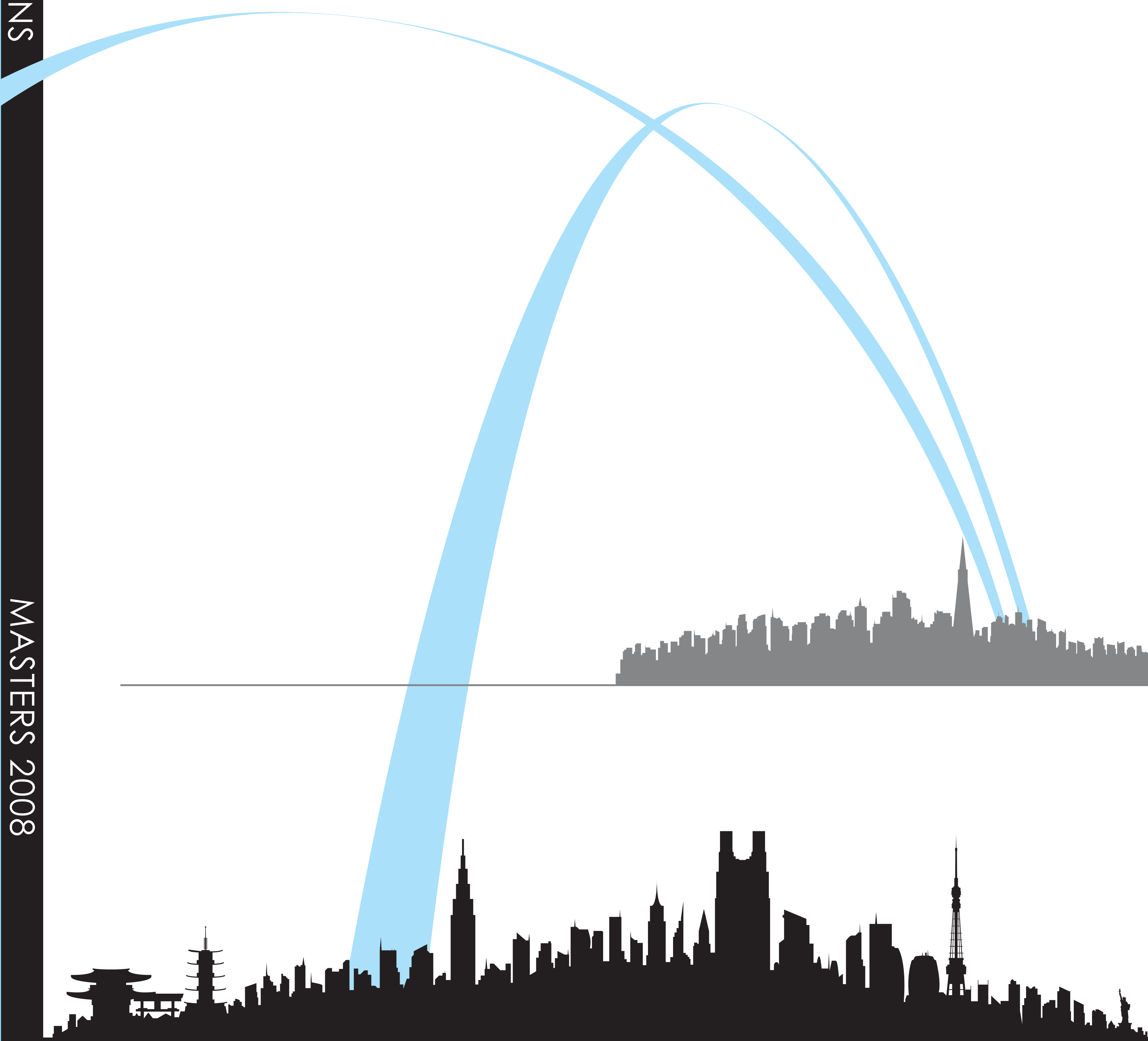
GREAT EXPECTATIONS:

An Assessment of the Potential for Suborbital Transportation



International Space University

MASTERS 2008 - FINAL REPORT

GREAT EXPECTATIONS
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Great Expectations

Assessing the Potential for Suborbital Transportation

Final Report

International Space University

Masters Program 2008

The 2007-2008 Masters Program of the International Space University was conducted at the International Space University in Strasbourg, France.

The cities depicted on the cover of the report are Paris, Tokyo, and New York. These represent major travel hubs located around the world which may hold promise for the development of point to point suborbital transportation services. The cities are linked together by curves representing suborbital trajectories. The placement of cities on both the front and back covers represents the large distances between these cities, but a single trajectory connecting the cities illustrates the potential of suborbital transportation to bridge these cities together.

The cover art was developed by Amanda Stiles and Chris Kelly, with input from the entire team. The graphics are intended as a visual representation of the point to point suborbital transportation team project.

The Executive Summary and the Final Report may be found on the ISU website at http://www.isunet.edu/ in the "ISU Publications/Student Reports" section. Paper copies of these documents may also be requested, while supplies last, from:

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ACKNOWLEDGEMENTS

The Point to Point Suborbital Transportation team would like to acknowledge the ISU faculty and staff for their advice and support during the project.

In particular, the team expresses their sincere gratitude to the following members of the faculty and staff:

Nicolas Moncussi	For IT support during the Team Project and Literature Review
Joel Herrmann	For invaluable Report and Executive Summary logistics information
Walter Peeters	For extensive legal and business advice
Isabelle Scholl	For support as the Faculty Advisor during the Literature Review
Nikolai Tolyarenko	For technical advice on a variety of topics
Vasilis Zervos	For support as the Faculty Advisor during the Team Project

The Point to Point Suborbital Transportation team would also like to acknowledge the following people for providing their invaluable knowledge, advice, and input during the Team Project:

Kelly Alton	United Risk Solutions, USA
Dr. Tare Brisibe	SITA, Switzerland
Jim Dator	Director of the Hawaii Research Center for Futures Studies, USA
Jim Dunstan	Attorney, USA
John Gedmark	Personal Spaceflight Federation, USA
Doug Griffith	Attorney, USA
Joshua Neubert	X PRIZE Foundation, USA
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ABSTRACT

There has recently been a tremendous growth in the private funding of satellite and launch vehicle technology as well as various technical aspects of astronautics and space exploration. In the past this has largely been due to government support, via supporting international legal regimes and awarding contracts to private companies. Private initiatives in commercial launch vehicle development aimed at exploiting the potentials of a global space tourism market have also served to further strengthen the role that the private industries are taking in the space sector. With this growth in launch vehicle development, comes a revived focus on space technologies as means of transportation, with point to point suborbital flights being looked at as the next step. As key technologies mature, there is a possibility for suborbital space flight to become a viable method of transporting passengers and cargo around the world; however, there are many questions raised by this and the need therefore exists to lay a foundation for the successful realization of any such initiative. This report seeks to outline the conditions that would be required for this growth.

