Commercial Space Business Parks

Final Report of Contract #NAS8-50000, Task Order #TOF-021

Boeing Defense & Space Group

April 7, 1997 with Revisions dated May 8, 1997

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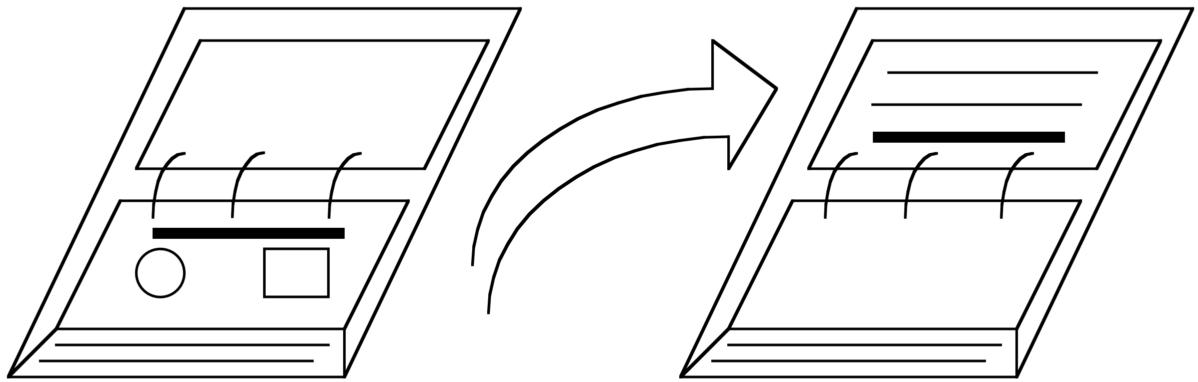
Document Format

This report is organized according to a facing page - text format, with a summary chart format on the front page (odd numbers), and a note text format on the following page (even numbers), as shown in the figure below. Text size on all pages has been set to 14 point minimum to accommodate use in slide presentations.



Summary chart on front of page (odd numbers).

Note text on following page (even numbers).

Credits

Commercial Space Business Parks

- NAS8-50000, TOF-021
- April 7, 1997, Rev. May 8, 1997
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NASA Headquarters Sponsors

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Credits

This report is a summary of a study performed by Boeing Defense and Space Group under contract to the National Aeronautics and Space Administration (NASA). The contract number was NAS8-50000, Task Order TOF-021. The period of performance was 7 August 1996 to 7 April 1997. Selected portions of the technical work were performed under subcontract to Orbital Properties, L.L.C. and to Gordon R. Woodcock, consultant.

The NASA study manager was David Smitherman, at NASA Marshall Space Flight Center (MSFC). NASA study participants included Mark Nall, Bob Armstrong, Carey Thompson, Sandy Montgomery, and Daniel O'Neil from MSFC; and Ivan Bekey and John Mankins from NASA Headquarters.

The Boeing study manager was Dr. Harvey J. Willenberg. Technical contributors included:

> Joe Hopkins, Boeing, market data base, entertainment case study analysis, infrastructure requirements, architecture concepts
>
> Mark Rubeck, Boeing, satellite servicing case study analysis, policy, and roadmaps
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> Dr. Larry Torre, Boeing, Micro-gravity case study analysis
>
> Chuck Lauer, Orbital Properties, travel case study analysis, business park operating model

Cover: The cover graphics is an early space station concept that illustrates many of the basic components envisioned for a space business park, including pressurized space station modules, remote manipulator arm, autonomous free flyer vehicle, attached payloads, and a human rated transportation system. The original art was prepared by Paul Hudson for Boeing.

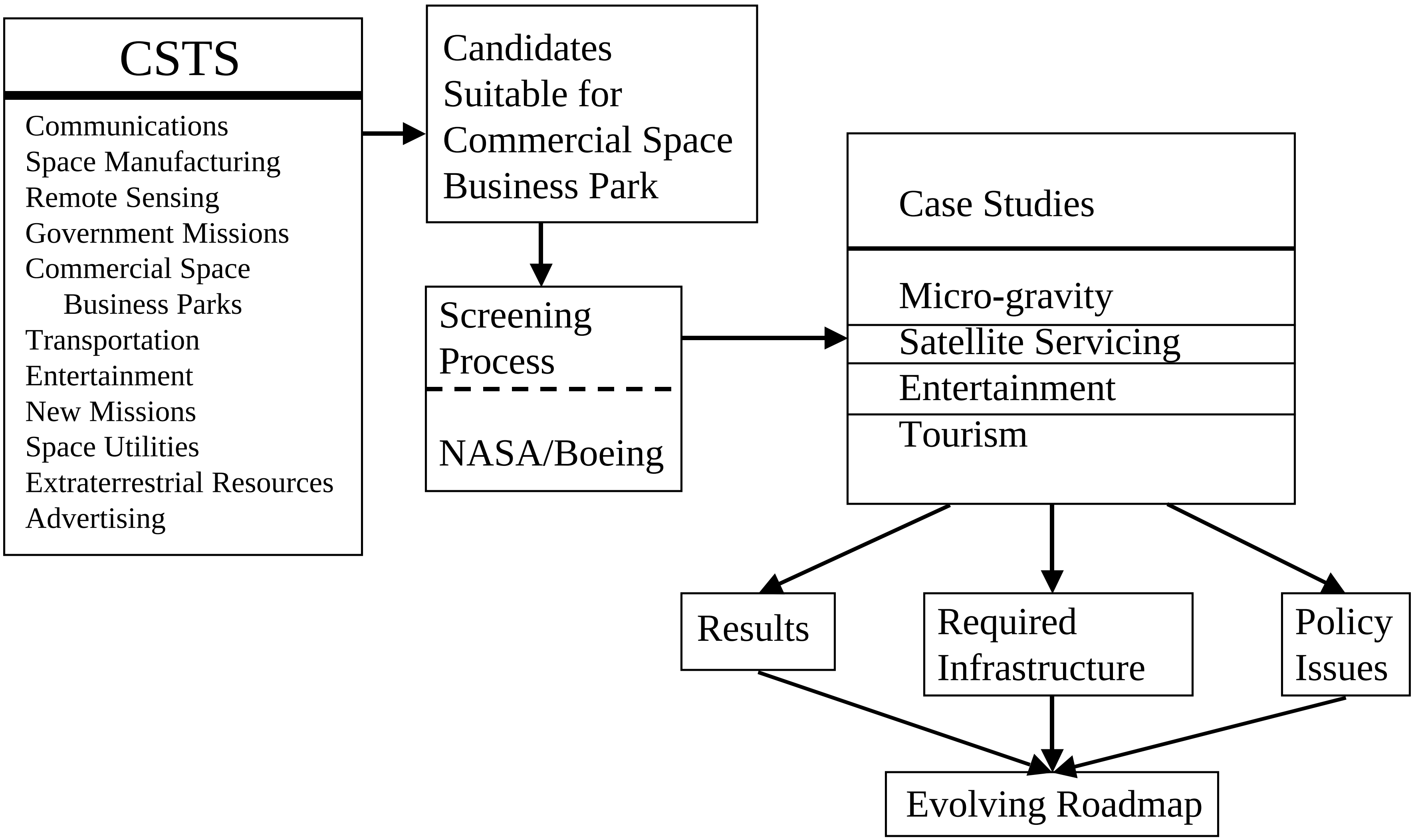
Executive Summary

Executive Summary

The Commercial Space Business Parks study was performed by Boeing Defense and Space Group for NASA Marshall Spaceflight Center as a task order to the International Space Station contract during the period from 7 August 1996 to 7 February 1997. The purpose of this study has been to identify promising commercial markets for space business parks and perform case studies to determine the conditions under which these markets could develop as single markets and/or the benefits which might accrue from a multi-use facility approach.

Executive Summary

Study Flow



Executive Summary

Study Flow

The study started with the results of the Commercial Space Transportation Study (CSTS), which was performed by six aerospace companies in 1993 and 1994. The CSTS identified a number of promising markets for commercial space transportation, provided that the transportation costs can be reduced to an acceptably low level.

Case studies were developed for commercial micro-gravity production, satellite servicing, entertainment, and tourism. These case studies identified potential market size and helped to determine cost thresholds required for market development. They were further used to identify the required infrastructure and some of the critical policy-related issues that must be addressed before commercial space business parks can evolve. A rough schedule has been assembled to enable the market, infrastructure, and policy resolution to move forward at a rate comparable to the low-cost space transportation development rate.

Executive Summary

Summary of Conclusions

- Several markets look very promising for development of commercial space business parks
- Multi-use business parks are likely to be more cost-effective, thereby enhancing business success by reducing overhead costs
- All concepts depend on affordable, routine access to space
- Through pathfinders, the U.S. government can encourage early commercial development
- Significant policy issues remain before the International Space Station can be considered as an initial step to commercial space business parks
- Any future activities must begin with market studies characterized by direct customer feedback

Executive Summary

Summary of Conclusions

Based on the price-based analyses, the markets for satellite servicing and for passenger travel look particularly promising. In the early phases of commercialization of these new markets, it is likely that sharing overhead expenses by sharing orbital facilities, utilities, and transportation should reduce the up-front investment costs, thereby making the initial business development less costly and less risky. The market for commercial micro-gravity manufacturing does not appear to be large enough to support a dedicated manufacturing facility, although it might become a valuable tenant industry in a multi-use business park. It was outside the scope of this study to assess the scientific value of micro-gravity research in space.

Throughout the cost and price analyses, the cost of space transportation was consistently identified as a driver to the market feasibility of almost all commercial space business park markets, so the study team strongly supports NASA and private industry activities aimed at reducing the cost of space transportation and stimulating routine access.

There are a number of ways in which the U.S. government can encourage early business park forerunners, both by being an early customer of space business park ventures, and by allowing commercial use of government resources. The International Space Station and its systems, tooling, test sites, ground systems, and transportation infrastructure may be a particularly attractive site from which to develop commercial space business park precedents.

There is a strong desire to utilize the International Space Station and its systems, utilities, modules, and infrastructure in the initial phases of commercial space business park development. There are significant policy issues which must be resolved before serious consideration of ISS-derived business parks can be allowed. These include guarantees of service and price to commercial customers without scientific peer review competition.

Future studies and analyses related to space business parks must derive from direct customer communications and feedback.

Contents

Document Format 2

Credits 3

Executive Summary 5

Contents 11

1. Definition of Commercial Space Business Parks 13

2. Contract Description 17

3. Potential Markets 23

3.1 CSTS Market Identification 25

3.2 Screening Process 27

3.3 Screening Results 29

4. Case Studies 39

4.1 Satellite Servicing 41

4.2 Entertainment 61

4.3 Adventure Travel 73

4.4 Micro-gravity 83

5. Infrastructure Requirements 107

6. Architecture Concepts 121

7. Policy Issues 159

8. Roadmaps 177

9. Recommendations 181

Terrestrial Business Incubators 189

List of Acronyms 197

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1. Definition of Commercial Space Business Parks

1. Definition of Commercial Space Business Parks

Section 1 contains a working definition of Commercial Space Business Parks.

1. Definition of Commercial Space Business Parks

- A Commercial Space Business Park is a privately-owned and operated facility in orbit with multiple customers sharing common facilities and services.
- Operated as a multi-tenant facility with lodging, staff, utilities, operations, and transportation.
- Customers conducting multiple businesses
  - May contain a mix of private and government customers

1. Definition of Commercial Space Business Parks

The principal concept driving the definition of commercial space business parks is the economic value of sharing common resources among multiple businesses. Especially in the early phases of commercial enterprise in space, the costs of transportation, utilities, staff, and physical accommodations are likely to be a negative influence on any start-up space business. If these services can be shared among multiple, compatible users, the marginal costs should decrease, allowing a more favorable cost/benefit package. The concept is analogous to a shopping mall, where the commercial owner/operator provides real estate, common utilities, and a common parking, security, and maintenance infrastructure to the retail, entertainment, restaurant, hotel, and office customers. The mall becomes not only a means to share common resources, but becomes a business magnet itself.

2. Contract Description

2. Contract Description

Section 2 contains contract information for this Boeing contract with NASA Marshall Space Flight Center.

2. Contract Description

Commercial Space Business Parks Contract

- Task Order TOF-021 to NASA Marshall Space Flight Center Contract NAS8-50000
- Contract duration 7 August 1996 to 7 April 1997
- Objectives:
  - Assess the required market conditions and infrastructure
  - Identify related issues and actions that can stimulate the market for commercial space business parks
  - Identify the potential that the ISS and other space assets could contribute to the development of commercial space business parks

2. Contract Description

Commercial Space Business Parks Contract

This study was performed as a Task Order to the NAS8-50000 contract. The prime contractor is Boeing Defense and Space Group. The contracted activities were performed with Boeing staff in Huntsville, Alabama and Kent, Washington. A $8,000. subcontract was issued to Orbital Properties, Ltd. of Ann Arbor, Michigan to perform cost analyses of the space tourism market.

2. Contract Description

Contract Tasks

Kickoff Briefing

Select target markets
& industries for investigation

Create case studies to
prepare for customer contacts

Develop business & system architecture
concepts to support industries

Recommend integrated
planning roadmap

Submit final report

2. Contract Description

Contract Tasks

The focus of the contract was to begin to identify those markets which appear to be promising candidates for multiple-use business parks. Building on the results of the Commercial Space Transportation Study, performed in 1993-94, a variety of business areas were identified with commercial space potential. An initial screening was performed to limit the scope of analyses to that which fit the contract budget, and these four business areas were targeted for investigation.

- Satellite servicing
- Entertainment
- Tourism
- Micro-gravity materials processing

Case studies were performed for each of these four market areas to determine the following features:

- Costs required for market penetration
- Required infrastructure
- System architecture concepts for initial development scenarios
- Policy issues

A preliminary planning roadmap has been prepared to initiate planning discussions.

3. Potential Markets

3.1 CSTS Market Identification
3.2 Screening Process
3.3 Screening Results

3. Potential Markets

Section 3 describes the range of potential markets which were considered for investigation as Commercial Space Business Park candidate customer markets, the process by which a small number of markets were chosen for investigation in the current study, and the results of that process.

3.1 CSTS Market Identification

CSTS Study markets:

- Communications
- Space Manufacturing
- Remote Sensing
- Government Missions
- Commercial Space Business Parks
- Transportation
- Entertainment
- New Missions
- Space Utilities
- Extraterrestrial Resources
- Advertising

3.1 CSTS Market Identification

The Commercial Space Transportation Study (CSTS) was performed by six aerospace contractor study teams (Boeing, General Dynamics, Lockheed, Martin Marietta, McDonnell Douglas, and Rockwell) in 1993 through 1994. These teams identified eleven major market areas for a new commercial space transportation system. The market areas are listed here. The CSTS report, and the data bases that Boeing developed during this study, provided the initial market categories that were considered as targets for study in the current Commercial Space Business Parks (CSBP) study. Since the study funding did not allow a complete market survey of all of these markets, a screening was performed early in the CSBP study to select those markets that warranted further study within the contract resources.

3.2 Screening Process

- Process of voting
  - Multi-voting
- Scoring
  - Technical feasibility
  - Space adds value
  - Market size warrants investment
  - Represents spectrum of opportunities
  - Doable within scope of study (time, resources)
- Voters: who, affiliation

– Harvey Willenberg	Boeing	David Smitherman	MSFC
– Joe Hopkins	Boeing	Mark Nall	MSFC
– Mark Rubeck	Boeing	Bill Powell	MSFC
– Larry Torre	Boeing	Carey Thompson	MSFC
– Chuck Lauer	Orbital Properties	Jimmy Watkins	MSFC
– Bob Werb	Orbital Properties		
– Gordon Woodcock	Consultant, Boeing retired		

	Technical feasibility	Space adds value	Market size warrents investment	Some results achievable within study schedule, budget	Represents spectrum of market sectors
Entertainment (Exported)					
Earth imaging for cable/satellite TV services	3.55	2.91	2.36	Y	Y
movie/documentaries, music videos studio	1.91	2.64	2.36	Y	Y
TV show studio	1.82	2.55	2.27	Y	Y
advertising studio	1.82	2.45	2.55	Y	Y
advertising platform	2.60	2.40	2.50	Y	Y
sports (e.g. gymnastics)	1.64	2.45	2.45	Y	Y
orbital performance (e.g. ballet, dance)	1.60	2.30	1.90		
space art sculpture	2.00	2.20	1.60		
artist in residence	2.00	2.20	1		
Adventure Travel					
tours	2.18	2.91			
bed & breakfast/hotel	1.64				
resort	1.2				
gambling					
Education					
International Space University class					
consortium of universities bu					
Lunar Activities					
Lewis					

3.2 Screening Process

The selection of cases for study began with a review of the CSTS (Commercial Space Transportation Study, 1994). A list of candidate business opportunities was compiled. A multi-voting process employing experts from within Boeing, outside subcontractors (Orbital Properties) and NASA MSFC was used to prioritize the list. Factors such as technical feasibility, market size, and the value space adds to the product were all rated. Final Case Study selection was further based on choosing subjects for which results could be achieved during the time and budget of this study as well as representing a diverse spectrum of business opportunities and facility/operational uses.

3.3 Screening Results

3.3 Screening Results

The next three charts show the results of the screening process. In general, the micro-gravity light manufacturing markets scored highly on technical feasibility and on "space adds value", so two were selected for case study analysis. Heavy industry, on the other hand, scored low on all three rated criteria, and case studies were deemed out of the limits of the contract. Utilities scored well on "space adds value" and the market size was considered fair, but technical feasibility was ranked lowly. Also, a separate study was in progress to explore this market in detail. Some space operations rated well, so one was selected for case studies.

Entertainment scored highly on "space adds value" and the voting was split on market size. Technical feasibility was rated fair to low. Adventure travel was rated highly on two of the three criteria, with some skepticism in the technical feasibility.

3.3 Screening Results

Chart 1

		Technical feasibility	Space adds value	Market size warrents investment	Some results achievable within study schedule, budget	Represents spectrum of market sectors
	Biotechnology Light Manufacturing					
*	***protein crystal growth***	3.67	2.89	2.78	Y	Y
*	***cell culturing***	3.11	2.78	2.89	Y	Y
	purification of biological materials	3.11	2.56	2.56	N	N
	Inorganic Materials Light Manufacturing					
	contact lenses	3.11	2.33	2.33	Y	Y
	zeolites	2.56	2.33	2.33	Y	Y
	electro-optics materials	2.78	2.44	2.33	Y	Y
	advanced fiber optics	2.67	2.33	2.44	Y	Y
	Heavy Industry					
	structures	1.44	2.00	2.00	N	N
	bulk materials	1.33	2.00	1.89	N	N
	Utilities					
	express package delivery	1.64	2.09	2.27	N	Y
	EO telecommunication antenna farm	2.36	2.64	2.27	Y	Y
	er generation/transmission for Earth	1.36	2.73	2.45	N	N
	ration/transmission for space users	1.91	2.82	2.00	N	N
	equipment storage depot	2.45	2.18	1.82	Y	Y
	Information Processing					
	messaging	3.67	2.44	2.44	N	N
	financial services	3.33	2.11	2.33	Y	N
	business services	3.33	2.22	2.33	Y	N
	Space Operations					
*	***orbit satellite repair/servicing***	2.45	3.00	2.45	Y	Y
	pacecraft test and calibration facility	2.45	2.73	2.27	Y	Y
	satellite fuel depot	2.36	2.91	2.36	Y	Y
	commercial test bed center	3.50	3.00	2.00	Y	Y

* indicates market selected for case studies

3.3 Screening Results

Chart 1

From chart 1 the following items were selected for case studies.

