estimate, and four events in the low-probability/high-market estimate. (e.g., the US, Japan, Europe, and one other event). Since the total addressed populations are still significant market areas, the advertising unit revenues were kept constant, although the sensitivities of the results were tested to this assumption. Figure 3.6.4.3-2 indicates the threshold costs at which this venture reached 20% IRR.

Low Market Estimate	Nominal (Medium) Market Estimate	High Market Estimate
1 series per year (13 weeks usage)	2 series per year (26 weeks usage)	4 series events per year (52 weeks usage)
$0/lb (it was not possible to obtain 20% IRR, with a maximum of 16% at $0/lb)	$71/lb transportation cost	$126/lb transportation cost

Figure 3.6.4.3-2. Space Athletic Event Facility Threshold Costs for "Series" Type Event

3.6.4.3.4 Market Infrastructure

This market requires routine access to space and the ability to cost effectively build and launch an in-space facility suitable for broadcast sporting events. Outside of these needs, the largest lack in the market infrastructure is a lack of the awareness and expertise of what type of in-space sporting events are possible or visually attractive to a broadcast audience. This includes the technical aspects of how to capture the event on camera, the types of props or equipment necessary, or even the types of moves or structure of the competition. There are a few possible initial early experiments which can be taken in this area. On Skylab gymnastics demonstrations and some simple 0g tumbling demonstrations were made. Potentially, spacelab or space station could be used to demonstrate and develop some techniques for initial market penetration. However, it is likely a realistic venture is impossible until the advent of the commercially-oriented "space business park" described elsewhere in this report.

In the longer term, if an on-orbit sporting facility is to be accomplished, there must be a supporting infrastructure on the ground, including marketing, and merchandising to drive up market interest to obtain the favorable advertising rates needed for the market feasibility. And it should be noted that this ground-side of the marketing and promotion could provide substantial additional revenues through licensed merchandising and associated terrestrial promotions. It is possible that these terrestrial tie-in products may be sufficient to turn a marketing direct-advertising revenue product into a viable market venture.

As with the space move production facility, it should be noted that it is assumed that high-quality digital datalinks are provided between the orbital facility and the ground. The ability to transmit high-quality signals and produce an attractive and interesting competition will be a key driver in providing for the maximum audience. It is assumed that by the time this facility is operational (2005+), high-definition digital equipment will be available. This does place a requirement for two-way transmission of a large quantity of digital data, potentially of up to several hundred million bits/second (depending on the cameras used and the production of the event).

3.6.4.4 Prospective Users

The users of such an orbital facility will be found within the professional sports interest (existing and to be developed) community: promoters, advertisers, participants, and spectators, potentially in the gaming industry.

CSTS contacts included—

a. CBS Television, John Kruer, Director - Advanced Technologies.
b. Walt Disney Imagineering, Inc., Bran Ferren, Senior Vice President - Creative Technologies.
c. Warner Brothers, Ben Cowitt, Director - Future Productions.
d. Space Marketing, Inc., Mike Lawson, CEO.

3.6.4.5 CSTS Needs and Attributes

3.6.4.5.1 Transportation Characteristics

There are two key characteristics required for space transportation systems to support the space athletic event market area: reduced space transportation prices, and routine, scheduled use of the transportation system. The system is required to transport mixed cargoes of people and hardware, to support the in-space activities. Flight frequency can vary, depending upon the mix of high-visibility "championship" type events versus lower revenue "series" type competitions, but it may be necessary to offer scheduled services as often as every week. The schedule reliability needs to be high; for customer needs, the system must be able to offer highly schedule-reliable transport. Because the major revenues from any event are related to broadcasting rights (for promotional value), the reliability and availability of the transportation element cannot cause a delay or rescheduling of the event.

3.6.4.5.2 Transportation System Capabilities

The space transportation system must carry combination passenger/cargo payloads, totaling approximately 20 Klb, to and from LEO. The transportation system must rendezvous and dock with the space athletic event facility or with a generic docking module at the multifunctional facility. The space athletic event market has the potential to grow to necessitate routine access to space on a monthly or weekly basis.

3.6.4.5.3 Ground Handling

Small payload loading is required for equipment, props, and support logistics, presumably through standard cargo modules. Standard shipping containers will be used to eliminate special integration. Passenger boarding accommodations similar to commercial aircraft must be provided.

3.6.4.5.4 User/Space Transportation Interfaces

The users of the space transportation system need to interface with the space transportation system as close to use of a commercial aircraft as possible. The interfaces will require passenger use and the transport of simple pressurized hardware. The space transportation system must also provide the capability for pressurized payload transfer at an in-space facility, including docking and rendezvous to the facility.

3.6.4.5.5 Improvements Over Current

The space athletic event market is highly sensitive to total production net value. Commercial investment interest will be dependent upon broadcast-rights revenue-generation potential less production costs. The space transportation element represents a significant contributor to total production cost. To create a viable commercial space athletic event interest within market thresholds, the following improvements to the current space transportation systems are necessary:

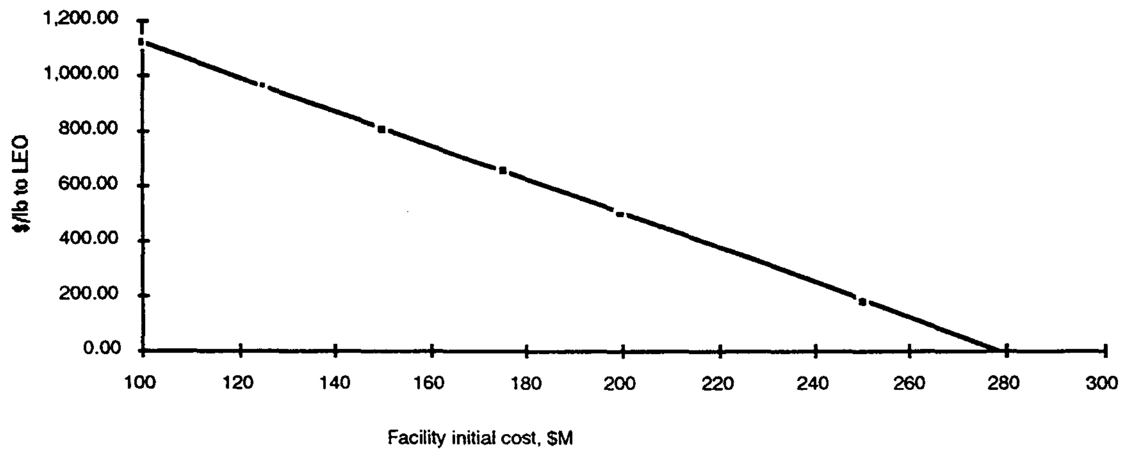
a. Reduced transportation price (to the vicinity of $500/lb and preferably to $100/lb or less).
b. Improved system availability and reliability.
c. Near-airline-type cargo and passenger handling.

3.6.4.6 Business Opportunities

3.6.4.6.1 Cost Sensitivities

Using the medium model as an illustration, figures 3.6.4.6-1 and -2 show the sensitivity of these results to the initial facility cost. This assumed that a 20% IRR was maintained on the ventures, in the nominal (medium-probability) case.

Two Major Events/Year in Facility—Nominal Projection



11264-140

Figure 3.6.4.6-1. Sensitivity of Initial Facility Cost to $/lb, 20% IRR

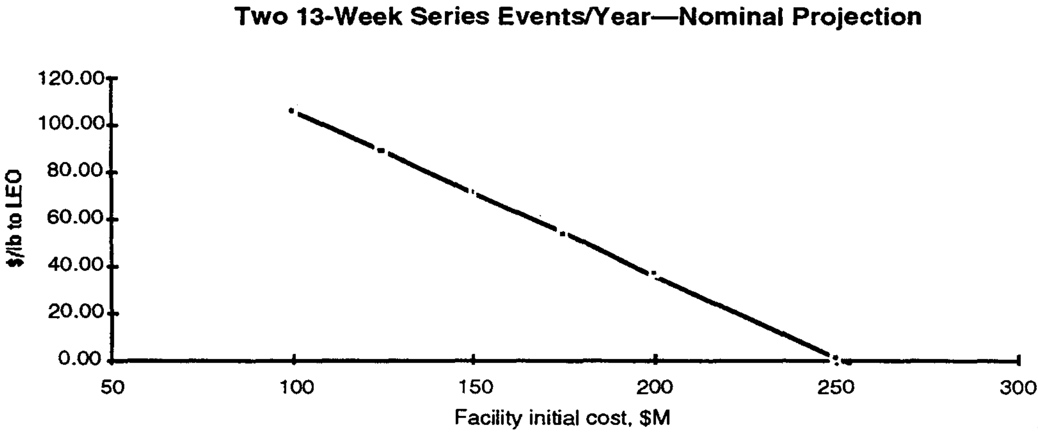


Figure 3.6.4.6-2. Sensitivity of Initial Facility Cost to $/lb, 20% IRR

Figures 3.6.4.6-3 and -4, below, indicate the sensitivity of these results to the advertising revenues per hour assumption in the two cases. Again, a 20% IRR was assumed maintained, in the nominal probability case.

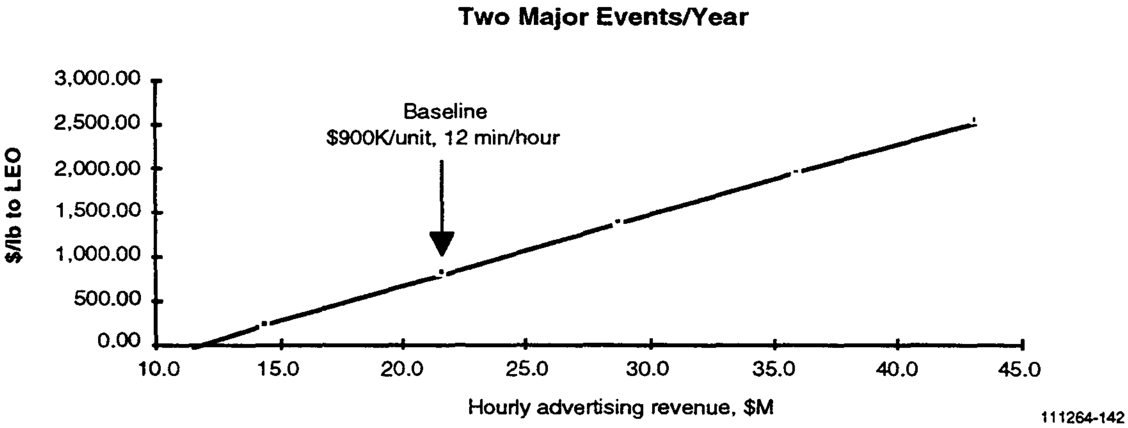


Figure 3.6.4.6-3. Sensitivity to Hourly Advertising Revenues

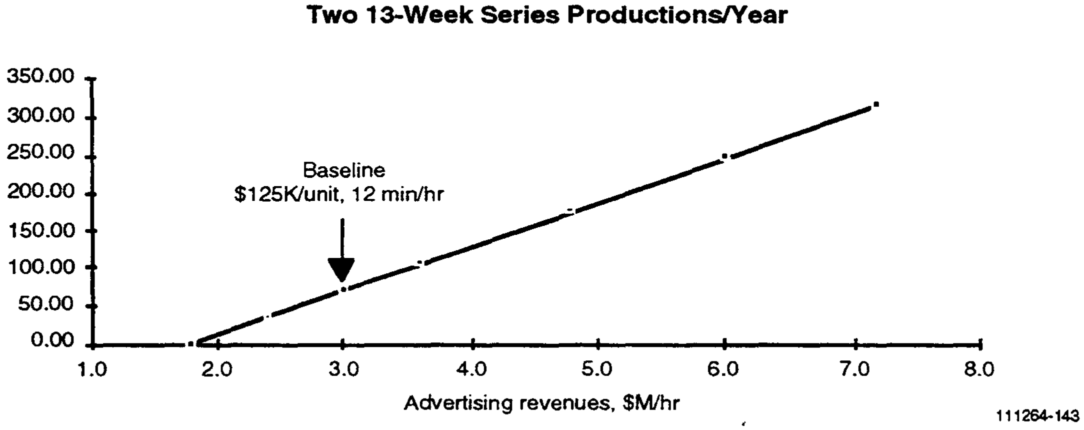


Figure 3.6.4.6-4. Sensitivity to Hourly Advertising Revenues

The primary competition in this market is from terrestrial sporting markets, and the primary risk from a market standpoint, is that this market area requires the development of a new type of sporting activity, with sufficient public interest to capture the viewing audience needed for the market revenues. While the market risk from the former cannot be accounted for, the later market risk is accounted for in this case by assuming low market revenues consistent with low-end national sporting events, and by not including the sale of subsidiary rights and not including potential nonspace revenues such as licensed merchandise. At the high-probability assessment, growth in this addressed market is not assumed to occur.

For growth numbers in spectator sports, the driving factor is the growth in advertising dollars available to fund advertising revenues(fig. 3.6.4.6-5). Advertising expenditures increased (after inflation) about 1.5% in the period from 1991-92—(Source: *Advertising Age Magazine*). This trend is expected to continue. The market for broadcast spectator sports, for major events, remained approximately constant (Nielsen rating of 16.7% in 1992-93 versus 16.6% in 1991-92—but a change in number of audience of 0.9%, or about 849,000 more viewer—for a total increase of about 1.5% in the viewing audience. This would indicate a reasonable estimate that the advertising dollars remain constant for the market addressed and would grow at least as fast as the U.S. population growth (1% per year average from 1980-90).

Model	Growth Rate
Low	Constant—0% per year
Nominal	As population—1% per year
High (optimistic)	As market —1.5% per year

Figure 3.6.4.6-5. Advertising Dollars Available (Grows as Population)

Development and growth of the space athletic event concept (fig. 3.6.4.6-6) is highly sensitive to transportation price, as well as the ability to provide simple, routine access to space.

	High Probability	Medium Probability	Low Probability
Klb/yr @ $5,000/lb	0	0	0
Klb/yr @ $500/lb	0	20	80
Klb/yr @ $100/lb	0	520	1040

Figure 3.6.4.6-6. Space Athletic Events Annual Klb/Orbit Demand per Cost Option

3.6.4.6.2 Programmatics

This market area is programmatically dependent upon both a new space transportation system capable of providing the routine, low-cost space transportation required for recurring operations, and also upon the existence of an in-space facility capable of providing the routine housekeeping utilities to the "sporting arena." (For a concept of this in-space support facility, see the "space business park" material, sec. 3.7.7). It is anticipated that the market could begin to arise in the nominal market case, in the 2008-2010 time period when both the facility and transportation system might become available. Growth in this market is possible, when either the market demographics have driven up a sufficient level of demand at then-current revenues and prices, or when new-generation systems could provide additional cost savings, and improve the cost numbers involved in this potential activity.

3.6.4.7 Conclusions and Recommendations

There is a potential for some initial market experiments in this area, using shuttle and space station activities to gauge public interest and acceptability for such a venture. In particular, in-space experimentation is required to establish which events are feasible and attractive to broadcast, and to establish the key techniques of broadcasting the event. The space athletic event should continue to be included as part of a total entertainment venue, but the key market challenge will be to develop a game that captures public interest enough that the broadcast rights are worth a significant price. That will require some on-orbit experience.

3.6.5 Artificial Space Phenomena

3.6.5.1 Introduction

Humans have always been fascinated by shooting stars as objects of mystery and beauty. The Earth's upper atmosphere can provide a backdrop for spectacular shows reaching large, regional, and potentially global audiences. Just imagine a light show from space being watched by millions to celebrate a spectacle event, a presidential inauguration, or a national holiday.

3.6.5.2 Study Approach

The artificial space phenomena market area was approached from two parallel paths. Consideration was given to defining what an "artificial space phenomenaon" may be and how to create one while simultaneously determining which market areas may benefit from this available capability. The market assessment process involved—

a. Brainstorming possible technical space productions/phenomena.
b. Identifying technical challenges or environmental issues.
c. Determining potential customers and assessing how much they currently pay for similar products.
d. Performing rough order of magnitude market assessments based on comparable terrestrial displays and shows.

3.6.5.3 Market Description

3.6.5.3.1 Space Application Description

There are unique features associated with the upper atmosphere and space environment that could be used to create interesting visual effects. Human sensory stimulation phenomena are an important entertainment medium; witness the popularity of fireworks, laser light shows, and water fountains. Significant international and regional events have been highlighted by major outdoors displays, visible over a wide area. Dynamic and transient, these displays invoke positive emotions and pleasurable feelings. Artificial space phenomena would create new and wondrous visual stimuli to be viewed from the ground with the unaided eye. Many of the concepts explored in this study are imitations of natural events, such as a meteor shower, that humans have been observing, enjoying, and worshipping for thousands of years. Indirectly, these experiences would enhance the perception of space in the public's eye.

In the same manner that civic organizations and/or promoters sponsor or commission displays (e.g. Fourth of July fireworks, inaugurations, victory parades), the market vision would be that similar sponsors would opt to buy the services of a company specializing in artificial space phenomena.

Several types of phenomena are envisioned; many others are likely as creative minds look to space as their "canvas." They include—

a. *Artificial meteor shower*—These are events in which, at a precise time, a bright and colorful series of meteors streaks over the heads of the audience. Brainstorming sessions suggest that modern reentry technology can produce multiple colors and shapes for these objects.

b. *Artificial space clouds*—Analogous to skywriting, colored "clouds" of low-density gas and/or particles would be dispersed in a very low orbit. Similar clouds have been generated using barium and other materials released in the upper atmosphere for scientific study. NASA and the USAF have launched the CRRES satellite specifically to perform these releases, and numerous sounding rocket launches have provided shorter lived equivalent phenomena.

c. *Synthetic auroras*—These are the recreation of one of nature's most awesome spectacles, the aurora borealis and australis, created when energetic solar particles interact with the Earth's magnetic field.

e. *Reflecting structures*—The reflected light of an orbiting object has been watched by humans since the beginning of the space age. A simple display billboard concept was presented to the Atlanta Olympics Committee to be considered as a display for the opening or closing ceremonies for the Atlanta Olympics in 1996.

f. *Luminous points*—Similar in concept to the reflecting structure, only potentially brighter and more colorful, luminous points would be created by controlled combustion. Similar effects have been demonstrated with near-sunset launches of missiles and launch vehicles over the Pacific from VAFB on the California coast. The launch trails and separation products are widely reported when visible over a region ranging from Monterey in the north, to San Diego in the south, and as far east as Las Vegas.

The anticipated phenomena should be spectacular; like fireworks, they should continue to be interesting to people beyond their initial exposure. Phenomena producers must be creative with new innovative ideas to prevent the novelty from wearing off quickly. The production must be competitive with terrestrial displays in terms of price per event per person viewing it, and for duration of display.

It was also identified that concurrent terrestrial publicity and/or advertising of the event would probably also be required. This publicity would induce the potential viewing audience to set outside and look at the event—increasing the market size for the product. This type of concurrent supporting advertising is not uncommon for large regional fireworks or other outdoor displays, usually performed for a promotional tie-in by a firm interested in increased advertising exposure.

3.6.5.3.2 Market Evaluation

The desire for unique and grandiose attention getters will drive this market area. The existing market is not expected to grow substantially and may potentially decrease; the fireworks industry has shrunk since the personal use of fireworks has been restricted and even outlawed in many communities. An artificial space phenomena market would have to capture a large enough share of the existing market base to warrant its technical development.

Furthermore, the wide area affected by the viewing of the space phenomena occurring at relatively high altitudes (400,000 feet and above) compared to terrestrial shows, may also increase complaints and complicate the process of obtaining the necessary permits and easements to perform such space-based phenomena.

3.6.5.3.3 Market Assessment

One event per year is estimated to fall into a category that may be accompanied by a spectacular show, party, or celebration. The market competition in the "artificial space phenomena" arena will come from comparable terrestrial-based displays. The prices of terrestrial displays were analyzed to determine the threshold for a space-based display. Fireworks shows, for example, cost local communities between $20,000 and $100,000 per event. Larger communities (such as major cities) have spent much more money on major celebrations (such as the reopening of the refurbished Statue of Liberty, or the bicentennial of the French Revolution in Paris).

Some communities recover a significant portion of the cost through admission fees and sponsorships. Special effects during major concerts are estimated in the $100,000 to $200,000 price range based on a percent of gross revenues. The sponsors of such events typically do not recoup their investment directly, since the total audience cannot be contained, as any space/skyline display will be visible to a large number of people outside of the target audience. However, this cost of the major display must be substantially less than the gross revenues from one concert or public event.

Assuming a 500-lb system to provide the phenomena to a localized region and transportation at $100/lb, the minimum price is already at $50,000. Once the price of the system itself (satellite structure, chemicals, etc.) is added to the transportation element, a total phenomena price approximately that of a terrestrial system is highly unlikely.

Based upon the few similar events in recent history, there is the possibility of significant negative public perception of this type of display if done on a regular basis. In 1992, when a space-based advertising sign was proposed, several public interest groups began a campaign to prohibit them, based upon "the public's right to an empty sky." In specific the in-space display was claimed to "hamper Earth-based astronomy, add to the growing pollution of the night sky by light and even infringe on everyone's enjoyment of nature's sunsets" (American Astronomical Society policy statement, May 1993). This objection culminated in international protests over the effect of the proposed sign on astronomical observations and a proposed "Space Advertising Prohibition Act," brought forward to the U.S. Congress by Sen. James Jeffords (Republican, Vermont) and Rep. Ed Markey (Democrat, Massachusetts).

A major spectacle display, visible over a wide area, might also generate such protests. If such activities were scheduled on a frequent basis, this would probably happen.

3.6.5.3.4 Market Infrastructure

The artificial space phenomena market area will emerge only after extensive environmental studies are conducted that will determine the effect of space emissions, consequences of added space debris, and obstruction of astronomer views. Additionally, this market area will require development of a policy on space advertising and establishment of regulatory/monitoring procedures.

As most of the phenomena envisioned involve expenditure of matter and/or the sacrificial use of hardware, reliable, periodic launches are required to maintain the capability; low transportation prices are essential to the affordability of displays. Similarly, the orbits into which the display phenomena-generating hardware is placed (beam generators, reentry objects, or large reflectors) must be tailored to provide the specific display over the desired region and the desired time. First-pass analysis indicates the generation of such displays will not allow the reuse of significant hardware nor the placement of simple general-purpose support platforms into orbit. Most probably, a dedicated launch or "sortie" mission will be required for each display.

3.6.5.4 Prospective Users

Potential users of an artificial space phenomenon were identified as local municipalities and special-events producers for such activities as presidential inaugurations, coronations, and spectacle events. Artificial space phenomena could be used during Olympic opening ceremonies to tie the "world" together as the world games begin.

Contacts were made with—

a. Space Marketing, Inc., Michael Lawson.
b. Atlanta Committee on Olympic Games, Neela Garcia, Public Relations.
c. City of Huntington Beach, California, Special Events Coordinator.
d. City of Placentia, California, Steve Pishel, Recreation Department.

3.6.5.5 CSTS Needs and Attributes

3.6.5.5.1 Transportation System Characteristics

This market segment requires a CSTS that is low in cost, reliable, and available. An orbital system with dormancy freatures and a reliable "wake-up" in space capability may be required. The market is directly tied to a scheduled special event or celebration. CSTS must be able to deliver the “phenomena” on schedule in order to capture or maintain any potential market.

The artificial space phenomena market area requires launch prices significantly lower than $100/lb.

3.6.5.6 Business Opportunities

The amounts spent on terrestrial displays such as Fourth of July fireworks are so low that an artificial space phenomena market could not easily be identified at any price. The most optimistic estimate at a price per pound to orbit of $100 or less was 5,000 lb/year market.

3.6.5.7 Conclusions and Recommendations

Defocus the artificial space phenomena market area, since no user base could be identified at any price.

3.6.6 Space Theme Park

3.6.6.1 Introduction

The space theme park market area was originally conceived as a mass market using an in-space facility to provide entertainment. As the market area was further examined, it evolved into integrated ground and space-based destinations, including attractions with a space theme for the purpose of education and entertainment. Part of this assessment identified a market opportunity to take advantage of immediate opportunities to establish ground-based capability with a transition into a space-based entertainment center. In the near term, a space adventure can be created on the ground in the form of a synthetic environment via telepresence and virtual reality techniques. This market opportunity can provide a near-term introduction into the future market for on-orbit theme parks with unique rides and attractions that provide entertainment and accommodations for space tourists.

3.6.6.2 Study Approach

The space theme park interviews investigated a spectrum of entertainment options. The following steps were taken to assess the market area:

a. Brainstormed to discover market opportunities and concepts.
b. Explored candidate immediate needs and future market opportunities.
c. Brainstormed with industry decision-makers to assess interest in the proposed market and to obtain comments and suggestions.
d. Gathered theme park attendance and hotel occupancy rates.
e. Obtained information on theme park and resort hotel investment costs for initial development and expansion options (new attractions, increased capacity).
f. Established the limits on prices to consumers, as defined by ground-based systems.
g. Identified market enablers and potential showstoppers.
h. Analyzed transportation market potential and growth rate.

3.6.6.3 Market Description

3.6.6.3.1 Space Application Description

As part of an integrated development strategy, a space theme park market area could be incrementally developed by starting with networked simulation activities at earthbound parks, in conjunction with small orbital assets. Initial capability can be provided with simple telepresence capability flown aboard the shuttle or on the space station, or with the use of a small satellite left on orbit to provide real-time video output. The opportunity to provide users with a visual experience associated with ascent or deorbit, or even a self-guided "look down from orbit," is intriguing enough that it has attracted market attention from developers of ground-based interactive attractions.

Through the use of this initial, near-term market, more and more functionality could be added. Brainstorming with potential users has identified the desire to include other data coming from the platform, to control the direction of viewing, or to allow simple interaction with surrounding objects in the space environment ("telepresence" or simple "teleoperation"). In the long term, this could lead to the development of dedicated small satellites that would maneuver or pursue each other under the control of earthbound users. Note that a substantial worldwide market can be developed up to this point, without requiring the costly and risky launch of tourists into space.

Based upon market evaluation and contacts with potential users, it is highly unlikely that an in-space theme park serving a market of space tourists can be justified within the next several decades. The ground-based option examined further in this analysis has the advantage of providing a nearer-term market, and generates near-term cash flows with near-term technology.

3.6.6.3.2 Market Evaluation

The ultimate driver for the space theme park market is people's desire to spend time in space. The attraction of being able to go to space (via telepresence or in person) appears to be sufficiently large to justify further refinement of this market. A recent public opinion poll conducted by Yankelovich Partners, during April and May 1993, indicates strong support for the current civillian space program (76% agreement) and for expanding human presence in space (57% agreement).[2]

As discussed in the space tourism section of this report, personal travel to space may attract a reasonable market demand, if costs of space transportation are sufficiently low and an in-space destination is provided. But this market is assessed as not large enough in the next several decades to justify a new in-space destination resort.

Meanwhile, terrestrial analogies for an in-space experience have appeared. Video arcades, including very sophisticated simulation systems, have increasing popularity and are introducing new technology simulators that allow personal interactions and high-fidelity simulations of travels through new environments. Virtual reality technologies are emerging from the entertainment industry. Entertainment centers that offer an interactive artificial experience are quickly opening up in the United States and Japan. One developer is projecting opening 50 locations over the next 5 years in Japan alone (ref. *Daily Variety*, "Disney's Virtual World puts new spin on VR," Matt Rothman, 15 July 1993). These attractions combine an amusement park ride with a video game, story line, and interactive computer-generated environments.

Two distinct examples of current theme park attractions are passive and interactive cases. Universal Studios Tours' "Back to the Future" ride is a passive experience. This ride takes the adventurer through the "future"; actual film footage and computer graphics provide the visual stimulation and a hydraulic platform provides the sensations of motion. The passenger does not interact with the surrounding simulated environment, but is driven through the ride. In contrast, Virtual World Entertainment, Inc., has embarked on emerging interactive gaming centers. Visitors can immerse themselves in an interactive computer-generated battle with fellow visitors or they can fly over the valleys and craters of another planet. This offers intensive interaction with the simulated environment and other players.

A recent market assessment by 4th Wave (VR consulting company) President John Latta, predicts that "the Virtual Reality industry will grow from $110 million in 1993 to $504 million worldwide by 1997." However, the exact level of public interest and the amount of premium prices that users will pay are still being debated within the industry. Based upon the success of the few "virtual theme parks" that have already been introduced, and the acceptance of the initial systems, it is expected that this market will grow substantially in number of locations, revenue potential, and technical capability.

There are several non-transportation-system issues to be resolved in order to mature this market area. The telepresence system resolution and image fidelity require improvements over current technologies. Active efforts are required to maintain and expand public interest to an increased general market (interactive video centers currently attract a predominantly male population with an average age of 24 to 25). Feedback from our interviews indicated a need to attract women and families to reach full revenue potential. A similar transition in the market offering can be seen in the ongoing transformation of Las Vegas resorts into increasingly family-oriented theme parks/resorts to attract a larger family-oriented market.

Several persons contacted during this assessment indicated that they felt that a science- and space-related theme of a ground-based facility would increase the attractiveness of such an offering, due to the public's interest in space-, technology-, and future-oriented offerings. The space-based space theme park will be developed as a total entertainment/tourism venue initially located at the multifunctional facility. Detailed analysis of the support infrastructure and personnel/staff requirements is required to assess the total investment and operating expenses.

3.6.6.3.3 Market Assessment

A cursory analysis of the in-space resort determined that such a facility could not sustain the revenues necessary for market viability. Given a minimum investment of at least several hundred million dollars to design, construct, and launch a facility, an annual revenue of several hundred million dollars is necessary to approach a market level of return. From the space tourism market assessments, it is unlikely that a market of more than several hundred persons is achievable in the next few decades with near-term launch technology. This implies that each user of the in-space theme park must pay in the vicinity of a million dollars for the use of the theme park.

While such costly options are not totally unreasonable, the market consisting of persons who could afford a ticket in the range of a few hundred thousand dollars for space transportation, and then also afford a million dollars for use of an in-space theme park, would reduce the available market even more. The demand for the in-space theme park under these conditions was assessed as too small to justify the facility in space. In-space attractions would have to be part of a larger space tourism infrastructure.

From a near-term business perspective, the "virtual" space theme park approach appears to be much more attractive. The use of space will provide the background for virtual travel to the space environment (such as the exteriors of the space station), or to differing areas on the surface of the Earth through near real-time observations. To provide this service, a high-fidelity video link from space is required, which is well within current technological capabilities. This market is very promising, based on our initial discussions with some of the world's leading theme park designers.

Ground-Based "Virtual" Space Theme Park

Based on discussions with theme park companies, development costs for a virtual reality/human interactive attraction currently run $2 to $3 million, with annual revenue potential estimated at $2 to $4 million. The prices charged for such attractions range from $4 for a 4-minute motion ride adventure, to $9 for an interactive battle (price includes briefing, 10-minute interactive battle, and debriefing for a half-hour experience), and up to $30/hr in a flight simulator.

Market analysis of Earth-based space telepresence attractions indicates that the venture is viable. Annual revenue potential per space-telepresence entertainment center with 30 "seats" was estimated at $7 million, based on $12 per ticket (six tickets per hours) and 1900 revenue hours/week. The space theme park developers will initially purchase telepresence capability (services) from the commercial communications industry.

An initial investment ranging from $3 to $4 million per center will establish the ground-based segment based on similar facility and equipment requirements for current interactive entertainment centers. Annual satellite operating expenses have been estimated at $4 million per entertainment center based on the above number of "seats" and transmission hours needed. Current service fees of $400/hr per transponder (based on current transmission fees for spot usage of satellite transponders for video relay) were used to determine the annual operating expenses. This hourly transmission rate can be reduced if long-term service agreements are arranged or video compression techniques are used.

Two options for delivering satellite transmissions were considered. The first, described above to determine annual operating expenses, involves purchasing commercial communication services on an hourly basis. Such services could be purchased today, if the systems to provide them were available and the data distributed over the existing telecommunications infrastructure. If the video feeds are provided as an add-on to an existing or planned space facility, the incremental cost of operating an individual system is very close to the cost of transmitting the information through the existing telecommunications infrastructure.

In the second case, developers would purchase satellites up front and pay the DDT&E and launch costs, which greatly reduce their hourly costs in exchange for a higher upfront cost. Purchase and emplacement of the facility's satellite infrastructure is estimated in the $60 to $120 million range for three dedicated satellites (to support a 30 "seat" center). The cost driver here is the satellite cost resulting from the transponder requirement necessary to provide interactive channels for each "seat" in the entertainment center (with today's technology, systems are limited to 10 channels per transponder). This cost estimate is based upon a small LEO satellite capable of accommodating 10 visual channels over a single 36 Mhz equivalent transponder, based upon current LEO small Earth observation satellite costs.

This level of investment is comparable to new attraction costs at major theme parks. Development of the MGM/Disney Studio Tours Muppet Vision attraction is estimated at $90 million and the Back to The Future ride at Universal Studio Tours at $60 million ($17 million for film footage).

The aggregate space transportation demand, in mass to LEO, required to support this market does not drive a new transportation vehicle but it does define additional small satellite payload handling requirements. Figure 3.6.6.3-1 presents an estimated annual transportation demand and resultant revenues at current space transportation costs. Current market projection for the "virtual" theme parks indicate that the U.S. population demographics support a demand for 100 centers located in large metropolitan centers. 1990 census data show over 70 metropolitan communities with populations over 500,000, of which 40 are over 1 million. Within each community, an estimated 18% of the population is made up of males between the age of 25 and 34[3] (currently the primary customers for such services).

For global demand, a total market of three times that of the United States (based upon population and income levels) was assumed for a combined market of 300+ entertainment centers. It should be noted the acceptance of such virtual theme parks and artificial reality simulation attractions is very high in other countries, with significant market ventures underway in Japan and Europe, as well as in the United States. Based on current demand for interactive video attractions we anticipate that the first location(s) for the space telepresence center will likely be in Japan.

	High Probability	Medium Probability	Low Probability
New centers per year	3	10	20
Pounds to LEO	4,500	15,000	30,000
Transportation revenues	$23M	$75M	$150M

Figure 3.6.6.3.-1. Estimated Market Size—Available Immediately

Based upon estimates by the CSTS alliance, an order of magnitude reduction in launch costs will reduce the satellite cost by a factor of 5 and the associated transmission cost, if leased, to 20% of the current amount to achieve the same levels of financial return. The cost reduction will stimulate a growth in the market by making the initial and recurring investment cost substantially lower. More centers will open up in more communities.

While the satellite mass increases (projected at a two-fold increase with an order of magnitude cost reduction based upon preliminary satellite design analyses), the cumulative mass to LEO requirement is anticipated to grow from a low of 15,000 lb/year to a high of 85,000 lb/year at launch prices of $400/lb. If the increased market growth is seen, new and replacement satellite needs (due to satellite degradation and technology advances) will sustain a growing demand in mass to LEO.

In-Space Theme Park. The market for an in-space theme park is driven by the number of persons who can afford the ticket to space, as well as the price of such a facility and the ticket cost necessary to justify the facility's development, launch, and operation. As further described in the space tourism section of this report, a conservative approach was taken to estimating the number of people who could afford to and would be interested in visiting an orbiting space theme park/resort. A household was assumed financially able to afford a vacation to the space facility if its income was three times larger than the price. From this statistical income group, the baseline assumption was that 1 person in 300 will visit each year (accounts for individuals taking such a trip once in their lifetime, and for a 10% capture of those capable of taking a trip as actually taking the trip). The baseline visitation rate was adjusted upward and downward to reflect increasing and decreasing affordability of income groups with more or less income.

Worldwide income distributions were estimated by aggregating the populations of countries with per capita incomes similar to that of the United States. These statistics include population adjustments to the year 2020. From this information, the number of households worldwide with income levels comparable to U.S. standards is four to five times greater than just U.S. statistics alone. The number of worldwide households with incomes above a specified level is shown in figure 3.6.6.3-2. The distinction between households and people is that for each of the 94 million households in the United States in 1991 there was an average of 2.63 people.

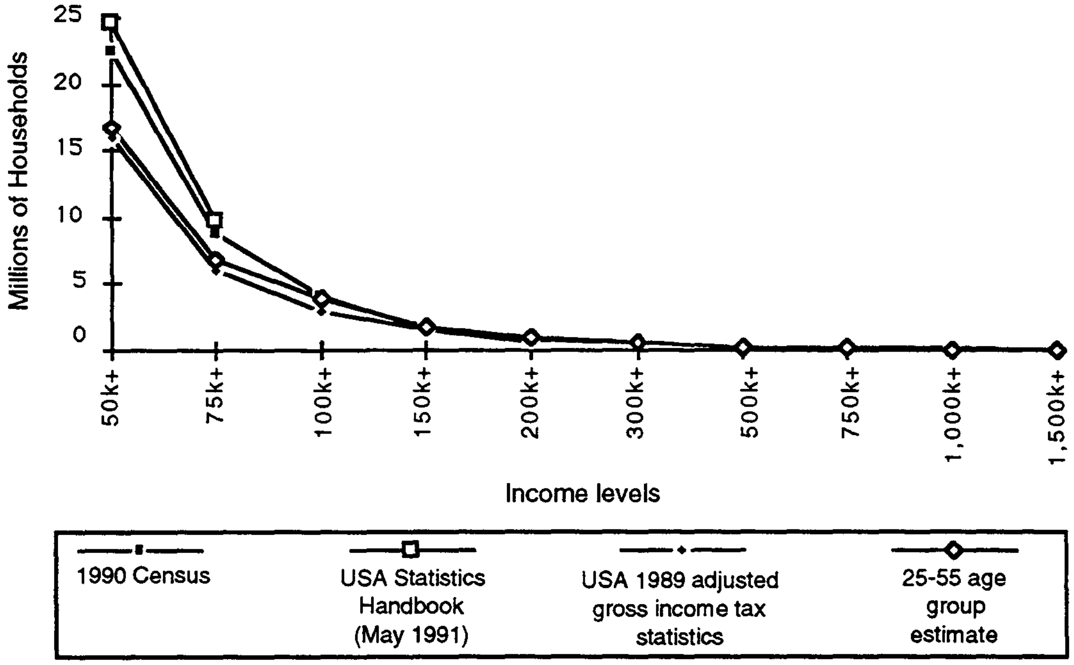


Figure 3.6.6.3-2. Worldwide Household Income Distribution Summary

The consumer's total price to visit the space theme park involves space transportation, hotel/resort accommodations, and space attractions. Recognizing that transportation is only a portion of the cost to the traveler, we conducted an assessment of the total revenue split between transportation, infrastructure, and support services to determine the demand for an all-inclusive vacation (Club Med type). Figure 3.6.6.3-3 depicts the high (bottom curve), medium, and low (top curve) probability market demand at various package prices in 1992 dollars.

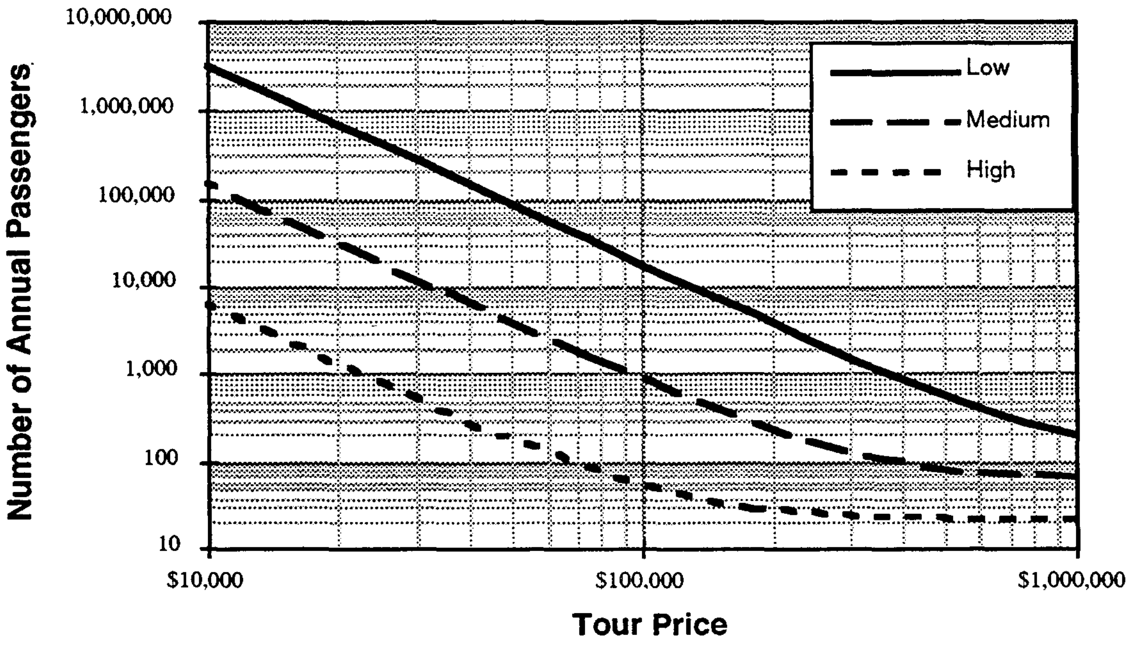


Figure 3.6.6.3-3. Annual Passengers to Space Destination/Resort Versus Ticket Price

3.6.6.3.4 Market Infrastructure

To make the space theme park concept a reality, incentives must be offered now to involve interactive video center developers such as Virtual World Entertainment, Inc., and Iwerks into expanding their capability to include space telepresence attractions. Just as important, industry must initiate educational and general awareness campaigns to spark public interest.

Current communication technology (channels per transponder) and limited available bandwidth may restrict the number of elements forming the resultant LEO satellite constellation. Therefore, for the immediate need, the demand to have space telepresence capability may be greater than the available resources. Breakthroughs in communication and transmission technology as well as signal processing are needed to meet anticipated demand growth.

The space-based theme park will require drastic regulatory and policy changes to permit civilian access to space. Current training regimes for astronauts will have to be highly modified or eliminated to make the transportation similar to air travel. The multifunctional facility infrastructure must already exist to provide auxiliary support systems for space travelers.

3.6.6.4 Prospective Users

The theme park market area conceptually includes everything from Earth-based entertainment centers to orbiting resort hotel-studio tourism complexes. Our efforts have been spent in contacting major studios (e.g., Columbia, Warner, Disney,), theme park operators, resort hotel developers (Hyatt, Marriott, Hilton) and casino developers (Caesar's, Mirage, Circus Circus, MGM/Grand).

Potential users have expressed immediate interest in starting right away with the most basic controlled viewing from cameras on the shuttle manipulator arm or off of a communications satellite.

CSTS contacts included—

a. Virtual World Entertainment, Inc., Tim Disney, Chairman.
b. Walt Disney Imagineering, Inc., Bran Ferren, Senior Vice President - Creative Technology.
c. 4th Wave Inc. (Theme Park Marketing/Financial Consultants), Dr. John N. Latta, President.
d. Warner Brothers, James House, Director - Theme Parks.
e. Hilton Hotels, James Philon, Vice President Corporate Development.
f. Hyatt Development Corporation, John Burlingame, Vice President.
g. Kloster Cruise Lines, Jon Rusten, New Build Department.
h. Interglobal Space Lines, Rand Simberg, President.

3.6.6.5 CSTS Needs and Attributes

3.6.6.5.1 Transportation Characteristics

Transportation system attributes differ for the ground- and space-based market segments. The immediate market for ground-based space-telepresence capability demands small payload (<1000 lb each) delivery to low Earth orbit. The satellite systems will form a LEO constellation for interactive communication. No return payload capability is required. These payloads can be flown on multiple-payload manifests, assuming they can be delivered to the required orbit. Note that the particular LEO destination may reduce comanifesting ability and/or practicality.

The future space-based market requires a human-carrying transportation system. A pressurized volume is required to bring passengers to and from a LEO space theme park.

To support the early ground-based segment the transportation system must support delivery of multiple small-satellite-type payloads (< 1000 lb each) annually to various LEO destinations. The LEO destinations may include polar orbits. The number of payloads (at 1000 lb) per year is anticipated to grow from 9 initially (3 satellites per center/3 centers opening per year) to 60 to 90 as the market expands and transportation costs are reduced. The peak demand is anticipated to be around 135 per year at $100/lb. As transportation costs are reduced, the size of these payloads is expected to double.

The space-based space theme park will be located in a low Earth orbit. The space-based segment will require initial facility infrastructure delivery and construction, which necessitates a vehicle with large payload delivery capability. Once the facility is operational, a commuter-type transportation system is required. Vehicle passenger capacity requirement will grow from 15 to 25 passengers initially to 75+ passengers later on. Early requirement is for transportation system to operate on a weekly basis, which supports 52 flights per year. As demand increases we anticipate the need for daily flights and multiple vehicles. Since the primary transportation system payloads are humans, the system safety must be comparable to commercial air transportation.

3.6.6.5.2 Ground Handling

Ground handling requirements will be minimal. Satellite systems will be designed and integrated into the vehicle as standard modules. The space-based segment will require passenger boarding accommodations similar to commercial aircraft handling requirements.

3.6.6.5.3 User/Space Transportation Interfaces

The early satellite payloads can be launched in groups or as secondary payloads. Launch services customers can manifest their payload into available slots or reserve the next open vehicle.

As the space-based segment opens up, the routine users of the space transportation system are passengers only. The space system will be booked and boarded just as commercial aircraft.

3.6.6.5.4 Improvements Over Current

Significant improvements over current space transportation systems are required to support the future goal of a space-based space theme park. They include—

a. Launch costs at $100/lb or lower.
b. Launch on schedule—predictable.
c. Routine scheduled service.
d. Airline-like passenger handling and safety.

3.6.6.6 Business Opportunities

3.6.6.6.1 Cost Sensitivities

In the immediate timeframe, with current launch costs, the only market for space theme parks is interactive ground entertainment ("virtual" space theme park). Based on industry interest, this market is "ready when we are." It is small, but steady in demand. If transportation costs are reduced an order of magnitude, the ground entertainment segment will grow and a space-based market will emerge. The numbers at $600/lb in the figure below represent a 18%/82% split between ground- and space-based transportation requirements. With further transportation cost reductions ($100/lb) the space-based space theme park takes off. At $100/lb there are overwhelming numbers of people who will be able to go to space and interested in doing so. Figure 3.6.6.6-1 shows the sensitivity to transportation price for the medium-probability space theme park market.

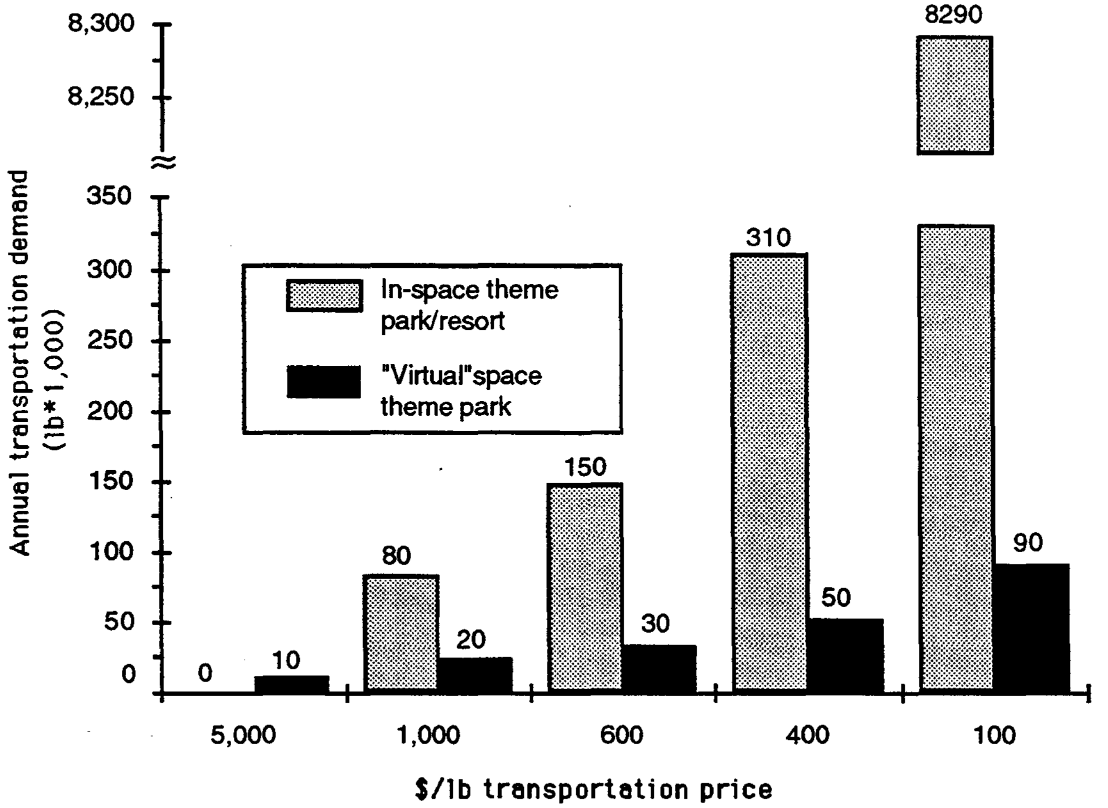


Figure 3.6.6.6.-1. Medium-Probability Annual Transportation Demand to Space Theme Park/Resort as a Function of Transportation Price

3.6.6.6.2 Programmatics

The ground-based space telepresence market has immediate revenue potential, which is driven timewise by the ability to put up the satellite (communication) infrastructure, and limited by the amount of available bandwidth. Annual transportation system revenues generated from the Earth-based segment are initially in the $25 to 75 million range. As transportation costs come down, the space-based theme park becomes commercially viable, which results in a significant increase in revenue potential. The space-based activity quickly dwarfs the ground-based demand. Figure 3.6.6.6-2 shows the predicted annual transportation revenue profile (medium probability) for the individual elements (ground- and space-based entertainment). As illustrated in the figure, introduction of a new, transportation system with a lower price to users results in a decrease in the Earth-based space telepresence revenues while enabling the on-orbit space theme park/resort market to emerge, resulting in a substantial growth in transportation revenues.

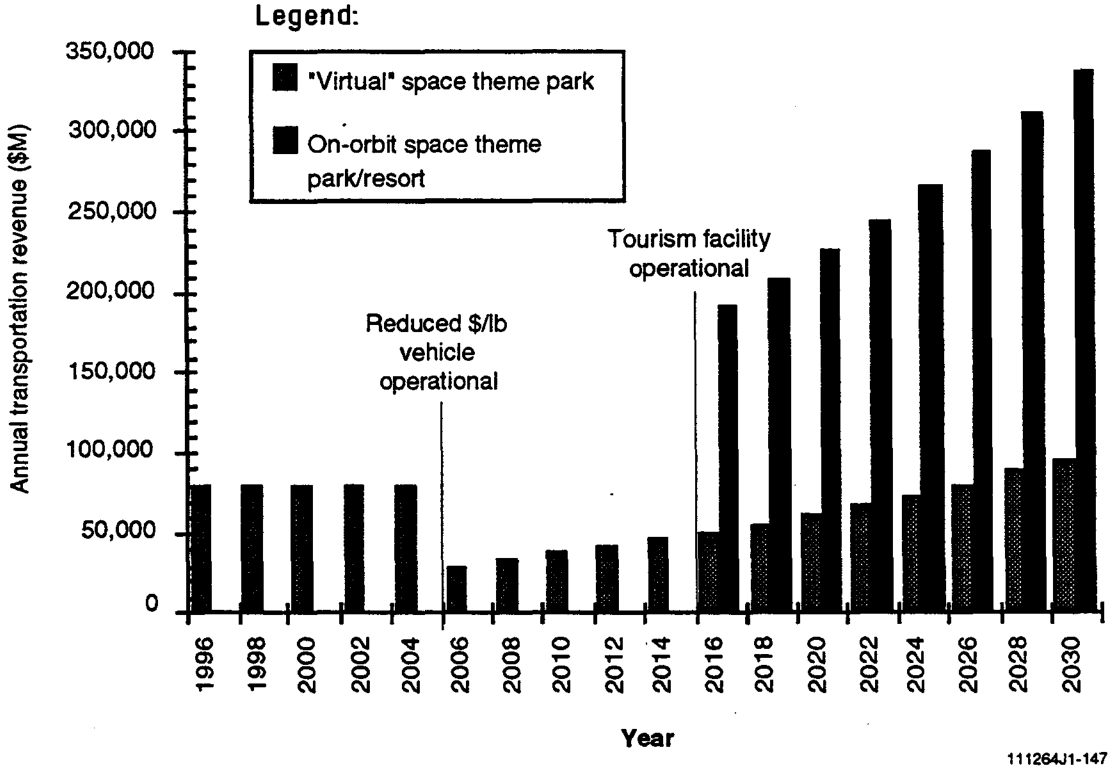


Figure 3.6.6.6-2. Space Theme Park Market Area Revenue Generation Assessment

3.6.6.7 Conclusions and Recommendations

The space theme park market appears to be significant, and it has immediate needs as well as future applications. The study of this market must continue with greater indepth research, including international interest (especially Japan and Europe). Bookkeeping related to transportation demand (lb/year to LEO) will be accomplished in coordination with tourism and the on-orbit facility infrastructure included in the space business park analysis.

REFERENCES

1. "Economic Impact Study of the Film Industry in California," KPMG Peat Marwick for the California Chamber of Commerce and the California Film Commission, 1989.
2. Yankelovich Partners, Newport Beach CA. Survey commissioned by Rockwell International Corporation, based on interviews with 1002 U.S. registered voters. Poll margin of error ± 3%.
3. World Almanac.

3.7 NEW MISSIONS

3.7.1 Introduction

3.7.1.1 Results Summary

The CSTS new missions category was established to recognize the existence of other areas of potential future space activity that did not fit easily into the other nine categories. The missions in this category include—

a. Space debris management, examining the market potential of mitigating the impact of orbital debris.
b. Space medical facilities, looking at the use of in-space facilities to provide unique medical treatments.
c. Space hospitals, examining the potential of an in-space site to treat and cure patients, including extended stays.
d. Space settlements, capturing the popular idea of large human habitations in orbit.
e. Space agriculture, representing the potential for agricultural activities in space.
f. Space business park, representing a multiuse commercially oriented facility in Earth orbit.

Many of these new missions address uncertain markets, and while they may have worthwhile missions, they may require very low transportation costs (well less than $100/lb to LEO) to be commercial viable. The only mission area that was evaluated as having substantial commercial viability was the space business park, representing a commercially oriented, multiuse facility in LEO. The space business park was estimated to have a commercially viable market rate of return at about $560/lb to Earth orbit, achieving a 20% internal rate of return (IRR) after 10 years of operations.

3.7.1.2 Associated Market Segments

Based upon market area brainstorming, reviews of the literature, and contacts with potential users, six different market areas were included in this category.

a. **Space Debris Management.** Orbital debris is becoming more and more of a significant problem in space operations. As future space operations increase, this problem may be expected to grow. This market area examined the market potential of mitigating the impact of orbital debris, including the market viability of dedicated debris removal systems. However, the market assessment showed that for LEO operations, this market may most effectively be addressed by regulation and additional shielding on LEO systems. No significant space transportation demand was identified for this market area.
b. **Space Medical Facilities.** Based upon market contacts, several promising medical treatments that used the space environment (primarily microgravity) were identified. However, there is large level of uncertainty in the use of these treatments, based upon a lack of clinical or experimental data on them. Furthermore, to ship a patient to space and provide the treatment on orbit at rates equivalent to terrestrial costs would require launch costs, of $100/lb or less.
c. **Space Hospitals.** This market area was assessed to be very similar to the space medical facilities, except that long-term care would be provided to patients in an in-space facility. Again, to ship a patient into space and provide a long-term stay on orbit at costs equivalent to terrestrial costs would require launch costs of $100/lb or less.

d. **Space Settlements.** Representing the popular idea of large human habitations in space, this market had the weakness that the participants of the large habitats needed some occupation and the settlement needed some cash flow to justify market investment and support. Such cash flows could only be found if other large-scale space business activities, such as solar power satellite (SPS) construction in GEO, were underway. Based upon the market area potentials for these other areas, the assessed market for space settlements was determined to occur with transportation systems cost well under $100/lb to orbit.

e. **Space Agriculture.** Initially, this market area was conceptualized as a large in-space facility providing high-density and high-intensity agricultural production. As with the space settlements market, this venture would require other very large in-space business activities to occur before justifying this market area. Based upon the market area potentials for these other areas, the assessed market for space agriculture was determined to occur with transportation systems cost well under $100/lb to orbit.

f. **Space Business Park.** Conceptualized to represent a multiuse commercially oriented facility in Earth orbit, this market area was identified from the preliminary results of several market areas that did not generate enough revenues by themselves to justify a separate space facility. As an aggregate of this market area's demand, it was assessed that a multiuse, commercially oriented space facility could be a viable commercial venture at launch costs of greater than $560/lb to orbit.

3.7.1.3 Assessment Approach

The overall assessment approach for this market area followed a two-pronged approach. The first path identified data to assess the current status and market forces for the particular area. These included contacts with potential users in the market area, identification of key players and regulators in the market, competing technology for the space market areas, and market factors that might drive the feasibility and competitiveness of a space solution.

The second prong of the assessment approach was to develop a business and technical feasibility model of potential ventures in this business area. In particular, these models were developed to answer the question, "Is this approach a good business deal?" (That is, Does this approach fit within current business ranges for investment size and returns?) As part of this approach, technical feasibility assessments were performed on the market concepts assessing if the project could be built and launched; identifying critical technology developments needed; and examining the production/engineering/technology resources needed for the business venture to see if they will be available in the time period considered.

To be included in the market projection, each market area assessed had to show business and technical feasibility for the market area—and match the market survey data such that there was some level of validation from the surveyed market data to establish credibility of the projections for the future market opportunities. From these assessments, sensitivities to market and technical assumptions were examined and a threshold cost, below which space transportation had to provide an acceptable rate or return, was determined.

3.7.2 Space Debris Management

3.7.2.1 Introduction/Statement of Problem

Near-Earth orbits contain a great deal of space junk, including discarded upper stages, dead satellites, and pieces of antisatellite weapons. The amount of debris (6,600 individual objects tracked by NORAD) is so great that it threatens to multiply through self-collisions. It is certainly technically feasible to identify, target, rendezvous with, and reenter the larger objects, but is it a commercially viable venture? Who will pay to remove the debris? Most of the debris is unclaimed and without ownership. If there were sufficiently valuable assets in LEO, then the owners might collectively pay to have a major threat removed as a kind of insurance against catastrophe.

The market for space debris management appears primarily driven by—

a. Removal or negation of space debris that could pose a hazard to other space assets.
b. Removal or negation of other systems that could develop into a space debris hazard, such as spent rocket stages or satellites that have exhausted their attitude-control propellant.

The sizing of the market for space debris management is determined by several factors, including—

a. The amount of activity in regimes affected by debris.
b. The effectiveness of international regulatory controls upon space debris-producing events.
c. The technical capability of removing debris or negating possible debris sources, including use of terrestrial-based systems.

The assessed primary customer for this market area is governmental organizations, although the possibility of an insurance-funded system has been raised. This future market is highly dependent upon the above market factors.

3.7.2.2 Market Evaluation

The assessment approach used to evaluate this market area was—

a. Use of brainstorming sessions to generate market concepts and customers.
b. Review of current literature to establish rough market sizing, forces, and prior data for market areas.
c. ROM market analysis to establish preliminary market impacts.
d. Examination of how a future low-cost space transportation system could affect these markets, including the size of the projected demand.

The primary driving force in this market is the desire of space operators to remove potential threats to their space systems. As economic activity increases in space (including for governmental purposes), risks also increase. Sources of debris multiply, greatly increasing the debris flux experienced by assets in orbit. This creates an economic risk from space debris, which is in turn dependent upon the debris flux and the amount of assets placed in the regions at risk. Other market forces include the ability to control events that contribute to space debris, such as regulation of space systems to prevent events that might cause an increase in debris and the technical cost and relative capability of a technical solution to remove or negate debris risks.

From discussions with market players and the CSTS assessment activity, probabilities for this market area will be two-pronged. First, regulations will be imposed upon space systems to reduce the number of space debris-causing events. The current rate of growth in debris[1] is estimated at 2% annually, and while such regulations will reduce the rate of change at which space debris is produced, they will not reduce existing debris. For a ROM market assessment, it is assumed that the regulations will reduce the rate of growth in orbital debris to the current 2% level, regardless of increase space systems usage.

Second, protection against debris is presumed to be done in the simplest method possible. Passive protection systems are preferred over active debris removal systems, unless there is a clear economic advantage for the

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[1] From Rockwell International SSD91D0771 "Orbiter Space Particle Impact Hazard Study," Oct. 1991.

active system. Debris in low-altitude orbits will be gradually swept out by atmospheric drag. It is assumed that the debris in low-altitude orbits will not substantially increase relative to the debris in higher orbits.

Last, it can be assumed if space transportation costs decrease, the mass of a satellite can be increased to provide additional debris shields. The cost of manufacturing these shields and adding it onto the spacecraft is expected to be much less than that of the transportation cost and significantly less than the core spacecraft $/lb to fabricate[2] . By first approximation, the cost of adding additional shielding to reduce the current level of debris protection is negligible, if space transportation costs decrease. This was assumed to be the high-probability demand market case.

If additional shielding is added to increase the current level of debris protection, this may be done at a reasonably low cost. A sample calculation based upon orbiter databases, LDEF data, and the orbiter debris impact methodology shows in the worst case that to reduce the probability of debris penetration by 10 times requires an increase in the thickness of the frontal shield by 2.5 times[3] . (Note: this is the frontal surface area; other sides are significantly less, and the impact on the total mass is dependent upon the volume, not area.) This implies that the cost of the surface shielding would increase by 2.5 times.

Using the parametric modeling data for the impact of low-cost space transportation upon satellite system design (ref: Boeing parametric data), it was estimated that the overall mass of the satellite would increase by a factor of 2 (not including this increase in shielding mass), and the cost of the satellite would decrease by 5 times. Current spacecraft cost $40,000/lb (and up) for hardware, which would indicate a decrease to about $4,000/lb for an order of magnitude decrease in space transportation costs.

It should be noted that orbital debris shielding is typically a very simple multilayer metallic wall design. The initial impact of the debris upon the outer layer of the debris shield vaporizes the incoming debris particle (and a small part of the outer layer of the shield) as the kinetic energy of the incoming debris particle is dissipated. The second layer of shielding stops this vaporized remainder of the debris particle. It is possible for the incoming debris particle to have sufficient high mass (and energy) to punch through the shield, but the vast preponderance of debris particles is quite small, and the fewer more dangerous particles can be tracked, their impacts predicted, and a space facility maneuvered away from a potential impact.

Whereas the additional mass to increase the orbital debris shielding is primarily simple structure, this indicates additional shielding will cost relatively little for a much lower $/lb to acquire and manufacture the shield. This is particularly true with larger satellites where the cube/square relationship of enclosed volume-to-surface area dominates the overall mass of the satellite. Adding another pound of shielding is relatively small in a large satellite where the average cost per pound of satellite is an order of magnitude higher.

This provides the basis for the high-probability and medium estimate of the demand for space debris management activities. At high probability, regulatory actions will occur to decrease the generation of space debris. Current space system designs include debris shielding, and for a conservative high-probability estimate, it can be assumed that there will be no increase in satellite mass other than volume to decrease unit cost. At medium

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[2] Shield material is basic structural materials: window panes, aluminum sheeting, and so forth. The fabrication cost of such structural items is typically less than $100/lb, which is significantly less than typical transportation costs and substantially less than for other elements of the spacecraft on a $/lb fabrication cost.

[3] For simplicity in these calculation (less than 1% occurrence) velocity in LEO of 15 km/sec^2. To increase the factor of safety, it is assumed the density of the window/frontal surface memberthe worst case is assumed -- a solid window pane of sufficient thickness to stop a heavy metal particle of debris (density 10 g/cm^3) traveling at a low-probability is increased sufficiently to decrease the probability of breakage by an order of magnitude, or to withstand a hit from a particle whose probability of hit (flux) is one-tenth the reference case. From SSD91D0771, for a satellite in LEO 28.5-degree orbit, it is found that the flux decreases by an order of magnitude with an increase of mass in the particle by 11 to 12 times. It is found that penetration depth (including cracking) is proportional to the relative mass^0.4. Thus, increasing the thickness of pane of glass by approximately 2.5 times would allow the withstanding of particles of sufficient size to reduce the probability of breakage by an order of magnitude.

probability, an increase in the space debris flux can be accommodated by a slight increase in the satellite mass, but natural debris removal mechanisms in LEO would discourage buildup to permanently high levels before the regulatory system would be able to implement controls. Therefore no significant increase in space debris control systems is projected for the medium-probability demand markets.

For a low-probability estimate, several active debris removal systems have been proposed[4], but the use of such systems is limited due to the wide dispersion and low density of space debris (~ 6,600 objects greater than 1 cm diameter in all of Earth orbits) and the difficult technical challenge of developing a system that can capture or destroy large pieces of debris with significant kinetic energy without rendezvousing with them. Similarly, these systems would have to overcome cost-effectiveness barriers since the probability of a major impact upon any single satellite is quite small, reducing each individual market participant's desire to pay for a space debris removal system. The cost of a specially built system to address this problem would be in the range of $200 million or higher, depending on the specific design of the system. (This is derived from a ROM estimate developed for a one-of-a-kind system massing about 10,000 lb in LEO, based upon current satellite hardware and transportation costs.) If such a system were proposed, it would probably focus upon sweeping out an economically valuable region and then relying upon regulatory processes to maintain the cleared volume free of additional debris.

Based upon brainstorming and contacts with experts in the field, a low-probability market projection might be a set of three debris removal satellites—one at LEO, one in GEO, and one in a high polar orbit. Sizing of these systems, based upon the orbital sweeper concept from the NASA Johnson Space Center, would range up to approximately 60,000 lb in LEO equivalent mass[5]. Assuming these systems operate upon a 10-year replacement cycle, this translates into an average of 6,000 lb in LEO equivalent mass per year.

This yields a ROM projected market as outlined in figure 3.7.2.2-1:

At current space transportation costs—	All probability estimates: No increase in transportation mass demand, due to no increase in satellite launch mass, but regulatory actions to decrease generation of space debris.
At one-tenth current space transportation costs—	High- and medium-probability estimate: No increase in transportation mass demand, due to no increase of satellite launch mass for shielding increase, but regulatory actions to decrease generation of space debris. Low-probability estimate: An average of 6,000 lb/year to support an active debris sweeper system.

Figure 3.7.2.2-1. Projected Market for Space Debris Management Market Area

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[4] Thermal Sciences Corporation, "Methods for Disposal/Recovery of Orbiting Space Debris, 5 July 1993. U.S. Patent 4991799, "Space Debris Sweeper" to NASA/JSC (Andrew Petro).

[5] This assumes three 5,000-lb active sweeper systems, based upon the JSC/Petro space sweeper concept. These would not remove debris but break up larger chunks into chunks small enough that shielding could handle them. This estimate assumes 1 GEO sweeper (LEO equivalent mass 45,000 lb), 1 LEO 28.5-degree sweeper (5,000 lb), and 1 polar orbiting sweeper (LEO equivalent mass 10,000 lb).

3.7.2.3 Market Infrastructure

This market can be served by the same infrastructure in place for other mission areas. In the high- and medium-probability markets, there is no demand. In the low-probability demand model, the active debris removal systems could use existing infrastructure elements such as upper stages and launch processing and control systems.

3.7.2.4 Prospective Users

The assessed primary customers for this market area are governmental organizations, although the possibility of an insurance-funded system has been raised. An individual's risk is fairly small in any year for a space debris hazard; however, in aggregate, risk is significant. Mitigation from these infrequent but highly consequential events is typically performed either by the largest user with the greatest assets at risk (currently the government) or through an insurance company acting as proxy for numerous individual users.

Prospective users contacted in this market survey included—

a. Satellite manufacturers (see app. B.2).
b. LEO space business park potential developers and users (see sec. 3.7.6 below).
c. Andrew Petro, NASA JSC (designer of space debris removal vehicle, U.S. Patent 4991799).

3.7.2.5 CSTS Needs and Attributes

No unique CSTS-specific system requirements were generated from this analysis. A system offering similar capabilities and services to current transportation was sufficient.

3.7.2.6 Business Opportunities

There is virtually no new business opportunity for space debris removal systems, even at very low transportation prices. At the low transportation prices, the cost of additional shielding is substantially less than a dedicated system for space debris removal. If additional shielding is added, this mass and cost are very small compared to the overall mass of launching new space systems. Even in the lowest probability demand model, only 6,000 lb of mass on the average is projected if space transportation costs were reduced by a factor of 10.

3.7.2.7 Conclusions and Recommendations

This market area was defocused due to a lack of sufficient market demand.

3.7.3 Space Medical Facilities

Vision statement: *In the year 2010, 0g facilities exist in LEO for the treatment of heart disease, pulmonary diseases, and severe burn patients.*

3.7.3.1 Introduction/Problem Statement

Space medical treatments were identified in some of the initial brainstorming sessions as a potential market for a new low-cost, space transportation system. Health care is a trillion-dollar industry worldwide and if the space environment can be successfully and affordably used to treat life-threatening or debilitating diseases, then space medicine could become a major driver for low-cost space transportation.

3.7.3.2 Assessment Approach

The medical field was divided into categories that might be future markets for in-space treatment, and then demographic studies were performed to estimate the U.S. market demand (in number of procedures and patients). In parallel with this effort, direct contact was made to specialists in these areas to obtain direct information on how such treatments could use the space environment. These direct contacts included some brainstorming sessions regarding the use of the space environment for medical treatments with experts in the field.

First, general statistics were gathered concerning illnesses and injuries that affect a large portion of the population and/or require long hospital stay times, expensive surgery, or expensive simulations of the zero-gravity environment of space. Then, those areas were further examined to predict the benefits and drawbacks to treating those patients in space. Some of the areas that are promising enough for further consideration are heart disease, pulmonary diseases, orthopedics, burn patients, physical therapy, rehabilitation, and quality of life (retirement in space). Each of these areas requires extensive research, which may also prove to be beneficial to patients on the ground. Pure medical research is the most promising area to apply to space, especially in cancer research and HIV research.

The field of medicine is quite extensive with an overwhelming number of areas to consider. To obtain a broad spectrum of medical applications for space, it was necessary to be in contact with many different specialties of medical personnel. Several excursions were made to hospital facilities and general statistics were obtained from major insurance companies and local hospitals. In this way, it was possible to estimate costs for running a medical facility in space and compare this to treating patients on the ground.

There are several adverse effects on the human body from space flight, such as muscle atrophy and calcium loss, that can be counteracted to some extent by exercises and conditioning. Several opinions have been obtained about the benefits for patients who are treated in space, assuming that proper countermeasures for the adverse effects are applied. Some areas, such as treating AIDS patients, were not extensively considered because it was reasoned that those patients would not benefit from a space hospital any more than a ground-based one.

3.7.3.3 Market Description

Although some of the major areas of application of the medical sciences to space are not included in mortal illnesses or injuries, it is helpful to see which diseases or injuries are the primary causes of death in the United States. Figure 3.7.3.3-1 has nationwide statistics on the leading causes of death.

Cause of death	Number of people affected
1. Heart disease	765,156
2. Malignant neoplasms (cancer)	485,048
3. Cerebrovascular diseases	150,517
4. Accidents (mostly motor vehicle)	97,100
5. Chronic obstructive pulmonary diseases	82,853
6. Pneumonia and influenza	77,662
7. Diabetes mellitus	40,368
8. Suicide	30,407
9. Chronic liver disease and cirrhosis	26,409
10. HIV infection	16,602

Figure 3.7.3.3-1. Ten Leading Causes of Death in the United States (1988)

The table above gives a pretty good idea of the leading causes of death in the United States; however, it does not go into the diseases or injuries that would require patients to be hospitalized or the prevalence of the cases.

3.7.3.4 Market Evaluation and Assessment

Heart Disease. The number of people who are potential candidates for a cardiovascular intensive care unit in space was determined for two groups of patients. The first group are those patients who require a coronary bypass, and the second group are those who require a heart transplant. The numbers are shown in figure 3.7.3.4-1 by financial status. Note that current costs for a coronary bypass is about $25,000 and a heart transplant around $100,000 (these prices are based upon market contacts).

As figure 3.7.3.4-2 shows, a large proportion of ailments treated at hospitals is for heart disease treatment; however, space hospitalization for injuries may also prove beneficial.

Coronary Bypass Patients Income per Procedure	**Potential Space Market Size Procedures per Year**
$50,000	133,268
100,000	21,967
250,000	2,973
500,000	875
1,000,000	330
2,000,000	160
Heart Transplant Income per Procedure	**Potential Space Market Size Procedures per Year**
$50,000	808
100,000	133
250,000	18
500,000	5
1,000,000	2
2,000,000	1

Figure 3.7.3.4-1 Market Size for Cardiovascular Patients Treated in Space

Disease Name	Mortality	Prevalence	Hospitalizations
Coronary heart disease	593,111	7,191,000	1,615,320
Stroke	159,204	2,714,000	660,750
Diabetes	37,178	5,547,000	473,863
Chronic obstructive lung disease	71,099	14,786,000	743,089
Malignant Neoplasms (cancer)	485,048	-	-
Breast cancer	40,415	139,816	202,975
Colorectal	55,811	-	195,785
Lung cancer	125,511	147,771	283,504
Cervical cancer	4,543	12,625	36,342
Chronic liver disease	26,151	-	66,325
Trauma	150,000	~57,000,000	~2,000,000
Spinal cord injury		15,000	-
Burns		160,000	80,000
Limb injuries		-	1,000,000

Figure 3.7.3.4-2 Chronic Diseases (1989) and Injuries (1992) Prevalent in the United States

Orthopedics. Many injuries would benefit from in-space care.

a.. *Spine and disk*—One area that may be helped by the 0g environment of space is in spine and disk injuries or diseases and bone quality.

1. Symptoms and Treatment. Some spine or disk problems may take a year to heal with physical therapy sessions two or three times a week. In particular, many of these treatments deal with building up muscles and spinal tissue to handle the full forces from the terrestrial 1-g field. Physical therapy includes posture and stabilization exercises and low-impact aerobics. Often the conditions of 0g environment are mimicked in order to reduce the stress on the spine from a person's body weight.
2. Support personnel required. A physical therapist and nurse's aide would be needed.
3. Space Application. In a space medical facility it would be possible to have that same person doing physical therapy and exercise to increase the support strength of the back muscles while allowing the trauma of the injury to heal without the pressure of 1g. Part of the physical therapy regime is low-impact aerobics, which could easily be carried out in a wide variety of ways if the patient could undergo treatment in space.

b. *Fractures*—It is not yet known whether weightlessness impedes or helps the healing process. Recent Spacelab life science experiments (yet unpublished) will provide initial data in this area.

1. Symptoms and Treatment. Clinically it has been found a bone will heal itself faster if it has to carry weight (Wolff's law). However, in many cases, placing the full weight of the patient upon the fracture will produce further injury until the bone achieves some level of healing. In ground-based hospitals, the broken bone is often immobilized in bed rest because the weight of the person is too much for it to handle. Patients are also treated by supporting the fracture to allow mobility. The bone is only slightly

stressed in this case and tends to heal better. The advantage of a space-based treatment is that the amount of weight placed upon the fracture may be varied over a complete range from 0g to full weight.

2. Support Personnel Required. A technician trained in setting fractures, an orthopedic doctor, and a physical therapist are required.
3. Space Application. If that same fracture were to be treated in 0g or reduced-g in space, then it is hypothesized that the person would be able to keep up mobility and a small amount of stress on the bone without overwhelming it, to encourage a faster healing time.

Burns. Burn patients, especially severe cases, seem to be the category that would benefit most from the 0g environment.

a. *Symptoms and Treatment*—Burn patients with severe burns over a large percentage of their bodies need immediate fluid resuscitation to replace the fluid that their bodies lose rapidly with skin loss. Some patients are flown into burn units from remote areas in order to receive adequate care. After about 72 hours, when they have been stabilized, the patients begin physical therapy to keep up their mobility. The discomfort of burn patients with severe burns over a large percentage of their body is immense. Special particle beds are used to apply as little pressure to the patient's body as possible. Skin grafting procedures also begin right away, grafting approximately 10% of the body in one session. These surgical procedures continue about once a week until the burned area has been adequately grafted. Physical therapy continues during this period in order to maintain the range of motion of the patients as the skin grafts "take."

   Because circulation is poor in the extremities of a burn patient, the blood often pools, causing discomfort and sometimes bleeding under the skin grafts. Once bleeding occurs under a graft, the graft will usually not take. More surgery is then required to repair the damage. After several weeks of grafting surgery, and once the grafts have taken, physical therapy is intensified to keep the new-forming scar tissue supple and stretched out. For a few months, the painful process of stretching out new scar tissue must be strictly implemented. Patients must see a physical therapist two to five times weekly in order to keep up mobility and range of motion. Special pressure garments are worn to shape the scar tissue correctly and provide support for the internal structure.

b. *Support Personnel Required*—A surgeon, physical therapist, dietitian, psychologist, and nurse's aide are required. Burn patients pay up to $2,500/day in the burn intensive-care unit.

c. *Space Application*—In the 0g environment of space, the first benefit that is realized is the increased comfort of the patient. Burn patients could be anchored in place with minimum surface area touching anything but air. Once the patients are stabilized and the skin grafting is begun, 0g will allow the surgeon to manipulate the patient much easier and less harmfully during surgery. In space, it has been noted that the blood comes up into the chest area rather than staying in the lower extremities, so patients would not have the trouble of blood pooling in the lower legs and causing bleeding under grafts. It is hypothesized that more grafts will take, requiring fewer surgical procedures, and the grafts will cause less scarring because they will stay on with less stitching. In 0g, patients can begin physical therapy at once, beginning with mostly range-of-motion exercises while the patient is still extremely weak, and then doing cardiovascular exercise soon after. When scarring begins, the patient could stay in 0g for continued physical therapy or go to a reduced gravity module and then to a full-earth gravity module in preparation for the return to Earth.

In all the categories above, the main market drivers are cost and patient needs. The cost to treat patients in space must be compared to the cost on the ground, and then it must be determined if the patient benefits are great enough to justify the extra cost. That is, would insurance companies pay the extra money for clients to have better medical treatment in space? But, as stated previously, the main difficulty with assessing the potential for this market is the very limited database upon treatment of ill persons in space. It is hoped, however, that this study will be able to target potential markets where additional research in space medicine can be performed.

The cost of a 1-week stay in an orbital facility can be estimated to be in the range of $100,000 to $600,000 per week, depending upon transportation cost. The space business park analysis in this market area (sec. 3.6.7) developed a cost of about $600,000 for a 1-week tourist ticket at about $560/lb, including one staff for every four visitors. This can be taken as a representative level of cost for a patient. Using this number as the basis for estimating space traffic demand for space medical procedures indicates a very limited market of a few high-cost procedures per year.

This market was assessed as low probability. There are too many unknowns remaining, primarily driven by the lack of a database on ill or injured patients in a space environment, to include in the high probability or medium probability cases. But there remains enough potential to include a low probability case of a few patients, in the range of one to five per year. Since these numbers are much less than that of the space tourism medium-probability model of a few hundred per year (see sec. 3.5.6), these numbers are assumed to be included in that value. No separate line in the demand model is shown for this market area.

3.7.3.5 Prospective Users

The biggest market enabler for space medicine is research. There has been little research done in space that could lead to treating patients in space. If research can be done it will more clearly show patient benefits or drawbacks, and it will illuminate potential markets that right now are invisible because of lack of knowledge. If research can be done on the musculoskeletal system, for example, then there will not only be knowledge that will help for sending patients to space, but there will also be applications to Earth medicine. There are still significant unknowns in the medical field, and research in space can provide key insights into understanding the human body as a whole. By taking it out of the Earth's gravity field, a new wealth of information about the human body can aid doctors in treating diseases on Earth.

A second enabler in the market for space medicine is the backing of the medical community. At this time, there is very little interest or knowledge in the medical community in space medicine and a lot of skepticism. However, the initial market contacts conducted in this survey indicated this level of interest is driven by unawareness of the potential advantages from the space environment, and by the lack of data on the impact of the space environment upon ill or injured persons. If the medical community at large can be educated to begin thinking in terms of a microgravity hospital facility, then there will be an increased pool of ideas for space applications, in addition to informed opinions on the direction space medicine should take.

The third biggest market enabler in the field of space medicine is public will. The medical field is one of the most prestigious and giving fields. If it can be made known to the public that there are benefits to patients if only they can be treated in the space environment, then the public support could initiate much-needed funding for a space medical facility. (Many people are more likely to support such a humanitarian effort.)

Specific CSTS contacts in this market area included—

a. Harborview Medical Center, Seattle, Washington.
    1. Tracy Varga—Physical Therapist/ Orthopedics.
    2. Merilyn Moore—Physical Therapist/ Burns.
b. University of Washington Medical Center, Seattle, Washington.
    1. Dr. Greenlee—Orthopedics.

2. Dr. Bassingthwaighte—Center for Bioengineering.
3. Dr. Kushmeric—Professor Radiology, Physiology, and Biophysics.

c. University of Southern California Medical School, Los Angeles, California.
   Ken Hayashida—USC Medical Student.
d. Baylor College of Medicine, San Antonio, Texas.
   Dr. Michael DeBakey—Baylor College of Medicine.

3.7.3.6 Business Opportunities

The two primary barriers to assessing a business venture to provide medical treatments in space are the lack of information on the market and the assessed minimum cost per patient. Shipping an average patient to space to enhance survivability or shorten rehabilitation makes sense only if the cost falls within current thresholds for existing treatments. There is little likelihood that average medical insurers will fund extraordinary costly methods to save lives in the future. Hence, the cost of shipping the patient to space and providing care on orbit for a few days to a few weeks must cost between $20,000 to $100,000, depending on circumstances.

Unfortunately, analyses developed to assess the space business park (sec. 3.6.7) show this to require launch costs of $100/lb or less, making space medical treatment beyond the capabilities of near-term launch systems. At transportation costs of $500 to 600/lb, the minimum cost for a 1-week stay would be at least $600,000. This makes such a business venture unreasonable at this price range.

However, there are possible exceptions. One is medical treatment for the very wealthy, who can afford to buy the very best care possible. This is possible, but not likely, because public funding is almost certainly required to develop the technology for low-gravity medical treatments.

3.7.3.7 Conclusions and Recommendations

Even without hard data on the response of seriously ill people in reduced gravity, it is apparent that one of the greatest areas that will be of use in space medicine is the application to burn patients and rehabilitation physical therapy. If surgery or long hospital stays can be avoided by sending patients to space, then it seems that those areas will be most beneficial to the patient and most cost effective. It is important to keep in mind, however, that most of the ideas are just hypotheses on the possible effects of space on the human body, due to the lack of a clinical database on ill and injured persons in space. This imposes a significant risk in any projections in this area. This area was defocused due to a lack of assessable market.

3.7.4 Space Hospitals

Vision statement: *In the year 2010, 0g facilities exist in LEO for the treatment of heart disease, pulmonary diseases, and severe burn patients. Rotating outpatient facilities with reduced gravity are used for orthopedics, physical therapy, rehabilitation, and permanent care of handicapped persons who can afford the enhanced quality of life available with retirement in space.*

3.7.4.1 Introduction/Problem Statement

Space hospitals providing long-term care using in-space facilities were identified in some of the initial brainstorming sessions as a potential market for a new low-cost, space transportation system. In conjunction with the space medical market area assessed previously, the potential for using long-term care on orbit to treat life-threatening or debilitating diseases, to reduce the suffering with chronic illnesses, or to improve the quality of life of the permanently disabled was examined.

3.7.4.2 Assessment Approach

As was done in the space medical market area, the medical field was divided into categories that might be future markets for in-space treatments, and then demographic studies were performed to estimate the U.S. market demand (in number of procedures and patients). In parallel with this effort, direct contact was made to specialists in these areas to obtain direct information on how such treatments could use the space environment. These direct contacts included some brainstorming sessions regarding the use of longer duration stays in the environment for medical treatments with experts in the field.

General statistics were gathered concerning illnesses and injuries that affect a large portion of the population, require long hospital stay times, expensive surgery, or expensive simulations of the 0g environment of space. Then those areas were further examined to predict the benefits and drawbacks to treating those patients in space. Some of the areas that are promising enough for further consideration are heart disease, pulmonary diseases, orthopedics, burn patients, physical therapy, rehabilitation, and quality of life (retirement in space). Each of these areas requires extensive research, which may also prove to be beneficial to patients on the ground. Pure medical research is the most promising area to apply to space especially in cancer research and HIV research.

The field of medicine is quite extensive with an overwhelming number of areas to consider. In order to obtain as broad a spectrum of medical applications for space as possible, it was necessary to be in contact with as many different specialties of medical personnel. Several excursions were made to hospital facilities and general statistics were obtained from major insurance companies and local hospitals. In this way, it was possible to estimate costs for running a medical facility in space and compare this to treating them on the ground.

There are several adverse affects on the human body from space flight, such as muscle atrophy and calcium loss, that can be counteracted to some extent by exercises and conditioning. Several opinions have been obtained about the benefits to patients who are treated in space, assuming that proper countermeasures for the adverse effects are applied. Some areas such as AIDS patients were not extensively considered because it was reasoned that those patients would not benefit from a space hospital any more than a ground-based one.

3.7.4.3 Market Description

Hospitalization tends to relate to higher hospital bills, so those illnesses or injuries that require hospitalization were examined more closely for the market for space hospitals. The costs can be broken down into several categories in order to highlight the most expensive procedures and patient care categories. From the 1990 Social Security Supplement, 4,170,000 recipients of Medicaid were general inpatients who received $13.378 billion in aid. This gives an average amount per person of $3,208. These values can be taken as an average amount of insurance that a typical patient receives for an inpatient stay. The yearly Federal budget for Medicare is $55 billion.

3.7.4.4 Market Evaluation and Assessment

In parallel with the market evaluation performed in section 3.7.3, Space Medical, the primary advantage of the space hospital is to produce an improved quality of life in a reduced gravity in-space facility.

a. *Retirement in Space*—It has been postulated that the elderly could benefit by retiring to space in order to increase mobility, ability to care for oneself, and general quality of life.

1. Market Size. Approximately 1 million Americans are admitted to nursing homes each year. Nursing home costs generally run $50 to $100/day for room, board, and services. About half of this money is paid by Medicaid.
2. Symptoms and Treatment. Generally, the elderly find that they do not have the energy and strength to carry out everyday tasks for survival, so they have to retire to a home where adequate care (i.e., cooking, cleaning, maintenance, and transportation) is provided for them. Up to 50% of the people who are being taken care of in a retirement center also have neurological problems and are not able mentally to take care of themselves either. Elderly people tend to keep the friends they have had all their lives rather than make new ones at the retirement center. However, the staff has found that the more tenants get out of their rooms, for meals for example, and talk with people and ambulate, the better they do both physically and mentally.
3. Personnel. A staff consisting of cooks, food servers, maintenance crew, cleaning personnel, and others would be required. Their numbers approximate 20% of the people in the retirement center.
4. Space Applications. For long-term residences in space, the elderly may be some of the people who could benefit from living in reduced gravity conditions. Because of the bone calcium loss in a 0g environment, the reduced gravity environment may be healthier in terms of calcium loss for long-term stays. Without the heavy weight of gravity pulling down on them, elderly people may find themselves far more self-sufficient than they were on Earth. If they were only able to get around a little in their room and dress themselves while on the ground, they may find that they are able to get around enough to completely take care of cleaning, cooking, or other chores. In some cases, they may want to perform some type of job. It is possible that very little staff would be required to maintain a retirement center in space because the tenants could care for themselves. Additional benefits to living in space would be the novelty of it, the great view, and the experience of renewed health because of reduced gravity. Psychologically, it would be necessary to screen tenants in order to avoid those with neurological problems. Another disadvantage would be proximity to friends and relations. It would be hoped that at least one close friend or relative could make the transfer to space living also, or that communications would be adequate for satisfying the tenant's need for old friends on Earth.

b. *Physically Impaired*—It has been postulated that the physically impaired elderly could benefit by retiring to space in order to increase mobility, ability to care for oneself, and general quality of life.

1. Market Size. In 1990, approximately 14,164,000 U.S. citizens had work disabilities that either prevented them from working or limited the kind or amount of work they performed. This was about 8.9% of the total U.S. population. For permanent and total disability, Medicaid payments averaged about $6,600 per person, with almost another $12 billion spent from private insurance on disability payments.
2. Symptoms and Treatment. The work disabilities can range from physical impairments such as loss of use of limbs or sensation to significant illnesses or mental impairments. In many cases, these can be treated through rehabilitation, and the person returned to gainful employment. In 1990, about 146,000 categorized as "seriously disabled" were rehabilitated into gainful employment. (For the seriously disabled, the wages earned from gainful employment are usually less than those of the able employed. This is particularly true for job-related accidents and work-related disabling events.)

   For many impairments, such as loss of use of a limb, the space environment may provide a better environment for work and other physical activities. This is particularly true if the impairment is related to the organs that provide support or locomotion on the Earth, such as muscular or limb disabilities.

3. Personnel. Given a mix of physical impairments, the support personnel required for an in-space facility (cooks, food servers, maintenance crew, cleaning personnel, etc.) could be staffed from the physically impaired inhabitants. Furthermore, these personnel could provide the support personnel for entire space facility, such as the space business park described below.
4. Space Applications. An in-space facility could provide improved quality of life and productive uses for physically disabled persons. These persons could also provide the staffing for other in-space facilities.

In all the categories above, the main market drivers are cost and patient needs. The costs of transporting and sustaining a person in space must be compared to the cost to treat and sustain and maintain the same person on the ground, with sufficient additional benefits to justify the extra cost. That is, would insurance companies pay the extra money for clients to have better quality of life in space? There are no data on the impact of the space environment upon the elderly and the physically disabled. Therefore, the benefits for long-term patient care or hospitalization in space are hard to predict. It is hoped, however, that this study will be able to generate interest in research in these areas for aerospace medicine research.

The market assessment for these market areas is primarily driven by the needs for supporting long-term working and living in space. Elderly people who need to be taken care of in a retirement center tend to be depressed and bored. If a space retirement center could offer mobility in a reduced gravity environment and entertainment (views in space, work to do, being independent), then it is possible that some people would want to spend the money to retire in space. However, at approximately $10,000 per day to stay in space, it is unlikely that the market of those who could afford to retire in space would be large. (Half the people in nursing homes rely on Medicaid to pay half the present cost.) And the number of severely physically disabled who could afford this (or whose insurance could afford this) would also be small.

No market was assessed from this area due to the lack of real market demand quantified for any probability demand market through the 2010 to 2020 time period.

3.7.4.5 Prospective Users

As with the space medical market area, the biggest market barrier is research. There has been little research done on the impacts of the space environment on the elderly or physically impaired. If research can be done it will more clearly show patient benefits or drawbacks, and it will illuminate potential markets that right now are invisible because of lack of knowledge. Specific CSTS contacts in this market area included—

a. Harborview Medical Center, Seattle, Washington.
    1. Tracy Varga—Physical Therapist/ Orthopedics.
    2. Merilyn Moore—Physical Therapist/ Burns.
b. University of Washington Medical Center, Seattle, Washington.
    1. Dr. Greenlee—Orthopedics.
    2. Dr. Bassingthwaighte—Center for Bioengineering.
    3. Dr. Kushmeric—Professor of Radiology, Physiology, and Biophysics.
c. University of Southern California Medical School, Los Angeles, California.
    Ken Hayashida—USC Medical Student.
d. Baylor College of Medicine, San Antonio, Texas.
    Dr. Michael DeBakey—Baylor College of Medicine.

3.7.4.6 Needed CSTS Attributes

There was not a sufficient level of demand to establish unique CSTS requirements and attributes for space transportation, other than the general requirements of personnel travel and low cost.

3.7.4.7 Business Opportunities

As with the space medical market area, there was no business opportunity identified for this market area. However, there is a possible exception: the market of the very wealthy, who can afford to buy the best living conditions possible. However, this market is smaller than the non-physically impaired tourist market, which was assessed at a few hundred persons per year for a transportation cost of $500 to 600/lb (see the space business park, sec. 3.6.7).

3.7.4.8 Conclusions and Recommendations

No market demand was assessed for this market area. Further research is needed to establish a better database upon the influence of the space environment upon the elderly and physically impaired.

3.7.5 Space Settlements

Vision statement: *In the year 2015, hundreds of people reside in low-gravity settlements and permanent care facilities in LEO (and possibly in higher orbits). Many of these people are retired, but many work at space transportation nodes connected with the settlements, many work to provide services for the settlements, and some telecommute to the ground, preferring the quality of life on orbit to a lesser existence on terra firma. Quite a few of the inhabitants are physically disabled to the point where they would require constant care on Earth, but are fully mobile and able to care for themselves in the low-gravity portions of the space settlement. These settlements operate with biological environmental control systems that are almost closed, and require a minimum amount of resupply from Earth.*

3.7.5.1 Introduction/Statement of Problem

Long-term manned settlements in space, even near Earth space, require tremendous upfront investment costs and a mostly closed environment to avoid heavy resupply costs. What fraction of the populace has enough capital and enough determination to put up with the danger, the lack of privacy, and the deprivations sure to be required in the initial space settlements? What work can be done at these settlements to pay the overhead costs and provide for expansion or improvement of the facilities? Is it more cost effective to build the first settlements using terrestrial or extraterrestrial materials? Are there enough space enthusiasts in the world with enough money to pay for the first settlement?

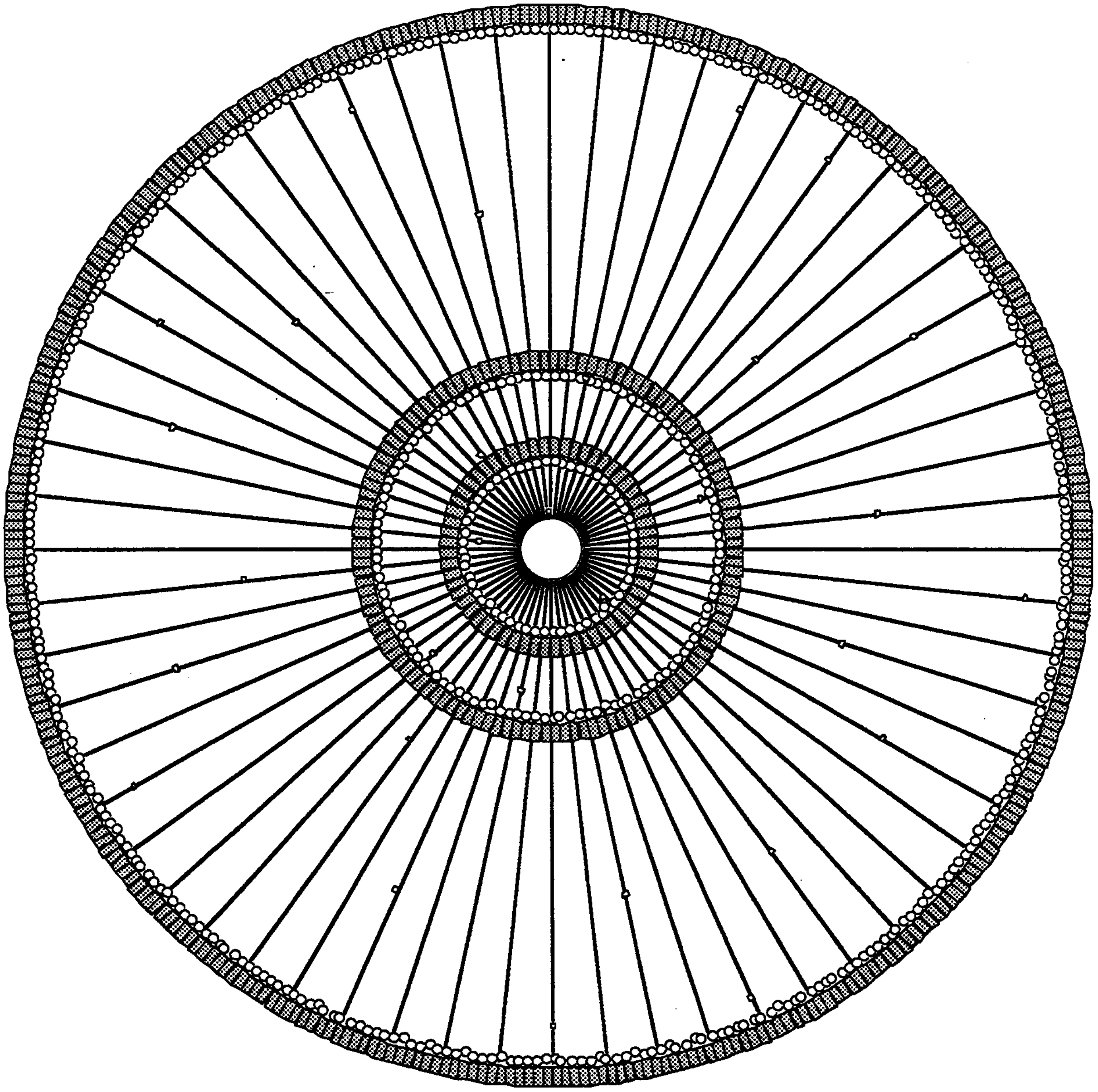

Figure 3.7.5-1. Rotating Space Habitat Concept

3.7.5.2 Study Approach

Our approach is rather straightforward. Using estimates of $8 billion to $15 billion to develop even minimal infrastructure to provide useful materials from lunar regolith and knowing this is to be a commercial development, we have chosen to defer analysis of the space colony approach espoused by Gerald K. O'Neill et al. and designed a rotating long-term habitat using hundreds of space station modules (fig. 3.7.5-1). Assuming no development costs and somewhat optimistic production costs, a module holding four persons would cost about $30 million including delivery and on-orbit assembly costs (@ $400/lb). Paying off this cost with a 30-year mortgage amounts to about $50,000 per month per person (@ 6.5% interest). There are people who could afford this expense but they probably would not put up with the crowding. Cheaper launches would certainly help, but even free launch and assembly only drops the cost to $15,000 per month.

3.7.5.3 Market Description

There appears to be no near-term commercial market in space settlements. The nonrecurring costs drive the price of a "space apartment" beyond what all except the extremely wealthy can pay.

The hidden assumption in many of the past space settlement concepts proposed in the literature are that there are also large-scale space activities under way either in space-manufactured products or in the in-space production of solar power satellites. The CSTS assessment is that many of the underlying assumptions for these large markets have changed since the 1970s and that the rapid and highly profitable growth of these markets cannot be depended upon to driven space transportation demand in the next two decades. Without this high level of other in-space activities, the economic infrastructure, that can justify these large-scale investments in large habitations is not present.

3.7.5.4 Prospective Users

As the assessed market demand for this area was not present, no prospective users were identified.

3.7.5.5 CSTS Needs and Attributes

The primary CSTS needs and attributes for these markets are driven by the general requirements of low cost and mixed payloads of people and cargo into orbit. Because a specific market was not identified from this assessment, specific needs and attributes were not generated.

3.7.5.6 Business Opportunities

No specific CSTS business opportunities were identified in this market area without other market areas providing large-scale economic activities in space.

3.7.5.7 Conclusions and Recommendations

This market area was defocused because of a lack of an assessed market demand.

3.7.6 Multiuse LEO Business Park

Vision statement: *In the year 2005, researchers regularly visit small commercial laboratory modules in LEO to activate and monitor various biological and materials processing experiments. These laboratories usually operate man-tended, but occasionally a researcher camps out on-orbit to provide hands-on attention to an especially important experiment. Some of these experiments show the way to constructing better materials and more efficient electronic devices, but a majority deal with developing new drugs and processes to heal diseases and rebuild bodies shattered by war or misfortune. Most of the breakthroughs discovered here will be used in production factories on the ground, but some will require either the 0g or the cheap hard vacuum of LEO to ensure commercial success.*

In the year 2010,combined-use, 0g commercial business parks flourish in LEO. These facilities provide volume and utilities for biological research and production, plus a destination for the first space tourists. Each facility is visited once a week to exchange crew members, products and process materials, and tourists staying in the plushly appointed visitors modules. The laboratory modules are doing a booming business growing cloned *human organs for transplants and the total tourist traffic is 500 to 1,000 persons/year per facility. Laboratory space is renting for about $1.2 million per double rack per year, a round-trip ride to the station is about $200,000, and a week in the visitors wing is another $50,000.*

In the year 2020, the first "orbitel" (orbital hotel) is operational. The "place in space" to visit. This large pressurized structure has a window-covered open area over 200 ft across for 0g recreation and network-sponsored sporting events. It also has two counterspinning sections, which simulate one-sixth gravity,. to provide comfortable long-term living quarters and the first conventional toilets and showers in space. Surrounding the central hotel/recreaction facility are myriad offices, light industrial complexes, and apartments. It functions as a destination resort, research park, and international banking center. This complex supports over 5,000 people with 3,000 long-term residents and 2,000 transient tourists. Constant access and resupply is provided by two round-trip flights per day.

3.7.6.1 Introduction/Statement of Problem

Currently, the vast majority of operations performed in space are done by machines. There will not be significant human involvement in commercial space operations, either as workers or as visitors, until some form of long-term, habitable, orbital facility is established. The international space station is a crucial first step in this direction, but it is a scientific research station run by government agencies and not designed to service commercial operations.

Numerous business opportunities have been identified that have the potential for using an in-space facility as part of their routine business operations. Among these are some aspects of space manufacturing, space tourism, and industrial research. Our business and market analyses indicate there is tremendous profit potential for industries that get the jump on their competition by using microgravity to improve their production processes or shorten their development cycle. Who are the potential users? What are their business needs? What sort of facilities are best suited to commercial operations? When should they come on line and what features and attributes are necessary for profitable operations? These issues and others are addressed in the sections following.

3.7.6.2 Study Approach

There are two aspects to any new commercial business: technology push and user pull. We have assumed the international space station development provides adequate technology push for a commercial facility in low Earth orbit (LEO), establishing the costs and operational characteristics of a commercially oriented in-space facility assuming space station technology and systems to reduce technical risk in future ventures. We also assessed the market demand (the "pull") from potential users and financiers to determine the timing, design, and operational characteristics desired by potential users.

We have tried to represent two communities during this process. The first is the facility developer, the entrepreneur who raises the venture capital, hires the facility manufacturer, arranges for the launch, and puts the privately owned research facility on orbit. The second is as the end user; that is, as the pharmaceutical company, the bioresearch company, the microchip producer, or the tour operator who pays for the goods and services offered at such a facility. We will discuss the issues related to developing the facility first, and then cover the issues with respect to end users.

Real Estate Development in Low Earth Orbit (LEO). The best analogy to this type of development is the extension of traditional real estate development practices into space. In this type of business ventures, a new real estate development is planned, financed, constructed, and either sold or operated in exchange for returns to a body of investors. The scale, scope, and complexity of large real estate development projects are analogous to what is required for space infrastructure development, with the one notable difference being that real estate projects are more often actually realized. Terrestrial business park developments manage budgets of up to billions of dollars contributed by many investors and lenders, over periods as long as decades, and coordinate the activities of hundreds of diverse suppliers to generate wealth and, along the way, physical infrastructure.

It is important to note that these ventures are highly market driven, and that the goals of successful investment by meeting user needs are in contrast to the usual aerospace approach of designing and building a system and then looking for commercial applications for it. Traditional aerospace goals, such as high performance and technology innovation, would be secondary to generating profit, because without significant assuredness of profit, potential investors would simply look elsewhere and such goals would forever remain moot measures of unrealized projects.

The approach of using a commercial "business park" is used instead of an international space station because the vast majority of commercial users want to deal with a service oriented private entity instead of a government bureaucracy. Contacts with potential users and developers specifically indicated this factor as part of their decision process. Government service providers have no need to meet demanding schedules, since they have no competition. In addition they are subject to the whims of congressional politics and users have little legal recourse when the services are arbitrarily changed or dropped completely. A commercial investor with significant monies at risk cannot accept this uncertainty. The key role of the government in the development of future space industrial facilities is to develop and demonstrate the technologies and operations needed for future commercial space operations through the international space station.

This analysis first compares the maturation of the real estate and aerospace industries, highlighting key differences. Terrestrial mixed-use business parks (the most applicable model for potential large-scale, space-based profit-making enterprises) are examined as a model for future space business park development, by analogy to the way they are developed on Earth. Next, this business model is applied to the development of research, production, and leisure facilities in LEO. The infrastructure services to be made available to industries in space are listed and discussed, and the enabling financial arrangements are specified. Finally the organizational requirements for developing such mixed-use LEO business parks are listed.

3.7.6.3 Market Description

The real estate industry, like the aerospace industry, is a child of World War II, but for different reasons. The rapid growth of the automobile industry after the war and the concurrent development of the interstate highway system (called a defense project at the time), together with consumer pressures of the Baby Boom generation, led to the largely unplanned result of suburban growth, shopping centers, and tract housing development. Since there was little or no active government involvement in this process, and no major firms dominating the industry nationally, the way was clear for thousands of small entrepreneurial builders and developers to sense the market demand in specific locales and bring projects to market. While not all projects and developers were successful during the building of suburbia, most people who entered the field during the 50s and 60s were able to make a good living, and consolidation of the industry into a few national players did not occur.

The economies of scale needed to control costs are generated at the component supplier level in the real estate development industry. Manufacturers of HVAC (heating, ventilation, air conditioning) systems, electrical equipment, lumber, structural steel, elevators, windows, and the like have developed lines of standardized building components useful in a wide variety of buildings and locations. Creativity in the real estate development industry is in how the standardized parts are integrated into unique (or not so unique) designs intended to meet specific market demands and price targets. Similarly, local and state building codes evolved to allow use of these standard components, without costly requirements for zoning and code variances and reviews.

In today's market, a significant difference between the aerospace and real estate industries is the highly fragmented business organization within the practice of real estate development when compared to aerospace. The aerospace industry is characterized by a few principal manufacturers (approximately a half dozen), and a limited number of principal players (about a dozen customers comprise over 80% of the total market). In contrast, the real estate industry has dozens of large players, hundreds of midsize players, and thousands of small players involved as principals in real estate deals. These firms in turn rely on thousands of small design, engineering, brokerage, and financial services firms, which all contribute to making deals happen.

A second principal difference between the two industries is in the fundamental premise in how the business operates. Members of the aerospace industry, and in fact most manufacturing companies, operate with a more or less consistent level of business activity. The airlines will always need a certain percentage of the fleet replaced in any given year, more so when markets are growing or increased fuel or operational efficiency can enhance operating margins. The aircraft and engine manufacturers can count on some level of continued new orders and service work on the existing fleet even during lean economic times, and the entire industry benefits from reducing costs and servicing an expanding market.

In contrast, the real estate development business operates in a different manner, because projects start and stop due to events beyond control of the developers. Figure 3.7.6.3-1 illustrates the risk factors affecting the success or failure of any particular real estate deal. Any single risk factor within the diagram has the capability of effectively killing a development, regardless of whether it is small or large, and regardless of whether the dozens of other factors are all favorable. For example, an office tower may have significant preleasing, cost and design advantages, financing commitments, and a top-level development and management team, but if the neighbors protest the proposed zoning and prevail in a referendum, the project will not happen. Political, environmental, and financial factors affecting a particular project are largely indifferent to whether the project happens or not, and the benefit of the doubt seldom falls in favor of a project proceeding.

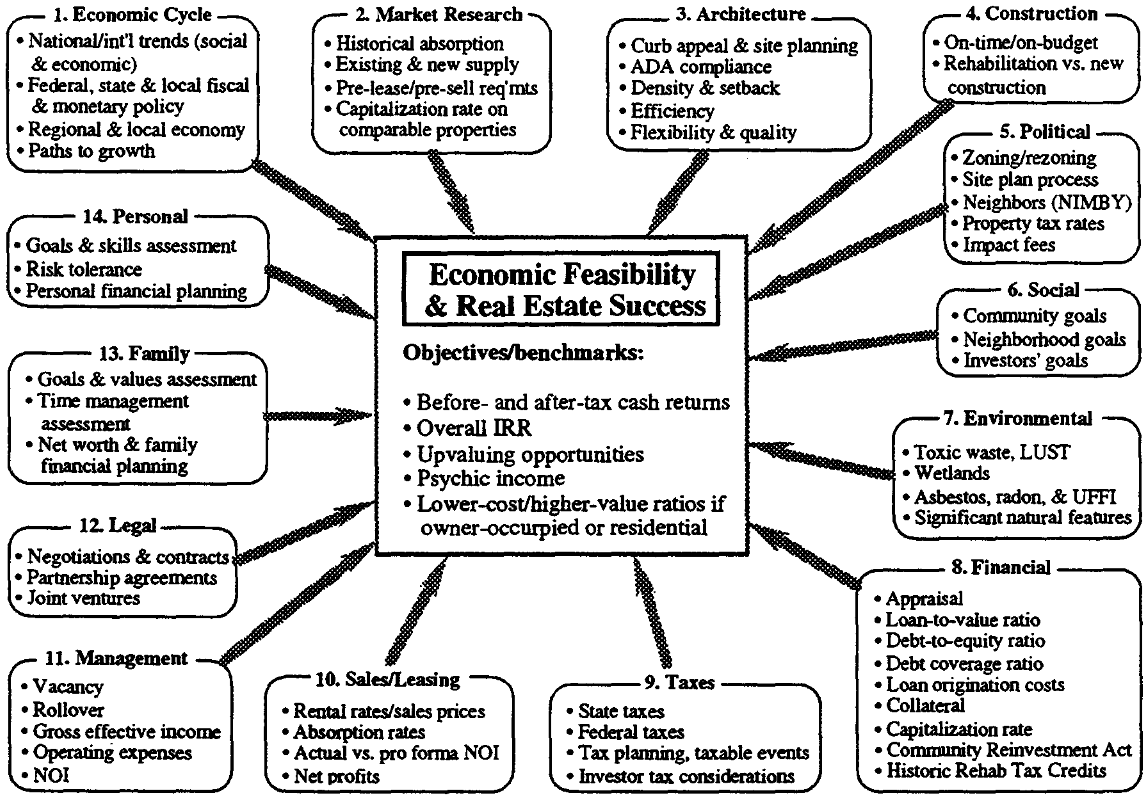

Figure 3.7.6.3-1. Economic Feasibility and Real Estate Success (Peter T. Allen © 1992)

Last, the corporate cultures of the two industries are widely disparate. In aerospace, both the manufacturers and their customers are large corporations or government agencies with tens to hundreds of thousands of employees sharing a consensus to continue to do business. In this work environment, individual performance is typically measured in terms of teamwork and efficiency of function within the system. Aerospace firms are very focused upon controlling risk, either in technical, market or political arenas, and they are driven by their need to sustain and maintain their highly important large-value product lines. In contrast, in real estate development all sites and projects are to some extent unique and are the responsibility of a relatively small number of people. Individual personality characteristics such as drive, imagination, salesmanship, and financial sense are much more important in being successful due to the inherent difficulties of making any project happen. Rational risk-taking is encouraged, in part driven by the awareness that new ventures must be constantly developed, nurtured, and executed as part of a portfolio of business activities.

Given the many differences between the two industries, an analysis of the comparative cost efficiencies between manufacturing and real estate reveals some surprising relationships. Figure 3.7.6.3-2 graphs the cost per pound and cost per cubic foot of product for airliners, heavy construction equipment, and cars and trucks as representative manufactured products against single-family homes, office buildings, cruise ships, and oil platforms as representative real estate projects.

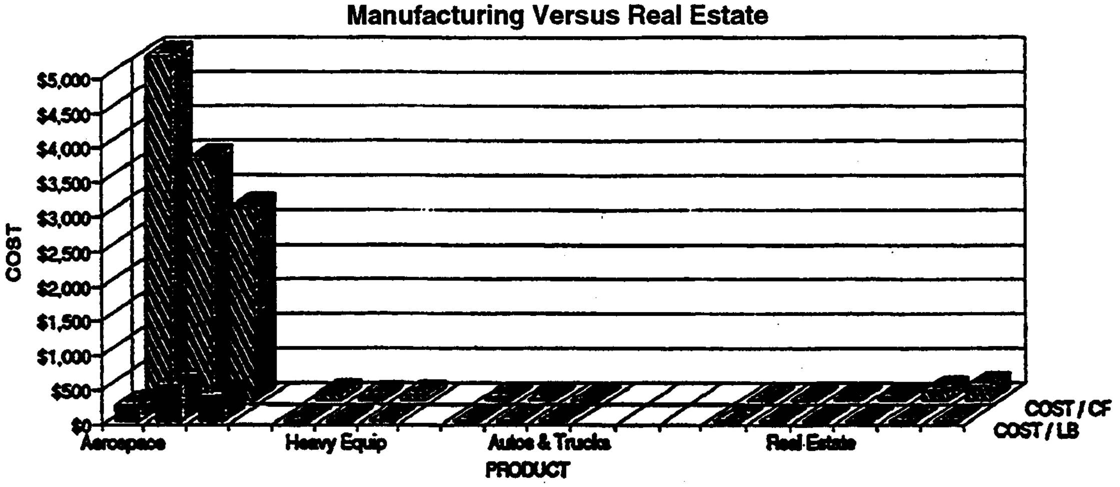

Figure 3.7.6.3-2. Comparing Cost Efficiencies

It is interesting to note that real estate products remain relatively flat in cost/lb and cost/cu ft over projects ranging upwards in size by four orders of magnitude. In contrast, manufactured products vary widely from industry to industry, with aerospace products two orders of magnitude more expensive than any of the other products. Part of this difference may be driven by the ability in real estate products to use common, mass-produced elements as the basic building blocks for larger elements.

Terrestrial Mixed-Use Business Parks. The best analogy to the space business park concept developed in this study is the terrestrial mixed-use business park. Terrestrial mixed-use real estate development projects are among the most difficult of all types of projects to develop due to the large scale of the investment and the political, design, and market positioning complexities of the various uses. Mixed-use projects are typically done on the largest available parcels in a given market in order to minimize absorption (selling) time and to spread the cost of common infrastructure over as wide a revenue base as possible. In addition, political considerations will often dictate some degree of mixed use development where a single use such as office or industrial may be the preference of the developer.