This report is a thorough appraisal of the technological, financial, marketing, safety, infrastructural, and legal requirements for the point to point suborbital transportation industry. Focused on the transport of passengers and cargo, the report analyzes in detail the conditions that should be put in place to foster and sustain this industry. It describes the existing challenges and discusses possible options for overcoming these while drawing from the experience of previous programs. The report includes an in-depth look at the feasibility of point to point suborbital transportation from the perspective of cost, funding, technology development, and the possibility of growth from a fledgling suborbital tourism industry. The conclusions are synthesized into a series of recommendations for the next generation of suborbital travel to go forth and prosper.

FACULTY PREFACE

A team of just over twenty graduate students (24-43 years old) from very diverse academic (education to engineering) and ethnic backgrounds (Africa, America, Asia, Europe) produced this report which carries a 25% weighting on their Master's degree here at the International Space University during the academic year 2007-2008.

An international effort to critically assess via a comprehensive and interdisciplinary study the case for point to point suborbital transportation has resulted in a high quality and definitive report. This task was accomplished by a group of students truly epitomizing intercultural and interdisciplinary collaboration leading to a balanced approach and conclusions. The individuals all have a story in terms of their experiences gained; this is usually of no interest or knowledge to the reader. For an applied academic environment this is however of equally high importance as the outcome itself. This is a piece that collectively the group can be proud of, as each and every individual in one way or another experienced moments of excellence in the process of completing it. This work is naturally dedicated to those moments and efforts associated with the team members. For my part it was a privilege and a very productive experience to facilitate the team's efforts and I thank them for their respect and intellectual sharing.

Associate Professor Vasilis Zervos,
on behalf of ISU's Resident Faculty

AUTHOR PREFACE

“"Take nothing on its looks; take everything on evidence. There's no better rul*e.”*

” - Mr. Jaggers, *Great Expectations*

As the inspiration for a study of suborbital transportation, a nineteenth century coming of age tale may initially strike some as an odd choice. *Great Expectations*, arguably Charles Dickens' finest work, is the story of a young boy, plucked out of poverty with the promise of easy wealth and a life of convenience. After the loss of his fortune and through many trials and tribulations, the protagonist eventually realizes that the road to luxury was not as clear as it seemed. However through great perseverance, he finally achieves his own modest success, though not nearly as easily as he had hoped. A certain parallel can be found here with our chosen topic; there exists a widely held assumption that, with the advent of suborbital tourist flights, the transition to suborbital transportation will be but a simple matter, rendering agonizingly long flights a thing of the past. Our research indicates that that is not the case. While this industry may well flourish in the coming decades, there is much to be done before such a leap can be made. The fantastic advances initially promised to us have been shown to be far more elusive than we realized. Only with great effort may we gain that which originally seemed inevitable.

When SpaceShipOne rocketed into history, the age of private, suborbital spaceflight was upon us. To the casual observer, this achievement opened the door to the possibility of commercial space travel. The perception that travel around the planet would soon be achieved in minutes rather than hours emerged; for if a vehicle can go straight up into space and back to the same spot, it must surely be a minor feat to use similar technology to land somewhere else instead.

This study purports to test that assumption via an interdisciplinary and critical approach. Our main ideas evolved after performing a literature review of suborbital transportation systems. We observed that ample information exists on vehicle concepts, but little on what is being done in the field of point to point suborbital transportation. We propose that point to point suborbital transportation may eventually become sustainable, so that the use of space becomes routine and no longer an adventure. However, we have concluded that there are many significant challenges to be met along the way.

This impartial and interdisciplinary report has been compiled by students from 13 different countries, with the aim of identifying the preconditions that must be met in order to become a viable industry. It examines the different technical aspects, possible trajectories, main routes, market demand, infrastructure requirements, regulations, and the possibility for international cooperation.

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LIST OF ACRONYMS

A

ATC	Air Traffic Control

C

CoC	Cost of Capital
COPUOS	United Nations Committee on the Peaceful Uses of Outer Space
CSLAA	Commercial Space Launch Amendments Act of 2004

D

ΔV	Change in Velocity

E

EASA	European Aviation Safety Agency
ECLSS	Environmental Control and Life Support System
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statements
EIU	Economic Intelligence Unit
ESA	European Space Agency

F

FAA	Federal Aviation Administration

G

GaWC	Globalization and World Cities Research Network
GCR	Galactic Cosmic Ray
GDP	Gross Domestic Product
GL	General License
GLOW	Gross Lift Off Weight

H

HNWI	High Net Worth Individuals
HTHL	Horizontal Takeoff, Horizontal Landing

I

IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICBM	Intercontinental Ballistic Missile
ISA	International Standard Atmosphere
ISFO	International Space Flight Organization
ISO	International Standards Organization
I_{SP}	Specific Impulse
ITAR	International Traffic in Arms Regulations

L

LAX	Los Angeles International Airport
LEO	Low Earth Orbit
LOX/RP-1	Liquid Oxygen and Rocket Propellant-1

M

Mach	Ratio of Vehicle Speed to the Local Speed of Sound
MMOD	Micrometeoroid and Orbital Debris
MP3	Multi Public Private Partnerships
mSv	MilliSievert

N

NASA	National Air and Space Administration
NOAA	National Oceanic and Atmospheric Administration
O	
OST	Outer Space Treaty
P	
PTP	Point to Point
R	
RLV	Reuseable Launch Vehicle
ROI	Return on Investment
S	
SATMS	Space and Air Traffic Management System
SFP	Space Flight Participant
SPE	Solar Particle Event
SS1/SS2	SpaceShipOne / SpaceShipTwo
STM	Space Traffic Management
T	
T/W	Thrust to Weight Ratio
TAL	Transatlantic Abort Landing
TLE	Transient Luminous Event
TPL	Third Party Liability
TPS	Thermal Protection System
TRL	Technology Readiness Level
V	
VC	Venture Capital
VTHL	Vertical Takeoff Horizontal Landing

1 INTRODUCTION

2,010 minutes: flight time from New York to Paris on the Spirit of St. Louis

198 minutes: flight time from New York to Paris on the Concorde

71 minutes: flight time from New York to Paris on a Point to Point Suborbital Vehicle

In 1976 the Concorde Supersonic Transport began daily flights between the United States and Europe, delivering passengers to their destination in less than half the time of a conventional transatlantic flight—a premium service for those who could afford the premium price. Initially perceived as a revolution in air travel, Concorde was considered a technological achievement; however, the program was cancelled after 27 years of service due to multiple factors that led to the demise of the business case. The decrease in travel time is, however, unquestionably remarkable, and parallels from the Concorde program can be drawn to the subject that is the focus of this report—point to point suborbital transportation.