- Biotechnology, light manufacturing
  - Protein Crystal Growth
  - Cell Culturing
- Space operations
  - On-orbit Satellite Repair/Servicing

3.3 Screening Results

Chart 2

		Technical feasibility	Space adds value	Market size warrents investment	Some results achievable within study schedule, budget	Represents spectrum of market sectors
	Entertainment (Exported)					
	Earth imaging for cable/satellite TV services	3.55	2.91	2.36	Y	Y
*	***movie/documentaries, music videos studio***	1.91	2.64	2.36	Y	Y
*	***TV show studio***	1.82	2.55	2.27	Y	Y
*	***advertising studio***	1.82	2.45	2.55	Y	Y
	advertising platform	2.60	2.40	2.50	Y	Y
	sports (e.g. gymnastics)	1.64	2.45	2.45	Y	Y
	orbital performance (e.g. ballet, dance)	1.60	2.30	1.90	Y	Y
	space art sculpture	2.00	2.20	1.60	N	N
	artist in residence	2.00	2.20	1.50	N	N
	Adventure Travel					
	tours	2.18	2.91	2.45	Y	N
*	***bed & breakfast/hotel***	1.64	2.91	2.36	Y	Y
	resort	1.27	2.91	2.45	N	N
	gambling	2.30	2.10	2.50	Y	N
	Education					
	International Space University classes/labs	1.82	2.55	1.73	N	Y
	consortium of universities buying lab space	2.45	2.82	2.18	Y	N
	Lunar Activities					
	Lewis & Clark bicentennial traverse	1.80	2.50	1.90	Y	N
	lunar remote theme park	2.09	2.91	2.27	Y	N

***** indicates market selected for case studies

3.3 Screening Results

Chart 2

From chart 2 the following items were selected for case studies.

- Entertainment
  - Movies/documentaries, music videos studio
  - TV show studio
  - Advertising studio
- Adventure travel
  - Bed & breakfast/hotel

3.3 Screening Results
Chart 3

	Technical feasibility	Space adds value	Market size warrents investment	Some results achievable within study schedule, budget	Represents spectrum of market sectors
Biological Microgravity Research					
plant growth	3.88	2.50	1.88	N	N
Materials Microgravity Research					
electro-optical materials research	3.56	2.67	2.00	N	N
combustion research	3.67	2.44	2.00	N	N
thermophysical properties research	3.56	2.56	2.00	N	N
Systems Microgravity Research					
teleoperation	3.63	2.13	1.88	N	N
robotics	3.44	2.00	1.89	N	N
Medicine					
basic research	3.67	2.56	2.11	N	N
clinical treatment	2.33	2.44	2.22	N	N
infirmary	1.44	2.22	1.67	N	N
Observation					
network news/camera stringer	3.10	2.50	2.20	N	N
disaster support	3.45	2.82	2.09	N	N
weather/climate	3.73	3.00	2.27	N	N
oil/gas, mineral, resources exploration	3.64	2.73	2.36	N	Y
resource management	3.45	2.73	2.36	N	Y
security	3.50	2.80	2.20	N	N
astronomy	3.82	2.91	1.64	N	N

3.3 Screening Results

Chart 3

No case studies were selected from chart 3.

3.3 Screening Results

Final Results of Screening

- These business activities scored high within their category and provide a range of opportunities over the spectrum of possible concepts
  - Satellite Servicing
  - On-orbit Sound Stage
  - Entry-level Adventure Travel
  - Micro-gravity
    - Protein Crystal Growth
    - Cell Culturing

3.3 Screening Results

Final Results of Screening

After reviewing the voting results, four areas were selected for case study analyses. These included two micro-gravity light manufacturing markets, one space operations market, an entertainment market, and a travel market. In the micro-gravity arena, protein crystal growth was chosen as the most mature of the potentially commercial markets, and cell culturing was chosen as one with a high market potential, although the scientific feasibility is yet to be confirmed.

On-orbit satellite repair and servicing was selected as a promising space operations market that could be made compatible with the micro-gravity manufacturing markets. The market size was considered large enough to warrant investment in a commercial space business park with associated transportation, space certainly adds value, and the technical feasibility was considered high.

In the entertainment arena, advertising and movie studios represent a large potential market area where space adds high value. An on-orbit sound stage is representative of the facilities and resources required for most of the entertainment markets in general, and so was selected for case study analysis.

The travel market chosen for case study analysis was entry-level adventure travel, where the travelers pay for the adventure and expect spartan accommodations, somewhat like mountaineering or safaris. This is the earliest expected market.

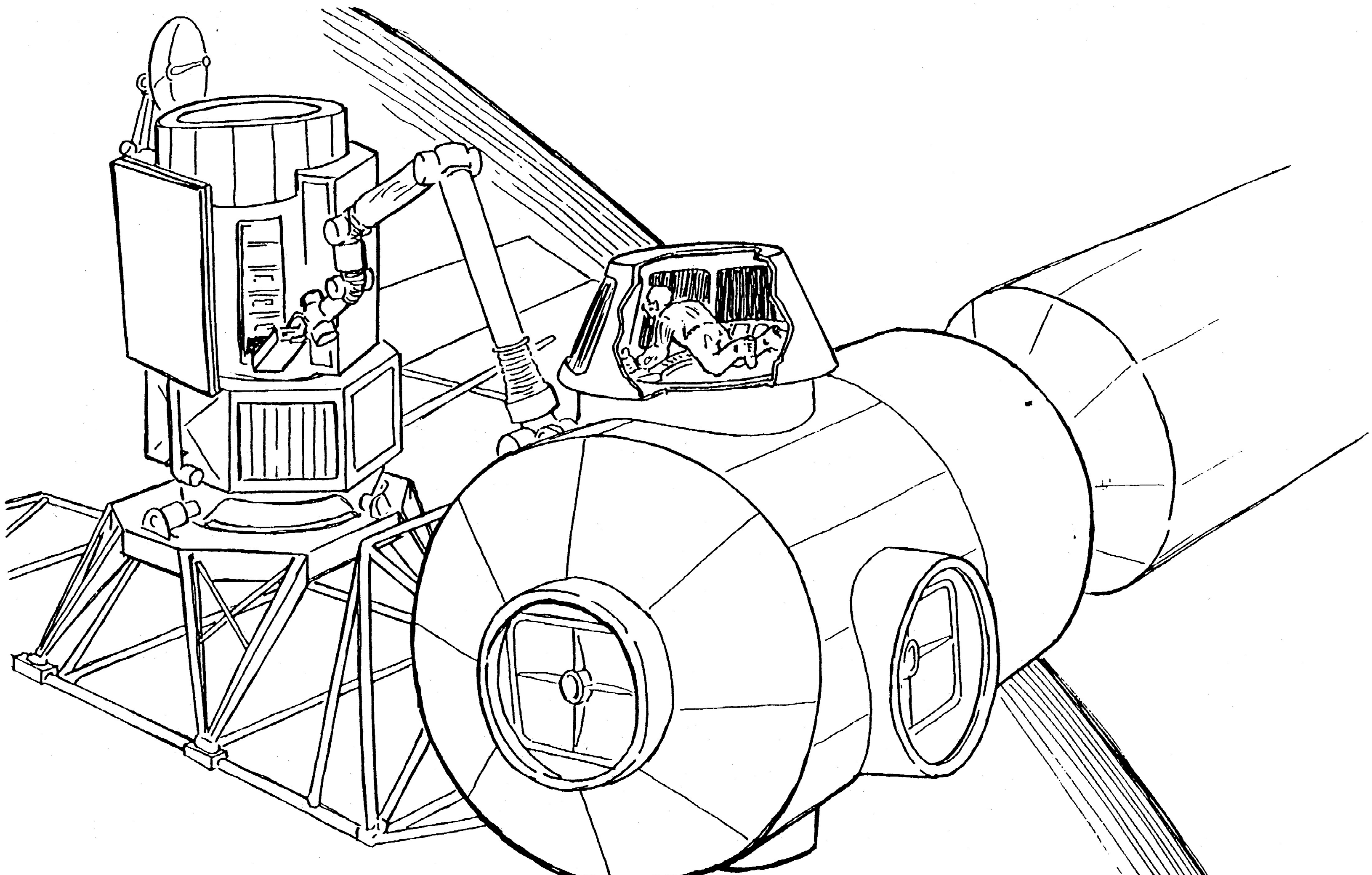
4. Case Studies

4.1 Satellite Servicing
4.2 Entertainment
4.3 Travel
4.4 Micro-gravity

4. Case Studies

Four case studies were performed for this contract. Section 4 summarizes these case studies.

4.1 Satellite Servicing



4.1 Satellite Servicing

This is an artist's conception of one possible approach to the servicing of satellites in space. It pictures the human servicing of an on-orbit satellite. The following charts will discuss some of the other approaches, as well as other topics pertaining to satellite servicing, and conclude with an affordability study.

4.1 Satellite Servicing

Potential Satellite Servicing Activities

- Repair or change out of failed components
- Payload change out or upgrade
- Propellant resupply
- Reboost
- Orbit or inclination change
- Scheduled maintenance (cleaning, decontamination, etc.)
- Testing/Calibration
- Salvaging
- Retrieval (decommissioning/graveyarding)
- In-orbit assembly

4.1 Satellite Servicing

Potential Satellite Servicing Activities

There are many activities which we consider to be included under the heading of satellite servicing.

1. Repair or change out of failed components - fixing of a broken satellite. It may be the repair of either a totally or partially non-functioning satellite.
2. Payload change out or upgrade - upgrading a satellite with improved technology or new on-board resources. It could be installing new transponders in a communication satellite or changing sensors on an Earth observation satellite.
3. Propellant resupply - refueling a satellite to extend its on-orbit life.
4. Reboost - using on-orbit propulsion to propel a satellite from orbit towards a higher orbit or a lunar or interplanetary destination.
5. Orbit or inclination change - moving a satellite from one orbit to another. This may be necessary to recover from a launch failure which has placed a satellite in an improper orbit, or to move a used communication satellite, which has been sold to a new owner serving a different location.
6. Scheduled maintenance - regularly scheduled satellite servicing for such functions as cleaning solar panels, replacing batteries, or any other activity which would prolong a satellite's life or improve its performance.
7. Testing/Calibration - on-orbit testing or calibration of scientific payloads such as telescopes or other sensors.
8. Salvaging - taking satellites which are considered no longer useful, and refurbishing them for resale, or removing reusable components for future use.
9. Retrieval - removing expired satellites from their orbital location at the end of their life.
10. In-orbit assembly - launching sub-assemblies and joining them on-orbit.

4.1 Satellite Servicing

Benefits to Customer of Satellite Servicing

- Reduce satellite down-time (and loss of revenue)
- Extend satellite lifetime
- Improve satellite performance
- Reduce need for spares
- Reduce need for replacement launches
- Reduce insurance costs
  - Ability to reposition satellite placed in bad orbit
  - Ability to repair on-orbit failures
- Remove satellites from orbit without use of on-board propellant

4.1 Satellite Servicing

Benefits to Customer of Satellite Servicing

There are many ways in which the ability to service satellites can be of value to a customer.

1. Reduce satellite down-time - Timely servicing can lessen the loss of revenue due to a satellite being out of service.
2. Extend satellite lifetime - Servicing can add years to a satellite's average productive life.
3. Improve satellite performance - Repair of a poorly functioning component or upgrading a functioning component with an improved one can yield improved satellite performance.
4. Reduce need for spares - The ability to service a satellite can reduce the need for spare satellites.
5. Reduce need for replacement launches - Repairing a satellite can avoid the need for launching a replacement.
6. Reduce insurance costs - The ability to recover from a partial launch failure or an in-orbit satellite failure should reduce the cost of satellite insurance.
7. Remove satellites from orbit without use of on-board propellant - Using an on-orbit facility to move a satellite out of its operating orbit would allow the satellite to use all of its on-board propellant for staying on station, giving it a longer useful life.

4.1 Satellite Servicing

Infrastructure Required for Satellite Servicing

- Reliable Earth-to-Orbit Transportation
- Orbital Transfer Vehicle
- Orbital Maneuvering Vehicle
- Robotic Satellite Servicing Vehicle
- Human Tended Servicing Platform
- EVA Suits, Hardware, Tools
- Fuel Tank Farm
- Space Based Communication System
- Space and Ground Based Mission Control Facilities
- Ground Cargo Handling and Module Repair Facility
- Crew Training Facilities

4.1 Satellite Servicing

Infrastructure Required for Satellite Servicing

There are several different approaches (and therefore architectures) that a satellite servicing business might adopt. Therefore, though all of the infrastructure elements on this list are not required for each approach, they represent the possible range of architectural elements.

1. Reliable Earth-to-Orbit Transportation - Reliable and affordable transportation to orbit is required for any satellite servicing scheme.
2. Orbital Transfer Vehicle - Moving satellites between orbits, or transporting GEO satellites to and from a LEO servicing facility would require an OTV.
3. Orbital Maneuvering Vehicle - Moving satellites within orbits, or to and from a servicing facility would require an OMV.
4. Robotic Satellite Servicing Vehicle - If satellite servicing is to be done remotely, say in GEO controlled from a LEO space business park or from an Earth-based control center, then a robotic servicer is needed.
5. Human Tended Servicing Platform - This would be required for direct human servicing.
6. EVA Suits, Hardware, Tools - If servicing is done in space, rather than in an enclosed facility, then these items would be necessary.
7. Fuel Tank Farm - This would be needed for satellite propellant resupply missions, and perhaps for refueling of the service vehicle itself.
8. Space Based Communication System - This would be needed for all approaches.
9. Space and Ground Based Mission Control Facilities - The approach used would affect the nature and location of control facilities.
10. Ground Cargo Handling and Module Repair Facility - The amount of work done on the ground versus in space would vary among approaches.
11. Crew Training Facilities - All approaches would have some crew training requirements.

4.1 Satellite Servicing

Satellite Customer Cost Issues

- Component Modularity
- Component Accessibility
- Satellite Attachment Points
- Ability to be Refueled in Space
- Satellite Upgradeability
- Commonality Among Satellite Manufacturers

Close cooperation between manufacturers and servicer is required for success.

4.1 Satellite Servicing

Satellite Customer Cost Issues

There may be some additional costs associated with designing and manufacturing “serviceable” satellites.

1. Component Modularity - Satellites must be made of modular components for easy on-orbit replacement.
2. Component Accessibility - Satellites must be made for easy access of components.
3. Satellite Attachment Points - There must be attachment points on the satellites for either robotic or human attachment while servicing, or for attachment during transport in space.
4. Ability to be Refueled in Space - Satellites will need to be compatible with refueling equipment.
5. Satellite Upgradeability - If it desired to allow for satellite upgrades with new technology after they are launched, then this must be built into them originally.
6. Commonality Among Satellite Manufactures - For satellite servicers to minimize their inventories of parts, tools, attachment hardware, etc. (and reduce their costs), satellites will need to have as much commonality as possible.

This is very much a “chicken and egg” situation. A satellite servicing business would only be attempted if it can be assured that these satellite design and manufacturing changes will occur. But likewise, satellite manufacturers will need to be convinced of the likelihood of a future satellite servicing capability before they absorb the cost of making these changes to their satellites. For this reason, close cooperation between the satellite servicing and satellite manufacturing industries will be necessary throughout the development and implementation of a satellite servicing capability.

4.1 Satellite Servicing

Satellite Servicing Affordability Analysis

Satellite Types	GEO Communication	GEO Communication	GEO Communication	LEO Communication	LEO Communication
	Direct Broadcast	Large BSS/FSS	Small BSS/FSS	Non-Teledesic	Teledesic
(example)	(HS702)	(HS601)	(HS376)	(Iridium)	(Teledesic)
Mission Types					
Repair or Replace Failed Component (total failure upon initial operation)	Sat. Repair - 1 year Sat. Replace - 3 yrs.	Sat. Repair - 1 year Sat. Replace - 3 yrs.	Sat. Repair - 1 year Sat. Replace - 3 yrs.	Sat. Repair Replace Spare	Sat. Repair / 2 Spares 4 Spares
Repair or Replace Failed Component (partial failure [50%] upon initial operation)	Sat. Repair - 1 year Sat. Replace - 3 yrs.	Sat. Repair - 1 year Sat. Replace - 3 yrs.	Sat. Repair - 1 year Reduced Revenue	-	-
Repair or Replace Failed Component (total failure halfway through design life)	Sat. Repair - 1 year Sat. Replace - 3 yrs.	Sat. Repair - 1 year Sat. Replace - 3 yrs.	Sat. Repair - 1 year Sat. Replace - 3 yrs.	-	-
Move Satellite to Proper Orbit (launch failure)	Sat. Move - 1 year Sat. Replace - 3 yrs.	Sat. Move - 1 year Sat. Replace - 3 yrs.	Sat. Move - 1 year Sat. Replace - 3 yrs.	-	-
Move Satellite to Proper Orbit (launch failure, recoverable with onboard propellant)	Sat. Move - 1 year Reduced Life	Sat. Move - 1 year Reduced Life	Sat. Move - 1 year Reduced Life	-	-
Refuel Propellant (once per satellite)	Extend Life - 3 yrs.	Extend Life - 3 yrs.	Extend Life - 3 yrs.	-	-
Move Satellite to Resale Location	Extend Life - 6 mos.	Extend Life - 6 mos.	Extend Life - 6 mos.	-	-
Satellite Graveyarding/Disposal	Extend Life - 6 mos.	Extend Life - 6 mos.	Extend Life - 6 mos.	-	-
Scheduled Maintenance (twice per satellite)	Extend Life - 5 yrs.	Extend Life - 5 yrs.	Extend Life - 5 yrs.	-	-
Satellite Parameters					
Satellite Cost ($M/satellite)	150	100	65	20	5
Satellite Launch Cost ($M/satellite)	75	60	50	10	5
Planned Satellite Life (years)	12	10	8	5	5
Satellite Revenue Potential ($M/year/satellite)	200	100	35	-	-
Number of Satellites per Spare	-	-	-	5	10
Affordable Price per Service Mission ($M)					
Repair or Replace Failed Component (total)	418	230	117	16	13
Repair or Replace Failed Component (partial)	266	154	64	-	-
Repair or Replace Failed Component (half life)	152	85	66	-	-
Move Satellite to Proper Orbit (unrecoverable)	418	230	117	-	-
Move Satellite to Proper Orbit (recoverable)	67	44	17	-	-
Refuel Propellant	168	101	44	-	-
Move Satellite to Resale	97	49	20	-	-
Satellite Graveyarding/Disposal	97	49	20	-	-
Scheduled Maintenance	118	86	44	-	-
Satellite Launches (over 20 year period)	100	350	50	200	800
Potential Missions (over 20 year period)					
Repair or Replace Failed Component (total) - 2% (GEO)	2	7	1	20	40
Repair or Replace Failed Component (partial) - 4%	4	14	2	-	-
Repair or Replace Failed Component (half life) - 2%	2	7	1	-	-
Move Satellite to Proper Orbit (unrecoverable) - 3%	3	11	2	-	-
Move Satellite to Proper Orbit (recoverable) - 1%	1	4	1	-	-
Refuel Propellant - 50%	50	175	25	-	-
Move Satellite to Resale Location - 40%	40	140	20	-	-
Satellite Graveyarding/Disposal - 60%	60	210	30	-	-
Scheduled Maintenance - 50%	50	175	25	-	-

4.1 Satellite Servicing

Satellite Servicing Affordability Analysis

The goal of this analysis is to get a feel for what customers might be willing to pay for satellite servicing. It looks at several scenarios and compares current approaches with approaches utilizing satellite servicing. It calculates the maximum amount a customer might be willing to pay for satellite servicing such that it would be economically advantageous.