Business parks can range in size from 100 acres to 10,000 acres. The largest developments, such as the Irvine Ranch (California) and Columbia (Maryland) are more closely related to British New Town projects than to traditional U.S. developments. Total investment in land, infrastructure, buildings, and amenities can range from $50 million to over $2 billion, depending on size and location. The period of active development and construction can range from 5 years to 20 years, with ownership and management of rental properties within a development continuing for another 10 to 20 years after completion of construction. Ultimately, rental properties are sold, syndicated, or refinanced to return the original equity investment and generate "back-end" profits.

Business park uses typically include land for sale for owner-occupied office research, and light manufacturing buildings; single-tenant and multitenant rental buildings for the same uses; a hotel or some type of transient or short-stay housing; varying degrees of commercial and retail space; and recreational amenities. Larger projects will also generally include single-family and multifamily residential neighborhoods, with both rental and ownership units, child care facilities, and, in the largest projects, schools and medical facilities.

When a developer is planning out and doing the financial analysis on such projects, there is little or no idea of who the actual users will be or what the specific building projects will look like. However, the requirements for the core infrastructure do not require specific users, only general market targets. Road systems; sewer, water, and utility service; site amenities; preservation of significant natural features; political realities of maximum allowable density; municipal impact fees; upgrading of sewer and water treatment plants when needed; local tax incentives for new business attraction; and similar issues are all considered when large scale mixed-use projects are designed and developed.

Once the overall project design and market mix are established, one of the key factors in financial success lies in the phasing plan for the infrastructure development. Ideally, the initial presales will cover the costs of the first phase of the infrastructure development, and the amount of negative cash flow required to bring the project to market will be minimized. Subsequent phases of development are financed through "recycling" of the same investment used to open the project, so the amount of additional cash required to finish the project is kept to a minimum. The true profit from the development activities does not actually begin to show until the project is typically 80% or more complete, although fee and management income to the developer is usually available throughout the life of a project.

In section 3.7.6.3.3, a direct comparison of the space business park to a typical terrestrial mixed-use real estate development will be made.

3.7.6.3.1 Market Evaluation

The market for a mixed-use space business park must address the different requirements for a mix of commercial users. Commercial users can capitalize on the space-based environment when it is available on a regular and controlled basis. They will pay for and profit from ready access to vacuum, variable gravity levels ranging from micro to hyper, extreme temperature ranges, direct sunlight, and clear views of Earth and space. In addition, isolation and extraterritoriality are available in orbit. Considerable research (and followon commercial exploitation) will focus on the effects of gravity variation. The control of gravity will open new windows into biology, chemistry, materials science, and operational capabilities. In addition to microgravity effects, it will be possible to vary the levels of gravity, providing insight and knowledge previously unobtainable. The space business park must provide a means to address these various customer needs.

Figure 3.7.6.3-3 details how the inherent characteristics of LEO space (several of which are typically regarded as operational problems) may in fact be marketed to business-park tenants as resources. Figure 3.7.6.3-4 expands this picture, by indicating which of these "controlled environment" and other services are required by, desirable to, or incompatible with various classes of potential users. Arranging and managing the provision of this array of services is the development and operation of the business park.

On-orbit facilities would offer a core of common, basic services to all customers. These services would include many typical at terrestrial business parks, such as power, delivered utilities, waste removal, structures, and administrative/financial services, telecommunications, computing, security, and maintenance. An important aspect of security includes maintaining the confidentiality of proprietary intellectual property. Available operational services unique to the space environment include station keeping, thermal rejection management, radiation shielding, debris armor, and, as necessary, pressurized volume, automation and robotics, and EVA support. These basic services could be offered by business park management directly or made available by franchise or outside service contracting.

Feature	Description	Explanation	Benefits to Users
Vacuum	~10E-6 to 10E-15 torr	Easy access to vacuum several orders of magnitude harder than economical/ feasible in Earth laboratories	Ultra-cleanliness; rapid outgassing; high-precision analysis & fabrication; vacuum-dependent processes (atomic/molecular deposition, sputtering, etc.)
Gravity	Variable, µg to hyper	Tethered/rotating facilities decouple weight from mass, allowing variable control of fundamental physical "constant"	Cancellation or emphasis of buoyancy, convection; containerless processing; dominance or suppression of diffusion, surface tension, film behavior; novel kinetics (micro & macro); macro-structures
Temperature	-100 - 170°F (passive) Source (sun) 5780K Sink (dark sky) 3K	Wide range using passive techniques; hard vacuum facilitates achieving/using extreme temps (cryogenic, high-temp with solar or nuclear)	Uses benefitting from exclusively radiative transfer; longterm thermal stability; superconductivity; IR observation; thermal processing
Sunlight	1470 W/cmE2	Unattenuated solar spectrum; can be virtually constant	Non-depletable energy source for direct thermal use or reliable electrical power; UV source; export to space and Earth users
Radiation	MeV - GeV particles, weak-flux trans-UV photons	Geomagnetically trapped e- and P, episodic solar proton events (high or polar orbits); cosmic rays; controllable with collimated shielding, filters	Irradiation-mediated chemical/biological sample processing;
Atomic oxygen ram flux	@ 300 km: v ~8km/sec, ~10E19 mE-2secE-1	Extremely erosive to oxidation-susceptible materials	Chemical milling, etching & sputtering processes
View	Optically unimpeded; everchanging Earthview	Orbit-geometry-dependent; map-like overview of Earth geology, meteorology, ecology, sociology, technology; best astronomical clarity, full-spectrum observ.	Astronomy; longrange optical monitoring; Earth sciences; security; entertainment imagery; new, unique type of tourism
Isolation	Infinite room; proximity controllable, costly, detectable	No ecology-based environmental contamination restrictions; extremely limited opportunities for information leaks, espionage, oversight, interference	Hazardous chem/bio processing; nuclear activities (orbit-dependent); greater freedom for all activities
Extraterritoriality	Orbits inherently trans-national	Affiliation selectable; choice of regulatory regimes and legal precedents/statutes; opportunity for novel arrangements	Flexibility to design conducive business address
Materials	Unlimited variety & quantity	Not immediately available; asteroidal/ luner sources; retrieval requires extensive, interplanetary operations infrastructure	Heavy manufacturing; material export (incl. Pt-group); space settlement; eventual autonomy from Earth

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Figure 3.7.6.3-3. LEO Business Park Resources

The business park would provide services for supporting on-orbit staffs and visitors, including lodging, food services, medical clinic and recreational opportunities. Businesses, universities, and governmental agencies could send their own researchers or purchase the services of bonded research staff stationed on orbit by the business park or third party providers.

An early and highly elastic market segment is tourism. Terrestrial mixed-use business parks commonly include hotel facilities to service the businesses in the business park or to cater to tourists into the region. For the initial market, the space business park should include facilities for short-term stays of researchers working at the business park.

Beyond the business travelers, market assessments indicate a percentage of the terrestrial tourism market will be eager to experience the absence of gravity, the extraordinary views offered of Earth and space, the frequent and unique sunsets and sunrises, and other recreational opportunities. (See sec. 3.5.6 for a further discussion of this market.) The earliest mixed-use business parks could offer tourist accommodations modeled on bed and breakfast operations, or on the pay-to-help EarthWatch lay-research assistant scheme[6]. As space operations increase and transportation costs decrease, facilities dedicated to tourism can evolve to offer resort-class hotels, with name entertainment, traditional resort recreation, and novel forms of culture.

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[6] The Earth Watch lay--research resident assistance program and others provide interested lay persons the option to participate in scientific research for a fee. These types of programs include such options as whale watching in the Pacific Northwest as part of oceanographic studies, dinosaur fossil excavation in the Dakota badlands, archeological site excavation in the U.S. Southwest, and forest ecological surveys in Central and South America. Costs of these volunteer research expeditions are roughly equivalent to adventure vacations.

		Research			Medicine			Earth Observation							Light Manufacturing			Heavy Industry		Exported Power		Exported Entertainment			Tourism			Information Processing			Transportation	
		Biological	Materials	Systems	Basic Research	Clinical Treatment	Infirmary	News	Disaster Support	Weather/Climate	Resource Exploration	Resource Management	Security	Astronomy	Pharmaceuticals	Electronics	High $/kg materials	Structures	Bulk Materials	Space Users	Earth	Imagery	Sporting events	Fine Arts	Tours	Hotel	Resort	Messaging	Financial Services	Business Services	People	Cargo
Accommodations	Recreation	◍	◍	◍	◍	●	◍	○	○	○	○	○	○	○	◍	◍	◍	◍	◍	◍	◍	●	●	●	●	●	●	○	◍	◍	◍	○
	Lodging	●	●	●	●	●	●	◍	◍	◍	◍	◍	◍	◍	●	●	●	●	●	●	●	●	●	●	●	●	●	◍	●	●	◍	◍
	Food	●	●	●	●	●	●	◍	◍	◍	◍	◍	◍	◍	●	●	●	●	●	●	●	●	●	●	●	●	●	◍	●	●	●	◍
	Life Support	●	●	●	●	●	●	◍	◍	◍	◍	◍	◍	◍	●	●	●	●	●	●	●	●	●	●	●	●	●	◍	●	●	●	◍
Transportation Support	Maintenance	◍	◍	◍	◍	◍	◍	◍	◍	◍	◍	◍	◍	●	●	●	●	●	●	●	●	◍	◍	◍	●	●	●	◍	◍	◍	●	●
	Servicing	◍	◍	◍	◍	◍	◍	◍	◍	◍	◍	◍	◍	●	●	●	●	●	●	●	●	◍	◍	◍	●	●	●	◍	◍	◍	●	●
	Traffic Control	○	○	○	○	◍	○	○	○	○	○	○	○	◍	●	●	●	●	●	●	●	◍	◍	◍	●	●	●	◍	◍	◍	●	●
	Shipping	●	●	●	●	●	●	○	○	○	○	○	○	○	●	●	●	●	●	○	○	○	○	○	●	●	●	○	◍	●	●	●
	Launch	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Tanking	○	○	○	○	○	○	○	○	○	○	○	○	○	●	●	●	●	●	●	●	○	○	○	●	●	●	◍	○	○	●	●
Material Handling	Warehousing	◍	◍	◍	○	○	○	○	○	○	○	○	○	○	●	●	●	●	●	◍	◍	○	○	○	●	●	●	○	○	○	◍	●
	Mining	○	◍	○	○	○	○	○	○	○	○	○	○	○	◍	●	●	●	●	●	●	○	○	○	◍	◍	◍	○	○	○	◍	●
	Recycling	◍	◍	●	◍	◍	◍	○	○	○	○	○	○	◍	●	●	●	●	●	●	●	◍	◍	◍	●	●	●	○	◍	◍	●	◍
	Handling	◍	●	●	○	○	○	○	○	○	○	○	○	◍	●	●	●	●	●	●	●	○	○	○	●	●	●	○	○	○	●	●
	Construction	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Operations Support	Maintenance	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	◍	◍	◍	●	●	●	●	●	●	●	●
	EVA Support	○	◍	●	○	○	○	◍	◍	◍	◍	◍	◍	●	●	●	●	●	●	●	●	◍	◍	◍	●	●	●	●	○	○	◍	◍
	Security	◍	◍	◍	◍	◍	○	◍	◍	◍	◍	◍	◍	◍	●	●	●	●	●	●	●	◍	◍	◍	●	●	●	●	●	●	◍	◍
	Automation & Robotics	◍	◍	●	●	◍	○	◍	◍	◍	◍	◍	◍	●	●	●	●	●	●	●	●	◍	◍	◍	●	●	●	●	◍	◍	◍	●
	Computing	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Telecommunication	◍	◍	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Admin/Financial Services	◍	◍	◍	◍	◍	◍	◍	◍	◍	◍	◍	◍	○	●	●	●	●	●	●	●	●	●	●	●	●	●	◍	●	●	◍	◍
	Presurrized Volume	●	●	●	●	●	●	◍	◍	◍	◍	◍	◍	◍	●	●	●	●	●	●	●	◍	●	●	●	●	●	◍	●	●	●	◍
	Structure	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Debris Armor	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Radiation Shielding	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	◍	●	●	●	●
	Waste Removal	●	●	●	●	●	●	◍	◍	◍	◍	◍	◍	◍	●	●	●	●	●	◍	◍	◍	◍	◍	●	●	●	○	●	●	◍	◍
	Delivered Utilities	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	◍	◍
	Thermal Reflection	●	●	●	●	●	●	◍	◍	◍	◍	◍	◍	●	●	●	●	●	●	●	●	◍	◍	◍	●	●	●	●	◍	◍	●	●
	Power	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Stationkeeping	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	○
Controlled Environment	Extraterritoriality	○	○	○	○	◍	○	◍	○	○	◍	◍	◍	○	◍	◍	◍	◍	●	◍	◍	○	◍	○	◍	◍	◍	◍	●	◍	○	○
	Isolation	●	◍	○	●	◍	◍	○	○	○	○	○	◍	●	●	●	●	●	●	●	●	○	○	○	○	○	○	◍	○	○	○	◍
	View	○	○	○	○	◍	◍	●	●	●	●	●	●	●	○	○	○	○	○	●	●	●	●	●	●	●	○	○	○	○	●	○
	Controlled Sunlight	◍	◍	◍	◍	◍	◍	○	○	○	○	○	○	●	●	●	●	●	●	●	●	●	●	●	●	●	○	○	○	○	◍	○
	Extreme temperatures	○	●	◍	◍	○	○	○	○	○	○	○	○	●	●	●	●	●	●	●	●	○	○	◍	○	○	○	○	○	○	○	◍
	Gravity Level (μ-hyper-g	●	●	◍	●	●	◍	○	○	○	○	○	○	◍	●	●	●	●	●	●	●	●	●	●	◍	●	○	○	◍	◍	◍	○
	Vacuum	○	●	◍	○	○	○	○	○	○	○	○	○	●	◍	●	●	●	●	●	●	◍	◍	○	◍	◍	○	●	○	○	○	◍

Requirements
- ● Essential
- ◍ Optional
- ○ Not Needed

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Figure 3.7.6.3-4. LEO Space Business Park Service Requirements

The prime decision in any real estate project is selecting the location. Users of a space business park will have different preferred orbits and launch sites to maximize their return. Minimizing launch costs to maximize return will prefer orbits selected to maximize the payload lift to orbit. Manufacturing users, especially those processing large amounts of material, will prefer orbits to minimize their recurring costs for transportation. Tourists will likely choose traveling to orbits with a higher inclination (or polar orbit) over a lower inclination orbit, so that they can observe more of the Earth's surface, given a specific ticket price. Many Earth observation users will find Sun-synchronous orbits better suited or required to accomplish their missions. Microgravity research users may not care what inclination is used.

Based upon discussions with potential users, a 51.6 degree inclination was selected for the space business park. This inclination was to maximize the Earth viewing opportunities for the space business park, and to place it into the vicinity of the international space station, which will maximize the possibility of access. This assumption may be revisited in later analyses if it is determined the payload capability to the system should be maximized, which would push for a lower inclination orbit.

3.7.6.3.2 Market Assessment of LEO Business Park

A major driver in the cost of a space business park is the initial cost. For a terrestrial mixed-use business park, this is the cost of the raw (unimproved) land for the business park. The LEO equivalent of raw land cost is the launch cost per pound to a given altitude and inclination. Since large projects require large tracts of land, it makes sense to buy in bulk using long-term contracts rather than buying an acre of land at a time. The raw land for virtually all large scale real estate projects is acquired in this manner. For orbital systems, however, the cost of land is free, but the initial cost is the cost for launching the system into orbit. (The nearest terrestrial analogy is a trucking contract for fill dirt, needed on some sites before initial construction and grading can begin.) The initial launch cost for a LEO space business park is determined by the mass required, and the price at which these launches are tendered. (Continuing the analogy to terrestrial development, a purchasing agent buying a million pound trucking contract would be indifferent to whether the trucks were Peterbilt or Kenworth, or whether the loads came in 20-ton or 50-ton increments, as long as the total cost is as low as possible and delivery is as fast as possible. Similarly, the commercial developer of a space industrial park buying a million-pound launch contract would be indifferent to the make of the launch system, assuming the system could deliver his systems at as low a price as possible, and with delivery as fast as possible.)

High confidence must be provided in the financial returns for the project before significant project financing can be obtained. The current catch-phrase used to describe the real estate industry is "market driven." Practically speaking, this means that a project must be largely preleased or presold before significant debt and/or equity financing can be procured. Users of space (either rental or sale) are courted and induced to sign "soft" letters or letters of intent that are then used to finalize designs and procure political and financial approvals. For larger users of office or research space, the process of evaluating locations and size requirements can take several years before any binding agreements are executed, with implementations taking several more years.

Assuming that LEO projects will be as (or more) difficult to finance as other large-scale real estate projects, the preselling process is that much more important to the project's business viability. Referring back to figure 3.7.6.3-3, a matrix of possible LEO business park users and the menu of possible services to support these users is illustrated. Every node in this matrix represents a discrete selling opportunity. As many of these nodes as possible would need letters of intent or contingent lease/purchase contracts in order for initial equity investors to become convinced of the viability of the market. Establishing this level of initial user interest, through the letters of intent, will be a critical step in establishing the ability to obtain financing for the space business park.

For example, hotels and tourism need established chains to provide name recognition, experienced operating staff, and market credibility. A selling strategy for this node would be to play off Hilton's pledge to be the first hotel in space against other large players such as Hyatt, Radisson, Resorts International, and Sheraton. The goal would be to execute a contingent management contract with the operating chain and include its input in the design and development process, hopefully with some seed money contributions on top. In addition, 2 to 3-week package tour itineraries need to be developed, including ground time in the tour plan and all transportation costs. This package could then be marketed through exotic and high-end travel agencies, with refundable reservations going into a growth mutual fund and converted to down payments on excursion packages when delivery dates become finalized.

The applied research and light manufacturing nodes would be sold exactly as Earth-based real estate is practiced. Growing companies in targeted industries are identified and contacted to "make them aware of the tremendous opportunities" of the project. The goal would be to get the prospects' creative minds working on what could be done with a given volume of space with appropriate utility connections and gravity levels, and how much money could be made from the endeavor. It should be noted that the space business park operating model, with routine scheduled service, a commercial service-oriented outlook, and the possibility of longer duration research operations on orbit at relatively low cost, meets almost all of the customer needs identified in the space manufacturing section of this final report, section 3.2.2.

Based upon inputs from the commercial real estate developers contacted in this market study, management of the financing requirements for multibillion dollar projects in LEO would be very similar to that for terrestrial projects of similar size. Large projects are first broken down into smaller units of $10 to $100 million each, where possible. Divisions are made by the smallest unit that can have a discrete legal description and separable mortgage. The largest projects within the mixed use development (brainstormed as such entities as casinos and resorts) where separated mortgages are impractical, are syndicated among multiple lenders with the loan consortium holding an undivided security interest in the property.

The financial model used for venture viability in virtually all real estate projects is the discounted cash flow model. Costs and income are placed in the analysis at their actual projected values factoring in inflation. Rents and expenses are typically assumed to rise at or slightly below the CPI inflation rate, producing a constant value revenue stream. Depreciation expenses, marginal tax rates, capital gains, and loan amortization are all calculated in the analysis, with the time value of the money being factored in at the end of the analysis. This discounting of the value of the money earned in future years results in a total yield calculation called an internal rate of return (IRR). The CSTS estimate of 20% IRR after 10 years of operations was felt by the commercial real estate developers contacted in this survey to be marginally acceptable, although the preferred yield should be in the range of 25% to 30% in order to attract the initial investors with such a new type of development. If this was more of a routine (less risky) venture, IRR yields of less than 20% could be considered.

The commercial developers contacted pointed out that one of the best ways of boosting IRRs is to compress the time from when the equity money is spent to when the cash flow from sales and rentals begins. As shown in figure 3.7.6.3-5, the discounting curves show a significant reduction after 5 years of project duration, so a 10-year schedule for construction and launch would need about twice the undiscounted return of a 5-year schedule in order to maintain the same IRR. This will place a premium upon the rapid development, manufacture, and launch of a space business park over the more leisurely development pace of governmental programs.

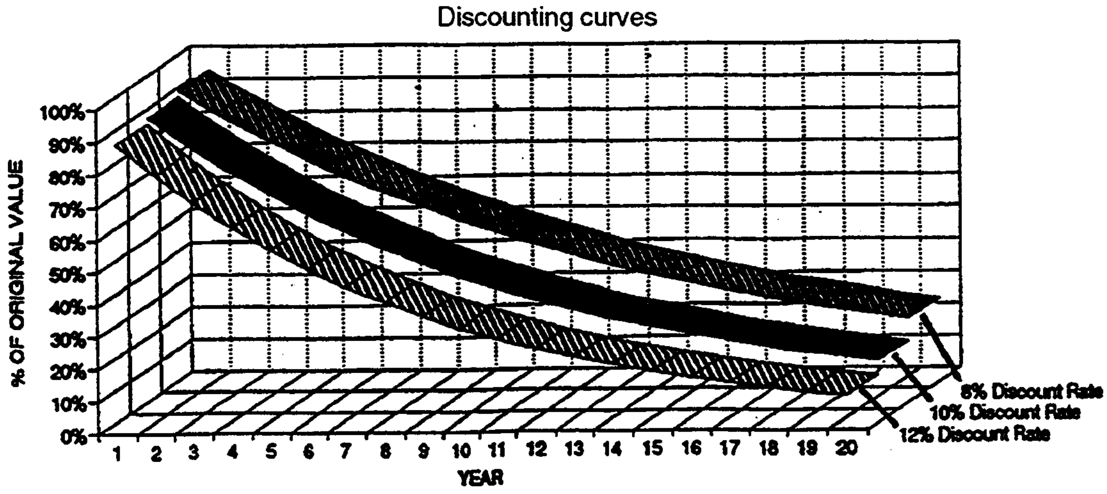
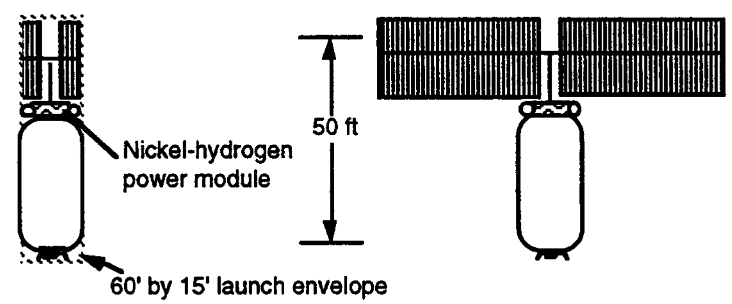


Figure 3.7.5.3-5. Net Present Values

LEO Business Park Concept

The LEO space business park concept evaluated in the CSTS was built in conjunction with several commercial real estate developers, architects, and entrepreneurs experienced in commercial space activities. To reduce cost and technical risk, the systems assumed are based upon space station technology and subsystems, which also allows reasonable confidence in the cost and development numbers.

An initial man-tended system, growing to a larger full-time commercially oriented system was developed; cost and revenues estimates were developed; and space transportation system needs were determined. Figures 3.7.6.3-6a and -6b show the overall configuration concept for the initial- and medium-term space business park.



Design characteristics:

- Single launch fully integrated module (32' by 15')
  - 40 kW high-efficiency solar arrays
  - Nickel-hydrogen batteries
  - Body-mounted thermal radiators
  - Reboost is continuous using waste gas and resisto-jet thrusters
- Man-tended operation with extended 0g processing periods
  - Experiments exchanged and samples returned each visit
  - Crew stayover permissible in campout mode (ECLSS built-in)

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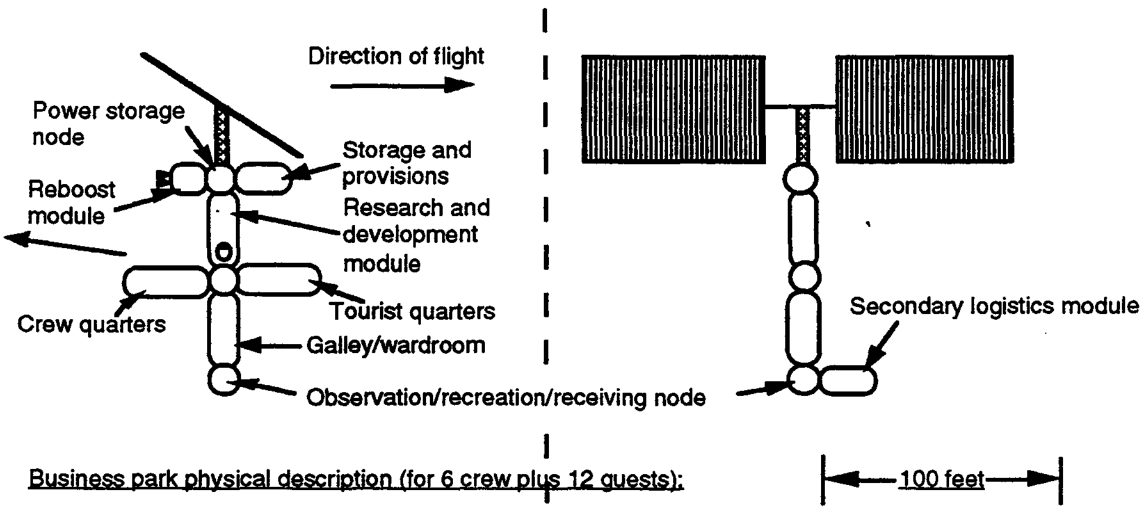
Figure 3.7.6.3-6a. Man-Tended LEO Microgravity Research Station



Business park physical description (for 6 crew plus 12 guests):

- Gravity gradient stabilized, low-drag configuration
- Four 32' by 15' modules containing laboratories, crew quarters, and bed and breakfast tourist quarters
- Two connector Nodes and one or two 24' by 15' logistics modules
- 120 kW of concentrator-type high-efficiency solar arrays
- One 15' by 15' power node containing ni-hydride batteries
- One 24' by 15' reboost module containing resistojets and nontoxic storable propellants
- Body-mounted radiators with debris shielding on all modules

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Figure 3.7.6.3-6b. Baseline Space Business Park Configuration

The LEO business park starts as a materials processing and biological test center and eventually grows to satisfy many other users. For the purpose of this analysis we have costed a medium-term business park, where the facility is initially developed to be a materials processing and research facility. As with a terrestrial development, a second phase of the development is financed through recyling the initial financing after initial cash flows have been established. After 3 years of operations, a small habitation module is added to handle well-to-do tourists (the bed and breakfast module). This additional revenue helps the business park to meet the target return rate of 20% after 10 years from first operations.

Revenues for the initial phase of the space business park as a commercially oriented research facility are based upon selling "lockers." As described more fully in the space manufacturing section of this final report (sec. 3.2.2), typical space research experiments are contained in lockers (based upon the standard payload accommodation on the space shuttle and Spacehab), which may be aggregated into "standard double racks," each containing 12 lockers. The CSTS projected demand sensitivity for the equivalent number of science lockers sold each year as a function of launch cost per locker is shown in figures 3.7.7.3-7 and -8. These numbers assume the 90% probability market capture case is for research flights only (i.e., no product ever goes to production), and that, as the cost per locker drops, space processing captures an increasing portion of the pertinent research monies up to 20% of the $1 billion currently available. The 50% case assumes one or two products go to production and CSTS can capture up to 50% of the pertinent research funds, and the 10% probability case assumes that several prospective products are "hits" and that space manufacturing becomes a major growth market capturing a significant fraction of the microprocessor and medical products markets. The logic behind these estimates found in appendix F.1.1.

	Equivalent lockers sold per year		
Price/locker/	90% Prob	50% Prob	10% Prob
$1,000,000	10	100	1000
$400,000	30	300	3,000
$100,000	300	3,000	30,000
$50,000	1000	10,000	100,000
$20,000	5000	50,000	500,000
$10,000	20,000	200,000	2,000,000

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Figure 3.7.6.3-7. Science Locker Traffic Versus Launch Cost

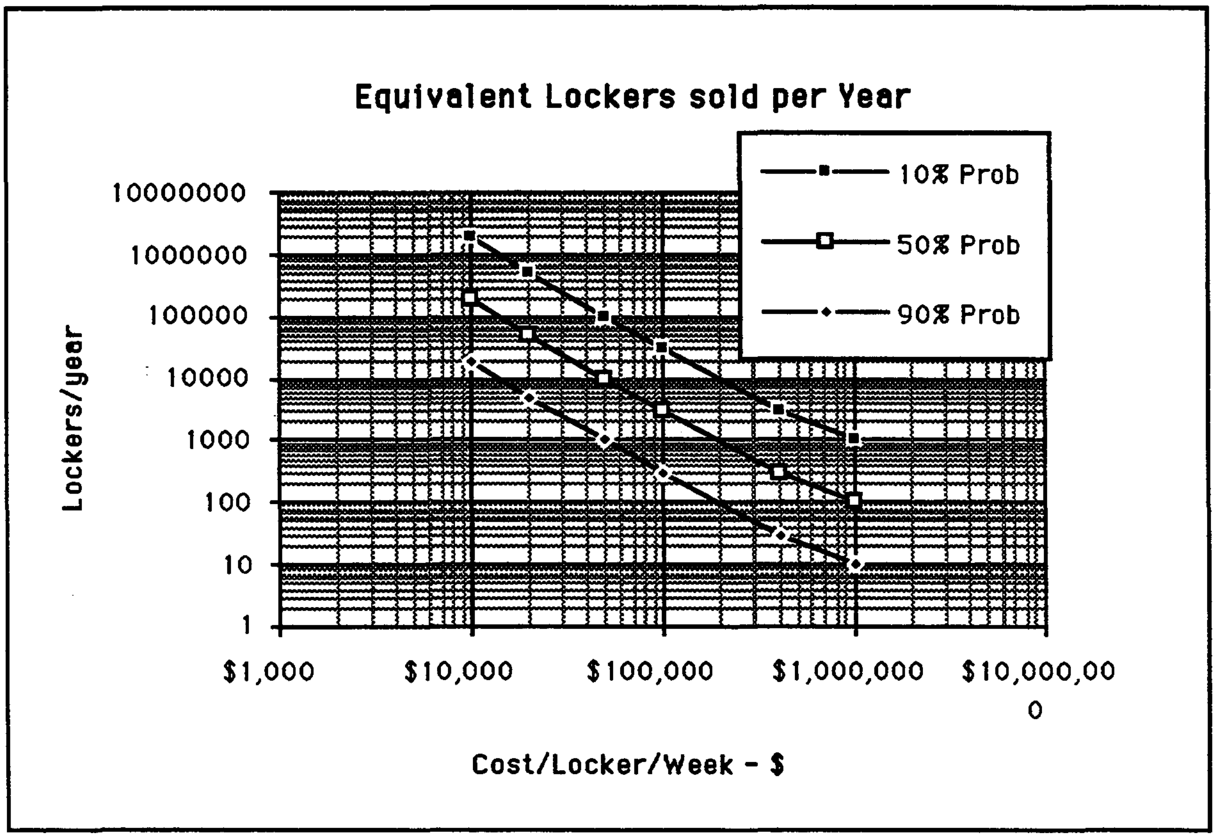

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Figure 3.7.6.3-8. Science Locker Traffic Versus Launch Cost

The price elasticity of demand for space tourist traffic for a 1 or 2-week space vacation in LEO is shown in figure 3.5.6.6-1. These data represent a composite of economic analyses and survey data from various references$^{1-7}$. It should be noted that the tourism market, as part of the space business park, is adjusted to ensure it is a profit center, and ticket prices are adjusted upwards to ensure that the space tourism business operations are not subsidized by the research and manufacturing operations. At the prices assessed for this condition, the tourism market just "skims the cream" from the available demand market. Tourist tickets are priced to pay off the added DDT&E and modules in 8-1/2 years (as are hotels and cruise ships).

These combined markets of research locker traffic and tourism traffic allow the sizing of the space business park as a function of cost per pound to orbit. These results are shown in figures 3.7.6.3-9 and -10, below, for the medium and low probability research locker and tourist traffic. The cost numbers assume a 25% surcharge on each locker for each additional week on orbit. The price per locker and price per ticket (and the corresponding numbers of lockers and tourists) have been adjusted to meet 20% IRR after 10 years of operation. The high-probability, low-traffic model could not provide a 20% IRR until launch cost fell below $50/lb, so it is not shown.

The CSTS analysis also indicated that LEO space transportation costs had to be less than about $560/lb to achieve the required 20% IRR after 10 years of operations. At costs over this value, the system could not capture a sufficient level of demand to meet this target level of returns.

An important design requirement for the CSTS is system payload capability, so the sensitivity to flight rate and logistic module sizing is included in the figures. Hypothetical payload masses of 10,000, 30,000, 55,000, and 100,000 lb to a nominal space business park orbit are shown on the figures.

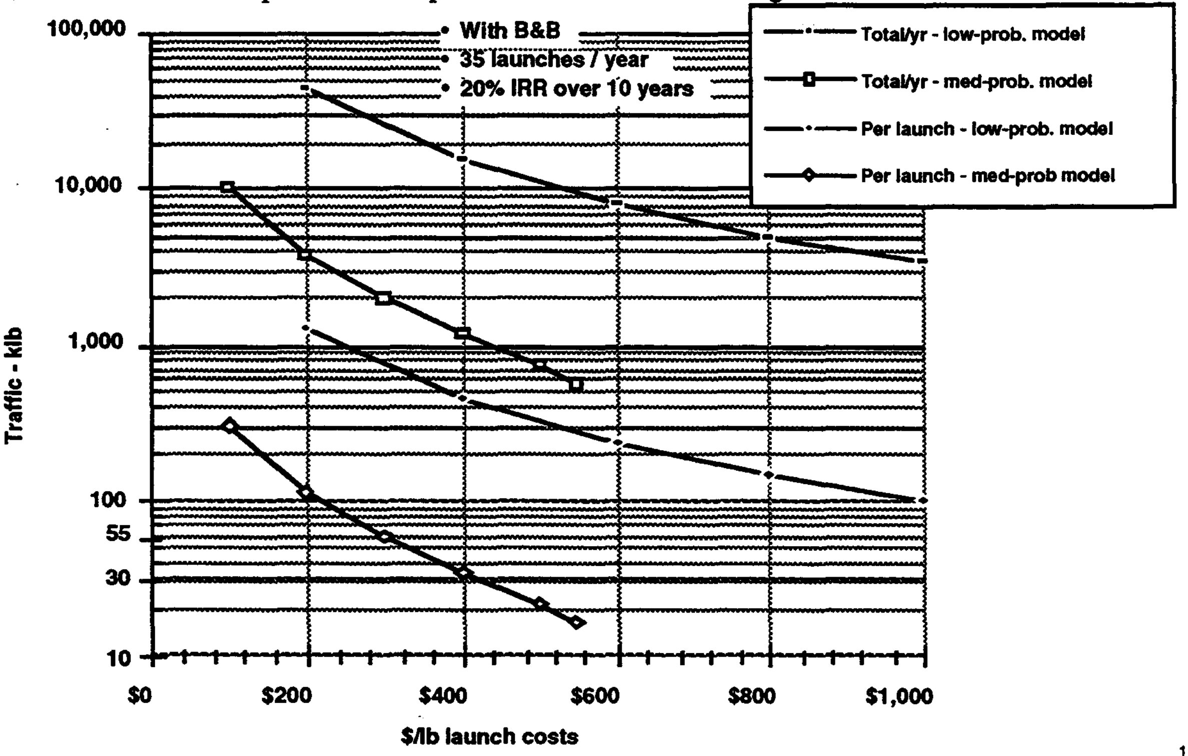

Figure 3.7.6.3-9. Launch Traffic to the LEO Business Park Versus $/lb

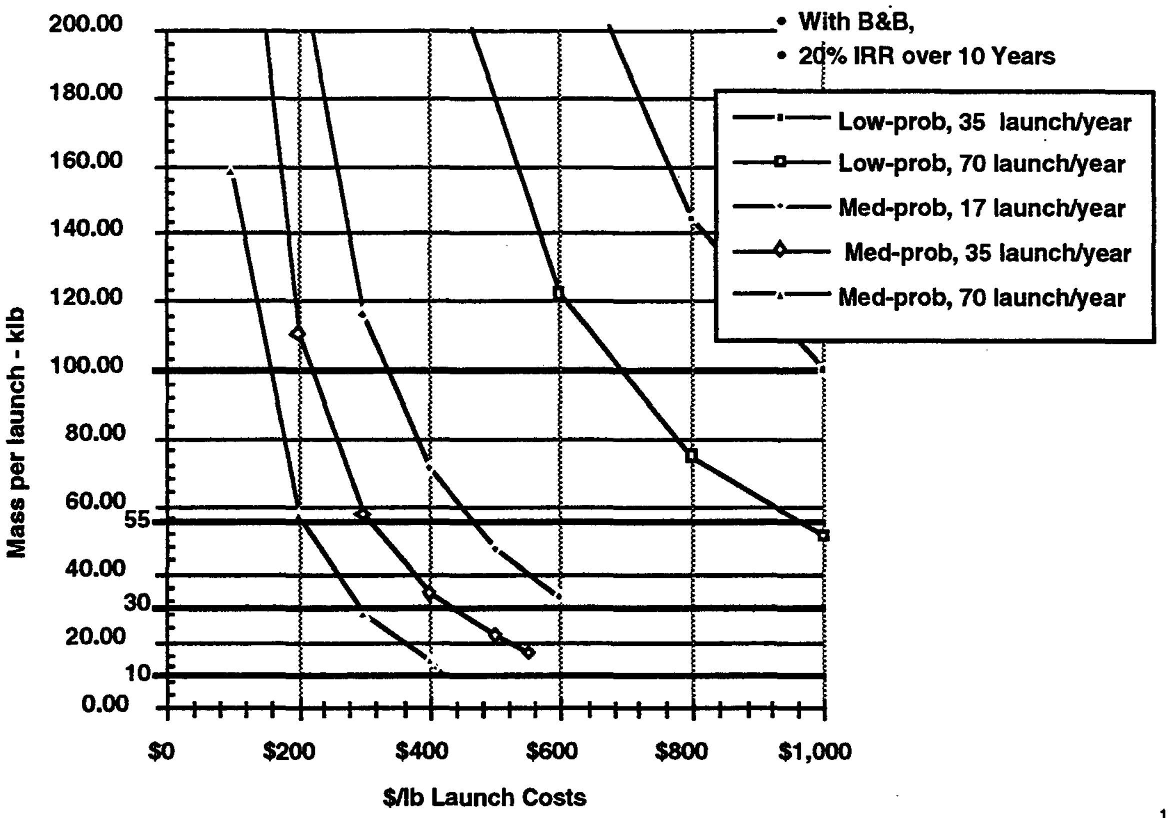

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Figure 3.7.6.3-10. Payload Size Sensitivity to Launch Price and Rate

Sensitivity of Results

Space business park economics will be driven by the space manufacturing traffic, as shown in figure 3.7.6.3-10 below for the medium-probability market. The overall business park IRR is not very sensitive to tourist ticket price and tends to optimize at around $600,000 per trip. At these prices, there only about 150 tourists/year, but this traffic provides enough profit to pay for one additional tourist module and adds a small margin to the 15-year IRR. The logistics module required to meet this level of traffic is identical to that currently planned for the international space station (see fig. 3.7.6.3-11), except that it is launched every week instead of four times a year.

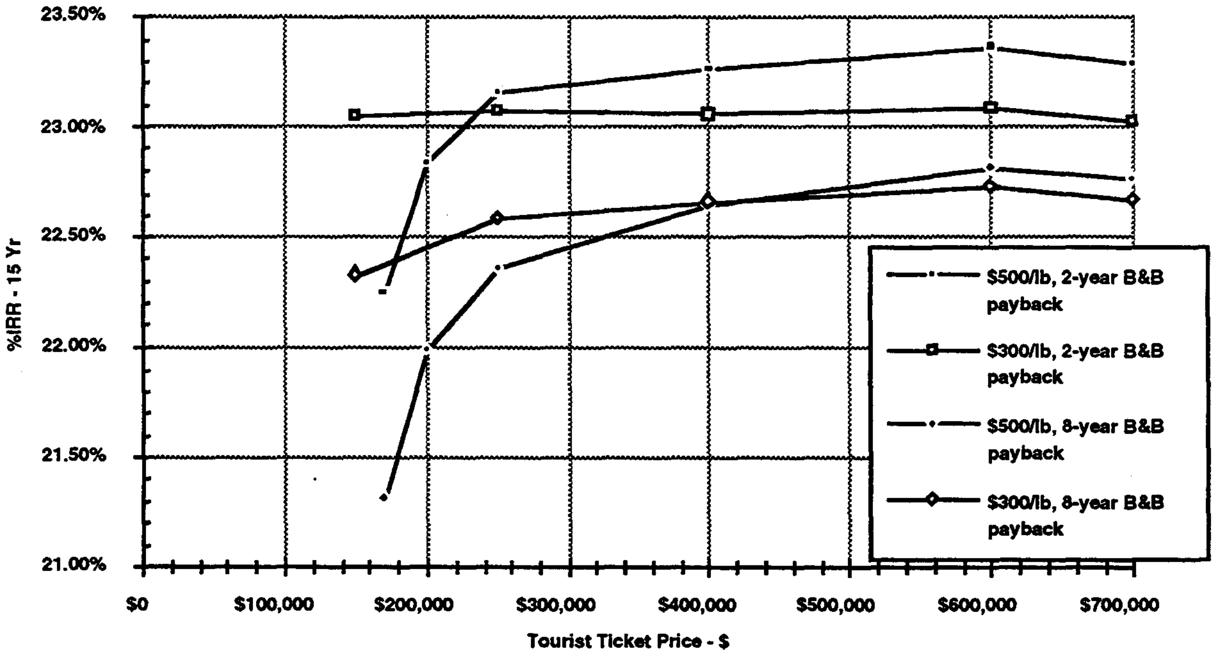

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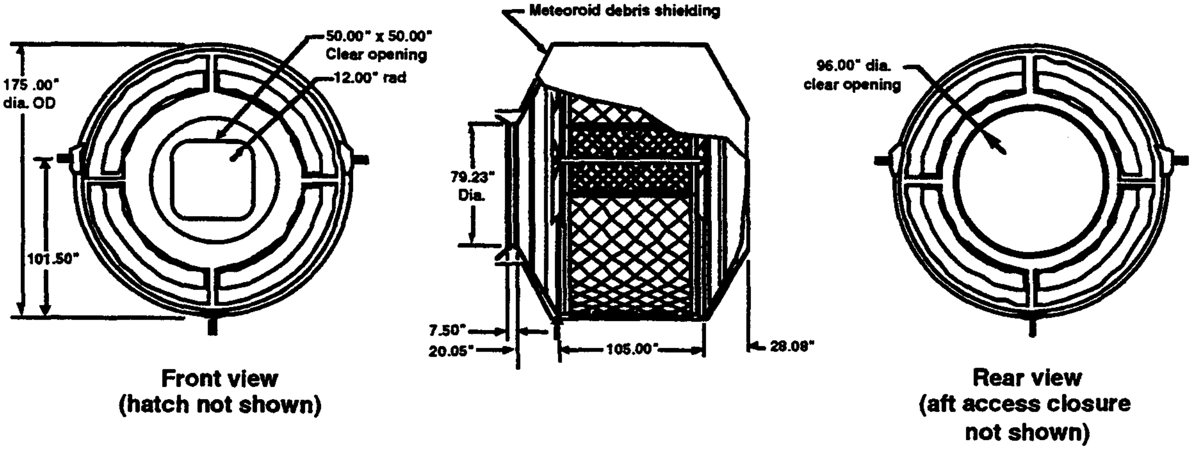
Figure 3.7.6.3-11. Sensitivity of Business Park IRR to Tourist Ticket Price (Medium Probability)



MPLM tare weight (spec) = 9,906 lb

MPLM outfitting:	**Cargo capability per rack**	**Total**
5 stowage racks (perimeter)	**(40 ft^3)x(20 lb/ft^3)(.65 PE) = 520 lb**	**6,240 lb**
2 conditioned racks (perimeter)	**(40 ft^3)x(23 lb/ft^3)(.50 PE) = 460 lb**	**1,380 lb**
	Total PLM Cargo Capability	**7,620 lb**

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Figure 3.7.6.3-12. Mini-pressurized Logistics Module Sized for Early Space Business Park

Figures 3.7.6.3-13 and -14 indicate the sensitivity of the returns to transportation cost and to development cost.

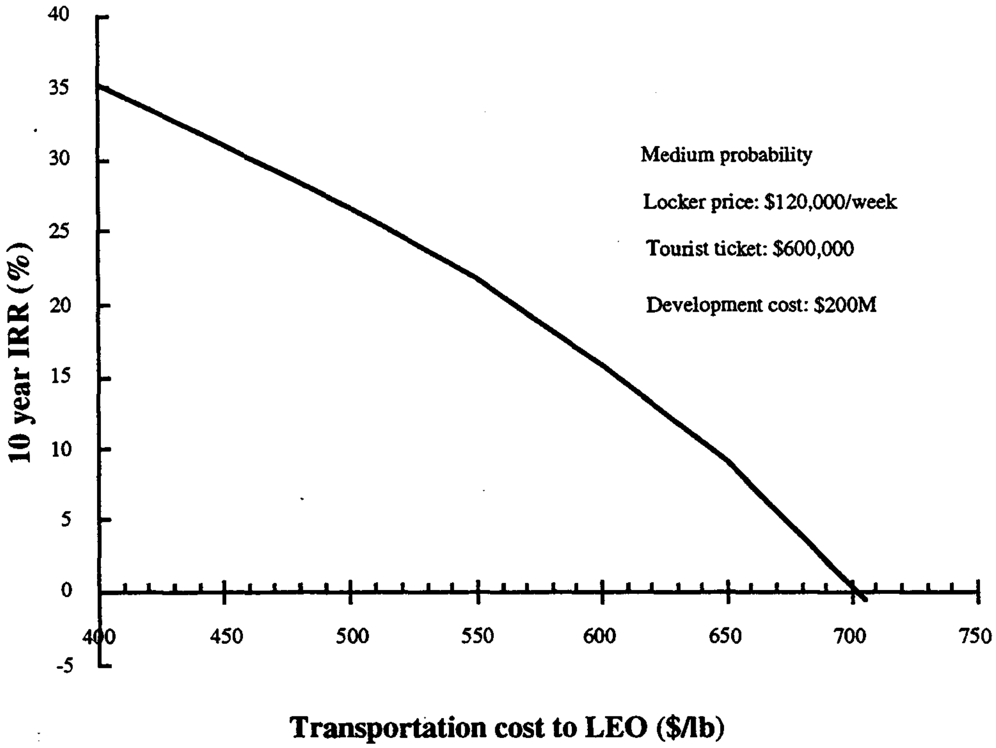

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Figure 3.7.6.3-13. Space Business Park IRR Sensitivity to LEO Transportation Cost

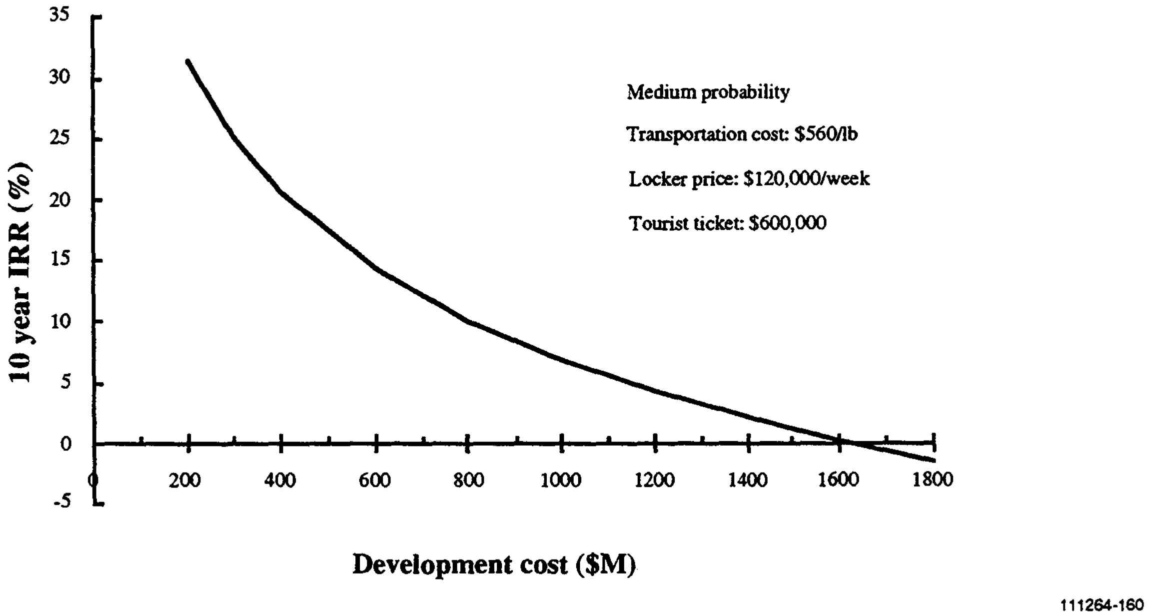

Figure 3.7.6.3-14. Space Business Park Sensitivity to Business Park Development Costs

Financing Issues

An issue raised in the market survey effort was whether this project's financing was achievable from typical real estate development sources. Historically, pension funds and insurance companies have been the long-term lenders for income producing property. Due to the financing excess of the 1980s and the continuing drag on commercial real estate markets by Resolution Trust Corporation inventories, long-term lending by these institutions has been significantly reduced. However, pension funds with vested interests in particular locations or industries (construction and municipal unions) often make loans when other financing is impossible to obtain. By analogy, aerospace unions would have a vested interest in seeing large-scale LEO construction happen, so their pension funds might be possible lenders for such a project. Preselling would give the loan underwriters for the pension funds the necessary degree of comfort to make load commitments, subject to verification of construction cost, launch cost, and operating cost.

Real estate investment trusts (REIT) have become much more active in the last few years as traditional lending has become less available. These publicly traded stocks acquire and hold real estate assets and are sold on the yields generated from rental income after all expenses. Currently, REIT offer yields of from 7% to 12%, plus whatever returns are generated from the appreciated value of the stock. Future profits from sale or refinancing of individual real estate assets are considered as part of the overall investment decision but are not as heavily weighted as current yield. While REITs were not considered by professionals in the real estate development field as suitable sources for initial financing, once an operating history in LEO is established, REIT could be excellent long-term financing sources for continuing LEO development. This is particularly true if initial returns are high enough and stabilized returns hold at or above casino/resort returns (13% to 16%).

3.7.6.3.4 Market Infrastructure

Organizational Requirements for Implementing LEO Real Estate Operations. In contrast to the well known terrestrial real estate development market, operations and organization for a space business park will encounter new organizational and operational issues. Operating expenses for LEO rental space, whether used for research, light manufacturing, or tourism, need to be closely analyzed and defined. Government-funded space stations provide a crucial step in quantifying these costs and providing the operating experience needed for larger facilities, without which the projected profit margins from LEO commercial facilities would not be believed by investment underwriters. Staffing requirements, replenishment of consumables, recycling/on-orbit food production, and long-term launch costs all need to be defined with a relatively high degree of confidence. The current international space station project provides crucial data and experience necessary to allow the successful implementation of a commercial space business park.

The unknown status of tax laws was identified as a potential roadblock to the space business park. One of the largest operating expenses in terrestrial real estate is property taxes. Multibillion dollar development at LEO will be impossible to finance until a clear determination is made as to the jurisdiction and tax status of the investment. While initial steps towards clarifying this issue have been made through legislative actions and tax code clarification, substantial uncertainties remain.

One of the standard clauses in all U.S. real estate contracts is a statement saying, "This contract shall be governed by the laws of the State of ______." This clause needs to be clarified for a space business park development. It should be noted this statement has both positive and negative implications for business considerations, such as the tax status of income earned in orbit, banking and securities regulations, gambling and vice laws, building code requirements, and security positions for the mortgage lenders who will be financing the infrastructure development. Some of these implications (such as a potential favorable tax treatment for commerce transacted in space versus commerce transacted on the Earth) may be positive.

An equivalent of a county register of deeds will be needed in order to provide a mechanism for recording mortgages and Uniform Commercial Code (UCC) filings for personal property financing. This is important to reduce the risk of mortgage positions through insurance of financial positions. Any title insurance company requested to insure a lender's mortgage position would need all of these jurisdictional issues resolved before it would be in a position to insure a mortgage loan.

The complexity of the tasks and the political and financial uncertainty inherent in large scale orbital construction are comparable in scope to the largest terrestrial real estate projects, such as Disney World or Research Triangle Park in North Carolina, so the organizational models used for such projects would seem to be an appropriate model for LEO development. All real estate projects, regardless of size, have at their core an entrepreneurial team of fewer than a dozen key design, marketing, construction, and finance people who coordinate the development process through all of the risk factors shown in figure 3.7.6.3-1. For LEO mixed-use business park developments to become a reality, these teams need to be assembled and a minimum level of seed money needs to be spent to bring in the various users. Soft commitments from the user groups are essential to design and develop facilities that will be well received in the marketplace and provide the returns on investment necessary to validate the concept of long-term commercial activities in space.

3.7.6.4 Prospective Users

The targeted market for the space business park concept developed above is the research and tourism markets. For the in-space research activities, our market analysis has indicated that key prospective users would be microprocessor producers, medical tissue suppliers, and industrial producers seeking to improve their fundamental production processes. For the tourism market, the prospective users are identified from the market demographics as suitable persons in an acceptable age and income bracket. See section 3.5.6 of this report for more data on the space tourism market.

3.7.6.5 CSTS Needs and Attributes

3.7.6.5.1 Transportation System Characteristics

Key characteristics needed for the space transportation system to support the space business park are driven by the customer needs from the research and manufacturing market area, and the space tourism market. These characteristics are summarized in figure 3.7.6.5-1, below.

Characteristic	Rationale
Mixed people and cargo payloads	Combination of persons (tourists and researchers) and research/production lockers and racks.
Mixed pressurized and unpressurized cargoes	Combination of logistics support to space business park, personnel and research/logistics support.
Scheduled launches (7 to 15 days)	Driven by expressed user needs for space access, including space tourism market data.
Rendezvous and docking capability	Access to space business park
Pressurized cargo transfer	People and Pressurized payload transfer to interior of space business park.
High reliability, approaching airliner reliability	Public acceptance for tourist flights. While some level of risk is acceptable, the reliability of safe transportation must be at least an order of magnitude higher than today's systems.
High system availability, with scheduled launches happening within 1 day of schedule	Routine access to space facility for production and research will require dependable transportation to ensure return of product and to ensure continued operation of manufacturing system. Significant revenue interruptions if system downtime. Tourist market will need to meet scheduled launches as part of packaged "tour" to space business park, and market survey results indicate <1 day schedule reliability.
Capability to handle space station-type modules and hardware	Driven by need to reduce development and risk. Maximizing the use of space station technology and system implies need to accommodate space station standard lockers, racks, and modules.
Return cargo, approximately the same as up cargo requirements	Return cargoes will include mixed personnel and cargo; pressurized and unpressurized payloads. Return cargo mass will approximate up-cargo masses since majority of flights will be logistics flights, transferring people to and from the business park and exchanging production and research lockers and racks.

Figure 3.7.6.5-1. Characteristics of Space Transportation System Needed To Support Space Business Park

3.7.6.5.2 Transportation System Capabilities

The space transportation capabilities needed to support the space business park include—

a. Capability of launching and returning payloads.

b. Payloads of 15-foot diameter and up to 60 feet long. This capability is driven by the use of space station technology to reduce development and cost risks. The diameter volume is driven by the use of space station orbital modules and subsystems, and the use of space station logistics modules for resupply.

c. Payloads of up to 30,000 lb into a 51.6-degree orbit at 220 nmi. For the medium-probability demand case, this value seemed to provide an optimum enough demand per flight to meet the schedule flight rates at about 7 to

10 day intervals. The 51.6-degree orbit assumes that the space business park will be placed into a higher inclination orbit to maximize its ground viewing opportunities, and to place it in the vicinity of the international space station currently under development by the U.S., Japan, ESA, Canada, and Russia. The payload requirement is driven by the need to transport a mixed cargo of personnel and resupply lockers and racks. This translates into an equivalent of about 55,000 lb into a 28.5-degree, 150 nmi orbit for comparison with other market areas. The sensitivity of this payload sizing is shown in figure 3.7.6.3-11, above.

3.7.6.5.3 Ground Handling

It was assumed that standard modular payloads, using the space station interface and packaging system would be used (lockers, racks, and modules). Ground handling should be relatively straightforward for the space business park because there are no new interfaces and very little checkout required. A simplified ground handling process, driven by the scheduled access characteristics for the space business park, was assumed to be in place. Ground handling systems for user systems would follow much of the existing procedures in place for space station payloads and systems. The research lockers and the passengers are loaded just before launch and the rest of the interfaces are standard for each flight.

3.7.6.5.4 User/Space Transportation System Interfaces

The primary user/space transportation system interface is through the logistics module described in figure 3.7.6.3-12, above. This module is identical to that currently planned for the international space station, and the user interfaces to the logistics module are identical. This module would be docked to the business park when the launch vehicle docked or be separated from the launch vehicle and berthed using a remote manipulator arm. The logistics module should be self-contained with respect to power and ECLSS.

Primary interfaces from the module to the space transportation system would be structural, with some data interfaces required.

3.7.6.5.5 Improvements Over Current

Improvements over current space transportation systems needed to support the space business park are evolutionary in nature. It is possible to deploy and sustain the space business park using the space shuttle and other launch systems, but if current costs and complex operations and integration procedures decrease the user demand to a level at which the system is no longer viable as a business venture.

3.7.6.6 Business Opportunities

As shown in section 3.7.6.3.3, the space business park venture as outlined above produces a commercially attractive 20% IRR within 10 years of operations. Net present values (NPV) over the life of the project for various payback periods and launch costs are shown in figure 3.7.6.6-1 below.

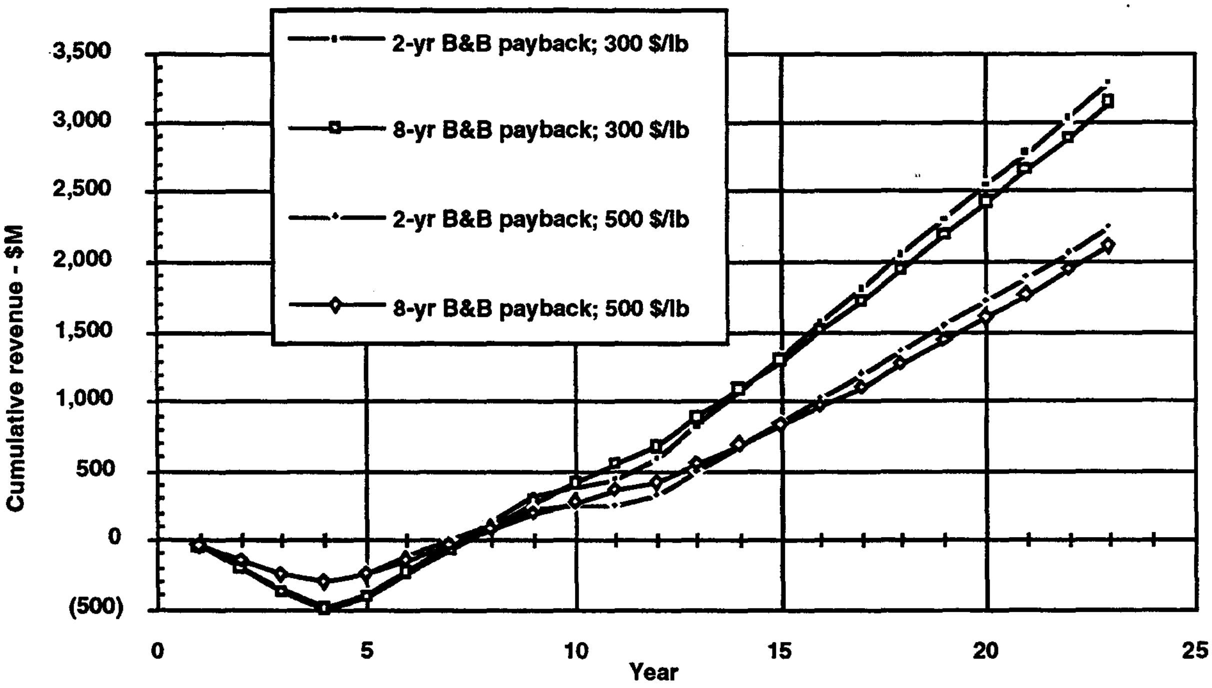

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Figure 3.7.6.6-1: Net Present Values for the Nominal Space Business Park (Medium-Probability Demand Model)

3.7.6.7 Conclusions and Recommendations

The LEO space business park, providing a mixed-use commercially oriented facility in orbit, appears to offer an attractive business opportunity at transportation costs of less than about $560/lb. As a commercial development activity, modelled after terrestrial mixed-use business parks, the venture falls within rough order of magnitude commercial criteria for financial requirements, rates of return, and scale. However, this conclusion is highly dependent upon the provision of a new, low-cost space transportation system, and the capture of increased market demand from research/manufacturing options and space tourism.

It is recommended that further analysis be peformed to develop a more complete preliminary design of a commercially procured space business park. This would answer specific questions about the subsystems design and systems cost, based upon space station technologies and operational experience. Similarly, further market analysis should be performed to reduce the uncertainty in the research/manufacturing markets and the space tourism markets.

3.8 SPACE UTILITIES

3.8.1 Introduction

The production of power in space and transmission to terrestrial users has long been recognized as a large potential market for future space transportation systems. Over the past decade, world use of energy has continued a slow but steady growth, averaging about 2.4% per year. This growth is directly related to worldwide standard of living and population, with per capita energy consumption continuing to grow as higher portions of the world population achieve a higher standard of living.

Worldwide, over 11 billion kWh of energy were produced in 1991 from primary sources—petroleum, natural gas, coal, hydroelectricity, and nuclear electricity (fig. 3.8.1-1). In 1991, three countries—the United States, the former USSR, and China —were the leading producers and consumers of energy. These three countries produced 47% of the world total and consumed 48%. The United States was the largest single producer and consumer of energy, consuming 23% of the world's total energy consumption. Of the U.S. energy consumption, over one-third (36.3%) is consumed to generate electric power. In the United States, the energy power industry's revenues were about $175 billion in 1992, of which about 71% were paid for residential or domestic uses.

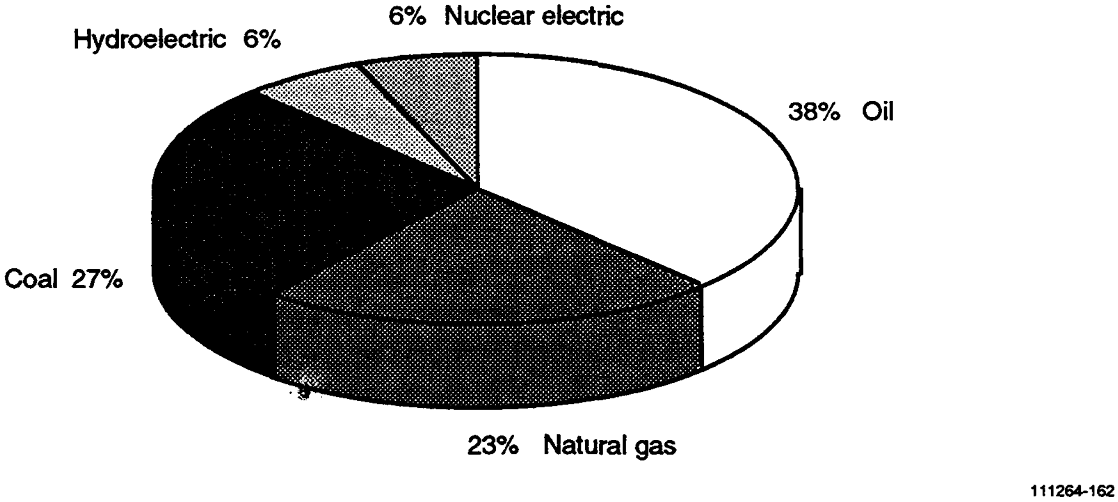

Figure 3.8.1-1. World Energy Production by Type

The energy industry has also been the object of significant environmental attention. The primary sources of power for terrestrial use—the fossil fuels of petroleum, natural gas, and coal—have been challenged as being environmentally unfriendly due to their production of carbon dioxide and its probable contribution to global warming trends. Scientific studies indicate that the percentage of carbon dioxide in the Earth's atmosphere has been steadily rising, and since carbon dioxide is one of several gases that tend to absorb reflected solar radiation, the Sun's heat is increasingly trapped within the atmosphere. This process may cause the average temperature of the planet to rise, causing uncertain, but potentially significant changes in global climate. Coal emits 80% more carbon dioxide per unit of energy consumed than natural gas, 20% more than fuel oil, and has particularly been singled out as a concern.

Nuclear power, since it does not produce greenhouse gases, offers a viable alternative to fossil fuels, but has several large political obstacles. The first is the "not in my backyard syndrome" which causes local bureaucracies to place countless obstacles in the path of licensees, sometimes increasing the time and cost of construction to the point at which ground-based nuclear plants are no longer competitive economically with fossil fuel plants. The second is the very real problem of nuclear proliferation and nuclear waste disposal. If these issues could be resolved, nuclear power could provide a major portion of the Third World's energy.

The use of renewable resources, such as solar, wind, geothermal, and hydroelectric resources, can provide some of the required resources. But these sources typically are much higher cost and have difficulty providing the baseload power requirements. While their use continues to grow, in 1990, renewable sources accounted for only about 10% of the total U.S. energy production. Figure 3.8.1-2 indicates the composition of the U.S. power generation in 1990.

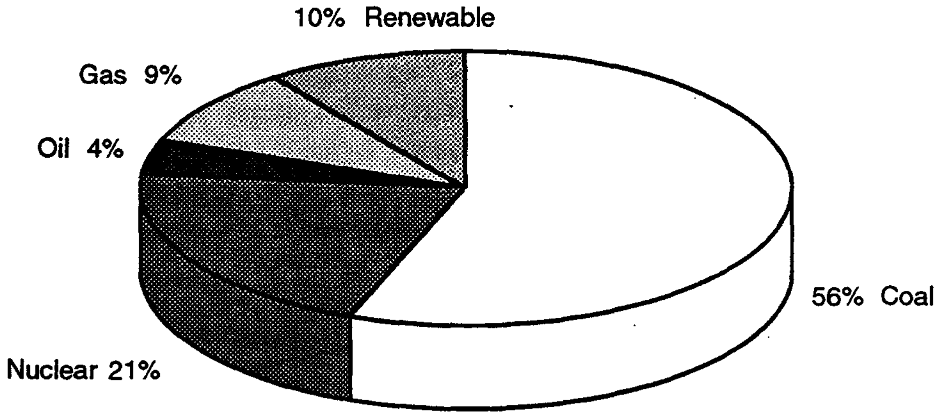

Figure 3.8.1-2. U.S. Electric Power Production by Energy Source

Space-based power systems have received much attention for their ability to transmit clean, solar-derived energy to ground stations. But these systems have always been challenged by the provision of low-cost space transportation. Space-based solutions offer potentially attractive options for providing future power.

The space utilities segment considered in the CSTS market study included the provision of power and other services to in-space and terrestrial users. Primarily, the service provided is power, using beamed power techniques to deliver power from a collection and processing point in space to in-space or terrestrial users.

These solar power satellites (SPS) offer inexhaustible, nonpolluting power but require construction of very large space structures. Options to reduce the large size and mass of the satellites necessary for base-power generation include addressing high-revenue niche markets, using extraterrestrial resources to bootstrap the production requirements, and entering into an initial space-to-space power market.

The CSTS analysis indicates that this market segment, under current market conditions, requires a very inexpensive space transportation system to produce a substantial amount of Earth-to-orbit space transportation demand. Of the market areas examined, the most promising is to address a niche market to provide power to high-latitude users using satellites in Molniya orbits. Other market areas, such as geosynchronous Earth orbit (GEO) power satellites and lunar-based power beaming systems, can produce power at market-competitive rates, but require such large upfront investments in development and infrastructure that they are not assessed as competitive in the reasonably near term (less than 20 years). Space-to-space power beaming may be attractive in some applications, but the market for this application does not produce a substantial space transportation demand.

3.8.1.1 Results Summary

The expected demand for energy is expected to grow worldwide. As world population continues to grow, and as the standard of living per capita increases, the demand for energy and electrical power will also grow. As pressures are put on the global energy usage system to reduce the consumption of fossil fuels, and as fossil fuel prices increase, there will be pressure to use more nonfossil fuel power sources. It also should be noted that as more and more electric vehicles are encouraged, electric power usage will also increase. Global energy production has increased by roughly 50% over the last two decades, with fossil fuels (coal, oil, and gas) together accounting for over 90% of production. In the developing countries, total consumption of commercial energy has almost tripled since 1970, with coal and oil being the major new sources. A further tripling of energy demand in developing countries is expected between 1985 and 2025, with fossil fuels expected to be the major energy source. Environmental damage can be expected to increase as the harder-to-reach and lower-grade deposits are recovered and used. Without the introduction of a new source of energy the fossil fuel deposits will be depleted within the next 40 to 400 years.

Coal is the most abundant of the three commercial fuel types and has proven reserves-to-production ratio of 390 years. Over 60% of world coal reserves are found in developing countries, 50% in China alone. North America has a proven coal reserves-to-production ratio of 201 years. The world's ratio is 40 years. Developing countries account for over 86% of the world's reserves. The world's industrialized countries have a proven oil reserves-to-production ratio of only 10 years, with North America's ratio also 10 years. For natural gas, the proven reserves-to-production ratios are 155 years and 39 years for the developing and industrialized nations, respectively, with each group having approximately 50% of the reserves; the North American ratio is 10 years. As these reserves dwindle, prices will rise and less economically desirable deposits will be recovered.

3.8.1.2 Associated Market Segments (Market Area Mapping)

Market area brainstorming, reviews of the literature, and contacts within the market, suggest that there are at least five different potential market approaches to space power utilities.

Power satellites in geosynchronous orbit provide base power to major population centers. Similar systems were extensively studied in the late 1970s by NASA and the Department of Energy, including significant contractual studies of the systems and the required developments. Staying in a constant position in the sky over the Equator, these very large satellites would beam back large quantities of power to terrestrial receivers. But, since these are very large satellites in a high-Earth orbit, they would require installation of large system infrastructures at high cost. For these satellites to offer a competitive rate of return, the price paid for energy would have to greatly increase.

Power satellites in Molniya-type orbits provide base electrical power to isolated industrial sites and settlements in the high latitudes. Power users in remote locations in the Arctic region currently pay high prices for power. Furthermore, these users cannot use solar power alternatives due to the long winter Arctic nights, and there are distinct environmental problems in transporting and burning fossil fuels into the Arctic regions. The Molniya orbits allow a series of power-generating satellites (either nuclear or solar powered) to hover in the sky over the Arctic regions, where they could deliver power. However, transportation and development costs still require a very low transportation cost for this market area to be viable.

Power satellites in Sun-synchronous orbits provide peaking power worldwide during the 6 a.m. to 9 a.m. and the 6 p.m. to 9 p.m. power peaks. Electric utilities pay higher rates for power provided at peak demand periods. Using a Sun-synchronous orbit, satellites can be positioned to provide power only during these peak periods.

Unfortunately, during most of the orbit the satellite is not in position to provide power to a utility (since 70% of the time the satellite is over water), and this market approach does not appear to be viable.

Lunar-based power stations provide base power to major population centers and isolated industrial sites and settlements. During the DOE- and NASA-sponsored GEO SPS studies in the late 1970s it was realized that most of the recurring costs of installing a system of GEO-based SPSs were driven by the transportation costs to ship equipment and components upwards in the Earth's gravitational well. Since that time several studies have generated an interest in producing SPS components and system on the lunar surface or mining the Moon to provide construction material for solar power satellites. The specific venture examined here is to produce and install large solar power generation and transmission systems on the lunar surface, and transmit power back to the Earth for terrestrial use. While this system offers the potential for large economies of scale in power production, the upfront developments and infrastructure required to accomplish this (including a large lunar base) require an upfront development estimated at hundreds of billions of dollars. Due to this large upfront investment cost, this concept was not justified as a viable commercial venture.

Space-to-space power beaming, as identified from the current literature, and as suggested by several of the organizations contacted in the market surveys, may serve an initial, smaller market by providing power from a centralized power generating station to other co-orbiting satellites. Satellite power generation and storage systems are typically among the most expensive components of satellite systems. However, the market assessment indicates that unless there is a very large concentration of power usage in a very limited location in orbit, this option is not cost competitive with typical distributed satellite power generating and storage systems.

Several other areas were suggested for in-space power utilities. Some, such as the beaming of power from ground-based lasers to satellites to replace power storage systems when the system was in eclipse periods, were judged not to drive space transportation significantly and were not examined in detail.

3.8.1.3 Assessment Approach

The overall assessment approach for this market area followed a two-pronged approach. The first path identified market data to assess the current status and market drivers for the market area. This included contacts with potential users in the market area, identification of key players and regulators in the market, competing technology for the space market areas, and market factors that might drive the feasibility and competitiveness of a space solution.

The second prong of the assessment approach was to develop a business and technical feasibility model of potential ventures in this business area. In particular, these models were developed to answer the question, Is this approach a good business deal? That is, Does this approach fit within current business ranges for investment size and returns? As part of this, technical feasibility assessments were performed on the market concepts; assessing if the project could be built and launched, identifying critical technology developments needed, and examining the production/engineering/technology resources needed for the business venture to see if they will be available in the time period considered.

To be included in the market projection, each market area assessed had to show business and technical feasibility for the market area—and had to match the market survey data sufficiently such that there was some level of validation from the surveyed market data to establish credibility of the projections for the future market opportunities. From these assessments, sensitivities to market and technical assumptions were examined, and a threshold cost below which space transportation had to be offered at provide an acceptable rate or return was determined.

3.8.2 Space Utilities Markets

3.8.2.1 General Market Description

In the United States for example, the market is dominated by municipal and investor-owned utilities. These utilities provide power to consumers and businesses as a "regulated monopoly," and in exchange for being the only provider of power, have regulated rates and rates of return. This regulation is typically provided by a state or municipal public utilities commission representing the public to which power is provided.

Current U.S. electrical power projections for 2010, based on utilities planning data (see fig. 3.8.2.1-1), show a reference capacity of 880 gigawatts, of which 352 GW will be from coal, 282 GW from oil and gas, 102 GW from nuclear, and 144 GW from renewable and other (primarily pumped storage hydroelectric with some waste heat and process gases). In 2010 the average price for electricity in the United States is projected to be 6.9¢ per kWh, of which capital cost represents 2.1¢, fuel represents 2.7¢, and O&M represents 2.1¢ per kWh[1]. During the period from 1990 to 2010 U.S. utilities plan to retire 47 GW worth of capacity and add 195 GW worth, primarily gas-fired turbine-powered generators with very limited renewable energy sources.

Outside the United States, the electrical market is only half as large as the U.S. market but prices are higher. German consumers pay an average of over 16¢/kWh and the Japanese residential rate is almost 23¢/kWh[3]. Current expenditures from the 117 investor-owned U.S. utilities are about $45 billion per year in the United States for new power-generating capability. However, about 80% of this new generating capability is being paid for out of current operating revenues.

The current drivers for the U.S. power industry are dictated by the regulatory structure of the industry, and the Public Utilities Regulatory Act (PURPA) of 1978, which requires public utilities to buy power at a premium over the "avoided" cost of installing equivalent capability themselves. Some utilities now purchase up to 40% of their energy from such independent power producers.

The current PURPA contracts were negotiated on a price basis that was established in the late 1970s; the negotiated rates are based upon late 1970s projections of energy costs. This has allowed such alternative energy sources as solar thermal, solar photovoltaic, wind, and geothermal to sell energy to the utilities as successful private ventures. However, the prices being paid to independent power producers are gradually being renegotiated to current energy costs and expectations as the existing contracts are renewed. This is expected to reduce the prices paid for some types of these renewable energy ventures and may substantially reduce their expected returns. Even with the decrease in prices paid for these alternative energy sources they are predicted to be cost competitive with fossil fuels after the year 2000, but they are not yet under serious consideration by the U.S utility companies[2] as primary sources of power.

		2010				
	1990	Reference	High Growth Economic	Low Growth Economic	High Recovery Oil&Gas	Low Recovery Oil&Gas
Net demand[a] (billion kWh						
Sales by Utilities	2,713	3,730	3,927	3,523	3,724	3,731
Self-Generation by Nonutilities[b]	111	182	203	171	184	183
Net energy for load (billion kWh)	**2,915**	**3,984**	**4,186**	**3,769**	**3,980**	**3,983**
Net electricity imports	2	54	54	54	54	54
Purchase from nonutilities	106	408	549	286	387	435
Generation by utilities	2,808	3,521	3,583	3,429	3,539	3,494
Generation by fuel type – utility and nonutility (billion kWh)						
Coal	1,593	2,032	2,179	1,908	1,967	2,122
Oil	122	174	168	170	173	179
Gas	364	735	786	644	798	639
Nuclear	577	636	647	636	636	636
Renewables/Other[c]	371	536	554	527	536	536
Total	**3,026**	**4,112**	**4,335**	**3,885**	**4,110**	**4,112**
Capacity – utility and nonutility (GW)						
Coal	305	352	377	332	341	370
Oil/Gas	216	282	302	257	293	264
Nuclear	100	102	105	102	102	102
Renewables	87	113	116	112	113	113
Other	23	31	31	31	31	31
Total	**732**	**880**	**930**	**834**	**879**	**880**
Fossil fuel consumption – utility and nonutility (quadrillion BTU)						
Coal	16.4	20.3	21.6	19.4	19.8	21.3
Oil	1.3	1.8	1.7	1.7	1.8	1.9
Gas	3.5	6.7	7.0	6.2	7.2	6.0
Cumulative Utility Retirements from 12/31/90 (GW)	--	47	47	47	47	47
Cumulative additions from 12/31/90 (gigawatts)	--	**195**	**245**	**149**	**194**	**195**
Utility (announced)	--	59	59	59	59	59
Utility (not announced to date)[d]	--	65	86	43	67	62
Nonutility (announced)	--	21	21	21	21	21
Nonutility (not announced to date)	--	50	78	26	47	53
Average electricity prices[e] (1991 cents per kWh)						
Capital	2.9	2.1	2.1	2.0	2.1	2.1
Fuel	1.7	2.7	2.9	2.5	2.6	2.8
O&M	2.2	2.1	2.0	2.2	2.1	2.1
Total	**6.8**	**6.9**	**7.0**	**6.7**	**6.8**	**7.0**

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[a] Demand is expressed net of demand-side management.

[b] Nonutilities include cogenerators, small power producers, independent power producers, and all other sources that produce electricity for self-use or for delivery to the grid, except electric utilities

[c] For utilities, renewables include pumped storage hydroelectric plus a small quantity of petroleum coke. For nonutilities, this category also includes waste heat, blast furnace gas, coke oven gas, and anthracite culm.

[d] Additions in this category are primarily facilities whose construction is projected beyond 2000, which utilities and nonutilities are not required to report to EIA.

[e] Prices represent average revenue per kWh of sales over all customer classes. Note: Totals may not equal sum of components due to independent rounding.

Figure 3.8.2.1-1. Predicted U.S. Electrical Energy Capacity and Consumption

It should be noted that power produced by the alternative energy sources is typically rated and paid for on a sliding hourly price scale. This scale recognizes that the demand for power typically varies over the space of a day, peaking in the early afternoon, and declining to a low ("baseload") demand level during the night. Alternative energy sources, such as wind energy, may not produce power at the optimum times and their revenues are reduced.

The demand for electrical power in the United States is continuing to increase, although the rate of increase has fallen, and the market projections reflect this. Figure 3.8.2.1-2 indicates the historical change in the projected demand level.

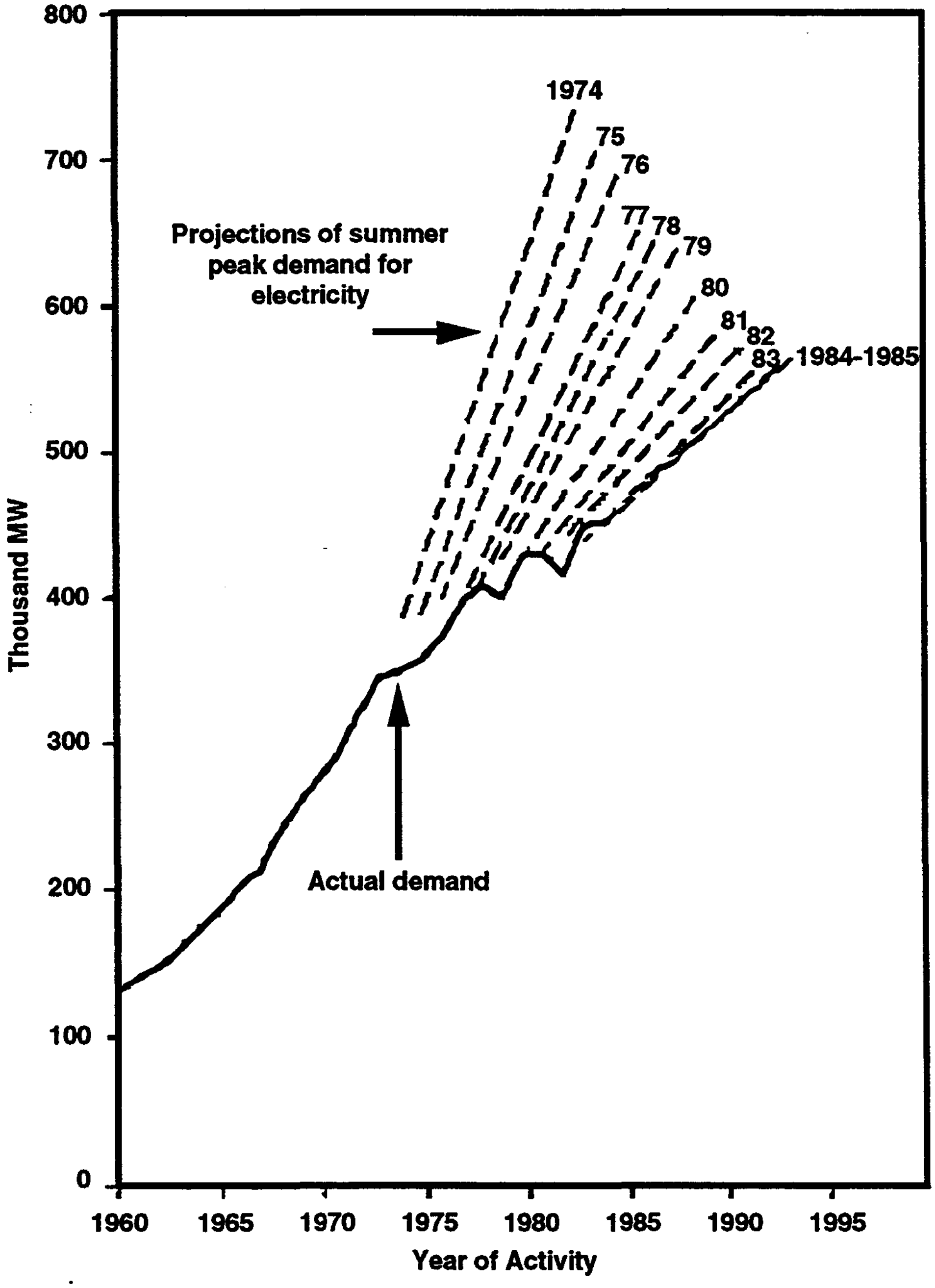

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Figure 3.8.2.1-2. Historical Data Show That the Demand Increase Has Fallen With Time

One of the most significant changes in the market over the last decade or so has been the development of a cadre of independent power producers. Under the PURPA, nonutility power producers were given the right to build their own generating plants and compete with utilities to provide power at the lowest cost. These firms raise their required funding in the commercial markets and then invest it into power systems on a global basis to serve new users. The systems they install are then operated to produce market rates of return. This has been very attractive, as state and local regulators have capped the rates of return for public utilities.

The growth of these independent power producers has been driven by a large increase in the power needs in the developing world, although they also have significant investments in the developed countries as well. The International Finance Corporation, the lending arm of the World Bank, estimates that $100 billion in annual investment is required to meet existing power requirements in the developing nations. General Electric Company, the largest provider of power generating systems, estimates that more than 460 billion watts of power will be ordered in Asia during the next decade for roughly $300 billion. China alone currently spends about $10 billion to $14 billion in new electric power generation facilities. As a point of comparison, Southern California Edison, a major U.S. public utility contacted in this market assessment produced 81.3 billion kWh in 1993, or had a generating capacity of about 9 billion watts. The Asian market represents about 5 SCEs per year, for at least a decade.

In recognition of this market potential, billions of dollars in capital in investment are being attracted to this market. As an example, in January 1992 a $10 billion investment pool named "Global Power Investments" was set up with an initial $450 million from GE Capital Corp., the Quantum Group, and International Finance Corporation (the investment arm of the World Bank).

This rate of growth in electrical power demand is not expected to slacken in the next several decades. The world's population has doubled in the last 40 years and may double again in the next century, approaching stability at 11 billion by the year 2100. Most of this increase will take place in developing countries. China is planning to build more than a dozen plants a year, India will add 5 plants a year, and even Japan's mature economy and population will be adding more than 50 plants to build a reserve of power the way U.S. utilities do.

Almost all of these new plants will be based upon fossil fuels. As a result of the developing countries' increased populations and fossil fuel usage they are expected to account for more than half of the global increase in CO_2 emissions by 2025.

Part of the high reliance upon fossil fuels is driven by the rapid returns needed to provide commercial rates of return of 16% to 20% per year, but a large reason is the large reserves of local coal or oil to provide a local source of energy supply. Market contacts have indicated that as of this time, environmental concerns are not a major driver for the type of power plant needed, and that local environmental regulations are not strict. Furthermore, the price pressures of the competitive bidding for these commercially procured power systems place a premium on lowest price production. But the international lenders that back the financing of these plants on 10-year-plus basis, place some environmental standards on these ventures.

The principal issue against a growth market for satellite-based power is the relative cost and risk of space power versus conventional power sources. There are currently no perceived energy crises in any of the developed nations, and a large functioning infrastructure is in place that uses existing energy sources. There is also a large margin between the cost and price of fossil fuels that can be exploited to fight a new major competitor such as space-based power satellites. On the horizon, ground-based solar electric power is about to enter mass-production, which will offer costs in the range of $2/watt installed[3]. This will provide a low nonrecurring cost entry to the Third World market and further dampen any enthusiasm for SPSs, which has a very large nonrecurring cost before any power is delivered.

On the positive side, space-based power offers tremendous operational flexibility and security to its owners. It is possible to service widely dispersed sites that have invested in relatively low-cost receiving antennas, called rectennas, with the same constellation of satellites. Once in place, no outside fuels or materials are required to maintain the flow of power, and solar power is environmentally clean and inexhaustible.

Short of waiting until the world runs out of fossil fuels, there appear to be only two ways to force space power into the energy equation. The first and best is to offer energy cheaper and in a more convenient form than the competition. This appears to be possible but not at the low power prices currently enjoyed by the United States and Canada. The second is through legislation, where fossil fuels are taxed to limit their use and to clean up the environment. This is possible but not highly likely in the near future.

It is expected that the current concerns about fossil fuel emissions of greenhouse gases and other environmental effects will not abate, and will grow stronger with time. While it is not expected that significant impacts upon the coal, oil, and natural gas-powered electric utilities will appear this decade, such considerations will increase in the 2000s and beyond. This offers a market opportunity for increased use of large solar power systems.

3.8.2.2 Space Utility Market Areas

3.8.2.2.1 GEO Solar Power Satellites

3.8.2.2.1.1 Introduction

Large power satellites in GEO were extensively studied in the late 1970s by various organizations, and in several large contractual studies from DOE to Boeing Aerospace and Rockwell International. These satellites were designed to provide high power levels (tens to hundreds of gigawatts) to terrestrial receivers by converting incident solar energy into microwave power for transmission to large rectenna sites on the Earth. The power was then transferred into the terrestrial power grid. These satellites were primarily designed to serve the base-power needs for terrestrial users. A subsequent preliminary study was performed by General Dynamics Corporation into the utility of using lunar resources to provide components of the GEO SPSs. A low level of enthusiast-fueled effort in analysis and development of GEO SPSs has continued since that time.

3.8.2.3.1.2 Study Approach

The past studies were examined, and wherever possible, past participants and principles in these studies were contacted. With the benefit of current technology and perceptions after almost 20 years of technology advancement, the technical and market feasibility of these systems were reexamined. The following steps were taken in assessing this market area:

a. Literature search of the available literature on GEO solar power satellites.
b. Contacts with participants and leaders of past studies.
c. Assessment of changes in the market assumptions and the underlying technology readiness, and assessment of competing technical solutions.
d. Development of analytical models of GEO SPS options, and assessment of the market opportunity.

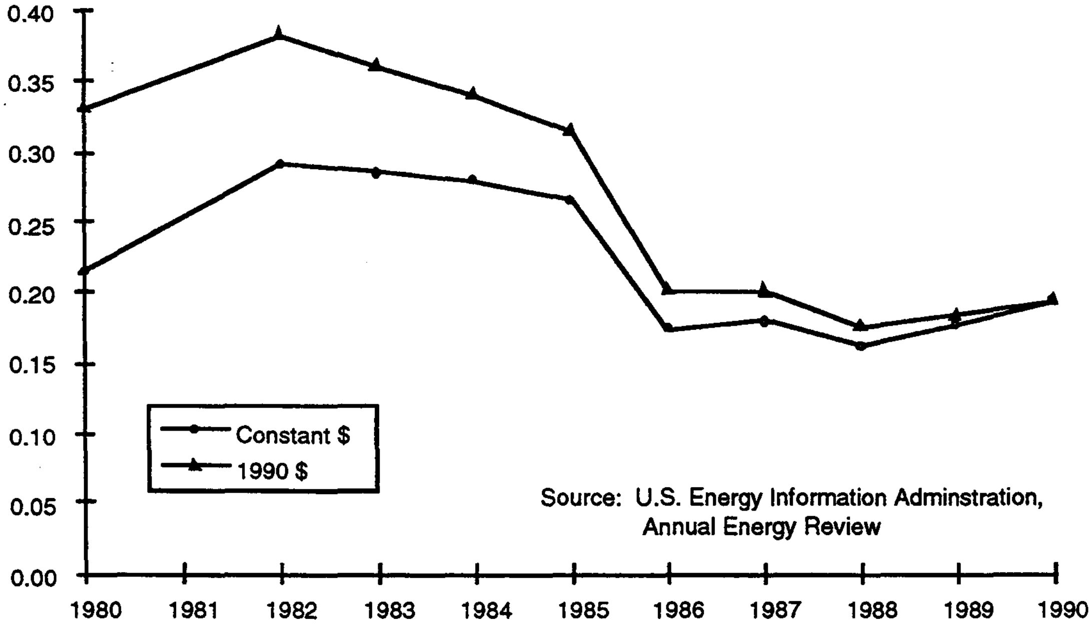
3.8.2.2.1.3 Market Description

3.8.2.2.1.3.1 Description Market Evaluation

The market for GEO SPSs consists of the major electric utilities. Current prices charged for electric power in the United States average about $0.065 per kWh. The large GEO satellites, which stay stationary in the sky over the Equator and which are in sunlight virtually 24 hours a day, seem to be best suited for providing base load power, in direct competition with nuclear or fossil-fueled power plants. Outside the United States, power prices charged are higher, with some markets having prices of up to $0.20 per kWh.

3.8.2.2.1.3.2 Market Evaluation.

At the time of the previous extensive conceptual studies in the late 1970s, energy costs for fossil fuels had been escalating rapidly due to political and economic pressures on existing terrestrial supplies. These market assumptions have since changed. Crude oil, coal, and natural gas prices have all dropped. Since the early 1980s the price of oil, for example, has dropped almost 50% in constant (inflation adjusted) dollars. The price rises experienced through the 1970s and expected to continue through the 1980s did not occur. As a composite, energy prices have dropped by about 50% through 1990, since they peaked in 1982 (see fig. 3.8.2.2-1).



Source: U.S. Energy Information Adminstration, Annual Energy Review

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Figure 3.8.2.2-1. Fossil Fuel Prices Composite Energy Prices

Similarly, these studies assumed that very optimistic space transportation systems would be developed and put in place to support the GEO SPS. These projected space transportation systems were expected to provide transportation at the cost of about $80 per pound (in today's dollars). In this current market assessment, space transportation systems have been assumed to have a variable cost per pound, and the concepts have been assessed to see under what $/lb to LEO a GEO SPS system would be viable.

3.8.2.2.1.3.3 Market Assessment

Figure 3.8.2.2-2 indicates the CSTS assessment of the current state of the GEO SPS satellite concept, comparing expected internal rate of return (IRR) after 20 years of operations versus the price for energy paid for power from the GEO SPS system.

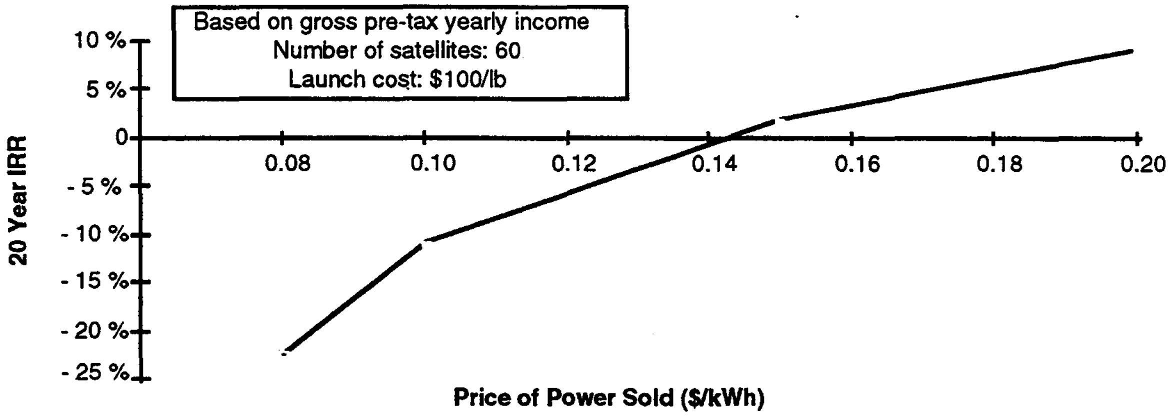

Figure 3.8.2.2-2. 20-Year IRR Versus Price of Power Sold (60-Satellite System)

To fully assess the system, both a single GEO solar power satellite system and a fully operational system of 60 satellites were examined. (The advantage in the larger system is that any nonrecurring development costs or investments would be spread over the larger number of satellites). Figure 3.8.2.2-3 indicates the rate of return for a single power satellite case.

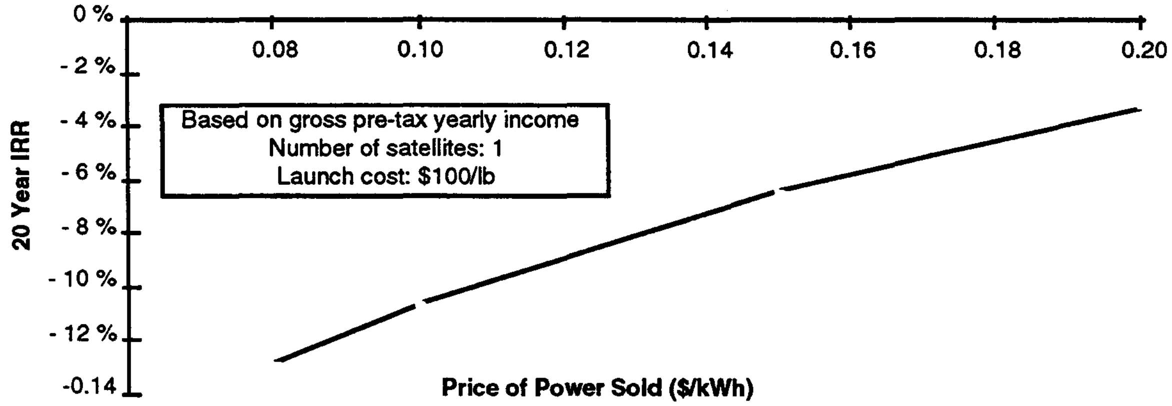

Figure 3.8.2.2-3. 20-Year IRR Versus Price of Power Sold (One Satellite)

GEO satellite concept costs shown are unit costs, based upon current technology assumptions, which are used to update the major study efforts of the late 1970s. Unfortunately, technology needed for such large satellites has progressed little versus the assumed technology in the 1980-vintage studies.

Also in contrast to the earlier studies, the development cost for an Earth-to-orbit transportation system was removed, and only included as a variable $/lb price to get to LEO. Figure 3.8.2.2-4 indicates the sensitivity of these results to LEO transportation cost.

Development costs were retained for other elements of the needed infrastructure, such as an orbital transfer vehicle and the GEO construction system, and for the satellite hardware itself. Nontransportation development costs were estimated based upon the 1978 DOE contract studies, at about $40 billion in 1993 dollars.

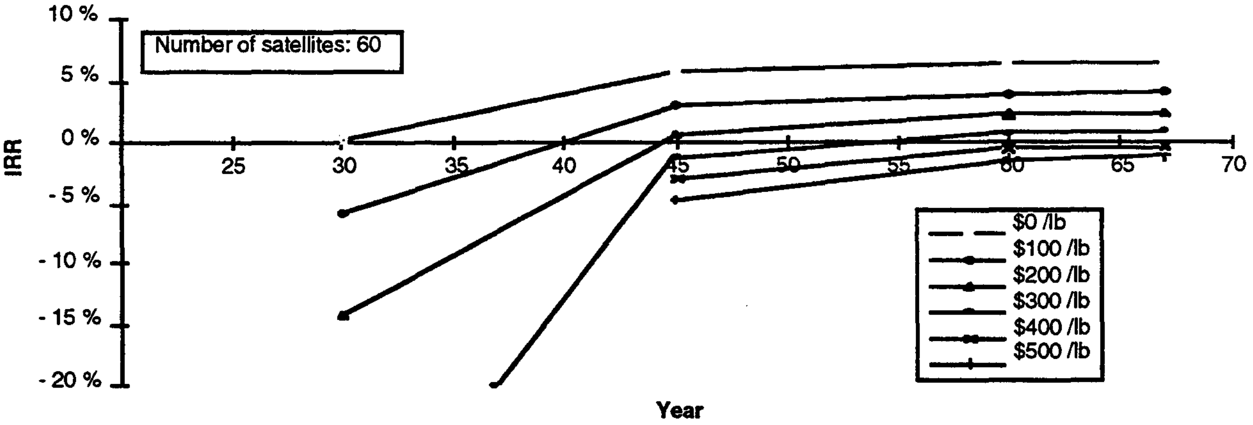

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Figure 3.8.2.2-4. IRR for Selected Launch Costs

Key assumptions in this market analysis included—

a. Power rate (unless otherwise noted): $0.06/kWh.
b. Satellite operational life: 30 years.
c. Power at ground interface (per satellite): 5.0 GW.
d. Mass to LEO required to construct first satellite: 54,612,535 kg.
e. Average mass to LEO required to construct each additional satellite: 42,096,498 kg.
f. Mass to LEO required for satellite operations: 10,083,157 kg per satellite/30 years.
g. Satellite operational life: 30 years.
h. Launch capability per year (maximum): 90,000,000 kg.
i. Interest rate: 5.5%.
j. DDT&E costs distributed over the first 5 years according to the following schedule:

Year 1	Year 2	Year 3	Year 4	Year 5
10%	20%	30%	30%	10%

k. Production starts in year six.
l. Satellites produce power for 100% of their operational life.
m. A 0.5% insurance rate is charges to the following items:
    1. Satellite: construction and O&M-RCI.
    2. Space construction and support: construction and O&M-RCI.
    3. On-orbit transportation: construction and O&M-RCI.
    4. Launch costs (HLLV & PLV).
n. All dollar figures are given in 1993 dollars.
o. Earth to LEO launch costs are calculated on a $/lb basis.

These results are reasonable assuming this project is equivalent to major utility operations, but very optimistic if a commercial venture is assumed, as per an independent power producer. An independent power provider raises money on the commercial capital markets, and would see a higher cost of money, and would have to provide a higher rate of return (typically 20% IRR after 10 years of operations) to be competitive with other commercial ventures also looking for financing.

The difference in these results from the past studies in the late 1970s is results primarily from different expectations for the cost of fossil fuels in the future and the removal of the assumption of very low-cost space transportation. In contrast to the past contractual studies, we did not assume that a new, dedicated space transportation system was developed solely for this usage. This is a conservative assumption, since this decreases the cost to the GEO SPS system and would tend to improve expected returns.

This result does not indicate that a GEO solar power satellite venture is commercially viable at any reasonable $/lb in LEO transportation price unless energy costs greatly increase. Even if transportation costs to orbit are free $0 /lb to LEO), it will take about 30 years just to recover the sunk investment at current energy prices. However, if energy costs increase, such that power could be sold at $0.50-1.00 per kWh, then these ventures might be more viable.

3.8.2.2.1.4 Market Infrastructure

Since this market area is not viewed as commercially viable at current energy prices and costs, no transition to establish the large-scale effort was developed. However, there is significant infrastructure needed to be put into place before a GEO SPS venture is established. Major infrastructure elements are needed to assemble major subelements of the satellites in LEO, then to transfer them to GEO, assemble them into working power stations, and then support and maintain these facilities. On the ground, rectenna sites to receive the beamed power from the GEO power satellites and distribute it into the utility grid are also required. Figure 3.8.2.3-5 summarizes the required infrastructure elements needed. Costs for all these elements are included in the market assessment.

3.8.2.2.1.5 Prospective Users

The primary users for this system are the major utilities, with the GEO SPS system providing baseload power. The costs involved in this venture are substantial, with development costs in the tens of billions of dollars. This level of required investment and the current level of technical risk in such a system removes it, however, from the consideration of conservative power system investors. To reduce the level of financial risk to any individual investor, a syndicate of investors must be developed, or government financial backing provided. Typical individual projects may include up to $500 million or so in financing from any one equity partner, so an investment syndicate for a GEO SPS venture may involve dozens of partners, which was described as "very challenging" in the market contacts. Similarly, the time scale of investment and the great uncertainty in returns may force the government to provide underlying finances and key market guarantees. At this point, since this venture does not appear commercially or financially feasible, only the government can be seen as a prospective user.

LEO assembly node	Stores and assembles major subelements before transport to GEO.
GEO transportation system	Transports cargo and crews to and from GEO. Supports GEO servicing and maintenance missions.
GEO assembly node	Assembles major subelements into power satellites. Supports crew as required for assembly. Supports servicing and maintenance operations during operational phase.
Terrestrial receiving site (rectenna)	Receives beamed power from GEO solar power satellites. Converts beamed power to output electrical power and transfers power into utility grid.

Figure 3.8.2.2-5. Required Infrastructure Elements for GEO Solar Power Satellite System

3.8.2.2.1.6 CSTS Needs and Attributes

The market analysis of GEO solar power satellites indicated the concept was not commercially viable, independent of space transportation system cost. Given the large investments required and the low price for power currently prevailing, the market analysis of GEO solar power satellites indicated the concept was not commercially viable independent of space transportation costs.

3.8.2.2.1.7 Business Opportunities

No viable business opportunities in this market segment were defined at this point.

3.8.2.2.1.8 Conclusions and Recommendations

The GEO SPS market area was defocused at this time, due to an assessed lack of market viability. Effort continued looking into niche markets or where economies of scale could offer the promise of better returns for other ventures.

3.8.2.2.2 Power Satellites in Molniya orbits

3.8.2.2.2.1 Introduction

Two different nonsynchronous orbit solar power satellite options were examined. Selection of the orbit is crucial to space-based power satellites performance and system cost. A high altitude requires large antennas and a low orbital period yields short dwell times. The orbit options examined in this market study are summarized in Figure 3.8.2.3-6. Orbits other than GEO are of interest, even though they require multiple satellites to service each rectenna site, because they require less propulsive energy or provide smaller transmission distances (which reduces antenna size and power requirements). The GEO SPS was described in the previous section.

Orbit	Time % View is Under 35 deg	Max Distance (km)	Orbital Inclination(deg)
Geosynchronous	100	35,785	0
12-hour Molniya	94	40,165*	63.4
8-hour Molniya	85	27,560*	63.4
4-hour Molniya	47	12,530*	131.3
3-hour Molniya	30	8.065*	115.2
2-hour Molniya	5	1,820	102.1

* Based upon maximum eccentricity for a perigee altitude of 300 km.

Figure 3.8.2.2-6. Orbital Options for Solar Power Satellite

Figure 3.8.2.2-7 compares the relative viewing angle between the rectenna and the space-based power satellites for four orbital options. The plot is generated using the maximum allowable eccentricity for each orbit defined by a 300-km perigee altitude and assuming that the rectenna is directly under the satellite's apogee.

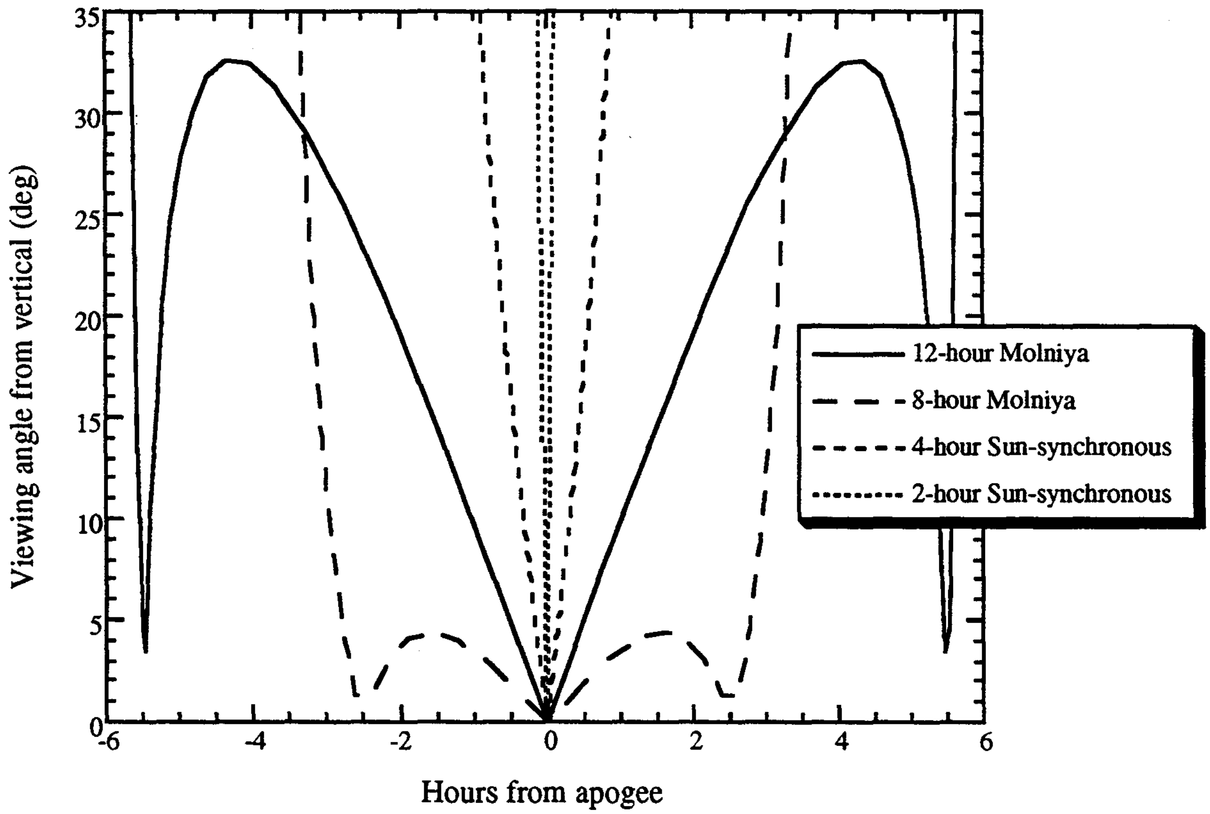

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Figure 3.8.2.2-7. Time Spent Within the Maximum Viewing Angle

Based upon a 35-degree maximum viewing angle envelope, the distance between the rectenna and antenna versus time is plotted in figure 3.8.2.2-8. Note that the Molniya orbits (highly elliptical orbits, inclined at 63 degrees to the equator, with an integer period of 24 ,12, 8, 6, or 4 hours) will require fairly large antennas because of their apogee height, but require few satellites because of their long dwell times at zenith. The Sun-synchronous satellites will have to be numerous because of their very short dwell times over the rectenna but only need small antennae. Note that if we launch into 4-hour Sun-synchronous orbits to provide peaking power from 6 a.m. to 9 a.m. and 6 p.m. to 9 p.m., then only four satellites are necessary.

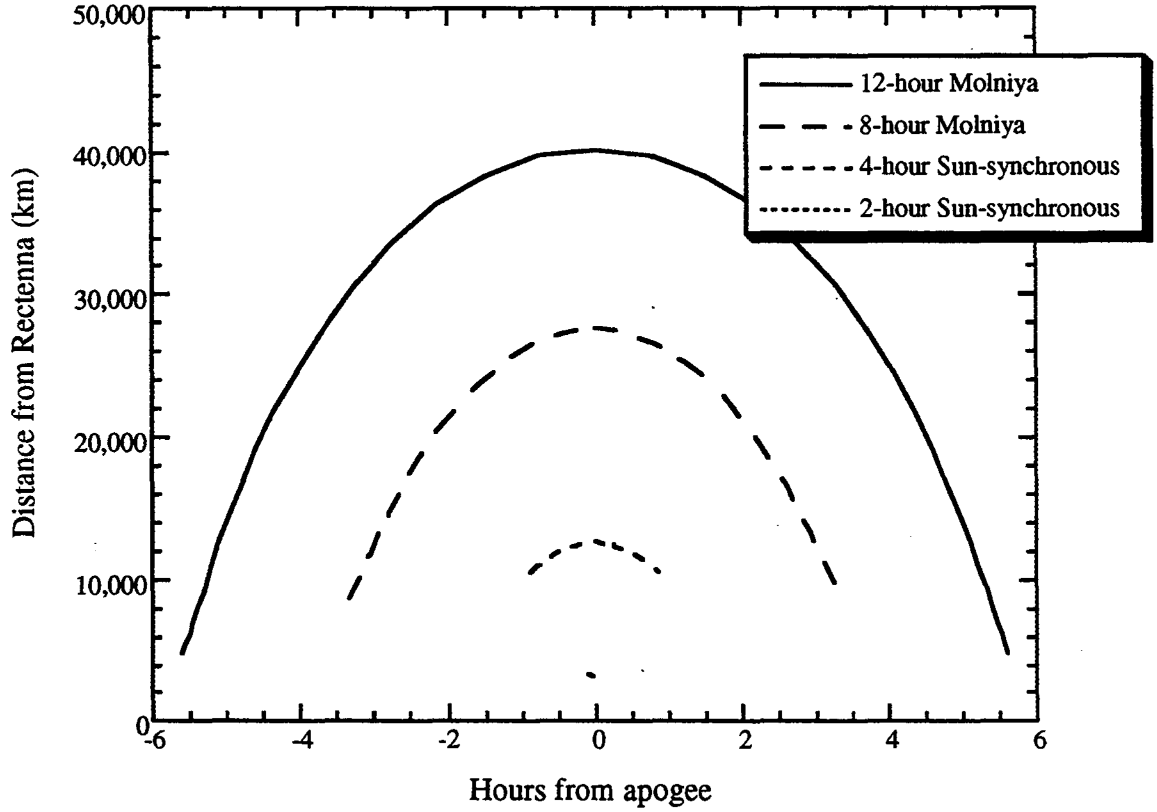

Figure 3.8.2.2-8 Distance to Satellite During Viewing Envelope

The 8-hour Molniya orbit is a compromise between maximum distance and useful percentage of the orbit. As shown in figure 3.8.2.2-9, it also seems to be very advantageous in terms of location of ground sites. With Molniya orbits, three rectenna sites in North America, Europe, and the Far East can be serviced with four satellites, and little time is spent over southern oceans where there are few markets. Ground site locations shown in the figure are arbitrary and are intended to show footprint size at various latitudes. Two of the ground site locations, Japan and central Europe, are currently buying high-priced electricity and would be definite candidates for space power. The third ground site location, central Canada/Alaska through North Dakota, currently burns predominately natural gas for power and might prove to be a hard sell. An abundance of electrical power might encourage industrial expansion there.

This figure indicates the coverage area for a typical Molniya orbit SPS, during the power transmitting portion of the orbit over Europe. (Since the satellite is in an 8-hour orbit, it will be in optimum power-transmitting position every 120 degrees of latitude. This allows it to serve the Alaskan region, northern Europe, and central Siberia.) The elliptical-shaped blob over Europe is the area visible to the satellite during the power-transmitting potion of the orbit. System customers could be located anywhere inside the boundary. This implies that a large number of prospective users are out there and must be identified.

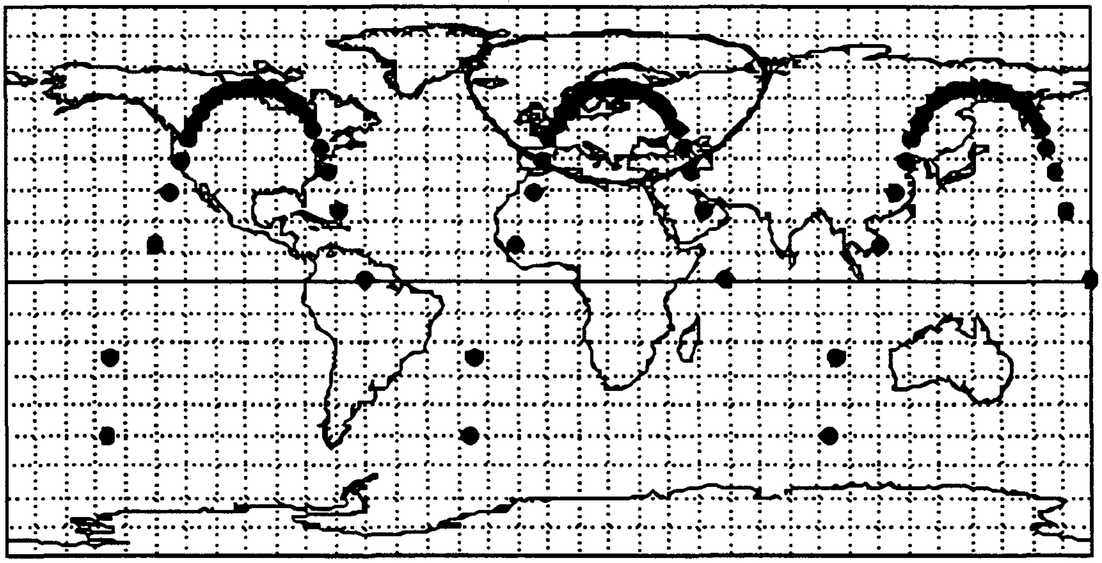

Figure 3.8.2.2-9. Possible Ground Station Locations for Solar Power Satellites in 8-Hour Molnyia Orbits

Remote site electrical power in Alaska currently runs as high as $1 per kWh, with average rates in the 10¢ to 15¢ per kWh range. Figure 3.8.2.2-10 indicates the percentage of power provided to Alaskan users as a function of price, based upon data from the Alaska Power Authority.