Point to point suborbital transportation has the potential to reduce travel times to tens of minutes, enabling a passenger to take off from New York and arrive in Paris in approximately one hour. Imagine being able to conduct business in a far-away land and return home the same day, or bridging a broken supply chain to sustain a production process. Such is the potential beauty of a point to point suborbital flight. Potential, in that these flights have not be realized yet, and this report seeks to define the conditions necessary from technical, market, financial, infrastructural, safety, and legal perspectives and recommend a way ahead for developing a viable suborbital transportation industry.

1.1 Motivation for the Report

In a world increasingly connected by electronic means, the physical links between cities, countries and continents seem increasingly outmoded. The advent of suborbital transport has the potential to supply high-speed physical connections appropriate for our "instant, on-demand" world. The new era of suborbital spaceflight will be an entrepreneurial, inspired and energetic new era, and has the potential to effect massive change.

1.2 Scope of the Report

The mission statement of the team, *To Conduct a Study of the Conditions for Sustainable Point to Point Suborbital Transportation Systems,* outlines the purpose and intent of this study.

The report is limited in scope to the study of the transportation of passengers and cargo, recognizing there are other potential missions suited to this type of trajectory. The authors did not address the suborbital tourism industry, except as it impacts the development of future transportation systems. Additionally, the use of suborbital vehicles for space-qualification of components, remote sensing, microgravity research, or to launch small satellites is not considered. While military use of a suborbital vehicle as a weapons platform is not covered in the report, the transportation of critical military equipment is considered briefly.

The authors did not attempt to design a spacecraft, as there are several designs already underway for suborbital joyrides that may be considered as early concepts for point to point suborbital flight. The authors feel this would have detracted from the interdisciplinary nature of the report, and a "black box" approach is assumed for the vehicle design, although broad design concepts and their implications are addressed. Reasonable assumptions have been made where necessary.

The six high level pairs of disciplines shown in Figure 1-1 were chosen for their relevance to point to point suborbital transportation and desire to make the report interdisciplinary.

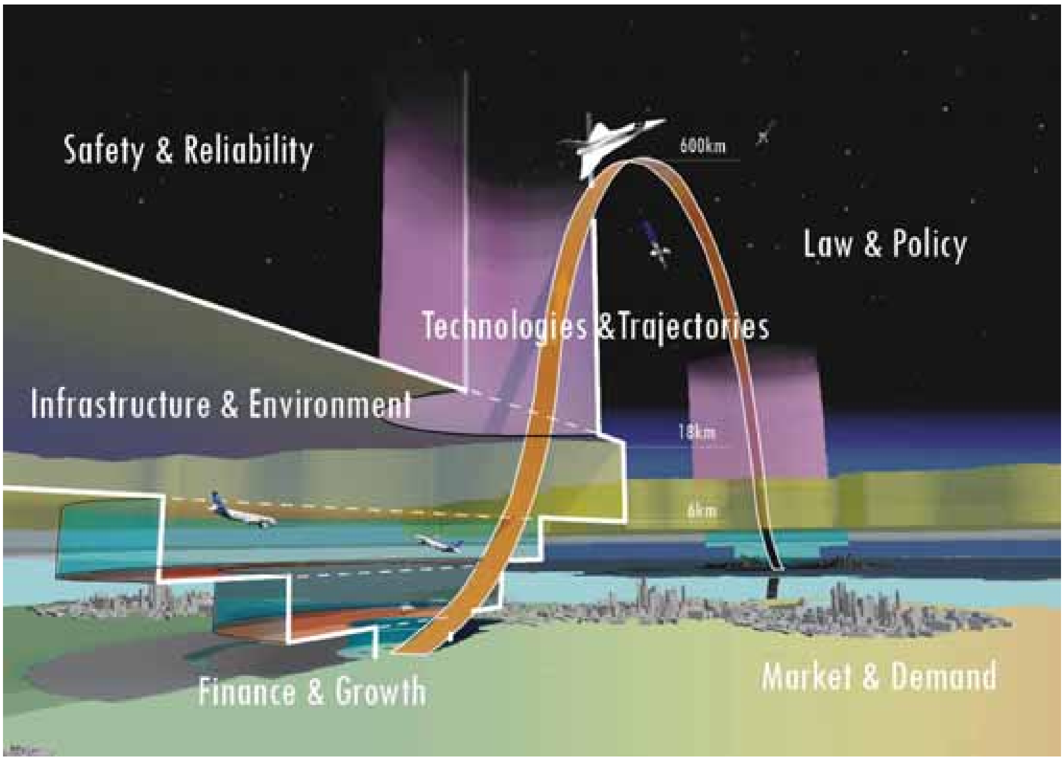

Figure 1-1: Point to point suborbital transportation and disciplines examined in study

1.3 Reader's Guide to the Report

The report has been structured in a logical way to guide the reader through a series of chapters, each of which elaborates on a particular set of related disciplines. While it is encouraged that the order of the chapters is maintained, they can be read as stand-alone documents, starting with an introduction to put the chapter in perspective and finishing with a set of conclusions. The conclusions from each chapter are summarized at the end of the report, and recommendations are made as to how to overcome the challenging issues faced in the development of point to point suborbital transportation.

1.3.1 Technologies & Trajectories

This chapter introduces the reader to the vehicle and the trajectory. A number of vehicle concepts are presented based on their combinations of takeoff and landing modes. The possible trajectories are examined with a detailed technical analysis, and each type of trajectory is examined for its utility and the extent of its viability. The chapter concludes with a discussion of the state-of-the-art in the vehicle technology and assesses the critical technologies based on their Technology Readiness Levels.

1.3.2 Market & Demand

No industry can survive without demand in the marketplace, and this chapter addresses that subject. A detailed analysis of viable flight routes for passenger and cargo transportation is performed to determine the potential demand based on the routes that are logical from a technical and economical point of view. An assessment of the alternatives and substitutes for point to point suborbital transportation is also performed.

1.3.3 Finance & Growth

The chapter undertakes a study of the main cost drivers and conducts parametric costing analysis to evaluate the costs associated with vehicle development, production, and operations. Sources of funding are also explored, and finally, a perspective on the potential for 'organic' growth from suborbital tourism is provided.

1.3.4 Infrastructure & Environment

This chapter looks at the infrastructure that will be required to support a suborbital transportation industry and addresses the following: spaceports, air traffic control, and space traffic management. A possible combined air & space traffic management regime is suggested. The chapter ends with a look at environmental issues and the challenges they impose on this potential industry.

1.3.5 Safety & Reliability

This chapter examines the safety and reliability aspects of point to point suborbital transportation. These issues include reliability level, safety standards, vehicle certification implications, abort procedures, and the hazards that may be encountered in the space environment. The safety of passengers is covered extensively, including life support and medical systems.