Rather than study all of the possible servicing missions and all the satellite types, we have chosen nine of the more likely missions and five of the most numerous satellite types. Three of the satellite types are GEO communication satellites: Direct Broadcast such as the HS702, Large Broadcast Satellite Service (BSS) or Fixed Satellite Service (FSS) such as the HS601, and Small BSS/FSS such as the HS376.

The nine missions which we looked at for each class of GEO communication satellite are as follows:

1. Repair or Replace Failed Component (total failure upon initial operation) - Immediately after launch and deployment a satellite fails to perform. The options we compared were to repair the satellite, which we assumed would occur within one year, or to build and launch a replacement satellite, which would take three years. In the case of repair, there would be no revenue generated by the satellite until after the repair at the end of the first year. There would be a servicing cost at the end of year one and revenue from year two through the remainder of the planned satellite design life. In the replace scenario, there would be no revenue for three years, an amortized cost to build a new satellite in years one through three, a launch cost at the end of year three, and revenue for the life of a new satellite beginning in year four.
2. Repair or Replace Failed Component (partial failure [50%] upon initial operation) - Immediately after launch and deployment the satellite performs, but not at its full capability, resulting in returning only 50% of its planned revenue until it is repaired after one year or replaced after three.

4.1 Satellite Servicing

Satellite Servicing Affordability Analysis

3. Repair or Replace Failed Component (total failure halfway through design life) - The satellite operates as planned initially, but undergoes a total failure halfway through its planned life. Again, repair after one year is compared with replacement after three. (Note that in this case the difference in the remaining life of the two options is significant, the repaired satellite would only have half its life left, while the replacement satellite would function for an entire lifetime.)
4. Move Satellite to Proper Orbit (launch failure) - A launch failure causes the satellite to be launched into the wrong orbit, where it has no revenue producing capability. The options are to move the satellite to the proper orbit in one year or launch a replacement satellite in three years.
5. Move Satellite to Proper Orbit (launch failure, recoverable with on-board propellant) - In this case, the satellite has the capability to use its on-board propellant to move itself to the correct orbit. Moving it with a servicing vehicle would allow it to preserve its propellant for station keeping and therefore prolong its life.
6. Refuel Propellant (once per satellite) - Halfway through the life of the satellite a refueling mission would allow the satellite to function for three years more than one that is not refueled.
7. Move Satellite to Resale Location - A used satellite is sold and needs to move to a new location. If it is moved by a servicer it avoids using its own propellant and extends its life by six months.
8. Satellite Graveyarding/Disposal - If the satellite can avoid saving its on-board propellant for this function it can function for an additional six months.
9. Scheduled Maintenance (twice per satellite) - Twice during its lifetime, the satellite is serviced on orbit, adding five years to its revenue producing lifetime.

4.1 Satellite Servicing

Satellite Servicing Affordability Analysis

In the case of the LEO satellites, we looked at two classes of communication satellites: the non-Teledesic constellations such as Iridium, and the Teledesic constellation. We felt that only one of the satellite servicing mission types would be applicable to these satellites. Due to their relatively low purchase price and launch cost ,when compared to the GEO satellites, the other mission types would not be cost-effective.

For the non-Teledesic constellations, a failure would be replaced by an on-orbit spare. Then this spare would have to be replaced by the launch of a new satellite. Utilization of satellite servicing would allow repair of the failed satellite and using it to replace the spare. For Teledesic we assumed that satellite servicing would permit reducing the number of on-orbit spares from four per ring to two per ring.

The next step in the analysis was to take the mission types described above and the input values listed under "Satellite Parameters" and perform a Net Present Value (NPV) calculation (assuming a 20% discount rate) to determine the customers' break-even price for satellite servicing . This would be the price for satellite servicing which would yield the same NPV as the alternative without satellite servicing. It would therefore be the upper bound of what a customer would pay for satellite servicing. This value is different for each of the mission types and each of the satellite classes. The results are presented under "Affordable Price per Service Mission". There is a wide range of values, as would be expected given the difference in potential savings for each mission (e.g. avoiding building and launching a new satellite is worth more to a customer than extending the life of a satellite by six months) and the difference in satellite costs and revenues.

4.1 Satellite Servicing

Satellite Servicing Affordability Analysis

Next we had to estimate the number of each mission that would be expected during the first twenty years of satellite servicing. The number of each satellite type we might expect to be launched over a twenty year period is presented under "Satellite Launches". The likelihood of each mission type is listed as a percentage under "Potential Missions". The percentages of the first five mission types are based on historical data. The percentages of the last four mission types are assumed values. The values in the matrix under "Potential Missions" are therefore the product of these percentages and the expected number of "Satellite Launches" from above.

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4.1 Satellite Servicing

Satellite Servicing Affordability Analysis

Affordable Price ($M)	Number of Missions over Twenty Years
418	5
266	4
230	18
168	50
154	14
152	2
118	50
117	3
101	175
97	100
86	175
85	7
67	1
66	1
64	2
49	350
44	54
20	50
17	1
16	20
13	40

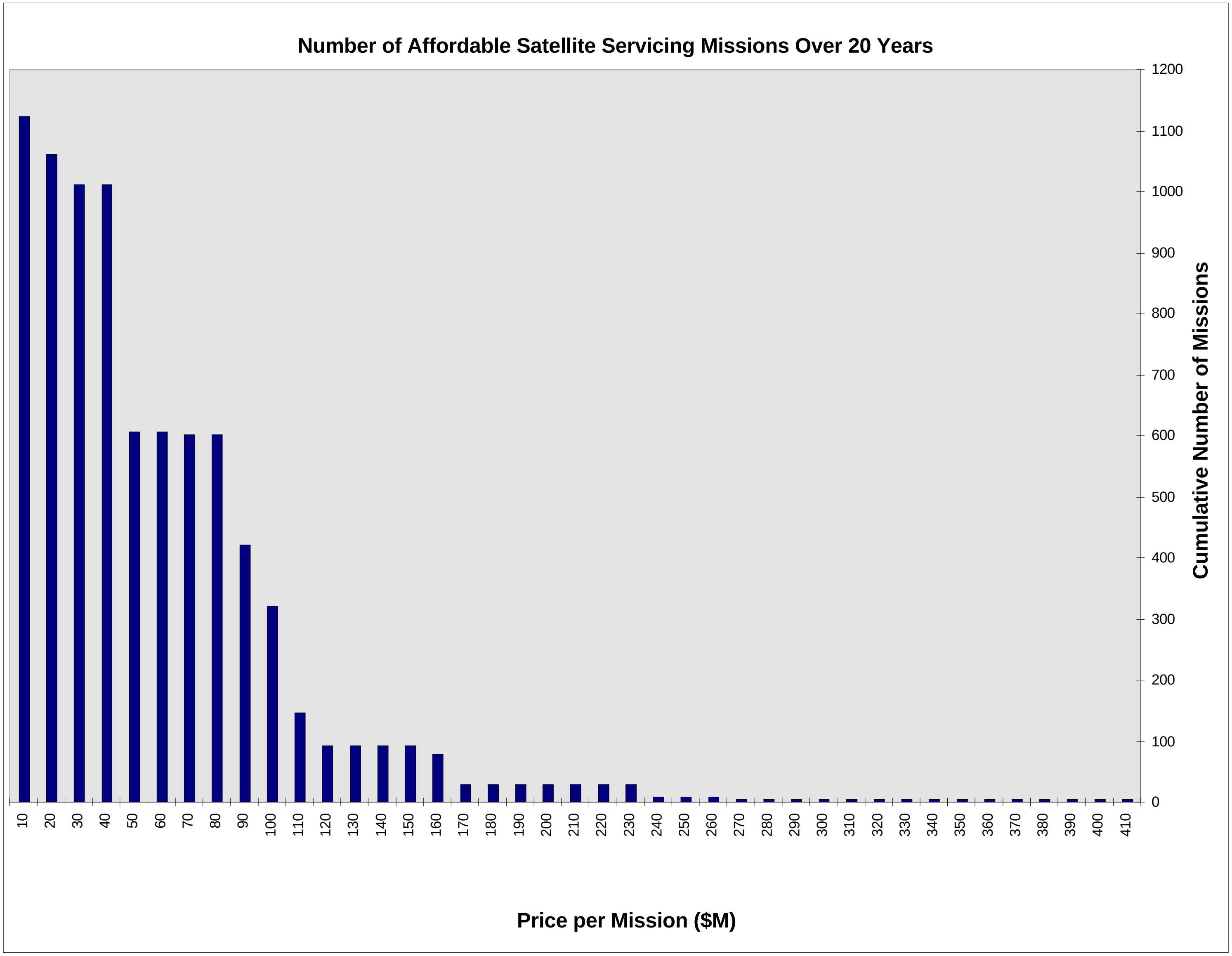
4.1 Satellite Servicing

Satellite Servicing Affordability Analysis

Taking the values from “Affordable Price per Service Mission”, and looking at the expected number of occurrences from “Potential Missions” allows us to construct a list of “Affordable Price” versus “Number of Missions”. This is then the maximum price that a satellite servicing business could charge for this number of missions over a twenty year period.

4.1 Satellite Servicing

Satellite Servicing Price Sensitivity



4.1 Satellite Servicing

Satellite Servicing Price Sensitivity

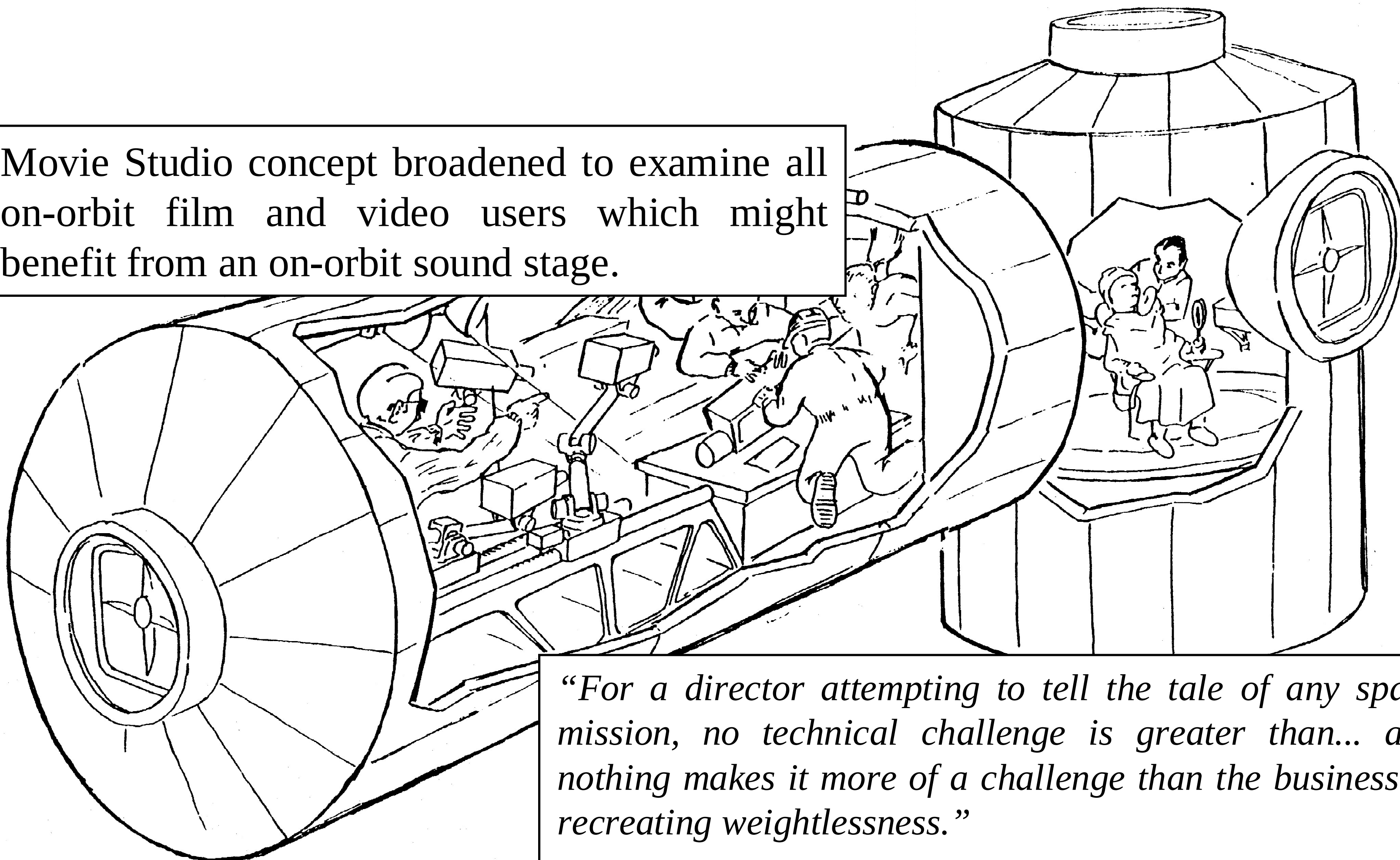
This is a plot of the data from the previous chart, showing the cumulative number of missions that would be affordable as the price of satellite servicing decreases. It shows that there are several high value missions, for which a customer would be willing to pay a high price, and dozens more which would only make sense if servicing were significantly less expensive, and finally hundreds which would require that satellite servicing be a very inexpensive service.

Remember that this is only a portion of all the possible satellite servicing missions. But it is valuable in providing insight into the price sensitivity of satellite servicing. The challenge will be to develop a concept and design of a satellite servicing operation whose costs are such that it can charge a price which allows it to capture enough missions to return a reasonable profit.

4.2 Entertainment

On-orbit Sound Stage

Movie Studio concept broadened to examine all on-orbit film and video users which might benefit from an on-orbit sound stage.



"For a director attempting to tell the tale of any space mission, no technical challenge is greater than... and nothing makes it more of a challenge than the business of recreating weightlessness."

Jeffrey Kluger, "Making of the Movie Apollo 13"

4.2 Entertainment

On-orbit Sound Stage

The on-orbit Sound Stage concept actually began as an investigation of providing a Movie Studio on-orbit. Investigation of the film industry showed that the same basic facility - a sound stage - is used for many different video products. While movies will potentially provide a strong revenue stream, broadening the capabilities and services to serve a full complement of sound stage users can make the venture more viable.

4.2 Entertainment

On-orbit Sound Stage Users

Users

- Movies
- Television
- Music Videos
- Documentaries
- Advertising
- Educational
- Stock video clips

4.2 Entertainment

On-orbit Sound Stage Users

In addition to movies, these are candidate sound stage customers.

4.2 Entertainment

On-orbit Sound Stage Infrastructure Requirements

- Pressurized volume for stage
- Un-pressurized platform for stage
  - OMV/CRV may be required to return crew to CSBP
- Booms
  - Camera, lighting, sound
  - Tele-operation capability for camera, lighting, sound
- Prep facilities for costuming, make-up
- Green room (holding room for cast, crew not actually working)
- Facilities for sets/props/costuming
  - Workshop
  - Storage

4.2 Entertainment

On-orbit Sound Stage Infrastructure Requirements

The chart shows the key elements that might make up the infrastructure requirements for an on-orbit sound stage.

4.2 Entertainment

On-orbit Sound Stage Staffing Requirements

- Cast/Crew
  - Actor(s)
  - Director
  - Props/sets
  - Costuming, makeup
  - TBD
- SBP Staff
  - Housekeeping
    - » Food/lodging support
    - » Off hours entertainment
  - Maintenance
    - » Technician(s) to maintain cameras, lights, sound, video/audio feed equipment

- Other Variables
  - Costs will keep crew to a minimum
  - Number of actors will vary depending on script
  - Crew to support costuming, makeup, sets and props will be required
  - Extensive video/audio feeds and tele-operation of cameras, sound and lights may be able to minimize number of crew required to support filming

4.2 Entertainment

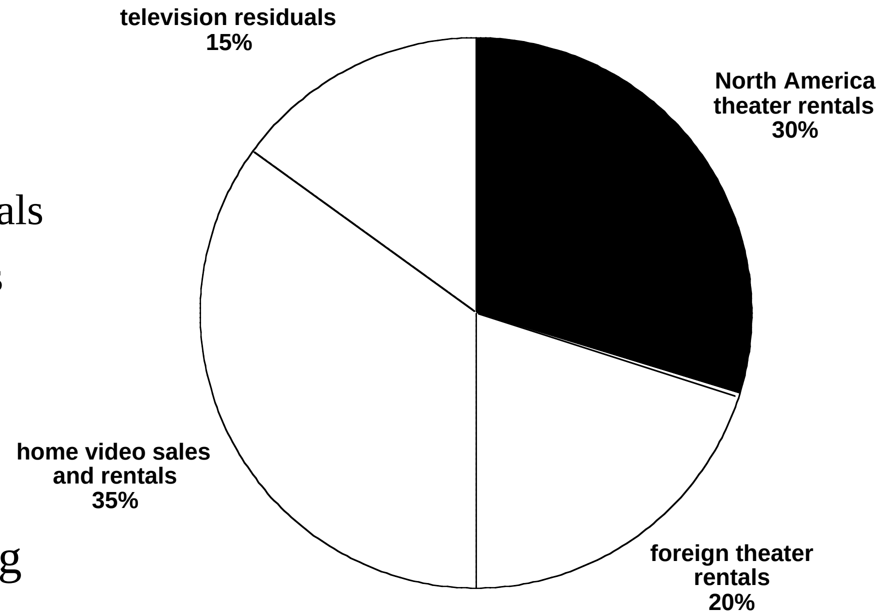
On-orbit Sound Stage Staffing Requirements

An understanding of the staff required to support a sound stage on-orbit will help size the support services and provide data defining transportation requirements for carrying passengers and logistics.