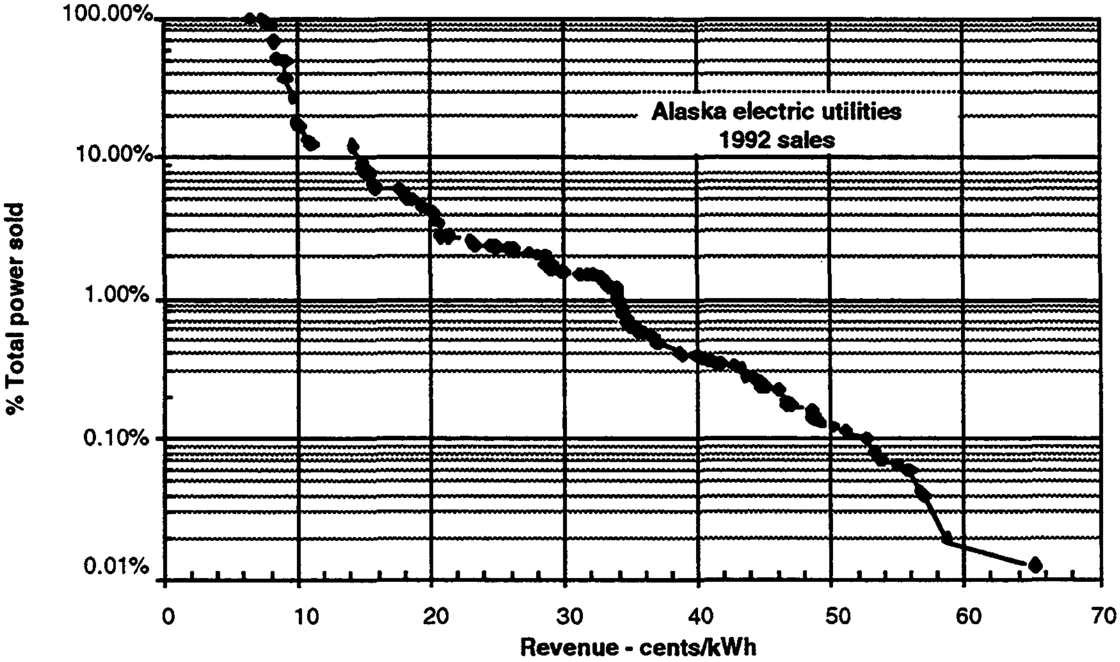

Figure 3.8.2.2-10. 1992 Alaskan Power Sales as a Function of Price

This makes space-based beamed power a lucrative alternative if transportation costs can be reduced to less than $100/lb. To maximize the payback on these relatively small power systems, the transmitting frequency was increased from 5.45 GHz to 15 GHz in order to minimize the size of the rectennas that receive the power on the ground. This results in an additional 2% transmission loss under normal weather conditions but up to 50% loss during worst case rain/snow conditions (25 mm of rain per hour, equivalent to a thunderstorm). This would require major plant operations to cease or switch to temporary power during heavy rain or snow. This may not be acceptable if SPS-provided power is used for baseload power. Other assumptions remain the same as with the GEO SPS.

3.8.2.2.2.2 Study Approach

To examine the possibility of using smaller power satellites in regions where a higher price for power is being paid, conceptual Molniya orbit solar power satellites were developed and tested to see if they offered the possibility of attractive rates of return. This was used to assess the likelihood of such a venture being a market for future space transportation services. Both nuclear- and solar-powered options were investigated. The following steps were taken to assess the market area:

a. Defined market potential user demand as function of price for power.
b. Developed conceptual solar and nuclear powered satellites.
c. Analyzed options in time-phased business model to assess achievable rates of return.
d. Analyzed transportation market potential.

3.8.2.2.2.3 Market Description

3.8.2.2.2.3.1 Description Market Evaluation

As described previously, the market addressed is to provide power to high-latitude power users who are currently paying higher than average prices for electrical power. Parametric data are developed to assess the size of the market as a function of price.

It is important to note that the users of this power are widely geographically distributed. To overcome this, it is important that the SPS system be able to provide power to them. Furthermore, since the satellite system provides power to different regions of the globe, with different distributions of users, it is important that the system be capable of "steering" its beam to these different sets of users, with different power-level requirements at each site.

3.8.2.2.2.3.2 Market Evaluation

Using the Alaskan power data to represent the high-priced end of the market, the European and Japanese data to represent the mid-priced power market, and the American and Canadian markets to represent the low-priced power requirements, we came up with a high, medium, and low estimate of future power market capture as a function of delivered power price (including 2¢/kWh for operations and maintenance). In this case, the high estimate represents 90% probability that this level of new power production can be captured at a given price; the medium estimate is for a 50% probability that a greater level of new power can be captured (at the same price); and the low probability estimate is for a 10% probability that even a larger portion of the new power market can be captured at the same price.

This market demand data are shown in figures 3.8.2.2-11 and -12, below. These capture estimates should be conservative because (1) prices and consumption are continuing to escalate and (2) we are assuming we capture only 20% of new construction at equivalent power prices (medium probability).

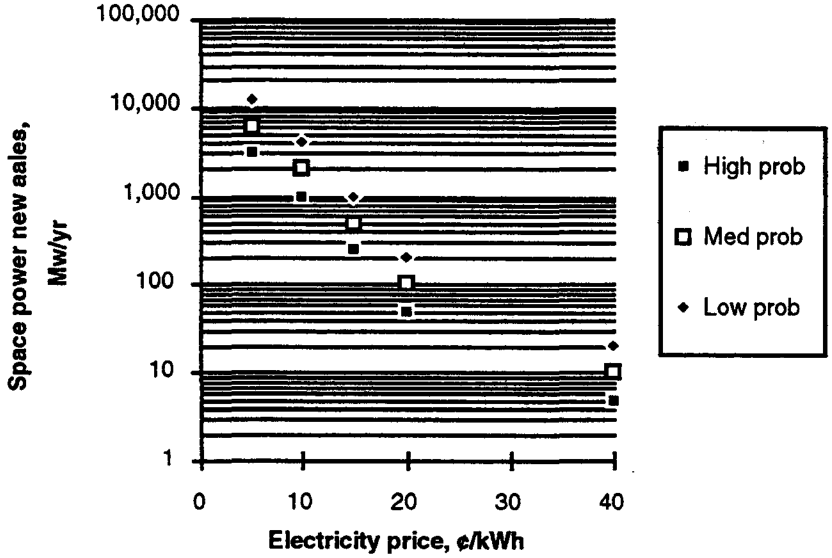

Figure 3.8.2.2-11. Space Power New Construction Market Capture

	High-Latitude Power Sales		
	New Power Sales, Mw/year		
Price, ¢/kWh	High prob	Med prob	Low prob
40	5	10	20
20	50	100	200
15	250	500	1,000
10	1,000	2,000	4,000
5	3,000	6,000	12,000

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Figure 3.8.2.2-12. Space-Based High-Latitude Electrical Power Demand Versus Price

Note that the power market saturates at very low prices and has a tailoff at high prices caused by the very high prices currently paid by very remote users such as fishing villages and mining camps.

An alternative approach, not assessed here, is to beam power from the ground using reflectors in high orbit to transmit microwave power from hydroelectric resources in the underdeveloped equatorial regions to the more developed northern latitudes. This approach makes sense from a technical standpoint, but has marginal cost benefit and real political issues. Once the power plants are in place, there would be little a developed nation could do to stop local takeover and local exploitation of a valuable resource.

3.8.2.2.2.3.3 Market Assessment

Both nuclear- and solar-powered satellite options were investigated. For a normal technology growth 2005 solar power plant (3.4 Kg/kW) described below in figure 3.8.2.2-13, the supply price per kWh at >$50/lb is always too high to match demand, so we get curves like those shown in figure 3.8.2.2-14, where the supply and demand lines never cross. If we extrapolate more advanced solar array technology available in 2005, to where the delivered specific power is 2.0 kg/kW, then we do get a match between supply and demand at about 1,500 MW/sat and 12¢/kWh.

Apogee altitude, km	27,250	Diameter of rectenna, km	0.93
Perigee altitude, km	600	Peak power intensity, mw/cm2	33.05
Semimajor axis, km	20,303	Rectenna cost, $M	34
Orbital period, hrs	8.00	Solar array learning curve	0.7
Delta V1, km/sec	2.17	Solar panel TFU, $/m*m	250,000
Delta V2, km/sec	1.42	Specific cost of array, $/m*m	343
Upper stage Isp, sec	470	Specific array cost, $/kW	$11.16
One-way mass ratio	1.60	Cost of power gen., $M	128
Busbar power, Mw	7,179	Cost per satellite, $M	1,261
Transmission freq, GHz	15	Visibility per site, minutes	360
Grid conversion efficiency	0.9	No of satellites reqd	4
Rectenna efficiency	0.9	Upper stage lambda prime	0.85
Transmission efficiency	0.96	Mass per satellite, kg	54,331,613
Klystron/magnetron eff	0.85		
Power conditioning eff.	0.95	Upper stage prop mass, kg	37,396,520
Satellite power, Mw	11,432.88	Total mass/satellite to LEO, kg	91,728,133
Solar conversion eff	0.25	LEO delivery cost, $/Kg	110
Collector area, km*km	37.18	LEO deliv cost/satellite, $M	10,090
Concentration ratio	100	Total launch costs, $M	40,360
No. of 1mX 1m solar cell panels	371,801	Total satellite purchase, $M	5,044
Power/panel	30.75	Total number of sites	215.4327
Spec. power of conv, Kg/kW	3.4	Average power per site, Mw	100
Power generation mass, Kg	38,871,795	Total rectenna purchase, $M	7,243
Klystron subarray mass, kg	15,422,956	System recurring cost, $M	52,647
No of 50kW klystrons	271,531	Busbar $/kWe	73
50 kW klystron TFU	$2,500	O&M cost, ¢/kWh	2
Klystron learning curve	0.82	30 year capital cost, ¢/kWh	0.93
Klystron ave price	$66	Power price, ¢/kWh	9
Antenna diameter, m	750	Yearly revenue, $M	13219.38
Antenna mass, Kg	36,862	Systems DDT&E	8,000
Antenna cost, $M	1,116	20-year IRR	20%

Figure 3.8.2.2-13. Solar-Powered SPS With 3.5 kg/kW Solar Array in 8-Hour Molniya Orbit

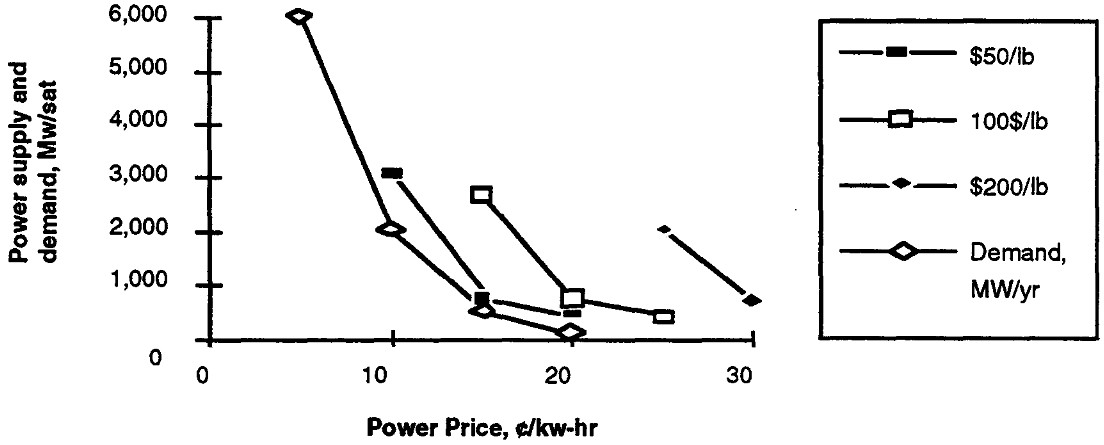

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Figure 3.8.2.2-14. Supply Versus Demand for Normal-Growth Technology SPS in 8-Hour Molniya Orbits

The nuclear-powered option, described in figure 3.8.2.2-15, has similar issues and we have baselined liquid-droplet radiators for the Brayton power cycle to keep the power plant mass low.

Apogee altitude, km	27,250	Specific cost of Brayton PP, $/kw	100
Perigee altitude, km	600	No of 600 MWt reactors in 20 yrs	956
Semimajor axis, km	20,303	600 Mwt reactor TRU, $M	^600
Orbital period, hrs	8.00	Reactor learning curve	0.8
Delta V1, km/sec	2.17	Ave cost of nuclear reactor, $M	$62
Delta V2, km/sec	1.42	Cost of power gen/satellite, $M	$653
Upper stage Isp, sec	470	Cost per satellite, $M	$819
One-way mass ratio	1.60	Visibility per site, minutes	360
Busbar power, Mw	1,000	No of satellites reqd	4
Transmission freq, GHz	15	Upper stage lambda prime	0.85
Grid conversion efficiency	0.9	Upper stage prop mass, kg	2,161,817
Rectenna efficiency	0.9	Total mass satellite to LEO, kg	5,302,617
Transmission efficiency	0.96	LEO delivery cost, $kg	110
Klystron/magnetron eff	0.85	LEO deliv cost satellite, $M	583
Power conditioning eff.	0.95	Total launch costs, $M	2,333
Satellite power, Mw	1592.58	Total satellite purchast, $M	3,277
Spec. power of conv, Kg/Kw	0.2	Total number of sites	30
Power generation mass, Kg	318,516	Average power per site, Mw	100
Electric generator mass, Kg	637,032	Total rectenna purchase, $M	1,009
DC-RF w/substructure, kg	2,148,390	System cost installed, $M	6,619
Power limited antenna dia, m	320	Incremental installation rate	1
Antenna diameter, m	750	Busbar $/kwe	2,206
Antenna structure, Kg	36,862	O&M cost, ¢kWh	2
Antenna cost, $M	166	System DDT&E/2, $M	5,000
Diameter of rectenna, km	0.93	Power price, ¢/kWh	12.4304
Peak power intensity, mw/cm2	33.06	Revenue/year, $B	2.74
Rectenna cost, $M	34	20-7ear IRR	20%

Figure 3.8.2.2-15. Design Characteristics for Nuclear-Powered SPS or Remote Sites in Molniya Type Orbits

Space-based power satellites and antenna masses were derived from work done by the Seattle Lunar Utilization Group. Some other important assumptions include—

a. Pellet-bed uranium-fueled nuclear reactor.
b. Thermodynamic Brayton cycle with recuperator (2,000K max, 38.7% cycle efficiency).
c. Liquid-droplet radiator-utilizing liquid tin (200 micron droplet radius).
d. Transmission frequency of 2.45 GHz, and rectenna diameter of 1 km.
e. Commercial power rate—operating expenses = .05 ¢/(kWh/day).

Figure 3.8.2.2-16 illustrates some of the design characteristics of the nuclear power satellite system. This system is designed to be modular, in chunks sized to match the launch vehicle capabilities. Individual, but complete, packages would be delivered to the destination orbit where they would be joined with other elements there into an operational satellite. This offers the ability to allow for individual system failures without significant degradation of the overall system capabilities. This approach also reduces the need for on-orbit construction to a "plug and play" automated assembly operation.

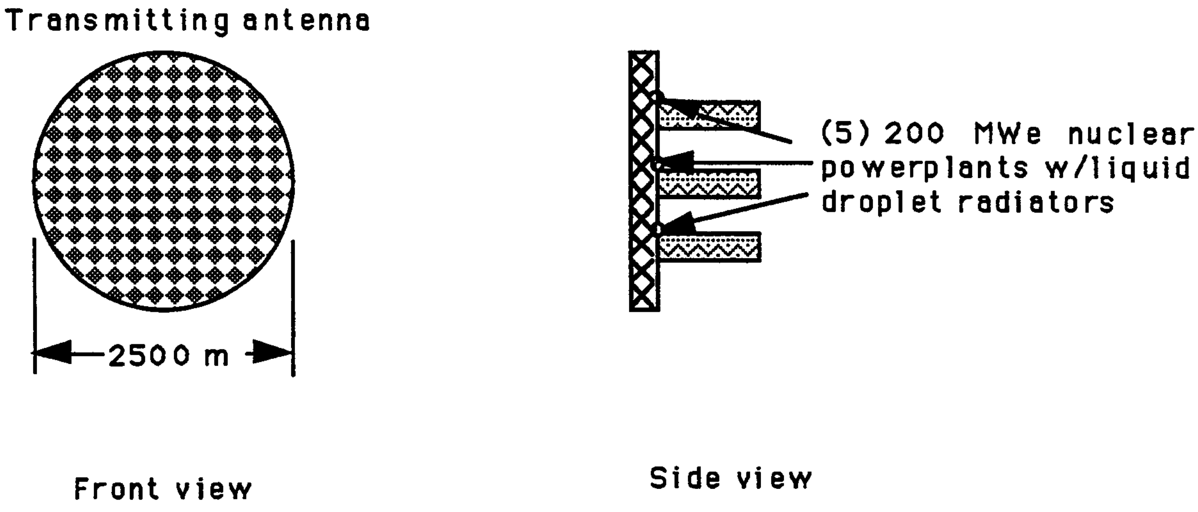

Figure 3.8.2.2-16. Space Nuclear Power Satellite for High-Latitude Remote Sites Concept

In comparing solar- versus nuclear-powered satellites, there are political as well as technical and cost aspects. The political ramifications of putting a nuclear reactor into Earth orbit will be significant. In fact, the safety requirements of such a system could easily be the highest cost factor of either concept. But, from a raw cost and transportation requirements standpoint, it appears competitive with solar arrays. Figure 3.8.2.2.-17 compares 100 MWe, 500 MWe, and 1,000 MWe satellites.

Both options look very attractive, with solar power being more advantageous at the lower power levels due to its lower development costs. The addition of the kinds of safety and environmental regulations that the ground-based nuclear power industry has had to deal with could make the nuclear option less competitive.

	100 MW_e		500 MW_e		1 GW_e	
	Nuclear	Solar	Nuclear	Solar	Nuclear	Solar
Satellite mass (Mg)	70	310	200	1,560	350	3,120
Satellite cost ($M)	730	1,350	2,060	6,750	3,530	13,500
Total cost *($M)	2,920	5,400	8,240	27,000	14,120	54,000
Power delivered (MW)	32		162		324	
Revenue* ($M per year)	170		852		1,704	

*Numbers include all four satellites

Figure 3.8.2.2.-17. Satellite Comparison Based Upon Three Satellites

Figure 3.8.2.2-18 indicates a comparison of the solar and nuclear power options as a function of launch cost and price paid for delivered power.

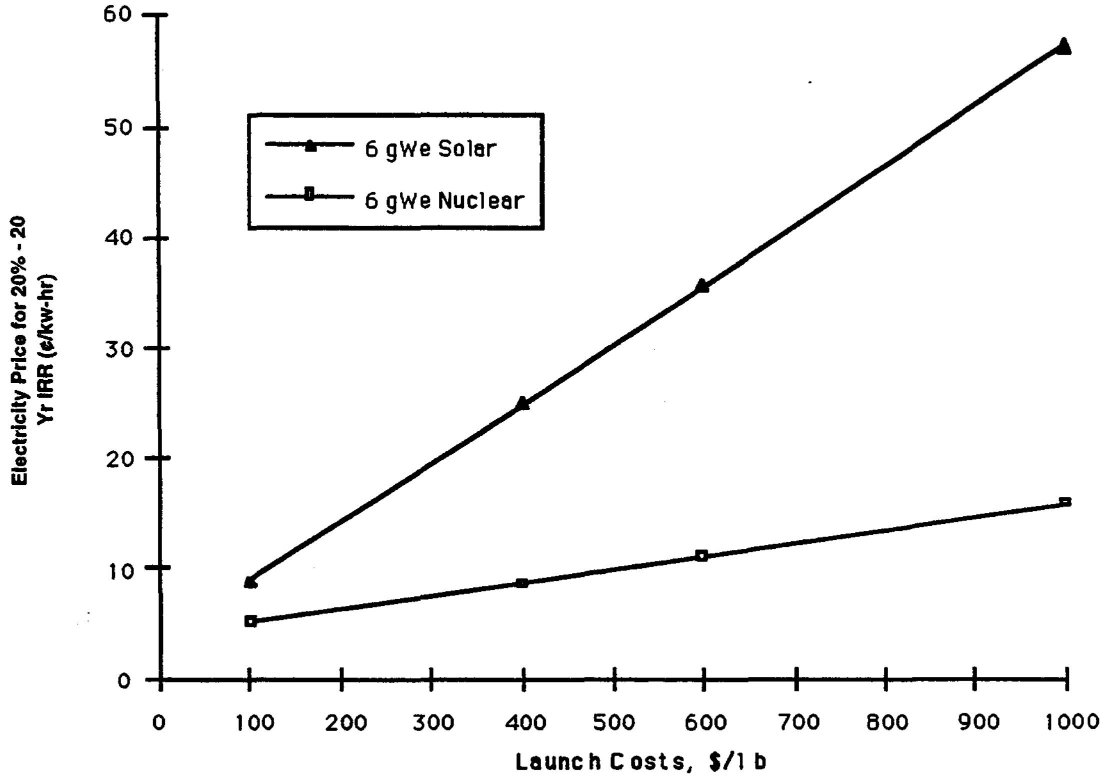

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Figure 3.8.2.2-18. Comparison of Type of Solar Power Satellites in 8-Hour Molyina Orbit

For solar-powered SPS, the high-probability demand markets do not show feasibility. The best answers in the nominal (medium) probability demand markets require transportation costs of less than $14/lb with current technology, and less than $20/lb with advanced technology. Even at the lowest probability demand market which offer the highest sized demand, such a system would require transportation costs of less than $46/lb to LEO. Doing such a venture as a purely commercial venture, with its higher interest costs and required rates of returns, appears unrealistic at any transportation cost. (This conclusion is driven primarily by the demand assumed and the high nonrecurring costs involved in this new technology).

For a nuclear-powered SPS, these costs get a little better. To maintain a 20% IRR after 20 years of operations, the transportation cost needs to be less than about $60/lb to LEO for the nominal demand case considered. If the highest demand model is considered (the lowest probability model), then these acceptable costs rise to about $123/lb. This venture also seems unrealistic as a purely commercial venture and would require the lower costs of money and the longer time horizons for a utility-type venture instead of a commercial venture. Again, the conclusions are driven primarily by the demand assumed, and the high nonrecurring costs involved.

3.8.2.2.2.3.4 Market Infrastructure

To serve this market requires that several elements in the supporting market infrastructure also be provided. These are summarized in figure 3.8.2.2-19 Note that this is inherently a simpler infrastructure than the assumed GEO SPS examined above, with the exception of the nuclear support site at the launch site.

In-space transportation system	Transports payload (modular SPS elements) from LEO into final destination orbit.
Launch site support system (nuclear SPS option only)	Receives and prepares nuclear power systems for launch.
Terrestrial receiving site (rectenna)	Receives beamed power from satellite power system. Converts beamed power to output electrical power and transfers power into utility grid.

Figure 3.8.2.2-19. Infrastructure Elements for High Latitude Satellite Power Systems

3.8.2.2.2.4 Prospective Users

The prospective users for this system would be local communities and industrial operations in the high-latitude regions. These users cannot rely upon solar power due to the long periods of darkness during the Arctic winter. Transportation of fossil fuels into these regions is typically quite costly and, in some cases, available only a few months per year. The supporting infrastructure (installed power grid) is small, and expansion is costly due to the dispersed nature of these sites over large geographical areas.

Environmental concerns with the use of fossil fuels in the Arctic are increasing. The need to transport fuel as high-latitude power needs grow has increased concern over the possibility of inadvertent spills or contamination from transportation. (The Exxon Valdez incident was mentioned by several market contacts, and the possibility of collision with an iceberg or pack ice was also mentioned). Also, during the winter months, the atmosphere circulation patterns promote the local buildup of emissions from Arctic power systems, a condition that is is becoming a concern for environmental quality.

3.8.2.2.2.5 CSTS Needs and Attributes

3.8.2.2.2.5.1 Transportation Systems Characteristics

The primary CSTS attribute needed for this market area is to offer highly reliable and safe transportation at low cost. Figure 3.8.2.2-20 indicates the traffic demand for launch in this large market in thousands of pounds per year to LEO. However, the launch demand does not occur until very low prices for space transportation are offered. And the launch of a nuclear power system, even if it launched "cold" as an inert payload, will place a premium upon safety and reliability in the launch system.

		Medium-Probability Markets			Low-Probability Markets	
Launch cost, $/lb	Traffic, klb/yr	Price, ¢/kWh	SPS size, MWe	Traffic, klb/yr	Price, ¢/kWh	SPS size, MWe
400	-	-	-	-		-
100	-	-	-	25,850	13.80	1,667
50	15,590	12.43	1000	77,200	9.10	5,000

Figure 3.8.2.2-20. Launch Traffic for Nuclear-Powered Satellite Power System 20% IRR Over 20-Year Operation (100 MW Ave Site)

3.8.2.2.2.5.2 Transportation System Capabilities

The sizing of the launch system can be adjusted to meet the market demand. Since the nuclear-powered SPS is assumed to be modular, the launch system can be tailored to launch one or two of the modules. Examination of the minimum sizing of these modules indicates that a launch capability of 50,000 lb equivalent to LEO is probably required to allow efficient packaging of these modules. Larger vehicles, in the range of 100,000 lb to LEO and up may be considered to launch two or more of the modules at a time.

Launch rates for these vehicles will be high and will be driven by the vehicle sizing. At the minimum, for a 1,000-MWe system, a 100,000-lb class launcher will require launching at the rate of about two per day to support this traffic demand. A 250,000-lb class launcher will require a launch rate of about one per day. Schedule reliability is not driven to be quite high, since there are a large number of recurring launches to the same destination orbits, but the large number of launches requires that few long delays are encountered in the launch cycles to avoid massive backlogs in the launch queues. Launches must occur within a specific launch window to efficiently insert the payloads into their desired destination orbits.

3.8.2.2.2.5.3 Ground Handling

Ground handling for these payloads will primarily involve the scale of integrating these modular power system onto the in-space transportation system, and then loading them into the vehicle. For the solar-powered SPS option considered, this should be similar to existing practices, although a much-simplified manner is required due to the large scale of operations.

For the nuclear-powered option considered, special ground handling and ground processing facilities may be required to support the nuclear reactors. It is assumed that the reactors are launched "cold" or in a nonactivated inert state. This means that the system will not be radioactive in ground handling, and will not produce significant hazards until activated in its final destination orbit. However, special handling systems may be required to store, check out, and process these systems before launch.

3.8.2.2.2.5.4 User/Space Transportation System Interfaces

The primary interfaces to be considered are modular power system to in-space transportation system, and then the integration of this package onto the launch system. There will be no other users comanifested on the launch system because of the large size and number of payloads for this market area and the large number of essentially identical packages to be launched; therefore, these interfaces should be designed as common, and modular.

3.8.2.2.2.5.5 Improvements Over Current

Major improvements over current operations in launch cost, launch processing, and launch reliability are required.

3.8.2.2.2.6 Business Opportunities

The business opportunity for the CSTS is to provide the transportation demand to this large market. Of all the areas considered in the CSTS market analysis, this is one of the largest for overall transportation demand, but it also requires some of the lowest $/lb to orbit to provide a good business opportunity to potential users.

3.8.2.2.2.6.1 Cost and Price Sensitivities

The business analysis performed earlier is highly dependent upon the analytical market demand model and the business model cost and price assumptions used. A range of market demand and price sensitivities were examined, with results as reported previously. However, the nonrecurring investment cost before constructing and launching a space power system is also a major driver. Figure 3.8.2.2-21 indicates the sensitivity of the results of this assessment for typical power price points on the nominal demand model

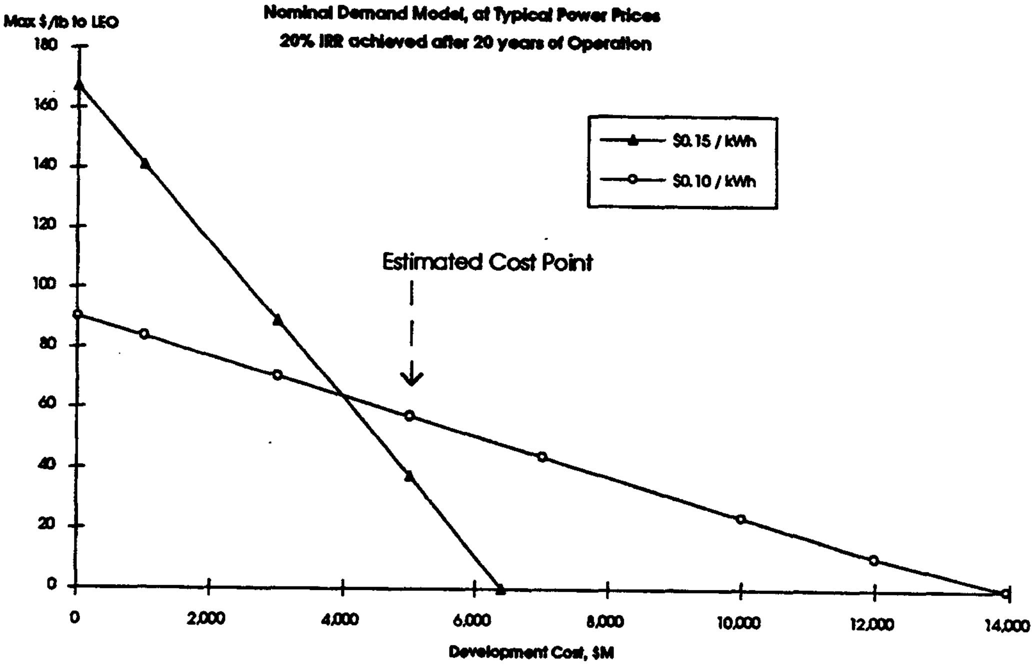

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Figure 3.8.2.2-21. Sensitivity of Analysis to Development (DDT&E) Costs

Another sensitivity of these results is to the allowable internal rate of return (IRR) used to judge a venture as a credible business investment. Based upon discussions within the power utility industry, an IRR of 20% after 20 years of operations was judged to be representative of a public utility-type investment, operating with lower costs of capital and a longer time horizon than purely commercial (deregulated) operations. For deregulated commercial operations, a venture operates under stricter limitations with higher capital costs and a shorter payback period. For such ventures, 20% IRR after 10 years of operations is representative. Figure 3.8.2.2-22 indicates the sensitivities of the results of this analysis to IRR and time period, for a representative case using the nominal demand model.

If shorter payback periods are required, either much higher revenues or substantially lower costs are needed.

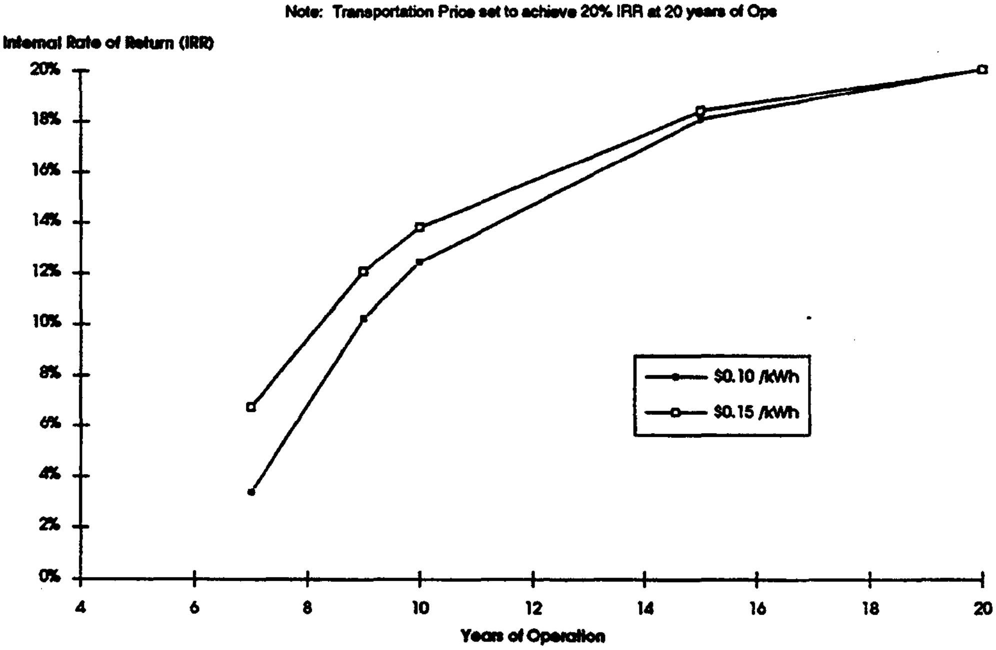

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Figure 3.8.2.2-22. IRR Sensitivity to Time Scale

3.8.2.2.2.7 Conclusions and Recommendations

At space transportation costs less than $100/lb into orbit, production of space power can be a significant demand driver, serving niche markets that are willing to pay a higher price per kWh. But to accomplish this, a public-utility-type operation must be considered to overcome the barriers presented by the competitive requirements of low prices and long paybacks.

3.8.2.2.3 Sun-Synchronous Power Satellites

3.8.2.2.3.1 Introduction

The major market for power is to the major metropolitan areas within the continental United States. Within this market, a premium is paid through existing systems for power provided during peak demand periods. This premium price is paid since generating systems are most efficient if run at constant level. During peaking power conditions, new assets or stored power must be brought on line and run solely for this peak power demand.

3.8.2.2.3.2 Study Approach

With the use of the data generated from the other market areas, a ROM assessment of the business feasibility of supplying peaking power from a set of Sun-synchronous satellites was developed. A return on investment using IRR of 20% in 20 years of operations was used to estimate the feasibility of such a venture.

3.8.2.2.3.3 Market Description

3.8.2.2.3.3.1 Description Market Evaluation

From orbital mechanics, it is possible to launch into near-polar orbits a satellite power system such that the same satellite is always over a terrestrial target at 6 a.m. and 6 p.m. to provide additional power into the grid. These "Sun-synchronous orbits" would allow a satellite power system to service terrestrial power grids at a repeatable time each day. If the constellation is placed into 4 hour orbits, it is possible to service 12 sites daily (2 per orbit - see fig. 3.8.2.2-23).

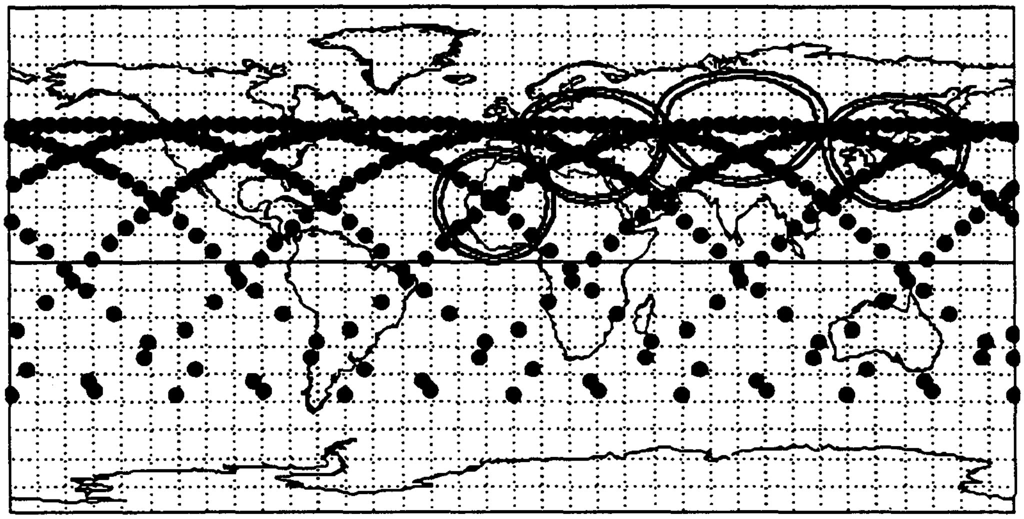
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Figure 3.8.2.2-23. Ground Track for Peaking Power Satellite Power System in 4-Hour Synchronous Orbits

The unit costs for this system are projected at about $1,200/kWe, which is excellent for this type of system (fig. 3.8.2.2-24). But remember, the costs used in the spreadsheet analysis are purposely aggressive. Peaking power is more expensive than base power, averaging about 9¢ per kWh in the United States (although some utilities pay up to 15¢ for this power). Feeding these data data into a time-phased spreadsheet, at 12¢/kWh the ROM returns are marginal until launch costs drop well below $100/lb.

Apogee altitude, km	**12550**	Specific cost of Brayton PP, $/kW	**100**
Perigee altitude, km	**300**	No. of 600 MWt reactors in 20 yrs	478
Semimajor axis, km	12,803	600 MWt reactor TFU, $M	$600
Orbital period, hrs	4.00	Reactor learning curve	0.8
Delta V1, km/sec	1.67	Ave cost of nuclear reactor, $M	$77
Delta V2, km/sec	1.27	Cost of power gen./satellite, $M	$388
Upper stage isp, sec	**470**	Cost per satellite, $M	$472
One-way mass ratio	1.44	Visibility per site, minutes	**45**
Busbar Power, MW	**500**	No. of satellites reqd	4
Transmission freq, GHz	**15**	Upper stage lambda prime	**0.85**
Grid conversion efficiency	**0.9**	Upper stage prop mass, kg	845,481
Rectenna efficiency	**0.9**	Total mass/satellite to LEO, kg	2,616,471
Transmission efficiency	**0.96**	LEO delivery cost, $/kg	**220**
Klystron/magnetron eff.	**0.85**	LEO deliv cost/ satellite, $M	576
Power conditioning eff.	**0.95**	Total launch costs, $M	2,302
Satellite power, MW	796.29	Total satellite purchase, $M	1,886
Spec. power of conv, kg/kW	**0.45**	Total number of sites	**12**
Power generation mass, kg	358,330	Average power per site, MW	**500**
Electric generator mass, kg	318,516	Total rectenna purchase, $M	244
DC-RF w/ substructure, kg	1,074,195	System cost installed, $M	4,433
Power limited antenna fia, m	226	Incremental installation rate	1
Antenna diameter, m	**443.74**	Busbar $/kWe	739
Antenna structure, kg	19,948	O&M cost, ¢/kWh	**2**
Antenna cost, $M	84	System DDT&E/2, $M	**0**
Diameter of rectenna, km	0.72	Power price, ¢/kW-hr	**12**
Peak power intensity, mw/cm2	272.70	Revenue/ year, $B	0.329
Rectenna cost, $M	20	20-year IRR	<0 %

Figure 3.8.2.2-24. Design Characteristics of Peaking Power SPSs in 4-Hour Sun-Synchronous Orbits

3.8.2.2.3.3.2 Market Evaluation

These results were placed in a time-phased business model to analyze the cash flows and costs. From this analysis, it was impossible for this system to meet a commercially viable rate of return, even at the relaxed constraints assumed for the public utility industry. The primary driver for this appears to be the revenue stream; this is because the satellites spend most of their time over water where they cannot produce revenue, and the price paid for power when they are transmitting is insufficient to produce an economic level of return.

3.8.2.2.3.3.3 Market Assessment

Figure 3.8.2.2-24 also illustrates one of the best cases found. Here $0.12/kWh is paid for peaking power, 12 sites are serviced each day, and there are no development (nonrecurring) costs for this system. Even with these optimistic assumptions, the system does not provide an acceptable return, even at $100/lb.to-orbit costs.

3.8.2.2.3.3.4 Market Infrastructure

The market infrastructure for this system is similar to that of the Molniya orbit satellite power system. An in-space transportation system, a ground processing system (if nuclear power sources are used), and ground receiving stations are needed. Since there was not viable market in this area, no further analysis was performed.

3.8.2.2.3.4 Prospective Users

The primary users for this system would be the major metropolitan utilities. However, since no viable business opportunity could be identified, no further contacts were made.

3.8.2.2.3.5 CSTS Needs and Attributes

Sun-synchronous satellites for peaking power were assessed not to be a viable market for a future space transportation system, independent of transportation cost. Therefore, CSTS needs and attributes were not defined.

3.8.2.2.3.6 Business Opportunities

No business opportunities were identified in this area at this point.

3.8.2.2.3.7 Conclusions and Recommendations

The Sun-synchronous power satellite concept for peak power provisions does not appear to be a viable market opportunity for space transportation systems, regardless of price. The drivers for this conclusion are the low price for power provided and the fact that these satellites do not have a high duty cycle per orbit.

3.8.2.2.4 Lunar-Based Power Station

3.8.2.2.4.1 Introduction

After the major contractual studies of the GEO satellite power systems were performed in the late 1970s it was identified that much of the cost was for transporting equipment and components upwards in the Earth's gravitational well. Since that time several studies have generated an interest in producing solar power satellite components and system on the lunar surface or mining the Moon to provide construction material for SPSs. The specific venture examined here is to produce and install large solar power generation and transmission systems on the lunar surface and transmit power back to the Earth for terrestrial use.

3.8.2.2.4.2 Study Approach

The approach followed in this analysis was to examine past analyses, and wherever possible to contact past participants and principals in these studies. From this, the technical and market feasibility of such an appraoch was examined. The following steps were taken in assessing this market area:

a. Literature search of the available literature on lunar power systems.
b. Contacts with participants and leaders of past studies.
c. Assessment of technical and financial feasibility, including development of analytical models of the lunar power option, and assessment of the market opportunity.

3.8.2.2.4.3 Market Description

3.8.2.2.4.3.1 Description Market Evaluation

Lunar power system requirements for a 1-, 10-, or 100-GW operation are shown in figure 3.8.2.2-25. These numbers assume a 10-year R&D period, a 3-year period for initial deployment of equipment, and then a 10-year period of emplacing power units on the Moon. These numbers are preliminary only, being scaled from the 1979 study by General Dynamics. These numbers also assume that no lunar base exists, that no Earth-to-Moon transportation system exists, and that the material required to establish them is brought from Earth. Once these pieces of infrastructure exist, the cost of adding capacity is small.

Even at these small capacities, the venture begins to make a profit somewhere between 10 and 100 GWe installed. The Moon and space tonnage figures can be evenly distributed over the 10-year R&D period. With current launch systems (such as the shuttle) a flight every other day would be required. Clearly, a heavy-lift launch vehicle is required and the cost of one is included in these numbers, even for these modest LPS. A dramatic reduction, on the order of 90%, could be made in these mass figures if a concerted effort is made to utilize lunar resources to the maximum extent possible and additional R&D time is allotted. This reduction assessment is based on the reduction made possible in the General Dynamics SPS study by utilizing lunar materials. Launch vehicle cost was assumed to be approximately $550/kg.

This proposed venture is even more demanding technically and financially than the GEO SPS markets, and would require the development of a substantial lunar base, manufacturing, and operational facility before power could be transmitted. Furthermore, orbiting reflectors around the Earth would have to be developed and emplaced to allow power beaming to the other side of the Earth from the Moon. This would require hundreds of billions of dollars in investment before power could be returned, and although the economies of scale may promise power at low prices, the investment cost is too high to be considered on a commercial venture basis.

It is possible such a large venture could be pursued as part of a major government program and be used as the centerpiece of a major governmental space or lunar development program. But such decisions and investments will have to be made on other than commercial grounds, and this market was not judged as a viable commercial market.

Item/GWe (10yr)	1	10	100
GWe-yrs	5	50	500
Rev. ($10^9\$$ @ 0.1$/kWe-h)	4.383	43.83	438.3
Net revenue ($10^9\$$)	-55.7	-46.8	194.9
Total costs ($10^9\$$)	60.1	90.6	243.4

R&D ($10^9\$$)	42.4	50.9	85.5
LPS Hrdw	10.7	10.7	10.7
Cnstr. syst.	1.1	2.9	10.9
Facilities and eq.	5.1	10.0	29.9
Transportation	25.5	27.4	34.7

Space and ops ($10^9\$$)	17.2	34.2	102.5

Rectenna ($10^9\$$)	0.6	5.5	55.4
$/kWe-H	1.37	0.21	0.06
Moon (tons)	2284	6194	21552
Space (tons)	974	2680	9677
People (Moon)	29	80	283
People (space)	1	5	23

Figure 3.8.2.2-25. Lunar Power System Requirements as Function of Size

3.8.2.2.4.3.2 Market Evaluation

Limited evaluation was done upon this market. The primary drivers for this market are the very large upfront investment costs, ranging from a few tens of billions to hundreds of billions of dollars. The CSTS assessment indicates on a theoretical recurring cost basis, the very large economies of scale and ROM assessments of the costs of such a system show promise that power can be produced for terrestrial usage at competitive costs to terrestrial systems and that transportation costs into orbit, if reduced, can improve this performance. Figure 3.8.2.2-26 indicates the results of a preliminary analysis on the recurring cost of producing power from a lunar-based power system.

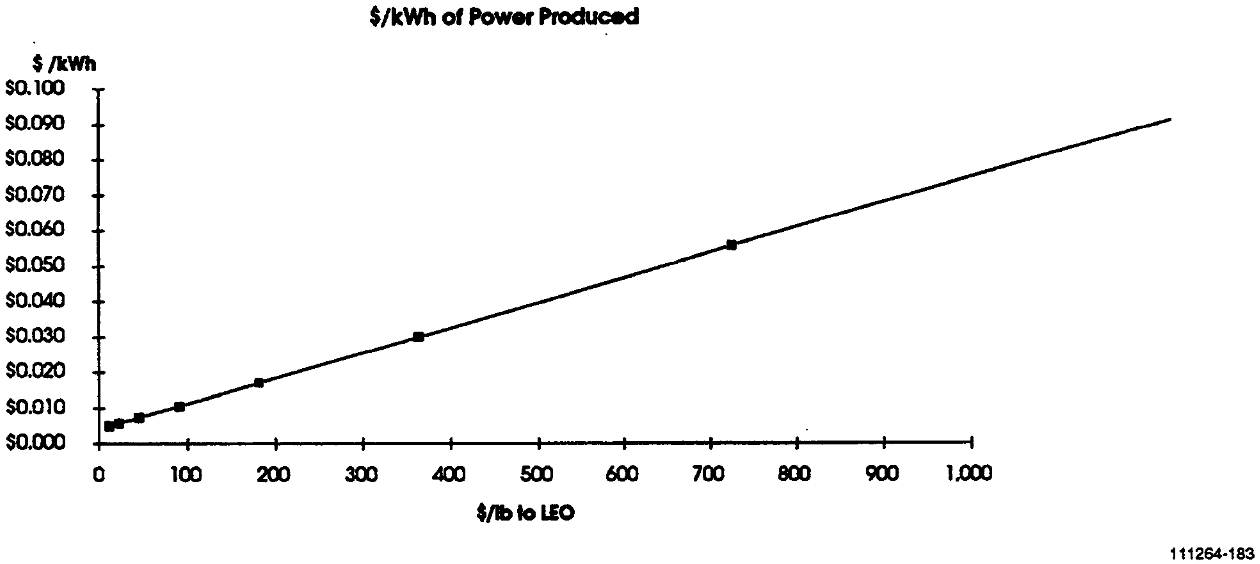


Figure 3.8.2.2-26. Recurring Costs of Power From Lunar Power System

However, the problem is not that the economies of scale will not work, nor that such a system is technically infeasible, compared to other large in-space power systems, such as the GEO satellite power system. Rather ,the difficulty, again, is in the large upfront investment.

The purpose of the CSTS is to identify markets of sufficient size for future space transportation systems. These markets are quite large, but the large upfront investments and long payback times involved remove them from commercial investment levels. Such markets will have to be developed from governmental coffers, and in some cases (e.g., a large lunar surface power system) will probably require multiple governments to invest in them.

As such, the CSTS assessment is that such markets are not driven by external market forces, and the price of transportation is not a primary contributor to these markets.

3.8.2.2.4.3.3 Market Infrastructure

Since this market area is not viewed as commercially viable (independent of transportation costs), no infrastructure assessment was performed. Besides transportation to orbit, several infrastructure elements need to be put into place before commercially large amounts of power are available from the lunar surface. They include—

a. In-space transportation system, to transport people and cargo to and from the lunar surface. This system must also provide the means of deploying and maintaining other in-space assets for this venture.

b. Lunar surface base, including habitat and manufacturing facilities. This base must manufacture and install the power system elements and components, and service them once they are installed.

c. Lunar power system, to transmit the power to the Earth for use.

d. Earth-orbiting reflectors. Since the Moon is not visible over half the Earth, providing power to users on the far side of the Earth will require orbiting reflectors that are deployed to reflect the beamed power from the lunar power system to terrestrial users.

e. Terrestrial ground receivers, to receive the transmitted power from the lunar surface, convert it into electrical power, and transfer this power into the utility grid.

3.8.2.2.4.4 Prospective Users

As with other space power systems, the primary prospective users for this system are the major utilities.

3.8.2.2.4.5 CSTS Needs and Attributes

The market analysis for lunar power systems indicates that this market is not primarily driven by orbital transportation costs. Therefore, CSTS needs and attributes were not defined.

3.8.2.2.4.6 Business Opportunity

No viable space transportation business opportunities in this market segment were defined at this point.

3.8.2.2.4.7 Conclusions and Recommendations

The lunar power system market area was defocused at this time, due to an assessed lack of market sensitivity to space transportation cost and due to the large investment sums required.

3.8.2.2.5 Space-to-Space Power Beaming

3.8.2.2.5.1 Introduction

Space-to-space power beaming for the purpose of providing power to orbiting satellites is another possible market area of interest. Several persons contacted during the CSTS market assessment identified this area as a potential near-term application of in-space beaming and as a potential market area.

The main attraction or advantage to space-to-space power beaming is to be able to simplify satellites by off-loading the power-generation system and thereby also extending the life of the satellite indefinitely. Options for doing this include microwave or laser power transmission options.

The primary concept for such a venture is to place a central "power station" in orbit equipped with large power-generating systems (usually solar arrays). From this centralized power station beamed power is transmitted to other orbital assets to provide them power. The advantages of this are claimed to be lighter, cheaper co-orbiting satellites and lower cost overall to the system architecture.

3.8.2.2.5.2 Study Approach

The approach used in this analysis was to examine the current literature for existing data on such systems, contact participants and potential users, and develop an independent analysis of the business feasibility of this market area. If this business and technical feasibility analysis showed promise, then an assessment was to be performed of the impact on future space transportation systems demand and the impact of reduced cost to orbit.

3.8.2.2.5.3 Market Description

3.8.2.2.5.3.1 Description Market Evaluation

The market evaluation for this activity focused on major power users in orbit and on the technical feasibility of implementing such an approach.

3.8.2.2.5.3.2 Market Evaluation

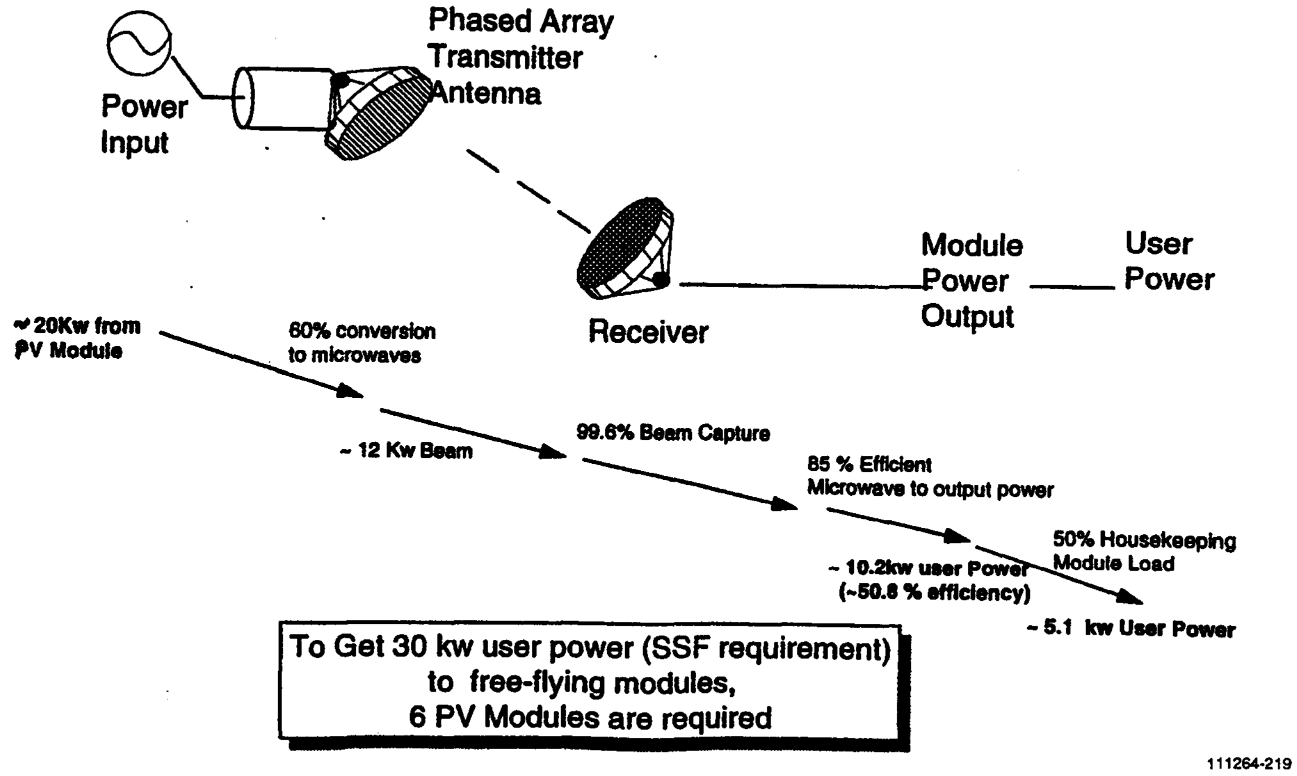
The market for in-space power beaming is concentrated upon regions where large users of in-space power systems and of concentrated orbital assets are available. These two areas are in the vicinity of the space station (and associated facilities) and in GEO.

In the vicinity of the space station there will be an installed market of about 100 kW of power, which is currently baselined to be provided from solar dynamic and photovoltaic arrays. In GEO, a typical current technology communications satellite represents 4 to 6 kW of power. These satellites are being replaced at about 20 to 25 systems per year, and even if all future satellites were to use the in-space power beaming capability, the market would be limited to growth of about 80 to 150 kW per year, spread over the geosynchronous orbital arc at 35,800 km of altitude.

3.8.2.2.5.3.3 Market Assessment

Power beaming was examined as a possible means of simplifying the space station by using co-orbiting satellite modules. Both laser and microwave transmission of power from a central power satellite to Station modules was examined. Laser transmission was found to be too inefficient compared to microwave transmission, primarily driven by the lower efficiencies in turning incident sunlight into laser light and then back into electrical power to be used. However, even with microwave transmission, power beaming was found to be less efficient in terms of mass required and cost compared to housing the modules directly on the SSF. Figure 3.8.2.2-27 represents the results of a preliminary assessment of this market.

Microwave Transmission Efficiency



Laser Power Transmission Efficiency - Carnot Beam Conversion

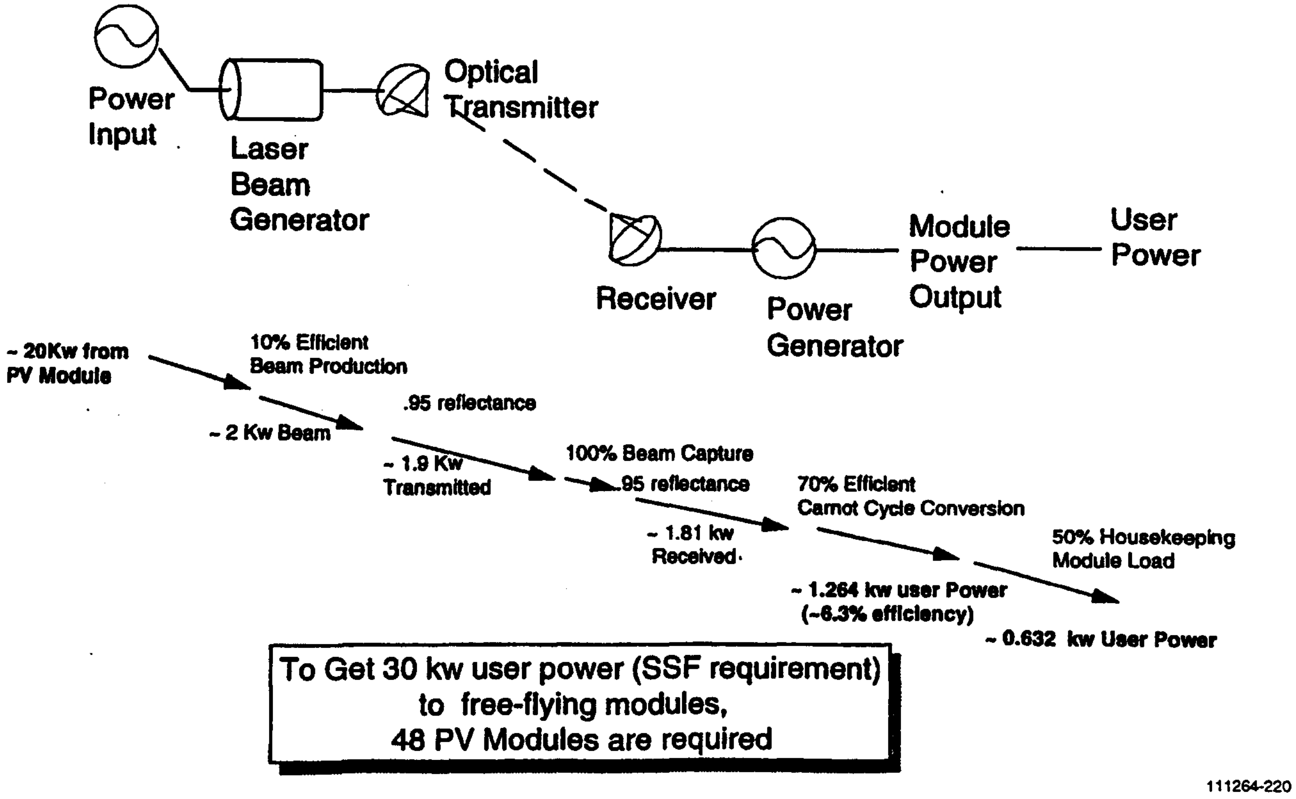


Figure 3.8.2.2-27. Comparison of Laser and Microwave Power Transmission for Space Station Power

For GEO satellites, this problem becomes worse. Satellites located at a typical spacing in GEO, 2 degrees apart, are about 1600 km apart. Over these distances, the efficiency of transmissions drops off, unless very large antennas are placed on the transmitting and receiving satellites. At this point, the mass efficiency of using beamed power to save mass (and transportation cost) versus using solar arrays and batteries becomes questionable.

While some simplification of satellite power system subsystems may be possible using beamed power, indefinite life extension (as suggested by some persons during this market survey) is questionable due to technology obsolescence, and limited life items in other subsystems. Current space systems are typically designed so that the system is not life-limited by a single subsystem. Removing the power system would merely shift end-of-life failure to some other system, assuming the power system is currently the life-limiting system. Furthermore, indefinite life extension does not seem desirable due to improvements made possible from evolving technology. As for simplification, the power system could be only partially eliminated since batteries would still be required to provide power during launch and installation, during periods of eclipse, or in the contingency event of noncontact with the power source. Having large numbers of co-orbiting assets rely solely upon a single centralized power system would provide a large single-point failure for the entire system if power were interrupted for some reason.

Furthermore, if space transportation costs are reduced dramatically, satellite power systems and their installed value should become cheaper. This will reduce the market advantage, if any, for space-to-space beamed power even further.

3.8.2.2.5.3.4 Market Infrastructure

The required market infrastructure for such a venture would require the switching of significant assets to a centralized in-space power system. Individual satellites would have to be equipped with the power receivers, and the centralized power generation and transmission system would have to be launched.

Before such a large change in current system operating practices is realized, this technology must be demonstrated and its reliability and usefulness demonstrated.

3.8.2.2.5.4 Prospective Users

Prospective users for this system would be primarily concentrated in assets that are relatively close. The two areas identified as meeting this criterion are in the vicinity of the space station and in GEO.

3.8.2.2.5.5 Business Opportunities

No significant business opportunities for low-cost space transportation were identified in this area.

3.8.2.2.5.6 Conclusions and Recommendations

The space-to-space power beaming market area has been defocused at this time because it was assessed not to be a driver for low-cost space transportation markets.

3.8.2.3 Prospective Users Contacted

a. Peter Glaser, Sunsat energy council.
b. Dave Criswell, Lunar Power Coalition.
c. Bob Waldron, Lunar Power Coalition.
d. Dieter Franz, Southern California Edison, Senior Planning Engineer.
e. John D. Edwards, Mission Energy Company, Project Director, International Business Development.

f. John T. Kostanecki, Mission Energy Company, Project Analyst, Business Development.
g. EPRI.
h. Jack Stone, National Renewable Energy Laboratories (NREL).
i. Jack Cashin, Edison Electric Institute.
j. Alaskan Power Authority.
k. Gary D. Bunch and Sid Greutz, DOE.

3.8.2.4 Overall CSTS Needs and Attributes.

Overall, the only market areas within the space utilities market area that show promise do so when transportation costs are less than about $100/lb, arising from the satellite power system in Molniya orbit, serving remote high-latitude sites. Technically, this is a very demanding requirement to reduce operating costs to this point.

There is no requirement for down-weight or return payloads, nor is there a primary requirement for passenger operations for this market area. However, if a nuclear power option is considered for the high-latitude SPS, then either highly reliable launch, or intact abort, capabilities are required in the launch system—to allow safe operation with these nuclear capabilities (although it is assumed that for safety's sake, any reactor is launched cold, in a safe, nonpowered state).

Once the system is in place, some amount of periodic maintenance can be expected. Since the revenue-generating capabilities of the system are crucial, these maintenance activities (both scheduled and unscheduled) must be capable of being launched on time, or very quickly on demand.

In aggregate, the CSTS needs and attributes from this market area are as follows.

3.8.2.4.1 Transportation Systems Characteristics

Highly reliable and safe transportation, is necessary, at very low cost. As stated previously, this market assessment primarily considered launch of payloads in the 55 to 100 Klb (LEO equivalent) range. Larger payloads can be considered and may be desirable to reduce the required launch rate.

3.8.2.4.2 Transportation System Capabilities

The transportation system must accommodate mass of 55,000 lb or more per single launch and high launch rates, with potential for over 750 launches per year with 100,000-lb payload launch vehicles. It should be noted that since these SPS systems are in specific constellations and planes, the launch windows will be limited for launch. Schedule reliability is driven by need to avoid massive backlogs in launch queues.

3.8.2.4.3 Ground Handling

Ground handling will require integration of modular power systems onto in-space transportation system, and then loading them into the vehicle. It will require much-simplified processes compared to current practices due to the large scale of operations. Specific ground handling requirements for these systems will be minimal. SPS payloads can be processed through standard launch operations facilities, except for a nuclear-power option, which may require special ground handling for the cold nuclear reactors. The primary driver for these launch systems for ground handling is that they may drive sizing and facility number requirements to handling the increased traffic even from the small SPS considered here.

3.8.2.4.4 User/Space Transportation System Interfaces

The SPS user interface between their system and the space transportation system is expected to be standard, and fairly minimal. Since it is assumed these payloads are modular, and there are very few differences between payloads, standard interfaces and launch processing operations can be used. However, it is important to note that the SPS system requires use of an orbital transfer system and that this system must also be integrated with the SPS payload and the launch vehicle.

3.8.2.4.5 Improvements Over Current

Major improvements over current operations in launch cost, launch processing, and launch reliability are required.

3.8.2.5 Market Assessment/Business Assessment

Short of waiting until the world runs out of fossil fuels and nuclear power is legislated into oblivion, there appear to be only two ways to force space power into the energy equation. The first, and better, is to offer energy cheaper and in a more convenient form than the competition. From our market assessment, this appears to be possible only at remote sites, where ground-based solar power is not a viable option, for example, in the Arctic or Antarctic regions. Since the market demand is much greater in the Arctic regions, this is the preferred option.

The second path is driven by politics and the current concern about environmental pollution. Costs of fossil fuels are increasing, not from supply/demand pressure, but from regulation and legislation that seeks to tax fossil fuels to limit their output of greenhouse gases, and toxic wastes, and to recover costs to clean up the environment. For example, recent attempts to add a "carbon tax" for carbon dioxide production and a "BTU tax" for energy usage are examples of these types of regulation. While this is a potential outcome in the future, its impact will primarily be seen in the developed countries.

Of the options considered, the most promising option is the high-latitude SPS with orbits in highly-eccentric Molniya orbits. Even at the low costs, this market yields a substantial revenue stream for space transportation. Figure 3.8.2.5-1 indicates the time-phasing of this launch revenue at the nominal model demand case ($50/lb).

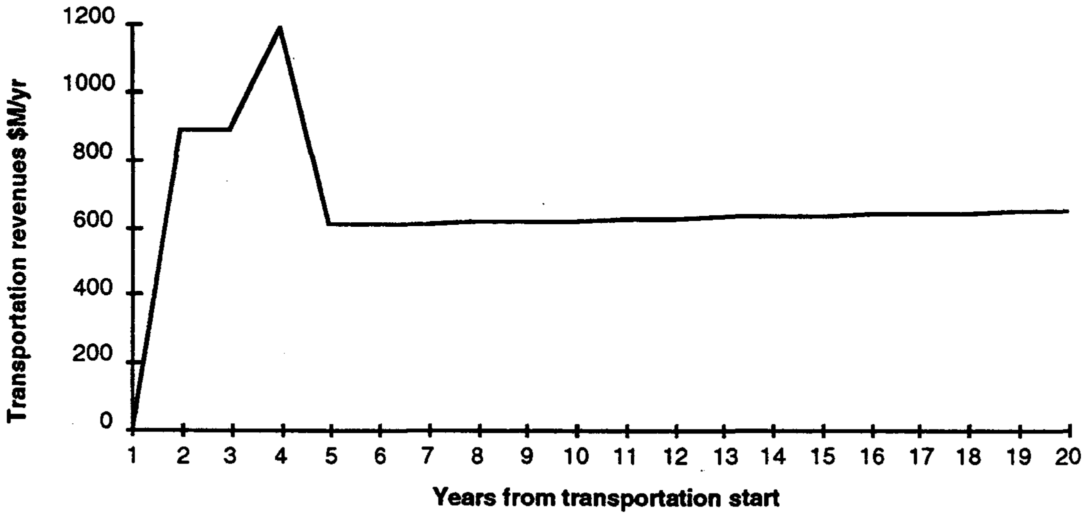


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Figure 3.8.2.5-1. Revenue Projection for Nominal Demand Case (Transportation Price $50/lb)

At transportation costs greater than $ 50/lb little if any transportation demand exists from these market areas in the nominal, or medium, market probability level.

The schedule at which the demand occurs is speculative. This demand is highly dependent upon the provision of low-cost, reliable demand. As such, it will not occur until the transportation system development is well along.

Because of the large upfront costs associated with most space power systems national and international support is required to establish the framework to support the venture. Much of the upfront development costs can be reduced through government development of space transfer systems and associated technologies. For example, the space transfer system developed for space disposal of nuclear waste can be used for emplacement of solar power satellites as well. Similarly, key technologies in the satellite technology can be demonstrated by government programs.

Another key enabler in this market area is the development of common international and national consortiums or investors to finance these investments. The size of the investments and the long time period needed for economic payback remove these ventures from most commercial investment options. This will require either government market guarantees or direct funding to make the ventures succeed.

No price/demand elasticity curve is shown for this market, since the primary driver is to obtain a threshold cost, where this venture is economically justified. If the cost is above $50/lb, as shown in section 3.8.2.3.2 , an acceptable rate of return is not obtained, and it is assumed that the market does not exist.

A viable SPS market was not assumed in any high-probability case, at any $/lb of transportation, since the market's development would require substantial infrastructure development and challenging financial conditions in the industry. However, the medium-probability model included a single high-latitude SPS system at $50/lb for our nominal case.

3.8.2.6 Conclusions and Recommendations

Much to the surprise of some of the members of the CSTS team, solar power satellites were shown not to be a viable market area, unless at very low launch cost. The best market potential identified was for niche markets, which have high revenue potential, and key competitive technologies (like ground-based solar energy) were excluded.

The nominal/medium probability market projection includes such an SPS system, serving the niche market of distributed high-latitude power users.

Additional study in this market area is recommended to further assess the design of SOS systems for this market area and to firm up the design of the support infrastructure (orbital transfer systems).

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3.9 EXTRATERRESTRIAL RESOURCES

3.9.1 Introduction

This market area was established to investigate the commercial potential for extraterrestrial (ET) resources. Man is restricted to the use of Earth resources at this time, but in the future resources from other parts of the solar system may become available for use either on Earth or in space. Development of ET resources is in the early exploitation stage and the time frame for more aggressive exploitation is dependent on the development of primary markets that would use these materials. The section is divided into three material resource areas: lunar liquid oxygen (LOX), lunar helium-3 (He3), and asteroids, comets, planets, and their moons.

Some planetary satellites may be captured asteroids (those of Mars, in particular) and there is a continua of characteristics of comets, asteroids, and the larger bodies.

Some ET resources are considered potentially valuable on earth, but are difficult and expensive to obtain. He3, a lunar regolith production product, is an attractive fuel for nuclear fusion reactors. Asteroids may offer platinum production and low concentrations of gold. Use of these materials will require a significant space transportation cost reduction.

Some ET resources are considered for their potential use in space. Liquid oxygen, for example, can be produced on the lunar surface and used in space to enhance planetary exploration and lunar base missions. At this time it is envisioned that the large-scale use of ET resources will begin in space and not on earth.

3.9.2 Lunar Liquid Oxygen (LOX)

3.9.2.1. Introduction

LOX produced on the lunar surface has the potential of replacing LOX transported from Earth for lunar orbit operations and for return of astronauts and equipment from the lunar surface. It also has the potential of being used in deep space or planetary missions.

3.9.2.2. Market Description

The primary market force is the potential for use of lunar LOX to enhance planetary exploration, lunar base development, or other missions. Since LOX is used in a resource support role for other missions, the market for lunar LOX is dependent on the planned activity levels for lunar exploration, science missions, and planetary exploration missions that use lunar LOX.

The cost of delivering LOX from Earth to the lunar surface has been estimated at $40 million per metric ton or approximately $18,000 lb[1-2]. This includes the following assumptions:

a. $2,000/lb for delivery to lunar Earth orbit (LEO).

b. A $300 million lunar transfer vehicle (LTV) with a payload of 20 metric tons that handles transfers between the LEO and lunar orbit (each LTV has a five-use lifetime).

c. A $300 million lunar excursion vehicle (LEV) with a payload of 20 metric tons that handles descent and ascent from lunar orbit to the lunar surface and back to lunar orbit (each LEV has a five-use lifetime).

The same examination estimated that LOX could be produced on the lunar surface for about 25% less than this amount if a commitment were made by the government to purchase 10 metric tons per year for 10 years from a lunar LOX production facility.

The development cost for this facility is estimated to be $500 million. The weight estimate for this facility is 10 metric tons, which would cost an additional $400 million in transportation to place it on the lunar surface.

3.9.2.2.1 ROM Market Assessment

Growth Projection

The primary growth path is by increasing the size and scope of primary missions, such as planetary exploration, lunar base development, and so forth to the point where lunar LOX can make a cost-effective contribution to the mission.

Elastic Analysis

The in-space use of lunar LOX is entirely dependant on demand from the primary missions such as planetary and lunar exploration. Initial missions will probably be designed to be self-contained and are not likely to use lunar resources. These resources will only be used when the cost of bringing additional LOX from Earth for larger missions exceeds the cost of the mining and processing equipment needed to use in situ lunar LOX.

3.9.2.2.2 Market Enablers

The key market enabler is the level of public will to fund lunar and planetary exploration efforts of a size that would justify using lunar LOX.

3.9.2.3. Prospective Users

The primary users of lunar LOX will be lunar missions that need to return personnel and/or material from the lunar surface to Earth.

3.9.2.4. Needed CSTS Attributes

The primary attribute needed from the CSTS is the ability to deliver cargo to orbit for a consistent low cost, which would increase the probability of primary missions that could use lunar LOX. A desirable attribute would be the capability to send payloads into a translunar orbit.

3.9.2.5. Conclusions and Recommendations

The use of lunar LOX is not likely to occur in the near term. The demand for lunar LOX will be driven primarily by a large and continuing lunar exploration and science program.

3.9.3 Helium-3 (He3)

3.9.3.1 Introduction/Statement of Problem

Demand for lunar He3 is predicated upon the commercial generation of electrical power from fusion power plants that use deuterium/helium-3 or helium-3/helium-3 fusion reactions. There is only enough He3 in weapons stockpiles for research and initial development of these types of fusion. Predictions for the achievement of commercial fusion of this type ranges from 2015 at the earliest to 2030 in more conservative projections.

A cost-to-orbit of $300/lb to LEO must be obtained before lunar helium becomes a viable space launch market item. This cost is based on achieving He3-generated electricity rates that are competitive with current rates.

He3 is an attractive fuel for nuclear fusion reactors. There are two reasons for this attractiveness: (1) the deuterium/helium-3 reaction does not produce any fast neutrons and (2) the helium-3/helium-3 reaction produces no radioactivity at all (fig. 3.9.3.1-1). Because of the very large amount of energy that can be generated by even small amounts of He3, it appears economically viable to mine it from the lunar surface. Figure 3.9.3.1-2 outlines an He3 mining strategy developed by the University of Wisconsin that produces 33 kg of He3 per year. Figure 3.9.3.1-3 indicates the required equipment and crew needed for a mining operation.

The He3 Fusion Reaction:

$$\begin{matrix}\text{1 Deuterium Molecule} & & \text{1 Helium-4 Molecule}\\ + & \longrightarrow & +\\ \text{1 Helium-3 Molecule} & & \text{18 Million Electron Volts of Energy}\end{matrix}$$

Energy per kg of He3

$$\frac{(\text{18 MeV/He3 Molecule}) \times (1.6 \times 10^{-13}\ \text{Joules/MeV})}{4.8 \times 10^{-27}\ \text{kg/He3 Molecule}} = 6 \times 10^{14}\ \text{J/kg He3}$$

Energy per Pound of He3

$$\frac{6 \times 10^{14}\ \text{Joules/kg He3}}{2.2\ \text{lb/kg}} = 2.7 \times 10^{14}\ \text{Joules/lb He3}$$

Electrical Energy per Pound of He3

$$2.7 \times 10^{14}\ \text{J/lb He3}\,) \times \frac{\text{1 Kilowatt-Hour}}{3 \times 10^{6}\ \text{Joules}} \times \underset{\substack{\text{Power}\\ \text{Plant}\\ \text{Efficiency}}}{30\%} = 22.5 \times 10^{6}\ \text{Kw Hr}$$

$$\boxed{1\ \text{lb He3} = 22.5 \times 10^{6}\ \text{Kw Hr}}$$

111264-185

Figure 3.9.3.1-1. He3 to KwHr Relationship

Key Parameters

Total earth mass	18 mt (39,600 lb)
Annual collection rate of He3	33 kg (72.6 lb)

Additional Parameters

Mining hours per year	3942 hrs (during lunar daylight)
Excavation rate	1258 metric tons/hour
Depth of excavation	3 meters
Forward speed	23 meters per hour
Area excavated per year	1 square kilometer
Processing rate (of 50 micron particles)	556 metric tons/hour
Width of swath	11 meters

Separates & Processes Regolith Particles <50 microns

- These particles constitute 45% of lunar regolith
- These particles contain 90% of lunar He3

111264-186

Figure 3.9.3.1-2. University of Wisconsin Mark II Lunar Miner

Assumptions:

- A crew of five is needed to operate/maintain the harvester
- Each crew's tour of duty on the lunar surface is 180 days
- The crew and supplies to operate for 180 days weighs 22,000 lb (10 metric tons, details below)
- No "assessment" is taken for initial delivery of the lunar miner machine, or for the initial establishment of the lunar base needed to support He-3 harvest ops
- Water for crew and return propellants are supplied from lunar LOX and hydrogen gas volatiles from the regolith

Breakdown of 22,000 lb Weight for 180-day Tour of Duty:

Crew (five people x 200 lb ea.)	1,000 lb
Food (2lb dehydrated food/person/day)	1,800 lb
Replacement parts/enhancements for life support system	2,000 lb
Crew/He3 Transport Capsule	10,000 lb
Clothing (50 lb/person)	250 lb
Personal possessions (50 lb/person)	250 lb
Medical Supplies (50 lb/person)	250 lb
Replacement parts/maintenance supplies for lunar miner	4,000 lb
Contingency allowance	2,450 lb
Total	22,000 lb

1 lb on lunar surface = 5 lb in low Earth orbit (LEO)

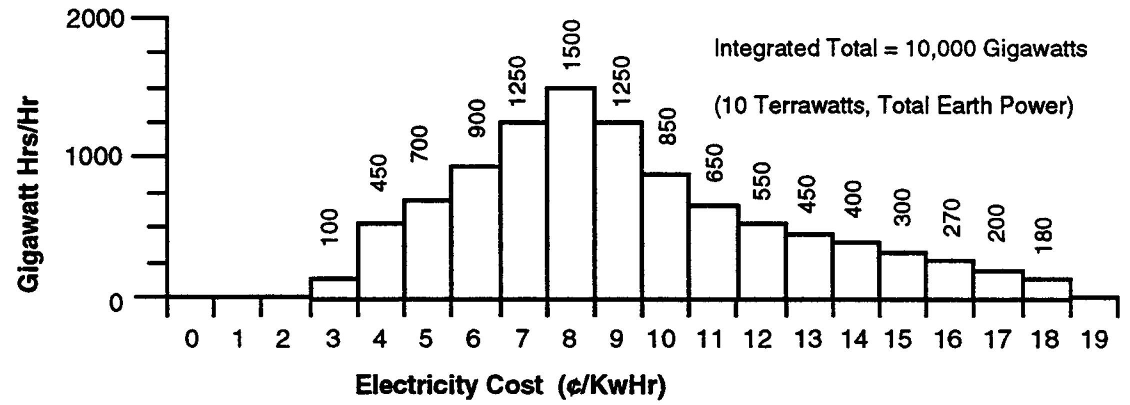
22,000 lb on lunar surface = 110,000 lb in LEO

111264-187

Figure 3.9.3.1-3. Lunar Payload Needed to Process He3

3.9.3.2 Market Description

The primary market force is the demand for electricity and the competitive price for electricity in different geographical regions. The cost of He3 fuel and the cost of the associated reactor hardware must be low enough to produce electricity at rates per kilowatt hour that are competitive with electricity produced by other methods. Figure 3.9.3.2-1 shows the world's electrical production distributed by cost per kilowatt hour. Hydroelectric production accounts for most power less than 6¢ per KwHr and with fossil fuel production in remote areas (e.g., equatorial Africa) accounting for the highest rates, up to 25¢ per KwHr.



Assumptions:

- The 10 Terrawatt total earth electrical power production level (per Dr. Zubrin)
- The cost distribution curve is an estimate, based on the following information:

Seattle-Everett	3¢/kwhr	(1)
U.S. City Average	8¢/kwhr	(1)
Rural India	12.6 - 18¢/kwhr	(2)
Northern & Equatorial Africa	25¢/kwhr	(2)

(1) - Statistical Abstract of the United States -1988, Table no. 757

(2) - Proceedings of "Engineering, Construction, and Operations in Space II," 1990, p.1184

111264-188

Figure 3.9.3.2-1. Electricity Market Versus Kilowatt-Hour Cost

3.9.3.3.1 Space Application Description

Growth Projection

The primary growth path is by increasing the share of the market that is captured by He3-produced electricity. The method of accomplishing this is to lower the cost of He3-produced electricity. Figure 3.9.3.2-2 correlates the consumption of He3 to electrical power output.

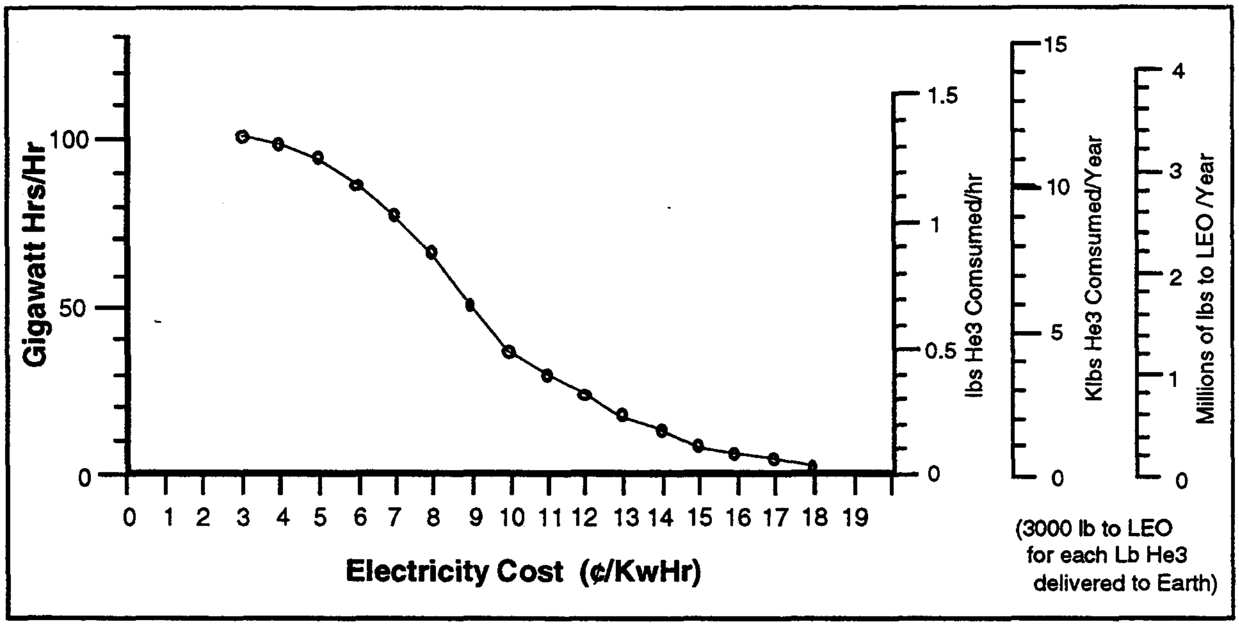


Figure 3.9.3.2-2. He3 Market Versus Kilowatt-Hour Cost

Elastic Analysis

The cost of electrical power varies significantly by geographical area. In areas with many large hydroelectric dam facilities (e.g., Pacific Northwest), the cost can be as low as 2 to 3¢ per kilowatt hour. In residential areas of developed countries, it ranges from 8¢/KwHr to 15¢/KwHr. In rural areas of undeveloped countries, it can approach twice these residential rates.

For the purposes of this study, the focus is on producing electricity in the 8¢ to 15¢ per kilowatt hour range. Rural areas of undeveloped countries would not provide sufficient demand to justify the large capital expenditure needed for a He3 production facility and distribution system, and it is probably not feasible to try to compete with 2¢/KwHr hydroelectric dam power. Figure 3.9.3.2-2 correlates He3 consumption to cost of other available electricity. This correlation is based on the ratio of 3,000 pounds of payload to LEO for every pound of He3 delivered to Earth. This ratio comes from an annual He3 production of 72 pounds (fig. 3.9.3.1-2) and 110,000 pounds delivered to orbit for each 6-month tour of duty for extraction teams (fig. 3.9.3.1-3). Figure 3.9.3.2-3 shows the market size based on a 1% share of those markets where other available electricity is more costly than He3 electricity. For example, at 8¢ per KwHr, the cumulative market is 66 Gigawatts.

¢/KwHr	Total Market at this cost (gigawatts)	He3 Market at this cost (gigawatts)	Cummulative He3 Market (gigawatts)
18	180	1.8	1.8
17	200	2.0	3.8
16	270	2.7	6.5
15	300	3.0	9.5
14	400	4.0	13.5
13	450	4.5	18.0
12	550	5.5	23.5
10	650	6.5	30.0
11	850	8.5	38.5
9	1250	12.5	51.0
8	1500	15.0	66.0
7	1250	12.5	78.5
6	900	9.0	87.5
5	700	7.0	93.5
4	450	4.5	99.0
3	100	1.0	100.0

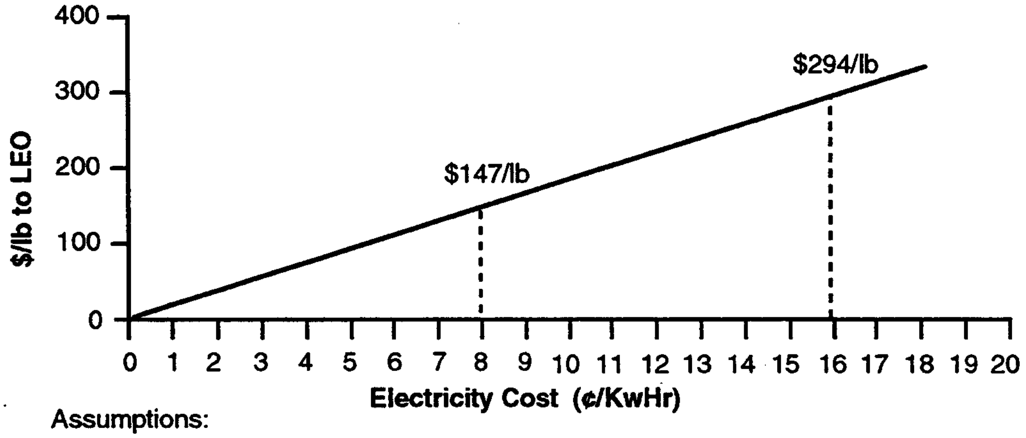
Total Earth
Electrical Power ≈
10 Terrawatts
(10,000 Gigawatts)

Assumption: He3 power systems can capture 1% of the market for energy that is of equal or higher cost per kilowatt-hour

111264-190

Figure 3.9.3.2-3. Cumulative He3 Versus Kilowatt-Hour Cost

Figure 3.9.3.2-4 illustrates the cost per pound to LEO that must be achieved to generate electricity with He3 at a given cost per kilowatt-hour. A sample calculation is provided to show how the information from figures 3.9.3.1-2 and -3 is used to calculate this relationship.



Assumptions:

- Fuel cost = 25% of electricity cost
- Earth power plant is 30% efficient

Sample Calculation:

- For 8¢/KwHr, fuel cost = 2¢/KwHr
- 36 lb He3 from a 6-month tour of duty (33 kg/yr/2)
- 36 lb x 22.5 million KwHr/lb He3 x 2¢Fuel Cost/KwHr = $16,200,000 fuel cost
- $16,200,000/110,000 lb to LEO = $147/lb to LEO launch cost

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Figure 3.9.3.2-4. LEO Cost Versus Kilowatt-Hour Cost

Figure 3.9.3.2-5 correlates the information from figures 3.9.3.2-2 and -3 to form a launch market elasticity analysis. If the cost per pound to orbit is above $330, the resulting cost for He3-generated electricity is over 19¢ per kilowatt-hour. There is no significant market for electricity at this cost (fig. 3.9.3.2-1), so there is essentially no launch market. However, as the cost per pound to orbit is lowered, the cost per kilowatt-hour becomes much more competitive, and the launch market increases dramatically. If the to-orbit cost can be lowered to $110/lb, then the launch market increases to 3 million pounds per year. This equates to 150 launches per year of a 20,000 lb payload class launch vehicle. However, it should be noted that it is a very significant challenge for a launch vehicle to reach even the $330/lb cost level.

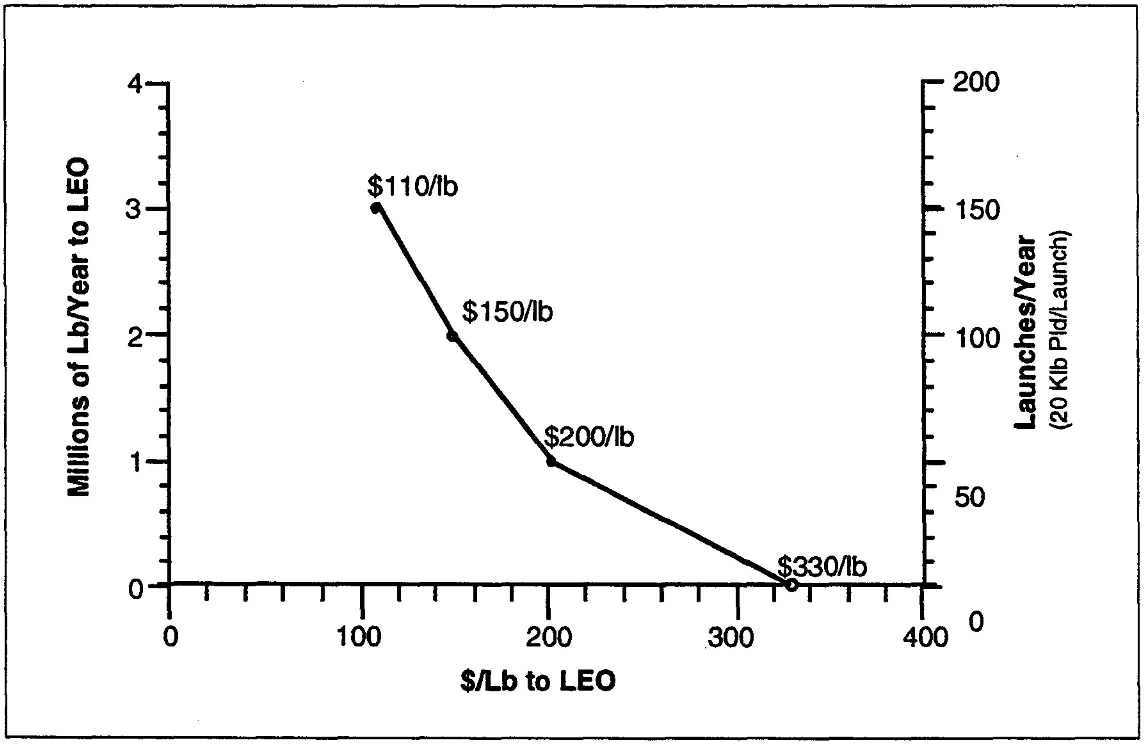

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Figure 3.9.3.2-5. He3 Launch Market Elasticity

3.9.3.3.2. Market Evaluation

The key market enabler is the achievement of sustained nuclear fusion. This technology has been pursued for several decades, and predictions for its achievement range from two to five additional decades. In addition, deuterium/tritium fusion is probably the first sustainable reaction to be achieved because it occurs at lower temperatures than the deuterium/helium-3 reaction. Production of significant amounts of electricity from He3 will require the following developments: (1) achievement of D-T fusion, (2) achievement of D-He3 fusion, and (3) development of commercially viable D-He3 reactor/generator facilities.

Per Dr. Kulcinski, the current fusion community plans will result in fusion plants that could use lunar He3 in about the year 2025 to 2030. The University of Wisconsin is pursuing a technology called inertial electrostatic confinement (IEC), which has the potential of being ready for lunar He3 in 2015 (research activities use He3 from weapons stockpile materials). Thus, the initial need for lunar He3 ranges from 22 years to 37 years.

Use of lunar He3 in fusion reactors will also require a lunar He3 mining operation. Achievement of this type of a mining operation will require the following technologies and capabilities:

a. The capability to transport humans to and from the Moon.
b. A lunar base capable of supporting long-term habitation by work crews (not just scientist and astronauts).
c. A logistics/transportation system to provide supplies, equipment, etc. to mining crews.
d. Mining equipment capable of extracting He3 from the lunar regolith.
e. Space suits suitable for hard physical work.
f. Telerobotic systems.

3.9.3.3.3 Market Infrastructure

3.9.3.4 Prospective Users

The near-term prospective users of He3 will be those electric utilities that take part in the development of the fusion reactors. Additional evaluation of the He3 market is based on interviews and reviewed articles of:

a. Dr. Gerald Kulcinski, director, Fusion Technology Institute, University of Wisconsin.
b. Dr. Duke, deputy for science, New Initiatives Office, NASA-JSC.
c. Dr. Robert Zubrin, Advanced Exploration Programs, Martin Marietta.
d. Review of proceedings of "Engineering, Construction, and Operations in Space" II and III (1990 and 1992).

3.9.3.5 CSTS Needs and Attributes

3.9.3.5.1 Transportation System Characteristics

The primary attribute needed from the CSTS is the ability to deliver cargo to orbit for a consistent low cost. The required cost level can be directly tied to the cost of electricity that the He3 production facility must achieve.

In conjunction with Dr. Zubrin and Dr. Kulcinski, a methodology was developed to correlate the cost per pound to orbit to the resulting cost per kilowatt of electricity. This methodology takes into account such factors as:

a. Net kilowatt hours per pound of He3.
b. Efficiency and rate of extraction of He3 from lunar regolith.
c. Weight of mining equipment, supplies, and crew needed on the lunar surface to extract a given amount of He3.
d. Pounds in LEO per pound delivered to the lunar surface.

This methodology indicated the CSTS would have to deliver cargo to orbit for $294/lb to achieve 16¢/KwHr electricity, and $147/lb to LEO to achieve 8¢/KwHr electricity (fig. 3.9.3.2-4).

3.9.3.6 Conclusions and Recommendations

Additional refinements of the methodology and associated numbers are possible, but only small changes would occur. The current numbers agree reasonably well with University of Wisconsin cost analysis numbers that predict commercial viability of He3 power generation at a cost of $1,000/lb (delivered to the lunar surface). Based on these factors, it is not recommended that significant additional resources be spent on this area.

3.9.4 Extraterrestrial Resources

3.9.4.1 Introduction

The use of ET resources can be considered in two categories: use on Earth or use in space. Whichever the site of usage, there are primarily four sources of ET materials. These are lunar, asteroids, comets, and planets and their moons.

These categories are not entirely precise and distinct. Asteroids are typically thought of as being like meteorites: stony, carbonaceous or metallic objects in orbits between Mars and Jupiter. Comets are usually thought of as "dirty snowballs," having "tails" due to the outgassing of volatiles. Comets may have very long, nearly parabolic orbit periods or shorter orbit periods when they have been captured by major planets.

As more information is obtained on the characteristics of objects in space, it is becoming apparent that there is a great deal of overlap between these categories. There are comets, or the relatively devolatized remnants of comets, in orbits more typically associated with asteroids, and there are asteroids in orbits outside Jupiter and well inside Mars. In fact, some asterioids have orbits with mean distances from the Sun less than that for Earth.

Some planetary satellites may be captured asteroids (those of Mars, in particular), and there is a continua of characteristics of comets, asteroids, and the larger bodies. Use of these resources on Earth has been confined to the scientific study of their characteristics, occurrence, and origin.

Use of ET resources will probably occur first in space, where they would be used to enhance planetary exploration, lunar base development, or other missions. Since they are used in a support role for other missions, the market for ET resources is highly dependent on the market for the primary missions. Use of ET resources is likely to decrease rather than increase the net space transportation demand for any given primary mission.

3.9.4.2 Market Description

The primary market force is the potential for use of ET resources to enhance planetary exploration, lunar base development, or other missions. Since they are used in a resource support role for other missions, the market for ET resources is highly dependent on the market for the primary missions. As resupply stations, they offer "a payback (on the order) of 100 times more mass to Earth orbit per trip than is initially launched."[3] Use of ET resources for resupply is likely to decrease rather than increase the net space transportation demand for any given primary mission, and the promise of more performance (increased duration and orbit) per pound of vehicle from earth may expand the market.

3.9.4.2.1 Space Application Description

Growth Projection

The primary growth path is by increasing the size and scope of primary missions, such as planetary exploration, lunar base development and other missions to the point where ET resources can make a cost-effective contribution to the mission.

If space transportation costs can be reduced sufficiently, it could become cost effective to obtain precious metals such as platinum from asteroids for use on Earth.

Elastic Analysis

The in-space use of ET resources is entirely dependent on demand from the primary missions such as planetary and lunar exploration. Initial missions will probably be designed to be self-contained and are not likely to utilize ET resources. These resources will only be used when the cost of bringing additional supplies from Earth for larger missions exceeds the cost of the mining and processing equipment needed to use in situ resources.

On-Earth use of platinum from asteroids would be determined by cost and market size issues. The current cost of platinum is around $360/oz. If platinum could be mined, processed, and returned to Earth for less than this cost, then a market potential would exist. The other aspect to consider is the size of the platinum market. The world platinum market is of the order of $10 billion per year. The price of platinum is based largely on its scarcity, and the introduction of even small amounts of additional supply would be likely to result in a significant reduction of platinum prices.

3.9.4.2.2 Market Evaluation

The key market enabler is the level of public will to fund lunar and/or Mars exploration efforts of a size that would justify use of ET resources.

3.9.4.3 Prospective Users

The primary users for ET resources is expected to be those entities currently using space systems, including both the booster and satellite operators. Mining, milling, reduction, and distribution entities will need to be developed.

3.9.4.4 CSTS Needs and Attributes

3.9.4.4.1 Transportation System Characteristics

The primary attribute needed from the CSTS is the ability to deliver cargo to orbit for a consistent low cost, which would increase the probability of primary missions that could use ET resources. On-time performance is not as great of a concern to most users in this area, especially as the payload size increases. Smaller replacement parts would impose better on-time performance.

For Earth utilization of most ET resources, the CSTS must reduce the cost of space access by one to two orders of magnitude—an optimistic expectation for the foreseeable future.

3.9.4.5 Conclusions and Recommendations

The use of ET resources on Earth is not likely to occur (except possibly for novelties) in the near term. Space transportation costs will need to be reduced by one to two orders of magnitude for ET resources to begin to be attractive for use on Earth. ET resources should be reevaluated in an iterative process as better assessments of primary markets beyond LEO and the lunar surface are available in this study.

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1. Proceedings from "Engineering, Construction, and Operations in Space II," 1990.
2. Proceedings from "Engineering, Construction, and Operations in Space III," 1992.
3. "Rocket Fuel to Earth Orbits From Near-Earth Asteroids and Comets," Zuppero,A., "Engineering, Construction, and Operations in Space III," 1992.

3.10 ADVERTISING

3.10.1 Introduction

The use of space for low investment cost advertising, demonstrating, marketing, and providing goods and services has not occurred often in our country. This market area capitalizes on the public's interest in space and the belief that it is the last frontier. This market area has been separated into four categories: (1) novelties, (2) space advertisement/orbiting billboards [Note: For the purpose of this study, consideration of orbiting space billboards has been delayed, pending the outcome of Congressional opposition], (3) space product demonstration, and (4) space burial. One of the key characteristics of this market area is that a dedicated flight would not be required for most items. Thus, there is potential for establishing a number of pricing strategies for maximizing revenue.

3.10.2 Novelties

3.10.2.1 Introduction/Statement of Problem

The novelties area covers the sale of used/spare space assets, objects captured from space, and items flown specifically to be resold as "space trinkets." Although this is an ongoing market, it has been severely limited by the availability of suitable items. Due to the scarceness of these items, their sale has been generally confined to highly specialized auctions. Considering the demand for such items and the prices at which they are sold, it may appear that there is a significant opportunity being missed. However, it must be remembered that it is the scarcity itself that forms the value of these items since their intrinsic value is generally negligible. For instance, moon rocks would have little or no value if it wasn't for their origin.

3.10.2.2 Study Approach

Our approach to characterizing this market area included the assessment of potential customers of used/spare space assets, objects captured from space, and items flown specifically to be resold as space-flown trinkets. As such, several specialized auction houses (e.g., Sotheby's), unique catalogue sales outlets (e.g., Edmund Scientific), exclusive high-end specialty stores (e.g., The Sharper Image and The Nature Store), and the television shopping networks (e.g., QVC) were identified as potential contacts. Each would have an interest in reselling space novelty items and would have insight into the potential revenue and price sensitivities.

3.10.2.3 Market Description

3.10.2.3.1 Market Evaluation

The availability of items for sale has been severely limited in the past, which contributes to the perceived value. The market for high-end, unique items (e.g., a space capsule) would be dictated solely by this demand. For space trinkets, it is envisioned that such items as a shuttle GAS can or mid-deck locker for patches, flags, and the like be used. These types of items could produce significant revenue through mass sales at reasonable prices, targeted specifically at visitors to museums.

3.10.2.3.2 Space Application Description

Obtaining the desired items is the largest technical challenge in the novelties area. It could be as easy as purchasing space in a mid-deck locker or GAS can for space-flown trinkets such as patches and flags, or the purchase of spares and/or returned actual flight items from NASA and other international space organizations. On the other hand, specific missions could be designated to return materials from the moon and other planetary bodies. As soil sample missions have only been accomplished on a few occasions to date and as the United States currently has no operating interplanetary landing and return vehicles, this would involve many technical, financial, and schedule complexities yet to be resolved. Once these items are obtained, they could be shipped for sale through stores, catalogs, TV shopping networks, and consignment auctions.

3.10.2.3.3 Market Assessment

Any terrestrial item flown in space has the same intrinsic value as an identical Earth-bound item. The apparent higher value of a space flown item is due to the mere fact it has flown in space. This increased value is a direct result of the relative rarity of space flown objects. A significant market for serious collectors of as-flown unique hardware currently exists, as evidenced by a December 1993 Sotheby auction which netted nearly $7 million (see sec. 3.10.2.6.1). Space trinkets seem to have a great potential, but no commercial venture has been pursuing them.

3.10.2.3.4 Infrastructure

This market area can only be successful if it works within the existing and evolving space infrastructure. Recouping "as-flown" merchandise for resale would only require negotiating a long-term contract with appropriate space agencies and would require no physical change to the existing infrastructure. To establish a new market in the low cost, higher volume space-flown trinkets would require contracting for mid-deck locker or GAS on the shuttle, but again there are contracting mechanisms in place to accomplish this without any changes to existing infrastructure.

We would not attempt to enter the market for extraterrestrial materials retrieved from the Moon and other planetary bodies until an interplanetary landing and return system was on line. We would work within the constraints and stipulations of that system and would not attempt to change its operating procedures. If possible, we would attempt to influence the design and operations plan early in the development program, but this market cannot support sharing in the development of such a system and expect to turn a profit. We would require a processing and packaging facility to prepare the items for mass distribution. Distribution and sales to final customers would be accomplished through a network of stores, catalogues, TV shopping networks, and auctions.

3.10.2.4 Prospective Users

There are two feasible methods of distribution of space novelties. First is to deal directly with a network of stores, catalogues, TV shopping networks, and auction houses. The second is to hire a single entity to interface with the network of distributors. It is not feasible to distribute directly to final customers. We have not determined which method is preferred.

The Home Shopping Network was the first contact made in the novelties area. They appeared eager to consider the sale of space novelty items should some become available. They were unable to provide much practical pricing and demand data specifically associated with space items, however, they have a wealth of information on the price/demand of earthbound items such as jewelry and objects of art. Art may be the best class of items comparable to space novelties in that the value is based on perceived value. That is, the items often have little intrinsic value and the price is set by the value the customers perceive that item commands.

Sotheby's was also contacted to discuss the December 1993 auction of Soviet space memorabilia. A detailed description of the event is included in section 3.10.2.6.1.

3.10.2.5 CSTS Needs and Attributes

3.10.2.5.1 Transportation System Characteristics

The impacts upon any transportation system would have to be negligible in order to minimize the novelty cost. There are no impacts on current launch vehicles for all markets excluding interplanetary retrieval. We would require the use of a mid-deck locker or GAS on the shuttle for space-flown trinkets for these markets, and there are already procedures in place to perform this type of mission. To capture the market for return materials from the Moon and other planetary bodies would require a new launch system. Currently, the United States has no interplanetary landing and return system. Thus, this market could not be pursued until such a vehicle is developed. Justification for development of such a system would be from other market areas, since this area could not support amortization of system development cost and still expect to turn a profit.

3.10.2.5.2 Ground Segment

Any ground segment impacts to a potential launch system could be minimized by design. We would work within the existing infrastructure. As above, we assume the ground segment for a interplanetary landing and return system would be in place prior to our entering such a market.

3.10.2.5.3 User/Transportation Interfaces

To minimize costs, the integration and interfaces for space-flown trinkets must be small. As-flown-unique items and other space memorabilia would not require any integration or interface. Returned extraterrestrial materials would require a minor investment in a processing and packaging facility to prepare items for final distribution.

3.10.2.5.4 Management and Policy

The management and dispensation of as-flown memorabilia is critical to maintaining its value over the long term. Investors and collectors must be assured that these items will not flood the market, thus maintaining the perceived value. It is likely that the historical value of these items will always limit the availability. However, we must develop and adhere to some formal policy and establish guidelines.

For space-flown trinkets a high volume business plan must be established. Long term agreements with both the launch provider and distribution network must be formalized. The integration of these items into a launch vehicle would be identical to any other payload integration effort.

It is not clear at this point whether extraterrestrial materials retrieved from the Moon and other planetary bodies would be marketed as low-volume space trinkets or as high-value unique items. This will be determined upon our cost and ability to retrieve these items.

3.10.2.5.5 Improvements Over Current

With the small investment required to enter this market, there is no requirement for improvements in terms of reliability or operations turnaround. For space trinkets and potentially extraterrestrial materials, we would be an auxiliary payload, and we must ensure this does not cause problems. Clearly we are launch cost sensitive, and any decrease in launch cost would be beneficial, but not a market entry barrier.

3.10.2.6 Business Opportunities

3.10.2.6.1 Cost Sensitivities

Due to the relatively limited revenue potential of this market, it is highly unlikely that the sale of novelties could finance entire missions on their own. However, if a mission were to bring back salable items as a consequence of lunar mining, sample returns, and the like, the sale of related novelties could supplement the scientific revenues of a mission by approximately $20 million. The sale of trinkets, Moon rocks, spare/used space suits, and returned capsules has been ongoing since the mid-1970s. Some auction houses such as England's Sotheby's say that although it is very difficult to estimate the sale prices of space items, a Sotheby auction in December 1993 sold more than 200 items from the heyday of the Soviet space program, including a dozen pieces of memorabilia connected with Yuri Gagarin's 1961 flight. The total of the sale was $6,817,197, which included items ranging from a Soyuz TM-10 capsule for $1.6 million, a Cosmos capsule for $500,000, $400,000 for several tiny moon pebbles returned during Luna 16, and $6,500 for two photographs of Gagarin. Sotheby's also auctioned two pieces of Soviet equipment still sitting on the moon. Those went for $60,000, even though the buyer had no guarantee he could ever get the Luna 21 descent stage and a remote-controlled research vehicle to Earth.

Figure 3.10.2.6-1 shows the potential revenue by year that could be generated through the sale of novelties. It assumes that some hardware from Space Station Alpha or a lunar/planetary mission becomes available beginning in 1996. This does not include novelty items based on TV or other fictional media such as Star Trek.

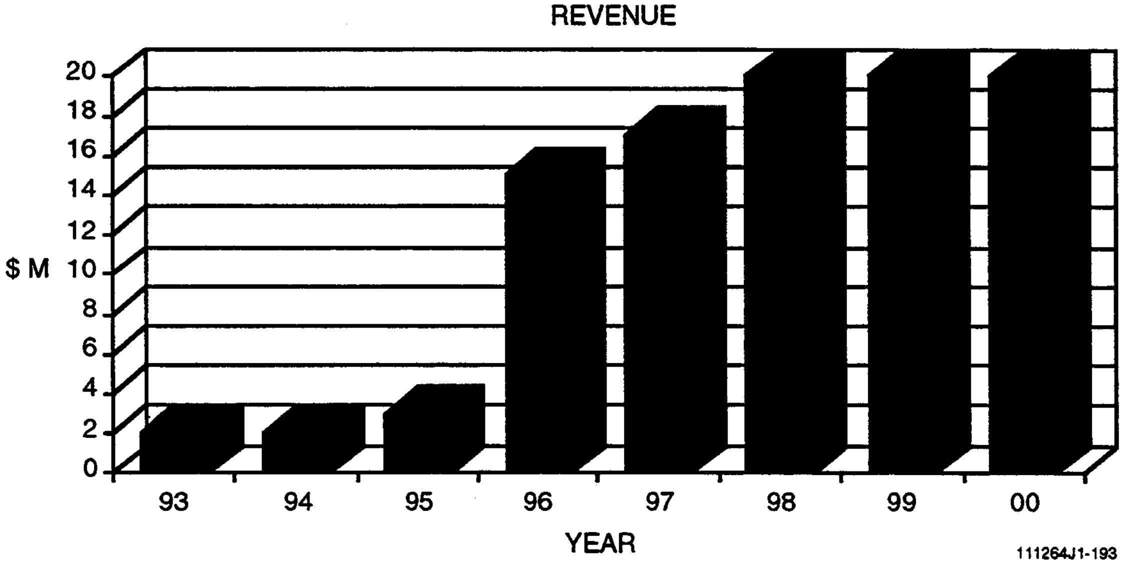

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Figure 3.10.2.6-1. Yearly Revenue Through Sales of Space Novelties

Figure 3.10.2.6-2 shows the sensitivity to price per pound for varying priced novelties ($100 to $1 million per item). This market is exceptionally sensitive to transportation costs. We assumed that items returned from other planetary bodies are free to those who are able to obtain them. Therefore, the major contributor to the cost of sale is the transportation costs of returning the items to Earth.

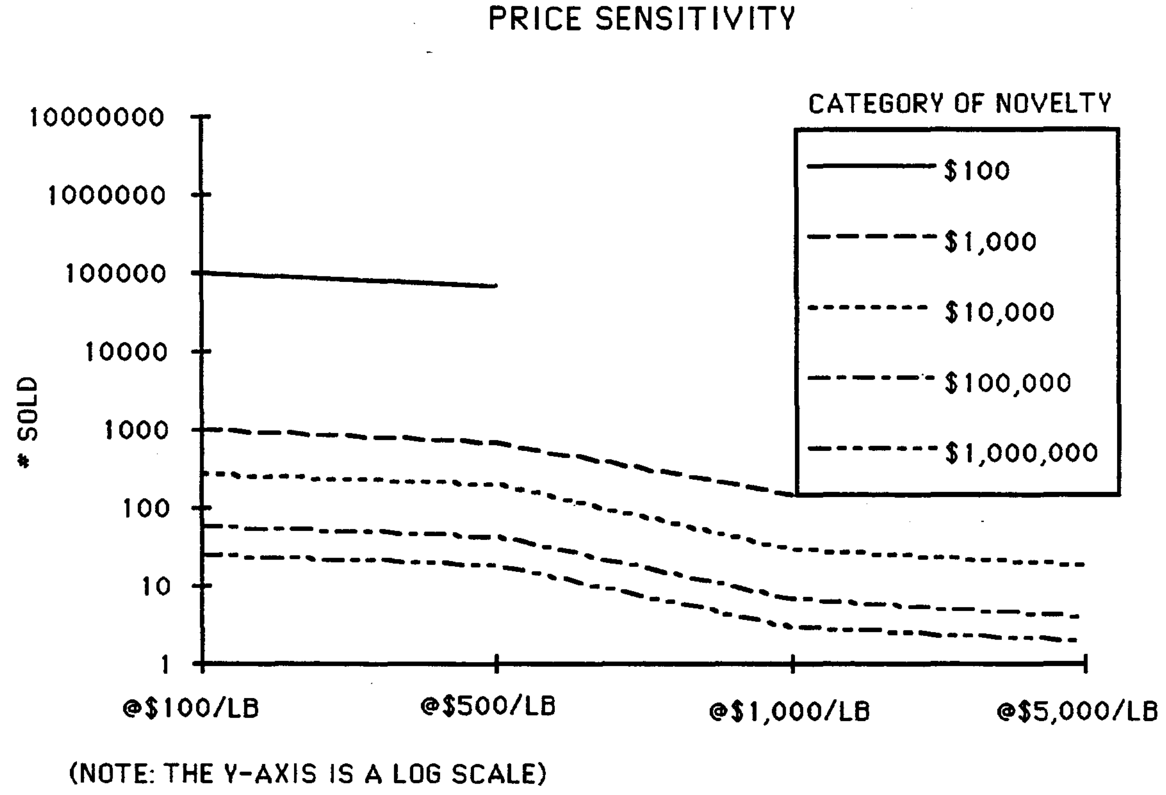

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Figure 3.10.2.6-2. Sensitivity of Sales to Item Price

3.10.2.6.2 Programmatics

A principal concern is availability of materials. So far, no commercial ventures have been started to lease a shuttle GAS can or mid-deck locker expressly for this purpose. For extraterrestrial material return, the primary concern is waiting for the development of a new interplanetary landing and return system, or purchase/lease of current Russian systems. Additional concerns for extraterrestrial material return are the legal and ethical questions such as who has the right to separate and return a piece of an asteroid. Extraterritorial rights may eventually have to be established.

Another sensitive issue involves the perception that the Russians have been reduced to selling off their national treasures. Although nearly all bidders at Sotheby's auction said they were thrilled to obtain such artifacts and memorabilia, some expressed discomfort that people were selling such valuable and historic items, such as the congratulatory telegram Khrushchev sent to Gagarin.