1.3.6 Law & Policy

In any technological project, despite the importance of law and policy considerations, these issues are often overlooked. The chapter aims to take a step-by-step view as to the role of government in the development of point to point suborbital transportation and assess whether this will need to be a national, bilateral, or multilateral international effort to ensure success. Through the analysis of government policy and of current legal frameworks for aircraft and space objects, this chapter serves as a guide to initiating and regulation of point to point suborbital transportation systems.

1.3.7 Conclusions & Recommendations

The report finishes with a summary of the conclusions from the individual chapters, and recommendations are made regarding the conditions required to make the suborbital transportation industry a reality.

1.4 Summary

This report aims to be of use to multiple stakeholders in the potential future suborbital transport industry. Its interdisciplinary nature and comprehensive scope provide a foundation on which more detailed and focused investigations can be made. While dreams and reality often clash, humanity's longing for faster and higher flight will continue to make suborbital transportation a goal in the eyes of many.

2 TECHNOLOGIES & TRAJECTORIES

Innumerable concepts for suborbital flight have been proposed over the years, and many candidate routes for supersonic, hypersonic, and suborbital transport have been hypothesized. The design of a vehicle and the choice of flight trajectory are intertwined, and the selection of appropriate vehicle technologies and trajectories is a critical factor in the following chapters, as the vehicle trajectory and technical characteristics have implications on safety, legal, cost, and infrastructure considerations. In assessing the potential for suborbital transport, the technical requirements imposed by specific trajectories must be compared to the current state of vehicle technologies. This chapter provides an overview of available vehicle concepts, discusses the most viable trajectory options, and investigates the most critical areas of technology development for point to point (PTP) suborbital transportation.

2.1 Vehicle Concepts & Flight Profiles

While many options exist, this section introduces the two most viable trajectory types for PTP suborbital transportation, ballistic and ricochet. Options for the takeoff and landing phases will also be examined, as they are critical elements of a profile. A summary of historical and current vehicle concepts in the context of their modes of flight is also provided.

2.1.1 Takeoff & Landing Phases

The selection of appropriate launch and landing systems is a complex task. Figure 2-1 and Figure 2-2 classifies the previous and current hypersonic transportation projects according to different takeoff and landing modes. Properly speaking, some of the projects below are not suborbital, as they do not reach a high enough altitude during the in-flight phase. Other projects were primarily designed for orbital flights, but may be applicable to suborbital flights since the technical requirements are less demanding than for orbital flights. In the table, when determining number of stages, boosters are considered as a separate stage.

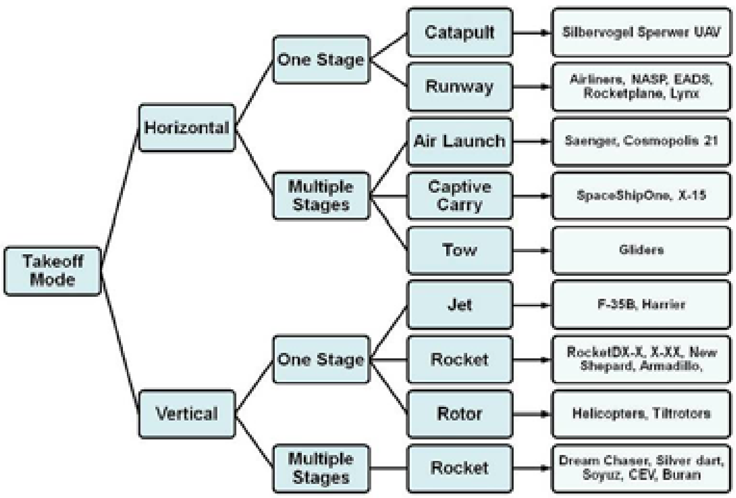

Figure 2-1: Vehicle concepts for takeoff

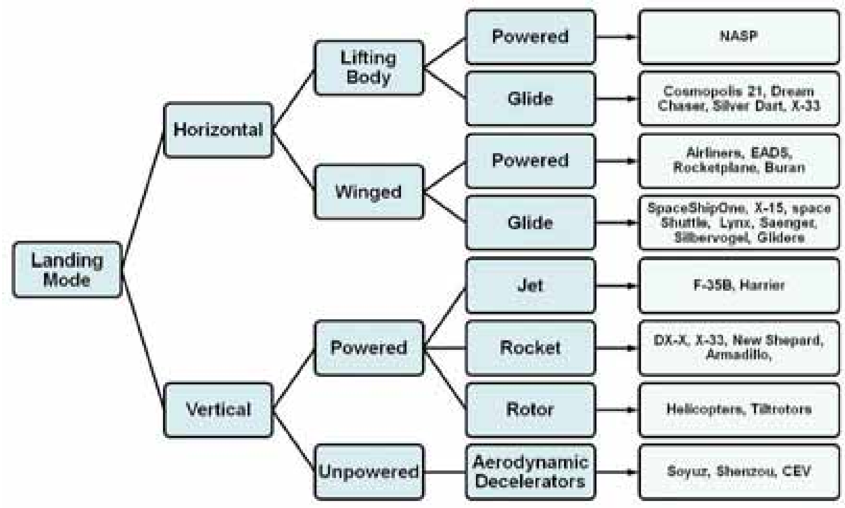

Figure 2-2: Vehicle concepts for landing

2.1.2 *In-Flight Phase*

All possible scenarios for the in-flight phase can be roughly divided into the 3 following types:

1. Steady-state flight in the denser levels of the atmosphere (e.g., Concorde, waveriders, National Aerospace Plane)

2. Ballistic trajectories (e.g., Intercontinental Ballistic Missiles)

3. Ricochet trajectories (e.g., Sänger's Silbervogel Project, Hyper Soar Project)

The maximum height of a steady-state flight in the atmosphere does not typically exceed 25-30 km, which is four times lower than a typical notional boundary of the Earth's atmosphere (100 km). Since this type of flight does not leave the atmosphere, it does not qualify as a suborbital space trajectory and is therefore excluded from the present discussion. Two trajectory types will be considered for the suborbital in-flight phase:

Ballistic trajectories: these include flights where a vehicle has a powered boost and then coasts along a part of an ellipse, as illustrated in Figure 2-3 below.

Ricochet trajectories: these include flights where the vehicle “skips” on the upper atmosphere using the principle of compression lift. When the vehicle descends at hypersonic speed from about 150 km altitude down to denser levels of the atmosphere, lifting force and engines move the vehicle back up out of the atmosphere (although to a lower altitude of apogee than the previous). The resulting trajectory, as illustrated in Figure 2-3 below, is a succession of ballistic flights of decreasing apogees.