4.2 Entertainment

On-orbit Sound Stage Business Analysis (Today's Market)

- 1995 movie revenues: $15 billion
  - North America theater rentals (26,000 theaters, est. 1.26 billion tickets sold)
  - Foreign theater rentals
  - Television and cable residuals
  - Video tape sales and rentals
- 644 (2289) movies produced
  - 35 (57) Science Fiction
  - 23 (36) Horror
- Average film costs (excluding "top" star salaries)
  - Production $35 million
  - Distribution $18 million



4.2 Entertainment

On-orbit Sound Stage Business Analysis (Today's Market)

The movie industry alone is a multi-billion industry, but an average movie only has a few tens of millions to spend on production. If an on-orbit sound stage is priced too high, few movies will be able to afford its services.

The original presumption in this analysis was that Science Fiction and Horror movies, by their subject and typically used special effects, might be ideal candidates for on-orbit moviemaking. However, after considering the themes and subjects of many movies, it is possible, that many other movies might also be candidates for on-orbit filming. For example, some film company might want to depict a "Lucy goes to orbit" or "Jimmy Stewart serves on space station" themed movie.

4.2 Entertainment

On-orbit Sound Stage Costing Process

<u>Addressable</u>
e.g. Science Fiction
Horror
Docu-drama

↓

<u>Capture</u>
5-10%
translates into
3-5 movies/yr

→

<u>ROM Costs</u>
Transportation
6 to 30 people
(@400 lbs to 700 lbs/person)
x 3 to 5 trips/yr
(@$500/lb to $2,000/lb)
Lodging
1 to 4 modules
(@ $80 to $100 million/module)
(amortized over 10 yrs)
Scene/Props/Costuming Mass
1,000 to 50,000 lbs/movie

4.2 Entertainment

On-orbit Sound Stage Costing Process

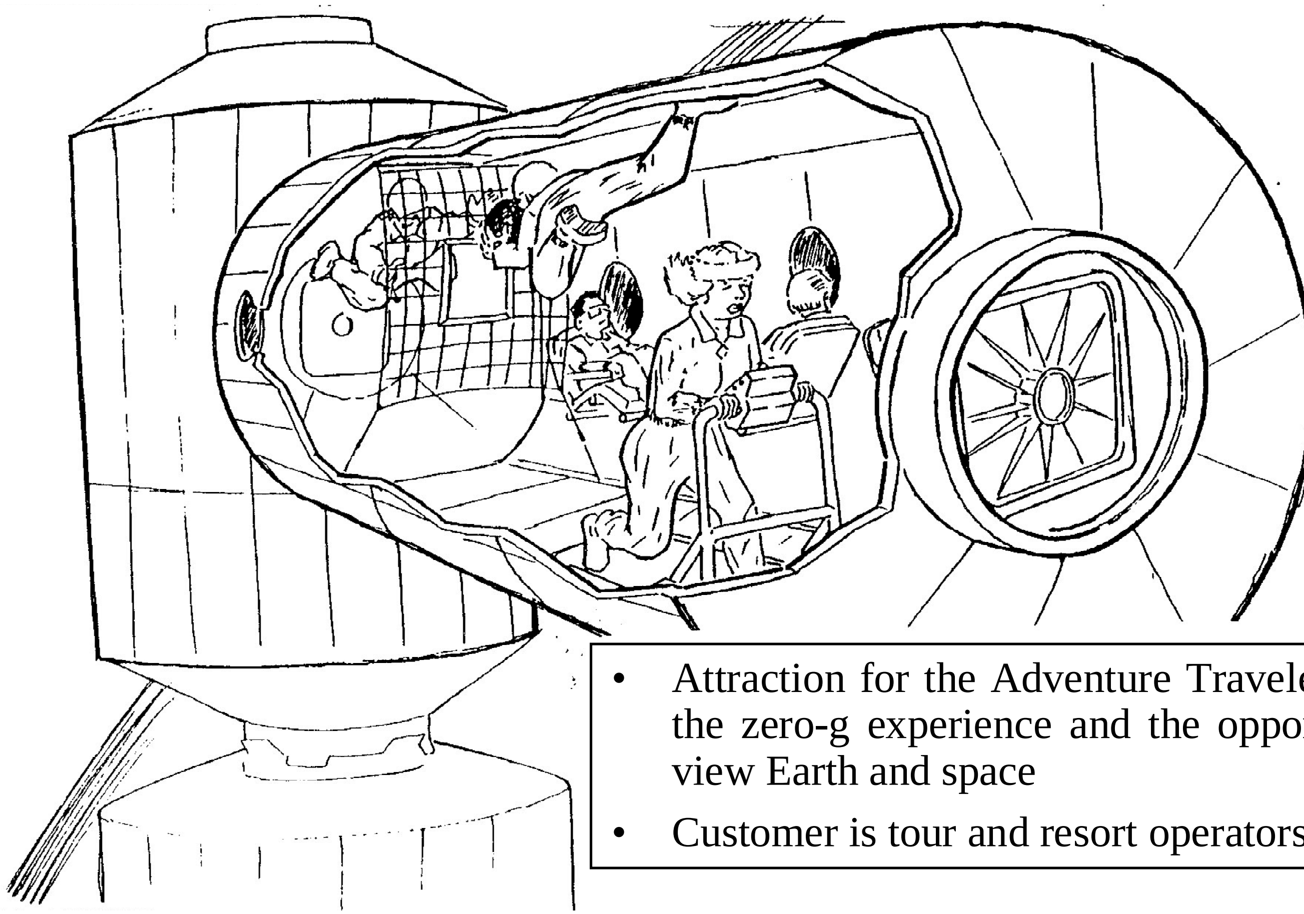
The addressable market for an on-orbit sound stage is expected to be equivalent to 5-10% of the science-fiction, horror, and docu-drama market, or 3-5 movies per year. As a check on the cost of providing a service, some ROM costs of a sound stage were generated. For such a unique(and expensive) site, each filming opportunity will require from 6 to 30 people and 1,000 to 50,000 lbs of scene, props, costuming, etc. to be on-orbit for a month or two. Each person is assumed to weight 400-700 lbs, with clothing, food, air, and water, supplies, and emergency equipment. At $500-2,000 per pound to orbit, which is anticipated to be achievable commercially within the next ten years or so, this means that transportation costs should be between $1 million and 40 million per trip. Based on 3-5 movies per year, the market could be somewhere between $3 million and $200 million per year.

The sound stage crew and cast can be accommodated in one to four modules that are analogous to the International Space Station common modules. Assuming that ISS common module designs and tooling can be used for a commercial space business park, the recurring cost of fully-outfitted modules can be in the ballpark of $80-100 million/module. If these are amortized over ten years, the amortization cost would be $15-100 million per year, adding another $3-30 million per movie.

These costs are high, but they are entirely within the budget of many movies being produced today.

4.3 Adventure Travel

Early space tourism will begin by providing a weightless experience and “views” for the Adventure Traveler.



- Attraction for the Adventure Traveler will be the zero-g experience and the opportunity to view Earth and space
- Customer is tour and resort operators

4.3 Adventure Travel

Much has already been discussed about passenger travel in space. Rather than developing business analyses of a mature, highly populated industry, we have focused the current study on the early fare-paying space traveler. This was done because the mature industry will not develop until the costs of human space transportation are dramatically decreased. The early space traveler is more likely to fit the profile of the young, adventurous, and very affluent travelers that currently climb mountains, go on safaris, visit Antarctica, etc. The attraction for these travelers is expected to be the thrill of micro-gravity and the opportunity to view the Earth from space.

4.3 Adventure Travel

Present Market Conditions

- Adventure Travel packages range from $30-50K
  - Can exceed $100K
- Cruise ship packages range from $5-10K/week
  - Average annual revenues per ship are $85 million
  - Average cost of new ship $330 million
- Luxury hotel rates can exceed $500-1000/night

4.3 Adventure Travel

Present Market Conditions

The market around which the travel case study was built is that of the entry-level adventure travel industry. This industry is characterized by a small population with sufficient resources that they can afford to pay in the neighborhood of $100,000 for an adventure trip-of-a-lifetime and that, further, they are adventurous and physically fit enough to do so. This is not yet a travel package for the middle-class. This is the traveler that climbs mountains, explores Antarctica, hunts wild game in Africa, etc. The conditions are often spartan and the risks are high, but understood.

To compare costs with current adventure travel packages, these packages current range between $30,000 and $50,000, and can exceed $100,000 today. Those agencies that specialize in this travel class are profitable and growing.

The capital cost associated with cruise ship packages can often approach $1 million, including the cost of the cruise ships and the destination resorts. Hundreds of people pay $5-10,000 per week for these cruise ships.

4.3 Adventure Travel
Infrastructure Requirements

- Lodging
  - Sleeping
  - Privacy
  - Viewing Earth
- Staffing
  - Tour Coordinator(s)
  - Housekeeping
  - Operations/Maintenance
- *Cost-sensitive Requirements*
  - EVA capability
  - Shirtsleeve human-rated OMV/OTV
  - High-bandwidth constant two-way communications

4.3 Adventure Travel

Infrastructure Requirements

The adventure traveler, as well as the business traveler, will require facilities for eating and sleeping, as well as staff to support those services. In addition, the tourist will need to have activities to occupy their time. Some of the desired activities may require significant development (and therefore cost) which could drive the resulting product pricing too high.

4.3 Adventure Travel

Costing Process

<u>Addressable</u>
e.g. Japanese Space Society Survey
STA/NSS study

↓

<u>Capture</u>
translates into
400 to 4000 tourists/yr

→

<u>ROM Costs</u>
Transportation
6 to 30 people
(@400 lbs to 700 lbs/person)
x 3 to 5 trips/yr
(@$500/lb to $2,000/lb)
Lodging
1 to 4 modules
(@ $80 to $100 million/module)
(amortized over 10 yrs)

4.3 Adventure Travel

Costing Process

Following a similar analysis to that performed for the on-orbit sound stage, each traveler is expected to carry between 400 and 700 lbs per flight to the space business park, including people, supplies, food, etc. At $500-2,000 / lb, this translates to transportation costs of $0.2-$1.4 million per person. Adding the cost of amortizing the lodging costs, this grows to $0.5-2 million per person per flight.

This analysis accentuates the sensitivity of space tourism markets to transportation costs. This is likely to be expensive even for the high-end adventure traveler, although even at these costs, there are always likely to be a few travelers willing and able to pay the price. Some public statements have already been made by several people willing to pay up to $10 million for a Space Shuttle flight, for example. Several people have already flown aboard the Mir Space Station at this price. Some market has been demonstrated to exist, but not currently at a level that justifies the total investment from scratch.

4.3 Adventure Travel

Very Preliminary Business Analysis

- Using Mir/Soyuz assets as an entry market builder is viable only for special, limited promotions
  - costs will exceed $20M / ticket
  - currently only 5-6 tourists could fly annually, though if Soyuz production returned to historic levels, up to 25 tourists could fly
- Using ISS/STS assets as market builders requires significant change in NASA policy
  - present policy does not allow civilian access on ISS/shuttle
  - costs are unknown for using ISS assets
  - policy changes and marginal pricing might allow up to 12 passengers annually at ticket prices of a few million dollars
- Probably viable as one element of a multi-use business park using dedicated LEO tourist facilities once low-cost space passenger service begins

4.3 Adventure Travel

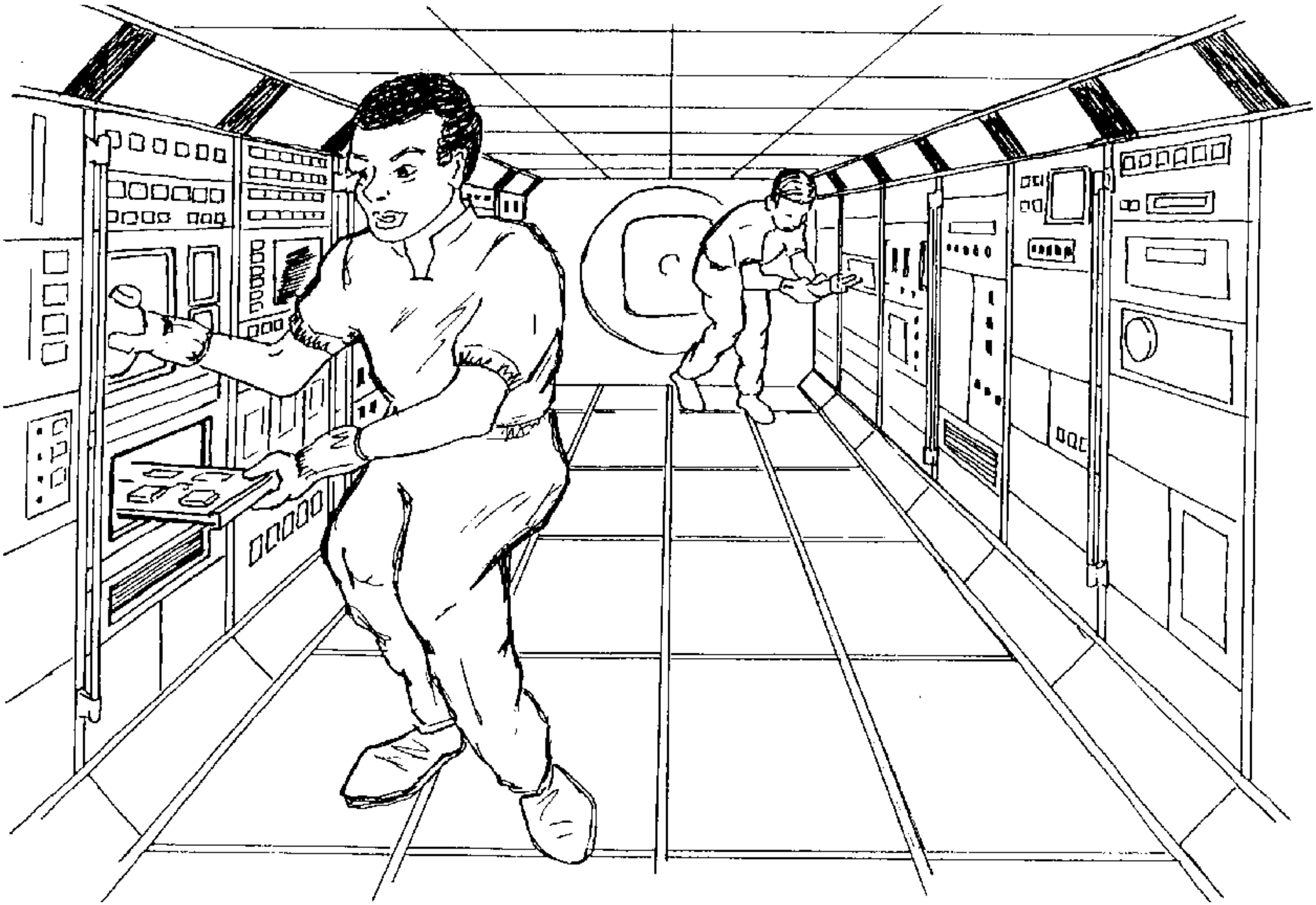
Very Preliminary Business Analysis

There are at least three different ways to start a space-oriented adventure travel industry. The first is to take advantage of the only system that has so far flown passengers for a fee. That is the combination of the Soyuz spacecraft as a transportation vehicle and the Mir Space Station as a travel destination. Each Soyuz vehicle is designed to carry three people, and actually requires two cosmonauts to operate it. Therefore, each Soyuz flight can carry at most one passenger. Soyuz and Mir is viable only for special, limited promotions and not as the basis of a growing market sector.

Present policy does not allow access to the International Space Station (ISS) and the Space Shuttle by private citizens who wish to pay the fare. Although the ISS/Shuttle combination may theoretically serve a few passengers per year, this is not considered a viable starting point for a commercial industry.

It appears that, as attractive as adventure travel might sound as a commercial space business park market, until transportation costs can be reduced even further than the $500-2,000 / lb assumed here, this will not be a stand-alone market. Once low-cost space passenger service begins, however, this is probably viable as one element of a multi-use commercial space business park using dedicated low-Earth orbit tourist facilities.

4.4 Micro-gravity



4.4 Micro-gravity

This is an artist's conception of human tended micro-gravity facility. It pictures human servicing of micro-gravity experiment racks similar to those used in Spacelab and planned for space station.

4.4 Micro-gravity

Protein Crystal Growth

Benefits to the Customers

- Diffusion-controlled growth
  - More perfectly-ordered crystals for x-ray and/or neutron diffraction studies
- No gravity-driven sedimentation allows crystal to stay suspended
- Lack of gravity to cause crystal to collapse during growth

Problem

- 1996 through 2005-2010
  - Ground-based technologies will replace need for micro-gravity-grown crystals

4.4 Micro-gravity

Protein Crystal Growth

Why Grow Protein Crystals in Space?

- Diffusion-controlled growth results in slower crystal growth rates resulting in lower defect densities, giving more perfectly ordered crystals for x-ray and/or neutron diffraction studies to determine the protein three-dimensional structure
- Lack of gravity-driven sedimentation allows crystal to stay suspended in growth media and continue to grow to larger, more useable size for diffraction studies
- Lack of gravity to cause protein crystals to collapse in on themselves during growth which results in defect formation

Window of Opportunity: 1996 through 2005-2010

- By this latter time, advanced ground-based techniques of directly imaging individual protein molecules in solution will be available, essentially eliminating the need to grow crystals of proteins as a route to determine their molecular structure.
- This means that the commercial market for micro-gravity protein crystal growth must be structured such that a satisfactory return on investment is made before 2005 or so, or there will be no commercial investment.