3.10.2.7 Conclusions and Recommendations

The novelties area covers the sale of used/spare space assets, objects captured from space, and items flown specifically to be resold as space trinkets. Although this is an ongoing market, it has been severely limited by the availability of suitable materials and sales have been generally confined to highly specialized auctions. Obtaining the desired items is the largest technical challenge in this area. Considering the demand for such materials and the prices at which they are sold, it may appear that there is a great opportunity being missed. A market for serious collectors of as-flown hardware currently exists, as evidenced by a December 1993 Sotheby auction that netted nearly $7 million for over 200 items. However, it must be remembered that it is the scarcity itself that forms the value of these items since their intrinsic value is generally negligible. Space trinkets, such as flags and patches flown for resale, seems to have a great potential, but no commercial venture has been pursuing this market.

The impacts upon any transportation system would have to be negligible in order minimize the novelty cost. This market is exceptionally sensitive to transportation costs, as evidenced from the price elasticity charts. Therefore, the major contributor to the cost of sale is the transportation costs of launching and returning the items to Earth.

Although this market is not large enough to justify the development of a launch system on its own, it does offer an attractive opportunity for entrepreneurs to supplement revenue on space ventures.

3.10.3 Space Advertisement/Orbiting Billboards

3.10.3.1 Introduction/Statement of Problem

The use of launch vehicles as an advertising medium is a newly evolving market with the potential to make substantial financial contributions. Several major commercial advertising firms have already contracted to place advertisements for their clients on both U.S. and international vehicles. In the past, launch vehicle manufacturers have used the advertising space to promote their subcontractors and suppliers, as well as the payload manufacturer or end user. These events have generally not involved any monetary compensation, but have been used to promote overall programs in hope of increased future sales.

Although it is extremely unlikely that advertisements could fund an entire mission, they may provide significant supplementary revenue. Advertisements may be purchased on their own, but they are generally integrated into overall promotional campaigns. As such, they have the potential to generate additional revenues on the order of $3 million to $5 million or more per mission. This may approach the funding necessary for a small launch vehicle mission, and the revenue from the additional payloads would be pure profit.

As noted in section 3.10.1, a group of Congressmen and Senators have initiated a bill to ban advertising in space. The bill is written so broadly that it could be implied that companies could not put their own names or their customers' names on their launch vehicles, space station components, or other hardware destined for space. It is also broad enough that any radio waves that escape into space and contain advertisements from television or radio would also be illegal. This bill has little support in Washington, but represents a real threat to this and other similar business prospects. Although some people believe that commercial sponsorship is the best thing that could happen to space in terms of bringing in general public support, others feel that space is a pristine environment, similar to our national forests, and should not be commercialized. For the purpose of this study, consideration of space orbiting billboards has been postponed, pending the outcome of this legislative effort.

3.10.3.2 Study Approach

Our approach to characterizing this market area included the assessment of potential customers of launch vehicles as an advertising medium. Providers of decals used for the advertising (e.g., Vision Graphics), enabling companies (e.g., Space Marketing, Inc.), users (e.g., Columbia Pictures, Coca Cola), and advertising agencies (e.g., Creative Artists Agency) would all have an interest in space advertising and would have insight into the potential revenue and price sensitivities.

3.10.3.3 Market Description

3.10.3.3.1 Market Evaluation

Several major commercial advertising firms have already contracted to place advertisements for their clients on both U.S. and international vehicles. The advertising firms view this medium as very similar to placing advertising on Indy cars, stock cars, or power boats, except with more hype, and, therefore, more media coverage. In the past, launch vehicle manufacturers have used the advertising space to promote their subcontractors and suppliers, as well as the payload manufacturer or end user. These events have generally not involved any monetary compensation, but have been used to promote overall programs in hope of increased future sales. These events are expected to continue; however, some space may be supplanted by revenue-generating advertising.

3.10.3.3.2 Space Application Description

Once contracted, the advertisement is generally painted on the vehicle using a method very similar to custom paint jobs on automobiles. Special paints must be used because of the harsh environments seen by the launch vehicle. Another option is to have a decal produced of the advertisement that can then be applied to the vehicle. These decals are generally applied in sections not exceeding two-foot square, ensuring a large piece will not become detached and interfere in the operation of the vehicle.

The process of putting the advertisement on the vehicle is relatively simple, but some of the associated technical issues may present a challenge. The advertisements can weigh from 10 to 220 pounds, and this may necessitate changes to performance and trajectory analysis depending upon the capabilities of the vehicle. This is not insurmountable, but it does present hidden costs to implementing the advertising. The costs of obtaining government approvals to place advertising on those vehicles that carry government payloads may also present a costly and time-consuming process, if possible at all.

3.10.3.3.3 Market Assessment

Although it is extremely unlikely that advertisements could fund an entire mission, they may provide significant supplementary revenue. Advertisements may be purchased on their own, but they are generally integrated into overall promotional campaigns. As such, they have the potential to generate additional revenues on the order of \$3 million to \$5 million or more per mission. For example, Columbia Pictures was willing to pay \$500,000 for space on the side of the first Comet launch to promote the release of "The Last Action Hero." This was split between Westinghouse (Conestoga) and Space Marketing, Inc.

3.10.3.3.4 Infrastructure

Painting or decals appearing on a launch vehicle would likely be applied at the place of manufacture on a noninterference basis. Thus, we could support this market by working within the current infrastructure. Paints and/or decals could be contracted through existing businesses, and the launch itself would be conducted within the current environment. This market could require additional mission analysis for those launch systems that are performance limited. This would be conducted by those already performing mission analysis for the system and would not require further infrastructure.

3.10.3.4 Prospective Users

There are three types of potential customers: (1) enabling companies (e.g., Space Marketing, Inc.), who would aggressively focus on attracting companies to advertise in space, (2) advertising agencies (e.g., Creative Artists Agency), who would examine space as one alternative for their customers, and (3) users (e.g., Columbia Pictures and Coca Cola).

The primary contact made in the advertising area was Space Marketing, Inc. (SMI). SMI has spent the last 2 years researching the placement of advertising on launch vehicles and has an extremely good feel for the overall market and its price points. Additionally, we have found that it is often more productive to go to the main advertising firms rather that directly to potential companies because the decisions driving funding allocations are actually made at the advertising firm. Going to the advertising firms, who represent a wide range of companies, served two functions: (1) they informed us of the applicability of space-based advertising to their various clients, thereby reducing the number of direct contacts required, and (2) they were very helpful in referring us to forward-thinking decision makers in firms that they did not represent. The beverage, movie, and auto industries seem to be the most receptive to pursuing this advertising option.

3.10.3.5 CSTS Needs and Attributes

3.10.3.5.1 Transportation System Characteristics

The impacts upon any transportation system would have to be negligible in order to minimize the advertising cost. For advertising, the decals would be of minimal weight and would need to be of significant size to be recognizable from a distance for photographic exploitation. Any other impacts would, by design, be minimal. The impacts to performance due to weight, especially on small launchers, would have to be addressed.

3.10.3.5.2 Ground Segment

Any ground segment impacts to a potential launch system would be minimal by design.

3.10.3.5.3 User/Transportation Interfaces

To minimize costs, the integration and interfaces for advertising would be, by design, small.

3.10.3.5.4 Management and Policy

Although no clear, consistent policy exists across all launch service providers for advertisement space, each has shown considerable interest. It is recognized that for a minimal weight penalty, a significant amount a revenue can be obtained. However, the advertisers are also highly schedule driven, which has been a stumbling block in the past. Since the launch providers are primarily interested in their deployable payload customers, a discord exists. This discord is not viewed as being significant or insurmountable.

3.10.3.5.5 Improvements Over Current

Currently, only fledgling efforts are being made into space advertising, and these are limited to the promotion of aerospace companies and/or programs. Relatively minor impacts to a launch vehicle by commercial ventures has the potential of increasing revenues for the launch services provider and improving visibility for both the vehicle and the commercial promotion.

It does appear that the launch variability of current systems is a concern. Most likely the advertisement on the launch would be tied to a larger advertisement campaign. It then is important to ensure we can launch close to the planned date. Any improvement in launch variability would increase the opportunities for business in this market.

3.10.3.6 Business Opportunities

3.10.3.6.1 Cost Sensitivities

For advertising, there will be a start-up period (2 to 3 years) where the novelty of placing advertisement on a launch vehicle will generate sales of $10 million to $20 million ($1 million per launch). After the initial thrill has dispersed, these ads will be integrated into promotional campaigns just as a television advertisement or billboard would be utilized. Figure 3.10.3.6-1 summarizes the expected revenues due to advertising while figure 3.10.3.6-2 summarizes the market elasticity. The elasticity is based on a price per advertisement basis and has little (if any) relation to the cost of launching a payload.

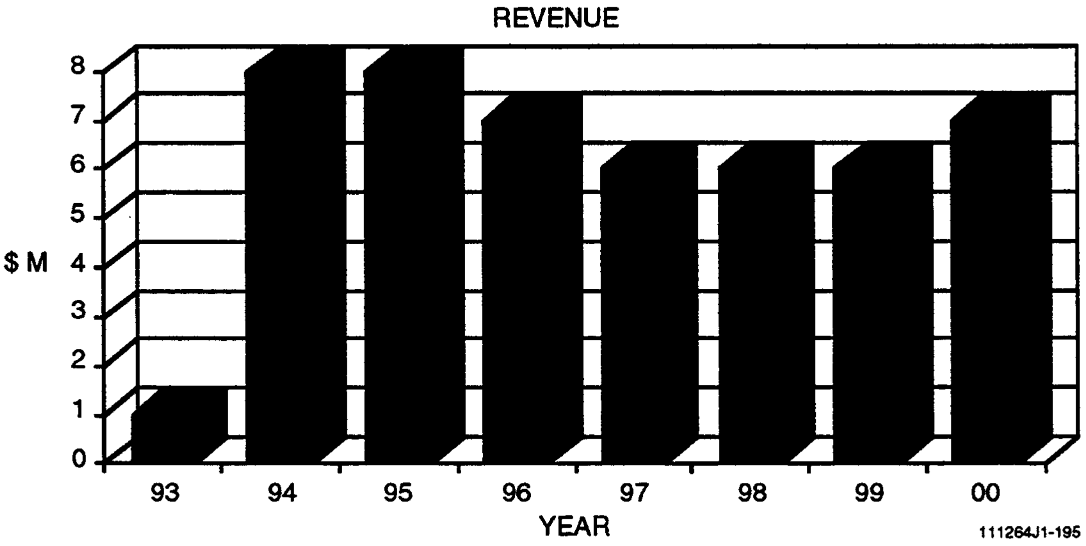

Figure 3.10.3.6-1. Yearly Revenue Through Sales of Space Advertisements

3.10.3.6.2 Programmatics

A significant issue will be to obtain government approval to place advertisements on vehicles that the government purchases or on which it places a payload for launch. This has proven to be a very cumbersome process for the launch vehicle manufacturers who have attempted to pursue this route, and many have received differing opinions from various officers within a service. Efforts up to this point have been directed towards purely commercial launches.

A concern of the commercial advertisers is the timing of the launch carrying their advertisement. The advertiser generally has specifically targeted his advertising at a specific event. This generally is the initiation of a new product. Based on weather, satellite, and launch vehicle delays, the launch may not occur on the prescribed day, or even within the originally planned week. This is unacceptable to many of the polled advertisers and must be contractually addressed. For example, Columbia Pictures was willing to pay $500,000 for a 40-pound decal to be placed on the side of the first Comet launch to promote the release of "The Last Action Hero." As promised launch dates slipped, Columbia became less and less interested in the project, eventually questioning the concept in general.

Another issue is access to the space complexes where vehicles are launched. Originally, only Air Force and contractor personnel were allowed at Cape Canaveral Air Force Station to view launches from the Florida launch sites. These restrictions are loosening; however, to date no one has attempted to bring in large TV and commercial film companies to film a launch. The first attempt is likely to meet with significant resistance. Other launch sites for international launch vehicles have not shown any hesitation to allow primarily unrestricted access to the launch sites. This situation may present a great disadvantage to U.S. firms as this market becomes increasingly competitive.

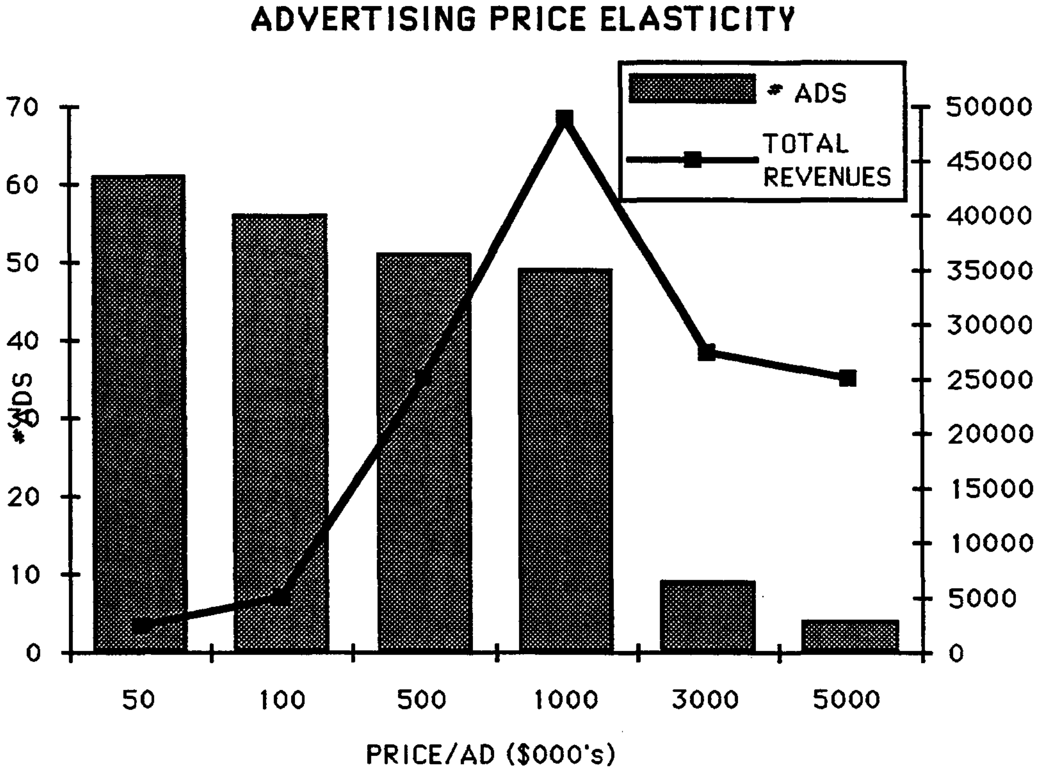

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Figure 3.10.3.6-2. Space Advertising Market Elasticity

3.10.3.7 Conclusions and Recommendations

The use of launch vehicles as an advertising medium is a newly evolving market with the potential to obtain substantial revenues. Several major commercial advertising firms have already contracted to place advertisements for their clients on both U.S. and international vehicles. In the past, these events have generally not involved any monetary compensation, but have been used to promote overall programs in hope of increased future sales. Although no clear, consistent policy exists across all launch service providers for advertisement space, each has shown considerable interest. Columbia Pictures was willing to pay $500,000 for a 40-pound decal on the side of the first Comet launch to promote the release of "The Last Action Hero." The beverage, movie, and auto industries seem to be the most receptive to pursuing this advertising option.

The process of putting the advertisement on the vehicle is relatively simple, but some of the associated technical issues may present a challenge. The ads can weigh from 10 to 220 pounds, and this may necessitate changes to performance and trajectory analysis depending upon the capabilities of the vehicle. In addition, some potential payload capability will be supplanted to accommodate the advertisement weight. It will be a revenue tradeoff to determine when payload capability should be sacrificed to accommodate the advertisement. For advertising, there will be a startup period where the novelty of placing advertisement on a launch vehicle will generate sales of $10 million to $20 million ($1 million per launch).

A significant issue will be to obtain government approval to place advertisements on vehicles that the government purchases or on which it places a payload for launch. Another primary concern of the commercial advertisers is the timing of the launch. The advertiser generally has specifically targeted his advertising at a specific event. Another issue is access to the space complexes where vehicles are launched. Current restrictions are loosening; however, to date no one has attempted to bring in large television or commercial film companies to film a launch.

Although it is extremely unlikely that advertisements could fund an entire mission, they may provide significant supplementary revenue on the order of $3 million to $5 million or more per mission (which may approach the funding necessary to justify a small launch vehicle mission).

3.10.4 Space Product Demonstration

3.10.4.1 Introduction/Statement of Problem

The ability to demonstrate commercial products on orbit has existed since the early 1980s with the initiation of several commercial launch vehicle companies. However, most commercial manufacturers have not been informed of the potential opportunities and therefore have not pursued such avenues. The response we received from the majority of companies that were contacted was one of surprise that such capabilities existed. Their immediate concern was, of course, cost. Space carries with it an air of infinity where the costs to access space are exceeded only by its physical size. When today's actual costs were communicated, there was a general indication that they were significantly lower than expected; still high, but potentially manageable.

The demonstration of products on orbit, like advertising, would be integrated into a company's promotional campaign. In general, demonstrating products on orbit serves little, if any, technical purpose. The companies considering such a demonstration, however, felt the use of their products on orbit provided them technical credibility and further added a feeling of "toughness" and "reliability." This change in public perception is the value-added contribution of an on orbit product demonstration from their point of view. Additionally, if any of these demonstrated products can be returned to earth, it appears that there would be a substantial market for the sale of such items.

3.10.4.2 Study Approach

Our approach to characterizing this market area included the assessment of potential users of the capability to demonstrate commercial products in space. Space Marketing, Inc. (SMI) was identified primarily due to its research of the overall market and its price points. Several large advertising firms were identified (i.e. Creative Artists Agency) along with firms that have already used space for demonstrations (i.e. Coca Cola Company). Each would have insight into the potential revenue and price sensitivities.

3.10.4.3 Market Description

3.10.4.3.1 Market Evaluation

Companies considering a space product demonstration felt the use of their products on orbit gave them technical credibility and further added a feeling of toughness, reliability, or intrinsic value. This change in public perception is the value-added contribution of an on orbit product demonstration from their point of view. The "stunt" value is also an important addition to any promotional campaign. Like advertising, the demonstration of products on orbit would be integrated into a company's promotional campaign. No firm has been actively pursuing this market area, as yet.

3.10.4.3.2 Space Application Description

Contracts and the actions performed in demonstrating products will vary widely. The actions begin with launching the desired products into orbit. At this point, commonalty disappears. Some products may have to be operated, while others may just have to show evidence of the trip. Demonstrating the product may be as simple as a video of the product in the desired space atmosphere or as complicated as performing a complex series of operations requiring human interaction and involving EVA. The location of the demonstration may range from low earth orbit to planetary ventures. The final destination of the product may range from random locations dependent upon other payloads to planetary bodies or even returning them to Earth.

3.10.4.3.3 Market Assessment

Any item flown or tested in space has an added feeling of toughness, reliability, or intrinsic value by the consumer. Since there has been evidence that commercial firms are willing to invest their own discretionary moneys to fund the development of their products for space demonstrations (Coca Cola and Pepsi), significant revenue could be expected. However, as with advertising, it is unlikely that product demonstrations could finance an entire launch.

3.10.4.3.4 Infrastructure

Potential customers interested in space product demonstrations will have requirements ranging from something as simple as a video of the product in space to something as complicated as performing a complex series of EVA operations. Any launch system would have to provide accommodations for both extremes, or limit the types of product demonstrations performed to be consistent with launch system capabilities. Something as extreme as requiring EVA operations could involve extreme crew safety and risk that would render the demonstration cost prohibitive. It is likely that revenues would be directly tied to the impacts and complexity placed upon the launch system, which would be minimized by design.

3.10.4.4 Prospective Users

As with space advertising, there are three types of potential customers: (1) enabling companies (e.g., Space Marketing, Inc.), who would aggressively focus on attracting companies to launch product demonstrations into space, (2) advertising agencies (e.g., Creative Artists Agency), who would examine space as one alternative for their customers, and (3) users (e.g., Coca Cola).

Space Marketing, Inc. (SMI) was also a very helpful contact in the area of product demonstrations. SMI has spent well over a year researching the market for the demonstration of commercial products on launch vehicles and has an extremely good feel for the overall market and its price points. As these demonstrations are also projected to be integrated into large advertising firms rather than directly to potential companies. The soft drink companies and several artists have been active in this area and show a desire to continue their involvement should an appropriate opportunity arise. Coca Cola has placed their specially developed soda can aboard both the space shuttle and MIR. The high-tech consumer product and auto industries also seem to be receptive to consider demonstrating their products in space.

3.10.4.5 CSTS Needs and Attributes

3.10.4.5.1 Transportation System Characteristics

Transportation systems characteristics could be as minimal as stowage of an autonomous demonstration as a secondary payload to as complex as the design of a payload destined for travel to other planetary bodies and return. The ground segment would be markedly different for each type mission, with the latter being the most complex. For the near term, it is unlikely that product demonstrations could finance an entire launch. As such, impacts to the transportation system would be minimized.

3.10.4.5.2 Ground Segment

With the exception of the design of an interplanetary landing and return vehicles (not justified solely by this market), any ground segment impacts to a potential launch system would be minimized by design.

3.10.4.5.3 User/Transportation Interfaces

Since it is unlikely that product demonstrations could finance an entire launch, impacts to the transportation system would be minimal. Some demonstrations could be as simple as a time sequenced event on-orbit to being as extensive as requiring significant crew interface or EVA, or a payload destined for travel to other planetary bodies and return. Each case has dramatically increased interface requirements.

3.10.4.5.4 Management and Policy

The fundamental restriction on the market for those products that require demonstration and return to Earth is the availability and frequency of transportation that can provide such a round-trip. The Russians have ELV-capsule combinations that can perform such tasks at much lower cost and higher frequency than can the U.S. shuttle. The development of a return capability probably could not be financed by users currently identified.

When EVA becomes a consideration, policies have to be developed to minimize the safety and risks that would be taken for this commercial venture. There would likely be significant reluctance from the astronaut/cosmonaut corps for the risks inherent in such an enterprise.

3.10.4.5.5 Improvements Over Current

Currently, no capability exists for simple, low-cost space product demonstrations. Commercial firms are unfamiliar with the costs and impacts of such a capability and how it could aid in the marketing or establishment of their product. The attempts made so far have been fairly simple and limited (e.g., Coca Cola), and a significant effort would be necessary to educate potential customers.

3.10.4.6 Business Opportunities

3.10.4.6.1 Cost Sensitivities

As with advertising, it is unlikely that product demonstrations could finance an entire launch. Product demonstrations and advertising will likely be integrated into a large promotional campaign. These campaigns may not have the potential to generate enough revenue to finance an entire launch, but depending on the complexity of the demonstration, they can be expected to contribute $3 million or more. As past examples of relatively simple demonstrations, commercial products such as paintings and compact discs have been flown up to the Russian MIR space station and returned to Earth for sale. The public was more than willing to pay substantially higher prices for these products than for their earthbound counterparts. As an example of a more complex demonstration, Coca Cola and Pepsi each developed special soda cans that were used to dispense their soft drinks aboard the U.S. space shuttle. Although these items have not been offered for sale to the commercial market, these commercial firms were willing to invest their own discretionary moneys to fund the development of these products.

The primary restriction on the market for those products that require demonstration and return to Earth is the availability and frequency of transportation that can provide such a round-trip. The Russians have ELV-capsule combinations that can perform such tasks at a much lower cost and higher frequency than can the U.S. shuttle. On the other hand, if it were relatively easy and inexpensive to perform such tasks, the value of these items may be dramatically reduced.

Figure 3.10.4.6-1 shows the potential revenue by year that could be generated through the sale of product demonstrations using today's vehicles. This chart encompasses all types of product demonstrations from orbital to planetary missions.

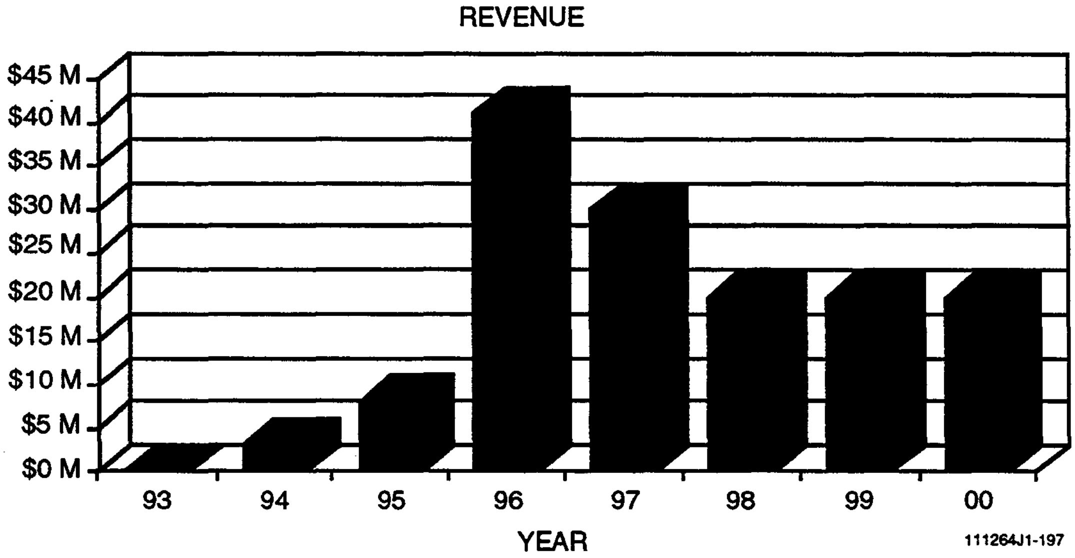

Figure 3.10.4.6-1. Yearly Revenue Through Sales of Space Product Demonstrations

Figure 3.10.4.6-2 shows the dispersion of product demonstration opportunities by the price. For instance, there appears to be approximately 21 potential payloads for which the demonstration complexity would require a price of $100,000 per payload whereas there is only a single payload where the complexity of the mission would require a price of $50 million and the customer would be willing to pay that price. The bars show the total revenues that could be generated by each class of demonstration.

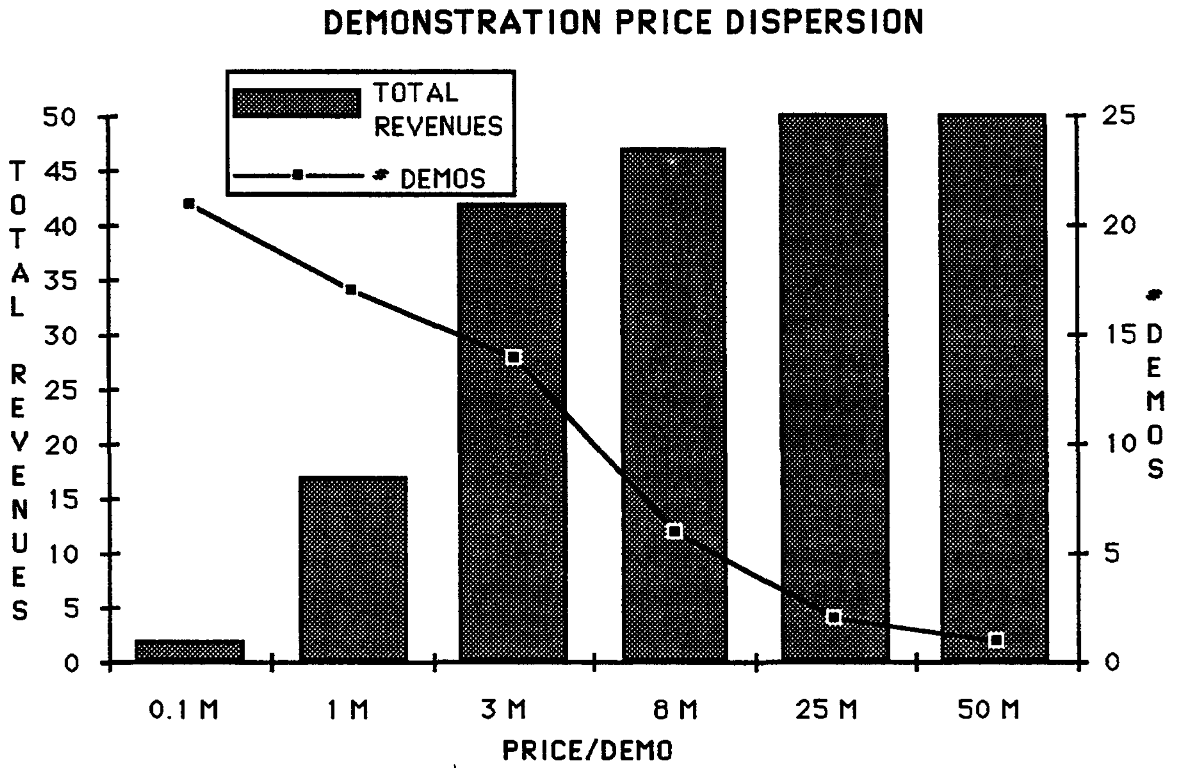

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Figure 3.10.4.6-2. Distribution of Space Product Demonstrations

Figure 3.10.4.6-3 shows the sensitivity to price per pound for varying levels of mission complexity ranging from missions that would command a price of $100,000 per demonstration to missions that would command a price of $50 million per demonstration.

3.10.4.6.2 Programmatics

Key issues that restrict current product demonstration activities are both the lack of opportunities for transportation to space and the lack of a capability to return items to Earth. Perhaps a vehicle such as a single-stage-to-orbit could satisfy these requirements. A return capsule that could de-orbit payloads launched on expendable launch vehicles could also perform this function. In the near term, impacts to interfaces and procedures would have to be minimized.

Additionally, the commercialism of space seems to have a questionable morality in the eyes of some people. This needs to be addressed before large commercial firms will risk their corporate image.

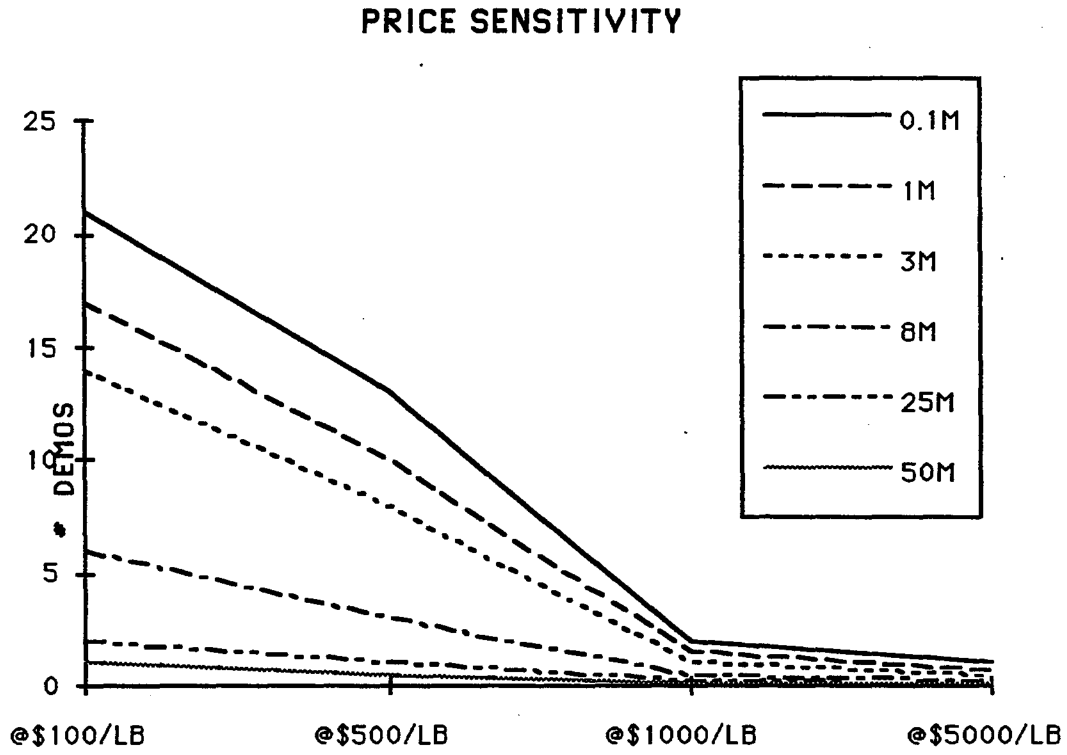

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Figure 3.10.4.6-3. Sensitivity of Sales to Launch Price Per Pound

3.10.4.7 Conclusions and Recommendations

The ability to demonstrate commercial products on orbit has existed since the early 1980s with the initiation of several commercial launch vehicle companies. However, most commercial manufacturers have not been informed of the potential opportunities and therefore have not pursued such avenues. The response we received from the majority of companies that were contacted was one of surprise that such capabilities existed, with their immediate concern being cost. There was a general indication that costs were significantly lower than they had expected; still high, but potentially manageable.

In general, demonstrating most products on orbit serves little, if any, technical purpose. The companies considering such a demonstration felt the use of their products on orbit provided them technical credibility and further added a feeling of toughness and reliability.

Demonstrating the product may be as simple as a video of the product in the desired space atmosphere or as complicated as performing a complex series of operations requiring human interaction and involving EVA. The soft drink companies and high-tech consumer product and auto industries seem to be receptive as do several artists. These customers may not have the potential to generate enough revenue to finance an entire launch, but depending on the complexity of the demonstration, they can be expected to contribute $3 million or more.

Key issues that restrict current product demonstration activities are both the lack of opportunities for transportation to space and the lack of an ability to return items to Earth. Perhaps a vehicle such as a single-stage-to-orbit or a return capsule that could de-orbit payloads launched on ELVs could satisfy these requirements. The development of a return capability probably could not be financed by users currently identified.

This market is not large enough to justify the development of a launch vehicle on its own. It could be anticipated that revenues of $3 million per launch could be realized with minimal impact to the launch system.

3.10.5 Space Burial

3.10.5.1 Introduction/Statement of Problem

In 1985 the Transportation Department granted mission approval for preliminary plans of Space Services, Inc. (SSI) to carry cremated human remains into space in 1986 or early 1987. SSI, whose president was former astronaut Donald K. "Deke" Slayton, developed the Conestoga booster as a commercial space venture. The launches were to be contracted for by the Celestis Group of Melbourne, Florida, a consortium of morticians and former KSC contractor engineers.

No cremains have as yet been sent into space by this group or any other. Celestis is waiting for SSI to begin regular launches before it reorganizes and starts taking orders.

3.10.5.2 Study Approach

The data for this market study was primarily obtained from published articles written in the mid-1980s and interviews with people involved in the project. SSI was bought by EER Systems after 1987 and started focusing on NASA programs. Contact was made with former SSI employees who identified people involved in the original space burial program. These individuals in turn led to contact with the Celestis Group.

After researching the published history of this project and having phone discussions with the principals, it was discovered that this market has the potential for purchasing multiple dedicated launches on an annual basis indefinitely. The nature of the payload and its requirements also make it a good candidate for piggyback payloads that could be included when excess payload capacity is available to help defray the costs of a nondedicated launch.

3.10.5.3 Market Description

The market for space burial is based on a variety of emotional desires as is most of the funeral industry. Burial in space is a modern day extension of burial at sea and probably appeals to the same type of person. A sense of permanence is achieved not by a stone monument but by essentially endless travel over an infinite distance. Space burial appeals to fans of the world's space programs, science fiction, and high technology in general. It also can be marketed as an environmentally clean method that doesn't take up dwindling real estate or pollute the ocean.

3.10.5.3.1 Market Evaluation

The research and experience of Celestis during their initial startup indicates that there is a substantial market for this service that should grow even as it becomes less of a novelty and more of a routine service. After the news broke that SSI had received permission to plan a launch, both SSI and Celestis received, and continue to receive, thousands of requests from all over the world to sign up for the plan.

All of this demonstrated interest in space burial has occurred with an expected cost per burial of over $3,000. The Conestoga 2's expected cost to low earth orbit is $10,000 per pound. The cost for an earth escape trajectory is

$50,000 per pound. All of the people contacted thought that reducing the cost per burial would significantly increase the market. The last quoted cost of $3,900 was more expensive than the cheapest cremation, but is competitive with low end embalming and casket burial. This figure includes a $700 fee for processing and recremating a three to four pound set of standard cremains down to 0.25 ounces.

If a new commercial launch vehicle would lower launch costs to less than $1,000 per pound, space burial could become cheaper than almost any traditional cremated remains memorial. Cremation, all by itself without any memorial service, costs between $350 and $1,250. The lower cost cremations are done by cremation societies such as the Neptune Society. The higher cost cremations are performed at the more elaborate funeral homes. Ground urn burial averages $1,000, depending on the size and type of marker. A wall niche in a mausoleum starts at $5,000. The nationwide average funeral cost for burial in an 18-gallon steel casket is $6,500.

An additional market segment that is harder to estimate, but is still expected to be substantial is the "at need" market. These potential customers are families who have cremated a family member, but haven't disposed of the ashes in a permanent fashion. In this country alone there are thousands of unclaimed remains in funeral-home storage rooms. Part of the difficulty is the increasing environmental restrictions, even for scattering at sea. Scattering over land is illegal in several states and most big cities. Space burial may appeal to families of recently deceased who were known to be interested in the space program or science fiction.

3.10.5.3.2 Space Application Description

The following technical description is based solely on the work that was done in the mid-1980s by Celestis, Inc., and Space Services, Inc. Since then, SSI has been bought by EER Systems and Celestis has essentially shut down because of lack of funds to maintain it while waiting for the Conestoga to begin launching regularly. Celestis was also hampered by Florida state regulations governing the funeral industry. These problems will be discussed in the Management and Policy section (sec. 3.10.5.5.4).

The process starts when a normal set of cremains are received and placed in a higher temperature retort until the ashes are reduced to 0.25 ounces. The refined cremains are then loaded into individually labeled capsules and placed in secure storage until enough capsules are processed for another launch.

Celestis asked potential customers if there was a specific time limit desired for the amount of time between delivery of ashes and launch. None was ever identified. In fact, there are deceased who have indicated in their wills that they wish their ashes to be launched as soon as the service becomes available.

Each loaded capsule weighs 0.5 ounces and a fully loaded Celestis-Conestoga spacecraft is designed to carry 10,330 capsules. Total weight is 350 pounds with a 32-inch height and a 24-inch diameter. The configuration is shown in figure 3.10.5.3-1.

The remains are not spread across space or released in any manner. The cylinders are labeled with name, religious symbol of choice, and identifying data to verify that they are not being illegally mixed together. The payload carrier is permanently welded shut prior to being stacked on the erect Conestoga. This capsule was to have a highly reflective exterior coating to make it visible from the ground with the aid of small telescopes or binoculars. This may be changed because of astronomer concerns.

A reflective coating was planned for the first vehicle because it was an orbital mission. Escape trajectory flights were being considered for subsequent missions because of the protests from astronomers after DOT permission was announced. An especially bright satellite passing through the field of view of a telescope with a digital camera can disturb measurements as well as cause streaks on the photograph.

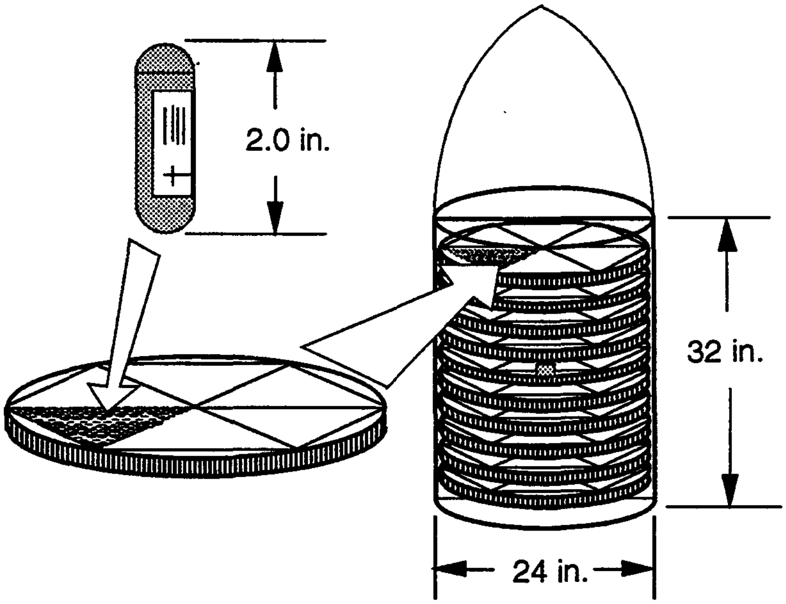

Figure 3.10.5.3-1. The individually labeled cremains capsules are placed in 10 separate trays.

3.10.5.3.3 Market Assessment

Preliminary discussions with some of the people involved in Celestis, and the old SSI, indicate that the biggest market probably will be the foreign market. Cremation is much more common in Europe and Japan than in the United States. Figure 3.10.5.3-2 indicates the size of that difference. Rates have increased since then and continue to do so. The percentage in the United States is expected to grow to 30% by the year 2000 as the cost of traditional burial gets more prohibitive and the population becomes more environmentally conscious.

The Japanese market appears to have the greatest potential for immediate success. Several major Japanese corporations and the Japanese government made official contact with Celestis concerning this project. The Japanese are very receptive to innovation and have a calmer approach to death than most Westerners.

The fact that the vast majority of Japanese are Buddhist lends itself to space burial of ashes. In addition to advocating cremation, the Buddhist religion has a tradition of separating ashes, sending portions to different relatives, friends, shrines, etc. A small portion could be sent into space without the cost of recremation.

Japanese interest in the concept resulted in Celestis being interviewed and featured on various Japanese television programs. In fact, Celestis has been featured on BBC-TV, German, and Norwegian television as well. In the United States, it was a show topic for Beyond 2000 on the Discovery Network.

The size of this market is large enough to where even very small market shares can result in substantial annual business. A market share of 1/2% of only the countries listed, at a launch fee of $3,000 per cremain, results in almost $150 million in annual sales. The market will increase along with the world's population and the spread of wealth to former Third World countries.

Nation/Region	Rate	Population	Cremations
Scandinavia	85 %	22.5 M	191.3 K
Germany	65 %	77.7 M	505.1 K
Great Britain	75 %	56.3 M	422.3 K
Spain	20 %	38.7 M	77.4 K
Italy	20 %	57.2 M	114.4 K
France	25 %	55.4 M	138.5 K
Soviet Union	50 %	280.1 M	1,400.5 K
Australia	65 %	16.0 M	104.0 K
Japan	90 %	121.5 M	1,093.5 K
China	50 %	1,052.5 M	5,262.5 K
Canada	25 %	25.6 M	64.0 K
United States	20 %	241.6 M	483.2 K
		TOTAL	*9.86 M*

(Assuming a typical 1% mortality rate.)

Figure 3.10.5.3-2. Annual Cremation Rates in Some Major Industrialized Nations (1985)

3.10.5.3.4 Infrastructure

Space burial companies in the future will deal directly with the public, without any connection to funeral homes. This significantly reduces the amount of regulation and state board involvement because the launch would be legally just another transportation service.

All transactions prior to launch can be handled by mail. The post office allows cremains to be sent as normal mail. Special shipping containers would be sent to friends or relatives of the deceased to be returned for processing. The capsule would be shipped to the vehicle launch processing site after enough cremains are received. Videotapes of the launch and trajectory data would be sent to the surviving families as proof of delivery.

3.10.5.4 Prospective Users

The following persons were involved in the original space burial project for SSI and/or are currently part of the Celestis Group. The literature search indicated that there were other organizations interested in the business, but none of them were as committed as SSI and Celestis.

a. Jack Koletty of EER Systems, Space Services Division, Washington, D.C., formally of SSI.
b. Mark Daniels of EER Systems, Space Services Division, Washington, D.C., formally of SSI.
c. Walt Paneano, formally SSI public relations coordinator.
d. Charlie Schafer of C-SAT, Washington, D.C., formally of SSI.
e. John Cherry of Fountainhead Mortuary, Palm Bay, Florida founder of Celestis.
f. Chan Tysor of Houston, Texas, current legal counsel for Celestis.

The majority of the data presented in this report was obtained from John R. Cherry.

3.10.5.5 CSTS Needs and Attributes

The market for space burial already exists. The main thing that is required to capture the market is an organization with reliable access to space. The launch provider must take the concept seriously and partner itself with someone in the funeral industry. The biggest attribute that will cause the market to grow is the publicity of successful launches. Advertising and competitive pricing will also increase the market, but the biggest driver will be the knowledge that it is a viable and respectable option in the near and distant future.

3.10.5.5.1 Transportation System Characteristics

The only technical data developed so far has been based on using a Conestoga 2 launch vehicle to place the remains in a 1,900-mile high circular orbit. This orbit, which is within the Van Allen belt, was chosen so as to minimize the orbital debris risk to other satellites. The radiation in the Van Allen belt is severe enough to damage electronics so it is an orbital altitude not normally used. It also is a high enough orbit to eliminate reentry concerns. The spacecraft is expected to remain in orbit for 63 million years.

Each Conestoga launch was expected to cost Celestis $15 million. At that rate 5,000 separate remains would be required on each flight at $3,000 each in order to break even. The Conestoga 2 can deliver 1,500 pounds to low earth orbit, but that drops to about 300 pounds for a 1,900-mile circular orbit or an Earth escape trajectory.

A possible option for Earth escape missions would be to use the Conestoga 4 vehicle, which can deliver 900 pounds beyond the moon. The complexity of escape trajectory missions should be similar to orbital missions using the same booster because there is no significant increase in accuracy or deep space tracking required.

3.10.5.5.2 Ground Segment

The ground segment of a space burial enterprise should only consist of a facility for receiving cremains, processing, storing, and encapsulating them in the spacecraft. Normal cremation reduces the human body to 3 to 4 pounds of ash, too much weight and volume for the number of cremains required for each launch. Celestis developed a technique to recremate the ashes, significantly reducing the weight and volume so that they can be packed into a 5/8-inch diameter by 2-inch long capsule.

Ashes that are to be recremated are placed in a small retort that burns a special gas mixture. The much higher temperature further reduces the ashes to their very base elements. These reduced cremains are then loaded into individually labeled capsules and placed in loading trays in secure storage until enough capsules are processed for another launch. Each loaded capsule weighs 0.5 ounces and a fully loaded Celestis-Conestoga spacecraft is designed to carry 10,330 capsules.

3.10.5.5.3 User/Transportation Interfaces

Technically, ashes are probably the easiest payload one can imagine to launch into space. They don't require any power, telemetry, cooling or heating, electromagnetic or acoustic shielding, clean room installation, or final inspection. The only structural requirement is that the capsule doesn't melt or burst during ascent. In a dedicated mission, internal packaging could completely collapse and it wouldn't effect mission success.

The only flight data that might be required is radar tracking of the trajectory. This information would assure relatives that the capsules were delivered as advertised and would eliminate fears that they might reenter the Earth's atmosphere or be a hazard to satellites.

3.10.5.5.4 Management and Policy

The issue that kept Celestis from actually offering this service on a nationwide basis was not a technical or marketing problem, but a Florida state law that governed the local funeral industry. That law forces any company selling future burial contracts to place the money in a trust with a very limited percentage allowed for operating expenses prior to the actual burial. This works for a cemetery that only requires minor grounds keeping but limits access to rocket launch providers who want and need money up front.

Celestis tried to convince the state that they were only a transportation service. However, the mortuary industry in Florida has, not surprisingly, a very strong lobby and they want to restrict cremation as much as possible. Caskets, tombstones, and family mausoleums are much more profitable. Celestis is currently trying to find a state to incorporate in that has more lenient preneed contract entrustment laws. The United States is the only country that has this type of funeral industry regulation.

This issue is significant due to the modern nature of the funeral industry. Preneed contracts are the most rapidly growing part of the industry. Nationally they account for 50% to 60% of all business, and that percentage is growing. In Florida it is over 90%. The contracts are insured by individual states and the funeral industry as a group. Nearly bankrupt funeral homes or cemeteries are quietly purchased by conglomerates and their preneed contracts honored to maintain the integrity of the business as a whole.

Entrustment laws pose a much smaller problem if a commercial launch service is developed that has the financial resources to await payment until immediately before or after launch. The national average time period between purchase of a preneed contract and customer death is 7 to 10 years.

If cremains are launched as a secondary payload, issues that have to be resolved include compatibility and liability to the primary payload. If the cremains carrier is a passive system attached to the upper stage this shouldn't be a problem. If the burial spacecraft is actively jettisoned or requires the upper stage to perform additional maneuvers, then it may pose a risk to the primary payload.

3.10.5.5.5 Improvements Over Current

Space burial is a commercial venture that can be done by almost every existing launch vehicle. The difficulty is not technical, but is primarily a matter of public image. The organizations that control the world's launch vehicles strive to impress potential customers and/or the general public with their technical genius. They do not want to risk public ridicule by agreeing to launch human remains without the assurance that it will be very profitable.

This problem should be reduced for a new launch system that is designed from the start for commercial payloads. Cost per launch will be more important than image, and any commercial payload or piggyback payload that helps to offset the cost of the system will be valuable.

The nature of ashes makes it a good piggyback payload. Its very low density and totally benign characteristics when completely sealed means that large numbers could be easily added to the manifest of a deep space mission. They would simply remain with the upper stage that separated from the primary payload if the stage had an acceptable post separation orbit. The amount of revenue they could generate (Celestis estimates approximately $100,000 per pound) is significant.

3.10.5.6 Business Opportunities

Business opportunities for space have always been based on delivering one, or a very few, high value payloads on each launch. The payloads are fragile and expensive machinery that have to survive the very extreme environment of space, perform a usually complex operation, and then transmit information about that function back to earth. A space burial payload has the exact opposite characteristics.

A space burial payload is not a single high-cost payload, but is many low-cost payloads combined to pay for each launch. The payload is very robust, virtually unaffected by the space environment, and has no mechanical, chemical, or electrical function it has to perform. In fact, it doesn't communicate or interface with the Earth again after it is launched. A space burial mission is successful if the launch is successful, and that simplicity enhances the chances for long-term profitability.

3.10.5.6.1 Cost Sensitivities

Figure 3.10.5.6-1 is an estimate by Celestis as to how cost might affect the market. The chart indicates that there is significant interest at current launch costs. Any reduction should create additional interest. The rapid increase in mass delivered as cost per pound is reduced by two orders of magnitude assumes that a large part of the market would want a larger amount of ashes or even DNA samples sent into space.

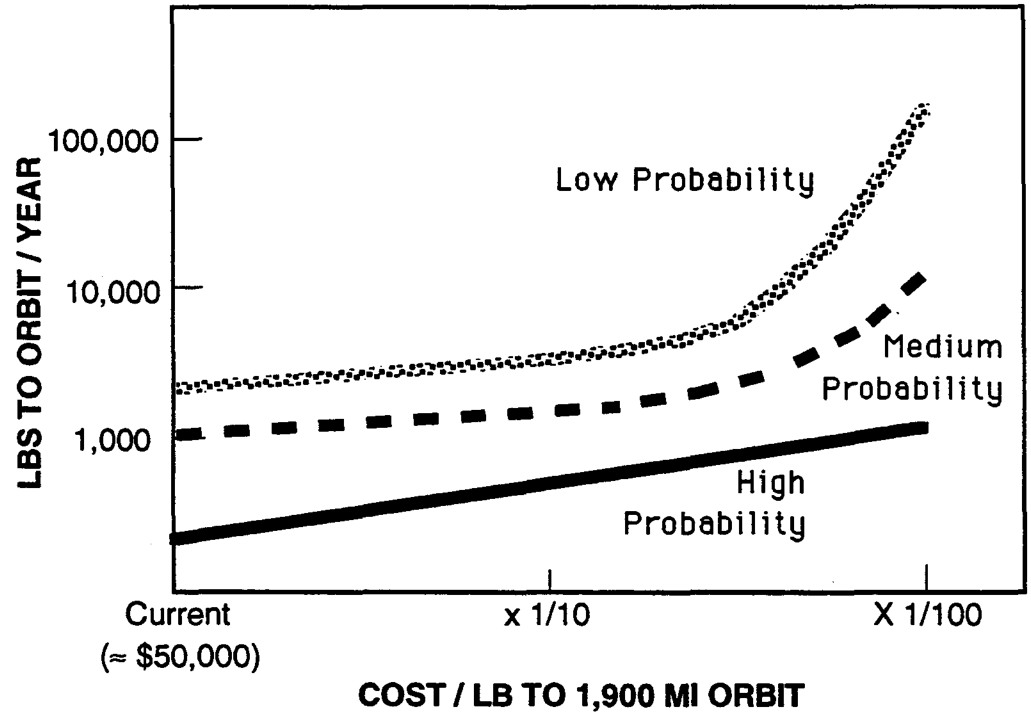

Figure 3.10.5.6-1. Estimate of Market Size as a Function of Cost per Pound to Orbit

Current launch costs per pound are so high that any reasonably priced space burial requires that a normal 3 to 4 pound set of cremains be divided up or recremated to a much smaller mass. Celestis believes that this additional reduction of a loved ones remains is distasteful to some potential customers. If the cost per pound into orbit is reduced by two orders of magnitude, recremation would not be required for every customer. It is estimated that this option would double the market for space burial.

3.10.5.6.2 Programmatics

There is no fixed schedule necessary to make this market viable. When it becomes easily available and a few missions prove that it is relatively reliable, it should become a self-perpetuating industry. To take advantage of the free worldwide publicity that a successful mission will generate, a system for taking orders and processing ashes promptly needs to be in place before the first launch. Advertising will be necessary to inform potential customers of the availability of the service and how it works.

3.10.5.7 Conclusions and Recommendations

Recorded public response to just the concept of space burial seems to indicate that there is a significant market for this service in the industrialized world. The technical difficulties are almost insignificant if a reliable launch system is available. The legal and logistical difficulties should be easy to overcome if a major space organization decides to pursue and/or endorse the business. The most difficult part will be to get that initial endorsement prior to going public and taking paid orders.

4.0 Conclusions and Recommendations

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 BUSINESS ANALYSIS

The objective of the business analysis was to develop decision criteria based on the target markets, the business risks, and the potential of realizing a return on the investment. The analysis was initially intended to show the return on investment (ROI) of a CSTS that was developed from a purely commercial standpoint. However, rather than focusing upon the financial viability of a specific concept, this analysis concentrated on developing a bounding set of parametric conditions with regard to the financial feasibility of any commercial system.

4.1.1 Methodology

Through the use of the market survey results and from the market capture analysis, an estimate of the vehicle flight rates and average annual revenues was calculated for transportation systems of differing payload capabilities and launch prices (fig. 4.1.1-1). Given these data, and using commonly agreed-to financial guidelines, the profit required per flight was determined for differing levels of initial investments. Differing mechanisms of investment risk mitigation to achieve these financial conditions were explored.

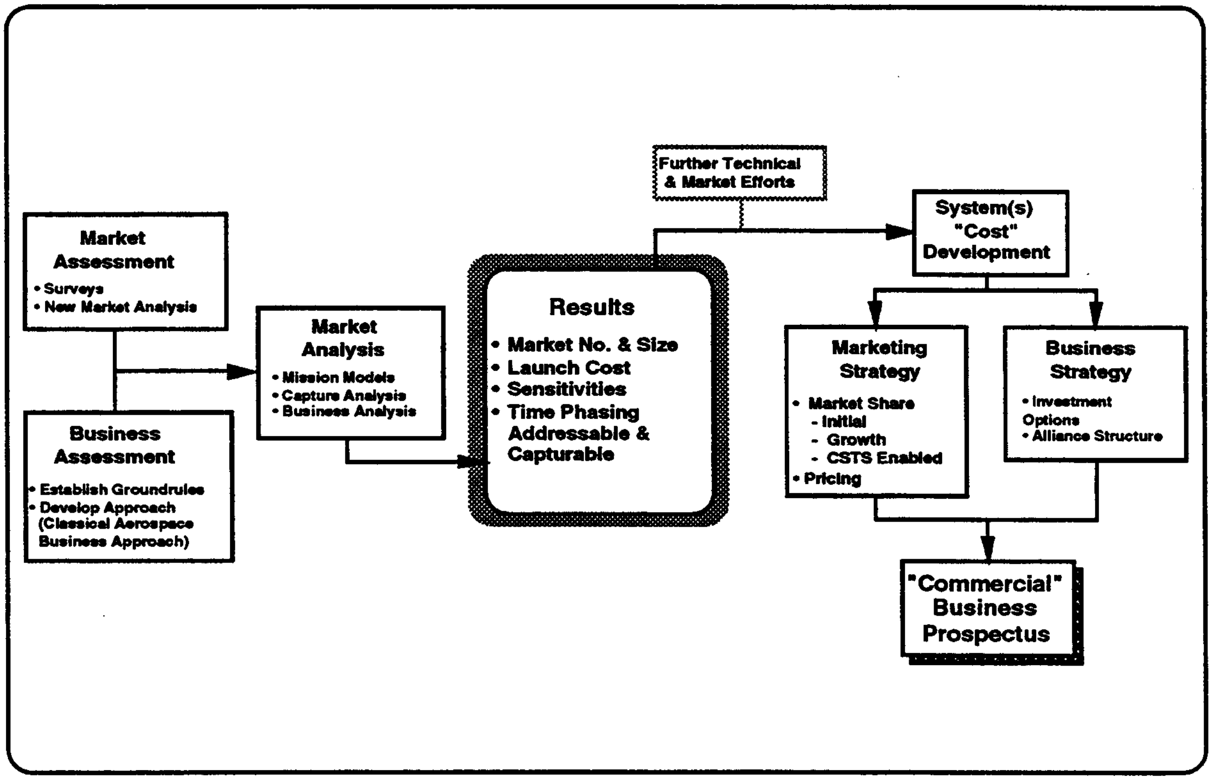

Figure 4.1.1-1. Business Analysis Methodology

4.1.2 Assumptions

Some basic guidelines were needed for the business analysis for the CSTS. It was assumed that the nonrecurring investments required to bring a CSTS to an initial operational point of readiness would be complete in 5 years from program go-ahead. This time span would allow for any required design and engineering, prototyping, testing, facility development, and initial production. The total funding required for the development was spread as follows: 10% in the first year, 20% in the second year, 30% in the third and fourth years, and 10% in the fifth year. The mission model assumed a 3-year ramp to the steady-state demand level with a 25% capture in the first year of operation, a 50% the second year, and a 100% capture in the third and subsequent years. The maximum allowable period over which to recover the investment was set at 10 years.

Other significant assumptions involved the time-value of money and the tax implications for a CSTS. Constant-year 1993 dollars were used in order to allow the analysis to ignore the effects of inflation. The cost of capital was assumed to be fixed at 8% per year. Tangible assets of the CSTS would be depreciated over a 7-year period beginning with the first year of operation. The marginal Federal tax rate was assumed to be fixed at 34%.

4.1.3 Results

Under current conditions, the space transportation market is considerably different from nonspace commercial markets. Launch infrastructure, principal launch assets, and manufacturing facilities are under the control of various branches of the U.S. government. The market is predominately determined by governmental budgets. This places a large element of market risk due to the uncertainties of annual appropriations. Transitioning to a market that is predominately commercial requires the development of new markets and a major cultural change in the ways of doing business in space.

Private investment in space transportation can only be a feasible venture if the investors can be repaid. One measure of success is the internal rate of return (IRR). An IRR of 15% to 25% over the first 10 years of operations has been selected as the target value to evaluate commercial feasibility. The revenues from each flight, based upon the payload capability and the price per flight, must be balanced against the recurring cost charged to that flight, repayment of the investment debt incurred in constructing the system, and some amount of return to the commercial investors. Figure 4.1.3-1 shows the minimum average annual revenues derived from the mission capture model for the medium-probability model.

Figure 4.1.3-2 shows the results from a hypothetical $5B investment scenario. The figure shows the payback cash flow per flight required to satisfy the IRR goal. It also shows the expected flight rates from the mission capture analysis at different launch prices and vehicle payload capabilities. As an illustration from the figure, a vehicle with 30,000 lb payload capability in the medium-probability model, and priced at $1000/lb pound will capture 38 flights per year. This system must achieve a payback cash flow of about $70 million per flight in order to service its debts and yield a 20% IRR after 10 years of operations. However, at $1000/lb, a 30,000-lb capability system can only achieve about $30 million in revenues, even before subtracting out recurring costs of operation. Obviously, it is not possible for such a system to be economically viable.

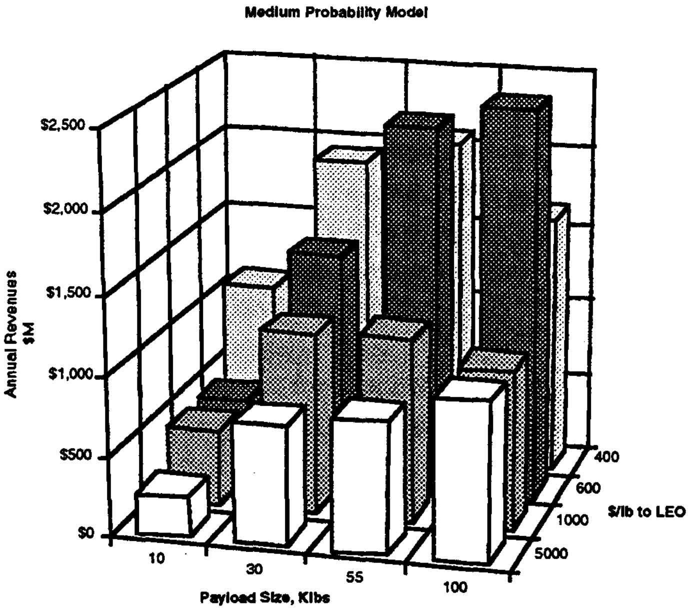

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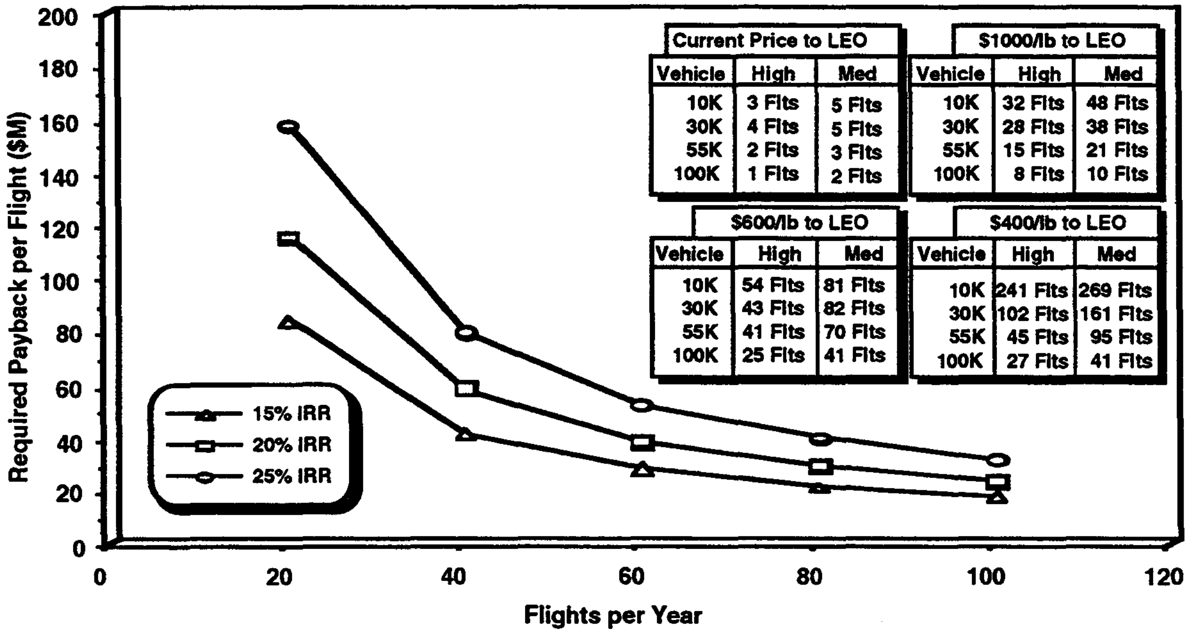
Figure 4.1.3-1. Minimum Revenue Potential for Medium Probability Model



Current Price to LEO		
Vehicle	High	Med
10K	3 Flts	5 Flts
30K	4 Flts	5 Flts
55K	2 Flts	3 Flts
100K	1 Flts	2 Flts

$1000/lb to LEO		
Vehicle	High	Med
10K	32 Flts	48 Flts
30K	28 Flts	38 Flts
55K	15 Flts	21 Flts
100K	8 Flts	10 Flts

$600/lb to LEO		
Vehicle	High	Med
10K	54 Flts	81 Flts
30K	43 Flts	82 Flts
55K	41 Flts	70 Flts
100K	25 Flts	41 Flts

$400/lb to LEO		
Vehicle	High	Med
10K	241 Flts	269 Flts
30K	102 Flts	161 Flts
55K	45 Flts	95 Flts
100K	27 Flts	41 Flts

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Figure 4.1.3-2. Payback per Flight Required With a $5 Billion Investment

Another example, using a vehicle with 55,000-lb payload capability priced at $600/lb, can capture 70 flights per year. It must achieve a payback cash flow of about $35 million per flight in order to service its debts and yield a 20% IRR after 10 years of operations. At a price of $600/lb, the 55,000-lb capability system can achieve about $33 million in revenues per flight. This case shows that if investors were able to accept a reduced IRR it might be possible to attain an economically viable payback.

The 70 flights per year of the 55,000-lb payload capability launch system priced at $600 per pound can generate about $2,310 million in annual revenues. From this annual revenue, the operating costs must be subtracted to determine the annual payback cash flow. Figure 4.1.3-3 can be used to illustrate how this level of payback cash flow can be used to show the maximum possible investment. If annual operating costs were zero, the $2,310 million annual payback cash flow would almost be sufficient to recover a $5,000 million investment at 20% IRR after 10 years of operation. However, if annual operating costs were one-half the transportation price charged, then only $1,200 million would be available for the payback cash flow. This would only allow an investment of about $2,500 at the 20% IRR. If the operating costs were higher, even smaller investments would be economically viable.

This market study did not address the cost of space launches, nor the technical requirements to achieve specific launch cost goals. However, this analysis indicates that as a commercial investment measured at standard industrial investment return levels, the investment cost for a new space launch system must be kept in the range of a few billions of dollars.

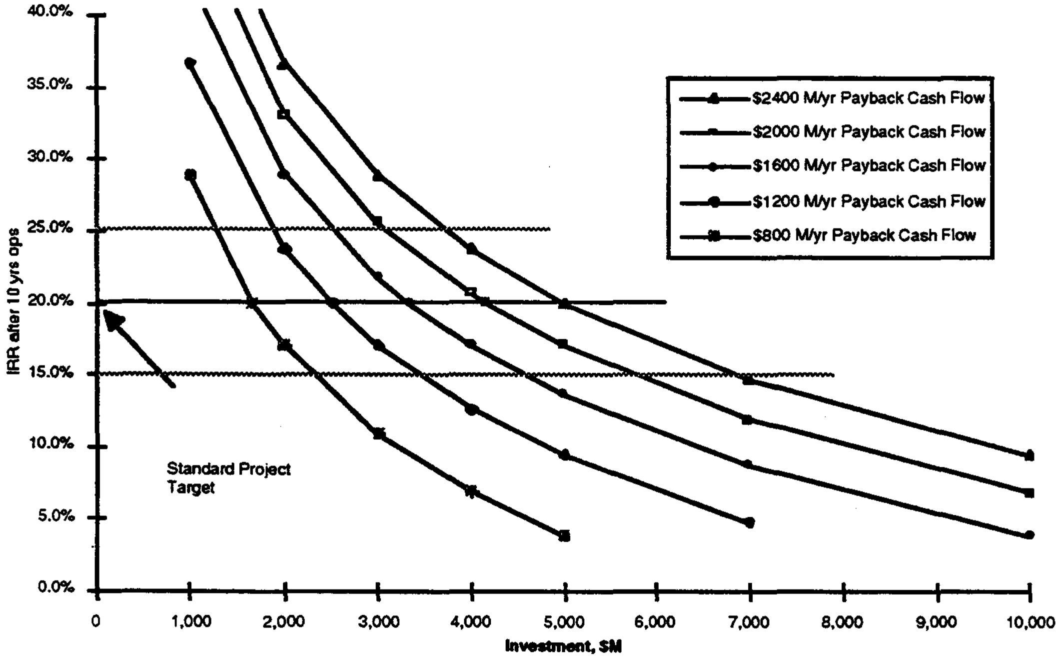

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Figure 4.1.3-3. IRR Sensitivities to Paybacks

This indicates a potential paradox in the commercial space transportation market. High flight rates appear to be necessary to reduce the price per flight. However, reduced price per flight reduces the revenue per flight, and consequently the cash flow available for investment payback.

We have not been able to prove the commercial space market elastic enough to enable the revenues per flight to be greater than the combined payback and operations costs per flight for a completely commercially developed system.

To attract commercial investment it appears that some level of government participation will be necessary. There are different options that can be considered for this, ranging from government development and commercial operation (which reduces the investment cost), to market and loan guarantees (which reduce the uncertainty in the revenues). Other options including corporate tax incentive and innovative financial arrangements may also be considered. Some of these investment options are outlined in figure 4.1.3-4, along with a brief discussion of the advantages and disadvantages of each option.

Non-Recurring Funding Option	Relative Advantages	Relative Disadvantages
Industry/Government Sharing	• Pooled Resources • Distributes Risk • Evolutionary Change in Industry Business Practices Required	• Dependent on Government Funding • Increased Organizational Complexity
Alliance Members Only	• Reduced Organizational Complexity • Moves Aerospace Industry Closer to a Commercial Environment • Bypasses Government Funding Constraints • Reduces Government's Risk	• Drastic Change in Industry's Practices & Culture Required • Places All Risk on Industry's Shoulders • Total Investment Reqts Exceed Industry Capabilities
Government Only	• Reduces Industry's Risk • No Change in Industry Business Practices Required	• Does Not Move the Industry Closer to Commercial Operations
Seek Investors from Outside of Alliance & Government	• Moves Aerospace Industry Closer to a Commercial Environment • Bypasses Government Funding Constraints • Distributes Risk	• Loss of Single Point Control of the Project

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Figure 4.1.3-4. Business/Investment Options

4.1.4 Summary

The business analysis for this initial phase of the CSTS has been used to define the economic thresholds associated with a commercially viable system. The CSTS specifically did not analyze the cost and technical constraints on a new space launch system. Parametric data relationships between investment and payback requirements indicates that a commercial space transportation system may be viable at low investment levels and higher launch rates. To achieve these demanding goals, it appears that joint government/industry investment into the development of this system will be required. There are many options yet to be examined for these investment and financial arrangements.

4.2 MARKET RESEARCH

The fidelity of the database must be refined to include more detail information on economic, technical, social, and legal issues and concerns for the most promising commercial markets. The added research should focus on increasing the confidence in the medium probability mission model, over the 2000 to 2030 time horizon, to accurately define the markets, their potential growth, the size of the markets available to a new commercial launch system, and the share that can be captured by the new launch system. For example, the hazardous waste disposal market requires assessing the major concerns about the disposal of nuclear waste in space. Additional study must identify and determine the credibility of social and legal issues, both pro and con, and the intent of responsible agencies, such as the Department of Energy, to consider a new launch system for nuclear waste disposal.

Our research disclosed that the startup of space launch activities in the most promising markets must be investigated in more depth and detail. Continuing research should focus on identifying the users and the business infrastructure in the emerging and new space markets. In both areas, more information must be collected on the key companies and the decision-makers who are or will be involved in using space. The infrastructure on how these companies will conduct commercial space business with the space launch and operations providers must be defined. The space manufacturing market, as an example, has a limited, fragmented infrastructure. Technical, operations, and contractual activities needed to purchase launches and the support required for successful space operations are not available. Similarly, new markets such as hazardous waste and space business parks have virtually no infrastructure to rely on for entering the commercial space market.

For emerging and new space market areas to realize their potential, more data are needed on the users' payload requirements, in terms of physical, environmental, and operational characteristics. These data must be interpreted and translated into launch system attributes that can be analyzed, consolidated, and categorized to assist the researchers in defining launch system requirements. Launch costs, as an example, must be one order lower than today's. Continuing research must assess the needs in terms of technology requirements.

More detailed data must be developed on the time-phasing plans for introduction of the commercial space products and services for the most promising markets. Indepth discussions will be needed with launch system customers to project the timing of their product/service introduction and the availability of a low-cost launch system.

Continuing market research must also examine the markets from a different perspective, one in which the operational mission requirements of several space markets are merged and translated into uniform requirements for a common launch system. For example, several markets have operational requirements indicating that a single launch vehicle design could uplift a substantial share of the mass to low Earth orbit at high inclination, polar, and geo-transfer orbits.

4.3 DEVELOP COMPREHENSIVE BUSINESS STRATEGY

A new space transportation system is dependent upon the ability to structure a business plan that shows a financially sound and realistically achievable venture. This plan must address three key elements to achieve this goal:

a. Financial.
b. Regulatory.
c. Alliance participation.

Financial. With the use of market information from the Phase I study, a detailed business strategy will be developed that addresses the financial and economic factors required to make this a profitable venture. Financing becomes a key driver, since development costs will be extremely high for a new space vehicle having significant improvements over current systems. Every avenue available will be reviewed/assessed and the results examined in detail by financial experts from all aspects of the business community before a final recommendation can be made. The following types of questions will need to be addressed:

a. What rate of return and payback period is required to obtain support from the financial markets?
b. Will initial niche markets be used to generate the revenue stream to finance subsequent market exploitation?
c. Will different pricing structures be employed for comanifested operations?

Regulatory. The role of Government in defining the liability laws, vehicle qualification and flight worthiness certification, and crew training/certification (if required) must be clearly defined/ interpreted.

Alliance Participation. The working relationships within the alliance must be aligned as necessary to ensure the most effective application of industry assets in developing the Phase II products (system concepts, technology development plans, etc.). This could possibly lead to the introduction of new business entities that are specifically chartered to perform this commercial business activity.

4.4 DEVELOPMENT OF TRANSPORTATION ARCHITECTURE AND SYSTEM CONCEPTS

The CSTS Phase I activity successfully predicted the demand elasticity for new and traditional space markets for the years 2000 to 2030. One of the primary objectives of Phase II will be to define a commercial launch system, composed of one or more vehicles, to maximize return on investment while meeting these market demands.

Our approach to conceptualizing the preferred CSTS transportation architecture leverages off three fundamental principles:

a. Concepts must support the CSTS business strategy as well as meet system requirements defined from Phase I market analysis.
b. Use of a two-step concept development process where lesser concepts can be screened prior to extensive design activities.
c. Conceptualization of an entire system, not just a vehicle, through allocation of cost, operability, and performance requirements.

Our process for concept development is shown in figure 4.4-1. CSTS will have established numerous business opportunities, or niches, that could be seized. Each business niche represents a potential market for CSTS and most likely will require a different launch system solution. For each business niche we will conceptually develop a number of potential solutions (a single system, family of vehicles, or a mixed fleet of differing systems), that capture all, or a portion, of the available market. These potential solutions will be screened to ensure that they meet the architectural requirements (individual customer needs, flight rate requirements, and preliminary cost targets).

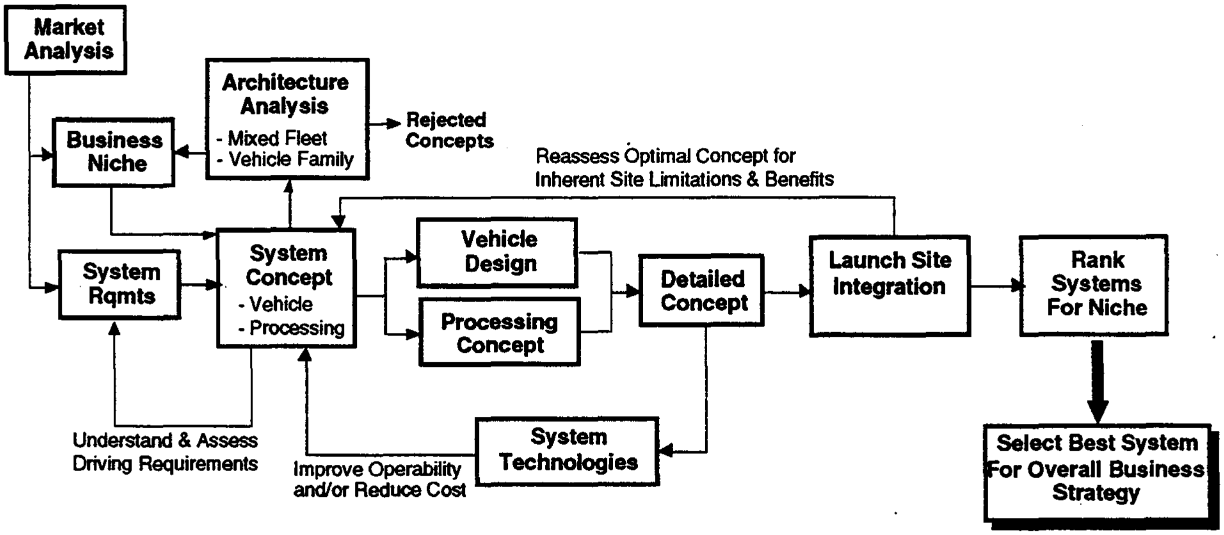


Figure 4.4-1. CSTS Transportation Architecture Analysis and Concept Development

The next step will be to develop the launch vehicle and ground processing concepts to a lower level of detail. The concepts will be designed to meet performance and other system attributes such as schedule leadtime, reliability, and availability. In addition, concepts will be optimized through integration of system technologies to meet the operational cost targets.

These solutions will then be ranked based on a number of criteria. The final step will be to examine the ranked solutions for each niche, and then select the system that maximizes the potential return. Special attention must be given to the process for building and operating the new system to cost. This will ensure that the business venture effectively meets the investment requirements and provides the most comprehensive understanding of the potential risks. This approach to conceptual design will keep the new commercial launch system focused upon the realization of a solid business venture.

4.5 ROLE OF A COMMERCIAL SPACE TRANSPORTATION SYSTEM

An important aspect of the study was the creation of a vision of space transportation's future. This vision can be divided into two distinct but interdependent elements. The first is the role the system would fill and the second is the projected evolution of the space marketplace. Together, these two constituents provide a definitive image of the alliance's perception of the future of space commercialization and the associated high-technology employment.

The evolution of space utilization into a new commercially motivated era is dependent upon the development of a modernistic commercial transportation system with a role that is diverse in nature, encompassing many aspects unfamiliar to the conservative culture pervasive in the U.S. space launch industry. The alliance's view of this new-fashioned role consists of the four fundamental elements shown in figure 4.5-1.

a. New Market Realization—As part of the study, a great deal of emphasis was placed on the evaluation of these market areas, and their potentials were found to be intriguing. The introduction of a new, low-cost launch system would enable the realization of these potential markets.

b. Competitiveness Improvement—The U.S. launch system industry dominated the international marketplace through the early 1980s. Foreign competition has steadily eroded the U.S. position, now capturing a 60% to

70% share of the commercial launch market. To regain the competitive edge, a new transportation system is required.

c. Launch Industry Rejuvenation—The development of a new commercial launch system accomplishes two objectives. First, the U.S. space industry would become less dependent on the Federal government for its continued existence and profitability. Second, it would enable the U.S. government to partially rely on commercial industry to maintain its technical and experience base in vital areas.

d. Public Benefits—A new space transportation system would provide tangible and intangible benefits to the general public. The development of new market areas would create new opportunities and capabilities, for example, space tourism. It would enhance productivity through the employment of space-based assets, such as communications and remote sensing. Additionally, the disposal of hazardous waste in space would enhance our management of the Earth's environment. Intangible benefits, with impacts difficult to predict, include increased public confidence in the space industry, resulting in increased public support for space-related endeavors, and the inspiration of society to accomplish even more difficult tasks, promoting the idea that almost anything is within our society's grasp.

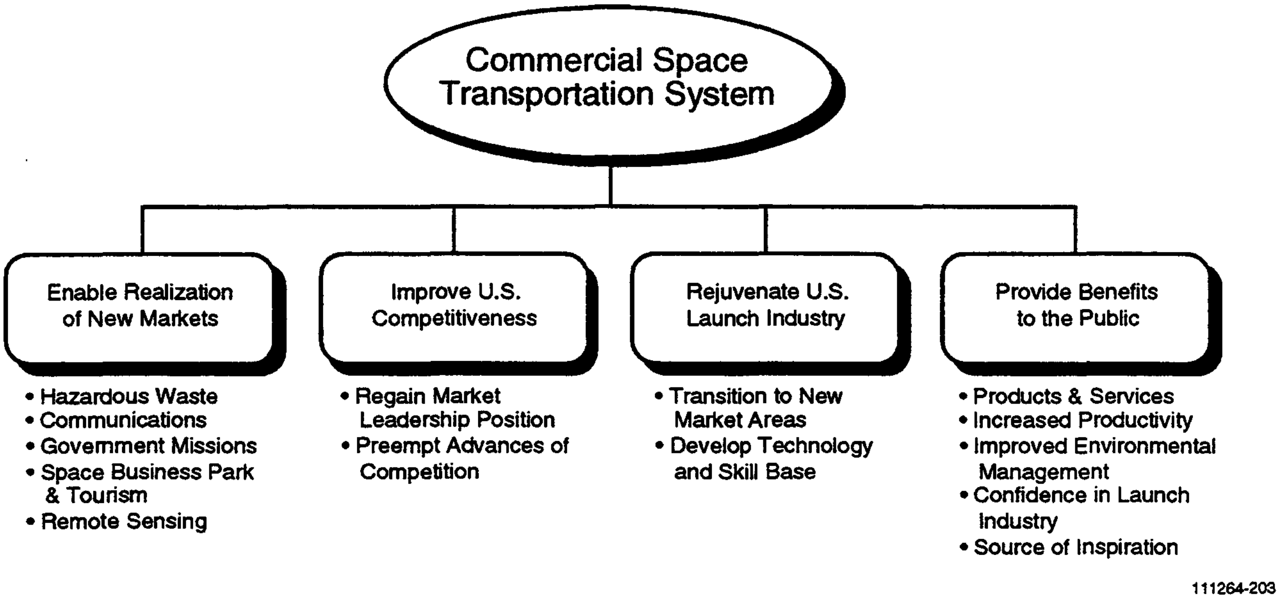


Figure 4.5-1. The Role of a New Commercial Space Transportation System

4.6 EVOLUTION OF THE SPACE MARKETPLACE

The second half of the study's vision is the foreseen evolution of the space marketplace. Figure 4.6-1 summarizes the high-level attributes of the current and projected future space marketplace. The current space industry is driven by the needs of the government and focuses on the requirements of its military and scientific communities. Launch system and spacecraft development efforts are funded almost exclusively by government agencies and are therefore captive to the politics associated with government-funded programs. Because of the specialized requirements of government agencies and the experimental attitude currently associated with space-related endeavors, the cost of doing business in space is high, for both transportation and operation. As a result, the public perceives space as a generally inaccessible resource, available only to government-sponsored programs.

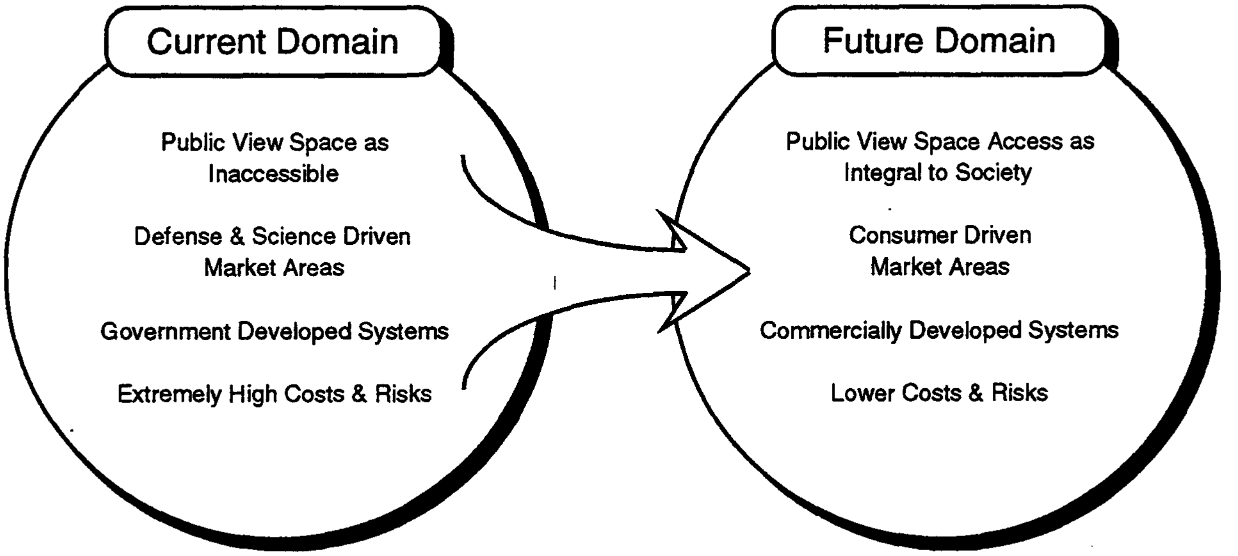


Figure 4.6-1. The Projected Evolution of the Space Marketplace

In 20 to 30 years, the alliance envisions space to be an entirely different enterprise. The alliance's underlying desire is for the public to view space as an integral and fundamental part of their existence, communicating globally, using products manufactured in space, vacationing at space-based amusement parks, etc. To attain this vision, changes to the culture underlying the space industry are necessary. The industry must evolve to commercial motivations and aspirations, including the commercial development of space. The government should not be the only source of revenue for space programs. The industry should eventually transition from a defense- and science-driven enterprise to be consumer driven. Lowering the cost of access to space is essential to the ultimate realization of this transformation and would be the top priority of the alliance.

Appendix A—
System Attributes and Requirements Overview

APPENDIX A SYSTEM ATTRIBUTES AND REQUIREMENTS OVERVIEW

A.1 INTRODUCTION

Early identification and definition of system attributes and requirements is essential to ensuring the transportation system meets the users' needs. This appendix contains the preliminary data base of these attributes and requirements which were identified during the market evaluation and analysis activities. This data base is essential for all concept development work.

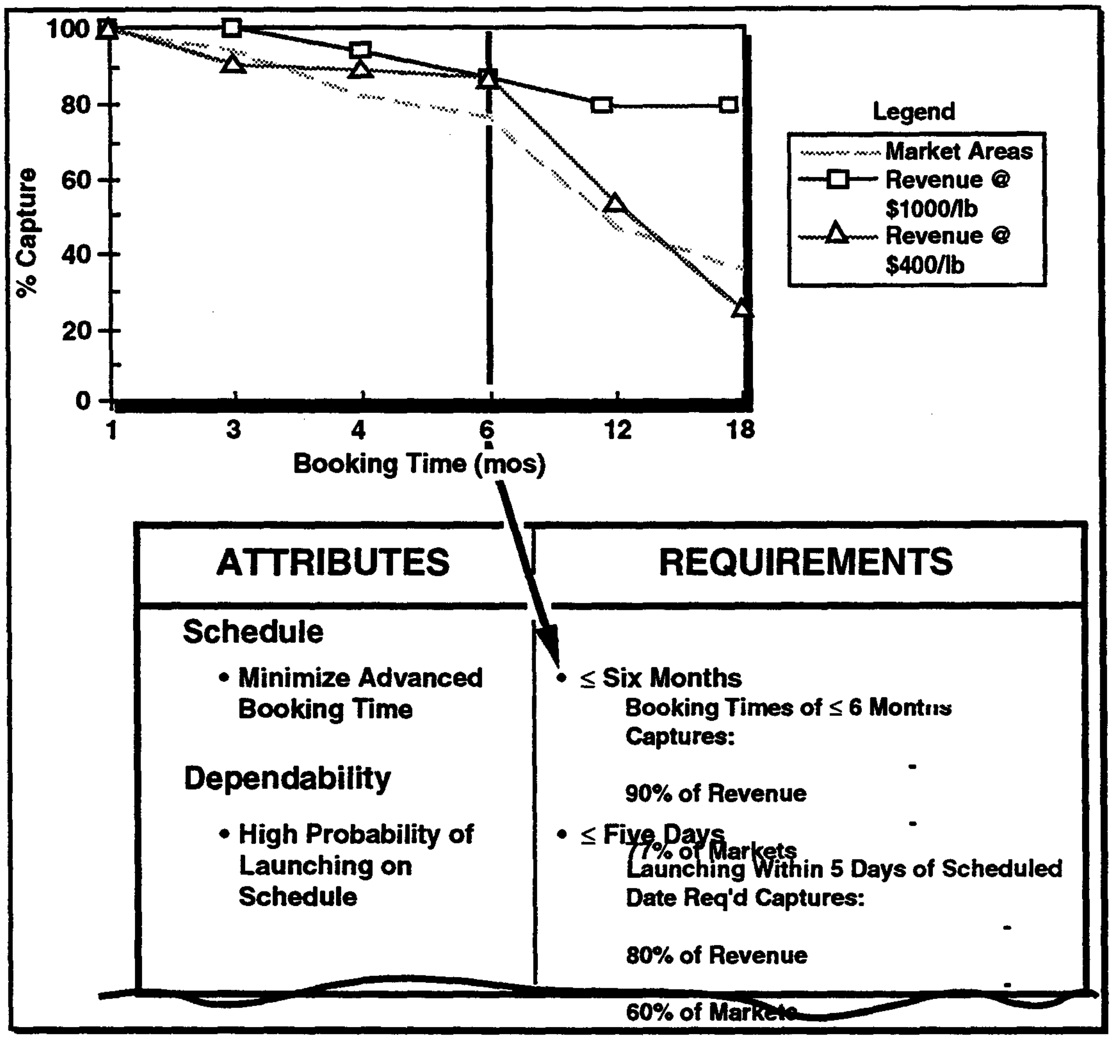
Key transportation attributes were derived based on data provided in each of the market areas. Theoretically, the goal is to provide a system which meets all of the attributes for all of the market areas. In practice this is often difficult because the users' needs may vary significantly. After reviewing the initial list of attributes it became evident that there was a core set of attributes which were common to many, or in some cases all, of the market areas. Some of the more common attributes are shown in figure A.1-1 below.

Category	Attribute
Dependability	High Probability of Launching on Schedule
Schedule	Minimum Advanced Booking Time
Reliability	≥ Current System
Cost	Minimum Cost Per Launch
Operations	Standardized and Simplified Payload Interfaces
Capabilities	Support Multiple Payload Classes Provide Delivery to Multiple Destinations Provide On-Orbit Rendezvous and Docking Capabilities Provide Delivery and Return Capabilities
Availability	High Probability System Will Be in An Operational Rather Than a Standdown State
Responsiveness	Minimum Response Time for Launching On Need

Figure A.1-1. Common CSTS Attributes

Ultimately the database information will be used to establish the system level requirements. We have developed an analysis process to evaluate differences in the quantified attributes and requirements. Our process allows us to make informed decisions when selecting the appropriate system level requirements. A preliminary example of the process is illustrated below using the booking time requirement.

The booking time requirement varied by market area and the values ranged from 1 month to 18 months. The potential range of values are plotted as shown in figure A.1-2 below. For each booking time value, we determine what percentage of the markets can be captured and what percentage of the revenue these markets represent. The percentage of revenue captured is based on the flight costs ($/lb). This figure shows that a system with a 6 month window captures 77% of the market areas and 90% of the potential revenue at both $1000/lb and $400/lb. The $400/lb system is very sensitive to booking times greater than 6 months. It is evident that a majority of the flights in the key market areas cannot tolerate longer booking times. Thus, 6 months appears to be a reasonable value for the initial system requirement.



ATTRIBUTES	REQUIREMENTS
Schedule • Minimize Advanced Booking Time	• ≤ Six Months Booking Times of ≤ 6 Months Captures: 90% of Revenue
Dependability • High Probability of Launching on Schedule	• ≤ Five Days 77% of Markets Launching Within 5 Days of Scheduled Date Req'd Captures: 80% of Revenue 60% of Markets

Figure A.1-2. CSTS Requirements Sensitivity Analysis

Basically, a preliminary attributes and requirement database has been established and will be utilized as a Point-of-Departure reference for further market, business, and technical evaluation activities. The database can be updated as revisions and modifications in the market evaluation become available.Commercial Space Transportation Study

A.2 Commercial Space Transportation Study Overview

Segment: 3.1 Communications
Market Area: 3.1.3 Fixed Satellite Services
Attributes:

Dependability	• High probability of launching on schedule
Responsiveness	• Minimal response time for launching on need (**Note:** Need to determine if launch on need is necessary)
Availability	• High probability that the system will be in an operational rather than a standdown state
Schedule	• Minimize advanced booking time • Maximize launch window size
Reliability	• Higher than current systems (US and foreign)
Cost	• Minimum cost per launch
Capabilities	• Multiple orbital delivery locations • Adaptable to market needs, with a clear growth path • GEO medium-large satellites
Operations	• Provide standardized user interfaces • User friendly launch site operations • Rapid payload changeout capability

Mission Requirements

GEO. The system shall have the capability of delivering a single payload weighing between 3,000 and 7,000 lbs into a GEO orbit(s) of **TBD** at inclination(s) of **TBD**.

System Requirements

Dependability. The system shall have a 90% **(TBR)** probability of conducting launches within 10 days of their scheduled dates. This includes external factors such as weather and internal factors such as production, assembly, and payload integration anomalies.

Launch on Need. The system shall not require more than 30 days between notification and launch for launch on need missions. (**Note:** Need to determine if LON applies to this market area.)

Availability. The system must maintain a system availability of at least 0.90, measured over the system life cycle. Availability is the fraction of time that a system is in an operational, rather than standdown state. Standdown time is associated with post-failure shutdowns, scheduled and unscheduled maintenance.

Mission Scheduling. Payloads can be scheduled for flight with 18 months notice.

Launch Window. The system shall maximize the payload launch windows. (TBD matrix will show inclination, destination (GEO), and window size)

Reliability. The system must deploy payloads to their intended mission orbits with a total success probability of at least 0.98. This includes reliability of the launch vehicle and the upper stage (if used).

System Growth. The system shall emphasize modularity to accommodate adaptability and growth to meet changing market needs.

Vehicle Requirements

Payload Volume. The system must accommodate payloads comparable to current volumes up to 2x current volumes (Note: Need to translate current volumes into length and diameter dimensions)

Payload Interface. The system shall provide **TBD** standardized payload interfaces with which the payloads must conform.

Operations Requirements

Launch Rate. The sytem must support an annual launch rate between 20 and 31 . (**Note:** This is extracted from December 93 Results. Assumes number of satellites equals the number of launches for the period 2005 to 2010. This needs to be verified.)

Payload Changeout Capability. To enhance system flexibility, the system must allow payload changeout (of the same payload) up to five days prior to launch and payload changeout (to a different payload) up to 30 days prior to launch. Payload replacement shall be completed within 5 days. Following the payload replacement, the launch system shall be at the same number of days before launch as when the payload change notification was received.

Payload Integration. Payload integration must be greatly simplified in comparison to current operations. This refers to the difficulty of the operations, standardization of integration procedures, the time required to perform the operation, and the number of personnel required.

Payload Access. The system will provide hands on access to their payload before the shroud is installed and limited access through a **TBD** stand fairing access in the launch vehicle integration facility, and no access after leaving the launch vehicle integration facility. There will be a maximum of two days (**TBR**) between the last payload access in the launch vehicle integration facility and launch.

Segment: 3.1 Communications
Market Area: 3.1.4 Broadcast Satellite Service
Attributes:

Dependability	• High probability of launching on schedule
Responsiveness	• Minimal response time for launching on need
Availability	• High probability that the system will be in an operational rather than a standdown state
Schedule	• Minimize advanced booking time • Maximize launch window size
Reliability	• Higher than current systems (US and foreign)
Cost	• Minimum cost per launch
Capabilities	• Multiple orbital delivery locations • Adaptable to market needs, with a clear growth path • GEO medium-large satellites
Operations	• Provide standardized user interfaces • User friendly launch site operations • Rapid payload changeout capability

Mission Requirements

GEO. The system shall have the capability of delivering a single payload weighing between 3,000 and 7,000 lbs into a GEO orbit(s) of **TBD** at inclination(s) of **TBD**.

System Requirements

Dependability. The system shall have a 90% (TBR) probability of conducting launches within 10 days of their scheduled dates. This includes external factors such as weather and internal factors such as production, assembly, and payload integration anomalies.

Launch on Need. The system shall not require more than 30 days between notification and launch for launch on need missions.

Availability. The system must maintain a system availability of at least 0.90, measured over the system life cycle. Availability is the fraction of time that a system is in an operational, rather than standdown state. Standdown time is associated with post-failure shutdowns, scheduled and unscheduled maintenance.

Mission Scheduling. Payloads can be scheduled for flight with 18 months notice.

Launch Window. The system shall maximize the payload launch windows. (TBD matrix will show inclination, destination (GEO), and window size)

Reliability. The system must deploy payloads to their intended mission orbits with a total success probability of at least 0.98. This includes reliability of the launch vehicle and the upper stage (if used).

System Growth. The system shall emphasize modularity to accommodate adaptability and growth to meet changing market needs.

Vehicle Requirements

Payload Volume. The system must accommodate payloads comparable to current volumes up to 2x current volumes (**Note:** Need to translate current volumes into length and diameter dimensions)

Payload Interface. The system shall provide **TBD** standardized payload interfaces with which the payloads must conform.

Operational Requirements

Launch Rate. A nominal launch rate of at least 2-3 **(TBR)** missions per year is required to satisfy the direct broadcast missions.

Payload Changeout Capability. To enhance system flexibility, the system must allow payload changeout (of the same payload) up to five days prior to launch and payload changeout (to a different payload) up to 30 days prior to launch. Payload replacement shall be completed within 5 days. Following the payload replacement, the launch system shall be at the same number of days before launch as when the payload change notification was received.

Payload Integration. Payload integration must be greatly simplified in comparison to current operations. This refers to the difficulty of the operations, standardization of integration procedures, the time required to perform the operation, and the number of personnel required.

Payload Access. The system will provide hands on access to their payload before the shroud is installed and limited access through a **TBD** stand fairing access in the launch vehicle integration facility, and no access after leaving the launch vehicle integration facility. There will be a maximum of two days **(TBR)** between the last payload access in the launch vehicle integration facility and launch.

Segment: 3.1 Communications
Market Area: 3.1.5 Mobile Satellite Service
Attributes:

Dependability	• High probability of launching on schedule
Responsiveness	• Minimal response time for launching on need
Availability	• High probability that the system will be in an operational, rather than a standdown state
Schedule	• Minimize advanced booking time
	• Maximize launch window size
Reliability	• Higher than current systems (US and foreign)
Cost	• Minimum cost per launch
Capabilities	• Adaptable to market needs, with a clear growth path
	• System can accommodate multiple payloads per launch
	• Multiple orbital delivery locations
Operations	• Provide standardized user interfaces
	• User friendly launch site operations
	• Rapid payload changeout capability

Mission Requirements

LEO. The system shall deliver between 16,500 lbs and 150,000 lbs per year to LEO orbits of < 1,000 nmi with inclinations from 55° to 98.6 °.

Comanifested Payloads. The system must be capable of delivering multiple (**TBR**) satellites per launch. Each satellite may weigh up to 3,000 lbs.

System Requirements

Dependability. The system shall have a 90% (**TBR**) probability of conducting launches within 10 days of their scheduled dates. This includes external factors such as weather and internal factors such as production, assembly, and payload integration anomalies.

Launch on Need. The system shall not require more than 30 days between notification and launch for launch on need missions.

Availability. The system must maintain a system availability of at least 0.90, measured over the system life cycle. Availability is the fraction of time that a system is in an operational, rather than standdown state. Standdown time is associated with post-failure shutdowns, scheduled and unscheduled maintenance.

Mission Scheduling. Payloads can be scheduled for flight with as little as 18 months lead time.

Launch Window. The system shall maximize the payload launch windows. (TBD matrix will show inclination, destination, and window size)

Reliability. The system must deploy payloads to their intended mission orbits with a total success probability of at least 0.98. The includes reliability of the launch vehicle and the upper stage (if used).

System Growth. The system shall emphasize modularity to accommodate adaptability and growth to meet changing market needs.

Vehicle Requirements

Payload Interface. The system shall provide **TBD** standardized payload interfaces with which the payloads must conform.

Payload Volume. The system must accommodate payloads up to **TBD** feet in diameter and length up to **TBD** feet.

Operations Requirements

Launch Rate. A nominal launch rate of **TBD** missions per year is required to satisfy the mobile communication missions.

Payload Changeout Capability. To enhance system flexibility, the system must allow payload changeout (of the same payload) up to five days prior to launch and payload changeout (to a different payload) up to 30 days prior to launch. Payload replacement shall be completed within 5 days. Following the payload replacement, the launch system shall be at the same number of days before launch as when the payload change notification was received.

Payload Integration. Payload integration must be greatly simplified in comparison to current operations. This refers to the difficulty of the operations, standardization of integration procedures, the time required to perform the operation, and the number of personnel required.

Payload Access. The system will provide hands on access to their payload before the shroud is installed and limited access through a **TBD** stand fairing access in the launch vehicle integration facility, and no access after leaving the launch vehicle integration facility. There will be a maximum of two days **(TBR)** between the last payload access in the launch vehicle integration facility and launch.

Segment: 3.1 Communications
Market Area: 3.1.6 Positioning Satellite Services
Attributes:

Dependability	• High probability of launching on schedule
Responsiveness	• Minimal response time for launching on need
Availability	• High probability that the system will be in an operational, rather than a standdown state
Schedule	• Minimize advanced booking time • Maximize launch window size
Reliability	• Higher than current systems (US and foreign)
Cost	• Minimum cost per launch
Capabilities	• Adaptable to market needs, with a clear growth path • LEO and MEO small-medium satellites • Multiple orbital delivery locations
Operations	• Provide standardized user interfaces • User friendly launch site operations • Rapid payload changeout capability

Mission Requirements

LEO and MEO. The system shall have the capability of placing payloads weight between current GPS mass and 2x current GPS mass into a **TBD** orbit at an inclination of **TBD**. (**Note:** The GPS system mass needs to be quantified)

System Requirements

Dependability. The system shall have a 90% probability of launching within one month of the scheduled date. This includes external factors such as weather and internal factors such as production, assembly, and payload integration anomalies. (**Note:** the one month value does not appear to reflect the urgency of launching on schedule which was reflected in early data. Need to verify that this is sufficient to meet needs, including need of replacing failed on orbit assets.)

Launch on Need. The system shall not require more than 30 days between notification and launch for launch on need missions.

Availability. The system must maintain a system availability of at least 0.90, measured over the system life cycle. Availability is the fraction of time that a system is in an operational, rather than standdown state. Standdown time is associated with post-failure shutdowns, scheduled and unscheduled maintenance.

Mission Scheduling. Payloads can be scheduled for flight with as little as 3 months lead time.

Launch Window. The system shall maximize the payload launch windows. (TBD matrix will show inclination, destination , and window size)

Reliability. The system must deploy payloads to their intended mission orbits with a total success probability of at least 0.98. This includes reliability of the launch vehicle and the upper stage (if used).

System Growth. The system shall emphasize modularity to accommodate adaptability and growth to meet changing market needs.

Vehicle Requirements

Payload Volume. The vehicle must accommodate payloads up to **TBD** feet in diameter and length up to **TBD** feet.

Payload Interface. The system shall provide **TBD** standardized payload interfaces with which the payloads must conform.

Operations Requirements

Launch Rate. A nominal launch rate of **TBD** missions per year is required to satisfy the survey and locate missions. This rate includes 2-5 annual missions for the GPS market.

Payload Changeout Capability. To enhance system flexibility, the system must allow payload changeout (of the same payload) up to five days prior to launch and payload changeout (to a different payload) up to 30 days prior to launch. Payload replacement shall be completed within 5 days. Following the payload replacement, the launch system shall be at the same number of days before launch as when the payload change notification was received.

Payload Integration. Payload integration must be greatly simplified in comparison to current operations. This refers to the difficulty of the operations, standardization of integration procedures, the time required to perform the operation, and the number of personnel required.

COMMERCIAL SPACE TRANSPORTATION STUDY

Segment: 3.2 Space Manufacturing
Market Area: 3.2.2 Space Manufacturing
Attributes:

Dependability	• Provide high probability of launching on schedule
Availability	• High probability that the system will be in an operational, rather than a standdown state
Schedule	• Minimize advanced booking time
Reliability	• Comparable to or better than current systems
Cost	• Minimum cost per flight
Capabilities	• Provide launch, orbital servicing and recovery capabilities
Operations	• Provide airline type operations • Provide launch facilities and recovery site facilities • Provide rapid turnaround technologies and processing facilities

Mission Requirements

Destination Orbit. The launch system shall deliver a maximum of 4500 lbs to a **TBD** sun synchronous polar orbit at 98°.

Rendezvous and Docking. The system shall be capable of performing on orbit rendezvous and docking operations.

Return Capability. The recovery module and 3000 lbs of product. shall be returned to earth.

System Requirements

Dependability. The system shall have a 90% (TBR) probability of conducting launches within 1 day of the scheduled dates. This includes external factors such as weather and internal factors such as production, assembly, and payload integration anomalies.

Availability. The system must maintain a system availability of at least 0.90, measured over the system life cycle. Availability is the fraction of time that a system is in an operational, rather than standdown state. Standdown time is associated with post-failure shutdowns, scheduled and unscheduled maintenance.

Mission Scheduling. Payloads can be scheduled for flight with 4 months notice.

Launch Window. The system shall maximize the payload launch windows. (TBD matrix will show inclination, destination, and window size)

Reliability. The system must deploy payloads to their intended mission orbits with a total success probability of at least 0.98. This includes reliability of the launch vehicle and the upper stage (if used).

System Growth. The system shall emphasize modularity to accommodate adaptability and growth to meet changing market needs.

Vehicle Requirements

Payload Volume. The system must accommodate payloads up to 75 ft^3.

Payload Interface. The system shall provide **TBD** standardized payload interfaces with which the payloads must conform.

Delivery Accuracy. The system shall provide TBD delivery accuracy.

Electrical Power. The system will provide a TBD orbital asset which maximizes the electrical power available for microgravity processing. Electrical power needs are estimated at 20 kW.

Orbiting Service Module. The system will provide an orbiting service module equipped with autonomous microgravity processing capabilities. These capabilities will be used to support the manufacture of electronic, photonic and detector materials, ultra-high vacuum processing, biological and organic materials processing and the support of research subunits for microgravity activities. The capabilities will include monitor and control facilities for each processing activity.

The service module will be design for 5 year on orbit operations and shall be configured with standard guidance, navigation and control function,s automated rendezvous and docking functions, command and communication functions, environmental control capability, high on-board continuous power system, an autonomous product module exchange facility for on-load/off-load of product material subunits.

Recovery Module. The system shall provide a recovery module which provides controlled on orbit maneuvering and autonomous rendezvous and dock capabilities with the service module.

The recovery module shall be designed for reentry and recovery operations.

Operations Requirements

Launch Rate. The sytem must support at least one launch every 30 days.

Payload Integration. Payload integration must be greatly simplified in comparison to current operations. This refers to the difficulty of the operations, standardization of integration procedures, the time required to perform the operation, and the number of personnel required.

The system shall integrate between 20-30 subunits of individual product/containment modules for each launch.

The system shall integrate pre-certified payloads. The payloads will conform to predetermined commercial Federal space regulations and shall not require individual government controlled safety reviews.

Payload Access. The payloads require late access of 12 hour for selected subunits.

Payload Unique Environment. The **TBD** Payload unique requirements will be addressed by use of an adapter system or self-contained servicing support sytem.

Routine Space Access. The system shall provide routine access to space, similar to flight travel opportunities offered by the commercial airline industries.

Automated Operations. The system shall emphasize automated payload launch processing, on orbit processing and processed sample return. Use of man in the system must be eliminated or minimized.

Provide regular routine flights dedicated to material process

Space Operations. The system shall provide a minimum of 30 days and a maximum of 90 days in the orbital microgravity environment.

Recovery Facilities. The system shall provide, maintain, and operate the recovery site facilities. The system shall provide post flight delivery of processed samples or products to a recovery facility.

Refurbishment Operations. The recovery modules shall be refurbished on a routine basis.

Segment: 3.3 Remote Sensing
Market Area: 3.3.2 Remote Sensing
Attributes:

Dependability	• Launch on schedule to position satellite to a specific point in space
Responsiveness	• Provide launch on need capability to replace failed satellites
Availability	• High probability that the system will be in an operational, rather that a standdown state
Schedule	• Minimize advanced booking time
Reliability	• Higher than current systems (US and foreign)
Cost	• Minimum cost per launch
Capabilities	• Launch commercial satellites, U.S. govt. satellites, and international satellites • Accurate placement in polar orbits. High precision trajectories with final trim capabilities • Provide fail safe modes
Operations	• Provide standardized user interfaces • Provide integration and test facilities to satellite operators • Provide technical support to satellite operators • Provide streamline regulations, procedures, paperwork, and requirements for payloads

Mission Requirements

LEO and GEO. The system shall have rated lift capabilities to accommodate the six major classes of remote sensing payloads as outlined in the table below:

Mass (kg)	Orbit	Primary User(s)
200 - 500	Low Earth Polar Orbit	Commercial, US Govt
900 - 1,400	Low Earth Polar Orbit	Comm, US Govt, Intl.
1,500 - 2,200	Low Earth Polar Orbit	US Govt, Intl
2,400 - 2,800	Low Earth Polar Orbit	US Govt, Intl
5,000 - 6,000	Low Earth Orbit	US Govt
700 - 2,400	Geostationary	US, Intl.

System Requirements

Dependability. The system shall have a 90% (**TBR**) probability of conducting launches within a month of their scheduled dates. This includes external factors such as weather and internal factors such as production, assembly, and payload integration anomalies. (**Note:** There is a concern that one month is not consistent with the urgency of launch on schedule expressed in the report. Need to clarify that this is sufficient or reduce to an acceptable level.)

Launch On Need. The system must be capable of launching a replacement satellite within 15 days of a failed satellite.

Availability. The system must maintain a system availability of at least 0.90, measured over the system life cycle. Availability is the fraction of time that a system is in an operational, rather than standdown state. Standdown time is associated with post-failure shutdowns, scheduled and unscheduled maintenance.

Scheduling. New payloads can be scheduled for flight with 3-6 months lead time. (**Note:** 3-6 months is referred to in the final report and 12 months is documented in the requirements matrix put together in December 93 at Langley.)

Reliability. The system must provide an ascent reliability, or probability of success, of .99

System Growth. The system shall emphasize modularity to accommodate adaptability and growth to meet changing market needs.

Vehicle Requirements

Payload Interface. The system shall provide **TBD** standardized payload interfaces with which the payloads must conform. The separation interface between the vehicle and the payload will use marmon clamps.

Payload Volume. The first generation of commercial space sensors require payload volumes of 3-6 m^3.

The system must accommodate payloads which range from current (**TBD**) up to 2x current. (**Note:** We need to be more specific and indicate lengths and diameters. It is also unclear if this is meant to include commercial, Govt, and Intl. payloads or if this pertains to some specified subset of users.)

Fail Safe Design. Design shall provide for a fail safe mode which allows the vehicle to sustain a failure and successfully complete its mission.

Delivery Accuracy. The system shall provide **TBD** accuracy for placement of satellites in polar orbits

Launch Environment. The maximum vehicle acceleration shall not exced 8Gs.

Operations Requirements

Launch Rate. The system launch rate must be adequate to deploy **TBD** % of the remote sensing satellites. Annual projections from 2000 to 2010 are shown in the table below.

	Deployment Year		
	00	05	10
Total	10	12	18
Commercial	3	4	6
Govt/Intl.	7	8	12

User Support. The system must provide technical support and make integration and test facilities available to the user.

Payload Integration. Payload integration must be greatly simplified in comparison to current operations. This refers to the difficulty of the operations, standardization of integration procedures, the time required to perform the operation, and the number of personnel required.

Payload Access. The system will provide hands on access to their payload before the shroud is installed and limited access through a **TBD** stand fairing access in the launch vehicle integration facility, and no access after leaving the launch vehicle integration facility. There will be a maximum of two days (**TBR**) between the last payload access in the launch vehicle integration facility and launch.

Segment: 3.4 Government Missions
Market Area: 3.4.2 Government Missions
Attributes:

Dependability	• High probability of launching on schedule
Responsiveness	• Minimum response time for launching on need
Availability	• High probability that the system will be in an operational, rather than a standdown state
Schedule	• Minimize advanced booking time
Reliability	• High reliability
Cost	• Minimum cost per launch • Minimum payload integration cost to facilitate changeovers from other systems
Capabilities	• Provide transportation for civil and DoD missions • Accommodate more than one payload per launch (**Note:** Need to verify this. It was not mentioned in final report inputs)
Operations	• Provide standardized user interfaces

Mission Requirements

The system shall deliver an average of 176,000 lbs/year to both low and high inclinations spanning from LEO at 90 nmi to GSO at 19,930n nmi from the year 2000 to 2020.

Mission classes. The system shall deliver payloads in the following mission classes: 1) 8,000-10,000 lbs to GTO and up to 12,500 lbs to GSO, 2) 18,000-20,000 and up to 40,000 lbs to LEO due East, 3)14,000-16,000 lbs and up to 32,000 lbs to polar orbits. (**Note:** Need to clarify wording and intent of (2) and (3). This wording was extracted from the final report inputs)

System Requirements

Dependability. The system shall have a 90% (**TBR**) probability of conducting launches within 10 days of their scheduled dates. This includes external factors such as weather and internal factors such as production, assembly, and payload integration anomalies. (**Note:** 10 days is based on recent ALS efforts, but requirements matrix of December 1993 from Langley meetings uses a month. Need to clarify numerical value)

Launch on Need. The system shall not require more than 30-45 (**TBR**) days between notification and launch for launch on need missions.

Availability. The system must maintain a system availability of at least 0.90, measured over the system life cycle. Availability is the fraction of time that a system is in an operational, rather than standdown state. Standdown time is associated with post-failure shutdowns, scheduled and unscheduled maintenance.

Mission Scheduling. Payloads can be scheduled for flight with as little as 18 months lead time.

Launch Window. The system shall maximize the payload launch windows. (TBD matrix will show inclination, destination, and window size)

Reliability. The system must deploy payloads to their intended mission orbits with a total success probability of at least 0.98. The includes reliability of the launch vehicle and the upper stage (if used).