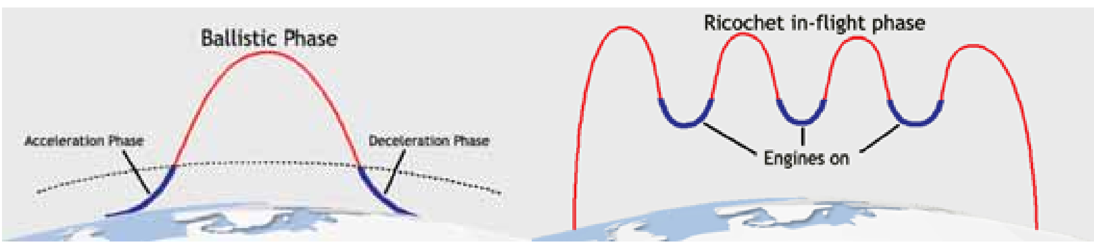

Figure 2-3: Ballistic and Ricochet flight profiles

2.2 Analysis of Trajectory Types

Suborbital flights can make use of multiple types of trajectories; among these, the most useful have been identified as ballistic and ricochet trajectories. This section is devoted to a more detailed look at each of these two trajectory types.

2.2.1 Ballistic Trajectory

Takeoff Phase

The main goal of this phase is to achieve enough speed to enter into the ballistic phase. The amount of energy needed to achieve a given speed is usually measured in delta-V (ΔV). During acceleration, part of the energy provided by the engines is lost due to external losses from gravitational and aerodynamic forces (losses due to steering are neglected here). An obvious goal is to minimize these losses, and this is a difficult optimization problem when designing flight profiles. If a vehicle has a high thrust to weight ratio (T/W), it can reduce gravity losses but suffers an increase in aerodynamic losses, since the vehicle would be traveling very fast at low altitudes. On the other hand, a low T/W can reduce aerodynamic losses but greatly increase gravity losses (Sarigul-Klijn & Sarigul-Klijn, 2003). The main input influencing a vehicle thrust-to-weight ratio is the choice of engine type. To assess specific impulse estimation, hydrogen is excluded as an option for the choice of a propellant because of its low density, which will lead to larger propellant tanks (as an aside, however, hydrogen engines with specific impulses (I_{SP}) of around 450 s have been in use for many years). Table 2-1 below gives an example of loss values for a vehicle with rockets engines, using methanol and oxygen as propellant.

Table 2-1: Losses for different engine types

Engine	I_{sp} (s)	Gravity loss (m/s)	Aerodynamic loss (m/s)
Air-breathing	1,300	200	700
Rocket	330	1,000	70

It can be seen that to obtain a rough estimation of ΔV, approximately 1 km/s must be added to the value of the speed of insertion into the ballistic phase to account for losses. The ballistic insertion speed will be discussed in the next section.

Ballistic Phase

During the ballistic phase, the engines are off, and the vehicle experiences free-fall. This phase of the trajectory appears at first glance to be parabolic. In fact, its shape is not a parabola, but part of an ellipse. If the altitude of the flight path is not very high, it can be assumed that the gravity force acting on the vehicle is constant, and the trajectory is parabolic. However, for the higher altitudes experienced by suborbital vehicles, the force of attraction of the vehicle by the Earth decreases at a rate that is inversely proportional to the square of the distance between the vehicle and the Earth. The vehicle's trajectory is guided by the laws of Kepler and Newton and will look like part of an ellipse with one focus at the center of the Earth, as shown in Figure 2-4:

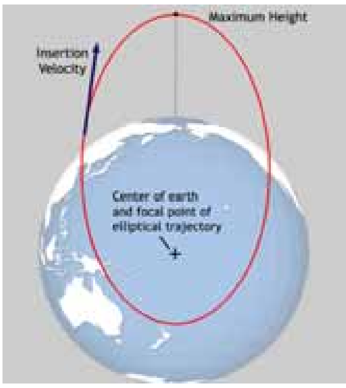

Figure 2-4: Visualization of ballistic trajectory

Figure 2-4 also illustrates the fact that shape of the ellipse is determined by the initial velocity when the ballistic phase begins, the 'insertion velocity', and the angle between the velocity direction and the horizon, the 'launch angle'. In other words, the characteristics of the ellipse including the maximum altitude are determined by the insertion velocity vector.

The trajectory analysis started by fixing the distance between the flight origin and destination points, which is measured as the shortest path on the surface of the Earth between these two points. Note that this path lies in a plane, called a "great circle", containing the two points and splitting the Earth into two hemispheres. The distances considered vary between 0 and 20,000 km (roughly half the circumference of the Earth, the distance corresponding to antipodal points). The following assumptions are made:

1. Entry into the ballistic phase is performed when most aerodynamic pressure loads are exceeded. If those loads are less than two kPa, they can be neglected. For the present study, 50 km is set as the minimum altitude at which further atmospheric losses can be neglected.

2. The exit from the ballistic phase starts at 90 km altitude.

3. The velocity in the beginning of the ballistic phase and the velocity at reentry are assumed to be equal in magnitude. Indeed, if the exit from ballistic phase was performed at 50 km altitude, those velocities would be equal according to energy equation governing the orbital motion. With the exit starting at 90 km, the insertion and reentry velocities differ by 200 m/s, which will be neglected for this analysis.

The reentry velocity is critical because it determines g-loads and thermal loads during the reentry. G-loads are proportional to square of velocity, thermal loads are proportional to the cube of velocity, and both depend on the reentry angle. Therefore, a primary goal is to choose a trajectory which minimizes the reentry velocity. Basic optimization analysis shows that for a fixed distance, considering all possible choices of launch angle, there is one combination in which achieves a minimum value for the insertion speed. Values of the minimum insertion/reentry velocity as a function of distance are illustrated in Figure 2-5 below.

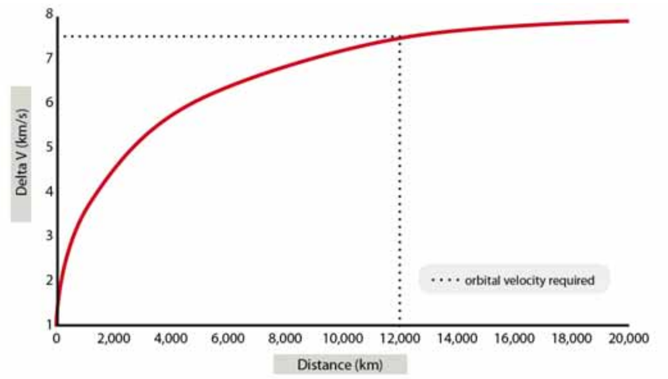

Figure 2-5: Entry into ballistic phase speed vs. distance

This leads to an important conclusion; for distances greater than 12,000 km, the required minimum velocity is exceeds minimum orbital velocity (~7.8 km/s).