4.4 Micro-gravity

Protein Crystal Growth Pricing Issues

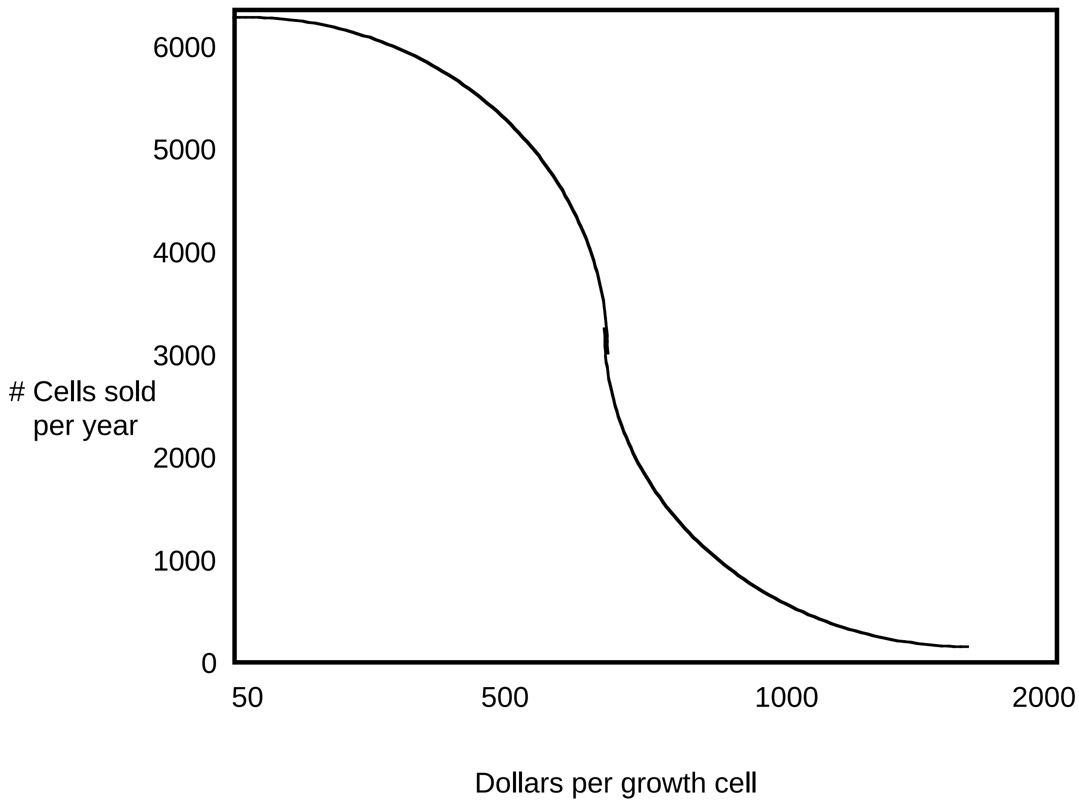
Previous Experience:

- Customers willing to pay \$100 < price < \$1000/cell
- 200-400 cells/year/ customer
- 10-50 customers
  - Large, medium, small
- Based on discussions with >12 pharmaceutical companies, large and small

Estimated Market Potential

- \$3 M/year for 6000 growth cells/year

Conceptual Price Elasticity



4.4 Micro-gravity

Protein Crystal Growth Pricing Issues

What would customers pay?

- A typical example from Boeing discussions: would pay $100 per growth cell, but would not pay $1000 per growth cell at an estimated purchase of 200-400 cells per year at the low end of this price range.
- Assuming $500/cell and 300 cells/year:
  - $500/cell x 300 cells/year = $150,000/year from a large biotech company
- Assuming 6 first-tier companies wish to fly per year at this estimate, assuming 12 second-tier companies to fly per year at 50% of this level, and assuming 24 third-tier companies to fly per year at 33% of this level:
  - $3 M/year at a total of 6000 growth cells/year
- This is the total revenue expected for commercial micro-gravity protein crystal growth. An investor must be able to provide the services and generate a profit from total sales of $2-12 M/year in a business that may become obsolete by 2010.

4.4 Micro-gravity

Protein Crystal Growth Infrastructure Requirements

- Low-cost, reliable space access
  - Thermal & biological instabilities of protein solutions and crystals require firm schedules
- Benign return conditions
  - Temperature, accelerations, vibrations, etc.
- Thermally-controlled transportation
  - Freezers, refrigerators during ascent/descent
- Rapid sample return
  - Every two weeks would be desirable
- On-orbit analytical capability (primarily x-ray diffraction)
  - QA of crystals pre/post descent
  - Analysis of unstable, very short-life crystals
- Teleoperations: support crystal mounting & manipulation on-orbit
  - Reduce crew training requirements
  - Limited crew time available
  - Reproducibility and accuracy required

4.4 Micro-gravity

Protein Crystal Growth Infrastructure Requirements

The requirements for micro-gravity protein crystal growth are fairly well established from more than a decade of space flight experience.

The requirements listed here are for International Space Station utilization. The requirements for commercial users on any manned platform, such as a Space Business Park, would be very similar or identical.

The first three requirements are firm requirements, and the remainder are to enhance throughput and make the business economically attractive.

4.4 Micro-gravity

Protein Crystal Growth Cost Estimate

- Transportation, processing, on-orbit crew time, resource costs all depend currently on as-yet undefined pricing policies for use of government resources.
- Assuming Spacehab pricing
  - Transportation costs: 2 lockers/resupply x $1M/locker x 4 resupplies/year = **$8 M/year**
- Commercially-purchased Commercial Protein Crystal Growth System cost estimate = **$5-7 M**

4.4 Micro-gravity

Protein Crystal Growth Cost Estimate

What would the costs be to do commercial micro-gravity protein crystal growth?

Operations and infrastructure costs will include transportation (ground and flight), processing/handling (ground and flight), on-orbit crew time and resource (power, data, etc.) costs, and administration/coordination, which are all difficult to determine since hard, reliable pricing policies have yet to be developed by NASA or other spacefaring international agencies.

Spacehab commercial pricing was used for the estimate, since few transportation pricing estimates exist. Although flexible on pricing, a mid-deck locker on Spacehab would cost approximately $1M to transport.

The non-recurring cost to develop, launch, and integrate a commercial protein crystal growth payload facility in orbit will be an expensive one-time expense (not including future upgrades or repairs). Based on a commercial copy of currently-available flight hardware suitable for commercial PCG operations, an estimate of $5-7 M is made for this non-recurring cost.

4.4 Micro-gravity

Protein Crystal Growth Preliminary Business Assessment

Not viable as a stand-alone business

- Gross revenue = $3 M/year
- Initial costs = $5-7 M; transportation costs = $8 M/year
- The potential cash flow does not support current or near-term projected infrastructure and pricing constraints.
- For the foreseeable future, NASA and the other national space agencies will continue to subsidize this activity for research purposes, making commercial competition difficult at best.

Possibly viable as one of many micro-gravity services offered.

- The potential cash flow may contribute to a total commercial space business park approach of a multi-functional space facility offering a multitude of on-orbit processing services.
- However, protein crystal-growth would appear at best to be a short-term opportunity for a space business park, and may not be viable by the time a Commercial Space Business Park is on-orbit and operational by late next decade.

4.4 Micro-gravity

Protein Crystal Growth Preliminary Business Assessment

The cost of providing a commercial protein crystal growth service has been estimated at $5-7 M for a Commercial Protein Crystal Growth System, and about $8 M/year for transportation. Other costs will likely include on-orbit crew time and resource utilization. The revenue to be generated has been estimated at $3 M/year for less than ten years. This negative cash flow does not appear to be attractive to medium-to-large companies or investors. Given the known and unknown costs to fly and support a commercial protein crystal growth payload in space, even a significant improvement in the market estimate yields a marginal investment risk.

Without competing with government-subsidized research programs, commercial protein crystal growth may be an attractive business opportunity/investment for smaller, leaner companies, particularly on a commercially-operated space platform where costs and schedules must be well-defined and consistent. This includes smaller tenants of a Commercial Space Business Park, and a commercially-operated International Space Station.

4.4 Micro-gravity

Cell & Tissue Culturing

- Worldwide, the biotechnology market was about $6 billion in 1993.
  - Primarily health care and agriculture
- This market is expected to growth to $40 - 100 billion/year by 2000.
- Two areas of most intense commercial development:
  - High-value, biologically-active products harvested from genetically-engineered cells and single-cell organisms
  - Production of live cells and tissues for medical and research needs

4.4 Micro-gravity

Cell & Tissue Culturing

Biotechnology, including cell and tissue culturing, is a newer, very dynamic business and technology arena, often with large investments required and very high returns for a winning product.

One major emphasis in cell and tissue culturing is the production of living cells and tissues for use in medical treatments and research. A major end goal would be the growth of new three-dimensional tissues and whole organs for transplantation needs. *In vitro* cell differentiation to self-organize into whole organs is technically not yet feasible, but may be in the next two decades.

A second emphasis area is the culturing of genetically-engineered cells (including single-cellular organisms) and tissues to produce desirable protein and hormone products. The value of some of these products **exceeds $100 M/gram**!

4.4 Micro-gravity

Cell & Tissue Culturing Benefits to the Customers

- Lack of gravity-driven sedimentation allows live cells and tissues to stay suspended in growth media and continue to grow, reproduce, and self-organize for longer duration than with similar ground-based culturing
- Lack of gravity enhances three-dimensional cellular organization rather than two-dimensional organization to produce bulk (rather than sheet-like) tissues.
- Micro-gravity research indicates cells grow slower in space, but differentiate faster.

4.4 Micro-gravity

Cell & Tissue Culturing Benefits to the Customers

This is a relatively new discipline for space operations and is still in a basic research phase to determine the value of culturing cells in micro-gravity. These benefits are based on the small, but growing, space flight experience by micro-gravity researchers. For three-dimensional tissue growth, lack of sedimentation under micro-gravity conditions allows much longer growth cycles, which results in larger, more fully-developed tissue structures than can currently be produced on the ground.

4.4 Micro-gravity

Cell & Tissue Culturing Infrastructure Requirements

- Low-cost, reliable space access
  - Thermal & biological instabilities of living cells and tissues require firm schedules
- Benign return conditions
  - Temperature, accelerations, vibrations, etc.
- Thermally-controlled transportation
  - Freezers, refrigerators, incubators during ascent/descent
- Rapid sample return
  - Every four to six weeks would be desirable
- On-orbit analytical capability
  - QA of cells and tissues pre/post descent
  - Process monitoring
  - Contamination identification and remediation
- Tele-operations: support processing operations on-orbit
  - Reduce crew training requirements
  - Limited crew time available
  - Reproducibility and accuracy required

4.4 Micro-gravity

Cell & Tissue Culturing Infrastructure Requirements

The requirements for micro-gravity cell and tissue culturing are still being established. The requirements listed here are for International Space Station utilization. These requirements would be very similar or identical for commercial users on any manned platform.

The first three requirements are firm, and the remainder are for economical enhancements to the process throughput.

Due to the extreme fragility and thermal sensitivity of the living products, transportation requirements are likely to be exacting and costly. There will be significant logistics impacts for large volumes of fresh and spent growth media transportation.

4.4 Micro-gravity

Cell & Tissue Culturing Cost Issues

What would customers pay?

- One estimate for transplantable tissue culturing on orbit is $7 K per culture
- Example values for cell-generated products:
  - Human nerve growth factor: $1.75 M/gram
  - Human stem cell factor: $27 M/gram
  - Human platelet-derived growth factor: $134 M/gram

4.4 Micro-gravity

Cell & Tissue Culturing Cost Issues

The actual value of cultured three-dimensional tissue products for medical applications is based on limited and uncertain estimates. The prices for cell lines and tissue specimens for research are typically on the order of a few dollars to a few tens of millions of dollars per 2 milliliter sample.

One recent start-up company proposing to focus on micro-gravity production of three-dimensional tissue cultures for medical use has estimated tissue product value at $7,000 per culture.

Genetically-engineered cell products can be extremely high-value and low-volume --- which are desirable characteristics of space products in general. The ultra-high value is partially due to the rarity or difficulty of production and purification of these bioactive products.

4.4 Micro-gravity

Cell & Tissue Culturing Cost Estimate

- Transportation, processing, on-orbit crew time, resource costs all depend currently on as-yet undefined pricing policies for use of government resources.
- Assuming Spacehab pricing,
  - Transportation costs: 6 lockers/resupply x $1M/locker x 4 resupplies/year = **$24 M/year**
- Commercially-purchased Commercial Cell & Tissue Culturing System cost estimate = **$3-5 M**

4.4 Micro-gravity

Cell & Tissue Culturing Cost Estimate

What would the costs be to do commercial micro-gravity cell & tissue culturing?

Operations and infrastructure costs will include transportation (ground and flight), processing/handling (ground and flight), on-orbit crew time and resource (power, data, etc.) costs, and administration/coordination, which are all difficult to determine since hard, reliable pricing policies have yet to be developed by NASA or other spacefaring international agencies.

Spacehab commercial pricing was used for the estimate, since few transportation pricing estimates exist. Although flexible on pricing, a mid-deck locker on Spacehab would cost approximately $1M to transport.

The non-recurring cost to develop, launch, and integrate a commercial cell and tissue culturing payload facility in orbit will be an expensive one-time expense (not including future upgrades or repairs). Based on a commercial copy of currently-available flight hardware, an estimate of $3-5 M is made for this non-recurring cost.

4.4 Micro-gravity

Cell & Tissue Culturing Preliminary Business Assessment

Possibly viable as a stand-alone business

- The high humanitarian value of three-dimensional tissue cultures for medical use, along with the possibility of eventual whole organ production, and the extremely high value of some engineered cell products will make this an attractive area for investors, once value-added is definitely shown for micro-gravity-based production.
- NASA and the other national space agencies will continue, for the foreseeable future, to subsidize this activity for research purposes, making commercial competition difficult at best.

Possibly viable as one of many micro-gravity services offered

- The potential cash flow may contribute to a total commercial space business park approach of a multi-functional space facility offering a multitude of on-orbit processing services.

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5. Infrastructure Requirements

5. Infrastructure Requirements

Section 5 describes the infrastructure required for multi-use commercial space business parks in low-Earth orbit.

5. Infrastructure Requirements

Common Infrastructure

- Transportation
  - Affordable
  - Regular
- Lodging
- Off-hours entertainment
- Logistics
  - Food
  - Air
  - Water
  - Cleanup/waste management
  - Clothes
- Orbital Maneuvering Unit

  (required for some activities)
  - Satellite servicing
  - Free flyer human tended access
  - Un-pressurized filming support
- Robust Crew Return / MediVac capability

5. Infrastructure Requirements

Common Infrastructure

The basic elements that are required for virtually all markets to be serviced by a space business park include transportation and logistics. The transportation must be both affordable and, equally important, regular. Schedule predictability is essential to any profit-making venture that provides a customer service. Logistics includes those factors related to repeated, regular services. For markets that involve human spaceflight, food, lodging, and emergency return transportation are required and, if the people are to remain on-site for more than a few days, some form of off-hours entertainment is required.

In addition, many of the potential markets for space business parks involve activities outside the pressurized home base. These require space-to-space transportation systems, such as orbital maneuvering units, and docking systems.

5. Infrastructure Requirements
Structure Element Options

- Space station elements
  - Racks
  - Modules
  - Nodes
  - Platforms
  - Power, thermal, utilities
- External Tank
- Inflatables
- Constructed on-site
- External Access Nodes
  - Airlock
  - Docking
    - » Transportation
    - » Orbital maneuvering unit

5. Infrastructure Requirements

Structure Element Options

Four different options have been identified for use in space business parks. These include:

1. Maximum use of the design, test, and tooling heritage developed for the International Space Station Program. This would include the pressurized modules and internal systems, external structures, and utilities.
2. Use of the NSTS external tank (ET) as a large initial structure in space. This could include linking multiple ETs, on-orbit internal outfitting of an ET, and/or modifications to allow habitable compartments, windows, docking ports, etc.
3. Use of inflatable structures.
4. On-site construction of the orbital infrastructure from common structural materials. This means on-orbit framing of the primary structures from pre-fabricated materials, joining, pressurizing, and testing on-orbit, and internal furnishing. This approach is analogous to the way in which buildings are constructed on Earth.

All structures that require transportation to and from a space business park require two additional elements. These are an airlock and docking/berthing systems.

5. Infrastructure Requirements

Common Utilities

- Power
- Air
- Water
- Other liquids, gases
- Waste Recycling/Disposal
- Telecommunication
  - Voice/fax
  - Computer (email, ftp, internet, web...)
  - Video
  - Teleoperations

5. Infrastructure Requirements

Common Utilities

These are the utilities that would be required for virtually all space business park customer markets.

There are at least three advantages to a multi-use commercial space business park. These are shared use (and therefore shared cost) of the transportation, shared use of these common utilities, and re-use by many customers of the basic structures.

5. Infrastructure Requirements

Common Staff / Skills

- Technician(s)
- Customer Coordinator(s)
- Housekeeping
  - Cook
  - Cleaning
- Operations/Maintenance
  - Stationkeeping
  - Communication
  - Medical care

Individuals with multi-disciplinary skills will be preferred during the early startup of commercial space business parks

5. Infrastructure Requirements
Common Staff / Skills

If humans are to be placed in a commercial space business park, then there are certain skills that will be required of either the fare-paying passengers or a paid staff. Since fare-paying passengers will not be professional astronauts, they will not be prepared for extensive (more than a week or two) training to prepare for their single mission. These chores will then be required to be performed by a well-trained, dedicated staff. Since it is expensive to fly each staff person to and from the space business park, there will be a strong advantage in developing individuals with multiple skills that will stay on-orbit as long as is feasible.

5. Infrastructure Requirements

Orbit Selection

- Many applications are orbit neutral
- Industrial applications benefit from low inclination orbits
- Adventure Travel and Observation benefit from high inclination orbits
- Satellite servicing
  - GEO telecommunications satellites benefit from 0° inclination
  - Multi-plane LEO constellations benefit from high (polar) inclination
- Research piggybacks on other activities

5. Infrastructure Requirements
Orbit Selection

A critical discriminator in deciding which multiple uses are compatible is the orbit in which the user can operate. Industrial applications, especially micro-gravity manufacturing, are orbit-neutral except for that fact that more payload can be launched to low-inclination orbits and therefore these applications benefit from lower launch costs to low-inclination. Tourist travel and Earth observation industries benefit from high-inclination orbits, where the passengers or observation equipment can see as much of the Earth as possible. Satellite servicing orbit requirements are very specific to the market conditions: servicing geosynchronous satellites favor equatorial orbits and low-Earth orbit constellations favor higher inclination. The latter market will be strongly influenced by a viable, cost-effective orbit transfer vehicle.

5. Infrastructure Requirements

Other Considerations

- Special Requirements of EVA
- Tele-operation of Cameras, Sound, Lighting
- “Window” for Tourism

5. Infrastructure Requirements
Other Considerations

Other factors that must be considered include special requirements for extravehicular activities (EVA), cameras, and tourists. EVA requires standard space suits for passengers and staff. It also requires airlocks and docking systems. It is likely that, even if current policies are modified to allow passenger travel to pressurized facilities in space, additional policy evolution would be required to allow fare-paying passengers to travel outside the space ship or business park.