System Growth. The system shall emphasize modularity to accommodate adaptability and growth to meet changing market needs.

Vehicle Requirements

Payload Interface. The system shall provide **TBD** standardized payload interfaces with which the payloads must conform.

Payload Volume. The system must accommodate payloads up to **TBD** feet in diameter and length up to **TBD** feet.

Operations Requirements

Launch Rate. A nominal launch rate of 8 missions per year from the East coast and 4 mission per year from the West coast is required to satisfy the government missions.

Payload Changeout Capability. To enhance system flexibility, the system must allow payload changeout (of the same payload) up to five days prior to launch and payload changeout (to a different payload) up to 30 days prior to launch. Payload replacement shall be completed within 5 days. Following the payload replacement, the launch system shall be at the same number of days before launch as when the payload change notification was received.

Payload Integration. Payload integration must be greatly simplified in comparison to current operations. This refers to the difficulty of the operations, standardization of integration procedures, the time required to perform the operation, and the number of personnel required.

Payload Access. The system will provide hands on access to their payload before the shroud is installed and limited access through a **TBD** stand fairing access in the launch vehicle integration facility, and no access after leaving the launch vehicle integration facility. There will be a maximum of **TBD** days between the last payload access in the launch vehicle integration facility and launch.

Segment: 3.4 Government Missions
Market Area: 3.4.4 Increased Space Station Missions
Attributes:

Dependability	• High probability of launching on schedule
Responsiveness	• Minimum response time for launching on need
Availability	
Schedule	• Minimize advanced booking time to provide rapid access to space
Reliability	• Higher than current STS system
Cost	• Minimum cost per launch
Capabilities	• Deliver payloads to Space Station • Return payloads from Space Station to earth • Frequent resupply capability • Provide civilian access to space (**Note:** This came from the Aug. 30 white paper, but it was not mentioned in the December 93 requirements matrix. Need to determine if this is still needed)
Operations	• Provide streamlined regulations, procedures, paperwork, and requirement for payloads • Improved ground processing for quick refurbishment and turn-around • Late access to payloads prior to launch and early access to payloads returning to earth

Mission Requirements

LEO. The system shall have the capability of delivering payloads weighing up to 25,000 lbs into a LEO orbit of 220 nmi x 220 nmi at an inclination 51.6°. (**Note:** Need to verify that this is still current. There were no numbers mentioned in final report inputs)

Rendezvous and Docking. The system shall accomplish rendezvous and cargo delivery to Space Station.

Return Capability. The system shall be designed to return experiments to earth. The launch system will meet **TBD** vibration, temperature, cleanliness, and data requirements.

Manned Capability. The system shall provide for delivery of people to station and return of people to earth.

System Requirements

Dependability. The system shall have a 90% (**TBR**) probability of conducting launches within one month of the scheduled dates. This includes external factors such as weather and internal factors such as production, assembly, and payload integration anomalies.

Launch on Need. The system shall not require more than 30 (**TBR**) days between notification and launch for launch on need missions.

Availability. The system must maintain a system availability of at least 0.90, measured over the system life cycle. Availability is the fraction of time that a system is in an operational, rather than standdown state. Standdown time is associated with post-failure shutdowns, scheduled and unscheduled maintenance.

Mission Scheduling. Payloads can be scheduled for flight with 18 months notice.

Launch Window. The system shall maximize the payload launch windows. (TBD matrix will show inclination, destination, and window size)

Reliability. The system shall have a higher reliability (relative to STS) for delivery and return of persons and high value payloads.

System Growth. The system shall emphasize modularity to accommodate adaptability and growth to meet changing market needs.

Vehicle Requirements

Payload Volume. The system must accommodate payloads up to **TBD** ft^3.

Payload Interface. The system shall provide **TBD** standardized payload interfaces with which the payloads must conform.

Operations Requirements

Launch Rate. The sytem must support 7-12 annual launchs.

Payload Integration. Payload integration must be greatly simplified in comparison to current STS operations. This refers to the difficulty of the operations, standardization of integration procedures, the time required to perform the operation, and the number of personnel required.

Payload Access. The system shall provide for late access, <72 hours **(TBR)**, to payloads prior to launch and for early access, <72 hours **(TBR)**, to payloads upon return to earth.

Payload Unique Environment. The system or a system provided adapter kit must provide sufficient power **(TBD)** and thermal capabilities **(TBD)** to meet the payload demands

Ground Processing. The system shall provide improved (relative to STS) ground processing for quicker refurbishment andturn around.

Segment: 3.4 Government Missions
Market Area: 3.4.6 Human Planetary Exploration
Attributes:

Dependability	• High probability of launching on schedule
Responsiveness	• Provide launch on need capabilities to support contingency operations
Availability	• High probability that the system will be in an operational state rather than a standdown state
Schedule	• Minimize advanced booking time • Maximize launch windows
Reliability	• Significantly higher than current systems (to support human rating)
Cost	• Minimum cost per launch
Capabilities	• Adaptable, with a clear growth path which takes advantage of previous efforts in other market areas • Deliver crew and cargo to lunar and Mars surfaces • Return crew and cargo to earth • Support extended surface stay • Provide launch and return capability any day during lunar cycle • (**Note:** Need an attribute for launch and return capabilities for Mars) • Delivery to multiple landing sites
Operations	• Provide standardized user interfaces • Minimize operational impact to users • Support rapid cargo changeout capabilities
Human Rating	• Provide capability for crew ingress, egress, and escape as necessary to support human payload launches

Mission Requirements

Lunar System Capability. The system shall be designed to deliver a crew of 4 and 5 tons of cargo or 33t of cargo alone to the lunar surface.

Mars System Capability. The system shall be designed to deliver a crew of **TBD** and **TBD** tons of cargo or **TBD** tons of cargo alone to the surface of Mars.

Surface Stay Time. The system shall be designed for a **TBD** day lunar surface stay and a **TBD** day Mars surface stay .

Cargo Return Capability. The system shall be designed to return **TBD** kg from the lunar surface and **TBD** kg from Mars.

Manned Flights. Support manned missions by the year **TBD.**

Rendezvous and Docking. The system shall be capable of performing on orbit rendezvous and docking operations.

System Requirements

Dependability. The system shall have a 90% **(TBR)** probability of conducting launches within 1 day of their scheduled dates. This includes external factors such as weather and internal factors such as production, assembly, and payload integration anomalies.

Availability. The system must sustain a system availability of at least 0.90, measured over the system life cycle. Availability is the fraction of time that a system is in an operational, rather than standdown state. Standdown time is associated with post-failure shutdowns, scheduled and unscheduled maintenance.

Launch Window. The system shall maximize the payload launch windows. **TBD** minutes for lunar missions and **TBD** minutes for Mars missions.

Mission Scheduling. Payloads can be scheduled for flight with as little as 18 months lead time.

Reliability. TBD

Commonality. System shall emphasize commonality with hardware, software, and operations which have been previously developed to fulfill other market areas and segments.

Vehicle Requirements

Payload Interface. The system shall provide **TBD** standardized payload interfaces with which the payloads must conform.

Payload Volume. The system must accommodate payloads up to 30 feet in diameter and length up to 100 feet.

Operations Requirements

Launch Rate. Minimum nominal launch rate shall be 4 (TBR) per year with growth to accommodate TBD flight per year by TBD. (Note recent STV efforts used 4 with growth, but the requirements matrix uses a low of 1-2 and a high of 4. This needs to be resolved.)

Facilities. The operations and processing facilities shall be designed in parallel with the vehicle system to achieve more efficient, reliable operations involving fewer people and shorter launch schedules.

Cargo Changeout Capability. To enhance system flexibility, the system must allow cargo changeout (of the same payload) up to five days prior to launch and cargo changeout (to different cargo) up to 30 days prior to launch. Cargo replacement shall be completed within 5 days. Following the replacement, the launch system shall be at the same number of days before launch as when the cargo change notification was received.

Payload Integration. Payload integration must be greatly simplified in comparison to current operations. This refers to the difficulty of the operations, standardization of integration procedures, the time required to perform the operation, and the number of personnel required.

Payload Access. The system will provide hands on access to their payload before the shroud is installed and limited access through a **TBD** stand fairing access in the launch vehicle integration facility, and no access after leaving the launch vehicle integration facility. There will be a maximum of two days **(TBR)** between the last payload access in the launch vehicle integration facility and launch.

Nuclear System Handling. The system should be capable of processing **TBD** nuclear systems.

Segment: 3.4 Government Missions
Market Area: 3.4.9 Space Science Outwards
Attributes:

Dependability
- High probability of launching on schedule

Schedule
- Minimize advanced booking time to provide rapid access to space
- Maximize launch windows

Availability
- High probability that the system will be in an operational rather than a standdown state

Reliability
- Comparable to current systems

Cost
- Minimum cost per launch
- Minimize payload integration cost to support reduction of payload/instrumentation development cost

Capabilities
- Support multiple payload classes
- Deliver and return payloads (**Note:** Early white papers mention return payloads, but requirements matrix of December 93 from Langley meeting does not. This needs to be clarified)
- Delivery to multiple destinations
- Accommodate more than 1 payload per launch

Operations
- Provide standardized user interfaces
- Support high annual launch rate for small missions
- Support moderate annual launch rate for medium missions
- Support low annual launch rate for large missions
- Provide launch site services and facilities for parallel independent payload integration
- Provide streamlined regulations, procedures, paperwork, and requirement for payloads

Mission Requirements

Payload Classes. The system shall have the capability of supporting multiple payload classes. The Ragship class includes payloads up to **TBD** lbs to **TBD** LEO, GEO, and escape orbits. The Discovery class includes payloads up to **TBD** lbs to **TBD** LEO, GEO, and escape orbits. The Explorer class includes payloads up to 1,000 lbs to **TBD** LEO and near earth orbits. **TBD**

or

The system must accommodate multiple payload sizes including 500 lbs into 100 nm, 250 lbs into 600 nm, Delta class payloads, Titan IV class payloads, and Titan IV/Centaur class payloads

(**Note:** The wording of this requirement comes from an early white paper, need to clarify which is preferred)

Delivery Locations. The system shall deliver science payloads to near earth orbit, heliocentric orbit, and interplanetary destinations (excluding manned missions).(**Note:** this wording is consistent with the payload masses referenced in the early white paper. Need to decide if requirements matrix or white paper should be used as source material)

Multiple Payloads. The system shall have the capability of delivering more than 1 payload per launch.

System Requirements

Dependability. The system shall have a 90% (**TBR**) probability of conducting Ragship class launches within the hour, Discovery class launches within a day and Explorer class launches within 10 days of their scheduled dates. This includes external factors such as weather and internal factors such as production, assembly, and payload integration anomalies.

Availability. The system must sustain a system availability of at least 0.90, measured over the system life cycle. Availability is the fraction of time that a system is in an operational, rather than standdown state. Standdown time is associated with pose-failure shutdowns, scheduled and unscheduled maintenance.

Mission Scheduling. Ragship class payloads can be scheduled for flight with 24 months notice. Discovery class payloads can be schedules for flight with 18 months notice, and Explorer class payload can be scheduled with 6 months notice.

Launch Window. The system shall maximize the payload launch windows. (TBD matrix will show inclination, destination, and window size)

Reliability. The system must deploy payloads to their intended mission orbits with a total success probability of at least 0.95.

Vehicle Requirements

Payload Interface. The system shall provide **TBD** standardized payload interfaces with which the payloads must conform.

Payload Volume. The system must accommodate: Ragship payloads of up to **TBD** feet in diameter and length up to **TBD feet**; Discovery payloads which have dimensions compatible with Delta and Atlas systems; and Explorer payloads which have dimensions compatible with Pegasus. (**Note:** We need to quantify the dimensions instead of referencing other systems)

Operations Requirements

Launch Rate. The system shall provide up to 25 launches per year for payloads ranging from 500 lb into 100 nm to 250 lbs into 600 nm.

The system shall provide up to 3 launches per year for Delta class payloads.

The system shall provide at least one launch of a Titan IV/Centaur class mission every 2 years.

(**Note:** These may need to be worded such that they are compatible with the terminology of Ragship, Discovery, and Explorer .)

User Support. The system must provide integration and test facilities available to the user.

Payload Integration. Payload integration must be greatly simplified in comparison to current operations. This refers to the difficulty of the operations, standardization of integration procedures, the time required to perform the operation, and the number of personnel required.

Payload Access. The system will provide hands on access to their payload before the shroud is installed and limited access through a **TBD** stand fairing access in the launch vehicle integration facility, and no access after leaving the launch vehicle integration facility. There will be a maximum of two days (**TBR**) between the last payload access in the launch vehicle integration facility and launch.

Payload Unique Environment. Payload unique requirements should be addressed by use of an adapter system or self-contained servicing support.

Segment: 3.5 Transportation
Market Area: 3.5.3 Fast Package Delivery
Attributes:

Dependability	• Assured on time delivery
Responsiveness	• Improved point-to-point delivery times
	• Provide launch on need capability
Availability	• High probability that the system will be in an operational rather than a standdown state
Schedule	• Daily flights
Reliability	• Comparable to aircraft
Cost	• Comparable to existing services
Capability	• Delivery to multiple world wide destinations
	• Accommodate multiple payloads per launch
	• Provide large annual delivery capability (tons/year)
	• Provide special handling provisions to user (i.e. perishable items)
	• Adaptable to market needs, with a clear growth path
	• Robust, weather resistant system
Operations	• Provide rapid vehicle turnaround
	• Minimum integration operations
	• Provide high level of confidence that package will not be lost or damaged
	• Compatible with existing package delivery infrastructure

Mission Requirements

Payload Capability. The sytem must be capable of delivering 3000lb. It is estimated that the system will deliver between 30 and 500 tons per year. (**Note:** The second part of this statement came from early presentation material. Need to confirm the quantity)

Delivery Locations. The system shall provide delivery of packages to multiple (**TBD**) world wide destinations.

Manned Flights. The system shall have the capability to accommodate man by year **TBD**.

System Requirements

On Time Delivery. The system shall have a .99 probability of delivery by the specified hour and .99999 probability of correct day delivery. (**Note:** The wording of this requirement is equivalent to federal express, but the requirements matrix of December 1993 suggests ± 2 hours with no particular probability stated. This needs to be resolved)

Noise Limitation. The system shall meet TBD noise limitations.

Air Traffic Compatibility. The system shall be compatible with existing air traffic

System Capability. The system shall be compatible with the existing package delivery infrastructure (in particular the distribution system))

Payload Compatibility. The standard payload containers shall be airline compatible .

Schedule. Packages can be scheduled for flight with as little as 24 hour notice.

Vehicle Requirements

Vehicle Range. The longest range of interest is 10,000 nmi. (TBR).

Payload Interface. The system shall provide a **TBD** standardized interface for the standard containers.

Payload Module Volume. The system will accommodate **TBD** containers. Dimensions of the individual containers will not exceed **TBD**.

Operations Requirements

Flight Rate. The system shall be able to operate two flights daily.

Payload Integration. Payload integration must be greatly simplified in comparison to current operations. This refers to the difficulty of the operations, standardization of integration procedures, the time required to perform the operation, and the number of personnel required.

Takeoff/Landing Operations. The vehicle will takeoff and land from the same location. This location shall be easily accessible by air and road transport, and will preferably be in close proximity to major commerce centers.

Market Area:	3.5 Transportation
Segment:	3.5.5 Hazardous Waste Disposal
Attributes:	
Schedule	• Maximize launch window size?
Reliability	• Higher than current systems (US and foreign)
Cost	• Minimum cost per launch
Safety	• Ensure safety of personnel and public
Operations	• Provide standardized user interfaces • Ensure safe ground handling operations

Mission Requirements

Lunar Delivery. The system shall have the capability of placing 8 tons of payload, consisting of nuclear waste and canisters, onto the lunar surface.

System Requirements

Dependability. The system shall have a 90% **(TBR)**probability of launching within one month of the scheduled date. This includes external factors such as weather and internal factors such as production, assembly, and payload integration anomalies.

Availability. The system must maintain a system availability of at least 0.90, measured over the system life cycle. Availability is the fraction of time that a system is in an operational, rather than standdown state. Standdown time is associated with post-failure shutdowns, scheduled and unscheduled maintenance.

Reliability. The system must deploy payloads to their intended mission orbits with a total success probability of at least 0.98. This includes reliability of the launch vehicle and the upper stage (if used).

Mission Scheduling. Payloads can be scheduled for flight with 12 months notice.

Vehicle Requirements

Launch Abort. The system must provide for an intact abort.

Payload Interface. The system shall provide a **TBD** standardized interface for the **TBD** canisters.

Payload Module Volume. The system will accommodate TBD canisters. Dimensions of the individual containers will not exceed TBD.

Operations Requirements

Launch Rate. The system must be capable of launching every 9 days.

Ground Processing. Ground operations must provide safe handling of nuclear waste payloads (potentially thermal).

Payload Access. The system will provide hands on access to their payload before the shroud is installed and limited access through a **TBD** stand fairing access in the launch vehicle integration facility, and no access after leaving the launch vehicle integration facility. There will be a maximum of two days **(TBR)** between the last payload access in the launch vehicle integration facility and launch.

Segment: 3.6 Entertainment
Market Area: 3.6.3 Orbiting Movie Studio
Attributes:

Dependability	• High probability of launching on schedule
Responsiveness	• Minimal response time for launching on need
Availability	• High probability that the system is in an operational rather than a standdown state
Schedule	• Minimize advanced booking time • Maximize launch windows
Reliability	• Significantly higher than existing systems
Cost	• Minimum cost per launch
Capabilities	• Deliver and return payloads • Provide delivery to and docking with orbital facility • Provide civilian access to space
Safety	• Provide system safety comparable to commercial ground transportation
Operations	• Provide standardized user interfaces • Provide a system which can be booked and boarded as if it were a bus, train, or commercial aircraft • Provide streamlined regulations, procedures, paperwork, and requirement for payloads

Mission Requirements

System Capability. The system shall deliver cargo and passengers to a LEO business park. The annual estimated mass of 650 klbs is based on launching 12,500 lbs on a weekly basis.

The system shall be capable of delivering the orbiting facility, with an initial launch mass of 80,000 lb to a **TBD** LEO orbit . The facility is to be operational by 2005-2006. (**Note:** Need to verify dates, they do not show up in the final report)

To capture the near term (**TBD**) opportunities, the system must provide a mechanism for 50lb , camera size, payloads to piggyback on its primary satellite missions which are scheduled to be returned to earth. (**Note:** This requirement does not show up in the final report. Need to verify if it is still applicable.)

Rendezvous and Docking. The system shall be capable of performing on orbit rendezvous and docking operations.

System Requirements

Dependability. The system shall have a 90% (**TBR**) probability of conducting launches within 1 day of their scheduled dates. This includes external factors such as weather and internal factors such as production, assembly, and payload integration anomalies.

Launch on Need. The system shall not require more than **TBD** days between notification and launch for launch on need missions.

Availability. The system must sustain a system availability of at least 0.90, measured over the system life cycle. Availability is the fraction of time that a system is in an operational, rather that standdown state. Standdown time is associated with post-failure shutdowns, scheduled and unscheduled maintenance.

Mission Scheduling. Customers shall be able to reserve transportation services with as little as 3 months lead time.

Launch Window. The system shall maximize the payload launch windows.

Reliability. The system must deploy payloads to their intended mission orbits with a total success probability of at least 0.98.

System Safety. System safety must be comparable to commercial air transportation.

Passenger Transportation Services. After the orbiting movie studio is operational, the system will function as a passenger transporter, moving groups of 12-20 people with personal effects and camera equipment to and from the facility.

The system must be designed to transport civilians with minimal or no training required.

System Cost. To capture this market, the system cost must be $400/lb or less.

Vehicle Requirements

System Design. The system must provide a docking module and a logistics module.

Payload Interface. The system shall provide a **TBD** standardized interface for the **TBD** modular cargo containers.

Payload Volume. **TBD**

Operations Requirements

Launch Rate. The system shall provide regular flights on a weekly basis.

Payload/User Interface. The system shall provide airline like cargo and passenger handling.

Space qualification requirements for payloads must be simplified **(TBD).**

On-orbit Facility Operations. The system must support the transfer of passengers and hardware to the orbital facility.

Segment: 3.6 Entertainment
Market Area: 3.6.4 Space Athletic Events
Attributes:

Dependability	• High probability of launching on schedule
Availability	• High probability that the system will be in an operational, rather than a standdown state
Schedule	• Minimize advanced booking time • Maximize launch windows
Reliability	• Significantly higher than existing systems
Cost	• Minimum cost per launch
Capabilities	• Deliver and return payloads • Delivery to orbital facility • Provide civilian access to space • Provide on orbit rendezvous and docking capabilities
Safety	• Provide system safety comparable to commercial ground transportation
Operations	• Provide system which can be booked and boarded as if it were a bus, train, or commercial aircraft • Provide streamlined regulations, procedures, paperwork, and requirement for payloads

Mission Requirements

System Capability. The system shall deliver cargo and passengers, approximately 20 klbs, to a LEO business park.

The system shall be capable of delivering the orbiting facility, approximately the size of an external tank, to a **TBD** LEO orbit. The facility is to be operational by 2005-2006.

At low transportation costs (<$100/lb), the system must accommodate 426-853 klbs/year. For costs of $500/lb, the system must accommodate 16.4-65.6 klbs/year.

Rendezvous and Dock. The system must be capable of performing on orbit rendezvous and docking operations.

System Requirements

Dependability. The system shall have a 90% (**TBR**) probability of conducting launches within 1 day of their scheduled dates. This includes external factors such as weather and internal factors such as production, assembly, and payload integration anomalies.

Availability. The system must sustain a system availability of at least 0.90, measured over the system life cycle. Availability is the fraction of time that a system is in an operational, rather that standdown state. Standdown time is associated with post-failure shutdowns, scheduled and unscheduled maintenance.

Mission Scheduling

Customers shall be able to reserve transportation services 6 months in advance.

Launch Window. The system shall maximize the payload launch windows.

Reliability. The system must deploy payloads to their intended mission orbits with a total success probability of at least 0.98.

System Safety. System safety must be comparable to commercial ground transportation.

Passenger Transportation Services. The system must be designed to transport civilians with minimal or no training required.

System Cost. The system must provide a reduced transportation cost relative to current system costs. Cost should be reduced to at least $500/lb and preferably to $100/lb or less.

Vehicle Requirements

System Design. The system must provide a docking module and a logistics module.?

Payload Interface. The system shall provide a **TBD** standardized interface for the **TBD** modular cargo containers.

Payload Volume. TBD

Crew and Cargo Accommodations. The vehicle shall be designed for 12 persons, estimated at 250 lb each, 4000 lb of props, 1000 lbs of production equipment and 8,400 lbs of additional personal allowance (100 lb per day per person).

Operations Requirements

Launch Rate. The system shall provide regular monthly, or preferably weekly flights.

Payload/User Interface. The system shall provide airline like cargo and passenger handling. Space qualification requirements for payloads must be simplified (**TBD**).

Segment: 3.6 Entertainment
Market Area: 3.6.5 Artificial Space
Attributes:
Dependability
Availability
Schedule
Reliability
Cost
Capabilities
Operations

Requirements

Segment:	3.6 Entertainment
Market Area:	3.6.6 Space Theme Park
Attributes:	
Dependability	• High probability of launching on schedule
Availability	• High probability that the system will be in an operational, rather than a standdown state
Schedule	• Minimize advanced booking time • Maximize launch windows
Reliability	• Significantly higher than existing systems
Cost	• Minimum cost per launch
Capabilities	• Deliver and return payloads • Delivery to Space Theme Park in LEO • Accommodate multiple payloads per launch • Provide civilian access to space
Safety	• Provide system safety comparable to commercial ground transportation
Operations	• Provide standardized user interfaces • Provide a system which can be booked and boarded as if it were a bus, train, or commercial aircraft • Provide streamlined regulations, procedures, paperwork, and requirement for payloads

Mission Requirements

System Capability. The system shall deliver cargo and passengers to a LEO business park

To support early ground based segment, the system must provide delivery of multiple small satellite payloads (<1000 lb each) annually to various LEO orbits, including polar orbits.

The system must provide transportation of the initial **TBD** facility.

Once the Space Them Park is operational, the system will function as a commuter service. Vehicle passenger capacity requirements will grow from 15-25 passengers initially to 75+ passengers later on (**TBD**).

At current transportation costs ($5,000/lb), the system must deliver 6-42 klbs/year. At a reduced cost of $500/lb, the system must support 362-826 klbs/year and at a cost of $100/lb the system must accommodate 703-7209 klbs/year.

System Requirements

Dependability. The system shall have a 90% (**TBR**) probability of conducting launches within 1 day of their scheduled dates. This includes external factors such as weather and internal factors such as production, assembly, and payload integration anomalies.

Availability. The system must sustain a system availability of at least 0.90, measured over the system life cycle. Availability is the fraction of time that a system is in an operational, rather that standdown state. Standdown time is associated with post-failure shutdowns, scheduled and unscheduled maintenance.

Mission Scheduling. Customers shall be able to reserve transportation services 6 months in advance.

Launch Window. The system shall maximize the payload launch windows.

Reliability. The system must deploy payloads to their intended mission orbits with a total success probability of at least 0.98.

System Safety. System safety must be comparable to commercial transportation.

System Cost. To capture this market, the system cost must be $100/lb or less.

Vehicle Requirements

Payload/User Interfaces. The system will provide standardized payload interfaces for the satellite systems.

Operations Requirements

Launch Rate. Initially, the system must support 9 payloads per year. (<1000 lb each to support ground based segment) The number of payloads is expected to grow to 60-90 annually as transportation costs are reduced. The peak demand will be around 135/year at $100/lb.

Initially the system must support 52 flights/year. As demand increases, the system may require daily flights and multiple vehicles. (**Note:** Need to verify that this is for passenger service and then clarify wording)

The system shall provide airline like passenger handling to support the space based segment..

Segment: 3.7 New Missions
Market Area: 3.7.7 Space Business Park
Attributes:
Dependability
Availability
Schedule
Reliability
Cost
Capabilities
Operations

Requirements

Segment: 3.8 Space Utilities
Market Area: 3.8.2 SpacePower Utilities
Attributes:

Dependability	• High probability of launching on schedule
Reponsiveness	• Minimal response time for launching on need
Availability	• High probability that the system will be in an operational, rather than a standdown state
Schedule	• Minimize advanced booking time to provide rapid access to space
Reliability	• Higher than current systems
Cost	• Minimum cost per launch • Minimize payload integration cost
Capabilities	• Deliver large payloads to highly inclined, elliptical orbits
Operations	• Provide standardized user interfaces • Provide streamlined regulations, procedures, paperwork, and requirement for payloads

Mission Requirements

Molynia. The system shall have the capability of placing payloads weighing 25-50 MT into a **TBD** Molynia orbit at an inclination of 63° or higher. (**Note:** 25 MT into Molynia at 63° From Requirements matrix. Final report uses 55,000-100,000lbs into elliptical, highly inclined ≥ 63°. Need to verify that wording is acceptable.)

Manned Flights. The system shall provide transportation for assembly crews by year **TBD**.

Rendezvous and Docking. The system shall provide rendezvbous adn docking capabilities to support user on orbit assembly and servicing.

System Requirements

Dependability. The system shall have a 90% (**TBR**) probability of conducting launches within a week scheduled dates. This includes external factors such as weather and internal factors such as production, assembly, and payload integration anomalies.

Availability. The system must maintain a system availability of at least 0.90, measured over the system life cycle. Availability is the fraction of time that a system is in an operational, rather than standdown state. Standdown time is associated with post-failure shutdowns, scheduled and unscheduled maintenance.

Launch on Need. The system shall not require more than **TBD** days between notification and launch to support unscheduled maintenance activities.

Mission Scheduling. Payloads can be scheduled for flight with as little as 6 months lead time.

Launch Window. The system shall maximize the payload launch windows.

Reliability. The system must deploy payloads to their intended mission orbits with a total success probability of at least 0.98. This includes reliability of the launch vehicle and the upper stage (if used).

System Growth. The system shall emphasize modularity to accommodate adaptability and growth to meet changing market needs.

Vehicle Requirements

Payload Volume. System will accommodate payloads up to 15 feet in diameter and length up to 40 feet.

Payload Interface. The system shall provide **TBD** standardized payload interfaces with which the payloads must conform.

Orbital Transfer System. The system shall provide an orbital transfer system.

Operations Requirements

Launch Rate. The system shall provide the capability of launching every several days (**Note:** 1 - 2 times per week. Verbal per telecon with Dana. Need to select preferred wording)

Payload Integration. Payload integration must be greatly simplified in comparison to current operations. This refers to the difficulty of the operations, standardization of integration procedures, the time required to perform the operation, and the number of personnel required.

Nuclear System Handling. The system should be capable of processing **TBD** nuclear systems.

Segment:	3.10 Advertising
Market Area:	3.10.5 Space Burial
Attributes:	
Dependability	• High probability of launching on schedule
Availability	• High probability that the system will be in an operational, rather than a standdown state
Schedule	• Ensure launch within a year of customer request for services (**Note:** Need to verify this with Mitch)
Reliability	• Higher than existing systems
Cost	• Minimum cost per launch
Capabilities	• Provide capabilities to comanifest space burial module with other payloads
Operations	• Provide standardized user interfaces • Provide for receipt, recremation, and storing of ashes until launch

Mission Requirements

LEO. The system shall deliver a **TBD** lb capsule to a **TBD** LEO orbit.

System Requirements

Dependability. The system shall have a 90% **(TBR)** probability of conducting launches within 1 month of their scheduled dates. This includes external factors such as weather and internal factors such as production, assembly, and payload integration anomalies.

Availability. The system must sustain a system availability of at least 0.90, measured over the system life cycle. Availability is the fraction of time that a system is in an operational, rather that standdown state. Standdown time is associated with post-failure shutdowns, scheduled and unscheduled maintenance.

Mission Scheduling. The system should be designed such that remains are launched within 1 **(TBR)** year of a request.

Reliability. The system must deploy payloads to their intended mission orbits with a total success probability of at least 0.98.

Vehicle Requirements

Operations Requirements

Launch Rate. The system must provide an average of 1.3 launches per year from 2000 though 2030.

Facility. The system shall provide a facility for receiving cremains, processing (recremating), storing, and integrating them into the capsule for launch.

A.3 Launch System Requirements

a. Launch system should be capable of meeting scheduled take-off time with approximately 95% schedule confidence.

b. System should significantly lower cost as compared to existing system based on life cycle costs.

c. Payload integration must be greatly simplified in comparison to current operations. This refers to the difficulty of the operations, standardization of integration procedures, the time required to perform the operation, and the number of personnel required.

d. System must allow payload substitution (within a given payload class and mission) prior to launch. Following payload replacement, the system shall be at the same number of calendar days before launch as when the payload change notification was received.

e. There will be no routine payload access after leaving the payload encapsulation facility

f. The system will minimize the time between payload encapsulation and launch to reduce payload support requirements including batteries.....

g. System will use integrate-transfer-launch operations philosophy. (to reduce cost improve reliability...)

h. Accomplish rendezvous and cargo delivery to xxx

i. System will accommodate payloads up to x feet in diameter and length up to x ft.

j. Provide hands on access to the payload in the PEF before the shroud is installed, or through access ports after the shroud is installed

k. Provide transportation of encapsulated payload or encapsulated payload/upper stage to VIF or VAB where is will be mated with the vehicle

l. Provided limited payload access through standard fairing access panel, for final payload flight preparation in the VIF/VAB

m. Provide no payload access after the vehicle leaves the VIF/VAB

n. There will be a maximum of xxx clock hours between the last payload access in the VIF/VAB and launch

o. Provide capability for fail-safe abort prior to launch commit, including safe liquid engine shutdown from a full thrust condition

p. Provide an operations and facilities concept wherein launch vehicles are both integrated and mated with their payload in off-line facilities, and then transported to the launch pad for fueling, final checkout and launch. In an ITL concept, minimum time is spent on the launch pad, thus requiring only a simple clean pad and enabling attainment of lower costs, improved schedule dependability , and higher launch rate capabilities.

q. System will define and develop standard payload interfaces with which payloads must conform. As a goal, payload-unique requirements should be addressed by use of adapter system and self-contained servicing support.

r. The system shall have the capability of placing payloads weighing between TBD and TBD lbs into a LEO orbit of 100 x 100 nmi at an inclination of xx.x°.

s. The system shall be capable of delivering a single payload to ....

t. The system will have rated lift capabilities of at least x lbs to x x x nmi, yy.y° orbit.

u. The system must maneuver cargo to effect orbit circularization, transfers, and/or phasing...

Appendix B—
Communications

APPENDIX B COMMUNICATIONS

B.1 INFORMATION SOURCES

Government Agencies	Service Providers
• Department of Commerce • Department of Transportation • Federal Communications Commission • NASA Headquarters	• INTELSAT • AT&T • GE Americom • Inmarsat • Calling Communications • Iridium
University	Service Users Programmers and Applications
• University of Colorado	• Westcott Communications • Jones Intercable • Satellite Management Incorp • ABC News • TCI • Rail Road Consultant • Shell Oil • Exxon • Martin Marietta FAA • Boeing
Satellite Manufactures	Published Data
• Hughes • Loral • Martin Marietta Astro Space • Rockwell • CTA	• Satellite Orders • Satellite Directory • News Articles • Annual Reports • Mission Models • Industry Papers

B.2 COMPILATION OF CURRENT SATELLITES

Satellite Database

1/20/94 Rev.1

Domestic Satellite Systems

Operator	**Country**	**Home Office**	**Satellite Family**	**Specific Satellite**	**Launch Date**	**Internat. ID #**	**Satellite Number**	**Mass in Orbit (kg.)**	**Stabil.**
Alascom Inc.	USA	Anchorage. Alaska		Aurora II	5/29/91			736	3 axis
AT&T Skynet Sat. Service	USA	Morristown, N.Y.	Telstar	Telstar 301	7/28/83			650	Spin
				Telstar 302	8/30/84			650	Spin
				Telstar 303	6/17/85			650	Spin
COMSAT Corp.	USA	Washington D.C.	Comstar	Comstar D-2	Jul-76			790	Spin
				Comstar D-4	Feb-81			790	Spin
				SBS-2				559	Spin
				SBS-3	Nov-82			559	Spin
			Marisat	Marisat 1	1976				
				Marisat 2	1976				
				Marisat 3	1976				
Deutsche Bundespost Tel	Germany	Darmstadt, Germ	Kopernikus	DFS1 - Kopernikus	Jun-89			875	3 axis
				DFS2 - Kopernikus	Jul-90	1990-63B		645	3 axis
				DFS3 - Kopernikus	Sep-92			645	3 axis
			TV-SAT2	TV-SAT2	Aug-89			7260	3-axis
Brazilsat - Empresa Brasile	Brazil	RiodeJaneiro, Bra	Brazilsat A	Brazilsat A-1	Feb-85			671	
				Brazilsat A-2	Mar-86			717	Spin
France Telecom	France	Paris	Telecom 1	Telecom 1C	Mar-88			684	3 axis
			Telecom 2	Telecom 2A	Dec-91	1991-84A		1005 or 1380	3 axis
				Telecom 2B	May-92	1992-21A		1005 or 1380	3 axis
				Telecom 2C	Spare				3 axis
GE AMERICOM	USA	Princeton, N.J.	Satcom C	Satcom C-1	Nov-90	1990-100A		510 or 1295	3 axis
				Satcom C-3	Sep-92			620	3 axis
				Satcom C-4	Aug-92			620	3 axis
				Satcom C-5 (see Alascom/Aurora II)					
			Satcom R	Satcom 1R	Apr-83			480	3 axis
				Satcom 2R	Sep-83			610	3 axis

				Satcom K	Satcom K1	Nov-85			780	3 axis
					Satcom K2	Jan-86			780	3 axis.
	GTE Spacenet	USA	McLean, Va.	Spacenet	Spacenet II	Nov-84			692	3 axis
					Spacenet III	Mar-88			692	3 axis
					Spacenet IV	May-91			692	3 axis
				Gstar	GSTAR1	May-85			715	3 axis
					GSTAR2	Mar-86			715	3 axis
					GSTAR3	Sep-88			715	3 axis
					GSTAR4	Nov-90	1990-100B		715 or 1295	
				ASC	ASC1	Aug-85			680	3 axis
					ASC2		1991-28A		730	3 axis
	Hispasat	Spain	Madrid, Spain	Hispasat	Hispasat 1A	Sep-92			1010	3 axis
					Hispasat 1B	to be launched 5/93				
	Hughes Communications	USA	Los Angeles	SBS	SBS4	Aug-84			559	spin
				(purchased Sat.	SBS5	Sep-88			559	spin
				Transponder	SBS6	Oct-90	1990-91A		2478	spin
				Leasing						
				Corp.)						
				Westar (military?)	Westar 3 (military??)	Aug-89				
					Westar 4 (military??)	Feb-82				
					Westar 5 (military??)	Jun-82				
				Galaxy	Galaxy I	Jun-83			654	spin
					Galaxy II	Sep-83			654	spin
					Galaxy III (USASAT 12B)	Sep-84			654	spin
					Galaxy IV	Jan-93				body-stab.
					Galaxy V	Mar-92	1992-13A		788 or 825	spin
					Galaxy VI	Oct-90	1990-91B		584 or 1212	spin
					Galaxy VII	Oct-92				body-stab.
				Leasat	Leasat 1 (all Leasats Navy Operatec	1984				
					Leasat 2	1984				
					Leasat 3					
					Leasat 5	1985				
	Indian Dept. of Space	India	Bangalore, India	Insat-1	Insat-1A	May-82				
					Insat-1B	Aug-83				
					Insat-1C	Jul-89			650	3 axis
					Insat 1D	Jun-92	1992-51A		650	3 axis
				Insat-2	Insat-2A	Jul-92			905	3 axis
					Insat-2B (under constr.)				850	3 axis .

					Insat-2C (under const.)				850	3 axis
					Insat-2D					
					Insat-2E					
	Italian Space Agency	Italy	Rome	Italsat	Italsat 1	Jan-91	1991-3A		1050	3 axis
					Italsat 2				1050	3 axis
	Japan Commun. Satellite C	Japan	Tokyo	Jcsat	Jcsat 1	Mar-89			1370	spin
					Jcsat 2	Jan-90	1990-1B		1370	spin
	Chinese Ministry of Posts	China	Bejing	Chinasat DFH	STW-1(DFH-1)	Apr-84			420	spin
					STW-2 (DFH-2)	Feb-86				
					DFH-2A	Mar-88			1024	
					Chinasat3 (DFH2-A3)	Feb-90				
					STTW4	Feb-90	1990-11A		1024	
	Russian Ministry of Postal	Russia	Moscow	Gorizont	Gorizont 12 (Stasionar 12)	Jun-86			not given	3 axis
					Gorizont 15 (Stasionar 4)	Mar-88			not given	3 axis
					Gorizont 16 (Stasionar 13)	Aug-88			not given	3 axis
					Gorizont 17 (Stasionar 5)	Jan-89			not given	3 axis
					Gorizont 18 (Stasionar 7)	Jul-89			not given	3 axis
					Gorizont 19 (Stasionar 14)	Sep-89			not given	3 axis
					Gorizont 20 (Stasionar 6)	Sep-90			not given	3 axis
					Gorizont 22	Nov-90	1990-102A		2125	
					Gorizont 23	Jul-91	1991-46A		2125	
					Gorizont 24	Oct-91	1991-74A		2125	
					Gorizont 25	Apr-92	1992-17A		2125	
				Raduga	Statsionar 2				not given	3 axis
					Statsionar 3	Mar-88			not given	3 axis
					Statsionar 8				not given	3 axis
					Statsionar 9	May-89			not given	3 axis
					Statsionar 10	Jan-86			not given	3 axis
					Statsionar 15				not given	3 axis
					Statsionar 20	Sep-90			not given	3 axis
					Statsionar 24	Jun-90			not given	3 axis
				Ekran	Ekran T1	Dec-88			not given	3 axis
					Ekran T2	Dec-88			not given	3 axis
				Molniya 3	Molniya 3 (set of four)	not given			not given	3 axis
	Optus Communications Pt	Austrailia	Sydney	Optus	Optus A1	Aug-85			566	spin
					Optus A2	Aug-85			566	spin
					Optus A3(Aussat A3)	Sep-87			566	spin
				Optus B	Optus B1 (Aussat B1)	Aug-92			1650 BOL	3 axis
					Optus B2 (Aussat B2)	planned				3 axis

	P.T. Telekomnikasi Indones	Indonesia	Jakarta	Palapa	Palapa B1	Jun-83			628	spin
					Palapa B2P	Mar-87			628	spin
					Palapa B2R	May-90	1990-34A		628 or 1200	spin
	Space Comm. Corp.	Japan	Tokyo	Superbird	Superbird A	12/1/1992 (scheduled)			1550	
					Superbird B	Feb-92	1992-10A		1550 or 2560	
	Telecomunicaciones de Me	Mexico		Morelos	Morelos F1	Jun-85			666	spin
					Morelos F2	Nov-85			666	spin
				Solaridad	Solaridad I	Nov-93			1672	3 axis
	Telecommun. Sat. Corp. of	Japan	Tokyo	BS2 "Yuri"	BS2 Yuri-B	Feb-86			not given	3 axis
				BS3 "Yuri"	Bs3 Yuri-A	Aug-90	1990-77A		1115	3 axis
					Bs3 Yuri-B	Aug-91	1991-60A		1115	3 axis
				CS2 "Sakura"	CS2 Sakura-A	Feb-83			not given	
					CS2 Sakura-B	Aug-83			not given	
				CS3 "Sakura"	CS3 Sakura-A	Feb-88			350	spin
					CS3 Sakura-B	Sep-88			350	spin
	Telesat Canada	Canada	Ontario	Anik C	Anik C1	Apr-85			633	spin
					Anik C2	Jun-83			633 BOL	spin
					Anik C3	Nov-82			625 BOL	spin
					Anik D1	Aug-82			655	spin
					Anik D2	Nov-84			649 BOL	spin
				Anik E	Anik E1	May-91	1991-67A		2930	not given
					Anik E2	Sep-91	1991-26A		not given	not given
Operational Regional Networks										
	Arab Satellite Communicat	Saudi Arabi	Ryadh	Arabsat	Arabsat 1A	Feb-85			680	3 axis
					Arabsat 1B	Jun-85			680	3 axis
					Arabsat 1C	Feb-92	1992-10B		680 or 1310	3 axis
	Asia Satellite Communicat	China-Hong	HongKong	Asiasat	AsiaSat 1	May-90	1990-30A		652	spin
	Eutelsat European Tele. Sa	France	Paris	Eutelsat 1	Eutelsat 1-F1	Jun-83			512/617	3 axis
					Eutelsat 1-F2	Aug-84			550/677	3 axis
					Eutelsat 1-F4	Sep-87			550	3 axis
					Eutelsat 1-F5	Jul-88			550	3 axis
				Eutelsat II	Eutelsat II-F1	Aug-90	1991-79B		1038	3 axis
					Eutelsat II-F2	Jan-91	1991-3B		1038	3 axis
					Eutelsat II-F3	Dec-91	1991-83A		1038	3 axis

					Eutelsat II-F4	Jul-92			1038	3 axis
					Eutelsat II-F5	planned			1038	3 axis
					Eutelsat II-F6	planned			1038	3 axis
Operational International Networks										
	Columbia Comm. Corp.	USA	Honolulu	TDRSS	TDRSS-4	Mar-89			2400	3 axis
					TDRSS-5	Aug-91			2400	3 axis
	Inmarsat Int. Maritime Sat	United King	London	Inmarsat-2	Inmarsat 2-F1				690	3 axis
					Inmarsat 2-F2	Mar-91			690	3 axis
					Inmarsat 2-F3		1991-84B		690 or 824	3 axis
					Inmarsat 2-F4	May-92	1992-21B		690 or 824	3 axis
	Intelsat Int. Telecomm. S	USA	Washington D.C.	Intelsat 5	Intelsat 501	May-81			1020 to 1090	3 axis
					Intelsat 502	Dec-80			1020 to 1090	3 axis
					Intelsat 503	Dec-81			1020 to 1090	3 axis
					Intelsat 504	Mar-82			1020 to 1090	3 axis
					Intelsat 505	May-83			1020 to 1090	3 axis
					Intelsat 506	May-83			1020 to 1090	3 axis
					Intelsat 507	Oct-83			1020 to 1090	3 axis
					Intelsat 508	Mar-84			1020 to 1090	3 axis
				Intelsat 5A	Intelsat 510	Mar-85			1160	3 axis - M. wheel
					Intelsat 511	Jun-85			1160	3 axis
					Intelsat 512				1160	3 axis
					Intelsat 513	May-88			1160	3 axis
					Intelsat 515				1160	3 axis
				Intelsat 6	Intelsat 601	Oct-91			2546	spin
					Intelsat 602	Oct-89			2546	spin
					Intelsat 603	Mar-90			2546	spin
					Intelsat 604	Jun-90	1990-56A		2546	spin
					Intelsat 605	Aug-91	1991-55A		2546	spin
				Intelsat K	Intelsat K	Jun-92				
	Intersputnik - International	Russia	Moscow		Gorizont 15 (Stasionar 4)	listed under Russian Postal see lines 100 - 101 above				
					Gorizont 16 (Stasionar 13)					
	Panamsat	USA	Greenwich, Ct.	PAS-1	PAS-1	Jun-88			1560	3 axis
Direct Broadcast Satellite Systems										
	British Sky Broadcasting	United King	Middlesex	Marcopolo	Marcopolo I	Aug-89				
					(sold to Norwegian Telecom)					
	Norwegian Telecom			Marcopolo	Marcopolo II					
				Bifrost	BSB2 (same satellite as line above?	Aug-90	1990-74A		1250	spin

	Deutsch Bundespost Telec	Germany	Bonn	(see TV-SAT2 above)						
	European Space Agency			Olympus	Olympus I	Jul-89				3 axis
				Marecs	Marecs A	Dec-81		13010	466	
					Marecs B2			15386	466	
	Hispasat	Spain	Madrid	(see Hispasat listing above)						
	Optus Comm. Limited	Australia	Sydney	(see above)						
	Societe Europeene Des Sa	Luxembourg		Astra	Astra 1A	Dec-88			1045	3 axis
					Astra 1B	Mar-91	1991-15A		1500	3 axis
	Swedish Space Corp.	Sweden	Solna	Tele-X	Tele-X	May-89			1280	3 axis
	Telecomm. Sat. Corp. of Ja	Japan	Tokyo	(see BS-3 listing above)						
	Telediffusion De France	France	Paris	DBS	TDF1					
					TDF2	Jul-90	1990-63A		2096	
Other										
	European Meteorological Services				Meteosat 5					
	Russia				Cosmos 2155 - telecomm.	Sep-91	1991-64A		2150	
					Cosmos 2172	Nov-91	1991-79A		2150	
					Cosmos 2085 - possibly Potok Com	Jul-90	1990-61A		2150	

Manufacturer & Model	Launch Vehicle	Engineering Life (yrs)	Calculated End of Life	End of Life Notes	Degrees East	Degrees West	World Sat. Dir. E/W	Inclin.	Notes	
GE Astrospace	Delta II	12	1993			139	139W			
Hughes HS 376	Delta 3920	10	1993			96	96W			
Hughes HS 376	STS	10	1994			85	85W			
Hughes HS 376	STS		1995			123	123W			
Hughes HS351	Atlas Centaur	7	1983	still op. (93)		17	76W	yes		
Hughes HS351	Atlas Centaur	7	1988	still op. (93)		17	76W	yes		
Hughes HS 376	Delta					97	97W	yes		
Hughes HS 376	STS? Delta					95	95W	yes		
					345	15		yes. 9.6		
								yes. 7.1		
								yes, 8.8		
Siemens, MBB [2]	Ariane 44L	10	1999		23.5	336.5	23.5E			
Siemens, MBB [2]	Ariane 4	10	2000		28.5	331.5	28.5E			
Siemens, MBB [2]	Delta II	10	2002		33.5	326.5	33.5E			
Eurosatellite	Ariane 44L	10	1999			19	19W			
Spar Aerospace	Ariane 3	8				65	65W			
Hughes HS 376	Ariane 3	8				70	70W			
Matra-Marconi, Alcatel	Ariane 3	7				5	5W			
Matra-Marconi, Alcatel	Aerospace	10	2001		3 east??	8	8W			
Matra-Marconi, Alcatel	Aerospace	10	2002		3 east??	5	5W			
Matra-Marconi, Alcatel	Aerospace									
GE Astrospace	Delta	10	2000			137	137W			
GE Astrospace	Delta ?	12	2002			131				
GE Astrospace	Ariane	12	2002			135				
GE Astrospace	Delta 394	10	1993			131	131W			
GE Astrospace	Delta 394	10	1993			72	72W			

GE Astrospace	STS	10	1985			85	85W			
GE Astrospace	STS	10	1986			81	81W			
GE Astrospace	Ariane 3	10	1994			69	69W			
GE Astrospace	Ariane 3	10	1998			87	87W			
GE Astrospace	Ariane	10	2001			101	101W			
GE Astrospace	Ariane 3	10	1995			103	103W			
GE Astrospace	Ariane 3	10	1996			125	125W			
GE Astrospace	Ariane 3	10	1998			93	93W	yes		
GE Astrospace	Ariane	10	1990			105 or 125??	105W			
GE Astrospace	STS	9	1994			128	128W			
GE Astrospace	Delta 2					101				
Matra Marconi, Eurost	Ariane 4	12 ? typo?	2004			30	30W			
							30W			
Hughes HS 376	STS					91				
Hughes HS 376	Ariane					123				
Hughes 393	Ariane 44L					97 or 99??				
	Delta	7	still oper. in 91		269	91				
	Delta 3920	10	still oper. in 91		261	99				
	Delta		still oper. in 91		237.5	122.5				
Hughes HS 376	Delta 3920	10	1993			133	133W			
Hughes HS 376	Delta 3920	10	1993			74	74W			
Hughes HS 376	Delta 3920	10	1994			93.5	93.5W			
Hughes HS601	Ariane	12	2005			99	99W		replaces Westar IV	
Hughes HS 376	Atlas	10	2002			125	125W			
Hughes HS 376	Delta or Ariane	10	2000			91 or 99 ??	99W			
Hughes HS601	Ariane	12	2004			91			replaces Westar 3 and SBS 4	
Hughes	STS						15W			
Hughes	STS						73E			
Hughes	STS						105W			
Hughes	STS						177W			
	Delta 3910									
	STS									
Ford Aerospace	Ariane V26	unusable since 1	unusable							
Ford Aerospace	Delta 4925	7	1997		83	277	83E			
ISRO(Govern. of India)	Ariane	9	2001		74	286	74E			
ISRO(Govern. of India)	Ariane	7								

ISRO(Govern. of India)		7								
Alenia	Ariane	7	1998		13.2	346.8	13.2E			
Hughes HS393	Ariane 4	10	1999		150	210	150E			
Hughes HS393	Titan 3	10	2000		154	206	154E			
	Long March 3	4	still op 1/93		125	235	125E			
					103	257				
	Long March 3	7	1993		87.5	272.5	87.5E			
	Long March 3	10	2000		98	262				
	CZ-3				98	262				
	Proton	5	1991		40	320	40E			
	Proton	5	1993		346	14	14W			
	Proton	5	1993		80	280	80E			
	Proton	5	1994		53	307	53E			
	Proton	5	1994		140	220	140E			
	Proton	5	1994		96.5	263.5	96.5E			
	Proton	5	1995		20	340	90E			
	SL-12				40	320				
	SL-12				103	257				
	SL-12				80	280				
	SL-4				103	257				
		5			35	325	35E			
		5	1993		85	275	85E			
		5			25	335	25E			
		5	1994		45	315	45E			
		5	1991		190	170	170W			
		5			128	232	128E			
		5	1995		70	290	70E			
		5	1995		49	311	49E			
		3	1991		99	261	99E	see note	collocated	
		3	1991		99	261	99E	see note	collocated	
					see note			high inclinatior	very elliptical orbit, non-GEO	
	STS	7	1992		160	200	160E			
	STS	7	1992		156	204	156E			
Hughes	Ariane 3	7	1994		164	196	164E			
Hughes	Long March 2E	17	2009			160	160W			
Hughes		14				156 (scheduled)				

Hughes HS 376	STS	8	retired 1990		118	242	118E			
Hughes HS 376	Delta 3920	8	1995		113	247	113E			
Hughes HS 376	Delta 6925	8	1998		108	252	108E			
Space Systems/Loral	Ariane	10	2002		158	202 (scheduled)				
Space Systems/Loral	Ariane	10	2002		162	198	162E			
Hughes HS 376	STS	10	1995			113.5	113.5W			
Hughes HS 376	STS	10	1995			116.8	116.8W			
Hughes HS 601	Ariane	14	2007			109.2				
not given	NASDA N-II	5	1991		110	250				
GE	H1	7	1997 (elect.probs)		110	250	110E			
not given	NASDA N-II	7	2000		110	250	110E			
	NASDA N-II	5	1988 (still op. 1/93)		127	233	128.5E			
	NASDA N-II	5	1988 (still op. 1/93)		128.5	231.5	126.5E			
	NASDA N-II	7	1995		128	232	131.5E			
	NASDA N-II	7	1995		132	228	136E			
Hughes	STS	13	1998				107.5W	yes ?		
Hughes	STS	8.5	1992				110W	yes ?		
Hughes	STS	9	1991				114.9W	yes?		
Spar Aerospace	Delta 3920	8	1990				104.5W	yes?		
Spar Aerospace	STS	9	1993				111W	yes?		
Spar Aerospace	Ariane	12	2003			111.1	111.1W			
Spar Aerospace	Ariane	12	2003			107.3	107.3W			
Aerospatiale & Loral Sp	Ariane 3	7	1992		19	341	19E			
Aerospatiale & Loral Sp	STS	7	1992		26	334	26E			
Aerospatiale & Loral Sp	Long March 3 ?	7	1999		31	329				
Hughes HS 376	Long March 3	9 to 10	2000		105.5	254.5	105.5E			
British Aerospace	Ariane 1	7	1990		25.5	334.5	25.5E	yes		
British Aerospace	Ariane 3	7	1991		1	359	1E	yes		
British Aerospace	Ariane 3	7	1994		36	324	36E			
British Aerospace	Ariane 4	7	1995		21.5	338.5	21.5E			
Aerospatiale	Ariane 4-V38	8.5	1999		13	347	13E			
Aerospatiale	Ariane 4	8.5	2000		10	350	10E			
Aerospatiale	Atlas Centaur	8.5	2000		16	344	16E			

Aerospatiale	Ariane 4	8.5	2001		7	353	7E			
Aerospatiale		8.5			36	324 (scheduled)				
Aerospatiale		8.5			13	347 (scheduled)				
TRW	STS	10	1999			41	41W			
TRW	STS	10	2001			174.3	174.3W			
British Aerospace	Delta 2	10			64.5	295.5	64.5E			
British Aerospace	Delta	15	2006			15.5	15.5W			
British Aerospace	Ariane	10	2001		178	182	178E			
British Aerospace	Ariane	10	2002			55	55W			
Ford Aerospace	Atlas/Centaur	7	1988		91.5	268.5	91.5E	yes		
Ford Aerospace	Atlas/Centaur	7	1987			21.5	21.5W	yes		
Ford Aerospace	Atlas/Centaur	7	1988			177	177W	yes		
Ford Aerospace	Atlas/Centaur	7	1989			40.5	40.5W	yes		
Ford Aerospace	Atlas/Centaur	7	1990		66	294	66E	yes		
Ford Aerospace	Atlas/Centaur	7	1990			50	50W	yes		
Ford Aerospace	Ariane	7	1990		57	303	57E	yes		
Ford Aerospace	Ariane	7	1991		180	180	180E	yes		
Ford Aerospace	Atlas/Centaur	7	1992			174	174W			
Ford Aerospace	Atlas/Centaur	7			177	183	177E			
Ford Aerospace	Atlas/Centaur	7				1	1 W			
Ford Aerospace	Ariane	7				53	53W			
Ford Aerospace	Ariane	7				18	18W			
Hughes	Ariane	13	2004			27.5	27.5W			
Hughes	Ariane	13	2002		63	297				
Hughes	Titan	13	2003		34.5	325.5	34.5E	yes		
Hughes	Titan	13	2003		60	300	60E			
Hughes	Ariane	13	2004		24.5	335.5	24.5E			
GE Astro Series 5000	Atlas Centaur					21.5	21.5W			
GE Astro Series 3000	Ariane 401	13.25	2001			45	45W			
	Delta I						30W			
						31	30W			
Hughes	Delta 6925	10	2000		329 ?					

British Aerospace	Ariane 3						19W			
Brit. Aersp., Aerospati	Ariane				19.7	340.3		yes, 4.7		
Brit. Aersp., Aerospati	Ariane				304.5	55.5		2.6		
GE Astrospace	Ariane 4	12.4	2001				19.2E			
GE Astrospace	Ariane 4	10	2001		19.2	340.8	19.2E			
Aerospatiale, SAAB, et	Ariane 2	8	1997		5	355				
	Ariane 2				341	19	19W			
	Ariane 44L				341	19	19W			
						4				
						23				
						14				

Sat Name	Mission		Status	Manufacturer	Payload Wt	Destination	DropOff Orbit	Est LEO Equivl	LV Class	Vehicle Selected	Life	Flts	1993	1994	1995	1996	1997	1998
ACTS	Comm - US	NASA Sponsored	O-O	MM Astro	3000	GEO	GTO	9,620		STS/TOS		1	1					
Afristar	Comm - Africa & Mid East	DBS Radio - Africa, Ground systems in production	Export License Applied	Afrispace	1850	GEO	GTO	5,932	Lite	LM	10	1		1				
Afristar - F/O	Comm - Africa & Mid East		Planned	Afrispace (?)	1850	GEO	GTO	5,932	Lite	LM ?	10	2						
AMSC	Comm - N.Amer Mobile	Joint NASA/Industry			2500			8,016				1		1				
AMOS	Comm- Israel	Small GEO Sat	In Work	IAI	1000	GEO		3,207	Lite	Ar4 - Amos1,		2			1	1		
AMOS - F/O	Comm- Israel		Planned		1000	GEO		3,207	Lite	Ar4		4						
ANIK-F	Comm - Canada				6500	GEO	GTO	20,843	ILV			4						
APSTAR	Comm - Asia		In Build	Hughes	3200	GEO	GTO	10,261	MLV	Long March		2		1	1			
APSTAR - F/O	Comm - Asia		Planned		3200	GEO	GTO	10,261	MLV	Long March		4						
ARABSAT	Comm - MidEast	201, 202 on contract	Planned	Aerospatiale	2000			6,413				2			2			
ARABSAT - F/O	Comm - MidEast		Planned		2000			6,413				4						
ARIES (Constellation Comm)	LEO Comm				2000	550x550, polar		6,413	MLV		5	240					16	16
ASIASAT	Comm - Asia	Asiasat-2 in '95	In Build	MM Astro	4000	GEO	GTO	12,826	MLV			2			1			1
ASIASAT - F/O	Comm - Asia				4000	GEO	GTO	12,826	MLV			2						
ASTRA	Broad- Europe	1D - 94, 1E-'95, 1F-'96	In Build	Hughes	5512	GEO	GTO	17,675	ILV			4	1	1	1	1		
ASTRA - F/O	Broad- Europe				5512	GEO	GTO	17,675	ILV			8						
AURORA	Comm - USA Alaska				4410	GEO	GTO	14,141	ILV			3						
BRAZILSAT	Comm- Brazil	B Series	In Build	Embratel (?)	3858	GEO	GTO	12,371	MLV	Ariane		2		2				
BRAZILSAT - F/O	Comm- Brazil				3858	GEO	GTO	12,371	MLV			4						
BS-3N	Comm - Japan (Broad)		In Build	MM Astro	2400	GEO	GTO	7,696	MLV			3		1				
BS-4	Broad - Japan				4410	GEO	GTO	14,141	ILV			6				2		
Calling Comm	LEO Comm				1600	378x378, 98.2deg		5,131	MLV		10	2310						210
Caribsat	Comm- Carribean	DBS Radio - Caribbean/ Afristar venture	US DoC listing - no Export license	Afrispace	1850	GEO	GTO	5,932	Lite	LM ?		1			1			
Caribsat - F/O	Comm- Carribean	DBS Radio - Caribbean/ Afristar venture	Planned	Afrispace (?)	1850	GEO	GTO	5,932	Lite	LM ?		2						
CELSAT	Copmm - US Mobile	GEO version of LEO cellsat	Proposed		3000			9,620				2						2
CELSAT-F/O	Comm - US Mobile	GEO version of LEO cellsat			3000			9,620				4						

B.3 PROPOSED NEW SATELLITE SYSTEMS

Sat Name	Mission		Status	Manufacturer	Payload Wt	Destination	DropOff Orbit	Est LEO Equivl	LV Class	Vehicle Selected	Life	Flts	1993	1994	1995	1996	1997	1998
CLASS	Comm- Brazil	DASA proposal for de-regulated Brazilian comsat			2000	GEO	GTO	6,413				1						1
CLASS- F/O	Comm- Brazil				2000			6,413				2						
COLUMBIA -DBS	Broad- US	DBS			2000			6,413				1					1	
COLUMBIA -DBS F/O	Broad- US				2000			6,413				2						
CONTINENTAL	Broad - US	No record of DBS License	Planned	Intraspace	2000			6,413				2				1	1	
CONTINENTAL - F/O	Broad - US		Planned		2000			6,413				4						
DFH (Dong Fang Hong) -3	Comm - China		Planned	FRC	3100	GEO	GTO	9,940	MLV			2		1	1			
DFH (Dong Fang Hong) -4 & F/O	Comm - China				3100	GEO	GTO	9,940	MLV			4						
DFS-3	Comm- Germany				3131	GEO	GTO	10,040	MLV			7						
Directsat	Broadcast- USA	Licensed 10 xpdrs @ 119W, 1 xpdr @110 W, 11 xpdrs @175W	2 In Build	MM Astro	3000			9,620				2			2			
Directsat - F/O	Broadcast- USA		Planned		3000			9,620				4						
DIRECTV	Broad - USA Hughes		1 O-O	Hughes	6835	GEO	GTO	21,917	ILV			2	1	1				
DIRECTV - F/O	Broad - USA Hughes		Planned	Hughes	6835	GEO	GTO	21,917	ILV			4						
DOMINION	Comm - Canada/US	Delta Reservation	In Build	MM Astro	2970	GEO	GTO	9,524	MLV	Delta		1			1			
DOMINION - F/O	Comm - Canada/US				2970	GEO	GTO	9,524	MLV			2						
Artemis /PSDE Sat/ DRS	Comm - ESA Data Relay	Also includes expt'l comm payloads	In Build - but budget probs	Alenia Spazio	4851	GEO	GTO	15,555	ILV			1				1		
Artemis /PSDE Sat/ DRS - F/O	Comm - ESA Data Relay	Assume ESA TDRS system			4851	GEO	GTO	15,555	ILV			4						
ECHOSTAR	Broad - US Comm	Licensed 11 xpdrs @ 119W	2 on contract	MM Astro	2000			6,413				3			2	1		
ECHOSTAR - F/O	Broad - US Comm		Planned		2000			6,413				14						
ECHOSTAR Expansion	Broad - US Comm		Options - Hi prob	MM Astro	2000			6,413				4					2	2
ELLISPO (Ellipsat)	LEO Comm				2000	1567x230, 63deg		6,413	MLV		5	24						8
ELLISPO (Ellipsat) - F/O	LEO Comm				2000	1567x230, 63deg		6,413	MLV		5	96						
EUROPESAT	Comm - Europe	Cancelled - German and France Pulled out		Matra	2000			6,413				0						

Sat Name	Mission		Status	Manufacturer	Payload Wt	Destination	DropOff Orbit	Est LEO Equivl	LV Class	Vehicle Selected	Life	Flts	1993	1994	1995	1996	1997	1998
EUROPESTAR	Comm - Europe	German firm - 3 lots applied for			2000			6,413				3						1
EUROPESTAR- F/O	Comm - Europe	German firm - 3 lots applied for			2000			6,413				6						
ETS	Expt'l Test Sat - Japan	6- Planned for H-2, 7 - planned for '97		Toshiba	1700	GEO	GTO	5,451	Lite	H-2		5		1			1	
EUTELSAT-2	Comm - Europe	F5-'94, F6-'94		Aerospatiale	3969	GEO	GTO	12,727	MLV		Ar	4	2	2				
EUTELSAT-3	Comm - Europe				4851	GEO	GTO	15,555	ILV			17						1
EUTELSAT "Hot Bird, HB-Plus"	Comm- Europe	Approved '93			4851	GEO		15,555				2		1		1		
EXPRESS	Comm - Intn'l	Intelsat Lease - 1 approved, 2 others optioned		Informcosmos	3000			9,620				3		1	1	1		
GALAXY	Comm - USA			Hughes	3087	GEO	GTO	9,899	MLV			0						
GALAXY-1R	Comm - USA				3087	GEO	GTO	9,899	MLV	Delta II		1			1			
GALAXY-F/O	Comm - USA				3087	GEO	GTO	9,899	MLV			4						
GE	Comm - USA	GE Americom		MM Astro	2000			6,413		Ar4		1				1		
GE- F/O	Comm - USA	GE Americom			2000			6,413				2						
GLOBALSTAR (Loral/Qualcomm)	LEO Comm				2000	750x750, 55 deg		6,413	MLV		7.5	192				16	16	16
Gramsat	Broad - India	Indian Educational DBS Sat	Expect Approval '94	ISRO	1000	GEO		3,207		PSLV		1					1	
Gramsat - F/O	Broad - India	Indian Educational DBS Sat			1000			3,207				2						
GSTAR		MM Data - no Matches - GTE??? Believed out of business			1500			4,810				3					1	2
HISPASAT	Comm - Spain/ Europe				4575	GEO	GTO	14,670	ILV			3	1					
INDOSTAR	Broad - Indonesia	Indonesian DBS - 5 xpdrs (3 TV, 2 radio), 4 slot applications - 1 sat announced Small GEOsat	Planned	ITI/CTA	1000	GEO		3,207				1				1		
INDOSTAR - F/O	Broad - Indonesia	Indonesian DBS	Planned		1000	GEO		3,207				5						
INMARSAT	Comm - Int'l Inmarsat				2800	GEO	GTO	8,978	MLV			0						
INMARSAT	Comm - Int'l Inmarsat			MM/ Marconi	4850	GEO	GTO	15,552	ILV			4		1	1	1	1	
INMARSAT - F/O	Comm - Int'l Inmarsat				4850	GEO	GTO	15,552	ILV			8						
INMARSAT-P	Comm- Int'l				2000			6,413				15						5
INMARSAT-P- F/O	Comm- Int'l				2000			6,413				30						

Sat Name	Mission		Status	Manufacturer	Payload Wt	Destination	DropOff Orbit	Est LEO Equivl	LV Class	Vehicle Selected	Life	Flts	1993	1994	1995	1996	1997	1998
INSAT-2AB	Comm/ Obs - India				4189	GEO	GTO	13,432	ILV			1	1					
INSAT-2CE	Comm/ Obs - India				4410	GEO	GTO	14,141	ILV			5		1	1	1		
INSAT- F/O	Comm/ Obs - India				4410	GEO	GTO	14,141	ILV			8						
INTELSAT F/O F1-6	Comm - Int'l Intelsat				12100	GEO	GTO	38,800	HLV			7						
INTELSAT VII F1-5	Comm - Int'l Intelsat	7F1- '93	Ordered	Loral	7950	GEO	GTO	25,492	HLV	Ar4- F1, F2 LM - F3		15	1	2		2		
INTELSAT VIIA F6-9	Comm - Int'l Intelsat	7AF7-'93	Ordered	Loral	10800	GEO	GTO	34,631	HLV	Mixed		10			1	1		
INTELSAT VIII F1-5	Comm - Int'l Intelsat		Ordered	MM Astro	8200	GEO	GTO	26,294	HLV	Ar4 - 801/ 802, TBD		11				2	1	
INTELSAT-K	Comm - Int'l Intelsat				6441	GEO	GTO	20,654	ILV			0						
IRIDIUM	LEO Comm			Lockheed	922	765	90	2,956	MLV		5	88			22	22	22	
IRIDIUM - F/O	LEO Comm					765	90	0	MLV		5	286						
ITALSAT	Comm - Italy		In Build	Alenia Spazio	3969	GEO	GTO	12,727	MLV			2		1	1			
ITALSAT - F/O	Comm - Italy				3969	GEO	GTO	12,727	MLV			4						
JC-SAT	Comm - Japan	Company reorganizing			5027	GEO	GTO	16,119	ILV			9			1			1
KOREASAT	Comm - Korea				3528	GEO	GTO	11,313	MLV			6			2			
Leo One Panamericana	LEO Comm Latin America				330	770x770, 80 deg		1,058	MLV		5	120			6	6		
LEOSAT	LEO Comm				110			353				24						8
LEOSAT- F/O	LEO Comm				110			353				48						
LOCSTAR	Position - Europe	MM Data - but Believed dead		Matra	2000			6,413				0						
LORAL DBS	Broad- US Comm	MM Data - no confirmation		Loral	2000			6,413				3			1	1	1	
LORAL DBS - F/O	Broad- US Comm	MM Data - no confirmation		Loral	2000			6,413				6						
MELITASAT	Comm - Malta	Ku-Band sat filed			2000			6,413				2					1	1
MELITASAT - F/O	Comm - Malta				2000			6,413				4						
MEXICO	Broad - Mexico	MM Data - no confirmation	Current Contract	MM Astro	2000			6,413				1			1			
MEXICO - F/O	Broad - Mexico	MM Data - no confirmation	Current Contract	MM Astro	2000			6,413				2						
MEASAT	Comm - Malaysia		Hughes		4000	GEO	GTO	12,826	MLV			1			1			
MEASAT - F/O	Comm - Malaysia				2000	GEO	GTO	6,413	MLV			4						
MSAT	Comm - Canada	MSAT-1 - '94		Spar/Hughes	5512	GEO	GTO	17,675	ILV			2		1	1			
MSAT - F/O	Comm - Canada				5512	GEO	GTO	17,675	ILV			4						

Sat Name	Mission		Status	Manufacturer	Payload Wt	Destination	DropOff Orbit	Est LEO Equivl	LV Class	Vehicle Selected	Life	Flts	1993	1994	1995	1996	1997	1998
MUGUNGHWA (see Koreasat)		MM Data		MM Astro				0				0						
NAHUEL	Comm - Argentina	Currently Used Leased Sat			4000	GEO	GTO	12,826	MLV			2				1		1
NAHUEL - F/O	Comm - Argentina				4000	GEO	GTO	12,826	MLV			4						
NATO-IVB	Comm - NATO				3159	GEO	GTO	10,130	MLV			1	1					
NATO-F/O	Comm - NATO				3000	GEO	GTO	9,620	MLV			2						
NILESAT	Comm - Egypt				2000	GEO		6,413				1					1	
NILESAT- F/O	Comm - Egypt				2000	GEO		6,413				2						
NSTAR	Comm- Japan			Loral	7000	GEO	GTO	22,446	ILV			2			2			
NSTAR - F/O	Comm- Japan				7000	GEO	GTO	22,446	ILV			4						
ODESSEY (TRW)	LEO Comm				2500	5400x5400, 55deg		8,016	MLV		15	24					4	4
ODESSEY (TRW) - F/O	LEO Comm				2500	5400x5400, 55deg		8,016	MLV		15	12						
OPTUS	Comm - Austrailia				5400	GEO	GTO	17,316	ILV			4						
ORBCOMM	LEO - Msg	Store/dump messaging			110			353				24				8	8	8
ORBCOMM-F/O	LEO - Msg				110			353				96						
ORION	Comm - Int'l US Comm'l			BAe	5000	GEO	GTO	16,033	ILV	Atlas		2		1			1	
ORION - F/O	Comm - Int'l US Comm'l				5000	GEO	GTO	16,033	ILV			4						
PACIFCOM	Comm - Int'l US	TRW Follow-on to Columbia Comm	Planned	TRW	2000			6,413				1			1			
PACIFICOM - F/O	Comm - Int'l US		Planned	TRW	2000			6,413				2						
PACSTAR (New Guinea)	Comm - Trans Pac	No data since '92	Planned		3087	GEO	GTO	9,899	MLV			1					1	
PACSTAR (New Guinea) - F/O	Comm - Trans Pac				3087	GEO	GTO	9,899	MLV			2						
PAKISTAN	Comm - Pakistan	Bid Request mid '93			3000	GEO	GTO	9,620	MLV			1						1
PAKISTAN - F/O	Comm - Pakistan				3000	GEO	GTO	9,620	MLV			2						
PALAPA-B	Comm - Indonesia				2866	GEO	GTO	9,190	MLV			0						
PALAPA-C	Comm - Indonesia	2 Firm, 1 option ('99)		Hughes	4000	GEO	GTO	12,826	MLV		Ar	2			1	1		
PALAPA-F/O	Comm - Indonesia			Hughes	4000	GEO	GTO	12,826	MLV			5						
PAS (Pan Am Sat)	Comm - Int'l Trans Pacific			Hughes	7430	GEO	GTO	23,825	ILV	Ar		3		2	1			
PAS (Pan Am Sat) - F/O	Comm - Int'l Trans Pacific				7430	GEO	GTO	23,825	ILV			6						
PHILCOMSAT (PhilippineSat)	Comm - East Asia	Philippine Sat -- Announce Nov /93			2000			6,413				1					1	

Sat Name	Mission		Status	Manufacturer	Payload Wt	Destination	DropOff Orbit	Est LEO Equivl	LV Class	Vehicle Selected	Life	Flts	1993	1994	1995	1996	1997	1998
PHILCOMSAT- F/O	Comm - East Asia	Philippine Sat -- Announce Nov /93			2000			6,413				2						
RASCOM	Comm - Africa	Regional African Space Comm - No data since '92			2000			6,413				1					1	
RASCOM - F/O					2000			6,413				2						
RIMSAT	Comm - Int'l	Pac Basin -- use of Russian sats	1 O-O, others planned	Informcosmos	3000			9,620		Proton		6	1	1	1	2	1	
RIMSAT - F/O	Comm - Int'l				3000			9,620				14						
Romantis	Comm - Europe	Bonn-based German/Russian venture - currently used leased sats			3000			9,620				7					2	3
Romantis - F/O	Comm - Europe				3000			9,620				14						
SAJAC (Sat Japan Corp.)	Comm - Japan			Hughes	6000	GEO	GTO	19,239	ILV			2		2				
SAJAC (Sat Japan Corp.) - F/O	Comm - Japan				6000	GEO	GTO	19,239	ILV			4						
SARIT	Broad - Italy	Italian DBS Sat - Go/no-go early '94	Planned	Alenia Spazio	2000	GEO	GTO	6,413				1				1		
SARIT - F/O	Broad - Italy		Planned		2000			6,413				2						
SATCOM - H	Comm - USA			MM Astro	3800	GEO	GTO	12,185	MLV			1			1			
SATCOM - F/O	Comm - USA				3800	GEO	GTO	12,185	MLV			7						
SEYSAT	Comm - Indian Ocea	Seychelles Islands - 2 slots filed for			2000			6,413				2					1	1
SEYSAT - F/O	Comm - Indian Ocea	Seychelles Islands - 2 slots filed for			2000			6,413				2						
Simon Bolivar	Comm - S. America	Venezulan C-Band System 3 slots filed for			2000			6,413				3					1	1
Simon Bolivar - F/O	Comm - S. America	Venezulan C-Band System 3 slots filed for			2000			6,413				6						
SIRCAL	Comm - Italy	Defense and Civil Gov't Comm - Phase C/D start '93		Alenia Spazio	2000			6,413				1				1		
SIRCAL - F/O	Comm - Italy				2000			6,413				2						
SKYNET-F/O	Comm - UK				4000	GEO	GTO	12,826	MLV			8					1	1
SOLIDARIADAD	Comm - Mexico		In Build	Hughes	6112	GEO	GTO	19,599	ILV	Ar4		2	1	1				
SOLIDARIADAD - F/O	Comm - Mexico		Planned		6112	GEO	GTO	19,599	ILV			4						

Sat Name	Mission		Status	Manufacturer	Payload Wt	Destination	DropOff Orbit	Est LEO Equivl	LV Class	Vehicle Selected	Life	Flts	1993	1994	1995	1996	1997	1998
SOV CAN STAR	International Comm	Soviet/Canadian Venture - 5 sats planned (3 CIS, 2 other)	Planned	Spar/NPO	3000			9,620				5				1	2	2
SOV CAN STAR - F/O	International Comm				3000			9,620				10						
SPACENET	Comm - Puerto Rico	Assumed Out of Business			5455	GEO	GTO	17,492	ILV			4						
Spaceway	Comm - US	Ka Band "Info highway in the sky"	Planned - Hughes		3000	GEO	GTO?	9,620			10?	2						2
Spaceway- F/O	Comm - US		Planned - Hughes		3000	GEO	GTO?	9,620			10?	4						
STARSAT	??	MM Data - No confirm Assume F/O to STAR-TV in East Asia, with 9+ xpdrs leased			2000			6,413				1					1	
STARSAT - F/O	??				2000			6,413				2						
SUNSAT	LEO Exptl	S. African smallsat			500			1,603				1		1				
SUPERBIRD-C	Comm - Japan			Loral	5494	GEO	GTO	17,617	ILV			2		1				
SUPERBIRD - F/O	Comm - Japan				5494	GEO	GTO	17,617	ILV			4						
TELECOM-2	Comm - France	2C-'94, 2D-'96		Matra	4850	GEO	GTO	15,552	ILV			2		1		1		
TELECOM - F/O	Comm - France				4850	GEO	GTO	15,552	ILV			6						
TELSTAR-4	Comm - USA	401-'93, 402-'94, 403-'95	In Build	MM Astro	6835	GEO	GTO	21,917	ILV			3	1	1	1			
TELSTAR - F/O	Comm - USA				6835	GEO	GTO	21,917	ILV			6						
TEMPO	Broad - US		Contract	Loral	2000			6,413				2				2		
TEMPO - F/O	Broad - US				2000			6,413				4						
THAISAT / THAICOM	Comm - Thailand	HS-376 Lite	O-O/ In build	Hughes	2866	GEO	GTO	9,190	MLV	Ar4		2	1	1				
THAISAT / THAICOM - Expand	Comm - Thailand		Planned		2866	GEO	GTO	9,190	MLV			1					1	
THAISAT / THIACOM - F/O	Comm - Thailand				2866	GEO	GTO	9,190	MLV			6						
TONGASAT - see Rimsat		Rimsat operates in Tongasat slots						0				0						
TURKSAT	Comm - Turkey		In Build	Aerospatiale	4851	GEO	GTO	15,555	ILV	Ar4	12	2		2				
TURKSAT - Expand	Comm - Turkey		Planned		4851	GEO	GTO	15,555	ILV			1					1	
TURKSAT - F/O	Comm - Turkey		Planned		4851	GEO	GTO	15,555	ILV			6						

Sat Name	Mission		Status	Manufacturer	Payload Wt	Destination	DropOff Orbit	Est LEO Equivl	LV Class	Vehicle Selected	Life	Flts	1993	1994	1995	1996	1997	1998
UNICOM	Comm - USA	No confirming data			3597	GEO	GTO	11,534	MLV			2		1	1			
UNICOM - F/O	Comm - USA				3597	GEO	GTO	11,534	MLV			4						
VITA	LEO Msg	No data for 93, MM list Smallsat Piggyback?	1 O-O					0				0						
ZOHREH	Comm - Iran			Alcatel	4410	GEO	GTO	14,141	ILV			6			1	1		
ZOHREH - F/O	Comm - Iran				4410	GEO	GTO	14,141	ILV			4						
TestSum											lbs	#REFI	198715	513241	#####	#####	#####	1,624,573
											klbs	#REFI	199	513	522	573	549	1,625
											3yr ave		356	411	536	548	916	1,197
											Payloads		13	35	64	82	93	299

Sat Name	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
ACTS																						
Afristar																						
Afristar - F/O						1										1						
AMSC																						
AMOS																						
AMOS - F/O							1	1									1	1				
ANIK-F			2											2								
APSTAR																						
APSTAR - F/O						1	1									1	1					
ARABSAT																						
ARABSAT - F/O							1	1									1	1				
ARIES (Constellation Comm)	16			16	16	16			16	16	16			16	16	16			16	16	16	
ASIASAT																						
ASIASAT - F/O							1			1												
ASTRA																						
ASTRA - F/O					1	1	1	1							1	1	1	1				
AURORA		1										1										1
BRAZILSAT																						
BRAZILSAT - F/O					1	1									1	1						
BS-3N						1										1						
BS-4								2										2				
Calling Comm	210	210	210							210	210	210	210							210	210	210
Caribsat																						
Caribsat - F/O							1										1					
CELSAT																						
CELSAT-F/O										2										2		

Sat Name	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
CLASS																						
CLASS- F/O										1										1		
COLUMBIA -DBS																						
COLUMBIA -DBS F/O									1										1			
CONTINENTAL																						
CONTINENTAL - F/O								1	1									1	1			
DFH (Dong Fang Hong) -3																						
DFH (Dong Fang Hong) -4 & F/O					1		1								1		1					
DFS-3	1	1		1						1	1									1	1	
Directsat																						
Directsat - F/O							2										2					
DIRECTV																						
DIRECTV - F/O					1	1									1	1						
DOMINION																						
DOMINION - F/O								1										1				
Artemis /PSDE Sat/ DRS																						
Artemis /PSDE Sat/ DRS - F/O								2										2				
ECHOSTAR																						
ECHOSTAR - F/O							2	1	2	2							2	1	2	2		
ECHOSTAR Expansion																						
ELLISPO (Ellipsat)	8	8																				
ELLISPO (Ellipsat) - F/O					8	8	8			8	8	8			8	8	8			8	8	8
EUROPESAT																						

Sat Name	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
EUROPESTAR	1	1																				
EUROPESTAR- F/O										1	1	1								1	1	1
ETS		1				1				1												
EUTELSAT-2																						
EUTELSAT-3	2	2	1							1	2	2	1							1	2	2
EUTELSAT "Hot Bird, HB-Plus"																						
EXPRESS																						
GALAXY																						
GALAXY-1R																						
GALAXY-F/O				1		2										1						
GE																						
GE- F/O								1										1				
GLOBALSTAR (Loral/Qualcomm)					16	16	16					16	16	16					16	16	16	
Gramsat																						
Gramsat - F/O									1										1			
GSTAR																						
HISPASAT				1	1																	
INDOSTAR																						
INDOSTAR - F/O		1						1				1						1				1
INMARSAT																						
INMARSAT																						
INMARSAT - F/O						1	1	1	1							1	1	1	1			
INMARSAT-P	5	5																				
INMARSAT-P- F/O										5	5	5								5	5	5

Sat Name	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
INSAT-2AB																						
INSAT-2CE								1										1				
INSAT- F/O					1	1	1	1							1	1	1	1				
INTELSAT F/O F1-6		1	2	2	1							1										
INTELSAT VII F1-5					1	2	1	1							1	2	1	1				
INTELSAT VIIA F6-9							1	2	1								1	2	1			
INTELSAT VIII F1-5							1	2	1								1	2	1			
INTELSAT-K																						
IRIDIUM																						22
IRIDIUM - F/O		22	22	22			22	22	22			22	22	22			22	22	22			22
ITALSAT																						
ITALSAT - F/O						1	1									1	1					
JC-SAT	1						1			1	1						1			1	1	
KOREASAT						1	1									1	1					
Leo One Panamericana		12	12				12	12				12	12				12	12				12
LEOSAT	8	8																				
LEOSAT- F/O										8	8	8								8	8	8
LOCSTAR																						
LORAL DBS																						
LORAL DBS - F/O							1	1	1								1	1	1			
MELITASAT																						
MELITASAT - F/O									1	1									1	1		
MEXICO																						
MEXICO - F/O							1										1					
MEASAT																						
MEASAT - F/O							1	1									1	1				
MSAT																						
MSAT - F/O						1	1									1	1					

Sat Name	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
MUGUNGHWA (see Koreasat)																						
NAHUEL																						
NAHUEL - F/O								1		1								1		1		
NATO-IVB																						
NATO-F/O					1										1							
NILESAT																						
NILESAT- F/O									1										1			
NSTAR																						
NSTAR - F/O						1	1									1	1					
ODESSEY (TRW)	4													4	4	4						
ODESSEY (TRW) - F/O														4	4	4						
OPTUS				2										2								
ORBCOMM																						
ORBCOMM-F/O			8	8	8			8	8	8			8	8	8			8	8	8		
ORION																						
ORION - F/O						1			1							1			1			
PACIFICOM																						
PACIFICOM - F/O							1										1					
PACSTAR (New Guinea)																						
PACSTAR (New Guinea) - F/O								1										1				
PAKISTAN																						
PAKISTAN - F/O										1										1		
PALAPA-B																						
PALAPA-C																						
PALAPA-F/O	1						1			1							1			1		
PAS (Pan Am Sat)																						
PAS (Pan Am Sat) - F/O						1	1			1						1	1			1		
PHILCOMSAT (PhilippineSat)																						

Sat Name	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
PHILCOMSAT- F/O									1											1		
RASCOM																						
RASCOM - F/O									1										1			
RIMSAT																						
RIMSAT - F/O					1	2	2	2							1	2	2	2				
Romantis	2																					
Romantis - F/O									2	3	2								2	3	2	
SAJAC (Sat Japan Corp.)																						
SAJAC (Sat Japan Corp.) - F/O						2										2						
SARIT																						
SARIT - F/O								1										1				
SATCOM - H																						
SATCOM - F/O		1		1			1					1		1			1					1
SEYSAT																						
SEYSAT - F/O									1										1			
Simon Bolivar	1																					
Simon Bolivar - F/O									1	1	1								1	1	1	
SIRCAL																						
SIRCAL - F/O								1										1				
SKYNET-F/O									2			1							2			1
SOLIDARIADAD																						
SOLIDARIADAD - F/O					1	1									1	1						

Sat Name	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
SOV CAN STAR																						
SOV CAN STAR - F/O								1	2	2								1	2	2		
SPACENET							1		1								1		1			
Spaceway																						
Spaceway- F/O										2										2		
STARSAT																						
STARSAT - F/O									1										1			
SUNSAT																						
SUPERBIRD-C																					1	
SUPERBIRD - F/O	1			1							1										1	
TELECOM-2																						
TELECOM - F/O			1		1		1						1		1		1					
TELSTAR-4																						
TELSTAR - F/O					1	1	1								1	1	1					
TEMPO																						
TEMPO - F/O								2										2				
THAISAT / THAICOM																						
THAISAT / THAICOM - Expand																						
THAISAT / THIACOM - F/O					1	1			1						1	1			1			
TONGASAT - see Rimsat																						
TURKSAT																						
TURKSAT - Expand																						
TURKSAT - F/O							2		1								2		1			

Sat Name	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
UNICOM																						
UNICOM - F/O						1	1									1	1					
VITA																						
ZOHREH							1	1									1	1				
ZOHREH - F/O							1	1									1	1				
TestSum	1,418,057	1,297,647	1,243,321	282,073	499,851	662,280	680,939	443,697	384,475	1,513,180	1,373,165	1,397,593	1,226,647	360,676	407,902	608,451	565,502	443,697	480,672	1,603,926	1,493,392	1,321,225
	1,418	1,298	1,243	282	500	662	681	444	384	1,513	1,373	1,398	1,227	361	408	608	566	444	481	1,604	1,493	1,321
	1,447	1,320	941	675	481	614	596	503	780	1,090	1,428	1,332	995	665	459	527	539	497	843	1,193	1,473	1,407
	261	274	258	55	62	67	96	75	72	279	256	289	270	75	52	57	79	75	87	294	273	294

APPENDIX C SPACE MANUFACTURING APPENDIX

C.1 COMMERCIAL ORBITAL SERVICE MODULE TRADE STUDY

C.1.1 Introduction

The concept for a commercial space manufacturing and processing system involves use of an orbiting service module equipped with autonomous microgravity processing capabilities. The service module is designed to accommodate rendezvous and docking with a separate recovery module which carries product materials to the service module for processing; the processed products will then be returned to earth using the recovery module which separates from the service module and accomplishes deorbit and reentry. The service module is designed for a five year life, and is a complete spacecraft incorporating subsystems such as command and control, thermal control, electrical power, and guidance and control.

C.1.2 Scope of Trade Study

It has been suggested that due to the high power requirements projected for the service module (up to perhaps 20 kw usable power) a sun synchronous orbit allowing continuous solar exposure might be more efficient than a 28.5 deg orbit which involves shadowing and additional battery as well as solar array requirements. However, a given launch vehicle can inject more payload into the 28.5 deg orbit, so it is not obvious which is the best approach. Therefore, a trade study was made to investigate the various influences and to develop conclusions concerning the desired orbit. A range of 10-20 kw usable power was evaluated to investigate the effect of power on the choice of orbit. In addition, the power system mass was bounded by two approaches, 1) a combination of silicon (Si) solar arrays and nickel-cadmium (NiCd) batteries, and 2) a combination of gallium arsenide (GaAs) arrays and nickel-hydrogen (NiH2) batteries. Of course, it is possible that cost considerations would result in a mixed case, but cost trades were not included in the study. A more comprehensive assessment including launch vehicle type, detailed subsystem design, service module cost, and life cycle cost was beyond the scope of this study.

C.1.3 Discussion

For purposes of comparison, a 400 nm circular orbit was assumed; the launch vehicle capabilities were taken to be 4500 lbm to 98 deg sun synchronous and 6075 lbm to 28.5 deg. The approach is to determine the spacecraft mass requirements for the two orbits, thereby allowing for an evaluation of mass margin relative to the launch vehicle capability. Margin can be defined as allowable on-orbit mass for uses other than spacecraft subsystem functions.

The assumptions and values associated with the spacecraft power system are critical to the trade results. Several references (listed at the end) plus data from actual programs were used in the study, and use of a particular reference is indicated in parentheses. A Direct Energy Transfer (DET) power system (ref.2) is chosen along with solar arrays and secondary batteries. The equation for the solar array power requirement (ref.1) is:

$$P_a = PT_e / X_e T_d + P/X_d$$

where: P_a = power required from array during daylight period
P = required spacecraft power (assumed the same for daylight or eclipse)
T_e = length of eclipse period in minutes
X_e = efficiency of path from arrays through the batteries to the individual loads
T_d = length of daylight period in minutes
X_d = efficiency of path directly from arrays to the loads

The efficiency factors (X_e and X_d) are assumed to be 0.65 and 0.85 respectively (ref.1). The above equation for the array requirement is further modified to account for array degradation in the LEO environment. The degradation factors used are 3% per year for silicon and 2% per year for gallium arsenide (ref. 1). There is some uncertainty regarding solar array specific power, but the values were based on expected technology and information provided in the three references. For silicon arrays, a value of 30 watts/kg is used, and for GaAs a value of 48 watts/kg is used; the wattage requirement is obtained from the above solar array power equation. Although a full sensitivity analysis was not conducted, a discussion of sensitivity is provided later in the paper. Mass must also be allocated for electrical power system electronics (power control, conversion), and a value of 0.02 kg/watt is used (ref.3). It should be noted that the number of watts used in this relationship refers to the usable onboard spacecraft power (e.g. 20 kw). As a point of reference, the LMSC Bus 1 value is about 0.015 kg/watt.

Although the sun synchronous mission involves continuous solar array illumination, backup or auxiliary battery power is still required. It is assumed that a capability of 1000 watt-hours is provided for this purpose. Very few cycles are involved for the sun synchronous mission, therefore 100% will be used for depth of discharge (DOD) for NiH2 batteries and 80% for NiCd batteries (ref.1). For the 28.5 deg orbit with thousands of recharge cycles, the NiCd DOD is taken to be 25%, and a value of 0.9 is used for transmission efficiency between battery and load (ref.1). For NiH2 batteries, a 50% DOD is used (ref.1,3). The required battery mass is:

$$M_b = (\text{watt-hours})/(DOD^* X_t^* X_b)$$

where: M_b = battery mass in kg
X_t = transmission efficiency
X_b = battery mass factor in watt-hr./kg

For the sun synchronous orbit, the watt-hours are 1000; for the 28.5 deg orbit, the watt-hours are based on the required spacecraft power (e.g. 20 kw) applied over the duration of the eclipse period. For the 400 nm orbit, the eclipse period is 35 minutes out of the 100 minute total orbital period. The battery mass efficiencies used are 35 watt-hr./kg for NiCd and 50 watt-hr./kg for NiH2 (ref.1,4). For reference, the value for the Bus 1 NiH2 batteries is approximately 48 watt-hr./kg. The much smaller Clementine spacecraft uses a NiH2 battery at 47 watt-hr./kg.

The mass for the other spacecraft subsystems was estimated as a percentage of dry spacecraft weight, using the following relationships:

Structures & Mechanisms: 15% (ref. 1,2)
Guidance,Nav. & Control: 5% (ref.1, based on FLTSATCOM and HEAO data)
Comm. and Data Handling: 2.5% (ref.1, based on FLTSATCOM and HEAO)
Thermal Control : 1.5% (ref.1, based on FLTSATCOM and HEAO data)
Harness/wiring : 2.5% (ref.1)

C.1.4 Results

Figure C-1 shows the results for the cases included in the trade study. At the baseline 20 kw power level using the conventional Si/NiCd power system the 28.5 deg orbit is at a severe disadvantage due to the eclipse effects which drive up solar array and battery weight tremendously. At the lower 10 kw power level, both orbital cases show positive weight margins, but the sun synchronous orbit is still clearly superior - the additional injected mass at 28.5 deg is more than offset by the larger power system mass (especially batteries). Shifting to the more efficient GaAs/NiH2 power system significantly increases the payload mass margins, and the array/battery weight reductions are very large for the 28.5 deg case. However, the capability to the sun synchronous orbit is still noticeably greater at the 20 kw power level. As the power level decreases, the 28.5 deg case looks more attractive, and at the 10 kw level the 28.5 deg case with GaAs/NiH2 gains the edge. Of course, the 28.5 deg service module is still larger and presumably more expensive than for sun synchronous, so it may not be cost effective. A more detailed study would be required to determine where the cost crossover point occurs.

Orbit	Sun Sync	28.5 Deg	Sun Sync	28.5 Deg	Sun Sync	28.5 Deg	Sun Sync	28.5 Deg
Altitude (nm)	400	400	400	400	400	400	400	400
Usable Power	20 kw	20 kw	10 kw	10 kw	20 kw	20 kw	10 kw	10 kw
Solar Cell Type	Si	Si	Si	Si	GaAs	GaAs	GaAs	GaAs
Solar Array Power (BOL)	27.06 kw	46.11 kw	13.53 kw	23.05 kw	25.88 kw	44.11 kw	12.94 kw	22.05 kw
Battery Type	NiCd	NiCd	NiCd	NiCd	NiH2	NiH2	NiH2	NiH2
Battery Capacity (watt-hours)	1250	51852	1250	25926	1000	25926	1000	12963
Mass injected (lbm)	4500	6075	4500	6075	4500	6075	4500	6075
Required Mass (lbm)								
Struct. & Mech.	675	1538	675	911	675	911	675	911
GN&C	225	513	225	304	225	304	225	304
C&DH	112	256	112	152	112	152	112	152
Thermal Control	68	154	68	91	68	91	68	91
Wiring	112	256	112	152	112	152	112	152
Solar arrays	1989	3389	994	1695	1189	2026	595	1013
Batteries	79	3267	79	1634	44	1143	44	572
EPS electronics	882	882	441	441	882	882	441	441
Total (lbm)	4142	10255	2706	5380	3307	5661	2272	3636
Available Margin (lbm)	358	- 4180	1794	695	1193	414	2228	2439

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Figure C-1. Commercial Service Module Trade Results

C.1.5 Sensitivity Assessment

The power system mass is the major driver for service module total mass and thus the greatest influence on usable payload to orbit. If the array and/or battery efficiencies are less than assumed in the study, the results are tilted even more strongly toward the sun synchronous orbit due to the relatively larger increases in power system mass for the 28.5 deg case. It seems unlikely that silicon array and NiCd efficiencies will exceed values used in the study for GaAs/NiH2 systems, therefore the 28.5 deg orbit is not likely to be competitive even with improvements in Si/NiCd technology.

For the 28.5 deg orbit to be competitive with sun synchronous in terms of usable payload to orbit at the 20 kw level, an increase in efficiency of greater than 50% over values used in the study for GaAs/NiH2 systems is required. Of course, even in this event, the service module would be larger and presumably more costly than the sun synchronous version.

C.1.6 Conclusions

a. From the standpoint of usable mass to orbit, the sun synchronous orbit is superior to the 28.5 deg orbit at the 20 kw power level unless solar array and battery efficiencies much higher than today's GaAs/NiH2 technology are incorporated into the service module.

b. Using GaAs/NiH2 technology, the usable mass capability at the different orbits is equivalent only at the lower 10 kw power level. The 28.5 deg service module would still be larger and presumably more costly.

c. If use of the lower cost Si/NiCd power system is desired, the sun synchronous orbit is clearly superior over the 10-20 kw range.

Note: Refinements to the above trade study comparing orbit inclination preferences could involve consideration of two additional factors, i.e. the mass assigned to power conditioning equipment and the relative degree of radiation exposure.

In a dynamic and AC load environment with drastic cycling between battery and solar power in the low inclination case (LIC) and almost no cycling in the high inclination case (HIC), the design of power conditioning equipment for the LIC must be quite a bit more complex than the HIC. This complexity and additional mass, if included in the evaluation, would further favor the HIC.

A quantitative analysis of the relative degree of radiation exposure was evaluated using radiation environments derived from the NASA spacecraft radiation design models (AP8MIC and AE8MAX) for the worse case (high solar activity) steady Van Allen belts environment, plus the JPL special model for solar proton events (SPE). SPE's are catastrophic solar explosions that occur about 3-4 times per 11 years for a duration of about 2 days each time.

A satellite in low earth orbit can encounter low altitude lobes of the radiation belts. For the HIC orbit, both belts will be encountered. For the LIC orbit, the inner belt only will be encountered. The South Atlantic Magnetic Anomaly (shift of the center of the earth's magnetic axis towards Brazil) causes local distortion of the inner radiation belt. A LEO satellite in a LIC orbit will encounter this local inner belt distortion in each of about 15 orbits daily.

Two orbit cases were evaluated: LIC =400 nmi altitude, 28.5 deg. inclination, and HIC = 400 nmi altitude. 90 deg.inclination. The combined Van Allen and solar proton event dose was integrated over 7 years, assuming 75% confidence level that a total of 2-3 SPE's will access the spacecraft over the polar caps. The following table shows the accumulated dose in particles/sq cm for electrons of energy greater than 1 MeV, and protons of energy greater than 4 MeV.

	Electrons	Protons	Solar Protons
HIC	2.2 x 10^11	4.5 x 10^9	4 x 10^10
LIC	2.6 x 10^10	6.7 x 10^8	assumed none

The conclusion is that HIC will receive 10 times the total dose of these damaging components of radiation. However, these levels for HIC are two orders of magnitude lower than that which is encountered at GEO (about 2.0 x 10^13). The net result is that weather satellites are almost never damaged by radiation in their HIC orbit, unlike the GEO satellites. The difference between HIC and LIC, in our opinion, is not worth application of any extra shielding of significant mass, perhaps only to critical components . The designs of sun-synchronous orbit weather satellites, such as DMSP and NOAA, follow this practice and normally function without degradation in these polar LEO orbits perfectly well for between 5 and 7 years.

References

1. Space Mission Analysis and Design (J.R. Wertz and W.J. Larson, 1991)
2. Satellite Technology and Its Applications (P. Chetty, 1988)
3. TRW Space Data (1992)
4. Key Small Satellite Subsystem Developments (AIAA-90-3576 by J. Stuart and J. Gleave, 1990)

Page 1 D

Space Manufacturing/Processing Launch System Estimate (includes recovery module flights)

	2000	01	02	03	4	5	6	07	08	09	10
Drug Production	3	3	3	4	4	4	4	5	5	5	5
Biotechnology Production	3	3	3	3	3	3	3	4	4	4	5
University/Industrial Research	3	4	4	4	4	4	4	4	4	4	4
Materials Processing	3	3	3	3	4	4	4	4	4	4	4
Total	12	13	13	14	15	15	15	17	17	17	18
Total Annual Revenue (w/o profit)	534.4	578.9	578.9	617.2	661	661	661	700	700	700	741

		R&D		Prod			Launch System Unit Price ($M)																		
		Invstmt		Cost	≤12 flts		≤3 flts	≤6 flts	≤9 flts	≤12 flts		≤15 flts	≤18 flts											
Product / Year	aa	($M)		(aa)	/year		/year	/year	/year	/year		/year	/year	2000	01	02	03	4	5	6	07	08	09	10
Service Module	a	500	f	150	8.333	s.	33.33	16.67	11.1	8.3	c	8.667	7.222											
Auto Space Docking H/W		50	f	10	0.833		3.333	1.667	1.11	0.8	c	0.80	0.667											
Recovery Module	b, e	400	f	75	6.667		26.67	13.33	8.89	6.7	c	6.33	5.278											
Launch Vehicles		100		25	26.67		33.33	28.33	28.9	26.7		26.33	26.11											
Launch Site facilities		15	r	0.100	0.35		1.1	0.6	0.43	0.4		0.30	0.27											
Recovery Site facilities		5			0.083		0.333	0.167	0.11	0.1		0.067	0.056											
Program Ops Centers	d	2.5			0.042		0.167	0.083	0.06	0.0		0.033	0.028											
Recovery Site Tracking		0.5			0.008		0.033	0.017	0.01	0.0		0.007	0.006											
Total H/W Costs	t	1073			43.0	u.	98.3	60.87	50.6	43.0		42.54	39.63											
		Start up																						
Operations Costs		Costs		(ab)																				
Launch Operations	l	0.125	g	.030	0.032		0.038	0.034	0.03	0.03		0.032	0.031											
Payload Processing	m	0.05	h	.050	0.051		0.053	0.052	0.05	0.05		0.051	0.051											
Recovery Operations	n	0.125	i	.025	0.027		0.033	0.029	0.03	0.03		0.027	0.026											
Refurbishing Recovery Modules	p	0.125	j	1.061	1.063		1.069	1.065	1.06	1.06		1.063	1.062											
Mission Operations	q	0.100	k	.050	0.052		0.057	0.053	0.05	0.05		0.051	0.051											
Program Support		0.500	v	.313	0.321		0.346	0.33	0.32	0.32		0.32	0.319											
Total Operations Costs	t	1.025			1.546	u.	1.597	1.563	1.55	1.545		1.543	1.54											
Total Launch System Costs ($M	t	1074			44.53	u.	99.9	62.43	52.2	44.5		44.08	41.2	534.4	578.9	578.9	617.2	661	661.2	661.2	700	700	700	741

Notes:

aa. Production costs are on a per unit basis and 12 flights per year baseline.
ab. Operations cost on a per flight basis.
a. On-orbit manufacturing/processing module. Five year lifetime. Assume 1 operational module plus ground spare (1 year lead time for replacement units).
b. Reusable reentry module. 10 flights per module. Assume 1 operational module plus one spare (1 year lead time for replacement units).
c. Assumes two operational Modules. For >12 flight/year add one additional module.
d. Two POCs required. One at high inclination and one spare.
e. Includes two recovery modules
f. Cost for third operational recovery module.
g. Ten persons for two weeks each launch. Cost is on per launch basis
h. Eight persons for one month per launch.
i. Two pilots ($5K for each recovery) and four technicians ($20K for each recovery). Also includes three persons at $75K for 12 flights for recovery tracking.
j. Total ten techs at $750K/year less $20K of four techs time spent on recovery operations for 12 flights.
k. Eight persons (3 shifts and 1 alternate shift) $600K/year for 12 flights.
l. Ten persons for two months at $75K/year.
m. Four persons at $75K/year for two months.
n. Ten techs at $75K/year for two months.
p. Ten techs at $75K/year for two months.
q. Eight persons at $75K/year for two months.
r. Cost to refurbish launch site after launch.
s. Assume R&D investment cost times 20% ROI/year
t. Totals do not include ROI of 20%/year for five year amortization.
u. Launch costs per launch
v. Includes sustaining engineering, planning, program management (50 people full time at 75K/yr = 3.75M for 12 flights).