Assuming that the vehicle is traveling on a trajectory with minimum insertion velocity, known as the "ellipse of minimal energy", the maximum altitude of the trajectory can be determined, as shown in Figure 2-6:

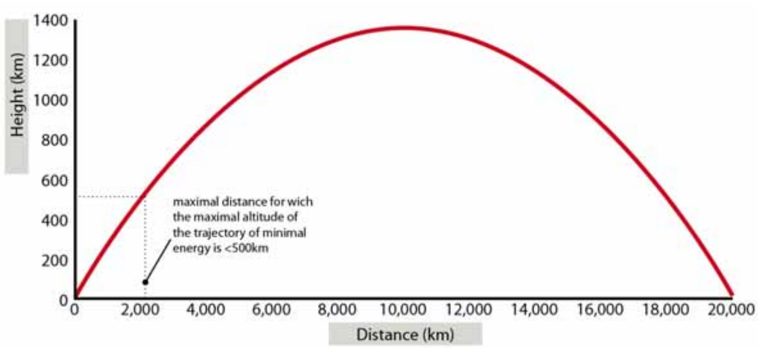

Figure 2-6: Maximum altitude vs. distance

The important conclusion is that the minimum insertion/reentry velocity is related to the maximum altitude of the flight. While the maximum altitude does not really matter for cargo, it could be a problem for passenger transportation due to the level of radiation exposure. Indeed, the space environment induces significant radiation levels at altitudes greater then 500 km. To minimize the exposure to harmful radiation, the maximum altitude of flights with passengers is recommended to be capped at 500 km, at the penalty of increasing the corresponding insertion velocity. For distances of less than 2,500 km, the maximum altitude does not exceed 500 km, and the flight will still travel on minimum energy orbit.

Insertion velocity as a function of distance and launch angle is illustrated below in Figure 2-7.

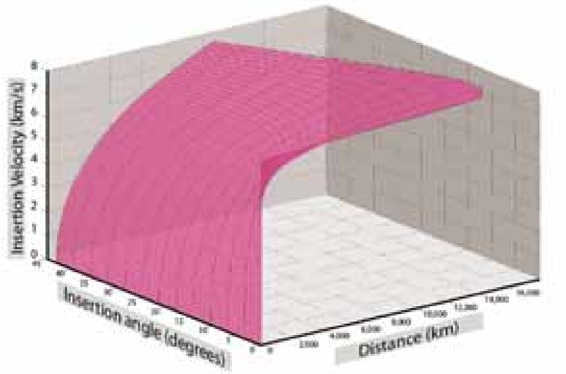

Figure 2-7: Distance vs. launch angle vs. insertion velocity

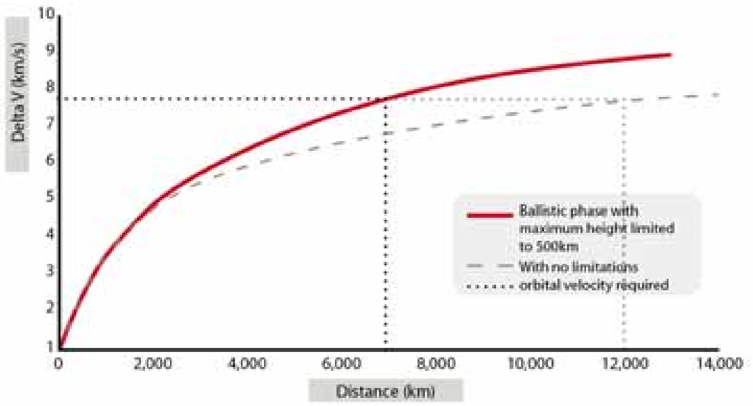

Figure 2-8: Insertion velocity vs. distance for maximum altitude of 500 km

It is observed that when apogee altitude is limited to 500 km, distances greater than 7,000 km require an insertion velocity exceeding minimum orbital velocity if a ballistic trajectory is used.

Another important characteristic of the trajectory is the time spent in the ballistic phase. This is approximately equivalent to the duration of microgravity that will be experienced by passengers. Figure 2-9 below illustrates how travel time varies with distance for flights with an apogee of less than 500 km. These travel times correspond to just the ballistic phase, and do not include takeoff, acceleration, and landing.

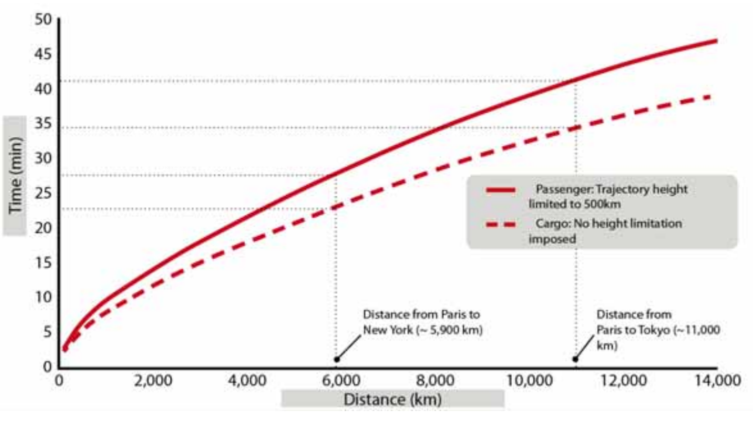

Figure 2-9: Time in ballistic phase vs. distance for passenger and cargo trajectories

As can be seen from the graph above, the ballistic portion of a flight from London to New

York takes approximately 28 minutes, while the ballistic part of a flight from New York to Tokyo takes 42 minutes.

Landing Phase

During reentry, the vehicle faces four primary challenges (Tolyarenko, 2007):

- Capture by the atmosphere
- Deceleration loads
- Atmospheric heating
- Achieving good landing accuracy

The worst case scenario for g-loads and thermal loads during reentry is realized when the reentry is unpowered; therefore, this scenario will be used for the subsequent calculations. In this section, the standard exponential model of the atmosphere has been used. The thermal load, or heat flow rate, during reentry is proportional to the cube of reentry velocity and square of atmospheric density at the reentry altitude. It also depends on the vehicle aerodynamic configuration. Figure 2-10 provides an approximation of thermal loads as a function of flight distance under the assumptions that the nose radius is 50 cm and the reentry altitude is 90 km.