One of the primary motivations to space travel is the panoramic view of Earth from space. It is clear that tourism will require large, high-quality windows.

6. Architecture Concepts

6. Architecture Concepts

Section 6 describes a number of options for evolution of commercial space business park architectures. It also describes possible evolution schedules, costs, and applicability to the four market areas for which case studies were performed in this study.

6. Architecture Concepts

Preliminary Architecture Options

- Minimum Delta from Space Station
- Pressurized Free Flyer(s)
- Mixed Use Facility
- Crew/Cargo Vehicle as Micro-gravity Free Flyer

6. Architecture Concepts

Preliminary Architecture Options

Four scenarios were developed for evolution of the commercial space business park (CSBP) architecture and infrastructure:

1. Minimum delta from the Space Station. This scenario uses the International Space Station (ISS) now under construction, as well as the design knowledge, tooling, and test experience. Space business parks built under this scenario resemble an ISS that is tailored to specific commercial markets.
2. Pressurized Free Flyer(s). These would resemble free-flying modules in low-Earth orbit, designed to operate independently of the ISS.
3. Mixed-Use Facility. Resembles the ISS with additional elements that are uniquely designed.
4. Crew/Cargo Vehicle. This option is specifically designed to be self-contained and not reusable. It launches as a complete system, operates on orbit for a specified period, and returns either the whole system or the critical payload to Earth.

6. Architecture Concepts

Minimum Delta from Space Station

- Existing and New Infrastructure
  - Rack(s)
  - Module(s)
  - External pallet(s)
  - Power and thermal
- Supporting Accommodations
  - Staff
  - Utilities
  - Transportation

Maximize use of pre-existing assets and knowledge gained during space station development

6. Architecture Concepts

Minimum Delta from Space Station

This scenario likely evolves from the ISS. Using as much common hardware, software, and design knowledge as is feasible, this begins with a commercial incubator aboard ISS. A business incubator is a multi-use facility with common infrastructure such as buildings, equipment, and staff, which is frequently established with the support of local governments to encourage the success of small, start-up businesses by minimizing the initial investment cost and risk. This ISS-based incubator may be a few racks inside one of the ISS laboratories (or nodes) or a pallet mounted externally. Internal or external, the rack/pallet and its payload would be privately-owned and, to the greatest extent feasible, privately operated. As the market grows, the pathway for evolution of pressurized payloads would be from a few racks to a commercial module (node or lab), to an independent pressurized facility that might piggy-back routine transportation to and from the ISS, to a totally commercial enterprise.

Starting aboard ISS allows use of already-existing equipment, transportation, and processes. This should minimize the costs associated with providing utilities and might minimize crew-related costs. Delicate policy issues related to this scenario include guaranteed access to services for commercial profit, and commercial priorities driven solely by bottom-line profitability, rather than "common benefit to society."

6. Architecture Concepts

Free Flyer

- In vicinity of space station
- Module(s)
- Rack(s)
- Human tended, teleoperated
- Orbital maneuvering vehicle
- Additional power, utilities
- Telecommunication

6. Architecture Concepts

Free Flyer

A variation on use of the ISS itself as an initial point is a human-tended free-flyer which operates in the vicinity of the ISS. This would be a facility, either pressurized or unpressurized, that operates in an ISS-compatible orbit to take advantage of the ISS as a transportation hub. It would likely not be permanently occupied, but rather would be used by human crew when required for satellite servicing, equipment servicing, and fare-paying passengers. Required infrastructure includes orbital maneuvering vehicles and additional power and telecommunications.

6. Architecture Concepts

Permanently-Occupied Mixed-Use Facility

- Use of components originally designed/developed for space station
  - Modules, racks, nodes
  - Other structures (inflatables, External Tanks...)
  - Power, thermal, other utilities
  - Telecommunication
  - Provisions for staff/visitors (e.g. lodging, food)
  - Free flyers may be part of facility, for operations dependent on high precision micro-gravity or other unique attributes
- Time-shared use of large space for making movies and common play area for tourists. Facility support staff provides services for lodging, food, technicians to make movies and/or service satellites

6. Architecture Concepts

Permanently-Occupied Mixed-Use Facility

This scenario is similar to the free-flyer, but would be a permanently-occupied and independent space station. It would use components originally designed and developed for the ISS, and would have provisions for professional staff and paying visitors. It may fly in formation with the ISS, or it may have its own transportation system and operate entirely independently of ISS.

6. Architecture Concepts

Crew/Cargo Vehicle (CCV) as Micro-gravity Free-Flyer

- Short stay (up to 3 months) flights launched by Sea Launch class vehicle, then reenter
- Racks
- Telecommunication, teleoperation
- Power, thermal
- Other utilities

6. Architecture Concepts

Crew/Cargo Vehicle (CCV) as Micro-gravity Free-Flyer

A crew/cargo vehicle that is self-contained for a single flight might be an attractive initial step for a micro-gravity market. The vehicle would be launched with its payload and operate for several months before returning to Earth intact. This would provide an ideal environment for materials processes that are sensitive to vibrations such as crew motion. Other equipment might be included as secondary payloads in a multi-use, time-sharing mode. This might include Earth-observation equipment as well as spacecraft components undergoing space qualification testing.

6. Architecture Concepts

Evolution Options

- ISS
  - govt only
    - ISS evolves
    - ISS + commercial free flyers
    - privatized ISS
    - ISS sold
  - Mir + ISS technology
    - Free flyer
    - Free flyer start, grows to multi-module facility
    - multi-module facility
    - multi-module facility + free flyer constellation
- Mir
  - Mir only
  - Mir + ISS technology
- External Tanks
  - ET only
  - ET + ISS technology
- Inflatables
  - Inflatables only
  - Inflatables + ISS technology
- On-orbit Framing
  - on-orbit framing only
  - on-orbit framing + ISS technology
- Micro-gravity Orbiter/Return Vehicle

6. Architecture Concepts

Evolution Options

Merging the architecture options with some possible evolution scenarios yields this option tree for evolution of space business parks (SBP).

1. ISS-based evolution. Starting with the international government-owned and operated facility, the ISS can evolve with commercial elements added to it, with commercial free flyers dependent on ISS access, or the facility can be privatized or sold to a commercial owner. Mir can be operated as a human-tended free-flyer, growing to either a free-flyer constellation or to multi-modular facility that grows and is eventually permanently-occupied again.
2. CSBP evolving from the existing Mir infrastructure. Either commercial purchase of the existing Mir station or adding ISS technologies to Mir.
3. Three other evolution options for space business parks involve starting with external tanks, inflatable structures, or on-orbit framing. In each case, they may take advantage of ISS technology.
4. Micro-gravity Orbiter/Return Vehicle. This branch has no further evolution, because it returns to Earth after each trip.

6. Architecture Concepts

Market Viability Evaluation Criteria

H High probability of market viability

- customer needs addressed
- market size large
- investment interest high
- transportation
  - available
  - affordable
- policy issues resolvable

M Medium probability of market viability

- customer needs addressed, with difficulty
- market large enough to suggest further study
- investment probable, but further study required
- transportation
  - less available
  - less affordable
- policy issues resolution challenging

L Low probability of market viability

- customer needs not addressed adequately
- market size small
- investment unlikely to obtain reasonable returns
- transportation
  - availability questionable
  - expensive
- policy issues resolution unlikely

6. Architecture Concepts

Market Viability Evaluation Criteria

Each of these evolution scenario branches was reviewed for market viability according to the four markets that were selected for case studies. For each of the markets: protein crystal growth & cell culturing, satellite servicing, on-orbit sound stage, and entry-level adventure travel; market viability was addressed according to these evaluation criteria. It is recognized that these evaluations are very subjective.

6. Architecture Concepts
Transportation Capability

- Current - for commercial users all systems considered expensive, with unacceptable availability
  - Shuttle
  - Soyuz
  - Expendable Launch Vehicles (Sea Launch, Proton, Ariane, Atlas, etc.)
- Near term - Next Generation Launchers (2001)
  - EELV ($2000-$3500/lb)
  - Sea Launch enhanced
  - Micro-gravity Orbiter/Return Vehicle
- Mid Term (2004)
  - Venture Star ($1000-$2000/lb)
- Far Term (2006-2008)
  - Highly Reusable Space Transportation System (<$500/lb)
- All systems assumed to be safe for human flight
- All prices assume transportation to low inclination LEO

6. Architecture Concepts

Transportation Capability

To try to place a timeline on each of the development scenarios, some assumptions must be made about the timescale for evolution of the space transportation infrastructure.

Activities that can technically be performed now must use either the Space Shuttle, Soyuz, or expendable launch vehicle such as SeaLaunch, Ariane, or Proton.

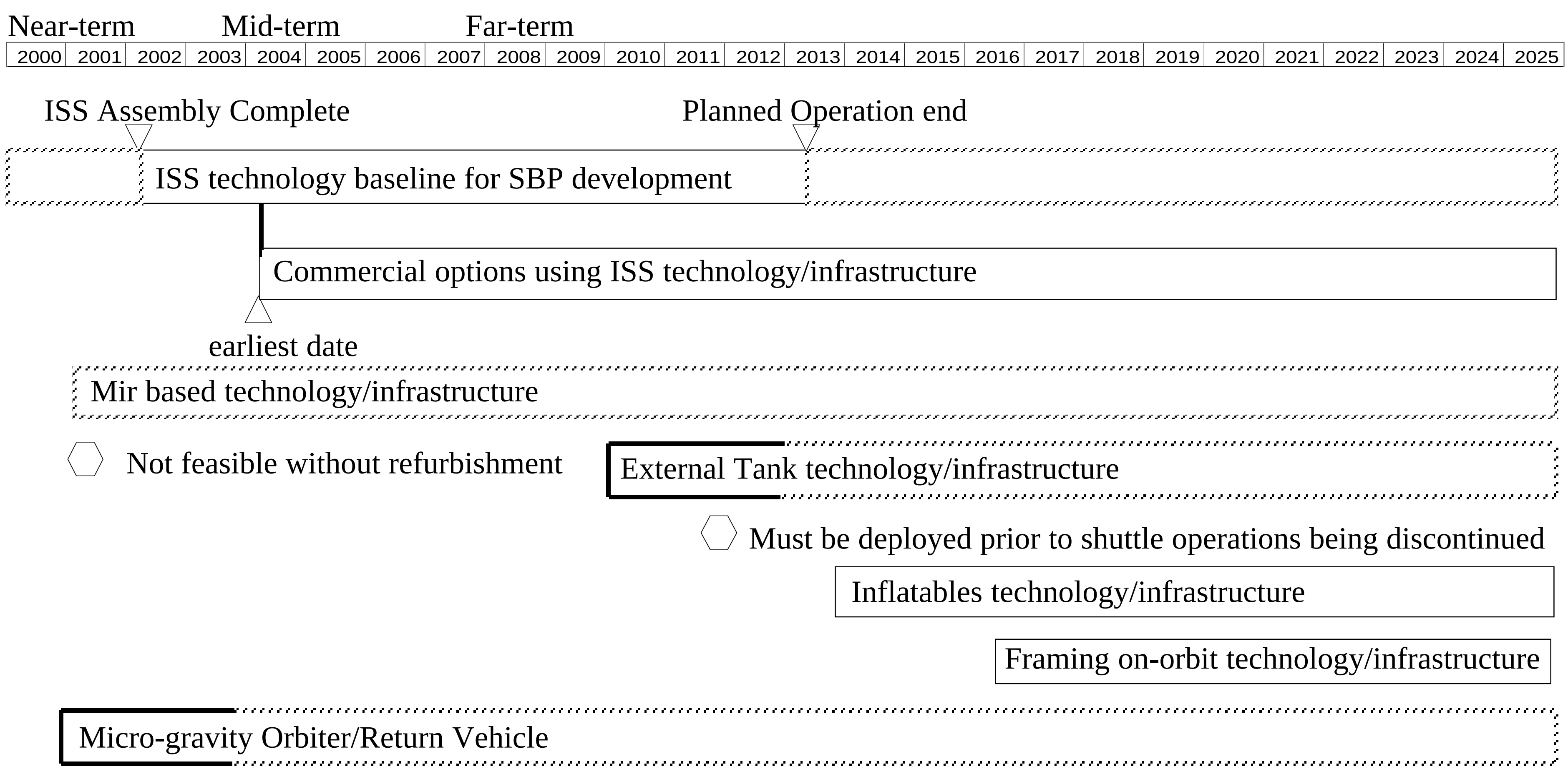
It is assumed here that the next generation of launchers, which will bring transportation costs down to $2000-3500/lb to LEO, will be available by 2001.

It is further assumed that an RLV, such as VentureStar, will bring transportation costs down to $1000-2000/lb by 2004.

Transportation costs of $500/lb or less are not considered to be likely before the 2006-2008 time frame.

6. Architecture Concepts

Alternative CSBP Time-Phasing



6. Architecture Concepts
Alternative CSBP Time-Phasing

A schedule overview comparing the various scenario options. Commercial Commercial Space Business Parks could begin as early as the turn of the century using a refurbished Mir as a facility. Alternatively short duration facilities which include a ‘return’ capability could be deployed in the near term. Once space station becomes operational there are many commercial space business park variants that become possible. The International Space Station itself could be an initial step with pathfinder business ventures using the space station assets for commercial purposes. After the space station demonstrates an operational capability, financing will likely be forthcoming to build and operate commercial space business parks utilizing assets derived from the International Space Station program.

Other space business park development scenarios are possible, but the DDT&E involved (none of which has yet begun) would push the operational deployment of systems using new technologies further into the future. Such systems might be based on shuttle External Tanks or inflatables. Even further in the future may be the on-orbit “framing” of facilities built up piecemeal from component parts, much as most construction is hand-crafted today on Earth.

6. Architecture Concepts

Mir CSBP

Near-term Mid-term Far-term

2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025

Facility continues with only Russian built Mir technology

ISS technology derived components (*e.g.* racks, modules, platforms, utilities) added

	Current	Near	Medium	Far
Micro-gravity	L	M	H	H
Satellite servicing	L	M	M	M
Entertainment, on-orbit sound stage	M	M	H	H
Entry level adventure travel	L	L	L	M

Costs

- estimated purchase price: $700 million
- estimated refurbishment price: $400 million

6. Architecture Concepts
Mir CSBP

This scenario presumes purchase and refurbishment of the Russian space station, Mir. This scenario could conceivably happen at any time. Analysis, negotiations, financing etc. and the follow on refurbishment could lead to a commercial operational capability as early as 2000 or 2001. Components derived from ISS technology could be incorporated into the facility. If refurbishment does not proceed soon, Mir will be abandoned.

6. Architecture Concepts

Micro-gravity Orbiter/Return CSBP

Facility developed independent of ISS technology derived components, however, would use ISS racks

Costs
- estimated price: $300 million

Current	Near	Medium	Far	
L	M	N/A	N/A	**Micro-gravity**
M	H	H	H	**Satellite servicing**
N/A	N/A	N/A	N/A	**Entertainment, on-orbit sound stage**
N/A	N/A	N/A	N/A	**Entry level adventure travel**

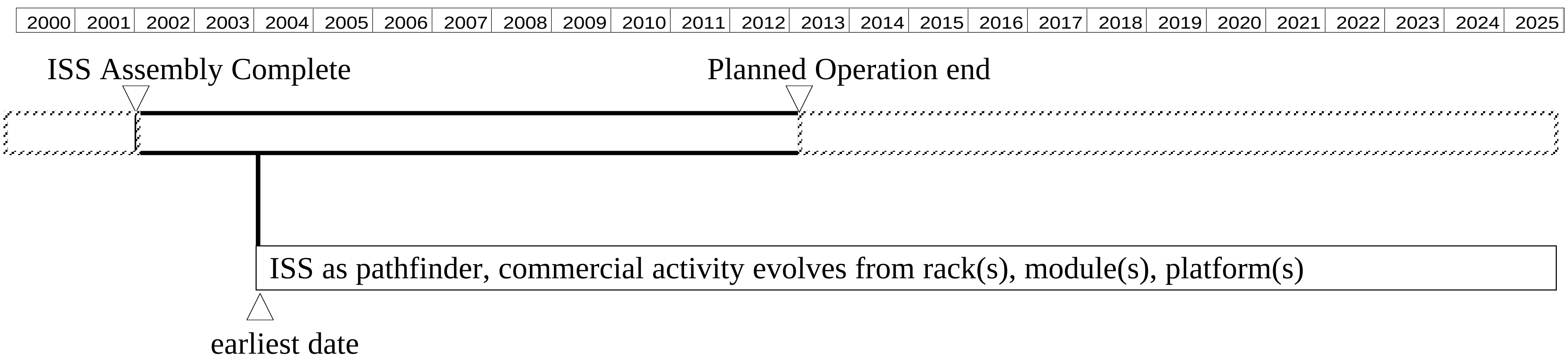
6. Architecture Concepts

Micro-gravity Orbiter/Return CSBP

This system would provide automated, tele-operated micro-gravity services for durations of up to 90 or 120 days. The Orbiter would be equipped with standard space station racks and sub-systems, including a source of power. It would be available pressurized or unpressurized. It could be launched by an expendable launch vehicle, Sea Launch class and would return on its own. This scenario will likely not be competitive if other facilities are available continuously on-orbit. However, this might be a viable “starter” scenario.

6. Architecture Concepts

ISS CSBP Incubator



Current	Near	Medium	Far	
L	M	H	H	**Micro-gravity**
L	M	H	H	**Satellite servicing**
L	M	H	H	**Entertainment, on-orbit sound stage**
L	L	M	M	**Entry level adventure travel**

Costs

- estimated price: $80-100 million/module, additional infrastructure estimated as ‘total cost of modules times 2’

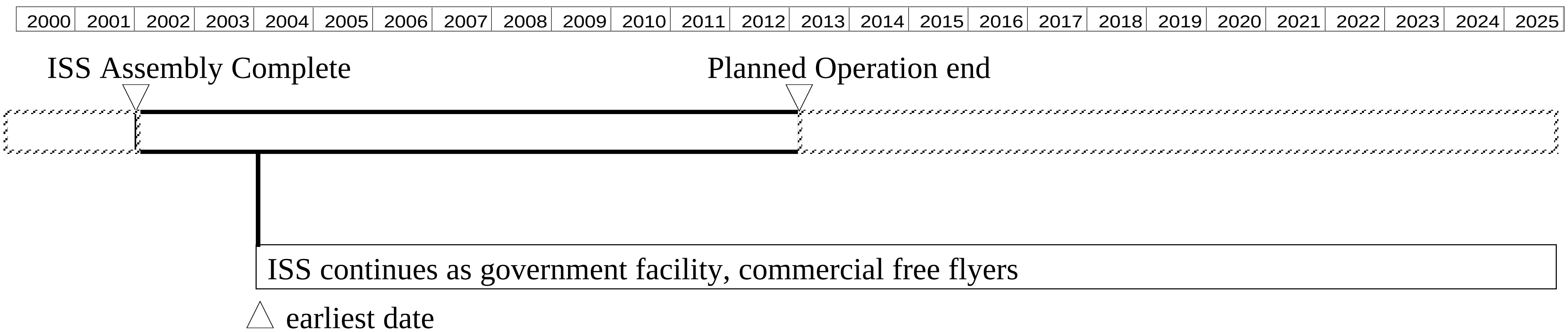
6. Architecture Concepts

ISS CSBP Incubator

A commercial incubator is a multi-use facility which is commonly initiated by a quasi-public local government to stimulate business growth by subsidizing common infrastructures for small, start-up businesses. This option assumes that International Space Station supports commercialization as an incubator, and therefore allows establishment of commercial business ventures through generous utilization fees and controls, such as pricing based on marginal costs of utilities and transportation, and long-term equipment leases to a broker. Commercialization may initially begin with one or two racks being provided for lease, or a module and/or external pallet, also provided for lease, may be added to the baseline facility. Additional power, thermal and other utilities would be added as needed to provide services to the commercial users. Needed human labor would be contracted, for a fee, by the government astronauts.