Space Manufacturing/Processing Launch System Estimate (includes recovery module flights)

	2000	01	02	03	04	05	06	07	08	09	10
Drug Production	3	3	3	4	4	4	4	5	5	5	5
Biotechnology Production	3	3	3	3	3	3	3	4	4	4	5
University/Industrial Research	3	4	4	4	4	4	4	4	4	4	4
Materials Processing	3	3	3	3	4	4	4	4	4	4	4
Total	12	13	13	14	15	15	15	17	17	17	18
Total Annual Revenue (w/o profit)	492.2	533.2	533.2	574.3	615.3	615.3	615.3	697.3	697.3	697.3	738.3

		R&D		Prod			Launch System Unit Price ($M)																		
		Invstmt		Cost	≤12 flts		≤3 flts	≤6 flts	≤9 flts	≤12 flts		≤15 flts	≤18 flts											
Product / Year	aa	($M)		(aa)	/year		/year	/year	/year	/year		/year	/year	2000	01	02	03	04	05	06	07	08	09	10
Service Module	a	500	f	150	8.333	s.	33.33	16.67	11.1	4.167	c	8.667	7.222											
Auto Space Docking H/W		50	f	10	0.833		3.333	1.667	1.11	0.833	c	0.80	0.667											
Recovery Module	b, e	400	f	75	6.667		26.67	13.33	8.89	8.333	c	6.33	5.278											
Launch Vehicles		100		25	26.67		33.33	28.33	28.9	26.67		26.33	26.11											
Launch Site facilities		15	r	0.100	0.35		1.1	0.6	0.43	0.35		0.30	0.27											
Recovery Site facilities		5	r	0.000	0.083		0.333	0.167	0.11	0.183		0.067	0.06											
Program Ops Centers	d	2.5	r	0.000	0.042		0.167	0.083	0.06	0.142		0.033	0.03											
Recovery Site Tracking		0.5	r	0.000	0.008		0.033	0.017	0.01	0.108		0.007	0.01											
Total H/W Costs	t	1073			42.98	u.	98.3	60.87	50.6	40.78		40.78	40.78											
		Start up																						
Operations Costs		Costs		(ab)																				
Launch Operations	l	0.125	g	.030	0.032		0.038	0.034	0.03	0.067		0.032	0.031											
Payload Processing	m	0.05	h	.050	0.051		0.053	0.052	0.05	0.026		0.051	0.051											
Recovery Operations	n	0.13	i	0.03	0.03		0.03	0.03	0.03	0.03		0.03	0.03											
Refurbishing Recovery Modules	p	0.125	j	1.061	1.063		1.069	1.065	1.06	1.063		1.063	1.062											
Mission Operations	q	0.600	k	.363	0.373		0.403	0.383	0.38	0.373		0.371	0.37											
Total Operations Costs	t	1.025			1.546	u.	1.597	1.563	1.55	1.556		1.543	1.54											
Total Launch System Costs ($M	t	1074			44.53	u.	99.9	62.43	52.2	41.02		41.02	41.02	492.2	533.2	533.2	574.3	615.3	615.3	615.3	697.3	697.3	697.3	738.3

Notes:
aa. Production costs are on a per unit basis and 12 flights per year baseline.
ab. Operations cost on a per flight basis.
a. On-orbit manufacturing/processing module. Five year lifetime. Assume 1 operational module plus ground spare
b. Reusable reentry module. 10 flights per module. Assume 1 operational modules plus one spare.
c. Assumes two operational Modules. For >12 flight/year add one additional module.
d. Two POCs required. One at high inclination and one spare.
e. Includes two recovery modules
f. Cost for third operational recovery module.
g. Ten persons for two weeks each launch. Cost is on per launch basis
h. Four persons for one month per launch.
i. Two pilots ($5K for each recovery) and four technicians ($20K for each recovery). Also includes three persons at $75K for 12 flights for recovery tracking.
j. Total ten techs at $750K/year less $20K of four techs time spent on recovery operations for 12 flights.
k. Eight persons (3 shifts and 1 alternate shift) $600K/year for 12 flights.
l. Ten persons for two months at $75K/year.
m. Four persons at $75K/year for two months.
n. Ten techs at $75K/year for two months.
p. Ten techs at $75K/year for two months.
q. Eight persons at $75K/year for two months.
r. Cost to refurbish launch site after launch.
s. Assume R&D investment cost times 20% ROI/year
t. Totals do not include ROI of 20%/year for five year amortization.
u. Launch costs per launch

Space Manufacturing/Processing Launch System Return on Investment Analysis - D

GOV FUNDS 100% R&D

				CY 01	CY 2	CY 3	CY 4	CY 5	CY 6	CY 7	CY 8	CY 9	CY 10	CY 11	CY 12	CY 13	CY 14	CY 15
ZZ		FLIGHTS				0	0	0	12	13	13	14	15	15	15	17	17	17
A		R & D INVESTMENT		20%	20%	20%	20%	20%										
B		R & D H/W		(25)	(25)	(25)	(25)	(25)										
C		R & D SERVICES		0	0	0	0	0										
D																		
E		TOTAL R & D INVESTMENT		(25)	(25)	(25)	(25)	(25)										
F																		
G		FIXED ASSET INVESTMENT				33%	33%	33%										
H		SERVICE MODULE				(167)	(167)	(167)					-150					
I		ASD H/W				(17)	(17)	(17)					-10					
J		REC MOD				(133)	(133)	(133)					-75					
K																		
L		TOTAL F/A				(316)	(316)	(316)	0	0	0	0	-235	0	0	0	0	0
M	5 YR SL	DEPRECIATION							190	190	190	190	190	47	47	47	47	47
N																		
O		RECURRING COSTS																
P		H/W							301	326	326	351	377	377	377	427	427	427
Q		OPS							18	20	20	21	23	23	23	26	26	26
R																		
S	P + Q	TOTAL RECURRING COSTS							320	346	346	373	399	399	399	453	453	453
T																		
U	E + L	TOTAL INVESTMENT		(25)	(25)	(341)	(341)	(341)	0	0	0	0	(235)	0	0	0	0	0
V																		
W	=M	DEPRECIATION							190	190	190	190	190	47	47	47	47	47
X																		
Y	S+W	TOTAL COST							509	536	536	563	589	446	446	500	500	500
Z																		
AA	Y/ZZ	UNIT COST							42	41	41	40	39	30	30	29	29	29
AB																		
AC																		
AD		PROFIT MARGIN NECESSARY TO ACHIEVE 20% ROI																
AE																		
AF	=U	GROSS CASH		-25	-25	-341	-341	-341	0	0	0	0	-235	0	0	0	0	0
AG	=Y X 90.5%	PROFIT (ON COST)	96.0%						489	515	515	540	566	429	429	480	480	480
AH																		
AI	AF + AG	CASH FLOW BEFORE TAX		-25	-25	-341	-341	-341	489	515	515	540	331	429	429	480	480	480
AJ																		
AK	=AI X 35%	TAXES	35%						-171	-180	-180	-189	-116	-150	-150	-168	-168	-168
AL	=E X 35%	LOSS CARRY FWD		8.7	8.7	8.7	8.7	8.7	43									
AM	=AL + AK	NET TAX LIABILITY		0	0	0	0	0	-128	-180	-180	-189	-116	-150	-150	-168	-168	-168
AN	=AI + AM	NET CASH FLOW		-25	-25	-341	-341	-341	361	334	334	351	215	279	279	312	312	312
AO																		
AP		NPV OF NET CASH	0															
AQ																		
AR																		
AS	= Y+ AG	TOTAL SALES		0	0	0	0	0	998	1051	1051	1103	1155	875	875	979	979	979
AT																		
AU	=AS/AG	RETURN ON SALES							49%	49%	49%	49%	49%	49%	49%	49%	49%	49%
AV																		
	=AS/ZZ	UNIT PRICE	$67.9						83.2	80.8	80.8	78.8	77.0	58.3	58.3	57.6	57.6	57.6

SPACE MANUFACTURING ASSUMPTIONS - D

ORIGINAL FLIGHT PROFILE

R & D BEGINS 5 YEARS PRIOR TO FIRST LAUNCH (STRAIGHT LINE)
R&D EXPENSE TREATED AS A SUNK COST AND RECOVERED THROUGH FUTURE PROFITS

SERVICE MODULE, AUTO SPACE DOCKING H/W & RECOVERY MODULE TREATED AS FIXED ASSETS
FIXED ASSET VALUE INCLUDES DESIGN COSTS
STRAIGHTLINE DEPRECIATED OVER USEFUL LIFE (5 YEARS)
1 YEAR LEAD TIME ON REPLACEMENT UNITS

UNIT PRICE CALCULATED TO PRODUCE 20% IRR
NET WORKING CAPITAL ADJUSTMENTS NOT INCLUDED
TAX RATE = 35%, LOSS CARRYFORWARD OF R & D COSTS
GOING CONCERN ASSUMED

Space Manufacturing/Processing Launch System Estimate (includes recovery module flights)

	2000	01	02	03	04	05	06	07	08	09	10
Drug Production	3	3	3	4	4	4	4	5	5	5	5
Biotechnology Production	3	3	3	3	3	3	3	4	4	4	5
University/Industrial Research	3	4	4	4	4	4	4	4	4	4	4
Materials Processing	3	3	3	3	4	4	4	4	4	4	4
Total	12	13	13	14	15	15	15	17	17	17	18
Total Annual Revenue (w/o profit)	492.2	533.2	533.2	574.3	615.3	615.3	615.3	697.3	697.3	697.3	738.3

		R&D		Prod			Launch System Unit Price ($M)																		
		Invstmt		Cost	≤12 flts		≤3 flts	≤6 flts	≤9 flts	≤12 flts		≤15 flts	≤18 flts												
Product / Year	aa	($M)		(aa)	/year		/year	/year	/year	/year		/year	/year	2000	01	02	03	04	05	06	07	08	09	10
Service Module	a	500	f	150	8.333	s.	33.33	16.67	11.1	4.167	c	8.667	7.222											
Auto Space Docking H/W		50	f	10	0.833		3.333	1.667	1.11	0.833	c	0.80	0.667											
Recovery Module	b, e	400	f	75	6.667		26.67	13.33	8.89	8.333	c	6.33	5.278											
Launch Vehicles		100		25	26.67		33.33	28.33	28.9	26.67		26.33	26.11											
Launch Site facilities		15	r	0.100	0.35		1.1	0.6	0.43	0.35		0.30	0.27											
Recovery Site facilities		5	r	0.000	0.083		0.333	0.167	0.11	0.183		0.067	0.06											
Program Ops Centers	d	2.5	r	0.000	0.042		0.167	0.083	0.06	0.142		0.033	0.03											
Recovery Site Tracking		0.5	r	0.000	0.008		0.033	0.017	0.01	0.108		0.007	0.01											
Total H/W Costs	t	1073			42.98	u.	98.3	60.87	50.6	40.78		40.78	40.78											
		Start up																						
Operations Costs		Costs		(ab)																				
Launch Operations	l	0.125	g	.030	0.032		0.038	0.034	0.03	0.067		0.032	0.031											
Payload Processing	m	0.05	h	.050	0.051		0.053	0.052	0.05	0.026		0.051	0.051											
Recovery Operations	n	0.13	i	0.03	0.03		0.03	0.03	0.03	0.03		0.03	0.03											
Refurbishing Recovery Modules	p	0.125	j	1.061	1.063		1.069	1.065	1.06	1.063		1.063	1.062											
Mission Operations	q	0.600	k	.363	0.373		0.403	0.383	0.38	0.373		0.371	0.37											
Total Operations Costs	t	1.025			1.546	u.	1.597	1.563	1.55	1.556		1.543	1.54											
Total Launch System Costs ($M	t	1074			44.53	u.	99.9	62.43	52.2	41.02		41.02	41.02	492.2	533.2	533.2	574.3	615.3	615.3	615.3	697.3	697.3	697.3	738.3

Notes:

aa. Production costs are on a per unit basis and 12 flights per year baseline.
ab. Operations cost on a per flight basis.
a. On-orbit manufacturing/processing module. Five year lifetime. Assume 1 operational module plus ground spare
b. Reusable reentry module. 10 flights per module. Assume 1 operational modules plus one spare.
c. Assumes two operational Modules. For >12 flight/year add one additional module.
d. Two POCs required. One at high inclination and one spare.
e. Includes two recovery modules
f. Cost for third operational recovery module.
g. Ten persons for two weeks each launch. Cost is on per launch basis
h. Four persons for one month per launch.
i. Two pilots ($5K for each recovery) and four technicians ($20K for each recovery). Also includes three persons at $75K for 12 flights for recovery tracking.
j. Total ten techs at $750K/year less $20K of four techs time spent on recovery operations for 12 flights.
k. Eight persons (3 shifts and 1 alternate shift) $600K/year for 12 flights.
l. Ten persons for two months at $75K/year.
m. Four persons at $75K/year for two months.
n. Ten techs at $75K/year for two months.
p. Ten techs at $75K/year for two months.
q. Eight persons at $75K/year for two months.
r. Cost to refurbish launch site after launch.
s. Assume R&D investment cost times 20% ROI/year
t. Totals do not include ROI of 20%/year for five year amortization.
u. Launch costs per launch

Space Manufacturing/Processing Launch System Return on Investment Analysis - D

GOV FUNDS 50% R&D

					CY 01	CY 2	CY 3	CY 4	CY 5	CY 6	CY 7	CY 8	CY 9	CY 10	CY 11	CY 12	CY 13	CY 14	CY 15
ZZ		FLIGHTS					0	0	0	12	13	13	14	15	15	15	17	17	17
A		R & D INVESTMENT			10%	10%	10%	10%	10%										
B		R & D H/W			(12)	(12)	(12)	(12)	(12)										
C		R & D SERVICES			0	0	0	0	0										
D																			
E		TOTAL R & D INVESTMENT			(13)	(13)	(13)	(13)	(13)										
F																			
G		FIXED ASSET INVESTMENT					17%	17%	17%										
H		SERVICE MODULE					(83)	(83)	(83)					-150					
I		ASD H/W					(8)	(8)	(8)					-10					
J		REC MOD					(67)	(67)	(67)					-75					
K																			
L		TOTAL F/A					(158)	(158)	(158)	0	0	0	0	-235	0	0	0	0	0
M	5 YR SL	DEPRECIATION								95	95	95	95	95	47	47	47	47	47
N																			
O		RECURRING COSTS																	
P		H/W								301	326	326	351	377	377	377	427	427	427
Q		OPS								18	20	20	21	23	23	23	26	26	26
R																			
S	P + Q	TOTAL RECURRING COSTS								320	346	346	373	399	399	399	453	453	453
T																			
U	E + L	TOTAL INVESTMENT			(13)	(13)	(171)	(171)	(171)	0	0	0	0	(235)	0	0	0	0	0
V																			
W	=M	DEPRECIATION								95	95	95	95	95	47	47	47	47	47
X																			
Y	S+W	TOTAL COST								414	441	441	468	494	446	446	500	500	500
Z																			
AA	Y/ZZ	UNIT COST								35	34	34	33	33	30	30	29	29	29
AB																			
AC																			
AD		PROFIT MARGIN NECESSARY TO ACHIEVE 20% ROI																	
AE																			
AF	=U	GROSS CASH			-13	-13	-171	-171	-171	0	0	0	0	-235	0	0	0	0	0
AG	=Y X 90.5%	PROFIT (ON COST)	57.6%							239	254	254	269	285	257	257	288	288	288
AH																			
AI	AF + AG	CASH FLOW BEFORE TAX			-13	-13	-171	-171	-171	239	254	254	269	50	257	257	288	288	288
AJ																			
AK	=AI X 35%	TAXES	35%							-84	-89	-89	-94	-17	-90	-90	-101	-101	-101
AL	=E X 35%	LOSS CARRY FWD			4.4	4.4	4.4	4.4	4.4	22									
AM	=AL + AK	NET TAX LIABILITY			0	0	0	0	0	-62	-89	-89	-94	-17	-90	-90	-101	-101	-101
AN	=AI + AM	NET CASH FLOW			-13	-13	-171	-171	-171	177	165	165	175	32	167	167	187	187	187
AO																			
AP			NPV OF NET CASH	0															
AQ																			
AR																			
AS	= Y+ AG	TOTAL SALES			0	0	0	0	0	653	695	695	737	779	704	704	788	788	788
AT																			
AU	=AS/AG	RETURN ON SALES								37%	37%	37%	37%	37%	37%	37%	37%	37%	37%
AV																			
	=AS/ZZ	UNIT PRICE	$49.5							54.4	53.5	53.5	52.7	51.9	46.9	46.9	46.3	46.3	46.3

SPACE MANUFACTURING ASSUMPTIONS - D

ORIGINAL FLIGHT PROFILE

R & D BEGINS 5 YEARS PRIOR TO FIRST LAUNCH (STRAIGHT LINE)
R&D EXPENSE TREATED AS A SUNK COST AND RECOVERED THROUGH FUTURE PROFITS

SERVICE MODULE, AUTO SPACE DOCKING H/W & RECOVERY MODULE TREATED AS FIXED ASSETS
FIXED ASSET VALUE INCLUDES DESIGN COSTS
STRAIGHTLINE DEPRECIATED OVER USEFUL LIFE (5 YEARS)
1 YEAR LEAD TIME ON REPLACEMENT UNITS

UNIT PRICE CALCULATED TO PRODUCE 20% IRR
NET WORKING CAPITAL ADJUSTMENTS NOT INCLUDED
TAX RATE = 35%, LOSS CARRYFORWARD OF R & D COSTS
GOING CONCERN ASSUMED

Space Manufacturing/Processing Launch System Estimate (includes recovery module flights)

	2000	01	02	03	04	05	06	07	08	09	10
Drug Production	3	3	3	4	4	4	4	5	5	5	5
Biotechnology Production	3	3	3	3	3	3	3	4	4	4	5
University/Industrial Research	3	4	4	4	4	4	4	4	4	4	4
Materials Processing	3	3	3	3	4	4	4	4	4	4	4
Total	12	13	13	14	15	15	15	17	17	17	18
Total Annual Revenue (w/o profit)	492.2	533.2	533.2	574.3	615.3	615.3	615.3	697.3	697.3	697.3	738.3

		R&D		Prod			Launch System Unit Price ($M)																	
		Invstmt		Cost	≤12 flts		≤3 flts	≤6 flts	≤9 flts	≤12 flts		≤15 flts	≤18 flts											
Product / Year	aa	($M)		(aa)	/year		/year	/year	/year	/year		/year	/year	**2000**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**
Service Module	a	500	f	150	8.333	s.	33.33	16.67	11.1	4.167	c	8.667	7.222											
Auto Space Docking H/W		50	f	10	0.833		3.333	1.667	1.11	0.833	c	0.80	0.667											
Recovery Module	b, e	400	f	75	6.667		26.67	13.33	8.89	8.333	c	6.33	5.278											
Launch Vehicles		100		25	26.67		33.33	28.33	28.9	26.67		26.33	26.11											
Launch Site facilities		15	r	0.100	0.35		1.1	0.6	0.43	0.35		0.30	0.27											
Recovery Site facilities		5	r	0.000	0.083		0.333	0.167	0.11	0.183		0.067	0.06											
Program Ops Centers	d	2.5	r	0.000	0.042		0.167	0.083	0.06	0.142		0.033	0.03											
Recovery Site Tracking		0.5	r	0.000	0.008		0.033	0.017	0.01	0.108		0.007	0.01											
Total H/W Costs	t	1073			42.98	u.	98.3	60.87	50.6	40.78		40.78	40.78											
		Start up																						
Operations Costs		Costs		(ab)																				
Launch Operations	l	0.125	g	.030	0.032		0.038	0.034	0.03	0.067		0.032	0.031											
Payload Processing	m	0.05	h	.050	0.051		0.053	0.052	0.05	0.026		0.051	0.051											
Recovery Operations	n	0.13	i	0.03	0.03		0.03	0.03	0.03	0.03		0.03	0.03											
Refurbishing Recovery Modules	p	0.125	j	1.061	1.063		1.069	1.065	1.06	1.063		1.063	1.062											
Mission Operations	q	0.600	k	.363	0.373		0.403	0.383	0.38	0.373		0.371	0.37											
Total Operations Costs	t	1.025			1.546	u.	1.597	1.563	1.55	1.556		1.543	1.54											
Total Launch System Costs ($M	t	1074			44.53	u.	99.9	62.43	52.2	41.02		41.02	41.02	492.2	533.2	533.2	574.3	615.3	615.3	615.3	697.3	697.3	697.3	738.3

Notes:

aa. Production costs are on a per unit basis and 12 flights per year baseline.
ab. Operations cost on a per flight basis.
a. On-orbit manufacturing/processing module. Five year lifetime. Assume 1 operational module plus ground spare
b. Reusable reentry module. 10 flights per module. Assume 1 operational modules plus one spare.
c. Assumes two operational Modules. For >12 flight/year add one additional module.
d. Two POCs required. One at high inclination and one spare.
e. Includes two recovery modules
f. Cost for third operational recovery module.
g. Ten persons for two weeks each launch. Cost is on per launch basis
h. Four persons for one month per launch.
i. Two pilots ($5K for each recovery) and four technicians ($20K for each recovery). Also includes three persons at $75K for 12 flights for recovery tracking.
j. Total ten techs at $750K/year less $20K of four techs time spent on recovery operations for 12 flights.
k. Eight persons (3 shifts and 1 alternate shift) $600K/year for 12 flights.
l. Ten persons for two months at $75K/year.
m. Four persons at $75K/year for two months.
n. Ten techs at $75K/year for two months.
p. Ten techs at $75K/year for two months.
q. Eight persons at $75K/year for two months.
r. Cost to refurbish launch site after launch.
s. Assume R&D investment cost times 20% ROI/year
t. Totals do not include ROI of 20%/year for five year amortization.
u. Launch costs per launch

Space Manufacturing/Processing Launch System Return on Investment Analysis - D

GOV FUNDS 100% R&D

					CY 01	CY 2	CY 3	CY 4	CY 5	CY 6	CY 7	CY 8	CY 9	CY 10	CY 11	CY 12	CY 13	CY 14	CY 15
ZZ		FLIGHTS					0	0	0	12	13	13	14	15	15	15	17	17	17
A		R & D INVESTMENT			0%	0%	0%	0%	0%										
B		R & D H/W			0	0	0	0	0										
C		R & D SERVICES			0	0	0	0	0										
D																			
E		TOTAL R & D INVESTMENT			0	0	0	0	0										
F																			
G		FIXED ASSET INVESTMENT					0%	0%	0%										
H		SERVICE MODULE					0	0	0					-150					
I		ASD H/W					0	0	0					-10					
J		REC MOD					0	0	0					-75					
K																			
L		TOTAL F/A					0	0	0	0	0	0	0	-235	0	0	0	0	0
M	5 YR SL	DEPRECIATION								0	0	0	0	0	47	47	47	47	47
N																			
O		RECURRING COSTS																	
P		H/W								301	326	326	351	377	377	377	427	427	427
Q		OPS								18	20	20	21	23	23	23	26	26	26
R																			
S	P + Q	TOTAL RECURRING COSTS								320	346	346	373	399	399	399	453	453	453
T																			
U	E + L	TOTAL INVESTMENT			0	0	0	0	0	0	0	0	0	(235)	0	0	0	0	0
V																			
W	=M	DEPRECIATION								0	0	0	0	0	47	47	47	47	47
X																			
Y	S+W	TOTAL COST								320	346	346	373	399	446	446	500	500	500
Z																			
AA	Y/ZZ	UNIT COST								27	27	27	27	27	30	30	29	29	29
AB																			
AC																			
AD		PROFIT MARGIN NECESSARY TO ACHIEVE 20% ROI																	
AE																			
AF	=U	GROSS CASH			0	0	0	0	0	0	0	0	0	-235	0	0	0	0	0
AG	=Y X 90.5%	PROFIT (ON COST)	6.0%							19	21	21	22	24	27	27	30	30	30
AH																			
AI	AF + AG	CASH FLOW BEFORE TAX			0	0	0	0	0	19	21	21	22	-211	27	27	30	30	30
AJ																			
AK	=AI X 35%	TAXES 35%								-7	-7	-7	-8	74	-9	-9	-10	-10	-10
AL	=E X 35%	LOSS CARRY FWD			0.1	0.1	0.1	0.1	0.1	0									
AM	=AL + AK	NET TAX LIABILITY			0	0	0	0	0	-6	-7	-7	-8	74	-9	-9	-10	-10	-10
AN	=AI + AM	NET CASH FLOW			0	0	0	0	0	13	14	14	15	-137	17	17	19	19	19
AO																			
AP		NPV OF NET CASH		0															
AQ																			
AR																			
AS	= Y+ AG	TOTAL SALES			0	0	0	0	0	339	367	367	395	423	473	473	530	530	530
AT																			
AU	=AS/AG	RETURN ON SALES								6%	6%	6%	6%	6%	6%	6%	6%	6%	6%
AV																			
	=AS/ZZ	UNIT PRICE	$29.9							28.2	28.2	28.2	28.2	28.2	31.5	31.5	31.2	31.2	31.2

SPACE MANUFACTURING ASSUMPTIONS - D

ORIGINAL FLIGHT PROFILE

R & D BEGINS 5 YEARS PRIOR TO FIRST LAUNCH (STRAIGHT LINE)
R&D EXPENSE TREATED AS A SUNK COST AND RECOVERED THROUGH FUTURE PROFITS

SERVICE MODULE, AUTO SPACE DOCKING H/W & RECOVERY MODULE TREATED AS FIXED ASSETS
FIXED ASSET VALUE INCLUDES DESIGN COSTS
STRAIGHTLINE DEPRECIATED OVER USEFUL LIFE (5 YEARS)
1 YEAR LEAD TIME ON REPLACEMENT UNITS

UNIT PRICE CALCULATED TO PRODUCE 20% IRR
NET WORKING CAPITAL ADJUSTMENTS NOT INCLUDED
TAX RATE = 35%, LOSS CARRYFORWARD OF R & D COSTS
GOING CONCERN ASSUMED

Space Manufacturing/Processing Launch System Estimate (includes recovery module flights)

	2000	01	02	03	04	05	06	07	08	09	10
Drug Production	3	3	3	4	4	4	4	5	5	5	5
Biotechnology Production	3	3	3	3	3	3	3	4	4	4	5
University/Industrial Research	3	4	4	4	4	4	4	4	4	4	4
Materials Processing	3	3	3	3	4	4	4	4	4	4	4
Total	12	13	13	14	15	15	15	17	17	17	18
Total Annual Revenue (w/o profit)	492.2	533.2	533.2	574.3	615.3	615.3	615.3	697.3	697.3	697.3	738.3

		R&D		Prod			Launch System Unit Price ($M)																	
		Invstmt		Cost	≤12 flts		≤3 flts	≤6 flts	≤9 flts	≤12 flts		≤15 flts	≤18 flts											
Product / Year	aa	($M)		(aa)	/year		/year	/year	/year	/year		/year	/year	2000	01	02	03	04	05	06	07	08	09	10
Service Module	a	500	f	150	8.333	s.	33.33	16.67	11.1	4.167	c	8.667	7.222											
Auto Space Docking H/W		50	f	10	0.833		3.333	1.667	1.11	0.833	c	0.80	0.667											
Recovery Module	b, e	400	f	75	6.667		26.67	13.33	8.89	8.333	c	6.33	5.278											
Launch Vehicles		100		25	26.67		33.33	28.33	28.9	26.67		26.33	26.11											
Launch Site facilities		15	r	0.100	0.35		1.1	0.6	0.43	0.35		0.30	0.27											
Recovery Site facilities		5	r	0.000	0.083		0.333	0.167	0.11	0.183		0.067	0.06											
Program Ops Centers	d	2.5	r	0.000	0.042		0.167	0.083	0.06	0.142		0.033	0.03											
Recovery Site Tracking		0.5	r	0.000	0.008		0.033	0.017	0.01	0.108		0.007	0.01											
Total H/W Costs	t	1073			42.98	u.	98.3	60.87	50.6	40.78		40.78	40.78											
		Start up																						
Operations Costs		Costs		(ab)																				
Launch Operations	l	0.125	g	.030	0.032		0.038	0.034	0.03	0.067		0.032	0.031											
Payload Processing	m	0.05	h	.050	0.051		0.053	0.052	0.05	0.026		0.051	0.051											
Recovery Operations	n	0.13	i	0.03	0.03		0.03	0.03	0.03	0.03		0.03	0.03											
Refurbishing Recovery Modules	p	0.125	j	1.061	1.063		1.069	1.065	1.06	1.063		1.063	1.062											
Mission Operations	q	0.600	k	.363	0.373		0.403	0.383	0.38	0.373		0.371	0.37											
Total Operations Costs	t	1.025			1.546	u.	1.597	1.563	1.55	1.556		1.543	1.54											
Total Launch System Costs ($M	t	1074			44.53	u.	99.9	62.43	52.2	41.02		41.02	41.02	492.2	533.2	533.2	574.3	615.3	615.3	615.3	697.3	697.3	697.3	738.3

Notes:

aa. Production costs are on a per unit basis and 12 flights per year baseline.
ab. Operations cost on a per flight basis.
a. On-orbit manufacturing/processing module. Five year lifetime. Assume 1 operational module plus ground spare
b. Reusable reentry module. 10 flights per module. Assume 1 operational modules plus one spare.
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j. Total ten techs at $750K/year less $20K of four techs time spent on recovery operations for 12 flights.
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m. Four persons at $75K/year for two months.
n. Ten techs at $75K/year for two months.
p. Ten techs at $75K/year for two months.
q. Eight persons at $75K/year for two months.
r. Cost to refurbish launch site after launch.
s. Assume R&D investment cost times 20% ROI/year
t. Totals do not include ROI of 20%/year for five year amortization.
u. Launch costs per launch

Space Manufacturing/Processing Launch System Return on Investment Analysis - D1

GOV PAYS 0% OF R & D

					CY 01	CY 2	CY 3	CY 4	CY 5	CY 6	CY 7	CY 8	CY 9	CY 10	CY 11	CY 12	CY 13	CY 14	CY 15
ZZ		FLIGHTS					0	0	0	12	13	13	14	15	15	15	17	17	17
A		R & D INVESTMENT			10%	20%	30%	30%	10%										
B		R & D H/W			(12.3)	(24.6)	(36.9)	(36.9)	(12.3)										
C		R & D SERVICES			(0.1)	(0.2)	(0.3)	(0.3)	(0.1)										
D																			
E		TOTAL R & D INVESTMENT			(12.4)	(24.8)	(37.2)	(37.2)	(12.4)										
F																			
G		FIXED ASSET INVESTMENT					33%	33%	33%										
H		SERVICE MODULE					(166.7)	(166.7)	(166.7)							-150			
I		ASD H/W					(16.7)	(16.7)	(16.7)							-10			
J		REC MOD					(133.3)	(133.3)	(133.3)							-75			
K																			
L		TOTAL F/A					(316.6)	(316.6)	(316.6)	0	0	0	0	0	0	-235	0	0	0
M	5 YR SL	DEPRECIATION								136	136	136	136	136	136	136	34	34	34
N																			
O		RECURRING COSTS																	
P		H/W								301	326	326	351	377	377	377	427	427	427
Q		OPS								18	20	20	21	23	23	23	26	26	26
R																			
S	P + Q	TOTAL RECURRING COSTS								320	346	346	373	399	399	399	453	453	453
T																			
U	E + L	TOTAL INVESTMENT			(12)	(25)	(354)	(354)	(329)	0	0	0	0	0	0	(235)	0	0	0
V																			
W	=M	DEPRECIATION								136	136	136	136	136	136	136	34	34	34
X																			
Y	S+W	TOTAL COST								455	482	482	509	535	535	535	486	486	486
Z																			
AA	Y/ZZ	UNIT COST								38	37	37	36	36	36	36	29	29	29
AB																			
AC																			
AD		PROFIT MARGIN NECESSARY TO ACHIEVE 20% ROI																	
AE																			
AF	=U	GROSS CASH			-12	-25	-354	-354	-329	0	0	0	0	0	0	-235	0	0	0
AG	=Y X 90.5%	PROFIT (ON COST)	99.5%							453	479	479	506	532	532	532	484	484	484
AH																			
AI	AF + AG	CASH FLOW BEFORE TAX			-12	-25	-354	-354	-329	453	479	479	506	532	532	297	484	484	484
AJ																			
AK	=AI X 35%	TAXES	35%							-159	-168	-168	-177	-186	-186	-104	-169	-169	-169
AL	=E X 35%	LOSS CARRY FWD			4.3	8.7	13.0	13.0	4.3	43									
AM	=AL + AK	NET TAX LIABILITY			0	0	0	0	0	-115	-168	-168	-177	-186	-186	-104	-169	-169	-169
AN	=AI + AM	NET CASH FLOW			-12	-25	-354	-354	-329	338	312	312	329	346	346	193	314	314	314
AO																			
AP		NPV OF NET CASH		0															
AQ																			
AR																			
AS	= Y+ AG	TOTAL SALES			0	0	0	0	0	908	961	961	1014	1068	1068	1068	970	970	970
AT																			
AU	=AS/AG	RETURN ON SALES								50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
AV																			
	=AS/ZZ	UNIT PRICE	$67.3							75.7	73.9	73.9	72.5	71.2	71.2	71.2	57.1	57.1	57.1

SPACE MANUFACTURING ASSUMPTIONS-D1

ORIGINAL FLIGHT PROFILE

R & D BEGINS 5 YEARS PRIOR TO FIRST LAUNCH (10%,20%,30%,30%,10%)
R&D EXPENSE TREATED AS A SUNK COST AND RECOVERED THROUGH FUTURE PROFITS

SERVICE MODULE, AUTO SPACE DOCKING H/W & RECOVERY MODULE TREATED AS FIXED ASSETS
FIXED ASSET VALUE INCLUDES DESIGN COSTS
STRAIGHTLINE DEPRECIATED OVER USEFUL LIFE (7 YEARS)
1 YEAR LEAD TIME ON REPLACEMENT UNITS

UNIT PRICE CALCULATED TO PRODUCE 20% IRR
NET WORKING CAPITAL ADJUSTMENTS NOT INCLUDED
TAX RATE = 35%, LOSS CARRYFORWARD OF R & D COSTS
GOING CONCERN ASSUMED

Space Manufacturing/Processing Launch System Estimate (includes recovery module flights)

	2000	01	02	03	04	05	06	07	08	09	10
Drug Production	3	3	3	4	4	4	4	5	5	5	5
Biotechnology Production	3	3	3	3	3	3	3	4	4	4	5
University/Industrial Research	3	4	4	4	4	4	4	4	4	4	4
Materials Processing	3	3	3	3	4	4	4	4	4	4	4
Total	12	13	13	14	15	15	15	17	17	17	18
Total Annual Revenue (w/o profit)	492.2	533.2	533.2	574.3	615.3	615.3	615.3	697.3	697.3	697.3	738.3

Launch System Unit Price ($M)

		R&D Invstmt		Prod Cost	≤12 flts		≤3 flts	≤6 flts	≤9 flts	≤12 flts		≤15 flts	≤18 flts											
Product / Year	aa	($M)		(aa)	/year		/year	/year	/year	/year		/year	/year	2000	01	02	03	04	05	06	07	08	09	10
Service Module	a	500	f	150	8.333	s.	33.33	16.67	11.1	4.167	c	8.667	7.222											
Auto Space Docking H/W		50	f	10	0.833		3.333	1.667	1.11	0.833	c	0.80	0.667											
Recovery Module	b, e	400	f	75	6.667		26.67	13.33	8.89	8.333	c	6.33	5.278											
Launch Vehicles		100		25	26.67		33.33	28.33	28.9	26.67		26.33	26.11											
Launch Site facilities		15	r	0.100	0.35		1.1	0.6	0.43	0.35		0.30	0.27											
Recovery Site facilities		5	r	0.000	0.083		0.333	0.167	0.11	0.183		0.067	0.06											
Program Ops Centers	d	2.5	r	0.000	0.042		0.167	0.083	0.06	0.142		0.033	0.03											
Recovery Site Tracking		0.5	r	0.000	0.008		0.033	0.017	0.01	0.108		0.007	0.01											
Total H/W Costs	t	1073			42.98	u.	98.3	60.87	50.6	40.78		40.78	40.78											
		Start up																						
Operations Costs		Costs		(ab)																				
Launch Operations	l	0.125	g	.030	0.032		0.038	0.034	0.03	0.067		0.032	0.031											
Payload Processing	m	0.05	h	.050	0.051		0.053	0.052	0.05	0.026		0.051	0.051											
Recovery Operations	n	0.13	i	0.03	0.03		0.03	0.03	0.03	0.03		0.03	0.03											
Refurbishing Recovery Modules	p	0.125	j	1.061	1.063		1.069	1.065	1.06	1.063		1.063	1.062											
Mission Operations	q	0.600	k	.363	0.373		0.403	0.383	0.38	0.373		0.371	0.37											
Total Operations Costs	t	1.025			1.546	u.	1.597	1.563	1.55	1.556		1.543	1.54											
Total Launch System Costs ($M	t	1074			44.53	u.	99.9	62.43	52.2	41.02		41.02	41.02	492.2	533.2	533.2	574.3	615.3	615.3	615.3	697.3	697.3	697.3	738.3

Notes:

aa. Production costs are on a per unit basis and 12 flights per year baseline.
ab. Operations cost on a per flight basis.
a. On-orbit manufacturing/processing module. Five year lifetime. Assume 1 operational module plus ground spare
b. Reusable reentry module. 10 flights per module. Assume 1 operational modules plus one spare.
c. Assumes two operational Modules. For >12 flight/year add one additional module.
d. Two POCs required. One at high inclination and one spare.
e. Includes two recovery modules
f. Cost for third operational recovery module.
g. Ten persons for two weeks each launch. Cost is on per launch basis
h. Four persons for one month per launch.
i. Two pilots ($5K for each recovery) and four technicians ($20K for each recovery). Also includes three persons at $75K for 12 flights for recovery tracking.
j. Total ten techs at $750K/year less $20K of four techs time spent on recovery operations for 12 flights.
k. Eight persons (3 shifts and 1 alternate shift) $600K/year for 12 flights.
l. Ten persons for two months at $75K/year.
m. Four persons at $75K/year for two months.
n. Ten techs at $75K/year for two months.
p. Ten techs at $75K/year for two months.
q. Eight persons at $75K/year for two months.
r. Cost to refurbish launch site after launch.
s. Assume R&D investment cost times 20% ROI/year
t. Totals do not include ROI of 20%/year for five year amortization.
u. Launch costs per launch

Space Manufacturing/Processing Launch System Return on Investment Analysis - D1

GOV PAYS 50% OF R & D

					CY 01	CY 2	CY 3	CY 4	CY 5	CY 6	CY 7	CY 8	CY 9	CY 10	CY 11	CY 12	CY 13	CY 14	CY 15
ZZ		FLIGHTS				.	0	0	0	12	13	13	14	15	15	15	17	17	17
A		R & D INVESTMENT			5%	10%	15%	15%	5%										
B		R & D H/W			(6.2)	(12.3)	(18.5)	(18.5)	(6.2)										
C		R & D SERVICES			(0.1)	(0.1)	(0.2)	(0.2)	(0.1)										
D																			
E		TOTAL R & D INVESTMENT			(6.2)	(12.4)	(18.6)	(18.6)	(6.2)										
F																			
G		FIXED ASSET INVESTMENT					17%	17%	17%										
H		SERVICE MODULE					(83.3)	(83.3)	(83.3)							-150			
I		ASD H/W					(8.3)	(8.3)	(8.3)							-10			
J		REC MOD					(66.7)	(66.7)	(66.7)							-75			
K																			
L		TOTAL F/A					(158.3)	(158.3)	(158.3)	0	0	0	0	0	0	-235	0	0	0
M	5 YR SL	DEPRECIATION								68	68	68	68	68	68	68	34	34	34
N																			
O		RECURRING COSTS																	
P		H/W								301	326	326	351	377	377	377	427	427	427
Q		OPS								18	20	20	21	23	23	23	26	26	26
R																			
S	P + Q	TOTAL RECURRING COSTS								320	346	346	373	399	399	399	453	453	453
T																			
U	E + L	TOTAL INVESTMENT			(6)	(12)	(177)	(177)	(165)	0	0	0	0	0	0	(235)	0	0	0
V																			
W	=M	DEPRECIATION								68	68	68	68	68	68	68	34	34	34
X																			
Y	S+W	TOTAL COST								387	414	414	441	467	467	467	486	486	486
Z																			
AA	Y/ZZ	UNIT COST								32	32	32	31	31	31	31	29	29	29
AB																			
AC																			
AD		PROFIT MARGIN NECESSARY TO ACHIEVE 20% ROI																	
AE																			
AF	=U	GROSS CASH			-6	-12	-177	-177	-165	0	0	0	0	0	0	-235	0	0	0
AG	=Y X 90.5%	PROFIT (ON COST)	58.2%							225	241	241	256	272	272	272	283	283	283
AH																			
AI	AF + AG	CASH FLOW BEFORE TAX			-6	-12	-177	-177	-165	225	241	241	256	272	272	37	283	283	283
AJ																			
AK	=AI X 35%	TAXES	35%							-79	-84	-84	-90	-95	-95	-13	-99	-99	-99
AL	=E X 35%	LOSS CARRY FWD			2.2	4.3	6.5	6.5	2.2	22									
AM	=AL + AK	NET TAX LIABILITY			0	0	0	0	0	-57	-84	-84	-90	-95	-95	-13	-99	-99	-99
AN	=AI + AM	NET CASH FLOW			-6	-12	-177	-177	-165	168	157	157	167	177	177	24	184	184	184
AO																			
AP		NPV OF NET CASH		0															
AQ																			
AR																			
AS	= Y+ AG	TOTAL SALES			0	0	0	0	0	613	655	655	697	739	739	739	769	769	769
AT																			
AU	=AS/AG	RETURN ON SALES								37%	37%	37%	37%	37%	37%	37%	37%	37%	37%
AV																			
	=AS/ZZ	UNIT PRICE	$48.3							51.1	50.4	50.4	49.8	49.3	49.3	49.3	45.3	45.3	45.3

SPACE MANUFACTURING ASSUMPTIONS-D1

ORIGINAL FLIGHT PROFILE

R & D BEGINS 5 YEARS PRIOR TO FIRST LAUNCH (10%,20%,30%,30%,10%)
R&D EXPENSE TREATED AS A SUNK COST AND RECOVERED THROUGH FUTURE PROFITS

SERVICE MODULE, AUTO SPACE DOCKING H/W & RECOVERY MODULE TREATED AS FIXED ASSETS
FIXED ASSET VALUE INCLUDES DESIGN COSTS
STRAIGHTLINE DEPRECIATED OVER USEFUL LIFE (7 YEARS)
1 YEAR LEAD TIME ON REPLACEMENT UNITS

UNIT PRICE CALCULATED TO PRODUCE 20% IRR
NET WORKING CAPITAL ADJUSTMENTS NOT INCLUDED
TAX RATE = 35%, LOSS CARRYFORWARD OF R & D COSTS
GOING CONCERN ASSUMED

Space Manufacturing/Processing Launch System Estimate (includes recovery module flights)

	2000	01	02	03	04	05	06	07	08	09	10
Drug Production	3	3	3	4	4	4	4	5	5	5	5
Biotechnology Production	3	3	3	3	3	3	3	4	4	4	5
University/industrial Research	3	4	4	4	4	4	4	4	4	4	4
Materials Processing	3	3	3	3	4	4	4	4	4	4	4
Total	12	13	13	14	15	15	15	17	17	17	18
Total Annual Revenue (w/o profit)	492.2	533.2	533.2	574.3	615.3	615.3	615.3	697.3	697.3	697.3	738.3

		R&D		Prod			Launch System Unit Price ($M)																	
		Invstmt		Cost	≤12 flts		≤3 flts	≤6 flts	≤9 flts	≤12 flts		≤15 flts	≤18 flts											
Product / Year	aa	($M)		(aa)	/year		/year	/year	/year	/year		/year	/year	2000	01	02	03	04	05	06	07	08	09	10
Service Module	a	500	f	150	8.333	s.	33.33	16.67	11.1	4.167	c	8.667	7.222											
Auto Space Docking H/W		50	f	10	0.833		3.333	1.667	1.11	0.833	c	0.80	0.667											
Recovery Module	b, e	400	f	75	6.667		26.67	13.33	8.89	8.333	c	6.33	5.278											
Launch Vehicles		100		25	26.67		33.33	28.33	28.9	26.67		26.33	26.11											
Launch Site facilities		15	r	0.100	0.35		1.1	0.6	0.43	0.35		0.30	0.27											
Recovery Site facilities		5	r	0.000	0.083		0.333	0.167	0.11	0.183		0.067	0.06											
Program Ops Centers	d	2.5	r	0.000	0.042		0.167	0.083	0.06	0.142		0.033	0.03											
Recovery Site Tracking		0.5	r	0.000	0.008		0.033	0.017	0.01	0.108		0.007	0.01											
Total H/W Costs	t	1073			42.98	u.	98.3	60.87	50.6	40.78		40.78	40.78											
		Start up																						
Operations Costs		Costs		(ab)																				
Launch Operations	l	0.125	g	.030	0.032		0.038	0.034	0.03	0.067		0.032	0.031											
Payload Processing	m	0.05	h	.050	0.051		0.053	0.052	0.05	0.026		0.051	0.051											
Recovery Operations	n	0.13	i	0.03	0.03		0.03	0.03	0.03	0.03		0.03	0.03											
Refurbishing Recovery Modules	p	0.125	j	1.061	1.063		1.069	1.065	1.06	1.063		1.063	1.062											
Mission Operations	q	0.600	k	.363	0.373		0.403	0.383	0.38	0.373		0.371	0.37											
Total Operations Costs	t	1.025			1.546	u.	1.597	1.563	1.55	1.556		1.543	1.54											
Total Launch System Costs ($M	t	1074			44.53	u.	99.9	62.43	52.2	41.02		41.02	41.02	492.2	533.2	533.2	574.3	615.3	615.3	615.3	697.3	697.3	697.3	738.3

Notes:

aa. Production costs are on a per unit basis and 12 flights per year baseline.

ab. Operations cost on a per flight basis.

a. On-orbit manufacturing/processing module. Five year lifetime. Assume 1 operational module plus ground spare

b. Reusable reentry module. 10 flights per module. Assume 1 operational modules plus one spare.

c. Assumes two operational Modules. For >12 flight/year add one additional module.

d. Two POCs required. One at high inclination and one spare.

e. Includes two recovery modules

f. Cost for third operational recovery module.

g. Ten persons for two weeks each launch. Cost is on per launch basis

h. Four persons for one month per launch.

i. Two pilots ($5K for each recovery) and four technicians ($20K for each recovery). Also includes three persons at $75K for 12 flights for recovery tracking.

j. Total ten techs at $750K/year less $20K of four techs time spent on recovery operations for 12 flights.

k. Eight persons (3 shifts and 1 alternate shift) $600K/year for 12 flights.

l. Ten persons for two months at $75K/year.

m. Four persons at $75K/year for two months.

n. Ten techs at $75K/year for two months.

p. Ten techs at $75K/year for two months.

q. Eight persons at $75K/year for two months.

r. Cost to refurbish launch site after launch.

s. Assume R&D investment cost times 20% ROI/year

t. Totals do not include ROI of 20%/year for five year amortization.

u. Launch costs per launch

Space Manufacturing/Processing Launch System Return on Investment Analysis - D1

GOV PAYS 100% OF R & D

					CY 01	CY 2	CY 3	CY 4	CY 5	CY 6	CY 7	CY 8	CY 9	CY 10	CY 11	CY 12	CY 13	CY 14	CY 15
ZZ		FLIGHTS					0	0	0	12	13	13	14	15	15	15	17	17	17
A		R & D INVESTMENT			0%	0%	0%	0%	0%										
B		R & D H/W			0.0	0.0	0.0	0.0	0.0										
C		R & D SERVICES			0.0	0.0	0.0	0.0	0.0										
D																			
E		TOTAL R & D INVESTMENT			0.0	0.0	0.0	0.0	0.0										
F																			
G		FIXED ASSET INVESTMENT					0%	0%	0%										
H		SERVICE MODULE					0.0	0.0	0.0							-150			
I		ASD H/W					0.0	0.0	0.0							-10			
J		REC MOD					0.0	0.0	0.0							-75			
K																			
L		TOTAL F/A					0.0	0.0	0.0	0	0	0	0	0	0	-235	0	0	0
M	5 YR SL	DEPRECIATION								0	0	0	0	0	0	0	34	34	34
N																			
O		RECURRING COSTS																	
P		H/W								301	326	326	351	377	377	377	427	427	427
Q		OPS								18	20	20	21	23	23	23	26	26	26
R																			
S	P + Q	TOTAL RECURRING COSTS								320	346	346	373	399	399	399	453	453	453
T																			
U	E + L	TOTAL INVESTMENT			0	0	0	0	0	0	0	0	0	0	0	(235)	0	0	0
V																			
W	=M	DEPRECIATION								0	0	0	0	0	0	0	34	34	34
X																			
Y	S+W	TOTAL COST								320	346	346	373	399	399	399	486	486	486
Z																			
AA	Y/ZZ	UNIT COST								27	27	27	27	27	27	27	29	29	29
AB																			
AC																			
AD		PROFIT MARGIN NECESSARY TO ACHIEVE 20% ROI																	
AE																			
AF	=U	GROSS CASH			0	0	0	0	0	0	0	0	0	0	0	-235	0	0	0
AG	=Y X 90.5%	PROFIT (ON COST)	4.2%							13	15	15	16	17	17	17	20	20	20
AH																			
AI	AF + AG	CASH FLOW BEFORE TAX			0	0	0	0	0	13	15	15	16	17	17	-218	20	20	20
AJ																			
AK	=AI X 35%	TAXES	35%							-5	-5	-5	-5	-6	-6	76	-7	-7	-7
AL	=E X 35%	LOSS CARRY FWD			0.0	0.0	0.0	0.0	0.0	0									
AM	=AL + AK	NET TAX LIABILITY			0	0	0	0	0	-5	-5	-5	-5	-6	-6	76	-7	-7	-7
AN	=AI + AM	NET CASH FLOW			0	0	0	0	0	9	9	9	10	11	11	-142	13	13	13
AO																			
AP		NPV OF NET CASH		0															
AQ																			
AR																			
AS	= Y+ AG	TOTAL SALES			0	0	0	0	0	333	361	361	388	416	416	416	507	507	507
AT																			
AU	=AS/AG	RETURN ON SALES								4%	4%	4%	4%	4%	4%	4%	4%	4%	4%
AV																			
	=AS/ZZ	UNIT PRICE	$28.5							27.7	27.7	27.7	27.7	27.7	27.7	27.7	29.8	29.8	29.8

SPACE MANUFACTURING ASSUMPTIONS-D1

ORIGINAL FLIGHT PROFILE

R & D BEGINS 5 YEARS PRIOR TO FIRST LAUNCH (10%,20%,30%,30%,10%)
R&D EXPENSE TREATED AS A SUNK COST AND RECOVERED THROUGH FUTURE PROFITS

SERVICE MODULE, AUTO SPACE DOCKING H/W & RECOVERY MODULE TREATED AS FIXED ASSETS
FIXED ASSET VALUE INCLUDES DESIGN COSTS
STRAIGHTLINE DEPRECIATED OVER USEFUL LIFE (7 YEARS)
1 YEAR LEAD TIME ON REPLACEMENT UNITS

UNIT PRICE CALCULATED TO PRODUCE 20% IRR
NET WORKING CAPITAL ADJUSTMENTS NOT INCLUDED
TAX RATE = 35%, LOSS CARRYFORWARD OF R & D COSTS
GOING CONCERN ASSUMED

Space Manufacturing/Processing Launch System Estimate (includes recovery module flights)

	2000	01	02	03	04	05	06	07	08	09	10
Drug Production	3	3	3	4	4	4	4	5	5	5	5
Biotechnology Production	3	3	3	3	3	3	3	4	4	4	5
University/Industrial Research	3	4	4	4	4	4	4	4	4	4	4
Materials Processing	3	3	3	3	4	4	4	4	4	4	4
Total	12	13	13	14	15	15	15	17	17	17	18
Total Annual Revenue (w/o profit)	**492.2**	**533.2**	**533.2**	**574.3**	**615.3**	**615.3**	**615.3**	**697.3**	**697.3**	**697.3**	**738.3**

		R&D		Prod			**Launch System Unit Price ($M)**																	
		Invstmt		Cost	≤12 flts		≤3 flts	≤6 flts	≤9 flts	≤12 flts		≤15 flts	≤18 flts											
Product / Year	aa	($M)		(aa)	/year		/year	/year	/year	/year		/year	/year	**2000**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**
Service Module	a	500	f	150	8.333	s.	33.33	16.67	11.1	4.167	c	8.667	7.222											
Auto Space Docking H/W		50	f	10	0.833		3.333	1.667	1.11	0.833	c	0.80	0.667											
Recovery Module	b, e	400	f	75	6.667		26.67	13.33	8.89	8.333	c	6.33	5.278											
Launch Vehicles		100		25	26.67		33.33	28.33	28.9	26.67		26.33	26.11											
Launch Site facilities		15	r	0.100	0.35		1.1	0.6	0.43	0.35		0.30	0.27											
Recovery Site facilities		5	r	0.000	0.083		0.333	0.167	0.11	0.183		0.067	0.06											
Program Ops Centers	d	2.5	r	0.000	0.042		0.167	0.083	0.06	0.142		0.033	0.03											
Recovery Site Tracking		0.5	r	0.000	0.008		0.033	0.017	0.01	0.108		0.007	0.01											
Total H/W Costs	t	1073			42.98	u.	98.3	60.87	50.6	40.78		40.78	40.78											
		Start up																						
Operations Costs		Costs		(ab)																				
Launch Operations	l	0.125	g	.030	0.032		0.038	0.034	0.03	0.067		0.032	0.031											
Payload Processing	m	0.05	h	.050	0.051		0.053	0.052	0.05	0.026		0.051	0.051											
Recovery Operations	n	0.13	i	0.03	0.03		0.03	0.03	0.03	0.03		0.03	0.03											
Refurbishing Recovery Modules	p	0.125	j	1.061	1.063		1.069	1.065	1.06	1.063		1.063	1.062											
Mission Operations	q	0.600	k	.363	0.373		0.403	0.383	0.38	0.373		0.371	0.37											
Total Operations Costs	t	1.025			1.546	u.	1.597	1.563	1.55	1.556		1.543	1.54											
Total Launch System Costs ($M	t	1074			44.53	u.	99.9	62.43	52.2	41.02		41.02	41.02	492.2	533.2	533.2	574.3	615.3	615.3	615.3	697.3	697.3	697.3	738.3

Notes:

aa. Production costs are on a per unit basis and 12 flights per year baseline.
ab. Operations cost on a per flight basis.
a. On-orbit manufacturing/processing module. Five year lifetime. Assume 1 operational module plus ground spare
b. Reusable reentry module. 10 flights per module. Assume 1 operational modules plus one spare.
c. Assumes two operational Modules. For >12 flight/year add one additional module.
d. Two POCs required. One at high inclination and one spare.
e. Includes two recovery modules
f. Cost for third operational recovery module.
g. Ten persons for two weeks each launch. Cost is on per launch basis
h. Four persons for one month per launch.
i. Two pilots ($5K for each recovery) and four technicians ($20K for each recovery). Also includes three persons at $75K for 12 flights for recovery tracking.
j. Total ten techs at $750K/year less $20K of four techs time spent on recovery operations for 12 flights.
k. Eight persons (3 shifts and 1 alternate shift) $600K/year for 12 flights.
l. Ten persons for two months at $75K/year.
m. Four persons at $75K/year for two months.
n. Ten techs at $75K/year for two months.
p. Ten techs at $75K/year for two months.
q. Eight persons at $75K/year for two months.
r. Cost to refurbish launch site after launch.
s. Assume R&D investment cost times 20% ROI/year
t. Totals do not include ROI of 20%/year for five year amortization.
u. Launch costs per launch

Space Manufacturing/Processing Launch System Return on Investment Analysis - D2

GOV PAYS 0% R & D

				CY 01	CY 2	CY 3	CY 4	CY 5	CY 6	CY 7	CY 8	CY 9	CY 10	CY 11	CY 12	CY 13	CY 14	CY 15
ZZ		FLIGHTS				0	0	0	4.5	9	18	18	18	18	18	18	18	18
A		R & D INVESTMENT		10%	20%	30%	30%	10%										
B		R & D H/W		(12.3)	(24.6)	(36.9)	(36.9)	(12.3)										
C		R & D SERVICES		(0.1)	(0.2)	(0.3)	(0.3)	(0.1)										
D																		
E		TOTAL R & D INVESTMENT		(12.4)	(24.8)	(37.2)	(37.2)	(12.4)										
F																		
G		FIXED ASSET INVESTMENT																
H		SERVICE MODULE				(166.7)	(166.7)	(166.7)							-150			
I		ASD H/W				(16.7)	(16.7)	(16.7)							-10			
J		REC MOD				(133.3)	(133.3)	(133.3)							-75			
K																		
L		TOTAL F/A				(316.7)	(316.7)	(316.7)	0	0	0	0	0	0	-235	0	0	0
M	5 YR SL	DEPRECIATION							136	136	136	136	136	136	136	34	34	34
N																		
O		RECURRING COSTS																
P		H/W							113	226	452	452	452	452	452	452	452	452
Q		OPS							7	14	28	28	28	28	28	28	28	28
R																		
S	P + Q	TOTAL RECURRING COSTS							120	240	479	479	479	479	479	479	479	479
T																		
U	E + L	TOTAL INVESTMENT		(12)	(25)	(354)	(354)	(329)	0	0	0	0	0	0	(235)	0	0	0
V																		
W	=M	DEPRECIATION							136	136	136	136	136	136	136	34	34	34
X																		
Y	S+W	TOTAL COST							256	375	615	615	615	615	615	513	513	513
Z																		
AA	Y/ZZ	UNIT COST							57	42	34	34	34	34	34	28	28	28
AB																		
AC																		
AD		PROFIT MARGIN NECESSARY TO ACHIEVE 20% ROI																
AE																		
AF	=U	GROSS CASH		-12	-25	-354	-354	-329	0	0	0	0	0	0	-235	0	0	0
AG	=Y X 90.5%	PROFIT (ON COST)	100.4%						257	377	617	617	617	617	617	515	515	515
AH																		
AI	AF + AG	CASH FLOW BEFORE TAX		-12	-25	-354	-354	-329	257	377	617	617	617	617	382	515	515	515
AJ																		
AK	=AI X 35%	TAXES 35%							-90	-132	-216	-216	-216	-216	-134	-180	-180	-180
AL	=E X 35%	LOSS CARRY FWD		4.3	8.7	13.0	13.0	4.3	43									
AM	=AL + AK	NET TAX LIABILITY		0	0	0	0	0	-46	-132	-216	-216	-216	-216	-134	-180	-180	-180
AN	=AI + AM	NET CASH FLOW		-12	-25	-354	-354	-329	210	245	401	401	401	401	249	335	335	335
AO																		
AP		NPV OF NET CASH	0															
AQ																		
AR																		
AS	= Y+ AG	TOTAL SALES		0	0	0	0	0	512	752	1233	1233	1233	1233	1233	1028	1028	1028
AT																		
AU	=AS/AG	RETURN ON SALES							50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
AV																		
	=AS/ZZ	UNIT PRICE	$66.7						113.8	83.6	68.5	68.5	68.5	68.5	68.5	57.1	57.1	57.1

SPACE MANUFACTURING ASSUMPTIONS - D2

NEW FLIGHT SCHEDULE (25%,50%,100%)

R & D BEGINS 5 YEARS PRIOR TO FIRST LAUNCH (10%,20%,30%,30%,10%)
R&D EXPENSE TREATED AS A SUNK COST AND RECOVERED THROUGH FUTURE PROFITS

SERVICE MODULE, AUTO SPACE DOCKING H/W & RECOVERY MODULE TREATED AS FIXED ASSETS
FIXED ASSET VALUE INCLUDES DESIGN COSTS
STRAIGHTLINE DEPRECIATED OVER USEFUL LIFE (7 YEARS)
1 YEAR LEAD TIME ON REPLACEMENT UNITS

UNIT PRICE CALCULATED TO PRODUCE 20% IRR
NET WORKING CAPITAL ADJUSTMENTS NOT INCLUDED
TAX RATE = 35%, LOSS CARRYFORWARD OF R & D COSTS
GOING CONCERN ASSUMED

Space Manufacturing/Processing Launch System Estimate (includes recovery module flights)

	2000	01	02	03	04	05	06	07	08	09	10
Drug Production	3	3	3	4	4	4	4	5	5	5	5
Biotechnology Production	3	3	3	3	3	3	3	4	4	4	5
University/Industrial Research	3	4	4	4	4	4	4	4	4	4	4
Materials Processing	3	3	3	3	4	4	4	4	4	4	4
Total	12	13	13	14	15	15	15	17	17	17	18
Total Annual Revenue (w/o profit)	492.2	533.2	533.2	574.3	615.3	615.3	615.3	697.3	697.3	697.3	738.3

		R&D		Prod			Launch System Unit Price ($M)																	
		Invstmt		Cost	≤12 flts		≤3 flts	≤6 flts	≤9 flts	≤12 flts		≤15 flts	≤18 flts											
Product / Year	aa	($M)		(aa)	/year		/year	/year	/year	/year		/year	/year	2000	01	02	03	04	05	06	07	08	09	10
Service Module	a	500	f	150	8.333	s.	33.33	16.67	11.1	4.167	c	8.667	7.222											
Auto Space Docking H/W		50	f	10	0.833		3.333	1.667	1.11	0.833	c	0.80	0.667											
Recovery Module	b, e	400	f	75	6.667		26.67	13.33	8.89	8.333	c	6.33	5.278											
Launch Vehicles		100		25	26.67		33.33	28.33	28.9	26.67		26.33	26.11											
Launch Site facilities		15	r	0.100	0.35		1.1	0.6	0.43	0.35		0.30	0.27											
Recovery Site facilities		5	r	0.000	0.083		0.333	0.167	0.11	0.183		0.067	0.06											
Program Ops Centers	d	2.5	r	0.000	0.042		0.167	0.083	0.06	0.142		0.033	0.03											
Recovery Site Tracking		0.5	r	0.000	0.008		0.033	0.017	0.01	0.108		0.007	0.01											
Total H/W Costs	t	1073			42.98	u.	98.3	60.87	50.6	40.78		40.78	40.78											
		Start up																						
Operations Costs		Costs		(ab)																				
Launch Operations	l	0.125	g	.030	0.032		0.038	0.034	0.03	0.067		0.032	0.031											
Payload Processing	m	0.05	h	.050	0.051		0.053	0.052	0.05	0.026		0.051	0.051											
Recovery Operations	n	0.13	i	0.03	0.03		0.03	0.03	0.03	0.03		0.03	0.03											
Refurbishing Recovery Modules	p	0.125	j	1.061	1.063		1.069	1.065	1.06	1.063		1.063	1.062											
Mission Operations	q	0.600	k	.363	0.373		0.403	0.383	0.38	0.373		0.371	0.37											
Total Operations Costs	t	1.025			1.546	u.	1.597	1.563	1.55	1.556		1.543	1.54											
Total Launch System Costs ($M	t	1074			44.53	u.	99.9	62.43	52.2	41.02		41.02	41.02	492.2	533.2	533.2	574.3	615.3	615.3	615.3	697.3	697.3	697.3	738.3

Notes:

aa. Production costs are on a per unit basis and 12 flights per year baseline.

ab. Operations cost on a per flight basis.

a. On-orbit manufacturing/processing module. Five year lifetime. Assume 1 operational module plus ground spare

b. Reusable reentry module. 10 flights per module. Assume 1 operational modules plus one spare.

c. Assumes two operational Modules. For >12 flight/year add one additional module.

d. Two POCs required. One at high inclination and one spare.

e. Includes two recovery modules

f. Cost for third operational recovery module.

g. Ten persons for two weeks each launch. Cost is on per launch basis

h. Four persons for one month per launch.

i. Two pilots ($5K for each recovery) and four technicians ($20K for each recovery). Also includes three persons at $75K for 12 flights for recovery tracking.

j. Total ten techs at $750K/year less $20K of four techs time spent on recovery operations for 12 flights.

k. Eight persons (3 shifts and 1 alternate shift) $600K/year for 12 flights.

l. Ten persons for two months at $75K/year.

m. Four persons at $75K/year for two months.

n. Ten techs at $75K/year for two months.

p. Ten techs at $75K/year for two months.

q. Eight persons at $75K/year for two months.

r. Cost to refurbish launch site after launch.

s. Assume R&D investment cost times 20% ROI/year

t. Totals do not include ROI of 20%/year for five year amortization.

u. Launch costs per launch

Space Manufacturing/Processing Launch System Return on Investment Analysis - D2

GOV PAYS 50% R & D

					CY 01	CY 2	CY 3	CY 4	CY 5	CY 6	CY 7	CY 8	CY 9	CY 10	CY 11	CY 12	CY 13	CY 14	CY 15
ZZ		<u>FLIGHTS</u>					0	0	0	4.5	9	18	18	18	18	18	18	18	18
A		<u>R & D INVESTMENT</u>			5%	10%	15%	15%	5%										
B		R & D H/W			(6.2)	(12.3)	(18.5)	(18.5)	(6.2)										
C		R & D SERVICES			(0.1)	(0.1)	(0.2)	(0.2)	(0.1)										
D																			
E		TOTAL R & D INVESTMENT			(6.2)	(12.4)	(18.6)	(18.6)	(6.2)										
F																			
G		<u>FIXED ASSET INVESTMENT</u>					17%	17%	17%										
H		SERVICE MODULE					(82.5)	(82.5)	(85.0)							-150			
I		ASD H/W					(8.3)	(8.3)	(8.5)							-10			
J		REC MOD					(66.0)	(66.0)	(68.0)							-75			
K																			
L		TOTAL F/A					(156.8)	(156.8)	(161.5)	0	0	0	0	0	0	-235	0	0	0
M	5 YR SL	DEPRECIATION								68	68	68	68	68	68	68	34	34	34
N																			
O		<u>RECURRING COSTS</u>																	
P		H/W								113	226	452	452	452	452	452	452	452	452
Q		OPS								7	14	28	28	28	28	28	28	28	28
R																			
S	P + Q	TOTAL RECURRING COSTS								120	240	479	479	479	479	479	479	479	479
T																			
U	E + L	TOTAL INVESTMENT			(6)	(12)	(175)	(175)	(168)	0	0	0	0	0	0	(235)	0	0	0
V																			
W	=M	DEPRECIATION								68	68	68	68	68	68	68	34	34	34
X																			
Y	S+W	TOTAL COST								188	308	547	547	547	547	547	513	513	513
Z																			
AA	Y/ZZ	UNIT COST								42	34	30	30	30	30	30	28	28	28
AB																			
AC																			
AD		PROFIT MARGIN NECESSARY TO ACHIEVE 20% ROI																	
AE																			
AF	=U	GROSS CASH			-6	-12	-175	-175	-168	0	0	0	0	0	0	-235	0	0	0
AG	=Y X 90.5%	PROFIT (ON COST)	58.8%							110	181	321	321	321	321	321	301	301	301
AH																			
AI	AF + AG	CASH FLOW BEFORE TAX			-6	-12	-175	-175	-168	110	181	321	321	321	321	86	301	301	301
AJ																			
AK	=AI X 35%	TAXES 35%								-39	-63	-113	-113	-113	-113	-30	-105	-105	-105
AL	=E X 35%	LOSS CARRY FWD			2.2	4.3	6.5	6.5	2.2	22									
AM	=AL + AK	NET TAX LIABILITY			0	0	0	0	0	-17	-63	-113	-113	-113	-113	-30	-105	-105	-105
AN	=AI + AM	NET CASH FLOW			-6	-12	-175	-175	-168	93	117	209	209	209	209	56	196	196	196
AO																			
AP		NPV OF NET CASH		0															
AQ																			
AR																			
AS	= Y+ AG	TOTAL SALES			0	0	0	0	0	298	488	869	869	869	869	869	814	814	814
AT																			
AU	=AS/AG	RETURN ON SALES								37%	37%	37%	37%	37%	37%	37%	37%	37%	37%
AV																			
	=AS/ZZ	UNIT PRICE	$48.1							66.2	54.2	48.3	48.3	48.3	48.3	48.3	45.2	45.2	45.2

SPACE MANUFACTURING ASSUMPTIONS - D2

NEW FLIGHT SCHEDULE (25%,50%,100%)

R & D BEGINS 5 YEARS PRIOR TO FIRST LAUNCH (10%,20%,30%,30%,10%)
R&D EXPENSE TREATED AS A SUNK COST AND RECOVERED THROUGH FUTURE PROFITS

SERVICE MODULE, AUTO SPACE DOCKING H/W & RECOVERY MODULE TREATED AS FIXED ASSETS
FIXED ASSET VALUE INCLUDES DESIGN COSTS
STRAIGHTLINE DEPRECIATED OVER USEFUL LIFE (7 YEARS)
1 YEAR LEAD TIME ON REPLACEMENT UNITS

UNIT PRICE CALCULATED TO PRODUCE 20% IRR
NET WORKING CAPITAL ADJUSTMENTS NOT INCLUDED
TAX RATE = 35%, LOSS CARRYFORWARD OF R & D COSTS
GOING CONCERN ASSUMED

Space Manufacturing/Processing Launch System Estimate (Includes recovery module flights)

	2000	01	02	03	04	05	06	07	08	09	10
Drug Production	3	3	3	4	4	4	4	5	5	5	5
Biotechnology Production	3	3	3	3	3	3	3	4	4	4	5
University/Industrial Research	3	4	4	4	4	4	4	4	4	4	4
Materials Processing	3	3	3	3	4	4	4	4	4	4	4
Total	12	13	13	14	15	15	15	17	17	17	18
Total Annual Revenue (w/o profit)	**492.2**	**533.2**	**533.2**	**574.3**	**615.3**	**615.3**	**615.3**	**697.3**	**697.3**	**697.3**	**738.3**

		R&D		Prod			**Launch System Unit Price ($M)**																	
		Invstmt		Cost	≤12 flts		≤3 flts	≤6 flts	≤9 flts	≤12 flts		≤15 flts	≤18 flts											
Product / Year	aa	($M)		(aa)	/year		/year	/year	/year	/year		/year	/year	2000	01	02	03	04	05	06	07	08	09	10
Service Module	a	500	f	150	8.333	s.	33.33	16.67	11.1	4.167	c	8.667	7.222											
Auto Space Docking H/W		50	f	10	0.833		3.333	1.667	1.11	0.833	c	0.80	0.667											
Recovery Module	b, e	400	f	75	6.667		26.67	13.33	8.89	8.333	c	6.33	5.278											
Launch Vehicles		100		25	26.67		33.33	28.33	28.9	26.67		26.33	26.11											
Launch Site facilities		15	r	0.100	0.35		1.1	0.6	0.43	0.35		0.30	0.27											
Recovery Site facilities		5	r	0.000	0.083		0.333	0.167	0.11	0.183		0.067	0.06											
Program Ops Centers	d	2.5	r	0.000	0.042		0.167	0.083	0.06	0.142		0.033	0.03											
Recovery Site Tracking		0.5	r	0.000	0.008		0.033	0.017	0.01	0.108		0.007	0.01											
Total H/W Costs	t	1073			42.98	u.	98.3	60.87	50.6	40.78		40.78	40.78											
		Start up																						
Operations Costs		Costs		(ab)																				
Launch Operations	l	0.125	g	.030	0.032		0.038	0.034	0.03	0.067		0.032	0.031											
Payload Processing	m	0.05	h	.050	0.051		0.053	0.052	0.05	0.026		0.051	0.051											
Recovery Operations	n	0.13	i	0.03	0.03		0.03	0.03	0.03	0.03		0.03	0.03											
Refurbishing Recovery Modules	p	0.125	j	1.061	1.063		1.069	1.065	1.06	1.063		1.063	1.062											
Mission Operations	q	0.600	k	.363	0.373		0.403	0.383	0.38	0.373		0.371	0.37											
Total Operations Costs	t	1.025			1.546	u.	1.597	1.563	1.55	1.556		1.543	1.54											
Total Launch System Costs ($M	t	1074			44.53	u.	99.9	62.43	52.2	41.02		41.02	41.02	492.2	533.2	533.2	574.3	615.3	615.3	615.3	697.3	697.3	697.3	738.3

Notes:

aa. Production costs are on a per unit basis and 12 flights per year baseline.
ab. Operations cost on a per flight basis.
a. On-orbit manufacturing/processing module. Five year lifetime. Assume 1 operational module plus ground spare
b. Reusable reentry module. 10 flights per module. Assume 1 operational modules plus one spare.
c. Assumes two operational Modules. For >12 flight/year add one additional module.
d. Two POCs required. One at high inclination and one spare.
e. Includes two recovery modules
f. Cost for third operational recovery module.
g. Ten persons for two weeks each launch. Cost is on per launch basis
h. Four persons for one month per launch.
i. Two pilots ($5K for each recovery) and four technicians ($20K for each recovery). Also includes three persons at $75K for 12 flights for recovery tracking.
j. Total ten techs at $750K/year less $20K of four techs time spent on recovery operations for 12 flights.
k. Eight persons (3 shifts and 1 alternate shift) $600K/year for 12 flights.
l. Ten persons for two months at $75K/year.
m. Four persons at $75K/year for two months.
n. Ten techs at $75K/year for two months.
p. Ten techs at $75K/year for two months.
q. Eight persons at $75K/year for two months.
r. Cost to refurbish launch site after launch.
s. Assume R&D investment cost times 20% ROI/year
t. Totals do not include ROI of 20%/year for five year amortization.
u. Launch costs per launch

Space Manufacturing/Processing Launch System Return on Investment Analysis - D2

				GOV PAYS 100% R&D														
				CY 01	CY 2	CY 3	CY 4	CY 5	CY 6	CY 7	CY 8	CY 9	CY 10	CY 11	CY 12	CY 13	CY 14	CY 15
ZZ		FLIGHTS				0	0	0	4.5	9	18	18	18	18	18	18	18	18
A		R & D INVESTMENT		0%	0%	0%	0%	0%										
B		R & D H/W		0.0	0.0	0.0	0.0	0.0										
C		R & D SERVICES		0.0	0.0	0.0	0.0	0.0										
D																		
E		TOTAL R & D INVESTMENT		0.0	0.0	0.0	0.0	0.0										
F																		
G		FIXED ASSET INVESTMENT				0%	0%	0%										
H		SERVICE MODULE				0.0	0.0	0.0							-150			
I		ASD H/W				0.0	0.0	0.0							-10			
J		REC MOD				0.0	0.0	0.0							-75			
K																		
L		TOTAL F/A				0.0	0.0	0.0	0	0	0	0	0	0	-235	0	0	0
M	5 YR SL	DEPRECIATION							0	0	0	0	0	0	0	34	34	34
N																		
O		RECURRING COSTS																
P		H/W							113	226	452	452	452	452	452	452	452	452
Q		OPS							7	14	28	28	28	28	28	28	28	28
R																		
S	P + Q	TOTAL RECURRING COSTS							120	240	479	479	479	479	479	479	479	479
T																		
U	E + L	TOTAL INVESTMENT		0	0	0	0	0	0	0	0	0	0	0	(235)	0	0	0
V																		
W	=M	DEPRECIATION							0	0	0	0	0	0	0	34	34	34
X																		
Y	S+W	TOTAL COST							120	240	479	479	479	479	479	513	513	513
Z																		
AA	Y/ZZ	UNIT COST							27	27	27	27	27	27	27	28	28	28
AB																		
AC																		
AD		PROFIT MARGIN NECESSARY TO ACHIEVE 20% ROI																
AE																		
AF	=U	GROSS CASH		0	0	0	0	0	0	0	0	0	0	0	-235	0	0	0
AG	=Y X 90.5%	PROFIT (ON COST)	4.3%						5	10	21	21	21	21	21	22	22	22
AH																		
AI	AF + AG	CASH FLOW BEFORE TAX		0	0	0	0	0	5	10	21	21	21	21	-214	22	22	22
AJ																		
AK	=AI X 35%	TAXES	35%						-2	-4	-7	-7	-7	-7	75	-8	-8	-8
AL	=E X 35%	LOSS CARRY FWD		0.0	0.0	0.0	0.0	0.0	0									
AM	=AL + AK	NET TAX LIABILITY		0	0	0	0	0	-2	-4	-7	-7	-7	-7	75	-8	-8	-8
AN	=AI + AM	NET CASH FLOW		0	0	0	0	0	3	7	13	13	13	13	-139	14	14	14
AO																		
AP		NPV OF NET CASH	0															
AQ																		
AR																		
AS	= Y+ AG	TOTAL SALES		0	0	0	0	0	125	250	500	500	500	500	500	535	535	535
AT																		
AU	=AS/AG	RETURN ON SALES							4%	4%	4%	4%	4%	4%	4%	4%	4%	4%
AV																		
	=AS/ZZ	UNIT PRICE	$28.4						27.8	27.8	27.8	27.8	27.8	27.8	27.8	29.7	29.7	29.7

SPACE MANUFACTURING ASSUMPTIONS - D2

NEW FLIGHT SCHEDULE (25%,50%,100%)

R & D BEGINS 5 YEARS PRIOR TO FIRST LAUNCH (10%,20%,30%,30%,10%)
R&D EXPENSE TREATED AS A SUNK COST AND RECOVERED THROUGH FUTURE PROFITS

SERVICE MODULE, AUTO SPACE DOCKING H/W & RECOVERY MODULE TREATED AS FIXED ASSETS
FIXED ASSET VALUE INCLUDES DESIGN COSTS
STRAIGHTLINE DEPRECIATED OVER USEFUL LIFE (7 YEARS)
1 YEAR LEAD TIME ON REPLACEMENT UNITS

UNIT PRICE CALCULATED TO PRODUCE 20% IRR
NET WORKING CAPITAL ADJUSTMENTS NOT INCLUDED
TAX RATE = 35%, LOSS CARRYFORWARD OF R & D COSTS
GOING CONCERN ASSUMED

APPENDIX C.3 SPACE MANUFACTURING PROSPECTIVE USERS

C.3.1 Instrumentation Technology Associates (ITA) with John Cassanto

Mission Area

Space Manufacturing (Space Research)

Date

9 August 1993
Revised: 10 August 1993

Organization Contacted

Instrumentation Technology Associates (ITA)
35 East Uwchlan Avenue, Suite 300
Exton, PA 19341

Tel: 215/363.8343
FAX: 215/363.8569

Researchers

Bill Walsh, Lockheed, and Henry Hillbrath, Boeing

The researchers met with John Cassanto, president and Ulises (Al) Alvarado, System Engineering Manager, on 8/6/93 for three hours at ITA , Exton, PA to discuss the commercial space manufacturing markets and applications for space and the related launch system attributes.

Summary

The firm has been in business since 1982, providing technical space services and space hardware (instrumentation and materials processing in space (MPS) hardware and containment devices) to university researchers, and biotechnology and drug companies who want to perform experiments in space. They employ about five full time personnel, with an additional 10 to 20 part-time personnel available, as required to support specific projects, or space shuttle launches.. Messrs. Cassanto and Alvarado, and other personnel previously worked for GE Aerospace, Valley Forge, PA. Mr. Cassanto left GE/VF to start Instrumentation Technology Associates (ITA).

The firm provides their engineering services and hardware to drug (pharmaceutical, chemical, biotechnology, etc.) companies. They provide the technical understanding of space to drug company researchers who want to place their experiments on the shuttle, Spacehab, or the MIR.

ITA developed the Materials Dispersion Apparatus (MDA) minilab which can accommodate as many as 150 sample data points during protein crystal growth, casting thin film membranes, cell research, encapsulation of drugs, and conducting biomedical and fluid science experiments. Four MDA units are accommodated in current shuttle flights, in mid deck lockers, and provide 500 to 600 data points. Mr. Cassanto says other types of experiment holders that are available to researchers typically provide six sample points.

A major product area for ITA includes providing their services and equipment to researchers who are experimenting with space-grown protein crystals. Researchers have demonstrated they can grow larger, more uniform protein crystals faster in a micro-gravity environment than can be done on earth. The three-dimensional molecular structure of the larger, space grown crystals can be determined using X-ray diffraction. Determining the molecular structure is an essential step in several areas of medical research and rational drug design.

At the current cost and infrastructure, the experimenters will continue their current level of space research, primarily to exploit the two principal attributes of space: the diminution of gravity and the attendant virtual absence of convection. There have been no scientific breakthroughs that would indicate a high growth space market. There is no certainty that a breakthrough will occur in the foreseeable future.

ITA Personnel believe that the probability of a biomedical breakthrough could be enhanced by increasing the data yield per mid deck locker. One approach to accomplish this is to use high density space processing hardware devices that allow multiple techniques to process samples. This can be made available through the private sector. ITA has the technology and equipment on hand to increase the data yield by an order of magnitude, e.g., from the present ~ 60 samples to 600 samples per mid deck locker.

1. What is the maturity of the users' space applications?

The users of space are in various stages of space experimentation, according to ITA. No single end user has made a decision to use space for processing, manufacturing or production of a product. ITA provided a Mission Operation Report, which listed 23 separate examples of space experiments that the company has been involved with through its affiliation with the CCDS program and directly with university researchers, and biotechnology and drug companies. The main commercial applications include: protein crystal growth, micro-encapsulation for drug delivery, cell research, and thin film membranes. The firm also are performing experiments to demonstrate that high quality Zeolite crystals can be produced in space.

2. What are the payload form factors?

Mr. Alvarado said the requirements for growing crystals in space are:

Most experiments operate in 1 atmosphere, and a temperature range of 4 to 37 degrees centigrade. Power is 110 Watts, continuous. Vibration/shock on orbit should be limited to 10E-5 to 10E-6 Gs, 1 to 10 Hertz.

A quasi steady state micro gravity environment of 10E-6 is optimum. The shuttle acceleration environment, while on orbit, is typically from 10E-3 to 10E-5 Gs.

Typical payload weights (for growing protein crystals) are 40 pounds for the crystal growing containers, and 30 pounds for the refrigerator; approx. 70 pounds total.

A low g (<3g) environment during reentry from space is required for the delicate crystal experiments, and physical specimens, such as cells and micro capsules. However, some crystal experiments can tolerate 8 to 10 Gs. Greater than 14 Gs will destroy the crystals.

Mission duration on orbit vary from experiment to experiment, with the min/max varying between 8 to 60 days.

Flights other than on the shuttle, require a reentry system because the researchers want the space grown crystals returned to earth for evaluation and assessment.

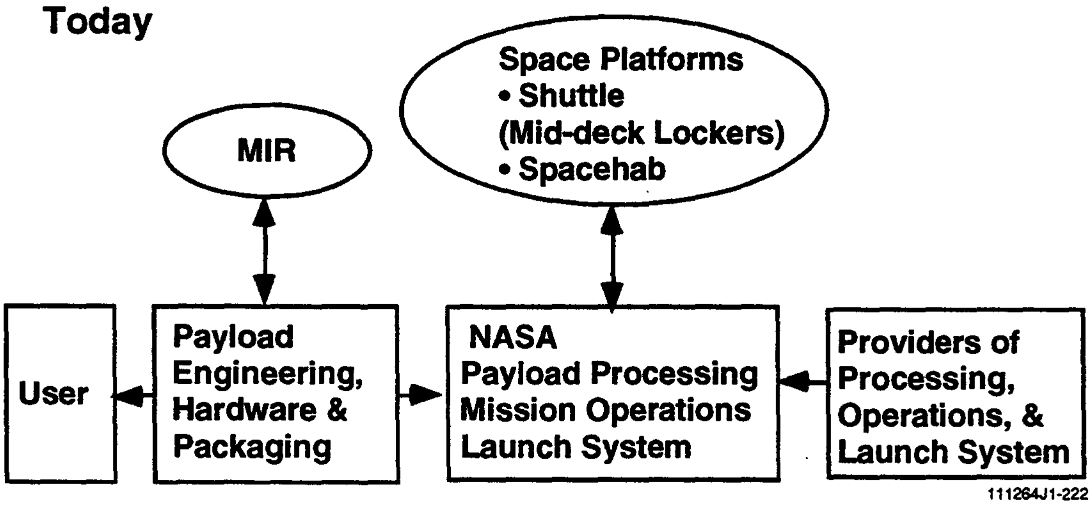
3. What infrastructure and support to the user must the launch system company provide?
The launch system provider should reduce the number of organizations that the end users and ITA, as their technical space representative, must interface with. ITA spends a significant amount of time interfacing with NASA/JSC and their support contractors on technical and safety requirements before they can get approval to fly in the shuttle mid-deck locker. There are also numerous integration and safety documents, and flight readiness review meetings that ITA must attend before they get final certification from NASA to fly on the shuttle. These add complexity, more planning and lead time, and added expense that ITA passes on to the experimenters. The firm estimates it costs them $68,000 worth of expenses to provide a crew for ground processing, integration and launch operations, when flying on the shuttle. That equivalent work costs only $15,000 when flying on a sounding rocket.

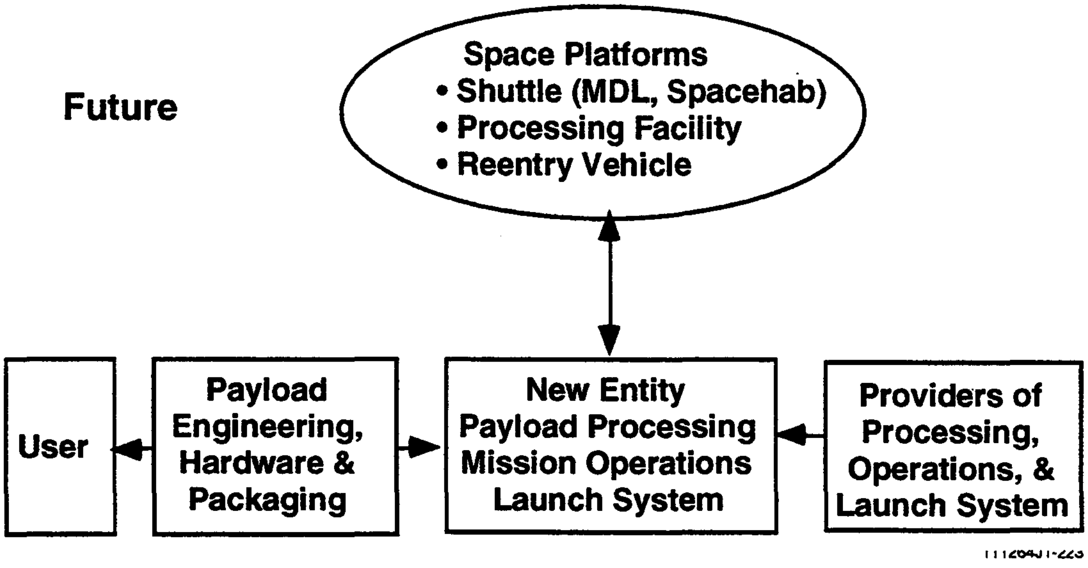
Because some of the ITA experiments require extended times on orbit, i.e., 30 to 60 days, ITA has pursued agreements with NPO Energia for launches to the Russian MIR orbiting facility. ITA is now able to provide to their customers access to MIR which include Russian launch services.

4. What is the end user market infrastructure?
The end users are not familiar with the technical and NASA imposed requirements for performing space experiments. They select companies, such as ITA, to represent their interests in preparing the experiments for space.

See the figure below, entitled -- Space Manufacturing Infrastructure -- for a notional summary of the space infrastructure.

Space Manufacturing Infrastructure





5. What changes or improvements are needed in the market infrastructure to reduce the costs of space produced products?

There are too many governmental organizations and government contractors involved with flying on the shuttle. To respond to all the government organizations cost time and money. The infrastructure must be streamlined to reduce the time and expense. Eliminate or at least ease the burden of the shuttle constraints in areas of integration, documentation and safety

6. If the users are performing experiments now, when will they begin producing commercial products in space?

Some protein crystals that are grown on Earth are not suitable in size or degree of perfection to characterize the molecular structure by means of X ray diffraction. Researchers are continuing to experiment with medically important proteins whose molecular structure can be determined from space grown crystals but not from Earth grown crystals.

Mr. Cassanto believes that researchers will find such a protein crystal within the next five years. However, experts have been predicting this breakthrough for the past ten years. When and if this breakthrough occurs, the demand for space crystals will accelerate rapidly, requiring a major increase in launch vehicle traffic to LEO and return to Earth to support the growth.

Another reason for the delay in crystal experimentation is that there are too few shuttle flights and the number of space experiments must be stretched. With the introduction of Spacehab, experimenters can reduce these delays by paying for an equivalent standard mid-deck shuttle locker. ITA says the costs for a Spacehab locker is $1.8 M to the experimenter. This price level can only be afforded by government organizations at this time and appear to be more than most experimenters are willing to pay to increase their frequency of space experiments. For instance, Spacehab has no commercial users. Most experimenters will opt for longer delays between flights by going through the CCDS industrial affiliate membership approach, which provides a shuttle flight to the commercial experimenter with no launch vehicle costs.

7. What are the current and near term costs associated with using space?

The cost (and length of time) of getting to space is too expensive for the researchers. If researchers perform their experiments through the CCDS', they must deal with the NASA infrastructure, which can be costly and time consuming. The researchers, biotech and drug companies select a company with space engineering experience, such as ITA , to ensure that their experiments meet all NASA-imposed bureaucratic requirements, safety and technical (ground processing, launch, on-orbit, and re-entry) criteria which must be met before flying on the shuttle.

8. How sensitive is user demand to launch system cost? How many more times will they use space if the launch costs is reduced?

Launch System Demand Elasticity: To the CCDS affiliates, NASA provides free shuttle launches. Some drug companies become CCDS affiliates to get free access to space. ITA has customers who are CCDS affiliates and others who are not. For the latter, the cost to the end user is ITA's value added expenses for their technical services and equipment, and the launch cost. The launch costs for a shuttle mid-deck locker range from $150,000 to $200,000, depending on the complexity of the experiment.

Launch Price	<5 Years	< 10 Years
Prevailing (a)	1	1
75%		no change
50%	2	2
25%	4	4
10%	6 (b)	8 (b)

a. Prevailing cost is estimated at $200,000 for a mid-deck shuttle locker.
b. This presumes a technological breakthrough.

Another figure of merit is price per data point. NASA studies estimate the market price for space crystals to be approximately $10,000 per data point. ITA's price to their customers is significantly below this market price.

The recent addition of the Spacehab has provided an alternate to going through NASA for space on the shuttle mid-deck lockers. The Spacehab can provide between 30 to 40 equivalent mid-deck lockers. According to ITA, a Spacehab locker costs about $1.8 million. The end users think this is too expensive.

The firm indicates there is a trend to use the MIR orbiting facility to get lower cost access to space. ITA has an agreement with the Russians for space experiments on the MIR. The company says the costs for launch, space on MIR, and recovery of experiments are proprietary.

9. What decision making business process is used to decide on the use of space?

ITA says that the drug and biotech companies do not have enough empirical data to make a decision on expanding their use of space. There have been too few experiments to reach a conclusion to expand the use of space research. Consequently, the drug companies have not set a high priority on space research. Decisions on expanding the use of space are normally made by drug company executives who are involved with setting the firms' research budget.

10. What are titles and names of executive managers who are making the business decisions to invest their resources into producing products in space?

ITA focuses their customer contacts at the researcher and lab manager level in the university, biotechnology and drug companies. They could not provide the names of decision makers who make the research decisions at the senior executive level.

Review and Revision Status

8/9/93 Submitted research report to ITA for review, comments and concurrence with data.

8/10/93 Messrs. Cassanto and Alvarado replied with comments and concurrence. Research report revised and closed out.

C.3.2 Consortium for Commercial Crystal Growth (CCCG) with Dr. William Wilcox

Mission Area

Space Manufacturing (Space Research)

Date

31 August 93
Amended with CCCG's comments 11 October 93 .

Organization Contacted

Consortium for Commercial Crystal Growth
Clarkson University
Camp Building, Room 320,
Potsdam, NY 13699-5700

Who Contacted

Dr. William Wilcox, Center Director
Mark Pasch, Director of Technology Development
Professor Liya Regel, Professor of Research & Associate Director.

Researchers

Don Barker (Lockheed)/Richard Freeman (Martin Marietta)/Henry Hillbrath (Boeing)

Summary

The Center, established in 1986 under NASA Code C funding, conducts technology development for commercial growth of electronic, photonic and detector crystalline materials.

Crystal growth activities in space are experimental rather than commercial manufacturing and the Center has been involved with five Shuttle based micro gravity related experiments in 1992.

Their experience indicates skepticism about immediate space applications from the commercial sector due to high costs. Their view is that a preferred facility for conducting micro gravity experiments should be automated, unmanned and should provide extended duration orbital flights.

They believe that one of the greatest benefits achieved by the CCDS's is the development of ground based capabilities in commercial crystal growth.

The launch system company should provide support to the user by affording on schedule launches, return of samples to a predetermined location, access to extended duration orbital flights in a simple straight forward way with an absence of bureaucratic procedures.

Commercial value added companies should be encouraged to provide instrumented sample containment equipment for general application in ground and space related activities. There appears to be little short term benefit in "manufacturing" crystalline material in the space environment since to date there has been no statistically significant evidence of a higher performing infrared or semiconductor crystal material which has been produced using methods unique to the space environment.

With reference to space application activities, there appears to be currently near zero sensitivity of user demand to launch system cost. This is due to the free rides currently offered by NASA and also the fact that few higher performing materials have been produced using methods unique to the space environment.

The lack of experience with regard to space applications, shown by non-space commercial companies, is such that informed opinions on the investment potential of space based business is difficult to obtain at this time.

1. What is maturity of users' space application?
The center was established in 1986 under NASA Code C sponsorship with the original title of "Center for the Development of Commercial Crystal Growth in Space." The Center title has evolved into The Consortium for Commercial Crystal Growth. The center mission statement as quoted by Clarkson University is "to enhance the global competitiveness of North American industry by developing improved crystal products and processing through space and ground based research and development."

The Consortium's main goal is to develop the technology for commercial growth of electronic, photonic and detector crystals – activities include vapor growth for cadmium telluride, solution growth of triglycine sulfate (TGS) and L-arginine phosphate (LAP) and floating zone growth of gallium arsenide, cadmium telluride, bismuth germonate and germanium cadmium arsenide and solidification of Cd Te et al. These crystalline materials have commercial application to high speed integrated circuits, infra-red sensors, optical communication and radiation sensors.

The Consortium has a Technical Advisory Committee (TAC) whose members are primarily from companies with interests in crystal growth and related technologies.

Literature obtained from Clarkson University lists 18 consortium participants, two of which (Metrolaser, Irvine, CA, and Potsdam Semiconductors Research, Potsdam) are partners, six of which are industrial affiliates (including Electrofuel Manufacturing Co., Ontario, Canada) and two co-operating institutions which are Canadian Government Federal Agencies (Canadian Space Agency and Canada Centre for Mineral and Energy Technology). The balance of participants are those in which Principal Investigators at U.S. universities are supported by CCCG funding. The National Institute of Standards and Technology (NIST) is also involved as a participant.

A consortium partner may have ownership of intellectual property rights as opposed to an affiliate membership where experimental data may be publicly shared . This appears to offer a methodology of preserving commercial proprietary data. With reference to the maturity of the center's space applications, Appendix I to this report lists the center accomplishments and capabilities. They have been involved in two STS flights which carried micro gravity related experiments namely IML-1 (STS-42, January 92, ~ 8 days on orbit) and USML-1 (STS-50, June 1992, ~ 14 days on orbit).

The Center personnel confirmed that no manufacturing in space was occurring. All space applications are experimental and most involve the Shuttle configured with various experimental facility inserts – International Micro gravity Laboratory, the US Micro gravity Laboratory and Spacehab. These experimental facilities provide up to 14 days in orbit.

The Center personnel noted that a preferable facility for conducting micro gravity experiments would be automated, unmanned and would provide extended duration orbital flights, i.e. unmanned would eliminate extraneous platform vibrations and avoid costly provision for life support with attendant safety considerations. In addition, the facility would stimulate the development of dual use robotic subsystems which would be applied on earth as in orbit.

The Center personnel expressed enthusiasm about the U.S. COMET program which, if developed, would provide an unmanned free flyer on orbit for 30 days.

***Authors note:** It is interesting to note that an ESA sponsored European Retrievable Platform (EURECA-1) was deployed by the Shuttle in August 1992 and recovered by the Shuttle in about April 1993. This provided about 9 months of automated capability for extended duration micro gravity experiments.*

Again, with reference to maturity of space applications, the Center personnel confirmed that in their experience there was skepticism about space manufacturing from the commercial sector. The Challenger accident in 1986 dampened enthusiasm with regard to access to space; the current NASA way of doing business is incompatible with quick turnaround, simple access and low cost; payload manifest changes are frustrating to commercial schedule containment and the resolution of safety issues associated with manned flights are extensively time consuming and costly.

It was also stated that the largest benefits of the CCDS is from ground based experiments and theory in preparation for space flight and from spin off technology.

2. What are payload form factors?

Specific form factors were not recommended by the center at the time of interview. A description of such form factors for protein crystal growth are referenced in the Lockheed Engineering Memo relating to Payload System Inc. dated 19 August 1993 and revised 22 September 1993. The form factors pertaining to crystal growth of IR detector and semi-conductor materials will generally demand larger weights, higher power requirements and may be more tolerant of higher ascent and descent accelerations.

3. What infrastructure and support to user must launch system company provide?

The launch company should provide an unmanned orbital experimental facility which affords an extended duration time on orbit with automated experimental facilities.

Experimental packages need to be launched specifically to an agreed schedule and returned to a guaranteed predetermined location.

The process of obtaining orbital flights must be simple and straightforward with an absence of bureaucratic procedures.

4. What is end user market infrastructure?

The current end user market infrastructure is to become a partner or affiliate of the CCDS and obtain access to space through the center affiliations with NASA. The CCDS involve other commercial companies in the design, development and instrumentation of experimental materials containment and processing equipment. In some cases, the CCDS invite the participation of these commercial companies in the packaging design and development activity and subsequently license the company to manufacture these facilities for general application for both ground and space use.

5. What changes or improvements are needed in the market infrastructure to reduce costs of space produced products?

Reduced cost of space produced products (space experiments in the near term) will be obtained by a payload pre launch processing cycle unencumbered with review processes associated with manned experimental facilities, fixed and dedicated payload manifesting, reduced time to launch and launch/recovery on schedule.

6. If users are performing experiments now, when will they begin producing commercial products in space.

According to the current view of this CCDS, there appears to be little short term hope of "manufacturing" crystals in the space environment with current costs and procedures.

There is an advantage obtained for the experimental production of relatively large, pure crystal structures in a micro gravity environment in low earth orbit. However, to date, there has been no statistically significant evidence of IR or semi-conductor crystal materials having been produced in space which have not been duplicated on earth. This is because space experiments relevant to a particular material have not been repeated rather than due to scatter in the sample measurement data obtained.

7. What are current and near term costs associated with using space?

No specific figures were offered with reference to the use of space. It is known however that the CCDS's provide access to space without charge to the user other than the cost of commercial company in kind and cash support of the CCDS organization as a partner or affiliate and the cost of commitment in labor and materials necessary throughout the experiment preparation, conduct and subsequent analysis.

8. How sensitive is user demand to launch system cost. How many more times will they use space if launch costs are reduced?

With reference to this CCDS's space application activities, which are currently in an experimental phase, there is currently near zero sensitivity of user demand to launch system cost. This is probably due to the NASA Office of Commercial Programs having a signed flight agreement, called the Center for Commercial Development of Space Flight Agreement, with each CCDS. This agreement serves to delineate all responsibilities, procedures and activities involved in the use of the Shuttle by the CCDS's including provisions for Shuttle services at no charge.

The level of demand is thought to be simply a function of the fact that, to date, there has been no statistically significant evidence, demonstrated and widely publicized, of a higher performing infrared or semiconductor crystal material which has been produced using methods unique to the space environment.

9. What decision making process is used to decide on the use of space?

Decision making process with regard to commercial space application must rest with the premise of a demonstrated enabling technology unique to the space environment, the exploitation of which would lead to a business base whereby financial returns would significantly outweigh costs and risks.

10. What are titles and names of executive managers who are making business decisions to invest their resources into producing products in space?

The Center did not disclose specific identifies of executive managers who may be involved in decisions to invest resources into producing products in space. It was reiterated that currently, and probably within the next five years or so, commercial space applications would be for experimental purposes and certainly not full scale manufacturing of products.

In addition, the lack of experience with regard to space applications, as generally pertains to non-space commercial companies, is such that informed opinions on investment potential of space based business would be difficult to obtain at this time.

C.3.2.1 Consortium for Commerical Crystal Growth, Clarkson University, Potsdam, NY

Accomplishments

a. Developed a new furnace for vapor growth and a low-velocity laser Doppler velocimeter.
b. Developed a low-cost, low-power, gradient freeze furnace.
c. Determined the influence of vibrations, accelerated crucible rotation, and current pulses on InSb, InGaSb, and MnBi-Bi eutectic solidification.
d. Achieved seeded vapor transport of large diameter CdTe at commercially useful rates.
e. Developing an automated floating zone melting mirror furnace.
f. Successful solution crystal growth of doped triglycine sulfate (TGS)and L-arginine phosphate (LAP), improving device performance and reducing material cost.
g. Coated growth ampoules with pyrolytic boron nitride (PBN) for improved crystals; developed eddy current technique to aid in crystal growth analysis.
h. Developed computer models for heat transfer, thermal stress, and convection during crystal growth.
i. Float zoned GaAs using liquid encapsulant; float zoned CdTe, yielding single crystals.
j. Solution crystal growth of higher quality TGS on IML-1.
k. Crystallization of larger zeolite crystals on USML-1.
l. Measured mechanical properties of CdTe at high temperature and observed dislocation movement in real time.

Additional Capabilities

a. Directional solidification and floating zone melting of CdTe; floating zone melting of GaAs, BGO (bismuth germanium oxide), BiSO, and GeCdAs4.
b. Materials processing in high gravity, with the world's only centrifuge facility dedicated to materials processing and flow visualization research.
c. Robotic thermal processing of device structures.
d. Real time synchrotron x-ray topography and neutron diffraction for observation of crystallographic defects.

C.3.3 Payload Systems Inc. with Dr. Javier de Luis

Mission Area

Space Manufacturing (Space Research)

Date

19 August 1993
Revised 22 September 1993

Organization Contacted

Payload Systems Inc.
276 Third Street
Cambridge, MA 02142

Tel: 617/868.8086
FAX: 617/868.6682

Researchers

Bill Walsh, Lockheed; and Henry Hillbrath, Boeing

Summary

The researchers met with Dr. Javier de Luis, president, Payload Systems Inc. (PSI), and with Dr. Anthony Arrott, formerly with PSI, on 8/3/93 to discuss the commercial markets for space. For reference: Dr. Arrott can be reached at Arthur D. Little, Acorn Park, Cambridge, MA 02140-2390. Tel 617/498.5886 and FAX: 617/498.7007. The firm began business operations in 1984 They currently employ about __ personnel. The three hour meeting focused on applications in commercial space research markets.

PSI provides space experiment containment devices or holders and instrumentation, the combination can be referred to as "mini-labs." They also provide space engineering and payload integration services to drug companies (i.e., pharmaceutical, biotechnology, medical), universities, and government researchers who want to perform experiments in space. Recently, the firm received a contract from the Canadian Space Agency to develop a furnace and data management system that will support Canadian researchers needs. The equipment will fly on Spacehab.

The company was flying 3 missions per year on NASA's C-135 parabolic, zero G flights. However, they have stopped these flights because NASA-HQs lawyers redefined the liability to the user to include the aircraft and crew. The insurance is now more than the flight costs.

Dr. de Luis commented ... "they are helping experimenters get into space." PSI has moved aggressively into providing innovative space services to the users. In 1988 they began contracting with the Russians to fly on MIR. This move has been successful for the company and they are seeing an increase in the frequency of biomedical research. Some key reasons why researchers want to fly on MIR are:

a. MIR provides the researchers with more than two weeks on orbit.
b. The experimenters do not have to disclose the specific research compounds.
c. The Russians can accommodate an increased frequency of space experiments.
d. There is less lead time for reserving space on MIR.

e. There is much less preplanning, meeting, reviews than with NASA flights.

Dr. de Luis thinks protein crystal research in space is a growing market. The experimenters want to do much more research in space. The number of protein crystal space experiments is increasing significantly. The actual increase or growth, however, is confidential to the experimenters.

Payload Systems' customers include:

a. **USA:** BioServe Space technologies, .Kansas State, Penn State (CCR/CCDS), Bionetics, MIT, Instrumentation Technology Associates, Los Alamos National Laboratory.
b. **Japan:** Hitachi, Fujitsu Laboratories, Ishikawayima-Harima Heavy Industries.
c. **Europe:** Novaspace, Kayser-Threde, OHB System.
d. **Canada:** Alberta Research Council, National Research Council of Canada.

1. What is the maturity of the commercial users' space applications?

Their primary use is space research. Commercial users are performing research experiments in space. Drug companies, universities, and government labs involved in biomedical research are growing protein crystals. The drug companies are not using space for processing, manufacturing or producing products.

2. What are the payload form factors?

The requirements for growing crystals in space are:

a.	Ambient pressure:	1 Atmosphere operation in space
b.	Temperature range:	4 to 23° C
c.	Gravity:	< 10E3 minimum, note a
d.	Power:	TBD Watts, continuous
e.	Experiment Weight:	TBD lbs, note b
f.	Vibration:	note c, d
g.	Shock:	note c, d
h.	Time on orbit:	>15 days, note e
i.	Recovery:	Crystals must be returned to earth.

Notes:

a. Quasi steady state micro-gravity environment of 10E-6 is optimum during protein crystal growth. During orbital maneuvers rating can range from 10E-3 to 10E-5 Gs.
b. 70 pounds total. Typical payload weights (for protein crystals) is approx. 40 pounds for the materials, holders, and instruments; and approx. 30 pounds for refrigeration.
c. On orbit vibration/shock should be limited to <10E-5 to <10E-6 Gs, 1 to 10 Hertz.
d. A low G environment (< 3g) during reentry is required for delicate crystal experiments. However, some crystal experiments can tolerate 8 to 10 Gs. Greater than 14 Gs will destroy the crystals.
e. Mission duration's vary from experiment to experiment, with the min./max. varying between 15 to 60 days.

3. What infrastructure and support to the user must the launch system company provide?

The launch system company must provide an interface control document which defines the complete form, fit and functional requirements of the overall launch system. The provider should also provide facilities at the launch complex for the user to set up a portable lab, and space for the payload to be assembled and validated for flight. The user would also like to rely on the launch system infrastructure to provide the mission operations, related support activities, and provide the recovery site and operations. Although it is not required now, down linking of experiment data , during the mission would be extremely useful.

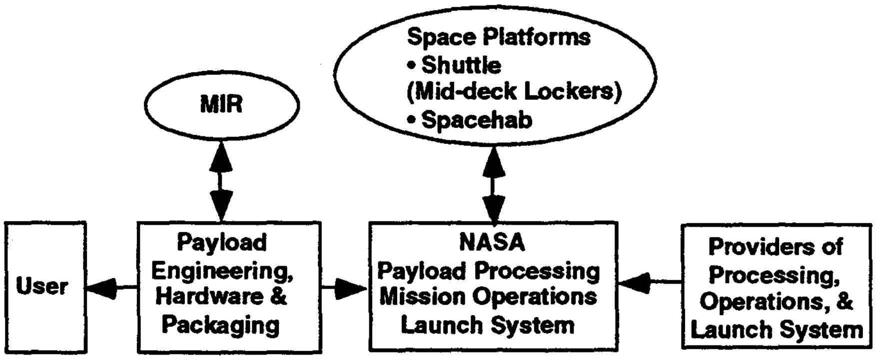
Other issues: reduce the numbers of layers that the users must interface with for performing their space experiments. Set firm dates for launch, on-orbit operations, and recovery.

4. What is the space research market infrastructure?

The end users, i.e., drug companies, universities, and government labs, are not familiar with the technical requirements for performing space experiments. They select companies, such as Payload Systems Inc., to provide the proper packaging of experiments, technical support and to represent their interests in preparing the experiments for space.

The infrastructure illustrated below was developed in agreement with Drs. de Luis and Arrott.

Access to Space Infrastructure



111264-224

The firm has two alternatives for access to space. Initially, they supported their customers with flights on the shuttle mid-deck lockers and Spacehab lockers. However, over the last few years, they have arranged for flights on the MIR.

5. What changes or improvements are needed in the market infrastructure to reduce the costs of space produced products?

Shorten the time it takes to prepare to fly on the shuttle. Some suggestions include: reducing the number of technical, flight, and programmatic reviews; and reduce the certifications and documentation that is required before flight. This could be done by reducing the number of governmental organizations and government contractors involved with flying on the shuttle. Today, there are several different NASA organizations and their support contractors involved with approving a flight experiment before the actual shuttle flight. To respond to all the government organizations cost the end user time and money.

Reducing flight delays can also reduce the user's costs. Each time a shuttle launch is delayed, the end user's and their support contractor's must standby. Improving launch reliability is essential to eliminating stand-down costs of the customer.

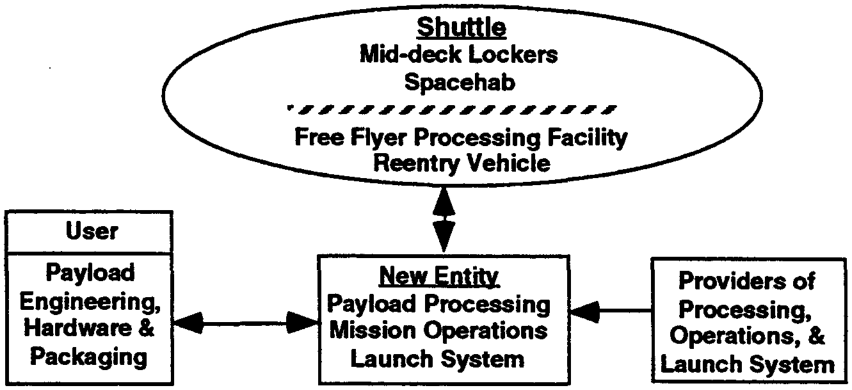
The Russian's approach to flying on MIR is much more streamlined and business-like. When PSI flies on MIR, the firm interfaces with a single organization. The technical, schedule, programmatic requirements, and documentation for MIR flights are much less onerous.

In general, PSI thinks the U. S. launch system infrastructure must be streamlined to eliminate a lot of the time and expense associated with reviews and documentation. Eliminate or at least ease the burden of the shuttle constraints in areas of -- integration, documentation and safety

Reducing the overall launch and recovery system costs will stimulate more space research.

In discussion with Drs. de Luis and Arrott, the infrastructure below was defined as a future approach to reduce flight lead time and costs. The premise for this notional approach is that a launch system infrastructure without NASA involved is essential in the long term for the commercialization of space.

Launch System Infrastructure to Provide
Low Cost, Timely Access To Space



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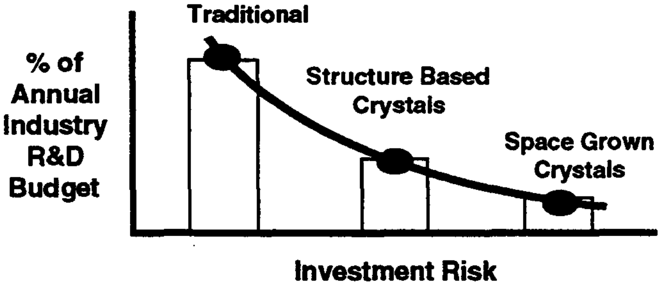
Writer's Conclusions: For commercialization of space to occur, the space research market has to expand. End users think access to space is too expensive and are reluctant to spend their limited research dollars on getting to space. A "New Entity," with a substantially lower cost structure must be conceived to replace the existing government infrastructure. On the long term, this includes replacing the shuttle as the primary launch system. On an interim basis, the shuttle, Spacehab , and MIR will be needed to provide the space platforms for commercial users. However, on the longer term, new free flying facilities, for performing research and manufacturing in space, and reentry vehicles will be required to substantially reduce the launch system costs and the lengthy schedules typical of today.

6. If the users are performing experiments now, when will they begin producing commercial products in space?

It is not clear when commercial products will be produced in space by the drug companies. There have been no examples of research that has lead to producing commercial products. Much more research must be accomplished before it will be possible to estimate producing products.

The researchers anticipate there will be breakthroughs in crystal growth that will prove-in the benefits of space, but they cannot predict when. Researchers have been predicting a breakthrough for several years. Much more empirical data on how to use space for research must be accumulated and disseminated in the research community. However, industry thinks there is too much risk. This is demonstrated in how they spend their R&D budget. As illustrated in the figure below, the "Traditional" research approaches receive the largest share of the funds.

Drug Industries R&D Expenditures



111264-226

The figure illustrates how the drug industries spend their R&D budgets. The Traditional approaches receive the largest share. Structure based crystals receive the next largest share, and space grown crystals receive the least share.

7. What are the current and near term costs associated with using space?

Drug companies consider $1,000 per Well for growing protein crystals in space as an upper cost limit. A Well is about 1 cubic inch, and there are 50 wells per holder (referred to as a "brick," because the physical dimensions are similar to a brick's). A shuttle mid-deck or Spacehab locker can accommodate 10 bricks, or about 500 wells. Using these data, the drug companies will decide not to use a Spacehab locker at $2 million per locker, i.e., equivalent to $4,000 per well.

A graduate student growing crystals for six months can produce 500 trial cells for a total cost of $50,000, or approximately $100 per crystal.

A commercial New Jersey lab can produce 10,000 protein crystal trial cells for about $300,000 per year, or approximately $30 per crystal.

A Russian Institute can produce protein crystals for considerably less than the graduate student and the commercial lab. For reference, a protein research lab and equipment cost about $30,000 per year. However, the Russian prices are being reviewed and subject to major upward revision.

8. How sensitive is user demand to launch system cost? How many more times will they use space if the launch costs is reduced?

Launch System Demand Elasticity: Drug companies become CCDS affiliates to get free access to space. PSI has customers who are CCDS affiliates and other customers who are not. For the latter, the cost to the end user is PSI's value added expenses for their technical services and equipment, and the launch cost. As discussed in 7 above, the Spacehab locker cost is about $4,000 per well.

Launch Price	<5 Years	< 10 Years
Prevailing (a)	0	0
75%		no change
50%		no change
25%	1	1
10%	5	5
1%	10	20 (b)

a. Prevailing cost is estimated at $4,000 per well. Assuming 500 wells are contained in a locker.
b. This presumes a technological space research breakthrough.

Another approach to estimate demand elasticity relative to the cost of a Spacehab locker, which is approximately $2 million per flight. If the cost to the user were reduced by one magnitude there would be significant interest in micro gravity research. If cost were reduce by 2 magnitudes of order, there would be substantial interest in space experiments. This is summarized below:

Launch Price	Level of Interest by Drug Companies
Prevailing (a)	Few commercial users
Prevailing X 0.1	Significant commercial interest
Prevailing X 0.01	Substantial commercial interest

a. Prevailing cost is estimated at $2 million for a Spacehab locker.

Drug companies need a minimum of 6 wells to complete a specific protein crystal experiment. More likely, the companies would want to use 50 wells per experiment. Assuming drug companies would pay $10,000 per flight experiment, the cost would range from $2,000 to $200 per well. Dr, Arrott thinks the companies would pay much more than $200 per well.

Another perspective: Since the inception of the CCDS's (Commercial Centers for the Development of Space) seven years ago, approximately $360 million has been spent on space research. Approximately $130 million from industry and $230 million of NASA funds, exclusive of launch costs. This indicates a substantial research investment for commercialization of space.

9. What decision making business process is used to decide on the use of space?
The drug companies do not have enough research data to make a technical decision on expanding their use of space research. There have been too few experiments to reach a conclusion on expanding their research in space.

Decisions on expanding the use of space are normally made by drug company executives who are involved with setting the firms' research budget.

10. What are titles and names of executive managers who are making the business decisions to invest their resources into space research?
Dr Arrott suggested we get in touch with the following persons:

Protein Crystals: Drake Eggleston, Smith, Kline, Beecham, King of Prussia. PA. 215/270.6690.

Osteoporoses Research: John Termine, Executive Director, Lily, Indianapolis, IN, 317/276.0670. Mr. Termine has been involved with the Penn State CCDS.

Protein Crystallographer: Dr Alex McPherson, U. C. Riverside, 714/787.4227. Dr McPherson has been involved with a broadest range of protein crystal growth research. He has been involved with nearly every company, university, and government initiative, including foreign activities.

Review and Revision Status
8/19/93 Submitted research report to Payload Systems for review, comments and concurrence with data.

8/21/93 Separate copy of research report sent to Dr. Anthony Arrott for review, comments, and concurrence with the data.

9/21/93 Verbal inputs from Dr. deLuis received and entered.

9/22/93 Added additional data from Anthony Arrot. Report reviewed, revised and completed.

C.3.4 University of Alabama – Birmingham with Dr. Charles Bugg

Mission Area

Space Manufacturing (Space Research)

Source Contacted

Dr. Charles Bugg, Director
Center for Macromolecular Crystalography (CMC)
Univ. of Alabama - Birmingham
Box 79 - THT, UAH Station
Birmingham, AL 35294-0005
Tel# 205/934.5329
FAX # 205/934.0480

Contacted by

Bill Walsh, Lockheed, 408/742.4781

Person Contacted

The writer met with Dr. Charles Bugg, at the UAB Basic Health Science Center, Room 262, on 7/16/93 to discuss the Center for Macromolecular Crystallography (CMC) projects he manages as part of the NASA CCDS program. Dr. Bugg is the Research Center director for theCMC projects at the Univ. of Alabama, Birmingham (UAB).

Summary of Contact

The CMC specializes in space grown crystals of biological materials which are identified by participating firms in pharmaceutical, biotechnology, and chemical industries (i.e. drug companies). The goal is to work with companies to develop the technology and applications for space based materials processing of biological crystals. The mission of the center focuses on:

a. Developing new techniques for protein crystal growth on Earth and in space. (This report summarizes the space related activities.)
b. Structural studies of biological macromolecules using protein crystallography for drug design and protein engineering.
c. Definition and development of hardware and software for performing various macromolecular crystallography experiments.

Since 1988, the center has flown 17 protein crystal experiments on the space shuttle. The next shuttle flight (STS-51) will include another CMC experiment. The last shuttle flight had one CMC experiment in the Spacehab module. Other CMC experiments are scheduled on future shuttle flights.

There are also plans to perform CMC flights on free flyers in space. CMC experiments had been designated to fly on the Comet free flyer, however, the Comet project is on hold (see Comet Summary below) pending additional funding to complete the development. Another alternate is the LABS, a new free flyer project discussed below.

Launch Frequency/Experiment Form Factors and Cost

Currently, the demand for space launches which support CMC experiments is established by the availability of the shuttle. Other factors which influence the rate are the funding of experiments by the NASA-CCDS program and the drug companies. The CMC experiments are typically about 100 lbs each and have been housed in shuttle mid-deck lockers and more recently in lockers on the Spacehab module.

There are no launch cost to the drug companies for flying their experiments aboard shuttle. Dr Bugg stated that the drug companies would stop experimenting in space if they were charged a proportional amount of the launch cost, or even a nominal amount.

An estimate of the flights under various scenarios for a five year period are included in the table below. The current level of NASA support to the CCDS program and to the CMC results in a flight rate of about 5 space flights per year, (see scenario 1). In scenario 2, Dr Bugg estimated the CMC is able to manage up to 12 flights per year in the near term. Under ideal conditions, Dr Bugg would like to increase the frequency to one flight per week, scenario 3. As discussed above, scenario 4 predicts that the drug companies would discontinue their space experiments if they were charged for the launch system cost.

Space Experiments, Macrocrystal Growing

Scenario	Launch Cost	1993	94	95	96	97
1. CCDS schedule	Free to user (a)	5	5	5	5	5
2. Nominal growth schedule	Free to user (b)	12	12	12	12	12
3. Maximum growth schedule	Free to user (c)	52	52	52	52	52
4. Demand elasticity	Prevailing costs (d)	0	0	0	0	0
90% Prevailing	0	0	0	0	0	
75% Prevailing	0	0	0	0	0	
50% Prevailing	0	0	0	0	0	
35% Prevailing	0	0	0	0	0	

Notes:

(a) Flight schedule assumes zero launch cost to the CMC experimenter. Also assumes the current CCDS and shuttle funding levels will continue at the same level.

(b) Nominal flight rate assumes zero launch cost to the CMC experimenter, no CCDS program funding constraints, and the shuttle or other launch vehicles can support the CMC flight rate.

(c) Growth rate assumes zero launch cost to CMC experimenter, no CCDS funding constraints, and shuttle or other launch vehicles can support the CMC flight rate.

(d) Launch system "Prevailing" costs are estimated in the range of $5000 per lb to LEO.

Space Applications

Dr Bugg has several active projects with drug companies in the pharmaceutical, biotechnology and chemical industries. He classifies the work as mostly Space Research. Some Space Manufacturing work has been done in the past, but to a much smaller extent.

In Space Research, pharmaceutical, biotechnology and chemical companies perform experiments to form new protein crystals in space. It has been demonstrated that these space experiments sometimes produce improved crystals that cannot be formed in an Earth based laboratory. The space grown crystals have no intrinsic value.

After the crystals are formed in space, they are X-rayed to determine their molecular structure. The structure is used to design new pharmaceuticals, which can then be manufactured on earth.

The experiments performed to date have not demonstrated a technical or costs advantage over other research protein products developed in an earth based lab. The goal is, however, to begin flying experiments that would demonstrate consistent superior experimental results to an earth-based research facility.

The approach being used for the experiments requires a host platform, such as the shuttle, for the companies to perform their experiments in a microgravity, pressurized compartment. The companies provide the materials for the experiment and NASA makes available the pressurized equipment bay and the launch system. Dr. Bugg mentioned the experiments have been flown on the shuttle, and with the most recent flight, in the Spacehab module. He said that COMET is a candidate for free flyer missions, however, that project is in trouble with funding to complete development and first flight, and it may not be available for future experiments.

Dr Bugg says drug companies do not have technical aerospace staff and consequently the firms are not able to respond to technical questions about the use of space. They do not have a staff that can discuss the form factors of the satellites that would be required to support their experimental payloads . Dr. Bugg is familiar with the drug companies applications and thinks he is able to respond to any space related questions CSTS researchers may have.

The U. S. pharmaceutical industry spends approximately $15 billion annually in research on new drugs. Nearly all of the research funds are spent in earth-based labs. Typically, the companies will spend about $3 to 4 million to prepare their experiments for space.

There are executive decision makers (VPs or directors) within the companies that manage these research budgets, however, he cannot provide their names.

In Space Manufacturing, Dupont Corporation was interested in space manufacturing in the past. However, the company has recently moved its space manufacturing group to the newly-formed DuPont/Merck venture, according to Dr Bugg.

Comet Summary

The Comet free flyer is a development project managed by the NASA. The project is on hold, waiting for additional funding. NASA and the Comet contractors are arguing over who should absorb the development cost overruns. Westinghouse has pulled out of the project. Space Industries remains involved, although they are not investing any more company money in the project. According to Dr Bugg, a lawsuit was initiated to force the contractor(s) to continue work on the project or recover the costs from them for completing the project.

The estimated cost of a COMET flight is $30M, which includes: ground operations and launch vehicle, the on-orbit free flyer, a recovery module, and the mission and recovery operations. The launch vehicle candidate includes the EER Corp. Conestoga launch vehicle.

Other Free Flyer Projects

A follow-on free flyer project to the Comet is the Laboratory for Automated Biomedicine in Space (LABS). The launch vehicle is unknown.

Boeing has been talking to pharmaceutical companies about a free flyer vehicle. The space hardware part of the program is a joint effort between Boeing and the Russians. A Russian launch vehicle would be used.

The Boeing contact is Harvey Willingberg, Hunstville, Alabama.