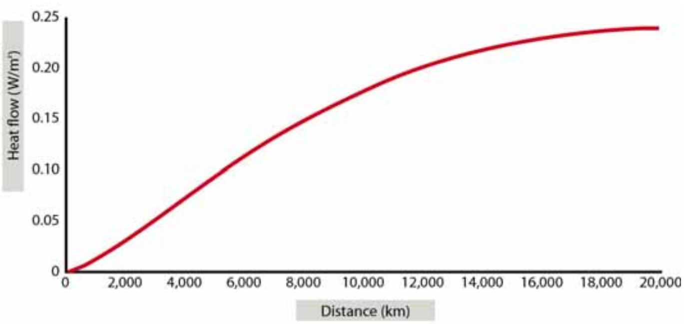

Figure 2-10: Heat flow vs. Distance

Figure 2-11 illustrates a first approximation of the reentry temperature for a vehicle traveling at 6 km/s, with a comparison to existing vehicles (Tolyarenko, 2008a).

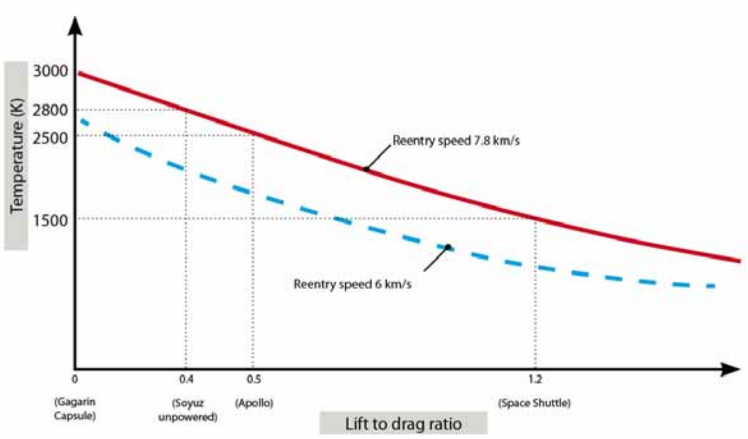

Figure 2-11: Reentry temperature as a function of aerodynamic characteristics

Figure 2-12 shows on the left the variation of g-loads with distance, for the worst case scenario of unpowered reentry with no lift forces due to the aerodynamics shape of the vehicle. These g-loads are considered extremely high and unsafe for manned flight. The graph on the right estimates the target hypersonic lift to drag (L/D) ratio required to reduce the g-loads to approximately 2 g.

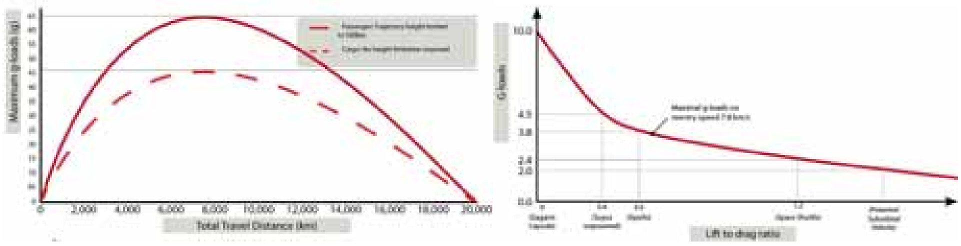

Figure 2-12: G-loads for worst case (L) and hypersonic L/D for optimal g-loading (R)

2.2.2 *Ricochet Trajectory*

This type of trajectory first appeared in the Silbervogel project by Sänger and Bredt in 1944 (Sänger & Sänger-Bredt, 1944). There is a growing interest in ricochet trajectories because such flight profiles may reduce the effectiveness of anti-missile systems. Silbervogel's trajectory is radically different from a conventional ballistic flight, and is described in this section.

The Silbervogel mission starts with the vehicle traveling along a 3 km monorail track using a rocket-powered sled to accelerate up to Mach 1.5 (0.5 km/s). The vehicle starts to climb vertically, and at an altitude of 2 km, the rocket engine fires and accelerates the vehicle to a speed of Mach 17 (5.6 km/s) at an altitude of 60 km. With this speed, the vehicle enters the first of several ballistic phases during the flight, reaching altitudes up to 250 km. As the aircraft accelerates and descends under the force of gravity, it encounters denser air at approximately 35 km and "skips" back up, like a stone skipping across the surface of a pond, to start the next ballistic hop. Each subsequent peak of the trajectory is lower than the previous one because a fraction of kinetic energy is consumed during the passage through denser air.

With this mission, the rocket engines consume approximately 85 tons of fuel, but can travel distances up to 22,000 km. Analysis of ballistic trajectories indicates that with a speed of 6 km/s and a launch angle of 30 degrees, a distance of 5,000 km is reached in one hop, with a maximum altitude of 250 km. This combination of launch angle and velocity is not optimal, which explains why the peak altitude is lower than the previous section. By decreasing the entry speed, the hop length can be reduced, as shown in Figure 2-13:

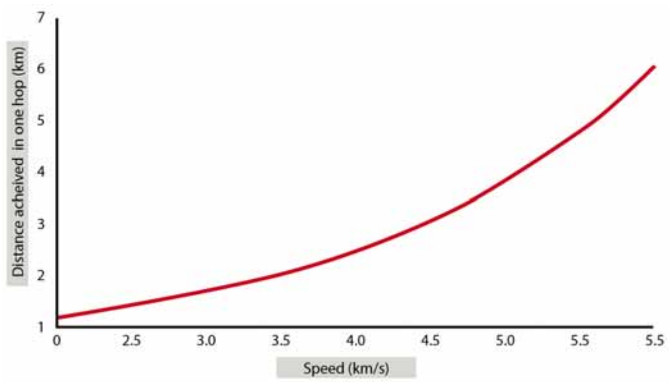

Figure 2-13: Ricochet trajectory - Distance achieved in one hop

During the launch, gravity, and aerodynamic losses contribute about 1 km/s in the ΔV budget.

The aerodynamic losses between hops do not exceed 300 m/s. Assuming the entry speed is 5.6 km/s, a rough estimation of the ΔV budget for a ricochet trajectory is illustrated in Figure 2-14.

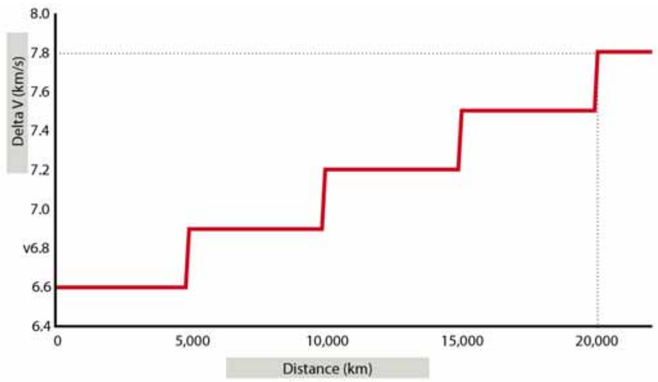

Figure 2-14: ΔV budget for ricochet trajectory vs. distance

This estimation can serve as a starting point for evaluating the optimal number of hops (or, equivalently, optimal height of the first hop) as a function of distance. For example, London to New York can be accomplished in two hops with an insertion velocity of 6 km/s, and London to Tokyo can be done in three hops with an insertion velocity 6.1 km/s.