6. Architecture Concepts

ISS CSBP Free Flyer



Current	Near	Medium	Far	
L	M	H	H	**Micro-gravity**
L	M	M	M	**Satellite servicing**
L	M	M	M	**Entertainment, on-orbit sound stage**
L	L	L	L	**Entry level adventure travel**

Costs

- estimated price: $200 million/module, additional infrastructure estimated as ‘total cost of modules times 2’

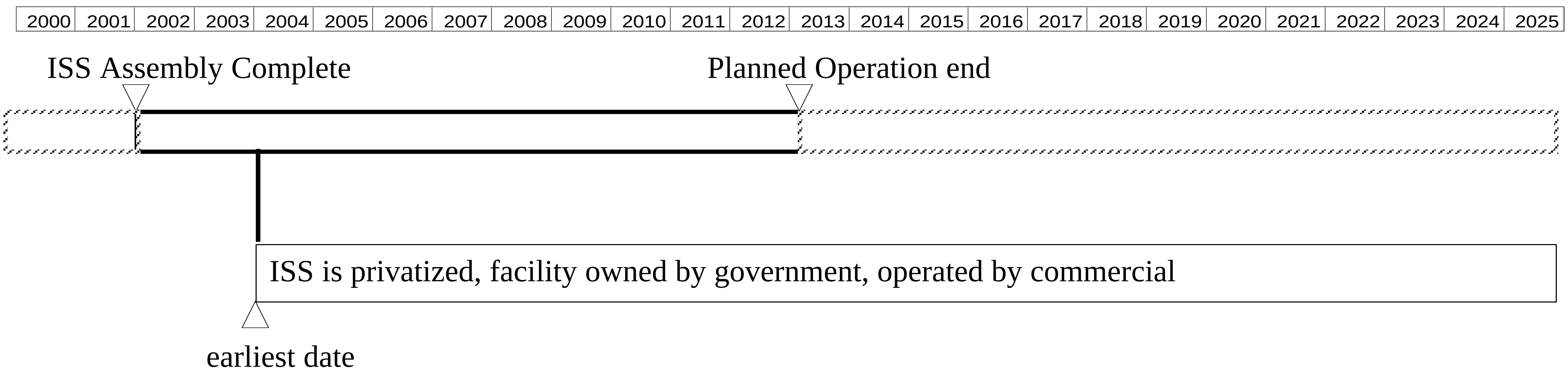
6. Architecture Concepts

ISS CSBP Free Flyer

This scenario uses ISS components in a free flyer configuration. As growth occurs new free flyers are independently deployed, still located in a common orbit with ISS, but each self-contained. All flyers would be derived from space station modules and equipped with standard space station racks and sub-systems, including power and thermal. Flyers would be available pressurized or un-pressurized. Racks would provide automated, tele-operated services and be human tended for calibrations, maintenance, feedstock initialization and product/waste removal, etc. Product and waste would be returned via some other system.

6. Architecture Concepts

ISS SBP Privatized



Current	Near	Medium	Far	
M	M	H	H	**Micro-gravity**
M	H	H	H	**Satellite servicing**
L	M	H	H	**Entertainment, on-orbit sound stage**
L	L	M	H	**Entry level adventure travel**

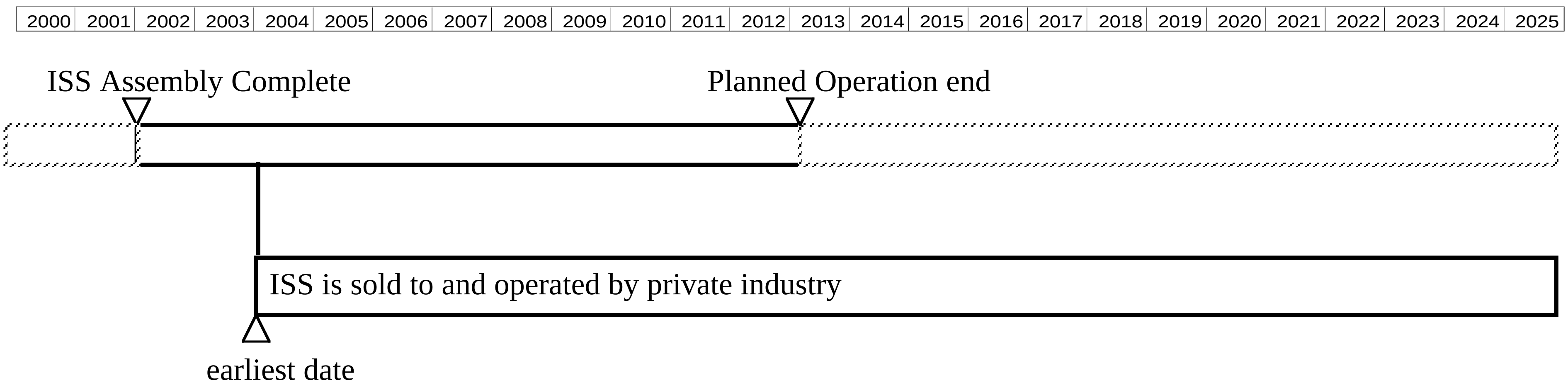
Costs

- estimated price: $200 million/module, additional infrastructure estimated as ‘total cost of modules times 2’

6. Architecture Concepts
ISS SBP Privatized

This scenario presumes the International Space Station is privatized a la Space Shuttle and the United Space Alliance. The resulting operating company would continue to serve the on-orbit space station needs of the government as well as creating and exercising commercial opportunities which can utilize the space station assets.

6. Architecture Concepts
ISS SBP Sold



Current	Near	Medium	Far	
M	M	H	H	**Micro-gravity**
M	H	H	H	**Satellite servicing**
L	M	H	H	**Entertainment, on-orbit sound stage**
L	L	M	H	**Entry level adventure travel**

Costs

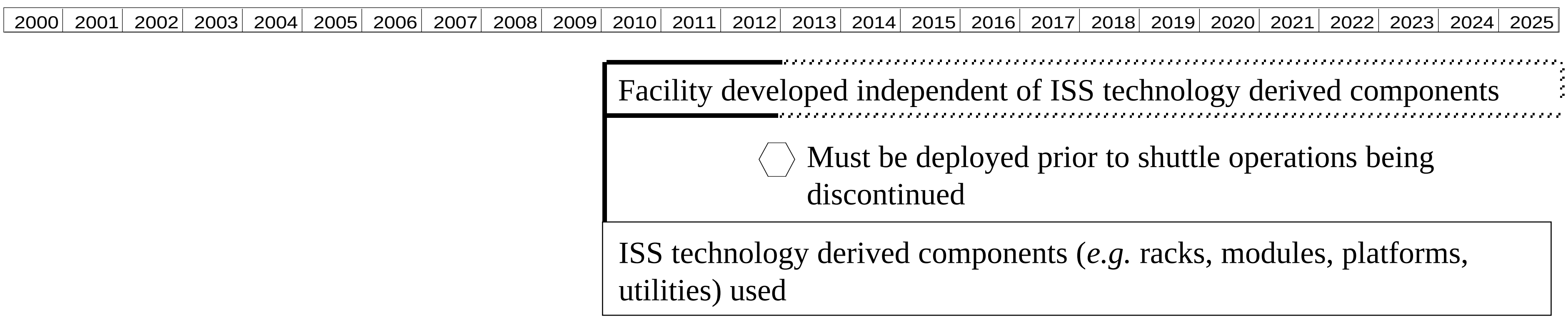
- estimated price: $200 million/module, additional infrastructure estimated as ‘total cost of modules times 2’

6. Architecture Concepts

ISS SBP Sold

This scenario presumes the government sells the space station to private investors. Government needs are contracted out for fulfillment by private interests. The commercial owners could use the space station facility in any way which serves their business plans.

6. Architecture Concepts
External Tank CSBP



Current	Near	Medium	Far	
L	M	H	H	**Micro-gravity**
L	M	M	H	**Satellite servicing**
L	M	H	H	**Entertainment, on-orbit sound stage**
L	L	M	H	**Entry level adventure travel**

Costs

- estimated price: $3 billion

6. Architecture Concepts

External Tank CSBP

This scenario presumes that the space shuttle external tanks are salvaged and refurbished to provide pressurized volume on-orbit. Technology derived from the ISS program, such as modules, airlocks, nodes, platforms and racks, might be incorporated into the facility.

6. Architecture Concepts

Inflatables CSBP

2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025

Facility developed independent of ISS technology derived components

ISS technology derived components (*e.g.* racks, modules, platforms, utilities) used

Current	Near	Medium	Far	
L	M	H	H	**Micro-gravity**
L	M	M	H	**Satellite servicing**
L	M	H	H	**Entertainment, on-orbit sound stage**
L	L	M	H	**Entry level adventure travel**

Costs

- estimated price: $5 billion

6. Architecture Concepts

Inflatables CSBP

This scenario presumes the technology for inhabited space modules is developed and deployed to provide pressurized volume on-orbit. Technology derived from the ISS program, such as modules, airlocks, nodes, platforms and racks, might be incorporated into the facility.

6. Architecture Concepts
Framed On-Orbit CSBP

2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025

Facility developed independent of ISS technology derived components

ISS technology derived components (*e.g.* racks, modules, platforms, utilities) used

Current	Near	Medium	Far	
L	L	H	H	**Micro-gravity**
L	L	M	H	**Satellite servicing**
L	L	H	H	**Entertainment, on-orbit sound stage**
L	L	M	H	**Entry level adventure travel**

Costs

- estimated price: $10 billion

6. Architecture Concepts

Framed On-Orbit CSBP

This scenario presumes that the Commercial Space Business Park is built on-orbit from the individual components (ie girders, panels, windows, etc.) to provide pressurized volume. Technology derived from the ISS program, such as modules, airlocks, nodes, platforms and racks, might be incorporated into the facility.

7. Policy Issues

7. Policy Issues

Section 7 describes policy- issues related to commercial space business parks. It covers both general issues related to commercial, multi-use space business parks, and policy issues related to the specific market areas identified in this study.

7. Policy Issues

- Procurement
- Commercialization
- Certification and Licensing
- Personnel
- Entertainment/Tourism
- Satellite Servicing

Most development scenarios start with the commercial use of government resources/assets.

7. Policy Issues

Depending on the approach taken to implement a Commercial Space Business Park, there are several government policy issues that will need to be clarified, modified, or in some cases, established. We have tried to identify some of these. They are divided into four categories: Procurement, Commercialization, Certification and Licensing, and Personnel. In addition, there are several aspects of policy that are unique to the business areas of Entertainment, Adventure Tourism, and Satellite Servicing, which will be discussed separately.

Though there are several configuration and implementation options for a Commercial Space Business Park, the assumption is that, in most cases, the path to a Commercial Space Business Park begins with the commercial use of government resources.

7. Policy Issues

Procurement

7. Policy Issues

Procurement

If a Commercial Space Business Park is to make use of the Space Station, Space Shuttle, or some other government asset, it is important that some pricing policy be established. Obviously, before any decisions on the economic viability of a Space Business Park can be made, the associated costs of operation (including those fees paid for use of government resources) must be identified.

Conversely, in order to project the revenue of a Commercial Space Business Park, we should know whether the government will be one of our customers. This could take the form of purchasing lab space from a private lab facility, purchasing fuel from a refueling depot, or buying satellite servicing for government satellites. There are precedents for this, either on a regular basis (such as the plan to buy commercial remote sensing data for Mission to Planet Earth), or for emergencies only (such as the Civil Reserve Air Fleet).

7. Policy Issues

Commercialization

- Use of Space Station by commercial interests
  - Ability to utilize Space Station without having to demonstrate the technical merit of the application (no public or peer reviews)
  - Ability to retain proprietary protection of commercial activity on Space Station
  - Ability to purchase utilities or labor services from Space Station
  - Guaranteed continuity of service
- Policy on transitioning technology, resources, or start-up business from government to the private sector
- Policy on government facility competing with commercial alternatives

7. Policy Issues
Commercialization

If Space Station is to be used for the initial commercial activities leading to a Space Business Park, there are several policy issues that need resolution. Would use of the Space Station be allowed without the users having to demonstrate the technical merits of their application? If someone paid the required fee, could they use the Station without having to go through a process of public or peer reviews? Could a private institution keep proprietary the findings they made on the Station? Would services such as utilities, rack space, or crew time be available for purchase by a private user from the Station? What guarantees of service continuity be made, i.e. usage contracts that will not be interrupted by a change in priority once the investment is made, such that private investment isn't wasted by reprioritization of essential services or a change in government policy on access to the Station?

Other policy issues that need to be understood involve how technology or business activity that begins as a government undertaking would be transitioned to the private sector.

Also, the need to minimize competition between a government facility and a commercial enterprise, could be very important.

7. Policy Issues
Certification and Licensing

- For commercial structures consisting of:
  - Attaching modules to Space Station
  - Docking of OMVs or free flyers with Space Station
- Need for structure “certification” or meeting of “structural codes”
- Safety and environmental acceptance
- Definition of liability of commercial structure with regards to Space Station

7. Policy Issues

Certification and Licensing

Several of the Commercial Space Business Park concepts involve either attaching modules to the Space Station, or docking orbital maneuvering vehicles or free flyers periodically with the Space Station. It is expected that in these cases there will be some sort of structural "certification" or "structural codes" which a module or free flyer will need to meet before it can come into physical contact with the Space Station. There would also need to be regulations concerned with issues of safety and with impact to the Space Station and its surrounding environment. Even with all of these rules and regulations, there still is a chance that an accident might occur, requiring clear definitions of liability.

7. Policy Issues
Personnel

- Policy on non-government individuals in space
  - Corporate staff access to space
  - Corporate staff EVA (perhaps a licensing requirement, even if being performed at a commercial site)
  - OSHA-like regulations for commercial space business park employees functioning in orbit

7. Policy Issues
Personnel

Policies will need to be established regarding non-government individuals in space. Many of these would deal with the Commercial Space Business Park employees, and their access to space. Special policies will probably be required for those planning EVA functions. (Perhaps some sort of licensing process analogous to that for a private pilot would be a solution.) It is also expected that some OSHA-like regulations to protect Space Business Park employees would be developed.

7. Policy Issues

Entertainment and Tourism

- Policy on use of government facilities and the need for government approval of intended use
  - Policy on producing movies, TV shows, etc. on a government facility and eliminating the need for script approval or finished product review
- Policy on use of Shuttle or Space Station for tourism purposes
- Ability to use liability waivers for tourists in space
- Private citizen access to space
- Private citizen EVA

7. Policy Issues

Entertainment and Tourism

There are some policy issues that relate specifically with the entertainment and tourism businesses. One of these would be a policy on using government facilities for an entertainment product (television show, movie, etc.) without getting government approval on the content of the finished product. This would allow producers to avoid any type of script approval, even if a government facility were used in the production.

A policy on use of the Shuttle or Space Station for tourists would be necessary if the tourism business is going to initially depend on these government resources. There would also need to be specific policies on use of liability waivers, on private citizens in space, and on private citizens performing EVA maneuvers

7. Policy Issues

Satellite Servicing

- Design of serviceable government spacecraft
- Policy on spacecraft disposal
- Policy on ownership of salvaged spacecraft
- Policy against proliferation of orbital debris
- Facilitating development of commonality among satellite manufacturers

7. Policy Issues

Satellite Servicing

Several government policies, if enacted, could make the development of a satellite servicing business significantly more attractive. If the government were to take the lead in requiring that their spacecraft be manufactured with consideration for in-space serviceability, this would be a big step forward in satellite servicing. Requirements on the disposal of non-functioning or obsolete satellites could also give a boost to satellite servicing. Policies on the ownership of salvaged spacecraft might be needed to avoid future legal problems. A strong policy against continued creation of orbital debris could become a major source of business for a satellite servicing company. And finally, anything the government or industry associations could do to facilitate commonality among satellite manufacturers, by mandating standards or even sponsoring industry standards boards, would benefit a satellite servicing industry

7. Policy Issues

Policy Matrix

	Micro-g	Sat Serv.	Entert.	Tourism
Procurement				
Pricing policy for private use of government space resources	M	M	M	N/A
Policy on government procurement of privately owned space services	M	H	N/A	N/A
Commercialization				
Use of Space Station by commercial interests				
Ability to utilize Space Station without having to demonstrate the technical merit of the application (no public or peer reviews)	H	H	M	N/A
Ability to retain proprietary protection of commercial activity on Space Station	H	H	H	N/A
Ability to purchase utilities or labor services from Space Station	M	M	M	N/A
Guaranteed continuity of service	M	H	M	N/A
Policy on transitioning technology, resources, or start-up business from government to the private sector	H	M	N/A	N/A
Policy on government facility competing with commercial alternatives	L	M	N/A	N/A
Certification and Licensing (for attaching modules or docking of OMVs or free flyers to Space Station)				
Need for structure "certification" or meeting of "structural codes"	H	H	H	H
Safety and environmental acceptance	M	M	M	M
Definition of liability of commercial structure with regards to Space Station	M	M	M	N/A
Personnel				
Policy on non-government individuals in space on private facility				
Corporate staff access to space	H	H	H	H
Corporate staff EVA	M	M	M	M
OSHA-like regulations for commercial space business park employees functioning in orbit	H	H	H	H
Entertainment/Tourism				
Policy on use of government facilities and the need for government approval of intended use	N/A	N/A	N/A	L
Policy on use of Shuttle or Space Station for tourism purposes	N/A	N/A	N/A	L
Ability to use liability waivers for tourists in space	N/A	N/A	N/A	M
Private citizen access to space	N/A	N/A	N/A	M
Private citizen EVA	N/A	N/A	N/A	L
Satellite Servicing				
Design of serviceable government spacecraft	N/A	H	N/A	N/A
Policy on spacecraft disposal	N/A	M	N/A	N/A
Policy on ownership of salvaged spacecraft	N/A	M	N/A	N/A
Policy against proliferation of orbital debris	N/A	L	N/A	N/A
Facilitating development of commonality among satellite manufacturers	N/A	M	N/A	N/A
H, M, L refer to High, Medium, or Low ease of implementing				

7. Policy Issues

Policy Matrix

This matrix takes the policy issues outlined in the last several charts, and for each of the five business areas addressed in this study (Micro-gravity-organic, Micro-gravity-inorganic, Satellite Servicing, Entertainment, and Adventure Tourism), specifies our estimate of the ease of implementing these policies. An H (High) in the matrix means that we believe that relative to this business area, the policy should be quite easy to implement. An L (Low) means that this policy/business area combination will be very difficult to implement. Another way to view the information, is that for those intersections marked H, the policies have a high likelihood of coming to pass, while for those marked L, they are much less likely to ever happen.