Space Processing Providers

There are a few companies, in addition to Space Industries/Westinghouse and Spacehab, who are trying to commercialize space develop in the payload processing area. They are focussing on providing space platforms for experiments and manufacturing or processing applications. The firms include:

a. Payload System, Cambridge, MA,
b. ITA Company, Exton, PA
c. INTOSPACE, in Europe

Market Research Data

Research on the market for space manufacturing was done by Peat Marwick about four years ago. The report included an analysis of the international market. A segment of the report included microprotein processing and crystal growth applications. Dr Bugg thinks the data and conclusions of the report related to the CMC work is still accurate for today and he believes it continues to reflect the status of the market place.

C.3.5 Space Vacuum Epitaxy Centers with Dr. Alex Ignatiev

Mission Area

Space Manufacturing (Space Processing)

Date

20 August 1993
Revised: 31 August 1993

Organization Contacted

Space Vacuum Epitaxy Center
Science and Research One, Building 1, Room 724
University of Houston
Houston, TX 77204-5507

Telephone: 713/743.3621 FAX: 713/747.7724

Researchers

Bill Walsh, Lockheed, and Robert Cleave, Rockwell

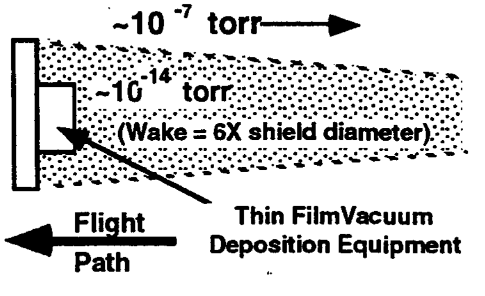
Summary

The researchers met with Dr. Alex Ignatiev, director of the Space Vacuum Epitaxy Center (SVEC), at the University of Houston on 7/29/93 to discuss the commercial markets for space, including space manufacturing. The SVEC is a NASA Commercial Center for Development of Space (CCDS). Their primary technical area is applied engineering on thin film epitaxy using molecular beam epitaxy (MBE) processes for producing a new generation of semiconductor, magnetic, and superconductor thin-film materials.

The 1-1/2 hour meeting focused on the SVEC's plan to produce higher quality thin films in space than can be produced in earth based, production vacuum chambers. Several years of work have led up to a space demonstration flight of the deposition of thin films of Gallium Arsenide (GaAs) wafers, layer-by-layer in a harder vacuum than can be achieved in a manufacturing environment on earth.

SVEC researchers conceived a Wake Shield Facility (WSF), with a 12-foot disc flying in low earth orbit. The free flying facility will deployed from the shuttle. The stainless steel disc is estimated to provide a vacuum of 10 E-14 torr on the wake side. The first of four flights, a two day mission, will demonstrate thin film growth of several Gallium Arsenide (GaAs) 6 to 7 micron wafers, using MBE processes. Three additional flights will expand the thin film processing capabilities and the autonomy of free flight WSF operations.

Wake Shield Free Flyer Concept



The first flight is on STS-60, scheduled for early 1994. The second and third shuttle flights will increase the duration of processing operations and autonomy of free flight operations. For the first flight, the WSF hardware is estimated to cost $12.5 million. Additional hardware through flight three will increase the facility costs to $22 million. The industrial partners are contributing an additional $3 million. Space Industries Inc., is the principal industrial partner for developing the WSF flight hardware. A fourth flight would demonstrate pilot commercial operations, but will require additional industrial funding. The WSF is a proof-of-concept (Mark I) demonstration program. Dr. Ignatiev has plans for a follow on program (Mark II), which will demonstrate commercial approaches to thin film deposition process on GaAs wafers.

The University of Houston Business School, estimated a free flyer Mark II facility, with a five year operational life, would be economically feasible. For commercial operations, approximately four resupply flights per year would be required. Each flight would deliver approximately 100 pounds of materials for processing; and return an equal weight of finished product to earth. The facility would cost about $30 million to build.

1. What is the maturity of the commercial users' space applications?

There are no commercial companies, such as semiconductor manufacturers, producing materials in space today. Through the NASA CCDS, Dr. Ignatiev is working with industrial affiliates to define viable epitaxial processes that can be used in space for synthesizing thin film electronic, superconducting, and magnetic materials and devices. The Wake Shield Facility represents the first flight demonstration of the thin film, vacuum deposition process. If successful, the space-based epitaxy process could revolutionize the manufacturing of microcircuit wafers, though higher quality, more uniform and capable products.

A few more years of space demonstrations and analysis are required to refine the space processes and produce the technical and economic data required to evaluate the costs and benefits of space processes to the semiconductor, superconductor, and magnetic materials industries.

2. What are the payload form factors?

The launch system will be the shuttle for the demonstration flights. The requirements for the Wake Shield Facility, Mark I variant are:

a.	Orbit:	Shuttle altitudes, any inclination, note a
b.	Operation:	Free flight in LEO, note b
c.	Deployment:	Deployed and recovered by shuttle
d.	Recovery:	Retrieved by shuttle RMA, stored in cargo bay, note c
e.	Experiment Weight:	7500 pounds, note d
f.	Volume:	1250 Cubic Feet,(12 feet diameter, 11 feet length)
g.	Time on orbit:	up to 90 days

Notes:

a. Epitaxial growth is not sensitive to inclination. However, a sun synchronous orbit may be preferred for providing solar power for the arrays.

b. Vibration/shock must be limited to 1 to 10 Hertz during processing operations.

c. Processed wafers must be protected during reentry from high G shock and vibration to prevent damage. < 3 G and < ___ Hertz are required.

d. Typical payload weights are 3500 pounds for the wake shield, and 4000 pounds for the carrier. A Mark II version could be made using lighter weight materials.

The launch system for the Mark II variant (production processing facility)of the Wake Shield Facility has not been determined. The requirements for deploying the facility and logistics flights are:

a. Orbit: 250 to 300 nmi altitude, sun synchronous inclination,
b. Operation: Free flight, note a
c. Resupply: Provide 100 pounds of raw material every three months.
d. Facility Weight: 4000 pounds
e. Volume: 900 Cubic Feet, (12 feet diameter, 8 feet length)
f. Time on orbit: 5 years minimum
g. Resupply: One flight every three months, with 400 lbs of raw materials.
h. Recovery: Return to earth with 400 pounds every three months, note b.
    1. Vibration/shock must be limited to 1 to 10 Hertz during processing operations.
    2. Processed wafers must be protected during reentry from high G shock and vibration to prevent damage. < 3 G and <10 Hertz are required.

3. What infrastructure and support to the user must the launch system company provide?

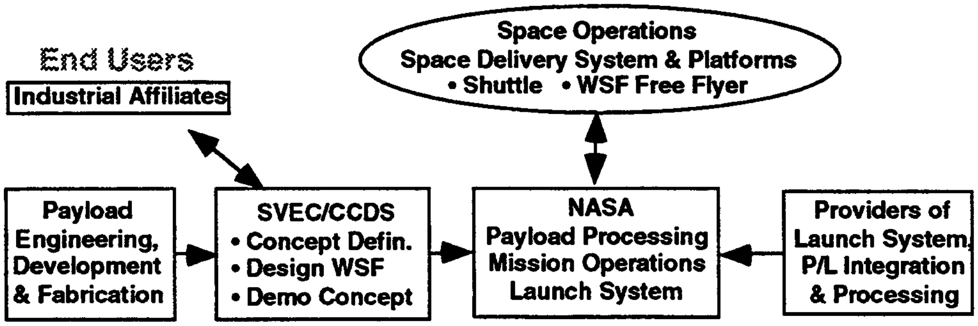
For the Mark II production processing facility, the launch provider must supply a low cost launch system for the resupply and recovery operations. These resupply flights will be on a quarterly basis, with growth potential to one per month.

Please provide any additional comments you think are appropriate for Mark II facility.

4. What is the space manufacturing market infrastructure today?

There are no end users performing space manufacturing. Industrial companies interested in space manufacturing are affiliates of the NASA CCDSs. The infrastructure illustrated below was discussed with Dr. Ignatiev.

Space Infrastructure For Commercial Applications



111264-228

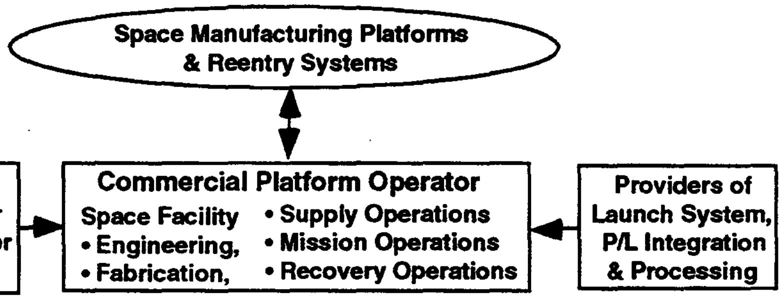
5. What changes or improvements are needed in the launch system infrastructure to reduce the costs of space produced products?

Shorten the time it takes to prepare to launch payloads. Some suggestions include:

a. Reduce the technical, schedule, programmatic requirements, and documentation requirements for flights. If they are much less onerous they will be less expensive.
b. Reducing flight delays can reduce the overall launch costs. Each time a launch is delayed, the payload customer and their support contractors must standby. Improving launch reliability would reduce these stand-down costs of the customer.

In the future, the space infrastructure for commercial markets should change from what we have today for the demonstration flights. When the economic viability of producing high value, low weight materials in space is accepted by commercial industries, a new business entity should evolve to support the end user industries. In discussion with Dr. Ignatiev, a possible infrastructure approach which could evolve could look like the following:

Future Space Manufacturing Market Infrastructure



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Writer's Conclusions: Space manufacturing must demonstrate its economic viability before the market infrastructure will begin to emerge. End user industries do not have the technical and management expertise to produce and operate a space manufacturing facility. It is most probable that they will initially acquire the space manufacturing capability from outside sources who specialize in providing these services.

6. When will end users begin manufacturing products in space?

The Wake Shield Facility demonstration flights must prove in the technical feasibility of growing thin films wafers in space. If the process proves-in, the Mark II Wake Shield Facility operating cost estimates indicate economic feasibility can be reached with only one percent of the wafer market.

The microcircuit industry produces $59 billion worth of chips annually. 99.9 percent of that market is silicon microcircuits. The Mark II facility must be able to accommodate the large wafers (8 to 10 inch diameter), which are the current industry standard. If the Mark II were capable of producing thin film wafers, one percent of the market would provide about $590 million in annual revenue. Dr. Ignatiev thinks this sales base would justify producing the Mark II Wake Shield Facility.

Other microcircuit operations, which require large facility expenditures, can also be performed in space. Photolithography operations used in manufacturing microcircuits can be performed in space. Class 10 clean rooms are required to perform these super clean operations. The facilities are very expensive to operate. Dr. Ignatiev's studies have concluded photolithography operations can be done in conjunction with space thin film processing in a cost effective manner.

7. What are the costs associated with manufacturing space products?

The space processing facility costs for thin film wafers are estimated as follows:

Mark II Facility	$15 to 20 million
Deployment (Mark II):	35 million, note a
Mission Operations:	5 million, note b
Resupply & Recovery:	37.5 million, note c
Total Operating Costs	97.5 million

The above costs would be amortized over the volume of microcircuit wafers produced.

Wafers produced:	$108 to 180 million, note d
Cost per wafer:	$ 6,000 to 10,000

Notes:

a. All launch system costs for deployment of the Mark II facility.
b. All ground mission control of the space facility for a five year period.
c. All resupply materials, launch system, and reentry system (including ground recovery site operations) over a five year period. Assume one resupply & recovery every three months.
d. All wafers produced over five years.

8. How sensitive is the user demand to launch system cost? How many more times will they use space if the launch costs is reduced?

Assume a Mark II facility is operational. The facility must be resupplied with about 100 pounds of wafers every three months. An equal weight of processed wafers must be returned to earth. The round trip cost for each flight depends on whether it is on a dedicated mission or is combined with other payloads.

Launch Price	<5 Years	< 10 Years
Prevailing (a)	4	4
75%	4	4
50%	4	4
25%	4	4
10%	4	4

a. Prevailing cost is estimated at $35 million per round trip flight.

9. What decision making business process is used to decide on the use of space for manufacturing?
The microcircuit companies will decide on the use of space processing if it cost effective, and can provide better products. Dr. Ignatiev estimates that a factor of five to ten increase in wafer performance may be realized by space processing. In current technology, a factor of two increase in performance is a factor of ten increase in value to the semiconductor manufacturers.

Another major factor to the end user is the reliability of the production process. There must be low risk to the stream of product produced by the space processing facility.

10. What are titles and names of executive managers who will make the business decisions to invest company resources in space manufacturing?

Review and Revision Status
8/23/93 Submitted research report to SVEC for review, comments and concurrence with data.

8/25/93 Dr. Ignatiev provided partial comments. Sent missing page of report to Dr. Ignatiev for consideration.

8/31/93 Dr. Ignatiev provided remainder of comments. Report completed.

C.3.6 University of Alabama—Huntsville with Dr. Charles Lundquist

Mission Area

Space Manufacturing (Space Research)

Date

2 July 1993

Organization Contacted

Dr. Charles Lundquist, Director
Univ. of Alabama in Huntsville
Research Institute Building M65
Huntsville, AL 35899
Tel# 601/688.2509
FAX # 601/688.2861

Contacted by

Bill Walsh, Lockheed, 408/742.4781

Summary of Contact

The writer contacted the Dr. Lundquist, director, UAH-HSV. They are a university organization working as part of the NASA Center for the Commercial Development of Space (CCDS) program. They are lead center for materials development in space.

Regarding CSTS, he commented there has been many studies, several per year. The companies and his activity are getting tired of so many studies.

Dr. Lundquist has 8 to 10 ongoing, active materials development initiatives as part of the CCDS program. Some are with small companies, other with large business.

Small business examples are with ITA, John Casanto, in Pennsylvania. They are selling space on a facility that can go into LEO to other companies.

Another small business is SHOT (Space Hardware Optimization Technology), Floyds Know, Indiana. Contact is Mark Duser, president. Application is biological separation.

Dr. Lundquist promised to send complete contact information for these referrals. He also promised to provide recent reports on their accomplishments.

An agreement was made to follow up with meetings or telecons in the later part of July to discuss these applications, when the alliance begins the market research phase.

C.3.7 Grumman Corporation with Mr. Louis Hemmerdinger

Mission Area

Space Manufacturing (Space Research)

Date

1 September 1993
Amended following Grumman validation 11 October 1993

Mission Area

Space Manufacturing (Space Research)

Organization Contacted

Grumman Corporation
Stuart Avenue
Headquarters Building
Bethpage, Long Island, NY 11714

Who Contacted

Mr. Louis Hemmerdinger, Corporate Technology Advisor
Dr. David Larson, Grumman, Corporate Head of Research
Mr. Grant Hedrick, Grumman Consultant

Researchers

Don Barker (Lockheed), Richard Freeman (Martin Marietta), Henry Hilbrath (Boeing)

Summary

Grumman has considerable experience in research and development of crystalline Group III-V materials. They have also been involved as a commercial member with the Center for Commercial Crystal Growth in Space at Clarkson University, Potsdam, NY.

This membership has been discontinued due to the perception that the Center activities seem to emphasize university based research rather than commercial based research. The apparent trend of the CCDS's is to conduct growth experiments on smaller samples, requiring less on orbit power, than is required for commercial products. In addition, the quality and size capability of ground based crystal growth furnaces is increasing rapidly whereas the NASA trend is to smaller size equipment for space applications.

A past Grumman proposal to utilize a limited number of initial no cost Shuttle flights to demonstrate proof of concept for an in-space commercial crystal growth venture was mutually terminated by NASA and Grumman following the Challenger disaster, due to a 4-5 year delay to launch the furnace system.

Grumman has no current plan to participate in space applications of crystal growth or subsequent manufacturing. Prevailing NASA sponsored flight qualified equipment and power limitations are considered inappropriate for the crystal materials they would be interested in producing.

In addition, the limited on orbit duration and extended turn around time between experimental proposal request and actual flight for Shuttle based flights is not compatible with Grumman's commercial scale requirements.

Grumman appears to favor a commercial access to space launch system which must provide reliable, launch on schedule, extended duration orbital facilities, recovery capabilities and with appropriate contractual agreements with regard to payload accommodations and multiple launch commitments.

Grumman does not anticipate a significant space manufacturing market until the current experimental exploitation of space for crystal growth has demonstrated a conclusive advantage for material processing in a micro gravity environment.

Given this successive demonstration and low cost of access, Grumman may use the system about four times annually.

The decision criteria for space application depends also on the availability of equipment (furnaces) and adequate power to support large crystal growth.

1. What is maturity of users' space application?

Grumman has been involved for many years in the research and development of crystalline materials including Silicon, Gallium Arsenide, Cadmium Telluride and Cadmium Zinc Telluride.

They have been associated as a commercial member of the Clarkson University, Potsdam, Center for Commercial Crystal Growth in Space working with Dr. Bill Wilcox. This association has now been discontinued although they are supporting independent research by a member of the Clarkson University research staff.

Grumman's perspective is that the CCDS are in general doing a good job promoting the commercial utilization of space. The Joint Endeavors Agreement, which affords a no cost Shuttle ride for access to space, is commendable.

Their decision to discontinue the association with the Center at Clarkson was due to a perception that activities tended to emphasize university based research rather than commercial based research. This decision was based on the assessment that the excellent ongoing work was simply not compatible with the commercial objectives of the corporation.

They did note that competition from Japan, with reference to crystal growth in the micro gravity space environment, was being aggressively pursued by that country.

A comment was made regarding the preferred physical sizes of useful ground grown crystals i.e. silicon (14 inch diameter), GaAs (4-6 inch diameter) and CdTe (3 inch diameter). Electrical power of about 6 kw are needed for such sizes. The apparent trend of the CCDS's is to conduct growth experiments for samples about 0.5 inches square using about 1 - 2 kw of power. These physical sizes and power requirements are appropriate for basic research but not for scale up to commercial products.

In addition, Grumman noted that the quality and capability of ground based crystal growth furnaces is rapidly increasing and that furnaces for space applications are somewhat lagging. The commercial market needs larger furnaces whereas the NASA trend appears to be to smaller furnaces for space application.

An opinion was expressed that even the Space Station Freedom power availability will not be sufficient to support the growth of commercial size crystals, but could be used to verify scale-up.

Grumman also advised that a few years ago they had proposed to NASA a program which would have utilized the Shuttle, with no cost initial flights, to demonstrate the feasibility of an in-space commercial crystal growth project with three flights leading to commercial confirmation of concept definition. Thereafter they would utilize ELV flights at around $25M each to service a commercial orbital facility visited on a 90 day periodicy. The project was mutually terminated following the Challenger disaster. A projected launch date for the program was estimated as 4 - 5 years beyond the earlier anticipated launch date.

2. What are payload form factors?

Grumman has no current plan to participate directly in space applications of crystal growth or subsequent manufacturing and therefore did not respond to this question with specifics. The prevailing NASA sponsored rack based hardware and experimental power limitations are not considered appropriate for the crystal materials they would be interested in producing.

In addition, the limited on orbit duration (≤ 14 days) and extended turn around time, between experiment proposal request and actual flight, for shuttle based flights is not compatible with Grumman's commercial scale requirements.

3. What infrastructure and support to user must launch system company provide?

Grumman appears to favor a commercial access to space launch system. The commercial concept they discussed (as above) seems to correlate well with the "concept" of the COMET program although the launch weight of the COMET program (~450 lbs) and on orbit power capability (~2 Kw) is not appropriate.

The launch system company must provide reliable, launch on schedule, extended duration orbital facilities, recovery capabilities and with contractual agreements with regard to payload accommodations and multiple launch commitments.

Grumman did not appear to need an intermediate value added payload accommodations contractor between themselves as the user and the commercial launch system company.

4. What is end user market infrastructure?

The end user of space grown crystal materials would initially be Grumman internally for research and evaluation. Subsequently Grumman's customer would be the military and their suppliers although a wider commercial market could result for unique material.

5. What changes or improvements are needed in the market infrastructure to reduce costs of space produced products?

Major change to reduce cost is to encourage the commercial ownership and operation of the launch system. The layers of bureaucracy associated with access to space as afforded by NASA is simply incompatible with commercial business practices.

6. If users are performing experiments now, when will they begin producing commercial products in space.

Grumman does not anticipate a significant space manufacturing market until the current experimental exploitation of space for crystal growth has demonstrated a conclusive advantage for material processing in a micro gravity environment. They also anticipate that major advances to ground based processing will occur based on results of micro gravity experimentation - if it is of adequate dimensional size of approximately equal to or greater than 2 inches in diameter.

7. What are current and near term costs associated with using space?

In the free ride scenario currently available, the costs are for labor, materials samples and experimental containment devices. No specific figures were offered.

8. How sensitive is user demand to launch system cost. How many more times will they use space if launch costs are reduced?

Grumman's opinion is that reduced launch cost for a commercially owned and operated launch system would stimulate demand and that price would be a function of the capability versus the potential market and selling price of the product. They would use such a system possibly 4 times annually.

9. What decision making process is used to decide on the use of space?

Decision process depends entirely on demonstrated material characteristics advantage and the availability of support equipment and adequate electrical power to support large crystal growth.

Crystal manufacturers would each use their own furnace since these devices are the discriminators for high quality crystals.

10. What are titles and names of executive managers who are making business decisions to invest their resources into producing products in space?

Lou Hemmerdinger and Dave Larson would directly recommend investment in space applications to the Grumman executive management.

C.3.8 Research and Development Facilities – Lockheed Missiles & Space Company with Mr. Chuck Rudiger

Mission Area

Research and Development Facilities

Date

13 August 1993

Organization Contacted

Lockheed Missiles & Space Company
1111 Lockheed Way, Sunnyvale, CA 94089

NASA Programs Office – Bldg. 580
Crossman Avenue, Sunnyvale, CA 94089

Who Contacted

Mr. Chuck Rudiger, New Business Manager, Lockheed NASA Programs Office

Researchers

Don Barker – Lockheed CSTS

Summary

Unique environmental conditions obtainable within an earth orbital asset should be a stimulant to space borne research and development particularly for materials and life sciences considerations. Payloads which feature research and development assets will be broad based and therefore no specific form factors were estimated at this time.

The launch system company must provide a go and return capability in support of an orbital R&D facility. In addition, human two-way transportation, stringent environmental and temporal constraints on access and return and autonomous rendezvous and docking capability may need to be provided. Current infrastructure involves NASA and the government central to the whole process of access to space. The incumbent bureaucracies, uncertain STS flight schedules and the potential for priority manifesting are not conducive to the concept of commercial use of space for R&D facilities.

The commercial user must be offered on-time, reliable, cost effective and efficient access to space and safe return of processed experimental assets to a guaranteed specific landing location. All these attributes must be available with absolutely minimum bureaucratic procedural processes.

The current costs burdened on the space experimenter user community are far too high even though the actual ride is free. These costs include the use of an in-flight protective container, resources and materials commitment to experiment planning, multiple sample preparation, recovery from landing sites and final analysis of resultant materials. Some of these costs are significantly influenced by STS flight schedule uncertainties and priority manifesting.

Acquisition of independent company funding for space based research is usually more difficult than for non-space based projects, is usually associated with business development opportunities for large programs and incurs the risk of cancellation due to Shuttle flight delays and NASA procurement decision fluctuations.

1. What is maturity of users' space application?

Lockheed's NASA Program Office has been actively involved in the development of products for space applications for many years. These products include subsystems for SSF, the Hubble Space Telescope and various scientific satellites with specific missions. The products have included life support, scientific observation of the solar system and earth observation research. The Space Systems Division with which this office is affiliated has developed and delivered over 350 satellites since 1964.

According to the interviewee the application of commercial R&D facilities in a space environment is relatively immature. NASA sponsored experimental shuttle based carriers such as Spacehab, Spacelab J and US Microgravity Payload have provided recent access to space for experimental research. About 50 individual microgravity experiments have been flown on these carriers. Prior to the Shuttle era (pre 1980's), Skylab (1973) provided the first opportunities for materials processing experiments and before that Space Processing Applications Rocket flights carried small experimental packages which typically provided 5 minutes of space environment exposure facilities.

The advent of US managed long duration and manned experimental R&D facilities await the introduction of the SSF. The Russian MIR Space Station currently represents the sole available human tended extended duration space environment R&D facility and has recently invoked support to foreign utilization.

A further NASA sponsored US effort (COMET), to provide a 30 day on orbit unmanned experimental space based platform, ELV launched and capable of reentry and recovery is currently subject to development and funding problems. A commercial spin-off of this program called WESTAR (Westinghouse Space Transportation and Recovery Services) is planned to utilize developments derived from COMET and is therefore also subject to delayed availability.

2. What are payload form factors?

This question was considered to be too broad for specific recommendations at this time for this topic. Payloads which will feature as research and development will be broad based – from small payloads of the COMET type (~ 450 lbs unmanned) intended for 30 day orbital missions to larger, more complex, payloads intended for delivery to SSF or MIR (acting as the host orbital R&D facility).

3. What infrastructure and support to user must launch system company provide?

The launch system company must provide a go and return capability in support of R&D facilities in space. Certain samples developed within an orbital asset may require return for proprietary comprehensive analysis. It is also conceivable that qualified personnel from specific commercial organizations may require to visit and work within the orbital facility.

Research payloads associated with biomedical or biotechnology products will impose stringent environmental and temporal constraints on both ascent and descent flight characteristics as well as pre and post flight preparation and temporary storage facilities.

For R&D space borne facilities consisting of a limited duration free flyer (e.g. COMET), or longer duration facilities (SSF or MIR), the launch system company will probably need to provide the means for autonomous rendezvous and capture of the space asset containing the experimental materials.

In addition it may be necessary to provide a R&D facility asset capable of commanded deorbit and safe landing.

4. What is end user market infrastructure?

Current infrastructure involves NASA and the government central to the whole process of access to space. The incumbent bureaucracies, uncertainty of flight schedules and potential for priority manifesting are not conducive to the concept of commercial utilization of space for R&D facilities. The end user currently interfaces as a member or affiliate to the NASA sponsored Centers for Commercial Development of Space (CCDS) with associated value added payload engineering/hardware and packaging companies.

5. What changes or improvements are needed in the market infrastructure to reduce costs of space produced products?

The end user market infrastructure should involve substitution of NASA by a commercial entity as the central agency involved in payload processing and certification, mission operations and interface with the launch system.

The user should have simplified access to space which could involve a one stop shopping whereby the launch system provider directly accommodates payload requirements.

The user must be offered on time, reliable, cost effective and efficient access to space and safe return of experimental processed assets without the lengthy bureaucratic procedures currently associated with the Shuttle access program.

6. If users are performing experiments now, when will they begin producing commercial products in space.

This question not strictly relevant to R&D facilities in space. However the response to the general question is that the advent of commercial production in space will depend on the demonstration of a useful product with market potential whose fabrication is uniquely limited to implementation in space. In addition, access to space must become routine, non bureaucratic and cost effective.

7. What are current and near term costs associated with using space?

Current costs burdened on the user community are far too high (even though, through the CCDS's, the actual flight may be free) and the uncertain schedules and bottleneck of over demand for Shuttle acommodation results in cost commitment for involvement. Safety issues associated with the crew carrying Shuttle vehicle are a major source of cost commitment to the commercial user from resources to redundancy design. The fish bowl scenario associated with STS is also a concern to proprietary interests of commercial users.

8. How sensitive is user demand to launch system cost. How many more times will they use space if launch costs are reduced?

Currently launch cost is free to commercial users of STS – costs are incumbent on use of an inflight environmental protective container (~ $2M/locker Spacehab) and in resources/materials commitment to the experiment planning and sample preparation, recovery and analysis.

Rudiger considers that if the current cost drivers as described above in (7) were relieved, coupled with reasonable launch costs, then this would certainly act as a stimulant for R&D facilities in space.

9. What decision making process is used to decide on the use of space?

Internal to Lockheed NASA – Programs Office, independent development funding is competed on the basis of new business development usually related to the capture of large programs. Acquisition of funding, specifically for space based research projects is usually more difficult than non-space projects due to the perceived reduced bang for the buck. Shuttle flight schedule delays and NASA procurement decision fluctuations also incur the risk of cancellation of independent company funding for research .

10. What are titles and names of executive managers who are making business decisions to invest their resources into producing products in space?

Gus Guastaferro is the executive decision maker within Lockheed NASA Programs Line of Business for investment recommendations to the Space System Division New Business Council chaired by Mel Brashears, VP & AGM -SSD.

C.3.9 Spacehab Incorporated with Mr. Al Reeser

Mission Area

Space Manufacturing (Space Research)

Date

7 August 1993
28 August 1993

Organization Contacted

Spacehab Incorporated
1215 Jefferson Davis Highway, Suite 1500
Arlington, VA 22202

Tel: 703/553.8100
FAX: 703/553.8107

Researchers

Bill Walsh, Lockheed; and Henry Hillbrath, Boeing

The researchers met with Mr. Al Reeser, president and CEO, and David Rossi, vice president - business development, from Spacehab Inc., Alexandria, VA on 8/4/93 for 1-1/2 hours to discuss the commercial space markets, applications, and the related launch system attributes.

Summary

Spacehab Incorporated is a commercial company which offers a pressurized habitant module that flys in the shuttle cargo bay. The SH-1 SPACEHAB module first flew on STS-57 on June 3, 1993. The module provides pressurized lockers, single and double rack enclosures for commercial and government researchers to conduct experiments in the micro-gravity environment of space. During the initial flight, crew members operated and monitored 21 laboratory experiments during the eight day mission.

The firm's headquarters are in Alexandria, VA, with business operations near Kennedy Space Center (KSC) and Johnson Space Center (JSC). They have a payload processing and launch operations facilities near KSC and mission operations offices near JSC.

1. What is the maturity of the users' space applications?

The users of space are in various stages of space experimentation, according to Mr. Reeser.

The types of experiments included in the STS-57 mission included: materials processing, biotechnology experiments (such as protein crystal growth, organic separation, cell research, etc), and thin film coating. In general, any experiments that can take advantage of a low G environment are candidates for flying in the Spacehab module.

Mr Reeser has given up on thinking you can manufacture products in space. He pointed out, however, that there may be a possibility of doing space processing of contact lens.

2. What are the payload form factors?
The Spacehab module weight is 4923 kg. Major dimensions are: 3 m long by 4 m diameter.

Overall volume of the module is 31.1 mE3.

The module is integrated into and remains in the cargo bay during all phases of flight. The module accommodates up to approximately 1360 kg of payload in a pressurized environment.

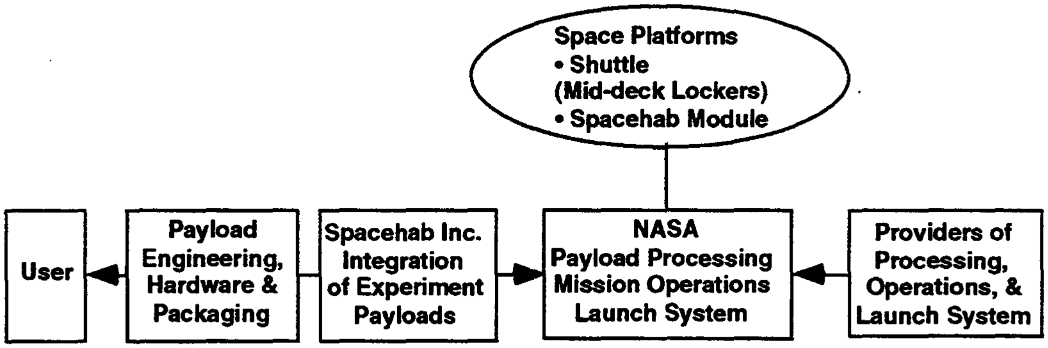
Orbital and environmental parameters are those available from the shuttle, i.e., nominal 28.5 deg. inclination, 460 km altitude. On orbit time is dependent on shuttle flight duration. A tunnel from the shuttle mid-deck locker compartment provides crew access to the Spacehab cargo.

3. What infrastructure and support to the user must the launch system company provide?
Spacehab is launched on shuttle. As the figure below illustrates Spacehab Inc. is dependent upon NASA for launch and mission services. Spacehab Inc. provides payload accommodations (integration of individual customer experiments) to each user that flys in the module.

The firm has a facility near NASA/KSC to assemble the Spacehab module and integrate the experiments. The company contracts with McDonnell Douglas for ground processing of the Spacehab module. McDonnell Douglas services include the processing of experiment payloads, and integration of the Spacehab into the shuttle cargo bay.

Many users do not have technical staff with the required engineering experience and capability to perform space experiments. The users typically contract with low costs specialty companies which can provide payload engineering, any unique space hardware required for performing space experiments, and the assembly and packaging of experiments to the format that will acceptable to the Spacehab module, the shuttle, and NASA.

Access to Space Organizational Infrastructure



111264-230

NASA manages all phases of a shuttle mission, but contracts with the providers of launch system services for launch operations, mission operations, recovery, and refurbishment/maintenance and servicing of the shuttle after completion of the mission.

4. What is the end user market infrastructure?

Commercial users can contract directly with Spacehab Inc for launch services, however, they usually decide to become industrial affiliates of the NASA CCDSs to avoid paying for the launch costs. The latter provide free launch services to their affiliates, along with expert technical assistance to the users in the specific science and technology areas of the experimenters.

Most commercial users opt for the CCDS approach because they are not familiar with the technical constraints of space and the NASA imposed requirements for performing biological experiments in the shuttle. Additionally, they do not have the space engineering staff capable of preparing the experiments properly for space. Consequently, as illustrated in the figure above, they contract with companies which specialize in providing payload engineering, space hardware, and packaging services. These value added companies are typically small businesses who are providing these services at very low costs to the experimenters.

5. What changes or improvements are needed in the market infrastructure to reduce the costs of space produced products?

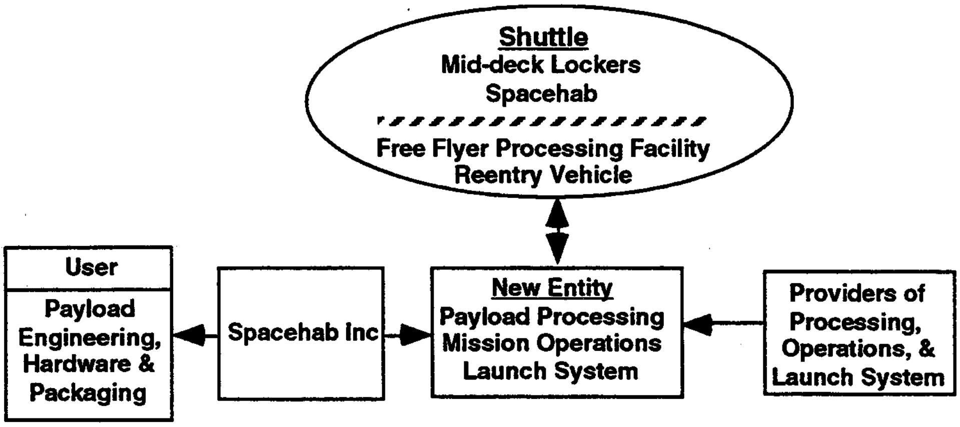
The number of people required to support the shuttle launches must be substantially reduced.

Mr Reeser said that the Spacehab company employs 44 people at its KSC payload processing operations. On the other hand, the combined NASA/KSC personnel and the contractor personnel who support the shuttle at KSC exceeds several thousand.

Mr Reeser agreed with the writer that the organizational infrastructure supporting the shuttle includes substantial redundancy and overlap; and results in higher costs than are necessary. He also acknowledged that it takes too long from the time a user makes a decision to perform a space experiment and the actual execution of the experiment.

For both cost and schedule to be reduced substantially, a new launch system infrastructure must evolve which avoids dependency upon the current approach described in #3 above. A new organizational infrastructure, see below, that should evolve and become operational in the future was defined and discussed.

Idealized Organizational Infrastructure to Provide Low Cost, Timely Access To Space



Writer's Conclusions: For space research activities to evolve into a robust commercial market and expand into producing commercial products in space, a separate commercial "New Entity" should replace the existing government infrastructure, which includes the shuttle launch system for commercialization of space.

An interim stage will be needed where the shuttle and Spacehab support the commercial users as space platforms for performing experiments. However, on the longer term, new free flying space processing facilities and reentry vehicles will be required to substantially reduce space launch system costs and schedules.

6. If the users are performing experiments now, when will they begin producing commercial products in space?

Mr. Reeser believes that manufacturing products in space is not a good idea. He does, however, think that processing, such as contact lens in space may be viable.

7. What are the current and near term costs associated with using space?

Commercial users are charged $1.8 million for a Spacehab locker. Spacehab's lease and integration is only $1 million. The remainder goes to to NASA for flight costs. A single locker provides the experimenter with 2.2 cu ft and up to 60 lbs. For a mid-deck locker in the shuttle, NASA charges $800,000 for an equivalent size locker.

If all the Spacehab module payloads are commercial the firm pays NASA $33 million per flight. However, NASA has committed to use some space on the module.

Mr. Reeser commented that it is very difficult to find commercial customers who will pay for the launch costs. NASA is providing free shuttle flights to space experimenters through the CCDS program. However, even though the ride is free, the companies will spend between $3 to $7 million of their own NRE funds to prepare and complete each space experiment.

The Spacehab was developed for $240 million. Mr Reeser estimated that it would have cost $1,200 million for NASA to develop the module.

The company has a fixed priced contract with NASA to fly twice per year. Spacehab has been manifested for seven more flights. The next flight was November 1993, but has been delayed by NASA until early 1994.

8. How sensitive is user demand to launch system cost? How many more times will they use space if the launch costs is reduced?

Launch System Demand Elasticity: To the CCDS affiliates, NASA provides free shuttle launches. Commercial companies become CCDS affiliates to get free access to space.

The recent addition of the Spacehab provides an alternate to going through NASA for space on the shuttle mid-deck lockers. The Spacehab provides a total of 61 equivalent mid-deck lockers, however, a typical configuration is 412 lockers plus 2 double racks. The end users think that $1.8 million for a Spacehab locker is too expensive.

Launches per Year

Launch Price	**Today**	**<5 Years**	**< 10 Years**
Prevailing (a)	2	0.5	0.5
75%		cannot predict	
50%		cannot predict	
25%		cannot predict	
10%		cannot predict	

a. Prevailing cost is $33 million for Spacehab module launch in shuttle cargo bay.

9. What decision making business process is used to decide on the use of space?

No answer provided.

10. What are titles and names of executive managers who are making the business decisions to invest their resources into producing products in space?

There are no companies producing products in space. They are performing space experiments.

Mr. Rossi promised to provide the names and contact information on all the commercial company Principal Investigators which flew in SH-1 on STS-57.

Review and Revision Status

8/16/93 Submitted research report to Spacehab for review, comments and concurrence with data.

8/28/93 Mr. Rossi replied with comments and concurrence.

C.3.10 Space Agriculture – Lockheed Missiles & Space Company with Dr. Steve Schwartzkopf

Mission Area
Space Agriculture

Date
13 September 1993
Amended following LMSC validation 11 October 1993

Organization Contacted
LMSC — Sunnyvale, CA

Who Contacted
Dr. Steve Schwartzkopf
Manager, Lifesciences & Biotechnology

Researchers
Don Barker/Bill Walsh (Lockheed)

Summary

Lockheed has participated in the STS based Life Science Flight Experiments program.

Pertinent to space agriculture, the program seeks to identify the role of gravity in plant cellular processes, embryonic development, morphology and physiology. An attempt is ongoing to identify mechanisms of gravity sensing and the transmission of gravity sensing perception information in plants. The interaction of light and stress stimuli are also being studied. Perhaps the main emphasis of understanding plant growth and metabolism is to provide for long term survival and self operation of bioregenerative systems for future space missions.

Lockheed has developed a number of flight qualified common module type life science laboratory equipment items which have flown on the Shuttle.

A general characterization for space agricultural payloads is that of similarity to those required for human transportation.

Experiments require a Life sustaining environment with nutrients, temperature, pressure, airflow, illumination and contaminants carefully controlled.

This Life sustaining environment is required throughout the flight experiment including prelaunch, recovery and delivery back to the original sample source, although the levels can be changed during launch and landing.

The enclosures must allow confident identification of the isolated effects of microgravity.

Flight durations of 14 days maximum as obtained via the Shuttle are only of limited value in the study of plant physiology in microgravity – durations of 30-90 days would be more valuable to researchers.

No agricultural products are currently being manufactured in space. Companies involved in ground based production of agricultural products are mostly inexperienced in space applications. The opinion was expressed that there is currently no predictable benefit to producing plants in space, in fact some plants have become sterile when exposed to microgravity. Effects observed to date are stochastic rather than deterministic.

The effects of microgravity on plant growth are not understood and there appears to be no reason to suppose that the environment of space "encourages" growth.

It appears that the primary reason for plant based research experiments in space are in support of development of a bioregenerative environment to sustain human life in space vehicles or planetary colonies rather than the discovery of a new generation plant species derived from growth in microgravity.

The interviewee felt that reduction in launch costs either direct or indirect would lead to an increased demand for experimental missions. This demand may be rapidly accumulative if a unique advantage of the space environment were demonstrated, particularly in the microbiology field rather than space agriculture.

The launch system must allow late access to samples (2 hours), have high launch reliability, launch on schedule and guaranteed return to a post flight collection point.

1. What is maturity of users' space application?
Lockheed has participated in the STS based Life Science Flight Experiments (LSFE) program in a major way. The program objectives are to conduct studies in the area of space biology and medicine, to understand the basic mechanisms of biological and medical processes achieved via research conducted both on earth and in space.

Three major program thrusts are 1) study of the physiological effects of the space environment including μ gravity and radiation, 2) study of in flight observation of humans experience in space environments and, 3) studies in exobiology with special emphasis on the origins and distribution of life in the universe.

The LSFE program includes experiment design, development, in flight execution, data analysis and reporting.

Pertinent to space agriculture are to identify the role of gravity in plant cellular processes, embryonic development, morphology and physiology. Identification of the mechanisms of gravity sensing (geotropism) and transmission of gravity perception information within plants. Identification of the interactive effects of gravity and other stimuli (light) and stresses (vibration) on metabolism. Use of gravity to study the normal (1G) nature and properties of living organisms. Extension of understanding of plant growth and animal growth and metabolism to provide for long term survival and bioregenerative systems.

Lockheed was involved in the development of a number of common modular life science laboratory equipments including a plant growth unit (flew 2 in 82), Research Animal Holding Facility (flew in 85/91, planned for Oct 93), General Purpose Work Station (flew in 91 and planned Oct 93) and a Vestibular Research Facility. Participation in development of the Variable Gravity Research facility program (now SSF Centrifuge Facility Project) is also anticipated in the near future.

2. What are payload form factors?
General rule of thumb for space agriculture payloads environment on launch and reentry is similar to that for human transportation. Each experiment requires a minimum sustaining controlled environment of about 2 cubic feet in volume; typical enclosure unit weight is ~ 50 pounds for 6 chamber unit each containing 16 seedlings and utilizes about 75 watts. Typical temp control is 74° and 78°F ± 1°F at night and day respectively. Plant growth in orbit also requires uniform lighting with spectral characteristics in the 400-700 nm wavelength band.

The above self contained enclosure is configured to provide continuous monitoring of temperature/pressure/air flow/chamber gas sampling.

3. What infrastructure and support to user must launch system company provide?

Payload accommodation with late access (say 2 hours) is a primary direct support required from the launch systems company. Payloads involving living organisms require sustaining facilities continuously outwards from the original users facilities to their safe return. This implies sustaining facilities prelaunch, during powered flight, on orbit, through descent and during off load and post flight, although the environment can be changed during launch and landing.

Enclosures containing organic materials must be designed as a comprehensive full cycle subsystem such that the true effects of unique characteristic such as microgravity associated with the orbital flight can be confidently identified.

High launch reliability, launch on schedule and guaranteed return to a specific post flight collection point must also be provided by the launch systems company.

The flight duration associated with STS spacelab experiments is between 8 and 14 days which is marginal for observation of many micro gravity induced changes (if any) in plant physiology and metabolism.

Preferable support to the user would be a launch/recovery system capable of providing 30-90 days on orbit for operational plant physiology payloads.

4. What is end user market infrastructure?

Companies currently involved in ground based production of agricultural products are likely to be inexperienced in space applications and therefore need an interface service.

This service is currently provided by the NASA sponsored CCD's or small independent "value added" companies, the latter offering proprietary protective containers. These containers also seemed to be designed only for installation into Spacehab or Spacelab host subsystems carried within the shuttle.

Given the availability of modular specimen containers (possibly by technology transfer from NASA), a CST may well select to contract directly with the end user for payload accommodation services.

5. What changes or improvements are needed in the market infrastructure to reduce costs of space produced products?

No agricultural products are currently being "produced." All experiments to date have involved the STS with incumbent extended time scales for payload manifesting and the usual NASA business culture. This provides a free ride to orbit but still involves commercial time and materials commitment to an uncertain launch slot and an uncertain return location.

The changes needed are reliable launch date, short prelaunch timescale, definitive landing location and avoidance of routine NASA safety reviews and prelaunch administrative problems.

6. If users are performing experiments now, when will they begin producing commercial products in space.

The interviewee considered that there is currently no predictable benefit to producing plants in space, in fact some plants have become sterile when exposed to µG. The effects of microgravity on plant growth are not understood and there is no reason to suppose that space "encourages" plant growth. He also disagrees that gene transfer in a micro gravity environment may be enhanced as suggested by the CCDS at the University of Winsconsin.

Effects observed to date are stochastic, not deterministic . He did think that space may provide an advantage for bacteriological production and noted that some companies are interested in the concept namely ALZA, GENENTECH and AMGEN. In fact, Genentech has already run a flight experiment with rats. (Note – the former two companies have been contacted by the CSTS previously and did not disclose that they were interested in or had actually conducted space application experiments.)

The primary reason for plant based research experiments in space are in support of developing a bioregenerative environment to sustain human life in space vehicles or planetary colonies. Interesting to note that some estimates indicate that a cultivation area of between 20-30sq meter is required to sustain each human in a bioregenerative enclosure.

7. What are current and near term costs associated with using space?

Most Lockheed work in this area has been under contract to NASA – the interviewee has no information on company intentions to pursue independently funded research in space agriculture.

8. How sensitive is user demand to launch system cost. How many more times will they use space if launch costs are reduced?

The interviewee felt that reduction in launch costs either direct or indirect would lead to increased demand for "experimental" missions. This demand may be rapidly accumulative if a unique advantage of the space environment could be positively demonstrated, particularly in the microbiological area.

The current low demand for experimental flights is coupled with perceived launch costs as well as to a combination of the current NASA way of doing business and the lack of a positive demonstrated advantage for in-space experiments.

9. What decision making process is used to decide on the use of space?

Internal company procedures for decision on the use of space for any particular project are no different than for non-space applications. Solicitations for independent company funds are made annually using a common format. Decisions are made at executive level based on return on investment evaluations with reference to future business forecasts. The company is certainly expanding its commercial and civil business share relative to defense business.

10. What are titles and names of executive managers who are making business decisions to invest their resources into producing products in space?

Steve Schwartzkopf would make recommendations to the Lockheed Director of Materials Science who in turn would solicit vice presidential approval (Joe Reagan/Ernest Littauer).

C.3.11 Space Industries with Mr. Ole Smistad

Mission Area

Space Manufacturing (Space Processing)

Date

30 June 1993

Contact

Ole Smistad, COMET Program Manager
Space Industries
101 Courageous Drive
League City, TX 77573
Tel# 713/538.6000 (X6079)
FAX # 713/334.4010

Contacted by

Bill Walsh, X24781

Summary of Contact

The writer contacted Space Industries to discuss their COMET program as part of the CSTS market research project. Smistad is the program manager for the COMET program.

The COMET is basically a Service Module, or space platform, which can be used to perform space manufacturing and processing. Space Industries views themselves as a service organization that provides the module to end users.

The end users buy space in the Service Module for performing processing and manufacturing in space. The service module weight is in the one ton range. Smistad says that the shuttle is too expensive for space manufacturing applications. An inexpensive ELV would be appropriate for the mission. The mission requires the payload to be recovered, and therefore, a Recovery Module is needed to return the payload to earth. Space Industries has developed the overall approach for supporting potential manufacturers with a service module and recovery module.

Space Industries has evaluated and is familiar with Pegasus for launching the Service Module. Estimated launch costs for Pegasus are about $12M.

Smistad summarized the overall costs for a COMET flight as:

Product Element/Activity	**Cost ($M)**	
	Now	Future
a. Expendable Launch Vehicle, including ELV and ground ops, is about	$18	6
b. Service Module	6	3
c. Recovery Module	6	3
d. Mission Operations, including ground stations	2	2
Total	**$32**	**$14**

A summary of the key points of the discussion included:

a. Reducing the launch vehicle cost by a factor of three to $6M will make it economically possible to sell space manufacturing to users.
b. The benefits would include increased launch rates
c. Lower operating costs for space manufacturing will cause innovation.

C.3.12 Syntex Discovery Research with Dr. Hardy W. Chan

Mission Area

Space Manufacturing (Space Research)

Date

13 September 1993

Organization Contacted

Syntex Discovery Research
Division of Syntex (U.S.A.) Inc.
3401 Hillview Avenue
P.O. Box 10850
Palo Alto, CA 94303

Who Contacted

Dr. Hardy W. Chan	VP and Director of Biotechnology
Dr. Randolph M. Johnson	Research Section Leader Dept. of Neuroscience Institute of Pharmacology

Researchers

Don Barker/Bill Walsh (Lockheed)

Summary

Syntex has no direct experience of space applications and does not budget to track developments which may be occurring.

Syntex is a "small molecule" pharmaceutical company with ground based annual manufacturing of 1000's of metric tons of materials. Research budget is $300M (~20% of profit) totally expended in non-space activities.

Syntex's assessment of space applications is that they have seen no evidence of benefit to their particular industrial interests. If a smaller biomedical or biotechnology company were to discover some kind of enabling technology derived from space application experiments then Syntex would simply buy equity in that company. This would provide the necessary production, distribution and marketing support necessary to commercially capitalize on the enabling technology.

Subsequent to the demonstration of enabling technology, Syntex may well become involved in space experiments targeted to drug development with multiple flights annually at $200K per flight.

Payload samples probably would not exceed a few kgms per year. Syntex would need appropriate sample containment enclosures and close support in the development of their in-house space application experience base.

A reliable, launch on schedule, late sample access and early retrieval, rapid turnaround space transportation system would be required. Commercial business practices are perceived as incompatible with NASA's current methodologies associated with space access via the Shuttle carrier. Syntex affirmed that they would never produce "small molecule" products in space. The company perceives that the overall cost of space application is high without specific reference to launch cost apportionment.

Pharmaceutical product pricing is a function of supply and demand rather than the recovery of specific investment in development of a particular product.

Syntex would only use space for product research and development if they become convinced that the space environment afforded a definite unique advantage.

They also are concerned that a good starting point for commercial space application be established by NASA funding.

1. What is maturity of users' space application?

Syntex (5500 employees) has no direct experience of space applications, have no affiliation or membership with any of the NASA sponsored CCDS and have not participated in conducting space experiments.

They are aware, in a general sense, of some of the activities being pursued by NASA in the Shuttle based experimental programs.

The biotechnology departments of the company have no allocated budget to track the on-going activities in biotechnology experimentation being conducted on various NASA programs. Their staff however do appear to keep themselves generally informed through observation of the technical literature.

Dr. Chan noted that Syntex does not involve themselves with large protein molecular materials as a basis for drug manufacture – rather they referred to their products as being based on "small molecules" and they manufacture typically in the 1000's of metric tonnes of these pharmaceuticals annually.

The Syntex research budget is about $300M (~ 20% of profit) which is expended on development of biomedical products manufactured in earth based facilities.

If a typical space experiment required about $200K of support expenditure then this would be within their anticipated budget and they might well conduct multiple experiments in a given year.

The main issue associated with Syntex's lack of commitment to space applications is their current reasonably informed assessment that they have seen no evidence of benefit to their particular industrial interests.

The perception that other smaller biotechnology companies may develop a unique enabling technology through space experiments is not a concern. In fact their view is to expect and encourage such entrepreneuralistic efforts by such companies and subsequently simply to buy equity in these companies to jointly capitalize on the enabling technology.

This view is a routine business practice characteristic of the current vibrant biotechnology industry which has spawned many hundreds of small entrepreneurial companies specializing in the development of new pharmaceutical materials and techniques. These small companies lack the means and resources to profitably bring a drug product to market with effective distribution and indeed they themselves fully expect the purchase of equity subsequent to new product development.

2. What are payload form factors?

Given the future development of a unique product from space experimental applications with demonstrated enabling technology, Syntex considers that their payload samples would comprise an aggregate of only a few Kgms per year in multiple flights (in contrast to many 1000's metric tonnes of earth based products). They considered that space derived/processed biomedical materials would probably require a transportation system (launch and recovery) with characteristics similar to a human rated system.

Syntex would also require appropriate sample containment enclosures from external sources.

3. What infrastructure and support to user must launch system company provide?

Syntex's lack of experience in space applications implies the need for a full payload services agency. This agency could of course be a service of the launch system company.

Syntex would provide sample materials and conduct internal processed specimen analysis but they would need support in the near term for all other aspects of space application.

A reliable, launch on schedule, late sample access and early retrieval, rapid turn around space transportation system would also be required to support a vigorous multiple launch use concept subsequent to demonstration of enabling technology.

4. What is end user market infrastructure?

Commercial business practices are perceived as probably incompatible with NASA's current methodologies associated with space access via the Shuttle carrier.

Syntex did advise however that time to market for new drugs may not be too critical. A six month margin of delay is not a problem in most cases other than for pharmaceuticals with potential to render benefits to patients afflicted with critical illnesses such as AIDS.

An example was given of two effectively identical drugs introduced by two different companies within six months of each other. The later drug, even though higher priced, gained comparable market share within a short period.

5. What changes or improvements are needed in the market infrastructure to reduce costs of space produced products?

Syntex offered no comment on this question.

6. If users are performing experiments now, when will they begin producing commercial products in space.

Syntex response was that they probably would never produce "small molecule" products in space. They may possibly produce about 2kgm annually of a product designated as a "high enabler," but this is an unqualified blue sky estimate.

7. What are current and near term costs associated with using space?

Syntex current costs are of course zero with reference to space applications. They do not even formally budget for tracking the published results of on-going biomedical related space experiments. The near term costs would only become finite in the event of demonstration of an enabling technology of interest to them.

8. How sensitive is user demand to launch system cost. How many more times will they use space if launch costs are reduced?

Syntex perceives that the overall cost of space application is high without specific reference to launch cost apportionment. Return on investment is recoverable by the sale of products.

Products are priced essentially by market supply and demand and only loosely coupled to the recovery of specific investment in development of a particular product. Drug development sequence from research to FDA approval and sale is usually long term (5 to 10 years), except for urgent demand products such as AIDS related, and is somewhat characteristically unpredictable with reference to human experienced side effects.

A product designed to mitigate a particular ailment can proceed successfully through many stages of assessment but subsequent fail latter stages of approval.

9. What decision making process is used to decide on the use of space?

Syntex would only use space for product research and development if they were convinced that the space environment afforded a definite unique advantage.

They also mentioned that the decision to commit company resources would depend on their perception of to what extent tax dollars have been used efficiently by NASA to provide a good starting point for commercial space application.

10. What are titles and names of executive managers who are making business decisions to invest their resources into producing products in space?

Dr. Hardy Chan would be the principal executive decision maker on the corporate board.

C.3.13 Space Hardware Optimization Technology (SHOT) with Mr. John Vellinger

Mission Area

Space Manufacturing (Space Research)

Date

18 August 1993
Revised: 14 September 1993

Organization Contacted

SHOT (Space Hardware Optimization Technology)
P. O. Box 351
Floyd Knobs, IN 47119

Tel: 812/923.9591
FAX: 812/923.9598

Researchers

Bill Walsh, Don Barker, and Deborah Tonnemacher, Lockheed

Summary

The researchers met with Mr. John Vellinger, vice president, SHOT (Space Hardware Optimization Technology) on 8/2/93 for two hours to discuss the commercial markets for space. The company is a small business with four full time personnel, and several part-time personnel. The firm began business operations in 1989.

SHOT provides space equipment, payload integration, and engineering services to drug company (pharmaceutical, biotechnology, etc) researchers performing space experiments. The firm provides the following type products and services to end users:

a. containment equipment for housing biological experiments in the mid-deck lockers onboard the shuttle and Spacehab
b. technical services (integration of biological experiments with space hardware)
c. launch integration services

SHOT's space hardware is designed to contain living organisms for space experimentation. They have provided their equipment and services on several shuttle flights and Concert 5 and 6 missions. The firm provided payload containment facilities for two successful Shuttle missions: 1) Chicken embryos experiment on STS-29 in March 1989 wherein Kentucky Fried Chicken Inc. were involved and 2) Organic Separation experiment on STS-57 in June 1993. In the former mission they provided flight certified hardware which contained both a suspension system and an environmental control system for experimental sample protection and containment.

Typically, SHOT provides an enabling interface between the commercial end user (e.g. KFC, drug companies) and the NASA shuttle organization or Spacehab organization.

The firm has a new business thrust to develop new containment equipment for the drug companies to use for housing or packaging their experiments for the space environment.

1. What is the maturity of the users' application(s) in space?

The drug companies primary use of space is for biological research. The users are attempting to demonstrate and assess the ability of micro-gravity available in LEO to separate cells in living organisms. These experiments are being flown on manned launch vehicles, such as shuttle, Consort, and Spacehab. The experiments must be returned to the researchers after the space flight for evaluation and assessment.

No end users are producing space products for commercial sale.

2. What are the payload form factors?

The space experiments conform to physical constraints provided by shuttle mid-deck lockers. The reference NASA document is NSTS 21000-IDD-MDK.

a. weight: up to 70 lbs
b. volume: 20.3 by 10.8 by 18.1 inches
c. altitude: 250 nmi
d. pressure: 14.7 +/- 0.2 PSIA normal operation (shuttle environment)
e. shock and vibration: < 3 Gs, Vibration 20 to 150 Hz +6.0 dB/Octave
150 to 1000 Hz 0.03 gE2 / Hz
1000 to 2000 Hz -6.00 dB/Octave composite 6.5 g (rms)

A typical SHOT container measures 20.3 by 10.8 by 18.1 inches & weighs 70 lbs including the experimental sample. These are the typical shuttle locker external dimensions and weights.

3. What infrastructure and support to the user must the launch system company provide?

The drug companies would like to have some way to lower their experiment pre-flight and post-flight costs. Biological experimental samples must have back-up samples immediately available for substitution in the event of launch delays. The samples must also have late access to the payload compartment (within 12 to 18 hours pre-launch) to enable confirmation of sample integrity and to maximize probability of successful flight experiment results.

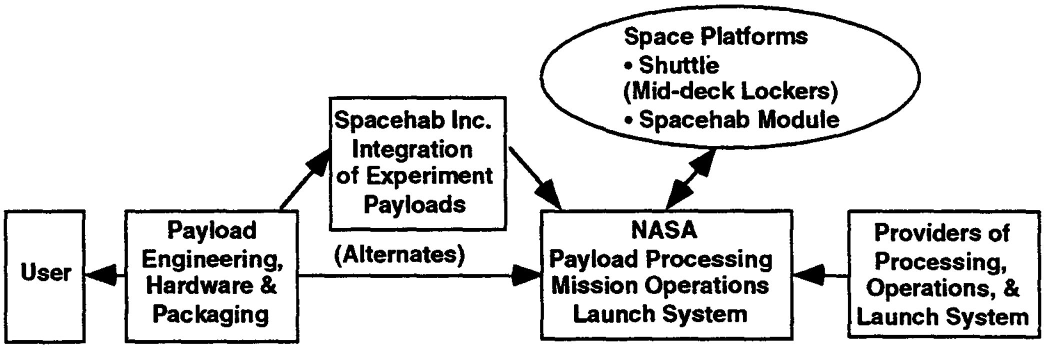
During post-flight, the drug companies have to commit staff and resources to recover samples within about 1.5 hours of shuttle touchdown. Consequently, these resources need to be duplicated since a shuttle touchdown cannot be guaranteed to occur at KSC, Edwards AFB, or alternate landing sites such as White Sands, due to variable weather conditions which occur during actual shuttle flights.

An alternate space processing facility may be needed to compensate for anticipated delays when the shuttle commits more support to the Space Station Freedom during its build up and servicing.

4. What is the end user market infrastructure?

The end users look at the infrastructure for access to space through the small value added companies, such as SHOT, Payload Systems, and ITA, which provide payload engineering, space hardware, and packaging of the experiments. These companies usually assist the end users with the interface with NASA, who require substantial experiment and design reviews, and flight readiness reviews before the experiments are flown on the shuttle. The illustration below summarizes the organizational infrastructures today.

Access to Space Organizational Infrastructure



(Including CCDSs and KSC)

111264-232

The drug company experimenters think that lower Gs which can be achieved at higher altitudes, than provided by the shuttle, may be important to improving the results of their space research.

NASA manages all phases of a shuttle mission, but contracts with the providers of launch systems and related services for launch operations, mission operations, recovery, and refurbishment or maintenance and servicing of the shuttle after completion of the mission.

End users that become industrial affiliates to the NASA CCDSs are receiving free launches on the shuttle. The users, however, have internal and contractor costs associated with flying their experiments on the shuttle.

The NASA practice of providing free rides is a stimulant to the use of space by commercial companies and can accelerate the demonstration of specific advantages associated with biological research in a micro-gravity environment.

5. What changes or improvements are needed in the market infrastructure to reduce the costs of space experiments and facilitate transition to producing products in space?

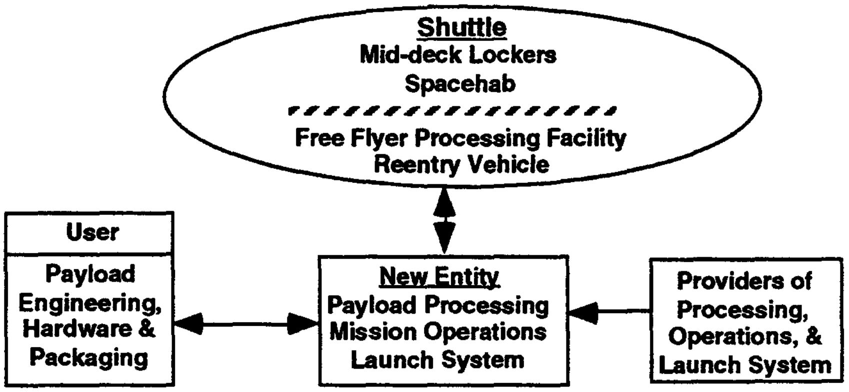
For commercial companies to expand their research, the cost must be reduced. Today's shuttle flight costs, exclusive of the free launch provided by NASA CCDSs, are too high. They must be substantially reduced.

The apparent trend of reliance on human-tended experiments tends to drive the configuration characteristics of the launch system into an expensive human rated option. Non-man rated space platforms that can offer the experimenters comparable capabilities can substantially reduce the researchers costs. This will require a free flyer and a reentry vehicle.

Also, the length of time between a decision to perform an experiment and the actual accomplishment of the experiment must be reduced. These long period usually are because of all the engineering, programmatic, and safety review analysis, studies, and meeting that are part of the current man-rated approach to space launches.

A new organizational infrastructure for access to space, see below, should evolve for the future that reduces overall costs to the end users. The attributes of this infrastructure should include shorter overall time to perform experiments, and lower experiment processing and launch costs.

Idealized Organizational Infrastructure to Provide Low Cost, Timely Access To Space



111264-233

Writer's Conclusions: For space research activities to evolve into a robust commercial market and provide the potential to expand into commercial market which manufactures products in space, a separate commercial "New Entity" should replace the existing government infrastructure, which includes replacing the shuttle as the primary launch system.

An interim stage will be needed where the shuttle and Spacehab support the commercial users as space platforms for performing experiments. However, on the longer term, new free flying processing facilities in space and reentry vehicles will be required to substantially reduce the launch system costs and lengthy schedules typical of today.

6. **If the users are performing experiments now, when will they begin producing commercial products in space?**

The build up of empirical technical data on the optimum physical space conditions for conducting experiments (i.e., such as optimum altitudes, g levels, etc) must be developed before an estimate can be made about transitioning from research into manufacturing commercial products in space.

The frequency of space experiments is relatively low. Therefore, there is too little empirical data about the variability of space for experiments. Researchers must have much more data on the physical attributes of space and how to use space in a research mode. The experimenters need this data to focus their research into the space regimes that may provide high pay off, e.g., technical results. For this to occur, there must be a substantial increase in the frequency of experimental flights. This will also require an expansion of the companies supporting the end users, such as SHOT, Payload Systems, and ITA.

7. What are the current and near term costs associated with using space?

NASA is providing free rides on the shuttle to commercial users who become affiliates of the CCDS. Otherwise, the cost to fly an experiment in a shuttle mid-deck locker is approximately $700,000.

A Spacehab locker, equivalent to a shuttle mid-deck locker, cost about $1.8 million.

Flying an experiment on the MIR costs the researcher about $ _______ .

The users internal costs include -- creating the biological samples, other internal costs related to processing and preparing the samples for flight, and the costs associated with post-flight recovery and assessment of the experiment. The sum of these costs vary according to the complexity of the experiments, and the time criticality of maintaining living organisms during pre and post launch phases of flight. The user's internal costs can typically range from $400,000 to $800,000.

The user's external costs, exclusive of shuttle launch costs, are primarily for value added services and unique space hardware required for the experiment, such as the products and services provided by SHOT, or similar type companies. These typically include:

a.	space hardware development and fabrication	$400,000 and up
b.	Integration costs	200,000 to 400,000
c.	Technical support	200,000 and up
	Total	$800,000 to 1,800,000

The cost range relates to the complexity and time critically of support required for biological samples during payload integration, pre flight, and post-flight.

8. How sensitive is user demand to launch system cost? How many more times will they use space if the launch costs is reduced?

The issue of costs related to access to space is not relevant at the present time since commercial users can receive free rides on the shuttle, if they become affiliates of the CCDSs. Mr. Vellinger believes the drug companies will not continue to perform space experiments if they have to pay for the shuttle launch system costs that NASA now offers to the companies free.

Launch System Demand Elasticity:

Sensitivity to launch costs is low, primarily because NASA is provides free launches to end users.

Launch Frequency:

Launch Cost	**Annual Launches** **< 5 years**	 **< 10 years**
Prevailing price (a)	0	0
75 %	0	0
50 %	declined to forecast	
25 %	declined to forecast	
10 %	declined to forecast	

Notes: (a) Prevailing price is $700,000 for a shuttle mid-deck locker

The number of times a drug company will fly experiments in space also depends heavily upon their research staff. They must have adequate research staff to support each flight.

9. What decision making business process is used to decide on the use of space?

Drug companies must decide if there is an economic advantage to weightlessness.

10. What are titles and names of executive managers who are making the business decisions to invest their resources into space research?

Contact Orbitech (Orbital Technologies?), which is an affiliate of the Wisconsin Center for Space Automation and Robotics.

Review and Revision Status

8/19/93 Submitted research report to SHOT for review, comments and concurrence with data.

8/25/93 Mr. Dueser telecom. He will be respond.

9/8/93 Mr Vellinger will respond by end of this week.

9/14/93 Mr. Vellinger FAXed replies to research report. Comments incorporated and report completed.

C.3.14 Center for Cell Research, Penn State University with Dr. Wesley Hymer

Mission Area

Biological Products

Date

2 September 1993

Amended by comments from Dr. Hymer

Organization Contacted

Penn State University
Center for Cell Research
207 Frear Laboratory
University Park, PA 16802-6005

Who Contacted

Dr. Wesley Hymer; Director

Researchers

Don Barker (Lockheed) / Richard Freeman (Martin Marietta) / Henry Hillbrath (Boeing)

Summary

The Center for Cell Research (CCR) was established in 1987 as a part of NASA's Centers for the Commercial Development of Space program. CCR focuses on commercial product and process oriented biotechnology projects in the areas of physiological testing, bioseparations and illumination.

Recently, as a spin off from the CCR, Penn State has formed a private enterprise for the production and marketing of various automated systems for use in conducting both space based and ground based biological research.

The discussions essentially indicated that significant potential exists for biological product development in space, but currently no commercial market exists.

Currently, space based biological production will be on the research and development level only. Any one user's needs would require only small payload weights to be placed in orbit on an intermittent basis. Dr. Hymer estimates that as many as ten bio payloads per year may be commercially sellable but would require some more work.

International government interest in space based biotechnology is increasing; the Japanese have indicated keen interest in space biotechnology and several European consortia (University/Industry/Government) will be in place in 1994 to do space biotechnology as well.

Human interaction is not an absolute requirement for conducting space based research. Ultimately space based processing (e.g. electrophoresis) may require manned interaction for routine maintenance on on-orbit laboratories.

Allowable cost per flight is difficult to estimate since payload space on current STS flights is provided at no charge. It is evident that low costs will be required ($50K to $100K per user) to develop the market.

In order for commercialization of biological products in space to occur, a concerted commercial venture must be undertaken to convince biological product firms of the potential profitability of space based research and production and coalesce these firms into joint investment ventures to conduct research. CCR has this charter. Six biotechnological/pharmaceutical companies have already flown experiments in the last three years because of the CCR. Applications for the space research include the concept that space can be used as a test bed in the drug development process leading to new pharmaceuticals for use on earth. There is a surprisingly large data base which shows that rodents and astronauts experience bone loss, muscle atrophy, immune dysfunction, etc., all symptoms which mimic diseases on earth.

General Topics of Discussion

In a less structured approach the following general topics were discussed. These specific questions were not directly asked but general discussion followed along these lines. The results shown are interpretations of discussion conducted.

1. What is maturity of the Center's space applications?

The Center for Cell Research has been and is currently engaging commercial affiliates and partners in space-based research encompassing the three primary areas of physiological testing, bioseparations and illumination. Currently there is no definitive U.S. commercial market for space based cell research but there is potential that future research results combined with concerted marketing programs could bring industry into the business of space processing. There is some interest among the CCR's affiliates to join in conducting research but the ultimate goal of unsolicited substantial commercial investment has not yet been realized.

Electrophoresis

A significant and visible effort currently involves the bioseparation (electrophoresis) program. Electrophoresis is a process used in separating cells, proteins or other biological materials based on differences in electrical charge. The theory, which forms the basis of space-based electrophoresis, has been demonstrated in space experiments. This theory holds that the lack of sedimentation and buoyancy-driven convection forces that are essentially lacking in a microgravity environment will allow better material separation in a charged field to the point where materials of relatively small charge difference can be separated. Commercial applications of bioseparation are many but include separation of products (e.g. proteins) for pharmaceutical manufacture. Prior to the STS Challenger failure 7 electrophoresis flights were conducted by McDonnell Douglas Corporation which showed evidence of significantly improved results relative to effective separable concentration (25% vs. 2.5%) as well as purity of separation. Detractors felt that ground based systems could equal these results by simply running the process for longer duration. Recent experiments by German scientists demonstrate that the quality of separations achieved in space is superior to that on the ground. In 1992, CCR founded the United States Commercial Electrophoresis Program (USCEPS) to provide a ground based research program coupled to an in-house hardware development program which would lead to flight of a new improved unit. That unit will be delivered to Kennedy Space Center in the Summer of 1994 for its first flight in the first quarter of 1995 (SpaceHab 04). The principal commercial affiliate has been McDonnell Douglas Corporation. New affiliates are in the process of being added. Recently the CCR has teamed with Separations Technology, Inc. to explore ground-based systems as a spin-off of space-derived technology. Japan, France and German governments have started programs in electrophoresis as well as other biotechnology applications. Of these the Germans have had perhaps the best results using sounding rockets and the French and Japanese have systems that have and will fly on STS SL-J and IML2. Using a TEXUS launch system, the Germans confirmed increased purity of separated red blood cells as a result of operation in microgravity.

Physiological Testing

Many physiologic responses are affected or initiated by exposure to a microgravity environment. As part of the CCR program, Genentech and Merck Corporations have each flown physiological experiments (1990 and 1992 respectively). Also, in collaboration with the Space Dermatology Foundation and four commercial partners, physiological space experiment (PSE-3) involving the first tissue repair study was conducted in June 1993 aboard the STS-57. Also, another experiment with animals is scheduled for 1994. It was noted that no known public or animal rights backlash has been observed relative to animal experiments and that the experiments are performed under strict guidelines set down by NIH, NASA and University Animal Care and Use Committees.

Applications for research are varied but include study of many human degenerative diseases with the end goal being an increased understanding of these diseases and, hopefully, cures or treatments for many. Effects which have been studied include bone loss (decalcification, muscle atrophy, cardiovascular deconditioning, and suppressed immune system function).

The CCR has also developed, patented, and flown its own hardware to do physiological testing on cells. This hardware is called the PSU Biomodule (see item 3). it will fly its first STS mission in January of 1994.

Illumination

Light is an important modifier of human biology and psychology. CCR, in conjunction with industry, is using portable, semi-portable, as well as permanent fixed light sources to study biological and behavioral effects in humans and animals. Bright light panels have been flown on USML-1 to test human response. Much of this work is ground-based.

Essentially, space-based biological research is in its infancy, but it is growing. Most commercial users operating through the CCR have found interesting findings and many have expressed intent to conduct further research in the future. CCR believes they will re-fly some users soon.

2. What are payload form factors?

Currently, the STS SpaceHab or middeck lockers are what is required. What eventually may be required is unknown. In the event a process is ultimately commercially operated in space a more substantial system (weight and volume) would be required.

The Penn State Biomodule weighs approximately 14 lbs.

3. What infrastructure and support to user must launch system company provide?

For some users, longer duration on-orbit is needed. Some biological processes and the need to conduct iterative experiments result in a 30 day on-orbit requirement. For enhanced research capability several aspects also need further development. These include:

a. Better temperature control. Shuttle temperature control in middeck is a major problem. Would like temperature control to with ± 0.5° F.

b. Microgravity zero g fluid handling systems. Penn State has developed an automated fluid mixing system called the "biomodule" which has flown three times on sounding rockets and is scheduled to fly twice next year (1994) on STS. A private for-profit company was formed by Penn State for the sale and marketing of this module as well as other products in work.

c. Automated laboratory.
d. Robotic applications.
e. Recoverable experiment (or production modules).
f. Low cost, routine payload integration.

4. What is the end user market infrastructure?

Currently, the end users are commercial companies ideally in the business of bioproduct development and manufacture. These companies are engaged in conducting research through the CCR which provides (via NASA) STS flights. In addition to biotechnology companies, hardware oriented companies are affiliates and involved with the development of automated equipment for conducting the experiments.

5. What changes or improvements are needed in the market infrastructure to reduce costs of space produced products?

There are many factors which hinder development of the commercial space biotech market. One factor is the difficulty in maintaining proprietary control over experimental results. The biotech industry is very competitive and a system which prevents or obstructs proprietary control of data is a strong deterrent to commercial interest. CCR imposes time delays between getting results and allowing broad based publication to allow principal members sufficient time to gain whatever advantages may exists. In this regard it is paramount that NASA not have access to experimental results. NASA has competing organizations involved in bio research. Code U is chartered with conducting the research for broad general public knowledge.

Food and Drug Administration (FDA) bureaucracy is another significant hurdle to market development. Currently, it takes 10 to 12 years and costs on average $237M to bring human drug or medicine to market due primarily to the FDA process. The process has four stages pre-clinical, and 3 clinical phases. The CCR's efforts in commercial space are directed toward shortening the preclinical stage, thereby shortening the entire time to market which would facilitate drug development.

Mission integration costs and bureaucracy must be reduced significantly to allow commercial development. The integration of payloads into the launch system must be routine and low cost.

6. If users are performing experiments now, when will they being producing commercial products in space?

A continued concerted effort to form industry cooperatives to conduct research may eventually lead to breakthroughs which are commercially profitable in space. At this time projections for when this will occur are not possible.

7. What are current and near term costs associated with using space?

Currently, cost of space transport is zero to the users. The users contribute dollars, personnel and in-houses resources, and equipment for the purpose of conducting experiments. The CCR requires the end users to contribute to the conduct of various experiments.

8. How sensitive is user demand to launch system cost? How many more times will they use space is launch costs are reduced?

Sensitivity to launch system cost is irrelevant at this point. In the foreseeable future any commercial launch system will have to be far less expensive than current systems. Before any costs are supportable by the market, additional research must be conducted.

9. What decision making processing is used to decide on the use of space?

Currently, based on data presented to the industry by the CCR as well as other government agencies, the commercial sector is enticed into contributing to the research. Ultimately, substantive results with clear commercial viability will have to be produced before the commercial sector is engaged to the point where more commercial ventures in space will be undertaken. Increasing the data base and making industry aware of the current data base is key to progress.

10. What are titles and names of executive managers who are making business decisions to invest their resources into producing products in space?

Dr. Hymer indicated that these companies would be difficult to talk to (from CSTS representatives) and that demonstrated expertise in the bio field would be essential to any discussions with them. Companies which are actively involved with the CCR include:

Genentech – bioengineering, genetics
Merck – pharmaceuticals
ConvaTec (A Bristol-Myers Squibb) – pharmaceuticals
Boehringer Ingelheim – pharmaceuticals
Merocel Corporation – pharmaceuticals
Clontech – start-up biotechnology
Bio-Brite, Inc. – lighting

Dr. Hymer suggested that we interview Mr. Jim Rose who formerly worked for NASA and was one of the founding fathers of the CCDS program. Mr. Rose currently is a private consultant in the area of commercialization of space and among things is working with the European RADIUS program which is the equivalent of the U.S. CCDS. This program begins officially in early 1994.

C.3.15 Wisconsin Center for Space Automation and Robotics with Dr. Ray Bula

Mission Area

Space Agriculture

Date

2 September 1993

Organization Contacted

University of Wisconsin
Wisconsin Center for Space Automation and Robotics (WCSAR)
Madison, WI 53706

Who Contacted

Dr. Ray Bula

Researchers

Don Barker (Lockheed)/Richard Freeman (Martin Marietta)/Henry Hillbrath (Boeing)

Summary

The Wisconsin Center for Space Automation (WCSAR), formed in 1987, works in a variety of areas among which is space agriculture.

Commercial interest in space agriculture does not directly exist. Essentially, commercial industry interested in controlled environment systems for plant growth on earth. Development of systems for space research is applicable to terrestrial plant growth.

Ultimately, space based agriculture may become commercial market in the event of lunar colonization or manned orbiting factories, hotels etc. Until such achievements are inplace no commercial interest in space agriculture.

General Topics of Discussion

In a less structured approach the following general topics were discussed. These specific questions were not directly asked but general discussion conducted along these lines. The results shown are in general not quotes but interpretations of discussion conducted.

1. What is maturity of the centers' space applications?

Current status is that several experiments have been flown which demonstrate concepts for nutrient and water transport to root systems in micro gravity environment. No plants have actually been flown, but rather the systems which would provide resources to the plants have been tested with root simulators. Plants will be flown in 1994.

Have identified that plants only need specific part of sun light spectrum. Work is on going to develop artificial light sources meeting plants optimum needs. Current trend is use all artificial light as opposed to using natural light available from the sun. Primary reason is light cycles associated with earth orbiting systems are detrimental to plant growth as well as due to technical issues of large pressurized transparent structures.

Other system aspects demonstrated include closed cycle environment control (humidity, lighting, CO2, temperature). WCSAR in conjunction with industrial partner has developed a humidity control system known as "Astropore" and plan to market this subsystem (via spin off company) for terrestrial based growing units. Most near term applications for these systems are terrestrial rather than space based. These applications include production of ultra high quality fruits and vegetables for gourmet cooking/ fine dining, propagation of cell tissues for production of annual plant stocks, growth of high value medicinal crops. Advantages of these systems for terrestrial use are elimination of viruses, insects, weather variations, exact nutrient delivery.

Astroculture was originally only 10% of total NASA WCSAR funding. Is currently 30% but growth and total dollars is too low to develop hardware quickly.

2. What are payload form factors?
Currently, the STS spacehab lockers would be adequate for research. What eventually may be required is unknown.

3. What infrastructure and support to user must launch system company provide ?
For some users, longer duration on-orbit is needed. Cell differentiation processes and the need to conduct iterative experiments result in a 30 day or longer on-orbit requirements. For enhanced research capability several aspects also need further development. These include:

a. Routine and simple payload integration.
b. CO2 control. Potential of using MIR for astroculture research hindered by high CO2 levels (5000 ppm vs 500 ppm normally).
c. Automated laboratory.
d. Robotic Applications.
e. Recoverable experiment (or production modules).

4. What is end user market infrastructure?
Currently, the end users are commercial companies in the business of agricultural products and/ or automated hardware systems. These companies are engaged in conducting research through the CCR which provides (via NASA) STS flights. Japanese are a big potential end user which if allowed into CCDS would double funding levels. Again, the primary interest utilizing results and systems obtained via space research for terrestrial applications. Currently US has a 2 year technology advantage over Japanese in controlled closed environment agriculture but gap is closing fast.

5. What changes or improvements are needed in the market infrastructure to reduce costs of space produced products?
Changes in the market infrastructure are clearly not going to significantly alter the viability of commercially produced space agricultural products. Most commercial interest is in terrestrial applications. Development and implementation of orbital human habitats (stations, hotels, etc) or lunar or planetary colonization would undoubtedly spark commercial interest once firmly and convincingly established. In the near term it appears only government interest in space agriculture for space use will be evident. Completion of development of the controlled environment plant growing units is anticipated to increase additional commercial interest.

6. If users are performing experiments now, when will they begin producing commercial products in space?

Commercial interest in space agriculture will arise coincident with large scale, long term extraterrestrial human habitation.

7. What are current and near term costs associated with using space?

Currently, cost of space transport is zero to the users. The users essentially contribute dollars, resources, equipment for purpose of conducting experiments. Once mission is identified takes approximately two years at current funding levels to ready hardware.

8. How sensitive is user demand to launch system cost. How many more times will they use space if launch costs are reduced?

Sensitivity to cost is irrelevant at this point. In the foreseeable future any commercial launch system will have to be far less expensive than current systems. Estimated investment threshold for commercial interest is on the order of $10K to $25K per user.

9. What decision making process is used to decide on the use of space?

Currently, industry is solicited by WCSAR for investment into space research with ultimate goal being commercialization. Most companies are currently either only interested in the ground based applications or development of hardware but view investment in space research as a mechanism for developing systems for ground based use. Ultimate near term goal is for industry to approach WCSAR with ideas and investment dollars for research. Unfortunately, the projections for near term future realization of this goal is dim.

10. What companies are investing their resources into producing agricultural products in space?

Companies which are actively involved with the WCSAR astroculture program include:

a. Wisconsin Alumni Research Foundation
   Involved with patenting "Astropore" and blue Light Emitting Diode work.
b. Agrisetus Co.
   Interested in controlled environment plant growing units.
c. Automated Agriculture Associates
   Interested in controlled environment plant growing units.
d. Quantum Devices Inc.
   Interested in lighting systems for plant growth and plant growth performance Instruments
e. Biotronics Inc.
   Sensor systems, on-line analysis of solutions, etc

C.3.16 Universities Space Research Association (USRA)-Washington, D.C., with Beth Ransom and Rick Zwirnbaum.

Academic Space Research

Date

17 February 1994
Revised: 24 February 94

Organization Contacted:

Universities Space Research Association (USRA)
300 D Street, S.W., Suite 801
Washington, DC 20024

Tel: 202/479.2609
FAX: 301/816.1443

Persons Contacted

Beth Ransom, Rick Zwirnbaum; STEDI Program

Researcher

Bill Walsh, Lockheed

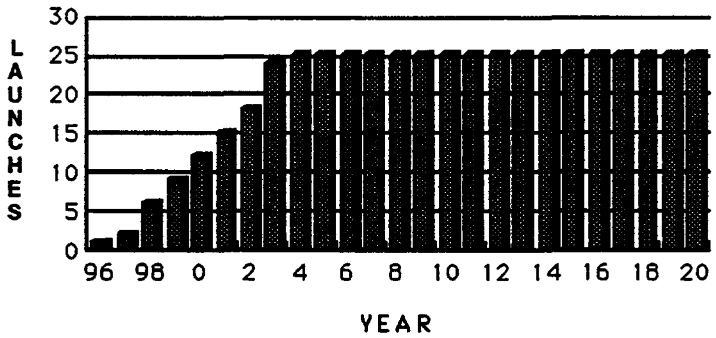
Summary

The researcher met with Beth Ransom and Rick Zwirnbaum; representatives of the Student Explorer Demonstration Initiative (STEDI) Program at the USRA, Washington, DC offices to discuss the "Academia Space Research market. Dr. Paul Coleman, USRA president, and Kevin Schmadel, Asst. executive director were not available for the meeting.

The objective of the STEDI program is to demomstrate that significant space flight missions can be performed for science and technology development at very affordable costs. USRA believes that if theSTEDI program is successful that it will be able to establish a steady stream of dedicated space flights for research and development at universities, government labs, and commercial research centers. Two important aspects of the program are: 1) support limited duration projects, e.g., PhD research, and 2) significant hands-on participation by students and entry-level engineers and scientists. The program is sponsored by NASA. The USRA will select a range of university experiments in 1994 to be built, launched and begin mission operations, flying three polar-LEO space flights beginning in 1996.

The science objective is to select small payloads that are designed to conduct research in space-related scientific disciplines, e.g., astrophysics, earth sciences, life and biomedical sciences and applications, micro gravity sciences, and space physics. Approximately $8 million per flight is planned for payload (up to 450 lbs) and launch vehicle. The cost for each flight is split evenly between payload and small expendable launch vehicle (SELV), i.e. $4 million for the payload and $4 million or less for the SELV. Cost per pound of payload is equivalent to approx. $9,000 /lb, assuming 450 lbs to 100 nmi orbit at90 degree inclination. The Multi-Service Launch Vehicle (MSLV) has been identified as the expendable launch vehicle.

Mr. Dan Goldin, the NASA Administrator supports the program. USRA estimates that a total of $24 million is needed to complete the initial phase of the STEDI program . Launch dates for the three flights begin in 1996. If the initial phase of the program is successful, then NASA would continue to support the program, leading to a robust academic research program, with a buildup of up to 25 space research flights per year. An estimate of the initial and follow on phase launches is forecast in the figure below.



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USRA is a non-profit organization that consists of approximately 76 member universities. The association was established in 1969 by the National Academy of Sciences at the request of NASA. The objective of USRA is to provide a mechanism through which universities and other research institutions could cooperate with each other, with the U. S. government, and with public and private organizations to further space science and technology. The Association operates a number of institutes, divisions, and programs, throughout the U. S., that sponsor exploratory research and aerospace education.

1. What is the maturity of the users' in university space science applications?

Universities perform space science projects in cooperation with government, private institutions and industry. They rely on funding from government and the private sector to develop and perform the experiments. The number of space experiments is limited by the cost of launching the payloads.

2. What are the payload form factors of space science payloads?

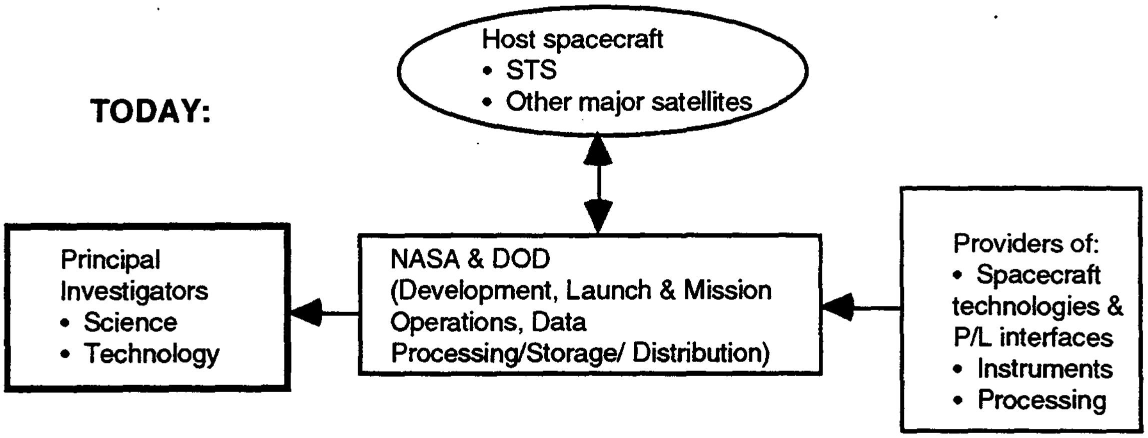
University science experiments are generally small in mass, and limited in power. Typically each of the experiments will be under 100 lbs and less than few cubic feet. Most have been launched on sounding rockets, and high-altitude balloons. However, there are also a relatively small number of larger experiments that are in the 100 to 1000 lbs range, and launched as secondary payloads on expendable launch vehicles and the shuttle.

3. What infrastructure and support to the user must the launch system company provide?

No reply.

4. What is the end user market infrastructure?

Today there are very limited opportunities for affordable research flight demonstrations. The infrastructure supporting these activities, as depicted below, is predominantly NASA and DoD research packages flown as tertiary missions on major satellites. STS provides a major share of this support. These missions must conform to externally imposed mission plans and schedules.



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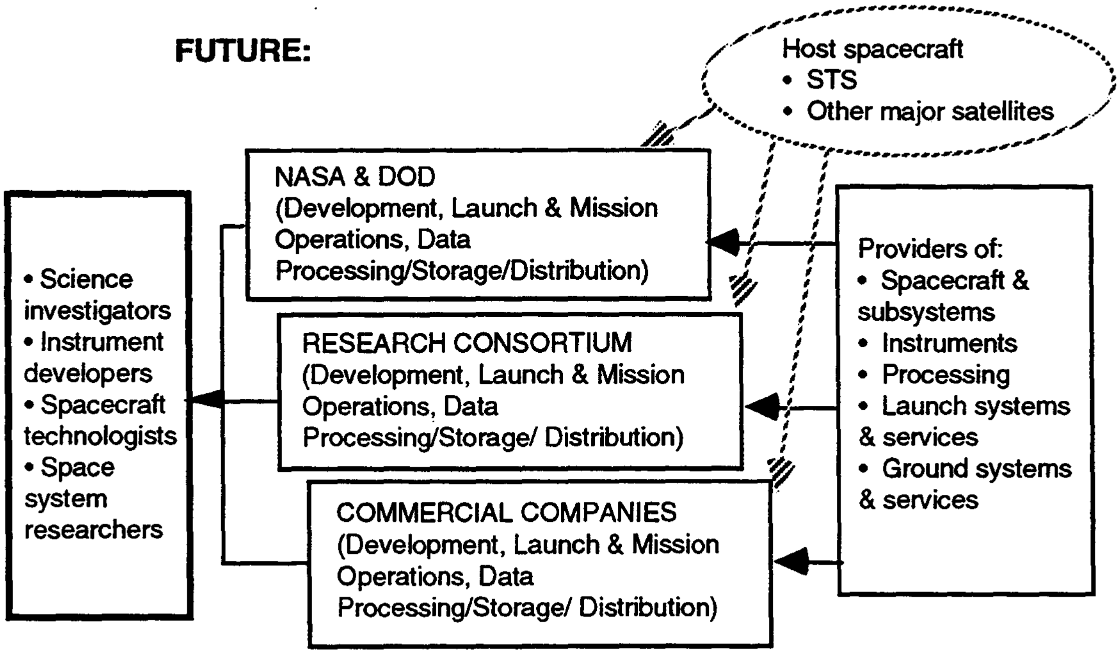
5. **What changes or improvements are needed in the market infrastructure to reduce the costs of space produced products?**

University research is limited by the long lead time (time it takes from inception of a science project to the flight) and the high cost of launching payloads. In the future, the successful STEDI demonstration and the emergence of capable, dedicated, low cost launch vehicles should foster a varied infrastructure of program sponsors, as illustrated below. The environment will continue to utilize, but not completely limited, to flying on host spacecraft. Strong collaboration is anticipated between ventures in universities, government, and corporations.



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6. If the users are performing experiments now, when will they begin producing commercial products in space?

University space research will not lead to production of products in space.

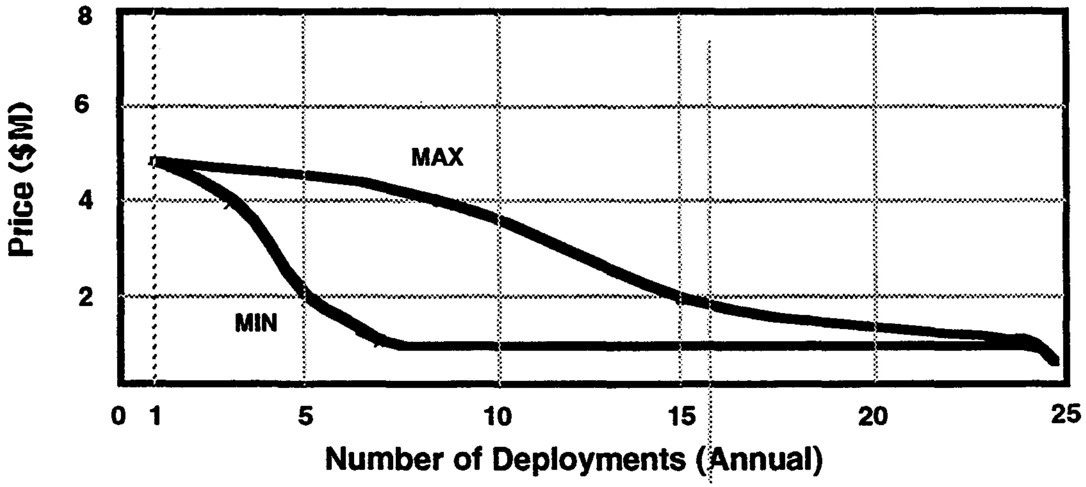
7. What are the current and near term costs associated with using space?

Launch costs vary over a broad range. However, costs are typically in the range of $10,000 to $100,000/lb. The USRA STEDI program intends to reduce launch costs to under $10,000/lb, during the phase one demonstration program.

8. How sensitive is user demand to launch system cost? How many more times will they use space if the launch costs is reduced?

In general the cost of a payload is not less than the launch vehicle cost. Consequently, as launch vehicle costs are reduced, an increasing number of additional experiment opportunities evolve. The figure below provides a preliminary estimate of launch vehicle elasticity associated with space science and technology research.

Preliminary Projection of Launch Vehicle Elasticity of Demand
(SCIENCE & TECHNOLOGY RESEARCH)



Assume that the USRA projection includes multiple science experiments in each payload deployment. The initial phase of STEDI includes payload mass of about 450 lbs to a 100 nmi altitude, polar orbit. The MIN curve represents the high probability of occurrence, and MAX represents the low probability of occurrence.

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9. What decision making business process is used to decide on the use of space?

No reply.

10. What are titles and names of research managers in academia who are making the decisions to perform space research?

No reply.

Review and Revision Status

Research was reviewed with Rick Zwirnbaum of USRA and comments were provided on 2/23/94.

Report was revised to include USRA's comments

Appendix D—
Remote Sensing Appendix

APPENDIX D REMOTE SENSING APPENDIX

D.1 WORLD REMOTE SENSING SATELLITE DEPLOYMENTS

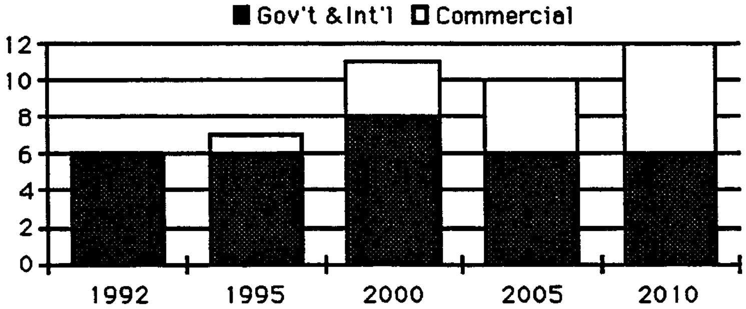
The CSTS researchers assessed several data sources to consolidate a list of remote sensing satellites. A data base of the satellite deployments was prepared for the 1991 through 2005 time frame. By inspection and analysis several significant conclusions were determined from the data base.

The majority of remote sensing satellites are deployed to low earth polar orbits. A small quantity of satellites are deployed to geostationary orbits, primarily for global weather forecasting. There will also be a few heavy government satellites to LEO, in the 3,500 to 6,000 kg range, that combine large suites of sensors for multiple missions.

Low earth orbit satellites' mass to orbit are classified in four ranges:

Mass (kg) to Polar Orbit	Comments
200 to 1,000	Mostly commercial deployments
1,000 to 1,500	Government and International deployments
1,500 to 2,200	Government and International deployments
2,400 to 2,800	Predominately International deployments.

Worldwide deployments of remote sensing satellites for government, international and commercial applications will reach seven deployments in 1995, and fluctuate between six to eleven through the end of this decade. Commercial operators who will begin deploying satellites in 1995 and ramp up to five deployments in 1997 before reaching an average of three per year for the 1996 through 2000 time frame. Commercial deployments will reach four annually, as illustrated in the figure D.1-1 below, by the year 2005. The share should climb to six, or 50-percent of the total launches by 2010.



Combined deployment of government, international and commercial remote sensing satellites. Source: CSTS remote sensing data base, Appendix D.1 and D.3.

Figure D.1-1. Remote Sensing Satellite Deployments

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D.2 SUMMARY OF WORLD REMOTE SENSING SATELLITE DEPLOYMENTS

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1														
3														
4	**Program Name**	Prognoz	Almaz	Meteosat 5 MOP-2	NOAA - 12 (NOAA-D)	ERS - 1	EOS	Nimbus	IRS IB	GOMS Elektron	JERS	INSAT 2	NOAA - 13 (NOAA - I)	LAGEOS - II
5	**Owner**	Russia	Russia	ESA	NOAA	ESA	NASA	NASA	National Remote Sensing Agency (NRSA)	Russia	NASDA	India	NOAA	NASA
6	**Country of Origin**	Russia	Russia	Europe	U.S.	Europe	U.S	U.S.	India	Russia	Japan	India	U.S.	U. S.
7	**Satellite Status**	Operational	Operational	Operational	Operational	Operational	Operational	Operational	Operational	Operational	Operational	Operational	Failed	
8	**Value (M94$ U.S.)**	*100*	*100*	300	60	850	25	50	50	*100*	275	*75*	60	100
9	**Design Life (yrs)**	2.5	1.5	5	2	4	2	5	3	2.5	2 yrs	3	2	3
10	**Mass (kg) (a)**	1600	6000	681	1700	2384	250	2000	975	2400	1340	875	1712	406
11	**Altitude (km)**	G E O	300	G E O	825	780	705	740	900	G E O	568	G E O	870	5950
12	**Inclination (deg.)**		72.7	4 W	99	98.5		polar	99	40-50°	98	74°	99	52
13	**Sensor Type(s)**	E O	Radar	Radar	E O, Microwave	Radar	E O	E O	E O	E O	SAR	E O	E O, Microwave	E O
14	**Average Resolution (meters)**	1200	15-30	2500	1100	20	50	5	36	1200	18	2000	1100	
15	**Swath (km)**		240			100			148	240	75			
16	**Primary Mission**	Earth Observation	Oil pollution & ice monitoring	Meteorology	Earth Observation	Global ocean	Earth Observation	Ozone watch	Earth Observation	Meteorology	Meteorology	Communication and Earth Observation	Earth Observation	Earth Observation
17	**Other Missions/Notes**			Dual Manifest								Dual Manifest		
18	**ILC Date**	02/91	03/91	03/91	05/91	07/91	08/91	08/91	08/91	12/91	02/92	03/92	06/92	06/92
19	**Launch Vehicle**	Proton SL-12	Proton	Ariane V42	Atlas E	Ariane 4	Pegasus	SL-14	SL-3 Vostok	Proton SL-12	H1	Ariane	Atlas E	Titan - 4
20	**Launch Costs**	43	43	61	42	121	13	16	28	43	90	61	42	250
21														
22														
23		**Assumptions: satellites listed have an operational lifetime of more than one year.**												
24		Notes: (a) Mass of payload at launch.												

	A	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB
1															
2															
3															
4	**Program Name**	Okean Platform B	The Ocean Topography Experiment (Topex) / Poseidon	Modified Okean-O	Meteor 2	FY 2	RESURS-02	SPOT 3	NOAA 14 (NOAA-J)	Landsat 6	IRS 1E	Meteor 3	Meteosat 6	GOMS 2	TOMS-EP
5	**Owner**	Russia	NASA/JPL	Russia	Russia	China	Russia	France	NOAA	NOAA (EOSAT)	NRSA	Russia	ESA	Russia	NASA
6	**Country of Origin**	Russia	USA / France	Russia	Russia	China	Russia	France	U.S.	U.S	India	Russia	Europe	Russia	U.S.
7	**Satellite Status**				Operational	Development		Operational	Operational	Failed	Failed	Operational	Operational	Planned	Planned
8	**Value (M94$ U.S.)**	*100*	550	50	*50*	*100*	*50*	250	67	220	150	*50*	400	*100*	60
9	**Design Life (yrs)**	1	5	2.5	2.5	1	1	5	2	3	5	2.5	5	2.5	2.5
10	**Mass (kg) (a)**	1600	2380	2000	2000	1250	2400	1870	1700	2750	850	2215	700	2400	380
11	**Altitude (km)**	670	1336	900	950	G E O	700	820	835	705	817	1200	G E O	G E O	TBD
12	**Inclination (deg.)**	Polar Sunsynch	66	82.5° Sunsynch	82.5°	105	98	98.7°	99	98	99	82.5°	4 W	40-50°	90
13	**Sensor Type(s)**	Radar	Radar	Radar	E O	Radar & EO	SAR & E O	E O	E O, Microwave	E O	E O	E O	Radar	E O	E O
14	**Average Resolution (meters)**	1500	10 (0.03)	1500	2000	1200	45	20/10	1100	30/15	20	500	2500	1200	1130
15	**Swath (km)**	2100		2100	2100	120	1200	117				2100		240	
16	**Primary Mission**	Ice monitoring	Ocean Topography	Ice monitoring	Meteorology	Meteorology	Earth Observation	Earth Observation	Earth Observation	Earth Observation	Earth Observation	Meteorology	Meteorology	Meteorology	Ozone Mapping
17	**Other Missions/Notes**												Dual Manifest		
18	**ILC Date**	06/92	08/92	01/93	03/93	06/93	06/93	09/93	09/93	09/93	09/93	09/93	11/93	01/94	03/94
19	**Launch Vehicle**	Zenit SL-16	Ariane 42P	SL-14	SL-14	CZ-3	SL-16 Zenit 2	Ariane 40	Titan 2	Titan 2	PSLV	SL-14	Ariane V42LP	Proton SL-12	Pegasus
20	**Launch Costs**	34	121	16	16	40	34	118	47	47	60	16	61	43	13
21															
22															
23															
24															

	A	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP
1															
2															
3															
4	**Program Name**	GOES - I (GOES-8)	Helios	SeaStar	IRS 1(E)	China/Brazil Earth Resources Satellite (CBERS)	ERS 2	GOES-J (GOES-9)	Radarsat	EOS-SAR	GS-01	NOAA 15 (NOAA-K)	Com'l	Modified Okean Platform B	Meteosat 7
5	**Owner**	NOAA	CNES	NASA	NRSA	China/Brazil	ESA	NOAA	Canada	NASA	South Africa	NOAA	Worldview	Russia	ESA
6	**Country of Origin**	U.S.	France	U.S.	India	China	Europe	U.S.	Canada	U. S.	South Africa	U.S.	U.S.	Russia	Europe
7	**Satellite Status**	Planned	Development	Planned	Planned	Development	Development	Planned	Development	Planned	Planned	Planned	Development	Planned	Planned
8	**Value (M94$ U.S.)**	200	350	60	150	150	500	200	400	250	30	75	30	*100*	500
9	**Design Life (yrs)**	5	4	5	5	2	5	5	5	5	4	3	5	3 yrs	5
10	**Mass (kg) (a)**	2000	2500	363	850	1400	2385	2000	2750	1300	316	1700	350	2500	700
11	**Altitude (km)**	G E O	850	705	817	778	780	G E O	743	620	460	833	460	670	G E O
12	**Inclination (deg.)**	75°W	99	Polar	99	98.5 Sunsynch	99.5	75°W	98.6 Sunsynch	97.5 sunsynch	72	99	polar	polar sunsynch	4 W
13	**Sensor Type(s)**	EO	E O	E O	E O	Radar & EO	Radar	EO	Radar	radar	E O	E O, Microwave	E O	Radar	Radar
14	**Average Resolution (meters)**	1000	3	1000	20/10	1100	30	1000	variable		2	1100	3	1500	2500
15	**Swath (km)**			1500		120	100		variable (45 - 500)					2100	
16	**Primary Mission**	Weather, Earth Observation	Surveillance	Ocean color data	Earth Observation (replaces IRS-1E)	Remote Sensing	Global Ocean Monitoring	Weather, Earth Observation	Global data on ice, crops, forests, oceans, geological forms	Earth Observation	Earth Observation	Earth Observation	Commodity markets management	Ice monitoring	Meteorology
17	**Other Missions/Notes**						Global ozone monitoring								Dual Manifest
18	**ILC Date**	04/94	05/94	07/94	09/94	09/94	03/95	04/95	04/95	06/95	08/95	09/95	10/95	01/96	03/96
19	**Launch Vehicle**	Atlas 1	Ariane 4	Pegasus	PSLV	CZ-4A	Ariane 5	Atlas 1	Delta 2	Titan 2	Taurus	Titan 2	Taurus	SL-16 Zenit	Ariane V42
20	**Launch Costs**	70	110	13	60	45	143	70	50	47	25	47	25	34	61
21															
22															
23															
24															

	A	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD
1															
2															
3															
4	**Program Name**	Com'l	NOAA 16 (NOAA-L)	Com'l (Eyeglass)	AdEOS	IRS 1D	Com'l	SPOT 4	TRMM (Tropical Rainfall Measuring Mission)	Com'l	Com'l	Polar Orbit Earth Observation Mission (POEM)	Com'l	Landsat 7	Com'l
5	**Owner**	Worldview	NOAA	Orbital Science,GDE and Litton OS	Japan	NRSA	ITD/SRSC	France	NASA	Unannounced	ITD/SRSC	ESA	ITD/SRSC	NASA-DOD	ITD/SRSC
6	**Country of Origin**	U.S.	U.S.	U.S.	Japan	India	U.S.	France	USA / Japan	U.S.	U.S.	Europe	U.S.	U.S	U.S.
7	**Satellite Status**	Development	Planned	Planned	Planned	Planned	Planning	Planned	Development	Planning	Planning	Planned	Planning	Planned	Planning
8	**Value (M94$ U.S.)**	30	75	*150*	250	50	30	175	200	170	30	300	30	411	15
9	**Design Life (yrs)**	5	3	5	2	5	7	5	5	7	7	5	7	5	7
10	**Mass (kg) (a)**	350	1700	500	3200	1000	205	2500	3500	1000	205	2400	205	2800	205
11	**Altitude (km)**	460	833	926	797	900	750	820	350	700	750	780	750	705	750
12	**Inclination (deg.)**	polar	99	polar	99	99	98	98.7°	35	98	98	Polar	98	98	98
13	**Sensor Type(s)**	E O	E O, Microwave	E O	EO & SAR	E O	E O	E O	Radar	E O	E O	Radar	E O	E O	E O
14	**Average Resolution (meters)**	3	1100	1	8	20/10	15	20/10		3	15	2500	15	5	15
15	**Swath (km)**						120	120							
16	**Primary Mission**	Commodity markets management	Earth Observation	Commodity markets management	Earth Observation	Earth Observation	Commodity markets management	Earth Observation	Precipitation measurment	Commodity markets management	Commodity markets management	Meteorology, ocean, climate	Commodity markets management	Earth Observation	Commodity markets management
17	**Other Missions/Notes**						2 satellites per launch				2 satellites per launch		2 satellites per launch		single satellite launch
18	**ILC Date**	03/96	09/96	10/96	12/96	03/97	06/97	06/97	08/97	09/97	10/97	12/97	02/98	03/98	04/98
19	**Launch Vehicle**	Taurus	Titan 2	Taurus	H2	PSLV	Delta 2	Ariane	H2	Taurus	Delta 2	Ariane 4	Delta 2	Titan 2	Taurus
20	**Launch Costs**	25	47	25	120	60	50	122	120	25	50	122	50	47	25
21															
22															
23															
24															

	A	BE	BF	BG	BH	BI	BJ	BK	BL	BM	BN	BO	BP	BQ	BR
1															
2															
3	Program Name	Helios	Com'l (Eyeglass)	EOS AM 1	Com'l	SeaWIFS II	NOAA -M	GOES - K (GOES-10)	Com'l	SPOT 5	EOS Aerosol 1	EOS PM 1	GOES - L	NOAA-N	Com'l
4															
5	Owner	CNES	Orbital Science,GDE and Litton OS	NASA	Unannounced	NASA	NOAA	NOAA	Unannounced	France	NASA	NASA	NOAA	NOAA	Worldview
6	Country of Origin	France	U.S.	U.S	U.S.	U.S	U.S.	U.S.	U.S.	France	U.S	U.S	U.S.	U.S.	U.S.
7	Satellite Status	Planned	Planned	Planned	Planning	Planned	Planned	Planning	Planning	Planned	Planned	Planned	Planned	Planned	Potential
8	Value (M94$ U.S.)	350	*150*	100	170	100	75	200	170	200	50	50	250	75	30
9	Design Life (yrs)	4	5	5	7	5	3	5	7	5	3	5	5	3	5
10	Mass (kg) (a)	2500	500	5450	1000	236	1700	2000	1000	2500	250	5580	2000	1700	350
11	Altitude (km)	850	926	705	700	705	833	G E O	700	820	705	705	G E O	835	460
12	Inclination (deg.)	99	polar	98	98	polar	99	75°W	98	98.7°	57°	98	75°W	99	polar
13	Sensor Type(s)	E O	E O	E O	E O	E O	E O, Microwave	EO	E O	E O	E O	E O	EO	E O, Microwave	E O
14	Average Resolution (meters)	1	1	?	3	5	1100	1000	3	5	5	5	1000	1100	3
15	Swath (km)									60					
16	Primary Mission	Surveillance	Commodity markets management	Earth Observation	Earth Observation	Earth Observation	Earth Observation	Weather, Earth Observation	Commodity markets management	Earth Observation	Earth Observation	Earth Observation	Weather, Earth Observation	Polar Meterology	Commodity markets management
17	Other Missions/Notes														
18	ILC Date	04/98	05/98	06/98	06/98	08/98	10/98	04/99	05/99	06/99	01/00	01/00	04/00	05/00	10/00
19	Launch Vehicle	Ariane 4	Taurus	Atlas 2AS	Taurus	Pegasus	Titan 2	Atlas 1	Taurus	Ariane	Pegasus	Atlas 2AS	Atlas 2	Titan 2	Taurus
20	Launch Costs	122	25	140	25	20	47	70	25	122	20	140	80	47	25
21															
22															
23															
24															

	A	BS	BT	BU	BV	BW	BX	BY	BZ	CA	CB	CC	CD	CE	CF
1															
2															
3															
4	**Program Name**	Com'l	EOS-SAR	Com'l (Eyeglass)	EOS Altimetry	EOS Chemistry	EOS AM 2	EOS Aerosol 2	NOAA - N'	LAWS	GOES - M	NOAA-O	Com'l	Com'l	Com'l
5	**Owner**	Worldview	NASA	Orbital Science,GDE and Litton OS	NASA	NASA	NASA	NASA	NOAA	NASA	NOAA	NOAA	ITD/SRSC	ITD/SRSC	Unannounced
6	**Country of Origin**	U.S.	U. S.	U.S.	U.S	U.S	U.S	U.S	U.S.	U.S	U.S.	U.S.	U.S.	U.S.	U.S.
7	**Satellite Status**	Potential	Planned	Potential	Planned	Planned	Planned	Planned	Planned	Planned	Planned	Planned	Planning	Planning	Potential
8	**Value (M94$ U.S.)**	30	250	150	50	50	50	50	75	100	250	75	30	30	170
9	**Design Life (yrs)**	5	5	5	5	5	5	3	3	4	5	3	7	7	7
10	**Mass (kg) (a)**	350	1300	500	2700	5450	5450	250	1700	400	2000	1700	205	205	1000
11	**Altitude (km)**	460	620	926	705	705	705	705	833	825	GEO	833	750	750	700
12	**Inclination (deg.)**	polar	97.5	polar	polar	polar	polar	57°	99	98.7	75°W	99	98	98	98
13	**Sensor Type(s)**	EO	radar	EO	Radar	EO	EO	EO	EO	EO	EO	EO	EO	EO	EO
14	**Average Resolution (meters)**	3		1	5	5	5	5	1100		1000	1100	15	15	3
15	**Swath (km)**												120	120	
16	**Primary Mission**	Commodity markets management	Earth Observation	Commodity markets management	Earth Observation	Earth Observation	Earth Observation	Earth Observation	Earth Observation	Polar Atmosphere	Weather, Earth Observation	Polar Meterology	Commodity markets management	Commodity markets management	Commodity markets management
17	**Other Missions/Notes**												2 satellites per launch	2 satellites per launch	
18	**ILC Date**	03/01	06/01	09/01	01/02	06/02	01/03	01/03	05/03	06/03	04/04	05/04	06/04	10/04	11/04
19	**Launch Vehicle**	Taurus	Titan 2	Taurus	Delta 2	Atlas 2AS	Atlas 2AS	Pegasus	Titan 2	Pegasus	Atlas 2	Titan 2	Taurus	Taurus	Taurus
20	**Launch Costs**	25	47	25	45	140	140	20	47	20	80	47	25	25	25
21															
22															
23															
24															

	A	CG	CH	CI	CJ	CK	CL	CM	CN	CO	CP	CQ
1												
2												
3												
4	**Program Name**	EOS PM 2	Com'l	Com'l	GOES - M'	SPOT 6	EOS-SAR	EOS Aerosol 3	GOES - M"	NOAA-P	EOS Altimetry	EOS Chemistry
5	**Owner**	NASA	ITD/SRSC	ITD/SRSC	NOAA	France	NASA	NASA	NOAA	NOAA	NASA	NASA
6	**Country of Origin**	U.S	U.S.	U.S.	U.S.	France	U. S.	U.S	U.S.	U.S.	U.S	U.S
7	**Satellite Status**	Planned	Planning	Planning	Planned	Planned	Planned	Planned	Planned	Planned	Planned	Planned
8	**Value (M94$ U.S.)**	50	30	15	250	250	250	50	250	75	50	50
9	**Design Life (yrs)**	5	7	7	5	5	5	3	5	3	5	5
10	**Mass (kg) (a)**	5600	205	205	2000	2500	1300	250	2000	1700	2700	5450
11	**Altitude (km)**	705	750	750	G E O	800	620	705	G E O	833	705	705
12	**Inclination (deg.)**	polar	98	98	75°W	99	97.5	57°	75°W	99	polar	polar
13	**Sensor Type(s)**	E O	E O	E O	EO	E O	radar	E O	EO	E O	E O	E O
14	**Average Resolution (meters)**	5	15	15	1000	2		5	1000	1100	5	5
15	**Swath (km)**		120			60						
16	**Primary Mission**	Earth Observation	Commodity markets management	Commodity markets management	Weather, Earth Observation	Earth Observation	Earth Observation	Earth Observation	Weather, Earth Observation	Polar Meterology	Earth Observation	Earth Observation
17	**Other Missions/Notes**		2 satellites per launch	single satellite launch								
18	**ILC Date**	01/05	02/05	04/05	04/05	06/05	09/05	06/06	04/07	05/07	08/07	09/07
19	**Launch Vehicle**	Atlas 2AS	Taurus	Pegasus	Atlas 2	Ariane	Titan 2	Pegasus	Atlas 2	Titan 2	Delta 2	Atlas 2AS
20	**Launch Costs**	140	25	15	80	122	47	20	80	47	45	140
21												
22												
23												
24												

Mass to LEO By User, Conservative Estimate

	1991	92	93	94	95	96	97	98	99	2000	1	2	3	4	5	*Extension*
Government	3950	4498	4450	8743	11000	1700	0	10186	4000	15530	1300	8150	7800	9700	14900	*105907*
International	23359	3815	15385	14350	5451	8500	9400	12500	15000	9600	8200	8350	12635	11900	8200	*166645*
Commercial	0	0	0	0	350	850	1820	1615	1650	350	1260	1600	3700	820	1615	*15630*
Total	**27309**	**8313**	**19835**	**23093**	**16801**	**11050**	**11220**	**24301**	**20650**	**25480**	**10760**	**18100**	**24135**	**22420**	**24715**	*288182*
(5-Year Total)					*95351*					*92701*					*100130*	*288182*

Satellites Deployed By User Group, Conservative Estimate

	1991	92	93	94	95	96	97	98	99	00	1	2	3	4	5	*Extension*
Government	3	3	2	3	3	1	0	4	1	4	1	2	4	2	3	*36*
International	6	3	8	4	3	3	4	5	6	4	3	3	5	5	3	*65*
Commercial					1	2	5	4	3	3	3	3	5	4	4	*37*
Total	**9**	**6**	**10**	**7**	**7**	**6**	**9**	**13**	**10**	**11**	**7**	**8**	**14**	**11**	**10**	*138*
(5-Year Total)					*39*					*49*					*50*	*138*

Long Range Deployment Summary

	1991-5	1996-0	2001-5	Total
Government	14	10	12	36
International	24	22	19	65
Commercial	1	17	19	37
Total	39	49	50	138

Mass to LEO Summary (X1000)

	1991-5	1996-0	2001-5	Total
Government	33	31	42	106
International	62	55	49	167
Commercial	0.350	6	9	16
Total	95	93	100	288

	Gov't	Int'l	Com'l	Total		Gov't	Int'l	Com'l	Total		Gov't	Int'l	Com'l	Total
1991-5	14	24	1	39	**1996-0**	10	22	17	49	**2001-5**	12	19	19	50

D.4 REMOTE SENSING SATELLITE EQUIPMENT WORLDWIDE FORECAST

	91	92	93	94	95	96	97	98
Government	3	3	2	3	3	1	1	4
Commercial	0	0	0	0	1	3	3	5
International	6	3	8	4	3	2	5	4
Total launches	**9**	**6**	**10**	**7**	**7**	**6**	**9**	**13**

	91	92	93	94	95	96	97	98
P/L Costs ($M)	1635	1160	1387	1070	1485	1105	1015	1431
LV Costs ($M)	410	598	455	354	407	312	549	501
Total ($M)	**2045**	**1758**	**1842**	**1424**	**1892**	**1417**	**1564**	**1932**

	03	04	05	06	07
P/L Costs ($M)	275	325	845	50	425
LV Costs ($M)	227	127	429	20	312
Total ($M)	502	452	1274	70	737
No of launches	4	2	4	1	4

Commercial Remote Sensing Investment

	95	96	97	98	Extension
P/L Costs ($M)	30	180	290	245	745
LV Costs ($M)	25	50	225	150	450
Total ($M)	**55**	**230**	**515**	**395**	1195

Government & International Remote Sensing Investment

	95	96	97	98	Extension
P/L Costs ($M)	1455	925	725	1186	4291
LV Costs ($M)	382	262	324	351	1319
Total ($M)	**1837**	**1187**	**1049**	**1537**	5610

D.5 MARKET ASSESSMENT APPROACH

The Alliance used a common and proven approach for performing the market assessment of the space remote sensing market. As illustrated in figure D.5-1, several preliminary steps were performed before conducting the field surveys with the end users.

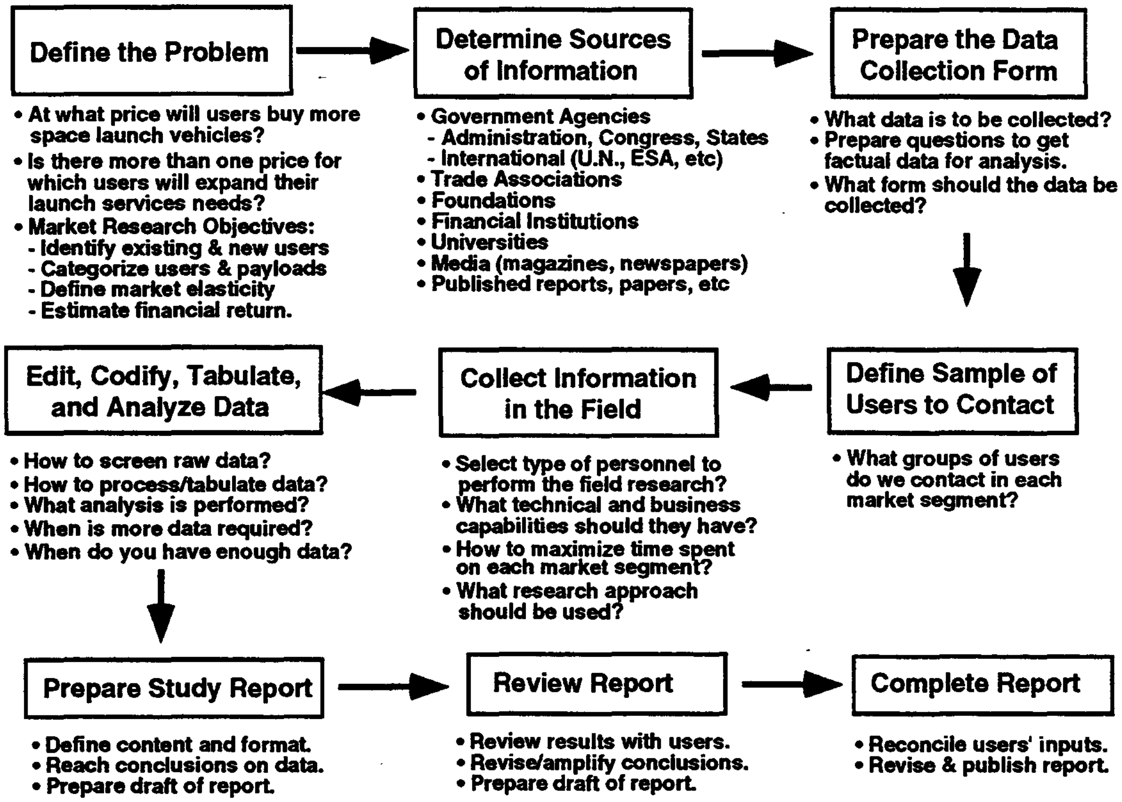


Figure D.5-1. Research Methodology and Issues

A literature search of trade literature to assess the current status of market, primary market forces, and primary market players were performed. Secondary sources were contacted to acquire similar data, to assess the major issues of the market, and to collect information on the key primary contacts, or users. Several field surveys and many telephone discussions were made with the primary contacts. These meeting and discussions with users attempted to assess potential future changes in the market if the cost of the launch system were lowered. Additional data was collected on the form factors for the payloads, and the potential business for a new generation low cost launch system.

D.6 FIELD RESEARCH REPORTS

D.6.1 Ball Space & System Engineering Division

Date
30 September 1993

Organization Contacted
Ball Space & Systems Engineering Division
P. O. Box 1235
Broomfield, CO 80038

Telephone: 303/460.3636 FAX: 303/460. _____

Researcher
Bill Walsh, Lockheed

Summary

The researcher held a telephone conference with Neal Anderson, Director, Commercial Programs, at Ball Aerospace in Broomfield, Colorado. The company is a major developer of satellites for government applications. The firm has developed a small satellite platform referred as QuickStar, which can be configured to integrate a broad range of payloads, including: remote sensing, communications, technology demonstrations, probes, science research, radiation testing, R & D testing, and others.

Mr. Anderson says that Ball does not have any plan to build , deploy and operate a remote sensor satellite for commercial applications. They have done some preliminary business assessments in the remote sensing market and decided that it was not feasible for them to pursue the market.

1. What is the maturity of the commercial remote sensor market?

There is not a commercial market today. There maybe a market emerging, since companies like Worldview Imaging have announced their plan to deploy satellites and market the imagery.

2. What are the form factors of the space remote sensing payloads?

The companies Quickstar satellite is the type of satellite that they would use for the remote sensing type applications. Typical mass would be in the 300 to 400 kg range, altitude of 400 to 800 km, and inclination would be polar.

3. What infrastructure and support to the user must the launch system company provide?

No answer, since they are not pursuing commercial remote sensing business.

4. What is the end user market infrastructure?

The infrastructure that the end user sees includes a satellite builders and operators, launch system companies, and second tier (value added) type companies who enhance satellite imagery to the end users unique applications.

5. What changes or improvements are needed in the market infrastructure to reduce the costs of space produced products?

Companies such as Ball would like to know a lot more about the end users and their product needs. Ball thinks that the second tier companies that are part of the supplier infrastructure which supports the processing and enhancement of images, and distribution to end users, should be more clearly defined and expanded.

6. When will user(s) begin deploying commercial space remote sensors?

Mr. Anderson mentioned the recent Worldview Imaging announcement of deploying two satellites, beginning in 1995.

7. What are their current and near term costs associated with using space?

He does not have any data to provide.

8. How sensitive is user demand to launch system cost? How many more times will they use space if the launch costs is reduced: 35 %, 50 %, 75 %, or 90 %?

Launch System Demand Elasticity:

Launch Frequency: The prevailing price is the launch costs for a Pegasus, which is currently at $13 to $15 million per launch.

	Launches per Year		
Product	**< 5 years**	**< 10 years**	
Prevailing Price	2	4	note a
66% ($8 to $10 million)	3	6	note a
33% ($5 million)	note b	note b	
10% ($1.5 million)	note b	note b	

Note a. The increase launches per year is based upon -- the need for replenishment satellites as well as growth satellites. Typical remote sensing satellite lifetimes are in the three to five year range today. Future technologies will increase lifetimes to five to seven years.

Note b. Launch vehicle costs are no longer a driver at this price level. Other elements of the supplier infrastructure, such as the value added companies and their costs would be a larger share of investment and operating expenses.

9. What decision making business process is used to decide on the use of space?

No specific answer. Ball has done a preliminary look at the market and decided not to pursue at this time. In general, the market must generate enough revenue to afford a return on the companies investment.

Companies entering the commercial field will find considerable competition between airborne and space remote sensors. Airborne are more responsive to real time, high resolution applications where long dwell time is needed. To compete, satellite sensors must be able to provide 1 to 2 meter resolution in multi-spectral electro-optic wavebands. Then they must find niche markets, or applications and users that need that kind of imagery. An example of an application is crop investation. A multi-spectral sensor, with three colors, would be able to detect the infestation over large areas. The hypothesis is that satellites could collect the data faster and more frequently that airborne platforms, and for less cost.

10. What are titles and names of executive managers who make the business decisions to invest their resources into deploying space remote sensors?

Mr. Anderson thought Worldview is the only company pursuing the market.

D.6.2 Bechtel Corporation

Date

16 August 1993

Organization Contacted

Bechtel Corporation
50 Beale St.
P.O. Box 193965
San Francisco, CA 94119-3965

Contact

Dr. H. A. Franklin – Space Programs
Dr. Sandra Feldman – Senior Geologist
Mr. Peter Mote – Manager, Geotechnical/Hydraulic Engineering Services

By whom

Don Barker – Debra Tonnemacher – Lockheed CSTS

Summary

Bechtel, as a private company, does use imagery derived from remote sensing orbital assets owned and operated by US or foreign governments.

Maximum purchase is 30/year each in response to support a unique customer requirement. Image enhancement and interpretation is conducted in-house as a proprietary value added function.

Bechtel company policy of minimum asset ownership precludes the consideration of owning and operating a remote sensing asset. They see great potential for higher resolution imagery and currently commit resources to keep track of new sensing technology under development.

Remote sensing data must be augmented by ground truth and therefore they are dubious about the prospect of lunar exploration.

The company will not be a customer of the launch systems provider. Bechtel doubts whether commercial activities could produce the remote sensing raw data at a lesser price than that offered by government agencies.

Their use of data from a space asset depends on the requirements of their customer. Some data collection may be achieved more cost effectively from aircraft surveillance. Each of Bechtel's contract opportunities is evaluated on an individual basis with reference to the use of data from a space asset.

1. What is maturity of users' space application?
Bechtel has been purchasing selected satellite imagery derived from US or foreign government space assets for a number of years. Bechtel operates on a contract basis, i.e. will obtain and analyze imagery when funded by a specific customer. A recent example is their involvement in management support to the extinguishing of the Kuwait oil-fires following the Gulf War (Desert Storm).

They have also used satellite imagery for large area surveying purposes associated with the management and planning of urban development and large scale facilities at specific sites.

Bechtel company policy is to minimize asset ownership (even their office building in San Francisco is not a company asset) and therefore they would not consider owning an orbital asset for proprietary remote sensing purposes

Bechtel has purchased a maximum of 30 images a year from government sources but strictly only in the execution of a customer contract. Value added from the company is that of image enhancement using mainly procured computer and software facilities and also enhanced image interpretation. They consider the enhancement and interpretation as a proprietary asset.

Bechtel is also actively involved in becoming cognizant about advanced imaging and multi-spectral detection technologies and sees great potential for the application of higher resolution capabilities. They stated that they are not actively involved in space research other than independent evaluation of new technology capabilities.

Bechtel also emphasized that remote sensing data must be augmented by ground truth (i.e. actual physical samples). Whilst the latter may be difficult to obtain for earth terrestrial scenarios, the corresponding requirement for lunar surface evaluations might well be impossible or at least prohibitively expensive for potential commercial opportunities.

2. What are payload form factors?
Bechtel as a private company has zero interest in procuring an independently owned and operated remote sensing satellite. This concept would conflict with their policy of minimum asset ownership. They therefore anticipate no requirement (and therefore no form factors) for a payload to be launched on a commercial launch system.

3. What infrastructure and support to user must launch system company provide?
Bechtel has not been and will not be in the future a customer of the launch system company. This question is therefore not applicable.

4. What is end user market infrastructure?
Bechtel purchases 15-30 remote sensing images per year in performance of contract obligations to their customers. These images are purchased from government sources – subsequent value added of image enhancement and interpretation is conducted in-house. Bechtel views NASA and other government agencies as responsible for the provision of remote sensing data.

5. **What changes or improvements are needed in the market infrastructure to reduce costs of space produced products?**

Higher resolution imagery and advanced technology possibly available in the future from DoD and other unspecified government agencies may reduce the data processing and interpretation cost but Bechtel will continue to conduct this value added function in-house. They doubt whether commercial activities could produce the imagery product at less cost than offered by government agencies.

6. **If users are performing experiments now, when will they begin producing commercial products in space.**

Bechtel has no plans to produce a product in space. They are tracking advanced technology development targeted for remote sensing applications but do not fund experimental research. They are also tracking the development of smart software for data processing and interpretation.

Bechtel expressed advocacy for lunar remote sensing but only on the basis of contractual involvement in data processing and expert analytical interpretation.

7. **What are current and near term costs associated with using space?**

Bechtel's costs are image purchasing (~ $5,000/image from Landsat and Spot) and in-house processing hardware, software and labor. These costs are compensated from contracts with specific customers.

8. **How sensitive is user demand to launch system cost. How many more times will they use space if launch costs are reduced?**

Bechtel advised that even if the cost of launch for an asset were totally free they still would not plan to own a remote sensing asset which would require a launch service.

9. **What decision making process is used to decide on the use of space?**

Use of space is predicated on the requirements of any particular customer. The Kuwait oil fire management contract required remote sensing data which was an obvious candidate for satellite remote sensing. Other area scanning requirements may be achieved more cost effectively by aircraft over flight. Each contract opportunity is evaluated on an individual basis with reference to the use of data from a space asset.

10. **What are titles and names of executive managers who are making business decisions to invest their resources into producing products in space?**

Dr. Andy Franklin and Mr. Peter Mote make recommendations directly to the executive management of Bechtel with reference to the use of space assets to accommodate customer requirements.

D.6.3 BHP Minerals

Date

16 August 1993

Organization contacted

BHP (Broken Hills Proprietary) Minerals
550 California Street
San Francisco, CA 94104-1020
Dr. Cory Williams, Manager, Exploration Administrative Services
Ms. Marion Rose, Senior Geophysicist

CSTS Researchers

Don Barker – Debra Tonnemacher – Lockheed CSTS

Summary

BHP Minerals is a major bulk commodities mining company with corporate headquarters in Melbourne, Australia. They commit about $75M (15% of profit) annually to exploration and are currently evaluating about thirty areas worldwide. Discovery to mining production is about a ten year time span. They have been purchasing raw imagery derived from remote assets owned and operated by US and foreign governments for many years. They do not appear to be interested in obtaining higher resolution imagery. Data processing, analysis and interpretation of the purchased data is an in-house activity supported by about $500K of internal research funding. BHP has zero interest in owning an orbital remote sensing asset and therefore would not be a customer of the launch system provider. Main problems experienced by BHP during exploration activities are communications from remote geographic locations, inaccuracies of geological and geographical reference material, preclusion from use of precision navigation capabilities of the GPS system, inaccuracies of topographical data and ground obscuration by vegetation and clouds. Improved remote sensing technology would increase their utilization of capable space assets and probably lead to more efficient and less costly exploration programs. BHP demand for use of remote sensing space assets is not directly related to launch costs rather it is a function of technology capabilities. Lunar mining is not being considered as a viable proposition since the bulk commodities market is strongly price dependent and the cost for recovery of lunar bulk material would be prohibitively expensive. The exploration personnel interviewed by CSTS representatives report directly to the company executive management in Melbourne, Australia.

1. What is maturity of users' space application?

BHP Minerals are in the business of providing bulk commodities including copper, iron ore, gold, platinum, etc. They are currently involved in exploration in about 30 areas worldwide. They have been purchasing "raw" imagery derived from foreign and U.S. governments for many years. This imagery is processed in house. Typical geological signature of a potentially profitable mineral deposit would be about 1.5 x 5 km. They compared the task of exploration for mineral deposits as "looking for a needle in a haystack."

Main problems with exploration are communications from remote locations (Iridium will help); accuracy of existing worldwide geological datum and geographic maps; navigational accuracy commercially available (have to use GPS-Y code rather than the higher precision P code which is limited to government agencies only); inaccuracy of altimeter based topographic data and finally observation through vegetation cover (trees) and atmospheric constituents (clouds). These problems are related to technology or administrative policy. BHP spends about 15% of profit on exploration i.e. about $75M of which about $500K is spent on research involving processing technology, geological interpretation and data processing enhancements. Typical process time line from exploration to production for the bulk commodity market is about 10 years and involves sequentially exploration, discovery, confirmation, business evaluation, government negotiations, investment procurement, site development and production.

2. What are payload form factors?

BHP have zero interest in owning a remote sensing asset which would require launch therefore the question is mute.

3. What infrastructure and support to user must launch system company provide?

BHP will not be a user of the launch system company. They do <u>not</u> appear interested in higher resolution imagery – data processing and interpretation is an in-house activity.

4. What is end user market infrastructure?

BHP currently purchase raw imagery from the government agencies which own and operate the remote sensing asset. They also anticipate use of the global mobile communications systems currently being planned (Iridium, etc.) but only from the purchase of portable ground access equipment. They also need other sensing capabilities but would purchase such data, if available, from the agencies which own the asset.

5. What changes or improvements are needed in the market infrastructure to reduce costs of space produced products?

Improved technology to overcome the limitations of current technology would increase their utilization of capable space assets. They would retain current in-house activities of image enhancement and analysis. More accurate data would tend to improve the process of exploration and possibly reduce time scales with incumbent cost savings.

6. If users are performing experiments now, when will they begin producing commercial products in space.

BHP has no plans to produce a product in space. They are anticipating the availability of improved space borne sensing technology, possible relaxation of current restrictions on P-code access for GPS navigation and the orbital placement of mobile communication assets. These refinements and additions will certainly lead to their increased use of space based facilities within their normal business operations. The prospect of lunar mining is not being considered as a viable proposition since the bulk commodities market is strongly price dependent and the cost for the return of lunar bulk materials would be prohibitive.

7. What are current and near term costs associated with using space?

BHP's only cost is the purchase of raw data, implementing the data processing and interpretation function and the procurement of appropriate ground support equipment for navigation and communications. $75M is the current annual cost of exploration which represents 15% of profit from mining operations.

8. How sensitive is user demand to launch system cost. How many more times will they use space if launch costs are reduced?

BHP assumes that launch costs are amortized in some way within the price of raw data and communications access rates. Their demand for utilization is not directly related to launch costs rather it is a function of space asset capabilities.

9. What decision making process is used to decide on the use of space?

The use of space assets appears to be a routine part of mineral exploration although BHP emphasized that they need increased confidence that any apparent deposit location identified is worth developing to mining production. The decision process appears to reduce to that of confidence in the capability of the remote sensing technology.

10. What are titles and names of executive managers who are making business decisions to invest their resources into producing products in space?

Dr. Cory Williams supported by Marion Rose, the resident Senior Geophysicist report directly to the executive management of BHP in Melbourne, Australia. They intend to communicate directly to the corporate office with reference to our prepared question list and CSTS data.

D.6.4 Center for Mapping

Date

16 August 1993

Organization Contacted:

Dr. John Bossler
Center for Mapping
1216 Kinnear Road
Columbus, OH 43212

Tel: 614/292.1600
FAX: 614/292.8062

Researchers

Bill Walsh, Lockheed; and Henry Hillbrath, Boeing

Summary

The researchers met with Dr. John Bossler, director, Center For Mapping (CFM), on 8/3/93 to discuss the commercial markets for space remote sensing. Also attending the meeting were CFM associates, Michael Varner, Dr William Anderson, Dale White, and Dr Carolyn Merry. The CFM organization is affiliated with the Ohio State University and is a member of the NASA/CCDS (Commercial Centers for Development of Space). They began business operations in 1986. The two hour meeting focused on applications for space remote sensing.

The CFM provides research and demonstration projects for commercial users in the area of land, water and farm management, in energy and power production, digital mapping, information systems and disaster management. Their research efforts have ranged from forecasting storm surge levels to analyzing the impact of drought conditions in the Midwest, from anticipating satellite orbits to monitoring gas leaks, and from predicting the effects of erosion to tracking ocean currents.

The CFM's mission includes advancing the conceptualization, design, testing, and evaluation of a commercially relevant total mapping system. Their primary areas of expertise are in: digital image mapping, GPS real time mapping, image processing and image enhancement. They provide expertise to industrial affiliates in the extraction of scene features from imagery, interpreting raster-scanned map data, and extracting three dimensional information from aerial imagery. The CFM takes a direct interest in promoting the development space remote sensors for commercial markets. However, they do work with other CCDSs, such as the ITD/SRSC at Stennis, which has a charter for space remote sensing commercialization.

1. What is the maturity of the commercial remote sensor market?

The "private satellite" commercial remote sensing system market is in the business development stage. Several entrepreneurial type companies are assessing the market for deploying relatively small satellites in sun synchronous orbits, which could produce imagery from low cost electro-optic sensors.

There is a trend in the remote sensing market that indicates only a small number of satellites will be put in LEO annually by companies that are set up to build, deploy, and operate the satellites; and to either -- 1) sell the raw images to commercial end users or Value Added (VA) companies (i.e., companies who process and enhance raw imagery); or sell enhanced images to the end users.

The need for small launch vehicles to deploy the satellites should require only a few flights per year. Follow-on launches for replacement purposes should be on intervals of between three to five years for today's remote sensing satellites. However, in the future, a broad range of new technologies will incorporated in satellite design to improve resolution, data latency, improved reliability, which will extend on-orbit operational lifetimes to five to seven years.

The reason for only a few commercial launches per year is because the government will continue to provide a broad range of satellite imagery from existing and new remote sensor satellites for the foreseeable future. Government remote sensors, such as the DoD/NASA's Landsat 6 & 7, and for the future, the NASA's EOS satellites, will provide a broad range of electro-optic and radar earth sensing and earth limb data from space to most government users. Additionally, recent legislation, i.e., Landsat Act of 1992, directed that commercial end users and third party VAs will be able to purchase the imagery at the government's marginal cost. A typical Landsat Thematic Mapper full scene image costs approximately $4400.00. The CFM respondents believe that the Landsat act of 1992 requires these prices to be substantially reduced. A ball park estimate of $800 per image was mentioned. There is also a two-tiered pricing structure, where government researchers receive a lower price, while others pay a higher price.

Commercial end users with an in-house processing capability will purchase the imagery directly from the government. Other users without an in-house image processing capability will purchase processed imagery from VAs for their unique applications. The VAs will acquire Landsat and EOS images directly from the Earth Observation Satellite (EOSAT) company.

Another trend is the availability of COTS (Commercial Off The Shelf) imaging software that will operate on high end PC and MAC based personal computers (workstations). Dr Carolyn Merry said that such software is commercially available now and that it will become more plentiful in the future. This trend has already migrated into the end users and VAs areas. They can buy government images and COTS software to produce their own enhanced images.

Writers Comment: the overriding trend in the remote sensing market indicates that commercial end users will be able to purchase adequate satellite imagery from government sources and COTS software to process remote images themselves at relatively low costs. This will attenuate the demand to purchase processed imagery from entrepreneurial companies who plan to fill the growing demand for remote earth imagery produced by their own private satellites and in-house image enhancement equipment. However, there should continue to be demand for custom image products in niche markets. Some other possible remote sensing applications include:

a. commodity assessments
b. environmental dumping and monitoring
c. news and public relations oriented images or pictures
d. emergency management, e.g., fires, hurricanes, earthquakes, and other disasters

Competing technologies and systems that can be viewed as alternates to space remote sensing approaches are -- high altitude drones that orbit for up to 72 hours in a circular pattern. Aurora Flight Sciences, Manassas, VA has an operational vehicle, named Perseus, which operates at an altitude of 40,000 ft and produces a 15 km scan. Contact is John Langford, president. Tel 703/369.3633.

2. What are the form factors of the space remote sensing payloads?

Mission Data:	Sun Synchronous orbit, 400 to 1,000 km altitude.
Weight:	125 kgs to 250 kgs
Environmental:	7 Gs from launch to orbit

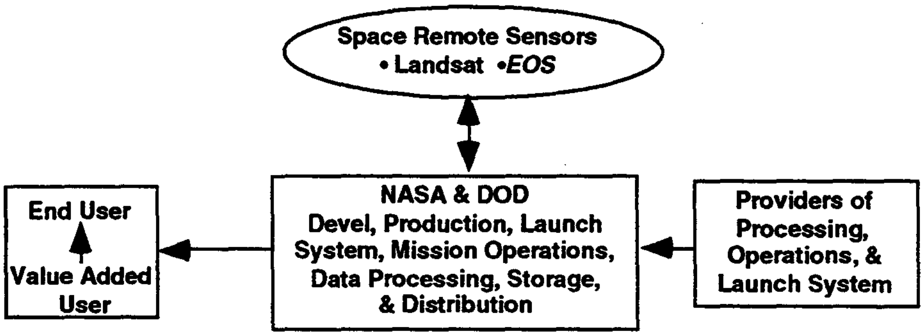
3. What infrastructure and support to the user must the launch system company provide?

The launch system provider must include payload accommodations to the user during the phases leading up to launch, and provide launch integration and testing.

4. What is the end user market infrastructure?

In the figure below, the U. S. government provides the raw images to the value added companies and to end users. The value added companies have developed a substantial market with the end users by providing comprehensive enhancement of the government provided images, and in turn selling the processed images to the end users. Additionally, because there is many software type companies selling image enhancement data directly to the end users, the latter are developing an in-house capability to enhance government provided images.

Space Remote Sensing Organizational Infrastructure



111264-240

The end user consumes the images provided by the space remote sensor. This market is potentially very large, perhaps $2 to $4 billion annually.

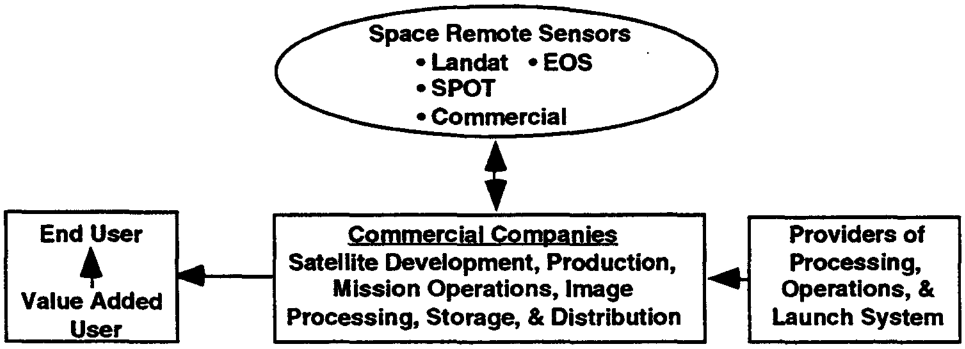
The market for imagery data provided by space remote sensors, such as Landsat and SPOT, was worth about $63 million in CY1992. SPOT Image sales were $43 million in 1992 ($33 M for satellite images and 10 M for ground stations). EOSAT sales for satellite images were $30 million.

There are several new entries into the space remote sensing market that are planning to deploy sensor satellites and sell the image data to the value added companies and to the end users. These new entries will face a lot of competition from the government supplied data. They must be able to provide raw images for comparable prices, or provide enhanced imaging data that are not provided by government, i.e., niche markets.

5. What changes or improvements are needed in the market infrastructure to reduce the costs of space produced products?

For an idealized commercial competitive market for remote sensing to emerge, the government must de-emphasize supplying data to commercial users. The government should also become a user of the commercial satellite operators. A new organizational infrastructure, see below, that should evolve and become operational in the future was defined and discussed. This type of commercial infrastructure is illustrated below:

Idealized Organizational Infrastructure For the Space Remote Sensing Market



The conclusion reached during the meeting was that if government continues to provide imagery data from Landsat, EOS, and other space remote sensors on a long term basis, the market for commercial space remote sensors will be small. Commercial companies will orient their space products towards niche markets that the government supplied imaging data cannot support.

6. When will user(s) begin deploying commercial space remote sensors?

A few start up companies are attempting to build space remote sensing satellites. Dr Bossler mentioned Worldview Imaging, Livermore, California; Utah State University with their Globesat; and Ball Aerospace, Boulder, Colorado, which has filed for a license to deploy a satellite, were mentioned as examples. Another company is the ITD/SRSC, Stennis, Mississippi, who is actively looking for investors for a three satellite constellation of space remote sensors. These organizations are in the planning and development stages. Their purpose would be to deploy and operate the satellites, and sell remote sensing imagery to commercial and possibly government users.

7. What are their current and near term costs associated with using space?

Commercial companies who evaluate the business potential for selling remote, space based images have to provide imagery at a price that is competitive with what the government is selling Landsat images to the same users, i.e., $4400.00 per image. Also, there will be substantial reductions in the image prices in the late 1990s, as prescribed by the Landsat act of 1992. The commercial companies will focus their product offerings in selective areas, including:

a. niche markets where Landsat images are not adequate or available, , including better resolution
b. provide real-time images, or with less data latency than provided by government sources, and
c. provide significant image enhancement capabilities.

8. How sensitive is user demand to launch system cost? How many more times will they use space if the launch costs is reduced: 35 %, 50 %, 75 %, or 90 %?

Launch System Demand Elasticity: Sensitivity to launch costs is low. The major users of launch systems will be the government, with only a few entrepreneurial companies attempting to exploit the growing demand for satellite produced imagery.

Launch Frequency: The major customers for launch services will be the U. S. Government, with a small group of additional launches consumed by commercial companies. The launch frequency of satellites is summarized below:

					Launches per Year							
Product	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**
Landsat 7				1								
EOS Satellites					1		3		2	1		2
ITD/CCDS			1	2				1	2			
Worldview Imaging		1	1				1	1				
Ball Aerospace		unknown										

Note: Landsat 6 will be launched in Sep. 1993.
CFM also thought the Globesat remote sensing satellite was a commercial program. Follow up on the project with EER Systems, Vienna, VA indicates that the company decided to suspend further work on building and deploying the Globesat.

9. What decision making business process is used to decide on the use of space?

Commercial companies who are considering their own remote sensing satellites will want a return on investment in the 20 to 50 % range. If the government is an anchor tenant for the commercial satellite data, investors will perceive less risk and may be willing to accept an ROI at the lower end of this range. Additionally, their perception on returns will be based on the share of the market for unprocessed imagery (to clients who provide their image enhancements), and to other groups of customers who want enhanced images for their specific needs or applications.

Investments will vary depending on the size of the constellation of satellites deployed and their on-orbit lifetime. Typically small business, who are relying on outside investors for capital will want to show a return to their investors within three years.

10. What are titles and names of executive managers who make the business decisions to invest their resources into deploying space remote sensors?

Commercial Space Transport Study Final Report

Bud Evans, CSAT, Washington, DC; telephone: 202/
Presidents of ITEK Optical Systems and Ball Aerospace
Dave Thompson, Orbital Sciences Corp., Reston, VA

Review and Revision status

8/18/93 Submitted research report to Center for Mapping for review, comments and concurrence with data.

8/25/93 Mr. Varney replied replied that review is not complete, but comments and concurrence will be submitted soon.

9/28/93 Research report revised and closed out.

D.6.5 CTA Incorporated

Date
16 August 1993

Organization Contacted
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FAX: 301/816.1443

Researchers
Bill Walsh, Lockheed; and Henry Hillbrath, Boeing

Summary

The researchers met with Mr. Martin Titland, president and Dr. Robert Pelzmann, vice president-systems development, at CTA, Rockville, MD on 8/4/93 to discuss the commercial markets for space, including remote sensing, space manufacturing, and communications.

1. What is the maturity of the users' space applications?

The drug companies are performing experiments in LEO to grow large, more uniform protein crystals than can be grown on earth. They are flying the experiments on the shuttle. These space grown crystals are examined on earth to determine their molecular structure and then reproduced on earth. The companies have found they can produce products on the earth more cost effectively than in space.

There is also the COMET Program, a joint NASA-Industry initiative to develop a low cost commercial free flyer facility with a reentry vehicle capability for returning space-produced products to earth. NASA and the industrial partners thought several types of space products could be produced, including protein crystals, materials processing, thin film coatings, etc. The program is in the process of being redefined by NASA, CCDS, and the contractors.

Another example is a McDonnell Douglas program which demonstrated the electrophoresis process in space. There has been no follow-on initiative to commercialize the space-based approach to the process. For drug companies to use space to produce products, they must perceive at least $100 million in sales of the space produced product. Otherwise the return on investment will not make good business sense.

In general, for commercial products to be produced or manufactured in space, they must have high value for a given weight. An example could be mining of He3 on the moon. This material is an extremely valuable source of save, clean reliable fusion fuel, that has a high value/unit of weight.

2. What are the payload form factors?

The physical configurations of payloads vary by specific mission. There are a wide range of missions. Consequently, there are a wide range of payload form factors.

In communications, there is a trend to use high density microcircuits in satellites, which reduce mass, volume, and manufacturing costs of the satellites. They are also more reliable and can potentially last longer, requiring longer intervals between replacement. There are several new commercial initiatives to develop low earth orbit comsats for emerging commercial markets. Examples include: Motorola's Iridium, TRW's Odyssey, Loral's Globalstar, and Constellation Communications Corp., which are large constellations for global cellular telephony, paging, position location, and navigation services; and smaller constellations such as the Orbcom are being proposed by Orbital Sciences to provide two way communications services.

Commercial communications markets will be limited in their growth, however, because the government regulates the RF spectrum. Additionally, the number of providers of satellite communications will be limited by the number of licenses issued by the government.

Remote sensing from LEO satellites is another growth commercial market. But the number of launches of satellites will be limited. Several companies are looking at the business economics, i.e. user demand, size of the market, ROI and other factors, to determine if it makes business sense. The major competitor for such a business venture is the existing remote sensing capability that the government is already providing through Landsat and other remote sensing satellites. Also, new Landsat satellites and the EOSAT program will expand the government imaging capability that will be coming on-line in the latter part of this decade. It will be difficult to compete with government provided images, which will be sold at marginal costs. A typical Landsat image costs about $4400. On the other hand, specialty companies with expertise in enhancing satellite images will find a growing commercial market for their products.

There will be niche markets for remote images taken from commercial satellites. These markets will require 3-meter data, and shorter data latency than can be provided by the government's remote sensing capabilities.

3. What infrastructure and support to the user must the launch system company provide?

The launch system provider must include payload accommodations to the user during the phases leading up to launch, and provide launch integration and testing.

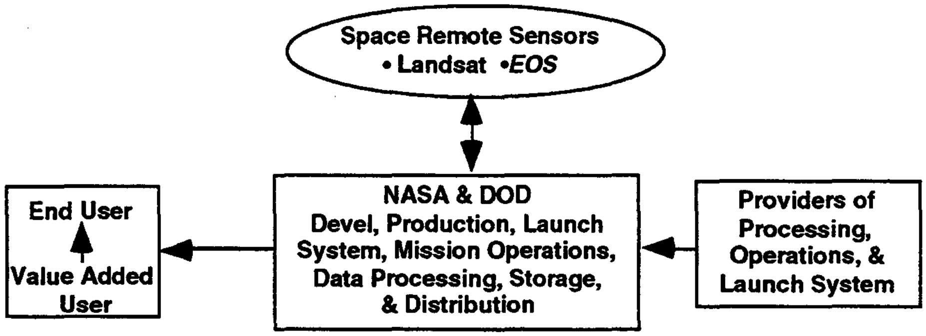
4. What is the end user market infrastructure?

The end user is the client who consumes the images provided by the remote sensor. This market is potentially very large, perhaps $2 to $4 billion annually, depending upon which market survey data you believe. However, the market for imagery data provided by space remote sensors, that are provided by Landsat and SPOT, was worth about $63 million in CY1992.

In the figure below, the U. S. government provides the raw images to the value added companies and to end users. The value added companies have developed a substantial market with the end users by providing comprehensive enhancement of the government provided images, and in turn selling the processed images to the end users.

Additionally, because there is many software type companies selling image enhancement data directly to the end users, the latter are developing an in-house capability to enhance government provided images.

Space Remote Sensing Organizational Infrastructure



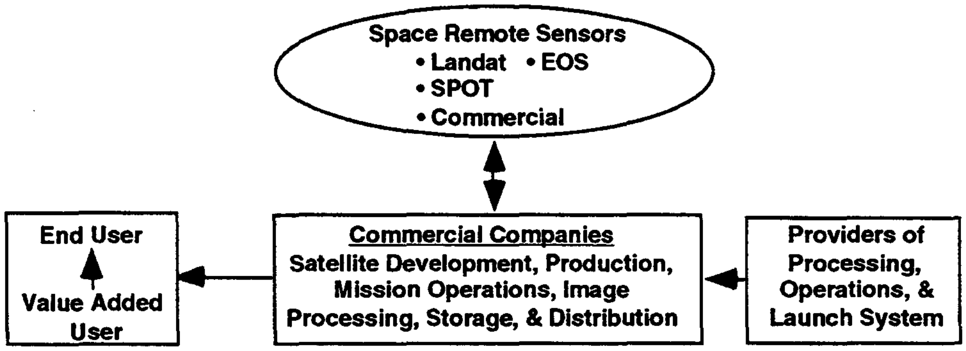
111264-242

There are several new entries into the space remote sensing market that are planning to deploy sensor satellites and sell the imaging data to the value added companies and to the end users. These new entries will face a lot of competition from the government supplied data. They must be able to provide raw images for comparable prices, or provide enhanced imaging data that are not provided by government, i.e., niche markets.

5. What changes or improvements are needed in the market infrastructure to reduce the costs of space produced products?

For an idealized commercial competitive market for remote sensing to emerge, the government must withdraw from supplying data to commercial users. A new organizational infrastructure, see below, that should evolve and become operational in the future was defined and discussed. This type of commercial infrastructure is illustrated below:

Idealized Organizational Infrastructure For the Space Remote Sensing Market



111264-243

6. If the users are performing experiments now, when will they begin producing commercial products in space?

7. What are the current and near term costs associated with using space?

8. How sensitive is user demand to launch system cost? How many more times will they use space if the launch costs is reduced?

Assume that the customer of launch services is planning to deploy a remote sensing satellite, which weighs about 500 lbs to a 400 nmi altitude.

	Launches per Year	
Launch Price	**Today**	**<5 Years**
Prevailing (a)	1 to 3	1 to 3
75%	1 to 3	1 to 3
50%	2 to 5	2 to 5
25%	4 to 8	4 to 8
10%	????	????

a. Prevailing cost is $14 million for launch of a single satellite.

9. What decision making business process is used to decide on the use of space?

For a commercial company to invest in one or more remote sensing satellites, the firm must recoup its investment in three years. This assumes the life of the space product, which generates the revenue, has a five year life.

10. What are titles and names of executive managers who are making the business decisions to invest their resources into producing products in space?

Review and Revision status

8/18/93 Submitted research report to CTA for review, comments and concurrence with data.

8/24/93 Asked Dr. Pelzmann for comments and concurrence. Promised reply by 8/30.

8/25/93 Mr. Titland provided few comments and corrections. Dr. Pelzmann is to provide additional review, comments and concurrence.

11/1/93 Dr Pelzmann comments not received. Closed out report.

D.6.6 Lockheed Missiles & Space Company

Date

18 June 1993

Mission Area

Remote Sensing

Attendees

Don Barker/Bill Walsh, LMSC

Fred Henderson , President, Geosat Committee Inc.

P.O. Box 1762, Norman, OK 73070. Tele. 405 - 799 - 1515

Location

BHP Inc. 550 California St., San Francisco (temporary visit location)

Summary

Fred Henderson's non-profit organization was created in 1976 and is dedicated to promoting use of civilian satellite remote sensing technology for geological applications. GCI has about 40 major US and international satellite remote sensing, oil and mineral companies as associate members. Focus has expanded to include marine offshore oil/gas and environmental applications.

The CSTS mission was briefly explained to Fred with emphasis on the long term objective of stimulating market demand for remote sensing services by reductions in launch costs.

Fred discussed difficulties associated with remotely sensed data derived from Landsat. Since the Landsat Act of 1992 this data is made available as tapes in unprocessed form but at a relatively high cost. However, the process of extracting useful information from this data is itself very expensive.

We asked the question " what is the total cost of information to the user " but did not get a definitive answer.

Geosat Comm. Inc. works with users to provide data relative to vegetation (crop growth) and geology (mineral surveys)

The proprietary control of data is a problem. Resource industries, in the past, have considered cost sharing of certain satellite remote sensing capability but pulled out of the deal when told by the government (NASA/DoC/FCC) that data derived from such an asset must be public domain information (i.e. made available equally to non-contributing agencies).

Fred strongly suggested that from an environmental viewpoint/corporate responsibility there is a need for on-demand rapid response capability to remotely monitor oil spills. The value of this capability derived from a satellite needs to be compared with the alternate technique i.e. fleet of 20 aircraft operating continuously with airborne remote sensors.

Fred expressed interest in the McMahon (LMSC) recent congressional testimony on high resolution satellite remote sensing capability (Action : provide a copy of testimony).

Fred suggested that the value of reduced launch cost was most critical to the " agency who puts together the asset which collects the data ".

Fred noted that the " open house " on remote satellite sensing as dictated by the government was a negative stimulus to commercial use of company funded platforms (and therefore the launch market).

Many oil companies have eliminated remote sensing research groups in-house and are concentrating on operational groups. Another problem is that satellite remote sensing of natural oil resources has not been proven to work. Exploration investment is giving away to investment in currently operational foreign oil fields currently strapped for capital (e.g. Russia).

Fred stated that environmental sensing is currently an embryonic field being led by the government.

Fred recommended a few further contacts :

a. Pete Mote - Bechtel - San Francisco - Remote sensing technical services for environmental applications. Telephone 415 - 768 - 6331

b. Chuck Giamonna - Marine Spills Response Corp. 1350 I St., NW, Washington DC, 20005 Telephone 202-408 - 5734

D.6.7 Intergraph Corporation

Date

4 October 1993

Organization Contacted

Intergraph Corp.
Huntsville, AL 35894-0001
Attn: Larry Ayers, vice president Mapping Science.
Tel No: 205/730.7888 FAX No: 205/730.6750

Researcher

Bill Walsh, Lockheed

Summary

The researcher had a telephone conference with Larry Ayers to discuss the key technical issues and concerns associated with the emerging commercial satellite remote sensing market.

1. What is the maturity of the commercial remote sensing market?

The market appears to be about $2 billion in 1992, and has substantial growth. The largest share is for aerial imagery. The Mapsat Market Study of 1991 appears to reflect the appropriate size of the satellite remote sensing market, which includes satellite data, image enhancements, and ground stations.

The three major forms of imagery include: Panchromatic, multispectral in electro-optice wavelengths, and microwave radar.

2. What are the key trends in the remote sensing market?

There is a trend with aerial platforms towarddigital orthographic photography. The typical resolution is 1/2 to 1-meter, which is required for example for city planning.

For large area imagery, greater than city planning, 3 to 5-meter resolution seems to be adequate. The large area sensing is where satellite imagery will be able to compete against aerial platforms.

The imaging format of the derived products is being standardized. Therefore, no matter which type of raw imagery is provided, the format that will be used by the end users will conform to a single format. This will take several years and major government funding to accomplish. The USGS has a six year, $400 to 500 million program to come up with derived products that have a unifrom Digital Ortho picture format. This approach is similar to the NATO standards, which have been adopted by European countries.

Another near term initiative is the National Spatial Data Infrastructure.

Aerial platforms are beginning to use digital cameras.

There is a trend to develop large image storage data bases, where original ximages can be stored and updates

3. What is the infrastructure of the remote sensing market?
For government satellite data, a service bureau type arrangement is part of the infrastructure. Typical providers are the NOAA and the DMS government organizations.

New imaging standards are being promoted in an attempt to unify the transfer of imagery in standardized formats. The approach is the SDTS, which means Space Data Transfer Standard.

Some types of applications for space remote sensing include:

- Traffic Flow
- Hydrography
- Crop Assessments
- Reforestation
- Urban Planning
- Biological

The following are becomng event driven:

- Oil Spills
- Floods
- Hazardous waste spills
- Crop Infestation
- Forest Fires

4. What is the end user market infrastructure?

5. What changes or improvements are needed in the market infrastructure to reduce the costs of space produced products?
Changes must be measured by the cost of the imagery per square mile.

6. When will user(s) begin deploying commercial space remote sensors?

7. What are the costs associated with space remote sensing?

8. What decision making business process is used to decide on the use of space?

9. What are titles and names of executive managers who make the business decisions to invest their resources into deploying space remote sensors?
General Dynamics - E, San Diego, CA. Contact Terry Strater to discuss their involvement in the remote sensing surveillence, intelligence community. They are familiar with the digital photogrammetery applications.

D.6.8 Mr. Jeff Manber

DATE

6 July 1993

Mission Area

Space Remote Sensing

Contact

Mr. Jeff Manber, Consultant
Washington DC area
Tel# 202/347.2414
FAX # 703/478.7281

Contacted by

Bill Walsh, Lockheed, 408/742.4781

Summary

Mr. Jeff Manber is a member of the Space Studies Institute and has a consulting business, providing business planning to companies. Manber recommends we talk to David Brannon, NASA/Stennis Code C, tel # 602/688.2042 for detailed information on the remote sensing markets. He is familiar with applications in the utilities industry. Brannon was involved in the creation of EOCAT (?).

Issues With the Remote Sensing Field

three major factors involved --

a. the cost of transportation, i.e., launch costs
b. government regulations
c. approvals to release high resolution images, i.e., <10-meter resolution.

Trends in the market: the growing miniaturization of electronics, availability of high resolution sensors, and low cost satellites (e.g., bus and related subsystems; in the range of $3 to 5M) will open up the remote sensing market to commercial use.

For the commercial market to expand, space remote sensing systems must be in the range of $9M plus transportation costs.

Other suggested commercial contacts in remote sensing include:

a. CTA, Martin Titland, 301/816.1200
b. Aero Astro Space, Rick Fleeter, tel # 703/709.2240, Herndon, VA
c. Ball Aerospace,
d. Defense Systems Inc.,, Jason O'Neil, tel # 703/883.1000, McLean, VA

Another source for referrals is Jill Stearn, 202/663.8380. She operates the ISSO (International Small Satellite Organization) which holds an annual symposia in March of each year.

D.6.9 OSC - Keith Lyons

Date

3 December 1993

From

Keith Lyons, program manager, OSC, 703/406.5422.

With

Bill Walsh, Lockheed, Sunnyvale

Subject

Comments on draft of Remote Sensing Market Study

Summary

Keith Lyons reviewed the draft of the Remote Sensing final report and had a few comments:

a. Correct the table for OSC programs. (Comments noted on master for change)

b. In five years, the mass to orbit (included in the report) will increase to about 600 to 700 kgs. This will be due to the 1-meter resolution requiring larger optics, structure, mass, etc.

c. Regarding the commercial market growth, there is a time delay between system availability and the users buying the products. Remote sensor suppliers to the final users will experience a delay between the time their system and image products are available and the time that the users will buy the products.

D.6.10 OSC - Gilbert Rye

Date

21 December 1993

From

Gilbert D. Rye, V.P.- business development, OSC, &03/406.5516

With

Bill Walsh

Subject

Comments of Eyeglass (Remote Sensing) Imaging System

Summary

a. One satellite planned for an ILC of 1996; other satellites planned for later.
b. Altitude/Mass: 500 nm, polar orbit, wouldn't disclose mass, assume 550 lbs.
c. Will be launched on a Taurus launch vehicle.
d. Sensor suite will not be multispectral.

D.6.11 Space Remote Sensint Center Institute for Technology Development (ITD)

Mission Area Revised: 24 August 1993

Space Remote Sensing Revised: 29 August 1993

Organization Contacted Date: 29 July 1993

Revised: 23 December 1993

ITD Space Remote Sensing Center (SRSC)
Institute for Technology Development
Building 1103, Suite 118
Stennis Space Center, MS 39529

Tel: 601/688.2509; FAX: 601/688.2861

Researchers

Bill Walsh, Lockheed and Robert Cleave, Rockwell

Summary

The researchers met with the Institute for Technology Development (ITD) Space Remote Sensing Center (SRSC), Stennis Space Center, MS on 7/28/93 to perform CSTS research on the Space Remote Sensing market. The SRSC is a research center for the NASA Commercial Center for Development of Space (CCDS). Dr. George May, the director of the ITD and the CCDS/SRSC appointed Keith J. Draper, ITD Senior Engineer, to meet with the researchers.

The two hour meeting focused on the SRSC's plan to produce a constellation of remote sensors for commercial space markets. The SRSC has conceptualized a constellation of three low cost, space remote sensing satellites that can provide 30-meter resolution imaging data for domestic agricultural, forestry, and environmental applications. Through the ITD, a non-profit company, they have prepared a business plan for development, production, deployment and operation of the satellite constellation. ITD also has another subsidiary company which processes satellite imagery, and markets the data to agricultural users, primarily major growers, in Wisconsin, California, and the state of Washington. The business plan is used to meet with investors to get the required funding, of approximately $135 million, to begin the program . The satellites are planned for deployment in 1996 and 1997.

1. What is the maturity of the commercial space remote sensing market?

The commercial market for remote sensing data exists today. What is new is that companies are beginning to develop and deploy their own remote sensing satellites. The companies believe that they can compete with government-provided space remote images, such as provided by EOSAT; and other value added companies which process and enhance government-provided satellite images.

ITD plans to deploy a constellation of three remote sensor satellites in the 1996 and 1997 time frame. ITD targeted the agricultural industry to sell their satellite imaging data. Their services would include remote sensing, interpretation, and dissemination of data for crop management, vegetation, catastrophic event monitoring, and change detection analysis. Their approach is to provide 30-meter images in 60 km swaths of the Earth. The multispectral sensor bands include green, red, near IR, and mid IR wavebands. No blue wavebands are included. ITD's image processing subsidiary would interpret and analyze the data. Agricultural users would be provided with personal computers in their office or home to access the data.

ITD is also involved in a remote sensing program which markets geographic data to the agriculture industry. Remote data is collected using three airplanes. Getting the industry to use the data is a key issue and major thrust of their marketing efforts. Another high potential user area is the forestry industry. At this phase in the agriculture, forestry and other remote sensing markets, gaining user acceptance is critical to stimulating demand for the data.

Mr. Draper compared the space sensor data with that which can be provided by airborne sensors. He believes that crop monitoring can be acquired substantially faster and cheaper by satellite than similar data collected by airborne sensors.

2. What are the form factors of the satellites to be put into space?

ITD has a development program to produce three satellites, with one spare, for deployment starting in the 1996 time frame. The sensor suite was designed using low cost off-the-shelf technology to reduce the sensor/satellite costs. The multispectral sensor bands include green, red, near IR, and mid IR wavebands. No blue wavebands are included, so that imagery of water cannot be provided from the sensor suite.

Mission requirements include a payload weight of 375 lbs, 720 km orbit at 98 degrees, and a 12:00 noon nodal crossing.

Satellite lifetime is seven to eight years.

The satellites will orbit the globe and observe specific points on the Earth every two days.

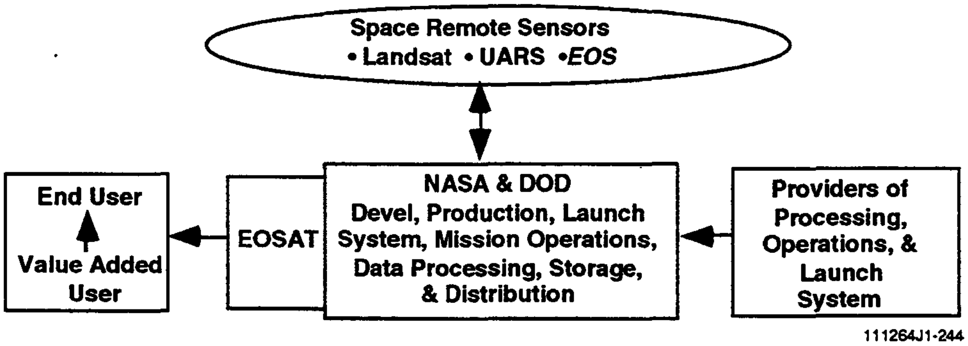
3. What infrastructure and support to the user must the launch system company provide?

The launch system provider must provide payload to launch vehicle interface coordination and installation; mission planning to orbital insertion; preflight systems check out; documentation; air traffic authorization; and all necessary launch operations.

4. What is the market infrastructure between the end user who produces the space product or service?

The government has a substantial position in the commercial infrastructure for producing remote sensing images and providing the data to value added companies and end users. The infrastructure can be described as follows:

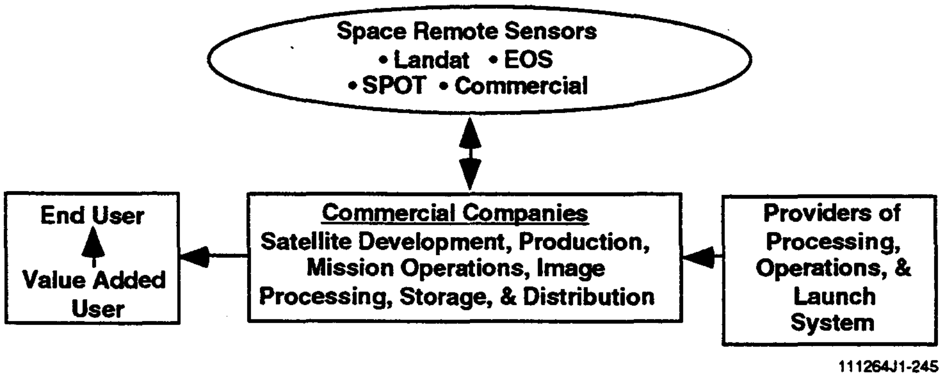
Infrastructure for Remote Sensing Market



5. What changes or improvements are needed in the market infrastructure to reduce the costs of space produced products?

For commercialization of the remote sensing field to evolve. there has to be less government involvement in producing the remote sensing images. A vision of how the infrastructure should look to accommodate competition and growth in the market is illustrated below:

Infrastructure for Commercial Remote Sensing Market



6. When will users begin deploying their commercial space remote sensors? How frequently will they deploy their satellites?

ITD plans to deploy a constellation of three satellites in the 1996-7 time frame.

Three satellites will be launched during 1996 and 1997. The satellites lifetime is estimated at seven years. A spare satellite is being built for contingencies, e.g., failure of a satellite. If a satellite failed, they would want immediate replacement if it occurred during the growing season, otherwise replacement would be on a less urgent basis, and dependent upon their customer demand for data.

ITD has no plans to build additional satellites beyond the initial constellation. However, assuming they continue to sell imagery to agriculture users, they will replace their satellite constellation at the end of their life. Therefore, a second generation of replacement satellites and related launches would be required approximately every seven years, e.g., the lifetime of the satellite.

Launch Frequency: End Users:

Product	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**
Agricultural	1	2						1	2			
Forestry, note a												
Environmental, note a												

Note a. Mr. Draper mentioned other applications where ITD's remote sensor constellation could be used are forestry and environmental monitoring and assessments. No data was provided on the whether additional satellites would be required for these applications.

7. What are their current and near term costs associated with using space?

ITD estimates launch costs at $15 million per satellite. Overall costs for the first launch is estimated at $50 million; and includes development costs, launch, and ground station. The deployment of the two remaining satellites is $85 million, which includes $30 million for launch costs.

8. How sensitive is user demand to launch system cost?

The sensitivity to launch costs is very low. Mr. Draper does not think that lowering launch costs, by as much as 90 percent would increase the number of launches. Launch is a required need. Cost is of secondary importance. However, lowering the costs is acceptable.

Launches per Year

Launch Price	**Today**	**<5 Years**	**< 10 Years**
Prevailing (a)	2		2
75%	2		
50%	2		
25%	2		
10%	2		

a. Prevailing cost is $15 million for launch of a single remote sensor satellite.

8/27/93 comments by Mr. Draper: Reducing launch costs would impact the business plan in a significant manner, and in that regard would be desireable. However, as discussed previously in our meeting, we have a schedule to launch three satellites and a cost based upon today's reality rather than tommorrow's vague expectations.

9. What decision making business process is used to decide on the use of space?

The image data is sold to large agricultural growers, usually major companies that have large land holdings. ITD believes they can provide comparable imaging data from their proposed sensor constellation that cost approximately the same; and provides the data on two-day intervals rather than 6-day intervals as currently available from Land sat.

ITD estimates their annual sales at $400 million for satellite images. They would be able to recover the $135 million (for deployment of the three satellite constellation and one ground station for constellation control and down linking of data) at $27 million per year over 5-years.

10. What are titles and names of executive managers who are making the business decisions to invest resources into space remote sensing?

Other companies involved with commercial remote sensing satelliets include:

Ball Space Systems Division, Boulder, Colorado
Contact: David L. Frostman, director, program development.

Worldview Imaging Corp., Livermore, California
Douglas B. Gerull. Tel: 510/373.8349. FAX: 510/373.8359.

Review and Revision status

8/25/93 Submitted research report to SRSC for review, comments and concurrence with data.

8/27/93 Mr. Draper replied with comments and concurrence. Research report revised and closed out.

D.6.12 ITD/SRSC

Date
23 December 1993

Telecon Report From
Keith Draper, system engineer, ITD/SRSC, 601/6882509.

With
Bill Walsh, Lockheed, Sunnyvale

Subject
Comments on draft of Remote Sensing Market Study

Keith Draper reviewed the draft of the Remote Sensing final report and provided the following comments:

ITD/SRSC has completed their business plan and are currently seeking investors. Their remote sensing program has changed significantly from the data collected in the 29 July 1993 field research interview.

a. Correct the table for ITD/SRSC program. Will deploy seven satellites beginning in 1997. Deploy two satellites per launch on 4/97, 6/97, 8/97, and one satellite on 10/97. Note; for purposes of the CSTS study, assume two sets of satellites deployed in 1997 (6/97 and 10/97) and two plus one deployed in 1998 (two on 2/98 and one on 4/98)

b. Launch characteristics include: 450 lbs (205 kg) per satellite to 760 km at 98 degrees inclination. This provides a three day revisit cycle.

c. Operational life is eight years. Draper says that they have sized their satellites to accommodate an orbital adjustment on a three month basis. Operationally, they have including a solid state memory to store imaging data, when they are not over a down link station. The sensor operates in the 0.8 micron range (includes one wavelength in the near-R range) and does not need cooling.

d. Resolution of the sensor is 15-meter, with a Swath of 75-mile (statute miles), or approximately 120 km.

e. Program cost: $196 million, which includes 7 satellites (at $14 million each) and two ground stations. One ground spare satellite is also included.

D.6.13 World View Imaging

Contact Report
23 November 1993

Organization Contacted
Walter Scott

World View Imaging
2111 Research Drive, Suite 3
Livermore, CA 94550
TEL: 510/339.9691
FAX: 510/339.9693

Subject
Follow Up Telecon Regardin gDraft Remote Sensing Final Report

Telecon with Walter Scott, President, Worldview Imaging.

Summary

He agrees with the data in the report on his companies activities.

He initially thought the remote space sensing market size may be understated. However, after I mentioned that the government missions market includes military remote sensing satellites, such as DSP, DMSP, etc, he agreed that the market for "space remote sensing" was about right for the near-term, i.e., five years. He said it was difficult to predict the market growth for the longer term.

Mr. Scott confirmed the recent public anouncements that Worldview would be building a third and fourth satellite later on, after they get the initial phase of the program under control, (management, finanically).

The data on the Worldview satellites in the final report data base, Appendix A.1 is very close. He thought the satellite and bus weight would be 330 kgs combined. He mentioned that the weight is at the upper end of the Pegasus XL capability and the lower end of the Taurus launch vehicle capability.

Scott said that the number three satellite will be launched 18-months after number two. Number four satellite will be launched 12-months after number three.

Satellite lifetimes of five years should be assumed.

D.6.14 U.S. Geological Service

Date

September 28, 1993

Organization Contacted

Dr. Bill Drager, Chief Data Products
U. S. Geological Service
Sioux Falls, SD
Telephone: 605/594.6141 FAX:

Researcher

Bill Walsh, Lockheed

Summary

The researcher called Dr Drager to discuss the Landsat satellites, cost of a Landsat image, and which organization will be responsible for selling government remote sensing data to non-government users.

Who is authorized by government to sell/distribute government remote satellite images?

Dr Drager said that Landsat 5 and 6 images will be sold to government and non-government users through the EOSAT Company, Landham, MD.

Landsat 7, however, is a joint NASA - DoD program and the images will not be sold to non-government users through EOSAT. Dr Drager was unsure which government agency would have responsibility for selling and marketing Landsat 7 imagery, however, he hinted that his organization EROS Data Center in Sioux Falls would be the responsible organization.

Drager said that a minimum of processing of Landsat images would be performed before the imagery was available to users.

What is cost of a Landsat image?

Note: current price list from EOSAT quotes a $4400 price for a thematic mapper full scene image from Landsat 5. Dr. Bill Anderson of the Ohio State Univ., Center For Mapping indicates that the price will go down to $800 per image as a result of the 1992 Landsat act.

Dr Drager thought the price was coming down, but could not confirm Dr Anderson's belief of $800. Drager did specify the price reduction would be the result of the 1992 Landsat act. He thinks that non-profit and university type organizations will get the reduced prices.

Drager requested that I contact Jim Love at EOSAT to discuss what the EOSAT pricing changes would be. Telephone 800/344.9933; 301/552.0537.

J. R. Thompson, at USGS, 605/594.6161 can provide a recent briefing on the Landsat 7 program. Thompson's secretary, Janet, will send the data package to my attention on 9/29.

The Landsat program manager at NASA is Stan Schneider, 202/358.0256

Appendix E—
Transportation Appendix

Commercial Space Transport Study Final Report

APPENDIX E TRANSPORTATION APPENDIX

E.1 MARKET ASSESSMENT/ANALYSIS

E.1.1 Contacts

During the performance of the Space Tourism study, contact was initiated with a number of cruise lines and other

CSTS Contact

Telephone Notes: Jerry Mallett
Jim Pierson
Adventure Tourism Society
Date: 17 December 1993
Alliance Member: William T. Boardman
McDonnell Douglas Aerospace

Yesterday, 16 December 1993, I sent an introductory letter and a brochure to the Adventure Tourism Society. This group was referred to us by the US Travel Data Center. Today I received a call from the Society's president, Mr. Jerry Mallett and his partner, Mr. Jim Pierson. They had just read the material and were quite enthusiastic about the prospect of space tourism. I explained that the Alliance consisted of six aerospace and that any meeting would contain representatives from more than one company and that the information would be shared with all. They expressed an interest in meeting with the Alliance.

They are of the opinion that there is a real market for space tourism. The numbers of people that are interested in being among the first to take unusual trips is growing rapidly. They also believe that the demographics in the early 21st century are good. A few of the facts that they mentioned are:

a. Tourism is the largest industry in the world. It amounts to between 5 and 6% of the world's GDP.
b. A permit to climb Mount Everest now costs $50K and there is a long waiting list.
c. The Russians opened one of their ice breakers at $19K for trips into the Arctic circle. They are sold out.
d. In the Denver area, NASA offered rides in a flight simulator at $1500 per hour. The demand was so great that additional time was provided.

These two gentlemen have met with groups from around the world. They mentioned two international organizations:

a. World Travel Organization located in Madrid.
b. World Tourism and Travel Council located in Brussels.

They volunteered to send me some material and further said that they would call me again early next year to set up a time for us to get together.

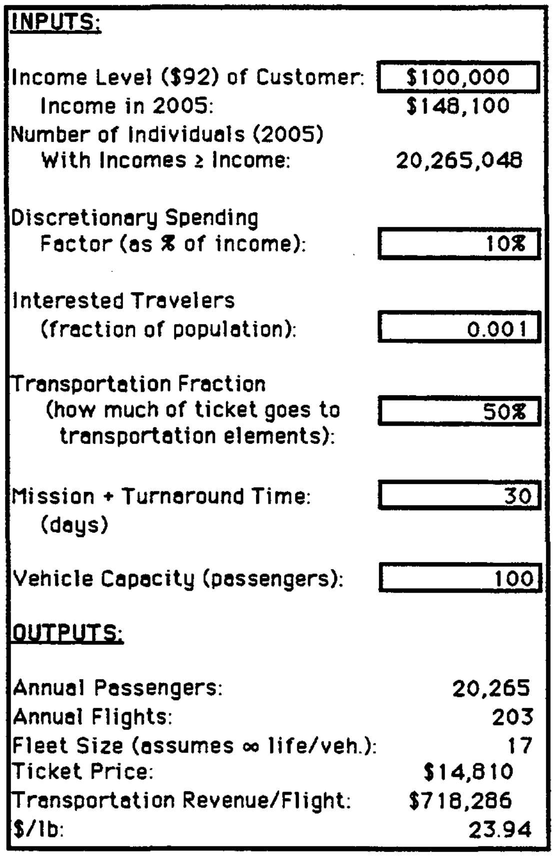
E.1.2 Business Model/Detailed ROI Analysis

As part of the analysis of the financial viability of Space Tourism, the CSTS Team conducted two similar "Bottoms Up" analyses. The results of these two analyses are summarized in section 3.5.6 of this report. The details of these alternate approaches is contained in this appendix.

E.1.2.1 First Approach

To determine the magnitude of the money available to develop space tourism, a model of worldwide personal income was developed. This assumes, as in other forms of tourism, that the sustained operations (including the costs of purchasing transportation hardware) are funded by the discretionary spending of interested individuals, and not subsidized in any significant way by a government. There are other analogies that suggest governments may be interested, for a number of reasons, in helping to subsidize the initial procurement of new systems; this will be discussed later as one approach to enhancing the probability that space tourism will be realized.

The simplicity of the equations used permitted the model to be effectively implemented on a spreadsheet. An example page of input/output is shown as figure E.1.2.1-1. Parameters in the boxes are input values, other numbers are calculated. The first line is an input of personal income level in CY92 dollars. This number was parametrically varied from $50,000 per year to $2,000,000 per year. This number is projected forward, and shown in the next line, at 2.337% per year (extrapolated from recent average growth trends) to the year 2005, which was selected as a representative date for the commencement of space tourism flights.



INPUTS:	
Income Level ($92) of Customer:	$100,000
Income in 2005:	$148,100
Number of Individuals (2005) With Incomes ≥ Income:	20,265,048
Discretionary Spending Factor (as % of income):	10%
Interested Travelers (fraction of population):	0.001
Transportation Fraction (how much of ticket goes to transportation elements):	50%
Mission + Turnaround Time: (days)	30
Vehicle Capacity (passengers):	100
OUTPUTS:	
Annual Passengers:	20,265
Annual Flights:	203
Fleet Size (assumes ∞ life/veh.):	17
Ticket Price:	$14,810
Transportation Revenue/Flight:	$718,286
$/lb:	23.94

111264-206

Figure E.1.2.1-1. Example of Spreadsheet Model

Next, a simplified representation of income distribution was made by obtaining data on the United States' population's income. Typically, the US personal wealth accounts for one-quarter of the worldwide figure; therefore the distribution was multiplied by four. Assuming the population of the world grows at an average rate of 0.8% per year until the year 2005, a histogram of number of people versus annual income was developed. It was further assumed that anyone with an income greater than the selected level would also buy a ticket commensurate with the price set by the population at the selected level. That is to say, by analogy, a wealthy person would buy a $500 airline ticket even though he or she could easily afford a more expensive ticket. The histogram was "integrated" to arrive at an equation that represents the number of people worldwide with personal incomes in excess of income level "IL":

people = e^x
where x = (.2599197 * ln(IL)^2 - 8.405613 * ln(IL) + 79.14591)

The third line of figure E.1.2-1 is the output of this equation. Figure E.1.2.1-2 graphically portrays the number of individuals worldwide with incomes greater than or equal to a given income level.

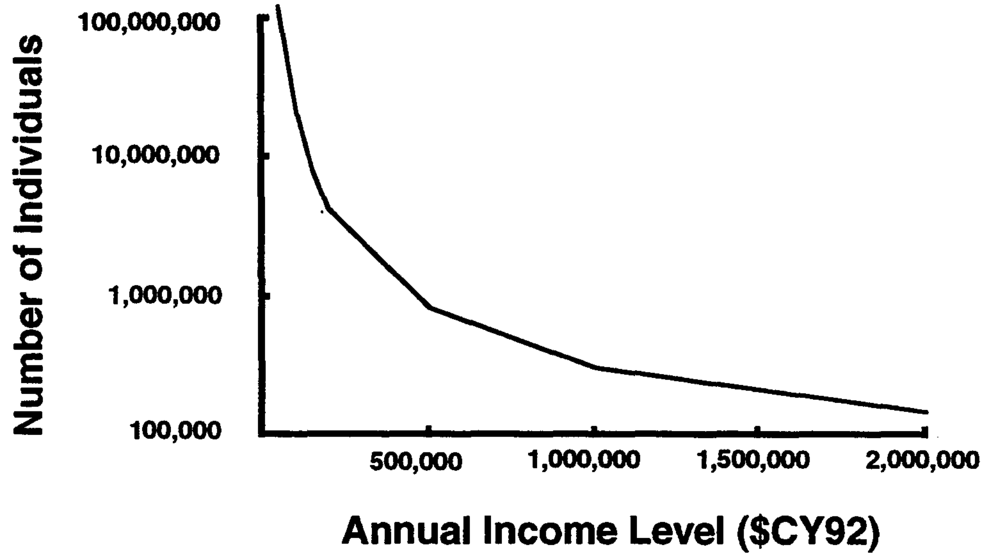


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Figure E.1.2.1-2. Model of Individuals With Incomes Greater Than or Equal to "IL"

The next input line, "Discretionary Spending Factor", is an estimate of how much the average person would spend for a ticket as a percentage of their annual income. This discretionary spending factor was parametrically varied from 5% to 20% (from a family vacation to a trip-of-a-lifetime).

The "Interested Travelers" input parameter represents an estimate of what fraction of the population would avail themselves to a space trip if they had the financial means to do so. Not everyone may wish to travel to space, and discretionary income for a space vacation has to compete with other travel destinations and consumer goods. Previous studies have indicated that younger adults (those with less disposable income) are more likely to want to travel to space than older adults. Therefore, there is probably a 20 to 30 year period within an individual's lifetime where both the desire and the means to consider space tourism are present. Within that period, it would be unlikely that the average individual would actually take more than one spaceflight. To account for all these considerations, the fraction of interested travelers within any given year was parametrically varied between .005 (1 in 200) and .0001 (1 in 10,000). Figure E.1.2.1-3 compares this range of interested travelers in combination with the range of discretionary spending with the often cited Society Expeditions market model (corrected for 1992 dollars and population). Point "A" represents the interest in space tourism, as indicated by monetary deposits made towards the Society Expeditions/Phoenix venture (ref. A-1).

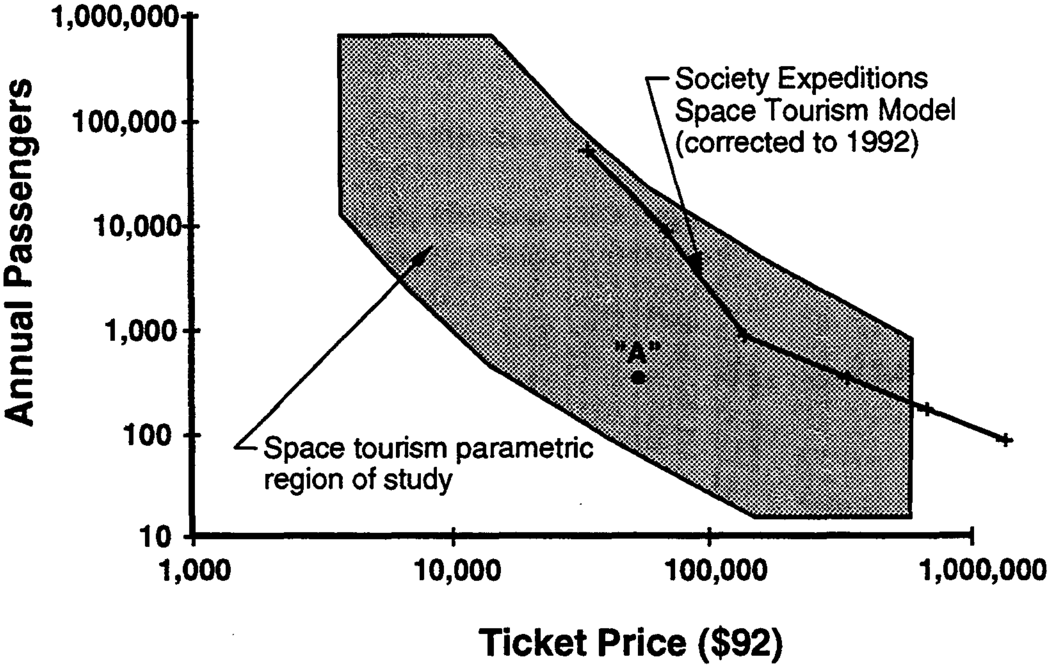

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Figure E.1.2.1-3. Range of Parametric Investigation of Space Tourism Elasticity

The next input is labeled "Transportation Fraction" and is an acknowledgment that not all of the ticket price goes to paying for the transportation. As in terrestrial tourism "packages", the amount of the tour price that pays for the airline ticket can vary significantly, depending on the nature of the trip. In the case of the "Joy Ride" scenario, the transportation fraction would be relatively high; in the case of an unsubsidized lunar resort, transportation costs are relatively small. This parameter was varied from 25% to 75%. The focus of this report is on the transportation elements; and does not assess whether the remaining revenue is consistent with the development and manufacture of other tourism assets (such as an orbital hotel).

The "Mission + Turnaround Time" input is fairly self-explanatory. The parameter was varied between 2 and 90 days to account for different mission types as well as technology/operations assumptions. In reality, mission + turnaround time is not independent of the "transportation fraction", but for this model, they were left as discreet inputs.

Finally, an input of "Vehicle Capacity" is made. Without the benefit of a specific design, it is still necessary to know how many passengers one vehicle can accommodate in order to determine the fleet size. Inputs ranged from 10 passengers to 250 passengers.

The output section contains several values which describe the characteristics of one solution to space tourism transportation. The first line of the output is the total annual passengers, simply calculated by multiplying the "Interested Travelers" fraction with the number of individuals with incomes in excess of the selected income level. From this, the next line shows the number of annual flights, a rounding up of the annual passengers divided by the vehicle capacity.

One significant assumption is that the transportation vehicles are reusable and feature essentially infinite life (no accounting for spares or attrition). This is perhaps optimistic in that it is presumed that expendable vehicles, or limited lifetime reusable concepts, will cost more and would make the realization of space tourism less likely. With this caveat, the fleet size is calculated by rounding up the annual flights multiplied by the mission + turnaround time input, divided by 365.25 days per year.

The "Ticket Price" (in 2005 dollars) output is simply the product of the selected income level and the "Discretionary Spending Factor". This ticket price is multiplied by the vehicle capacity, the "Transportation Fraction", and a postulated 0.97 load factor (to account for last minute glitches, illness, gratis flights, etc.) to arrive at the "Transportation Revenue/Flight" output. Load factors on commercial airlines typically average 0.6 to 0.7 across an entire fleet and route structure. Specialized air travel, such as the Concorde, experience similar load factors. Anecdotally, a common mistake with new airlines is basing economic projections based on load factors approaching 1.0; lending institutions have learned to be cautious with these optimistic projections. Our justification for selecting a high load factor is based on the idea that, for a first generation space tourism industry, scheduling will be flexible enough to only launch when 'all the tickets have been sold' in the manner of a charter operation rather than a scheduled airline flight. The "Transportation Revenue/Flight" can be thought of as similar to the cost/flight parameter typically associated with space launchers.

Finally, at this point in the output, a value for $/lb is shown (assuming 300 lbm/person including baggage). Although this metric has been used extensively in comparing launch vehicles, it is arguably of secondary interest to the space tourism operator: transportation revenue/flight is a more useful management measurement. As predicted by previous studies, these values do tend to be small compared to conventional launch vehicles.

Results of Parametric Analysis. At this point, it is possible to begin to bracket the range of possible solutions. Varying the input parameters as described resulted in the generation of several thousand individual cases. Understanding the output is not as simple as a single graph. Remember, any individual case must answer the following, multi-part question: Can one build a safe, reliable vehicle that carries N people paying $X each, is operable for $Y/flight, and can be developed and manufactured (M vehicles) for $Z? Before answering the last question, what can we exclude on the basis of violating the first part of the question?

Some restrictions on the range of interest are immediately apparent (fig. E.1.2.1-4). There is a lower limit on practical cost/flight that can be realized. Spaceflight will never be as inexpensive as other forms of transportation; fundamentally, there are large differences in the amount of energy stored and expended as well as the necessary complexity required to operate in hostile environments. All solutions below some agreed upon minimum (say for argument, $2M/flight) can be eliminated from further consideration. Specifically in this case, vehicles smaller than 100 passengers are only valid if one selects customers with income levels in excess of $500,000/year as the target market.

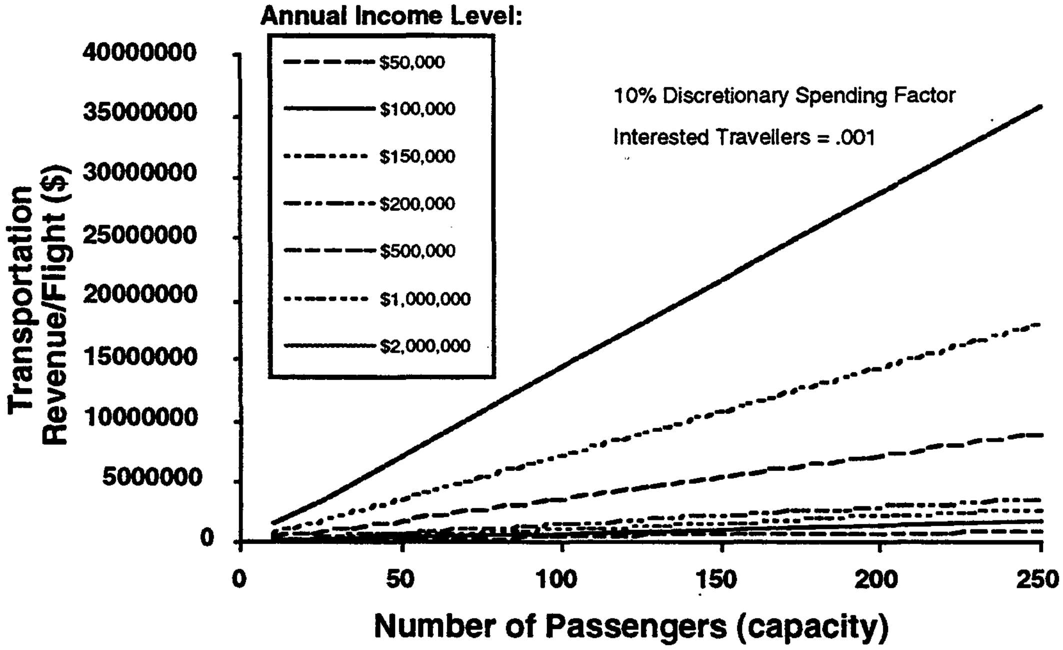

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Figure E.1.2.1-4. Example Model Output for Transportation Revenue per Flight Versus Vehicle Capacity

Likewise, in the related graph of figure E.1.2.1-5, a lower bound for vehicle size could be set by considering the cost involved in manufacturing such large fleets. {The Concorde has an average of 80-90 persons/flight and 12 vehicles in the active fleet.} Fleet sizes of one vehicle are unlikely as well - maintenance or failure would stop all revenue and would not be good business practice. Referring to the previous finding for this example, the same target market would seem to be best served by a 'fleet' of two vehicles sized in the 50-100 passenger range.

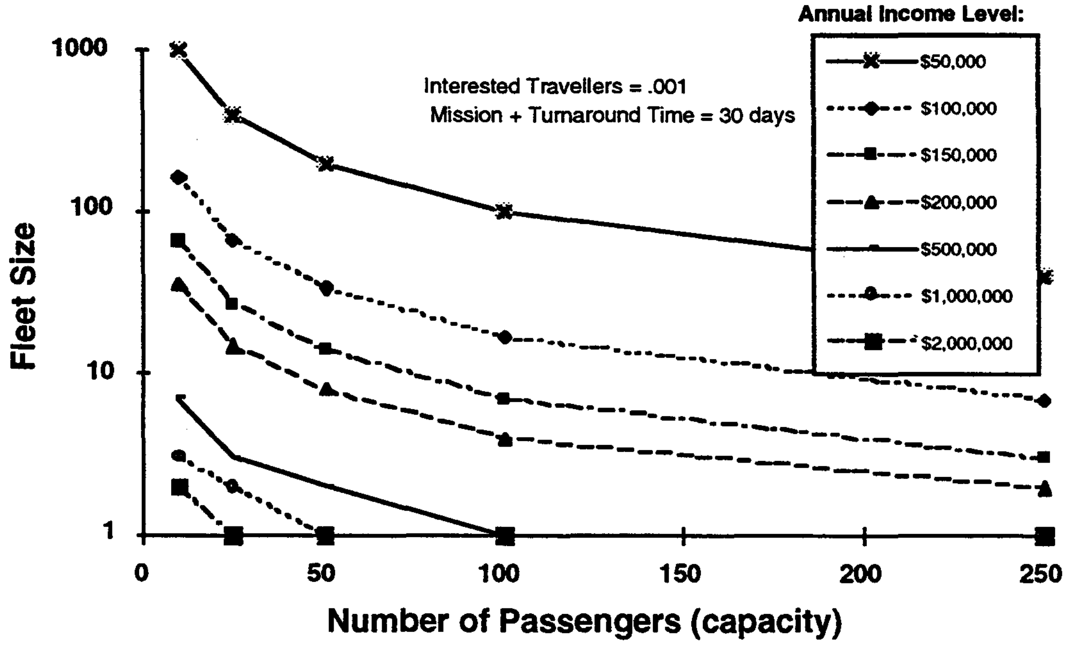

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Figure E.1.2.1-5. Example Model Output for Fleet Size Versus Vehicle Capacity

For the most promising cases, the spreadsheet analysis was carried further to estimate the size of the initial capital that could be invested, based on the amount of money for payments that could be generated as part of the revenue earned per flight. In an analogy to airplane transports, a portion of the ticket price (roughly half) is allocated to pay back the loan for the purchase of the airline's aircraft.

Figure E.1.2.1-6 depicts an example case from one spreadsheet run with parameters related to the case shown in figures E.1.2.1-4 and -5. The data that comes from the previous analysis is shown as the "Annual Income Level" entry; this number is simply the transportation revenue/flight multiplied by the number of annual flights and a parametrically varied percentage that represents the amount of the revenue allocated to amortization. One can also parametrically vary the period of time for amortization ("Years of return") and the "Rate of return". For a first pass, escalating to account for the exact year of introduction was ignored. The line labeled "max Capital" is the amount that can be amortized at the beginning of revenue operations. Finally, the "Init. Value" is calculated, using the variable 'Development Years"; this value represents the money available to develop the vehicle <u>and</u> to buy the fleet, or the amount of the loan from the lender. The total money available is related to the annual flights, which is in turn a function of the selected target income level of the customer market. After accounting for development, the funds available for manufacturing the vehicles would set the maximum likely fleet size.

This example, then, shows a ridiculously unlikely scenario; even without considering how many production units there are, there is only millions to tens of millions of dollars available for developing and building a new, reusable manned launch system. Using these calculations, one could subjectively screen out the cases where development is under funded to the point of questionable credibility.

Within the entire parametric trade space depicted in figure E.1.2.1-3, there are no credible solutions! There is nowhere near enough revenue to pay back lenders for the true costs of development and manufacture of a new, single purpose space tourism transportation system.

Figure E.1.2.1-6 yields other useful data. Large vehicles imply the fleet size is small; this is desirable in that larger fleets must be manufactured for roughly the same amount of money as a smaller fleet. Of course, larger vehicles are costlier to develop and build than smaller ones. On the other hand, large vehicles imply lower ticket pricing to enable the fleet to fly efficiently; lower ticket revenues result in the requirement for extremely low cost/flight. Is there an answer to this enigma? There are solutions, but only if one can separate the cost of developing and building the system from the technical and operational challenges, which many believe can be met.

Income Level:	$50,000	Discretionary:
Development Years:	5	10%
Years of Return:	10	Interested:
Rate of Return:	10%	0.001
Vehicle Capacity	Parameter	$M
10 Fleet Size = 1010	Annual Income	0.328
	Max Capital	2.015
	Initial Value	1.251
25 Fleet Size = 404	Annual Income	0.82
	Max Capital	5.039
	Initial Value	3.129
50 Fleet Size = 202	Annual Income	1.639
	Max Capital	10.071
	Initial Value	6.253
100 Fleet Size = 102	Annual Income	3.248
	Max Capital	19.958
	Initial Value	12.392
250 Fleet Size = 41	Annual Income	8.081
	Max Capital	49.654
	Initial Value	30.831

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Figure E.1.2.1-6. Example Worksheet for Calculating Initial Investment

E.1.2.2 Second Approach

Income Distribution. Space travel for purposes of entertainment will remain only within the domain of the rich or high income households for only they could afford the cost. As a general rule, the lower the cost per pound to orbit, the larger the segment of the world population that can afford to travel to space, given that they had the inclination to do so. Thus, there are two huddles that the operators of a space destination resort must overcome in finding customers: first, the costs must be low enough that a sufficient number of people can afford the trip and second, there must be sufficient attraction so that people would want to go.

The first huddle to the prospective space traveler is affordability. A trip to space is likely to financed similar to any high cost purchase with monthly payments spread over time. The travel agent, actively attempting to solicit business, would have to offer financing for such a 5 day vacation at the space destination resort. The prospective customers who file for a bank loan would be screened based on their ability to make monthly payments, not unlike financing for a new automobile or home. The financial rule of thumb for a customer to qualify for purchasing a house, considered a once in a life time purchase, is that the loan not exceed three times the household's current gross income, and amortized over 30 years. The financial rule of thumb for a customer to qualify for purchasing a new car, is that the loan should not exceed one-third the household's current gross income, and amortized over 5 years.

Applying similar financial rules of thumb, customers can be qualified for purchase of space resort tickets based on their annual income. Since the decision to purchase space travel tickets is a consumable purchase, it is more like an expensive vacation or perhaps an automobile. Thus, the appropriate financial rule of thumb is that household income should be at least three times greater then the purchase cost. Thus, if the household cost for a 5 day vacation at the space resort is $25,000, then to qualify for financing, the household income should exceed $75,000.

Income distributions have been collected by households from the three sources shown in figure 3.5.6.3-1: (1) 1990 census data, (2) the 1989 Adjusted Gross Income Tax Statistics, and (3) the 1992 Statistical Abstract of the United States. The income statistics used in this study was the one for households with adults aged 25 to 55. Below this age band, it is assumed that the average household income is insufficient to finance a trip into space, and above the age band, the physical condition of the average individual will severly limit their ability to take advantage of the opportunity.

Worldwide income distributions were estimated by aggregating the populations of countries with per capita incomes similar to that of the United States. For the remaining, less wealthy world population, five percent was assumed to have upper income levels similar to the United States. These statistics were obtained from the World Almanac with populations adjusted to the year 2020. From this information, the number of households worldwide with income levels comparable to USA standards is 4 to 5 times greater than just USA statistics alone. Specifically, the USA income distribution statistics was multiplied by a factor of 4.62 to arrive at the worldwide households with equivalent income levels. The number of worldwide households with incomes above a specified level is shown in Table 3.5.6-1. World wealth is growing at an uninflated rate of roughly 2% a year compounded. Thus, by the 2020, these population statistics could grow by another 67%. This has not been incorporated into this paper. The distinction between households and people is that for each of the 94 million households in the United Stated in 1991 there was an average of 2.63 people.

A major unknown in this study is the visitation rate to the space resort. In this study visitation rate was assumed to depend on two factors: 1) affordability and 2) propensity to consume (inclination to spend scare household resources on consumables such as vacations). To estimate the effect of affordability on visitation rate, the statistics on household income distribution was used to identify the number of households who could afford trip. The rule of thump on affordability was that only those households with an income three times greater than the cost of the trip were financially "qualified" to do so. As the statistics in the section of this report demonstrates, there are plenty of households that could afford to take the trip to the space resort. The primary issue is how many households would elect to do so and how often?

The cost of a five day vacation at the space resort will be a major expense for most households. Even the most optimistic economic scenario assumed in this paper, with space transportation costs at $25 a pound, the household cost of a 5 day space resort vacation is $25-35,000 or equivalent to the purchase of a luxury car - a BMW, Lexus, or Mercedes. Even at this comparatively low cost for a 5 day vacation at the space resort, there are simply too many economic choices competing for the consumer's money. For instance, a household could elect to spend a vacation in Paris, France and still purchase a luxury car (albeit a less exotic model) for the same cost as a trip to the space resort.

To estimate the effect of consumption propensity (willingness to spend scare economic resources on high priced consumables such as a 5 day vacation at the space destination resort) on visitation rate, the following rules of thumb were established. First, for those households with an inclination to visit the space resort, the trip was assumed to be a once in a lifetime experience. Since only households headed by adults between the ages of 25 to 55 were considered in our income statistics, a lifetime for a household is assumed to be 30 years for purposes of this study. Second, only one household in ten is assumed to have an inclination to visit the space resort.

These rules of thumb are arbitrary and therefore debatable. In their defense, one could claim that they are not unreasonable, provide a measure of the economic viability of space tourism based upon demand, and more importantly, they produce visitation rates that make the space resort economically viable. Thus, the visitation rates assumed in this study could be viewed as those required to make the commercial venture feasible rather then a prediction of how many households will actually visit. Visitation rates lower than those calculated in this report will tend to make space tourism and space entertainment considerable less economically viable. Likewise, higher visitation rates higher will make these market segments more attractive.

The actual visitation rate is difficult to predict because a visitation at the space destination resort is not currently an option. If surveyed, most people would probably consider a visit to a space destination resort as an absurd notion. But in the future, as space travel by ordinary people becomes safer and more common place, the notion will not seem as far fetched. In fact, once the space resort is in place, with its potential for extensive entertainment and adventures, it may become the one-of-a-kind place and experience that everyone will want to visit at least once in their lives.

An all-space television channel, broadcasting people and activities in space and watched periodically by most of the people who inhabit the planet will stimulate demand even more. The larger the space resort facility becomes and the more it is promoted from the all-space broadcasting channel on television, the more people who will want to experience the phenomena themselves. Thus, as space becomes more familiar and routine, it will become a focal point in people's lives. Something that must be experienced in one's lifetime. As space becomes a natural place to visit, space as a destination and experience, will take on a unique appeal unrivaled by anything on Earth. Households will begin to serious consider the trip to the space resort in the same way they consider the purchase an automobile, "Should we purchased tickets this year or next?"

In the model shown in figure 3.5.6.3-2, if household income level is at least three times greater than the estimated cost (the affordability rule), then the baseline visitation rate to the space resort is assumed to be one-tenth of once-in-a-lifetime or 1 in 300 per year. However, the baseline visitation rate is adjusted to account for incomes that are above or below the affordability rule. Thus, for each income group, the baseline visitation rate was multiplied by an adjustment factor, or multiplier, to account for the fact that as income increases relative to cost, a household unit is more likely to make the trip or at least not be discouraged because of its cost.

Thus, the demand curve for space tourism is the product of the baseline visitation rate and the affordability multiplier. The affordability multiplier has the effect of increasing or decreasing the visitation rate for households whose incomes lie above and below the level considered to be affordable (an income three times the cost). The logic of the affordability multiplier is that as the income-to-cost ratio gets larger, the cost is easier to absorb in the household discretionary budget. In the reverse, the smaller the income-to-cost ratio, the more difficult a household would have in justifying such an expensive expenditure, not only to themselves but to a financing loan officer. In other words, prosperity boosts the "propensity to consume" which rises and falls with household income levels.

The following example is intended to clarify the affordability multiplier. If the cost of the vacation at the space resort was $75,000, then the baseline demand is 1 in 300 for households whose income is three times the cost or $225,000. If the household income is greater than three times the cost, the demand is increased directly proportional to the higher income. The logic for this increase in affordability multiplier is that higher income households are less intimidated by the cost. Thus, a household with an income of $300,000 would have an affordability multiplier of 1.33 (calculated by the ratio: income-to-cost ratio divided by 3 or $300,000/$75,000/3). This factor has the effect of increasing by one fourth the baseline demand for households in the $300,000 income level. A household with an income of $750,000 would have a affordability multiplier of 3.33.

For households with less income than three times the cost, $150,000 for example, the demand is decreased. In fact, to reduce demand even faster for lower income households, I have elected to decrease the demand as the square of the income-to-cost ratio divided by three. For example, the affordability multiplier for households with an income of $150,000 and cost is $75,000 is only .44 (calculated as follows: ($150,000/$75,000/3)^2). The rationale for taking the ratio (which is less than one) and squaring it is to sharply reduce the demand as the income-to-cost ratio falls below three to account for affordability.

The overall effect of the affordability multiplier is as follows:

1. To increase the demand for space tourism higher than what would have prevailed if a straight multiplier of the baseline value of 1/300 was applied to all households with an income above three times the cost,
2. To decrease the demand rapidly for space tourism instead of cutting demand to zero for household's whose income is less than three times the cost, and
3. To set demand for space tourism at zero for household incomes less than the cost.

In summary, the visitation rate to the space resort is based on the following factors: 1) USA household income distribution statistics multiplied by a factor of 4.62 to account for worldwide population, 2) the baseline visitation rate is applied only to households with an income above the ticket price and an income-to-cost ratio of three, 3) a baseline visitation rate of 1 in 300, and 4) an adjustment to the baseline visitation rate to account for higher and lower income-to-cost ratios. The resultant household demand for a 5 day vacation at the space resort as a function of price is shown in figure E.1.2.2-6 To adjust this demand curve from household to individual, the demand was divided by 2.63, the number of people in a household. To adjust this demand curve from a 5 day vacation in space to a one day ride cruise on a space ship, the demand was divided by 3 to reflect the relative value of a 5 day vacation at the space resort compared to a one day cruise on a launch vehicle. Both of these are also shown in figure E.1.2.2-6.

Price	Annual Demand for a 5 Day Vacation at the space resort for a Household	Annual Demand for a 5 Day Vacation at the space resort for an Individual	Annual Demand for a One Day Ride into Space for an Individual
$25,000	170,000	65,000	22,000
$50,000	67,000	25,000	8,300
$100,000	20,000	7,600	2,500
167,000	5,900	2,200	700
$250,000	3,100	1,200	400
$500,000	700	270	90

Figure E.1.2.2-6. Five and One Day Demand for Different Ticket Prices

REFERENCES

A-1 Space Expeditions, Project Space Voyage, Society Expeditions, Seattle, 1987.

Appendix F—
New Missions Appendix

APPENDIX F NEW MISSIONS APPENDIX

F.1 BUSINESS PARK USER MARKET

F.1.1 Principal Microgravity Uses

a. Improved quality and size of protein crystals
b. Improved Separation Process (electrophoresis)
c. Improved capability for drug testing (rats)
d. Growth of replacement tissues for transplants
e. Improved quality of semi-conductor crystals

The total demand for micro-gravity processing is a composite of these totally separate and as yet unestablished markets. The estimated total demand for microgravity processing assuming a successfaul transition of the major products to production status is shown in figure F.1.1-1. Supporting data for this table follows. Note, that this table is the source for the low probability market projection at $20,000 per locker.

Market Sector	Market by Year ($M)							
	2001	2002	2003	2004	2005	2006	2007	2008
Pharmaceutical	100	300	600	1,000	1,200	1,600	2,000	2,500
Semi-Conductor	50	100	200	300	500	800	1,200	1,400
Other (Metals, Medical, etc.)	50	150	200	350	500	600	800	1,000
Total	200	550	800	1,650	2,200	3,000	4,000	4,900

Figure F.1.1-1. Estimated Total Demand for Microgravity Processing

Individual markets will be discussed in the sections following.

F.1.2 Pharmaceuticals

Protein Crystal Market

The principal customers for micro-gravity processing are pharmaceutical companies and microprocessor producers. Among the pharmaceuticals there are eight small research companies which focus on structure base drug design, thirty worldwide major pharmaceuticals with drug design departments and approximately one hundred biotechnology companies that currently conduct research, development, and commercialization. These potential users are listed below:

F.1.3 Pharmaceuticals Contacts

<table>
<tr>
<td>TL 797 G86 1990
Space Enterprise, Beyond NASA, Gump, D.P.
p.112</td>
<td>McDonald Douglas (MD)
Ortho Pharmaceuticals
3M's Riker Laboratories

French space agency, CNES
Matra Espace
Roussel Uclaf (French drug company)</td>
<td>$$$ in drugs, eg. a pound of interferon can be made into 4.5 million doses at $10 a dose, a pound is worth $45 million
MD spent $21 million to devolop continuous flow electrophoresis, to separate and purify biologicals (in this case erythropoeitin), advantage to space electrophoresis is faster production and greater purity.
Ortho Pharmaceuticals put in $8 million to develop the hormone
in 1988 MD gave up and donated its space processing hardware to NASA, including small units for shuttle's middeck crew and larger "factory" units for cargo bay
Ortho pulled out because it could bring the hormone to market faster using ground based techniques: "The partnership with Ortho failed from the primary threat to all space manufacturing plans: ground-based competetion that moves more quickly than space-based operations. Extremely long waits between flights often cripple space research--promising initial results are put on the shelf for months or years until follow-up experiments can be flown."
Europe plans for electrophoresis unit in Mir (1991), space shuttle (1993) and on SSF</td>
</tr>
<tr>
<td>TL 797 G86 1990
Space Enterprise, Beyond NASA, Gump
p. 139</td>
<td>Dr. Charles Bugg
Univ. of Alabama
Center for Macromolecular Crystallography
Burroughs Wellcome Company (British)
Merck & Company
Upjohn Company
Smith Kline & Beckman
Eli Lily
Kodak
DuPont
Procter & Gamble
Schering Corporation</td>
<td>(actually research, not production)
growth of giant protein crystals for cancer research
eg. the humac C-reactive protein and bacterial nucleoside phosphorylase (PNP) an enyzme that destroys cancer-fighting cells
start up firm, BioCryst Ltd, working thru the Univ. of Alabama with $5.2 million in funding from business, is trying to develop a commercial product for treating AIDS</td>
</tr>
<tr>
<td>629.1771 P943 v. 110
Commercial Opportunities in Space, "Commercial Bioprocessing in Space,"</td>
<td>D.W. Clifford
McDonnell Douglas</td>
<td>biologicals for processing in space
<table>
<tr><th>products</th><th>medical use</th><th>annual patients</th></tr>
<tr><td>immunoglobulins</td><td>emphysema</td><td>100,000</td></tr>
<tr><td>anthiemophilic factors VII & IX</td><td>hemophelia</td><td>20,000</td></tr>
<tr><td>beta cells</td><td>diabetes</td><td>600,000</td></tr>
<tr><td>epidermal growth factors</td><td>burns</td><td>150,000</td></tr>
<tr><td>erythropoietin</td><td>anemia</td><td>1,600,000</td></tr>
<tr><td>immune sereum</td><td>viral infections</td><td>185,000</td></tr>
<tr><td>interferon</td><td>viral infections</td><td>10,000,000</td></tr>
<tr><td>granulocyte stimulation factor</td><td>wounds</td><td>2,000,000</td></tr>
<tr><td>lymphocyteds</td><td>antibody production</td><td>600,000</td></tr>
<tr><td>petuitary cells</td><td>dwarfism</td><td>850,000</td></tr>
<tr><td>transfer factor</td><td>leprosy/MS</td><td>550,000</td></tr>
<tr><td>urokinase</td><td>blood clots</td><td>1,000,000</td></tr>
</table>
predictions for value of pharmaceuticals processed in spaceby 2000 to be between $2 to $14.9 billion (Center for Space Policy, 1985)</td>
</tr>
</table>

F.1.4 Semiconductor Growth/Microprocessor Manufacturing Markets

Currently Proposed Micro-gravity Research Materials

- Zn
- Zn-quartz
- Cd-Quartz
- Te-Se-quartz
- Te-Se
- Zn-Fe
- aluminium foam
- Hg_2Br_2
- Ge-Sb-S
- $PbCl_2$-CuCl
- BiOCl
- GaAs-Cr
- InSb
- GaSb
- Al + Cu
- PbTe
- Bi + Sb
- Fluoro-beryllate glass
- Ge(+I_2)
- $Bi_2(Se, Te)_3$
- Bi bTe_3
- GaP
- Ge alloyed with In
- AlGaAs/GaAs liquie
- saccharose crystals
- Pb(SeTe)
- CdHgTe
- $CuSO_4$-$5H_2O$
- V_2O_5
- PbSn
- Ge+Ga
- Sn +Pb
- $NdCo_2$-$CeMn_2$
- GaInP
- Ag-SiC
- NaCl-NaF
- Cadmium-Mercury-Tellurium

Superconduconductors

- Tin + 4% lead
- Molybdenum-gallium
- Niobium-tin

Pseudo Alloys

- Aluminium-bismuth
- aluminium-magnesium

F.1.5 Pertinent Micro-gravity Semiconductor Research

TITLE	CONTACT	NOTES
N92-19778 Microgravity science & applications progam tasks p. 172 1991	NASA Langley: Dr. A. L. Fripp Mr. W. J. Debman Dr. I. O. Clark Dr. R. K. Crouch, NASA headquarters	compound semiconductor growth in space. lead tin telluride--used in infrared detectors and tunable diode lasers to be flown on Space Shuttle
as above p. 176 8/90-5/93	Grunman Corporate Research Center: Dr. David J. Larson Jr. Dr. Alvin Levy Dr. J. Iwan Alexander, UAH Dr. Ratnaker R. Neurhaonakar, Rockwell Dr. Donald Gillies, NASA/MSFC NAS8-38147	orbital processing of high-quality CdZnTe Compound Semiconductors study to compare ground produced samples with samples grown on the Crystal Growth Furnace (CGF) on U.S. Microgravity Laboratory (USML-1)
as above p.179	NASA/MSFC Dr. Sandor L. Lehoczky Dr. Frank R. Szofran Dr. Donald C. Gillies	growth of solid solution crystals study to show advantages of $Hg_{1-x}Cd_xTe$ growth in space to be flown on USMP-2, Advanced Automatic Directional Solidification Furnace
as above p. 181	NASA/MSFC Dr. Sandor L. Lehoczky Dr. Frank R. Szofran Dr. Ching-Hua Su/ USRA Dr. Rosalia N. Andrews, Univ. of Alabama Ms. Lucia Bubalac, Rockwell	Crystal growth of selected II-VI semiconducting alloys by directional solidification to obtain a limited amount of high quality materials for testing $Hg_{1-x}ZnTe$ and $Hg_{1-x}Zn_xSe$ for CGF on USML
as above p.187 10/90-10/91	Rensselaer Polytechnic Institute: Prof. Heribert Wiedemeier	vapor growth of semiconductor crystals $Hg_{1-x}Cd_xTe\text{-}HgI_2$ compare ground tests to USML-1 flight experiment

F.1.6 Pertinent Micro-gravity GaAs Crystal Research

TITLE	CONTACT	NOTES
N92-19778 Microgravity science & applications progam tasks p. 171 10/90-9/91	GTE Lab. Inc.: Dr. Brian Ditchek Dr. David Matthiesen Mr. Alfred Bellows Mr. Glenn Duchene NASA, LeRC Dr. R. Lauver, NAS3-24644	Study to determine effects of buoyancy driven flow on melt grown Ga As crystals ground based tests GAS can on STS-40, June 5,1991
as above p. 183	GTE Lab Inc.: Dr. David H. Mattheisen Mr. Alfred Bellows Dr. Brian Ditchek NAS8-38148	Gravitational and thermal techniques for complete uniformity during crystal growth for Crystal Growth Furnace on United States Microgravity Laboratory
as above p. 27	MIT Prof. August F. Witt NAGW-1563	Growth control experiments using Bridgman and gradient freezes geometries, ground based experiment designed to be compatible with the Crystal Growth Furnace
N92-22659 NASA-TM-105320 "GaAs Crystal Growth Experiment Flown on Shuttle" Research and Technology 1991 LeRC Annual Report p. 117	Richard W. Lauver NASA/LeRC (216) 433-2860	Experiment was flown on STS-40 resulting in what "appears to be one of the finest crystals in the program." Hardware failures allowed only one crystal to be grown during the flight. Bibliography - D. Matthiesen has published the following papers: AIAA 90-0742, Jan. 1990, "Free Float Acceleration Measurements Aboard NASA's KC-135 Microgravity Aircraft" AIAA 90-0319, Jan. 1990, "Interface Demarcation in GaAs Current Pulsing"
TL 797 G86 1990 Space Enterprise, Beyond NASA, Gump p. 115	Exec. V.P. Russell Ramsland Jr. Microgravity Research Associates 1004 North Big Spring Suite 600 Midland, TX 79701 (915) 684-5693	todays GaAs sells for $100,000 per pound, space GaAs could sell for $500,000 per pound superspeed GaAs chips could work 100 times faster than todays silicon silicon moves electrons 12,000 cm^2/sV, space produced GaAs will go 1,500,000 cm^2/sV estimates full scale production factory 13 feet long, 7,500 pounds producing 50 pounds of crystal wafers
TL 797 G86 1990 Space Enterprise, Beyond NASA, Gump	Grumman Aerospace International Space Corporation	Both companies plan high temp. crystal furnaces

F.1.7 Pharmaceuticals

TITLE	CONTACT	NOTES
TL 797 G86 1990 Space Enterprise, Beyond NASA, Gump, D.P. p.112	McDonald Douglas (MD) Ortho Pharmaceuticals 3M's Riker Laboratories French space agency, CNES Matra Espace Roussel Uclaf (French drug company)	$$$ in drugs, eg. a pound of interferon can be made into 4.5 million doses at $10 a dose, a pound is worth $45 million MD spent $21 million to devolop continuous flow electrophoresis, to separate and purify biologicals (in this case erythropoeitin), advantage to space electrophoresis is faster production and greater purity. Ortho Pharmaceuticals put in $8 million to develop the hormone in 1988 MD gave up and donated its space processing hardware to NASA, including small units for shuttle's middeck crew and larger “factory” units for cargo bay Ortho pulled out because it could bring the hormone to market faster using ground based techniques: "The partnership with Ortho failed from the primary threat to all space manufacturing plans: ground-based competetion that moves more quickly than space-based operations. Extremely long waits between flights often cripple space research--promising initial results are put on the shelf for months or years until follow-up experiments can be flown." Europe plans for electrophoresis unit in Mir (1991), space shuttle (1993) and on SSF
TL 797 G86 1990 Space Enterprise, Beyond NASA, Gump p. 139	Dr. Charles Bugg Univ. of Alabama Center for Macromolecular Crystallography Burroughs Wellcome Company (British) Merck & Company Upjohn Company Smith Kline & Beckman Eli Lily Kodak DuPont Procter & Gamble Schering Corporation	(actually research, not production) growth of giant protein crystals for cancer research eg. the humac C-reactive protein and bacterial nucleoside phosphorylase (PNP) an enyzme that destroys cancer-fighting cells start up firm, BioCryst Ltd, working thru the Univ. of Alabama with $5.2 million in funding from business, is trying to develop a commercial product for treating AIDS

Pharmaceuticals (continued)

TITLE	CONTACT	NOTES
629.1771 P943 v. 110 Commercial Opportunities in Space, "Commercial Bioprocessing in Space,"	D.W. Clifford — McDonnell Douglas	biologicals for processing in space products medical use annual patients immunoglobulins emphysema 100,000 anthiemophilic factors VII & IX hemophelia 20,000 beta cells diabetes 600,000 epidermal growth factors burns 150,000 erythropoietin anemia 1,600,000 immune sereum viral infections 185,000 interferon viral infections 10,000,000 granulocyte stimulation factor wounds 2,000,000 lymphocyteds antibody production 600,000 petuitary cells dwarfism 850,000 transfer factor leprosy/MS 550,000 urokinase blood clots 1,000,000 predictions for value of pharmaceuticals processed in spaceby 2000 to be between $2 to $14.9 billion (Center for Space Policy, 1985)

F.1.8 Micro-gravity Metals and Alloys

TITLE	CONTACT	NOTES
N92-19778 Microgravity science & applications progam tasks p. 195	Vanderbilt Univ. Prof. Robert J. Bayuzick Dr. William H. Hofmeister NASA/MSFC Dr. Michael B. Robinson	Containerless processing of refractory metals and alloys Used drop tube at MSFC and electromagnetic levitation Ti-51at% Al
as above p. 197 9/90-12/91	MIT: Prof. Merton Flemings Prof. Harold Brody NASA/MSFC: R.C. Darty	Alloy undercooling experiments in microgravity Nickel and iron base alloys Columbia STS 61-C, Jan 1986 to be on IML-2

F.1.9 Miscellaneous Microgravity Projects

TITLE	CONTACT	NOTES
N90-11195 NASA TM 100378 Concepts for Microgravity Experiments Utilizing Gloveboxes	Roger L. Kroes, Donald A.Reiss Barbara Facemire Space Science Laboratory Science and Engineering Directorate	includes list of 87 experiments flown on Apollo, Skylab, or STS missions suitable for gloveboxes and description of 15 typical experiments proposed by Microgravity Science and Applications Division
N92-23600 thru N92-23642 NASA TM 4353		First International Microgravity Laboratory Experiment Descriptions including names of principal investigators for each experiment experiments in life sciences and microgravity science,
TL 797 G86 1990 <u>Space Enterprise, Beyond NASA</u>, Gump pp. 125-134	3M Corporation 3M Center St. Paul, MN 55144 (612) 733-7229	began space research in 1983 interests: "smart" adhesives, sticky on command super-strength plastics, hard at high temp. optical computers fiber optic communications experiments: organic crystal growth thin film experiment to see how molecules attach themselves to a surface creating plastics with a greater percentage of crystallization made deal with NAS to fly 62 experiments over the next ten years

REFERENCES

A-1. Eli Lilly and Company 1992 Annual Report.

A-2. Cost of Innovation in the Pharmaceutical Industry, 1991.

A-3. Conversations with Dr. Larry DeLucal, UAB Center for Macromolecular Crytallography, 1992.