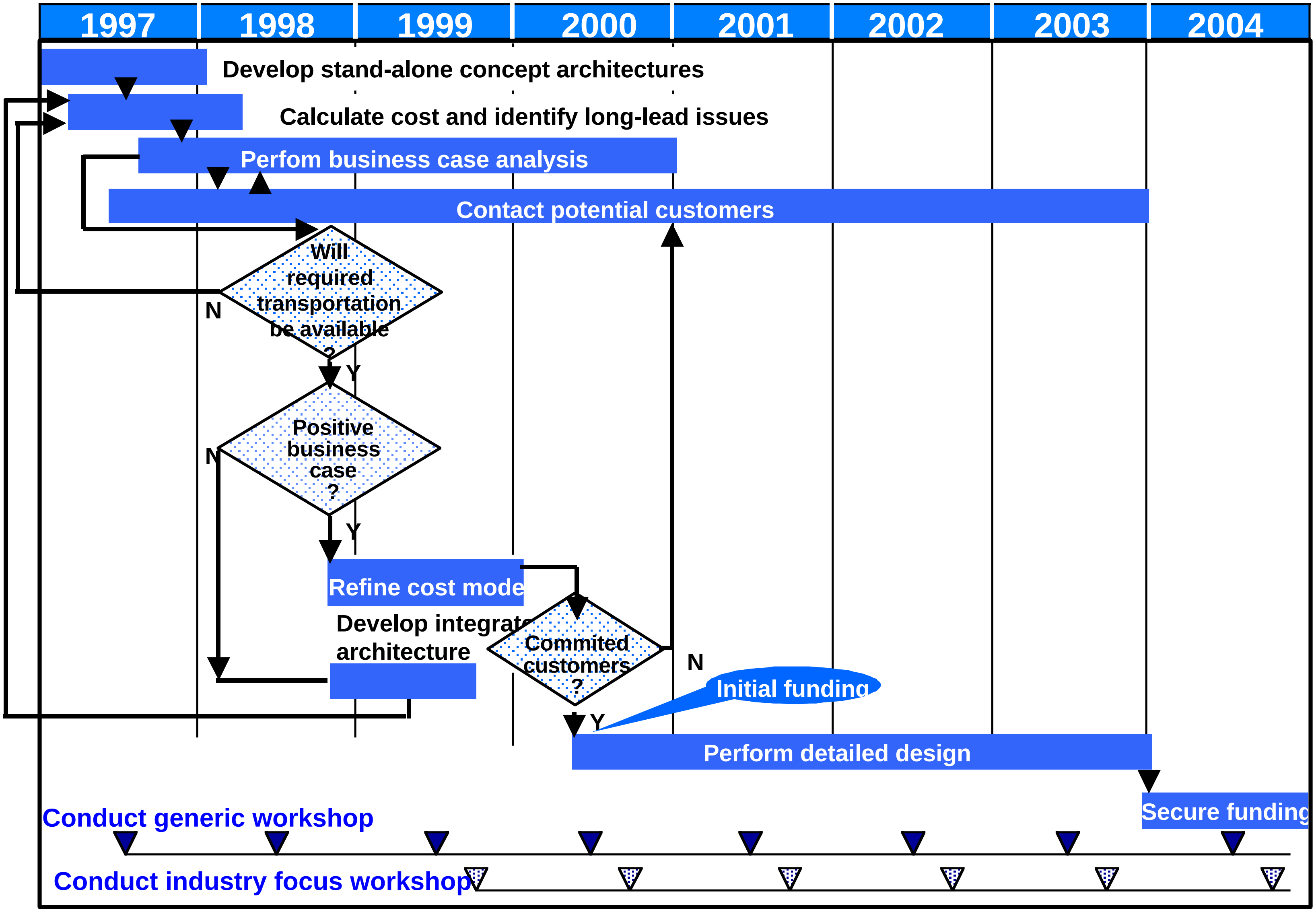
8. Roadmaps

8. Roadmaps

Section 8 contains a roadmap for further development of the market for commercial space business parks.

8. Roadmaps

Commercial Space Business Park Roadmap



8. Roadmaps

Commercial Space Business Park Roadmap

This chart displays how we would recommend proceeding, following the conclusion of this study. The first step would be to do some conceptual design work, developing architectures for each of the four business park business areas. It may be advisable to expand the scope to several additional business areas that were not addressed in the current study. This would allow us to do some costing of the concepts and identification of long-lead issues. As we are doing this, we would initiate contact with potential customers. We would use them to help refine our price sensitivity analyses. Combining the cost and potential revenue data would yield true business case analyses. A key decision point would involve the planned availability of transportation which meets our cost and performance requirements. It is reasonable to assume that the schedule will slide by at least one year for every year that the required low-cost transportation is not yet avaibable. Another key decision would involve the result of the business case analyses. If they did not give us a positive result, we could look at multi-function business parks and whether such an integrated architecture would result in an acceptable business case. The final key decision would be whether committed customers have been identified. If so, we could move into detailed design. In parallel with these activities, would be two yearly workshops: one for a general audience, and one with a specific industry target.

This roadmap is a great simplification of the highly iterative process of customer contact and analysis that we would go through, but gives some idea of the amount of work and time needed to move towards implementation of a Commercial Space Business Park.

9. Recommendations

9. Recommendations

Section 9 contains our recommendations for further analyses, market development, and policy modifications required for the realization of commercial, multi-use space business parks. These are divided into three areas: recommendations for additional market development; recommendations for policy development; and a strong recommendation for low-cost commercial space transportation.

9. Recommendations

Commercial Space Business Park Market Analyses

- Compile a broader scope of case studies
- Provide a clearinghouse of space business park market concepts
- Direct customer discussions
- Develop the evolutionary scenarios further
  - Include sequence from initial startup to mature industry
  - Identify architectural needs at each phase
  - Clarify expected relationships between government and private sector customer base
- Perform business case studies with estimated business costs
  - To allow a pro forma with expenses and revenues

9. Recommendations

Commercial Space Business Park Market Analyses

There have been many concepts suggested for commercial utilization of multi-use space business parks. Some were identified during the Commercial Space Transportation Study, some were first identified during the current study, some have been developed as targets for International Space Station commercialization, and many others have been suggested and promoted to NASA over the last few years. The current study was limited in scope to the four case studies and tasks that could be accomplished within the funding allocated. We recommend that NASA and Boeing establish a central library of concepts for space business park markets. This can be a simple library (paper or e-mail), or a data base, or a Web-page. This would provide a clearinghouse where ideas can be generated and recorded, related to similar ideas, and further refined to suit the user.

True market analysis can best be done by working directly with potential market representatives and investors. This can be done either one-on-one (the preferred method for serious business discussions) or through a series of customer workshops to generate new ideas and stimulate the market to consider the possibility of commercial space business parks.

For the case studies performed, estimates were made of the market size and price threshold, but little has been done on the crucial steps of defining the evolutionary scenarios for initial startup, market development and penetration, and industry maturation. More work should be done here to identify the costs and timelines for establishing this industry.

When this is done, we will be able to identify the expenses associated with the market, and compare them with the anticipated revenues for a financial spreadsheet analysis.

9. Recommendations
Policy

- Establish a clear pricing policy for commercial use of government resources
  - Including STS and ISS utilization
  - Ensure access guarantees
- Promote the concept of a commercial ISS pathfinder to focus on solving real policy issues
  - Policy would be driven by practical issues with real compromise, rather than broad-scope policy framework with little practical value
  - Initial success would encourage follow-on activities once policy hurdles have been overcome

9. Recommendations

Policy

There are virtually two evolutionary pathways to the development of commercial space business parks that are fundamentally different from each other: one pathway starts with limited commercial use of government assets; and one pathway is strictly commercial from the outset. Considering the large initial investment that would be required to establish the orbital infrastructure and the Earth-to-orbit transportation, it appears that the pathway that grows from government assets could start sooner. For this to happen, investors and customers must know unequivocally that these resources are available when needed at a price that has been agreed to before the investment is made. This involves a clear policy for pricing and guaranteed access to government resources, including transportation, facility usage, utilities, and crew activities.

Much effort has been directed toward developing policies for International Space Station (ISS) commercialization. We believe that the single most effective action that can be taken to establish policies for commercial use of ISS would be to promote a commercial pathfinder activity that will require resolution of real issues on a real schedule for the commercial activity to proceed. Once an initial pathfinder commercial program has resolved all the policy issues and is commercially successful, this success would encourage follow-on activities.

9. Recommendations

Space Transportation Recommendations

- Develop low-cost commercial space transportation systems
- Develop low-cost commercial space transportation systems that are licensed to transport fare-paying passengers to space

9. Recommendations

Space Transportation Recommendations

The principal driver to the cost-effectiveness of any commercial space activity is the cost and reliability of space transportation. Most of the case studies that we performed show transportation as the dominant cost. An added factor for commercial transportation with private passengers will be the licensing that such a transport vehicle will surely require.

Terrestrial Business Incubators

Terrestrial Business Incubators

Space as an Operating Model for Early Commercial Space Business Park Operations

Business incubators are specialized facilities which are most often set up and managed by quasi-public corporations chartered by a state or local unit of government. The mission of such organizations is to crate jobs and encourage growth and new investment in their particular community. Facilities are usually run on a non-profit basis, and permit tax deductions for donations of buildings, equipment, and in-kind services in the furtherance of the public purpose.

A business incubator is usually established in an obsolete or otherwise surplus corporate facility which is donated or leased at a nominal rate to the 501c(3) operating entity. The company closing the facility receives both the tax deduction and a positive media spin on an otherwise negative news story. Typically, these facilities are quite large and offer a variety of space and support infrastructure to support diverse business uses. One example is the Metropolitan Center for High Technology in Detroit. The building was the former headquarters of the Kresge Company, now known as K-Mart. The company moved its offices and donated the building to the city in the early 1980's. The technology center was Detroit's focal point for a statewide effort to reverse a decline in auto industry jobs and replace them with the almost mythical "high tech jobs of the future." Most of the major metropolitan areas in Michigan and most other states in the Northeast and Midwest had similar offerings.

Incubators are constructed of an amalgam of state and local tax abatements and job training incentives, free or below-market lease rates for office and shop space, cooperative agreements with local universities and community colleges for lab and research facilities, and business support services such as shared secretarial and bookkeeping staff. If new construction or major building modifications are needed, tax-exempt revenue bonds can be sold to finance the costs. In fact, most of the principal subsidies offered to encourage business growth are derived from provisions in the IRS and state tax codes.

In Michigan, 50% reductions in property taxes, up to 100% reductions in payroll and Single Business Tax, issuance of double tax-exempt Revenue Bonds, and cash grants for job training are all programs authorized by various State Acts. In addition, businesses locating in specially-designated districts in distressed areas can receive additional tax breaks through Enterprise Zone legislation.

The business incubator starts as a physical locus for a wide variety of state and federal business incentive and development programs that are in most cases available to any business wishing to expand. What differentiates the incubator from general development activity is a primary orientation towards the smaller, more front-end business growth activity, and existing buildings available for immediate occupancy at a subsidized rate.

The public policy rationale for providing subsidies to businesses is two-fold. First, there is the possibility (but by no means certainty) that the start-up businesses will succeed in implementing their business plans and become wildly successful. In these cases, the business quickly outgrows the incubator and moves to market-rate facilities, creating many new jobs in the process and ultimately providing new tax base which more than repays the original subsidies. A stereotypical example would be a group of university biomedical researchers that start a biotechnology business in an incubator facility to commercialize some basic research results done at the university. If the resulting product is clinically effective and approved by the Food and Drug Administration, the start-up could become “the next Amgen”, go public, and move out of the incubator and into new facilities in the same community.

The second public policy rationale for incubators and business subsidies in general is a marginal cost / marginal benefit argument. New or growing businesses typically require very little in the way of new public infrastructure or municipal support services, particularly when compared to new residential development where roads, schools, and public utilities grow in a linear fashion with the newly-constructed residences.

Terrestrial Business Incubators

Space as an Operating Model for Early Commercial Space Business Park Operations

Since incubators are typically located in existing buildings not currently in use, there is no significant tax revenue coming in on the unused facilities, and no need for any additional municipal support services. Putting these existing assets to new use in helping to grow new businesses and foster job creation therefore has little downside to the municipality. If nine out of ten businesses starting in the incubator ultimately fail, but the tenth one “hits a home run” and becomes successful, the net result is a positive contribution to the community.

The market presentation of a business incubator facility revolves around a “one-stop shopping” premise. It starts with a mission statement that the incubator facility exists for the sole purpose of growing new companies, and that the community welcomes and supports these entrepreneurial efforts and the new jobs which may results from the efforts.

The subsidies and charitable contributions used to set up the project determine what (if any) lease rate needs to be charged. Often a business will receive an initial period of free rent as the business is starting, with the lease providing a graduated payment schedule based on the revenue projections and the ability to pay. In addition, the Executive Director of the incubator becomes the primary contact point and ombudsman for the tenants of the facility in obtaining additional state and federal assistance and tax relief. Recruiting and hiring assistance, job training, business development counseling, assistance in preparing business plans and financial projections, informal networking with potential equity investment sources, and help with university technology transfer efforts are all services that are routinely offered in most incubators. With advanced technology incubators, access to common lab space and equipment is also provided, either on-site or through arrangements made for university facilities and staff. A business choosing to locate in an incubator in effect gets the whole community behind them helping in every way possible to make the venture a success.

The start-up businesses also benefit from significant down-side protection in the event that things do not work out as planned. The subsidized nature of the rent structure allows the company to move out of the founder's basement and present a professional appearance to customers and investors at an earlier stage than would otherwise be possible. Short-term leases with flexibility to grow and expand within the facility are important in managing business growth. In most cases, the company principals are not required to personally guarantee the lease payments, whereas in market rate commercial space, the landlord will almost always insist on personal guarantees for start-up tenants and push hard for longer lease terms. This flexibility allows entrepreneurial companies to give their business concepts a shot with a much lower entry threshold.

Implicit in this development model is an understanding that incubator tenants that are successful in their development efforts will "graduate" from the facility as soon as is economically practical. Moreover, successful companies which got their start in an incubator are expected to give back to the community by keeping the new jobs in the local market and helping other incubator tenants in their business development efforts. Most of this is informal peer pressure by other community businessmen and local politicians, but it is nevertheless real incentive. In the case of tax abatements, there is often a written contract between the business and the local unit of government which spells out the terms and conditions of the abatement, and provides for its revocation if the business does not meet its job creation and investment goals.

Several policy changes are needed if the business incubator model is to be used for some or all of the resources of the International Space Station, with the most important being the adoption of an appropriate Mission Statement. A pro-business policy which actively embraces true commercial ventures is not currently part of ISS management philosophy within NASA. The simple statement that "We want your business and are willing to help." is an essential first step that has not yet been taken.

Terrestrial Business Incubators

Space as an Operating Model for Early Commercial Space Business Park Operations

Most business owners will naturally gravitate to areas where they feel welcome. Communities that are ambivalent about development or have active "slow-growth" policies do not often succeed in landing new businesses. Current NASA policy and practice regarding ISS commercialization is at best ambivalent, and in some offices verges on active opposition. These policies must change quickly if ISS is to be seriously considered as a credible incubator for future commercial space business park development activities.

A rational pricing policy for commercial use of ISS assets needs to be adopted, and some sort of rough allocation of a percentage of available capacity needs to be set aside for commercial applications. Ideally, the pricing policy will include everything from the cost of leasing locker space in an EXPRESS rack for a a period of weeks or months, the cost of dedicated rack leases for a year or more, the hourly costs for common equipment such as furnaces, freezers, glove boxes, centrifuges, and the like, the hourly charges for crew time (both IVA and EVA), and the costs of transportation, power, thermal control, and logistics support. As with terrestrial business incubators, rent and labor charges may be deeply discounted at the earliest stages of business development in order to nurture and grow the companies into larger and financially stronger positions, but some sort of commercial "price list" is essential for space-based businesses to project their operating costs once they get past the early incubator stages.

Current NASA policy may be best summarized as "It's free if we like you and you pass the peer review process, unavailable at any price if we don't like you or what you are proposing to do, and since it's free we make no guarantees about if or when you will ever get to go again, if we let you go in the first place." This policy may be marginally acceptable for university and institute basic research, but is completely unacceptable in a business incubator paradigm. Companies need to know that facilities and support services will be there when they are needed for as long as they are needed to accomplish the business plan, and that costs will be known with a reasonable degree of certainty throughout the development process.

In addition, patent and proprietary technology protections must be both available and unambiguous. Even if facilities are initially made available at reduced rates, there will still be significant private investment required to bring any commercial space business to market. Without absolute assurances on the facilities access issues discussed above, and equally strong assurances that proprietary technology will be protected, there is simply no reason to consider the investment in the first place. There are always other places to invest money and other projects for entrepreneurs to work on. Fundamental organizational impediments within NASA may very well preclude any significant commercial use of ISS as a business incubator facility unless major policy changes are made soon.

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List of Acronyms

BSS	broadcast satellite service
CCV	Crew/Cargo Vehicle
CRV	crew return vehicle
CSBP	commercial space business park
CSTS	Commercial Space Transportation Study
EELV	Evolved Expendable Launch Vehicle
ET	external tanks
EVA	extra-vehicular activity
FF	free flyer
FSS	fixed satellite service
GEO	geosynchronous Earth orbit
ISS	International Space Station
LEO	low Earth orbit
MSFC	George C. Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NSS	National Space Society
OMV	orbital maneuvering system
OSHA	Occupational Safety and Health Administration
QA	quality assurance
ROM	rough order of magnitude
SBP	space business park
STA	Space Transportation Associates
STS	Space Transportation System
TBD	to be determined

Commercial Space Business Parks

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