2.2.3 Ballistic vs. Ricochet

It is apparent that to keep the insertion velocity from exceeding orbital velocities, ricochet trajectories are the only option to transport passengers across distances between 7,000 km and 20,000 km (where maximum altitude is limited to 500 km), and for cargo transport across distances between 12,000 km and 20,000 km (no maximum altitude). In particular, for flights between opposite points of the Earth's surface (antipodal flight), ricochet is the only suborbital option. This can be visualized as shown in Figure 2-15:

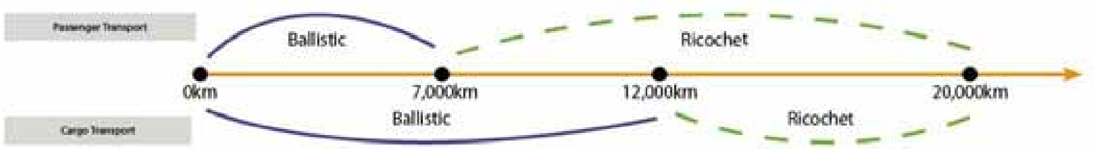

Figure 2-15: Ballistic vs. Ricochet for passenger and cargo transportation

There are two limiting distances: 7,000 km and 12,000 km; for distances close to these numbers, ballistic and ricochet trajectories require the same amount of ΔV. For two major routes, London-New York (5,585 km) and New York-Tokyo (10,858 km), the distances are close to these numbers.

An additional trade-off between ballistic and ricochet trajectories for those distances is of interest. The ricochet trajectory has a few disadvantages in comparison to the ballistic trajectory. As was mentioned earlier, by varying the initial ballistic speed, the number of hops can be changed. This is a complicated trade-off because by reducing the entry speed, the required ΔV is reduced at the expense of more "hopping", which may be less attractive to passengers. Another disadvantage of the ricochet trajectory is that every time the vehicle bounces against the atmosphere, a noise wave propagates to the ground. Finally, the ricochet trajectory requires precise maneuvers. At a reentry speed of 8 km/s, the required precision for the current perigee of the reentry orbit is about 1 km (Tolyarenko, 2008a). Global Navigation Satellite Systems can provide this level of accuracy and are available for near Earth flight.

Table 2-2 lists the basic parameters for ballistic and ricochet trajectories between major routes. It is important to note that these times are for the in-flight phase only and do not include takeoff and landing phases, as the durations of those phases depends on the modes employed.

Table 2-2: Ballistic and Ricochet flights parameters on major routes

London–New York: 5,585 km			
	Ballistic		Ricochet (2 hops)
	Passenger	Cargo	
Flight duration	28 min	23 min	35 min
G-loads	4.3 g	4.2 g	3.2 g
Insertion speed	7.2 km/s	6 km/s	6 km/s
ΔV budget	8.3 km/s	7 km/s	7.3 km/s
Reentry temperature	1,300 K	1,000 K	800 K
New York–Tokyo: 10,858 km			
	Ballistic		Ricochet (3 hops)
	Passenger	Cargo	
Flight duration	42 min	33 min	50 min
G-loads	4.6 g	4.3 g	3 g
Insertion speed	8.5 km/s	7.2 km/s	6.1 m/s
ΔV budget	9.5 km/s	8.2 km/s	8 km/s
Reentry temperature	1,700 K	1,300 K	900 K

Finally, to quantify the obvious observation that taking a suborbital flight is faster than regular air travel, Table 2-3 is a comparison of air travel flight times vs. suborbital flight times for three major routes, which are analyzed in subsequent sections. The suborbital flight times include an estimate of 43 minutes for departure/ascent, reentry, and approach, as listed in Table 2-3.

Table 2-3: Travel time comparison for different modes of transportation

Route	**Distance (km)**	**Aircraft Duration (hr)**	**Concorde Duration (hr)**	**Suborbital Duration (min)**
London – New York	5,900	7 h 30	3.5	66 - 71
London – Singapore	9,560	11 h 30	8*	75 - 78
New York – Tokyo	10,900	12 h 50	9*	81 - 85

*assuming no constraints on overland supersonic flight

It is clear that for the longer potential suborbital routes, vehicle capabilities approaching those required for orbital flight are necessary. Such capabilities push the limits of current technologies and naturally lead to the requirement for a review of the current status of critical technologies, as follows in the next section.

2.3 Technology Development

Even though the purpose of this report is not to propose a specific concept for a suborbital vehicle, there are several challenges in designing suborbital vehicles that should be noted. The goal of this section is to analyze those challenges from a technology development point of view.

The development of suborbital transportation vehicles relies heavily on the current status of applicable technologies. One approach to examining the issue is to start with a historical perspective on the development of high-speed air transportation technology. To be sure, suborbital vehicles draw their technologies from the development of hypersonic aircraft, experimental "X planes", expendable and partially reusable launch vehicles, and other related technologies.

Part of understanding these technological developments is quantifying the maturity level of a technology. Many agencies use the technology readiness level (TRL) definition used by NASA found in NASA Management Instruction (NMI 7100) "TRLs are a systematic metric/measurement system that supports assessments of the maturity of a particular technology and the consistent comparison of maturity between types of technology (Mankins, 1995)." A similar scale has been adopted by ESA.

Figure 2-16: Technology readiness levels

2.3.1 Required Technologies

An obvious but crucial starting observation is that suborbital transportation vehicles must be reusable. When designing a reusable vehicle, the key challenges are to achieve a high thrust to weight ratio, find an optimal airframe integration, and to successfully manage thermal constraints. Aside from that, a reusable vehicle must be highly reliable, require minimum maintenance, and have a long service life.

Table 2-4 below outlines key subsystems of suborbital vehicles with a corresponding comment on further required improvements.

Table 2-4: Technology challenges

Technology Area	Main Challenges Identified
Propulsion	Efficient engine with high performance and reusability Storage and handling of propellants Maintenance
Thermal protection and management	Development of precision sensors and durable material under highly dynamic thermal environment. System for automatic inspection and easy maintenance of thermal protection

Vehicle Design and structure	Sustainable structure with high strength to mass efficiency Adoption of structure for sub-, super-, and hypersonic flights Highly integrated design Vehicle health management system
Communications	Communication for all phases of flight—including travel through plasma
Guidance, Navigation, and Control	Refinement and integration of accurate and compatible navigation instruments for high-speed suborbital flights

With the challenges identified above, the next table summarizes the current status of components—focusing on particular development phases.

Table 2-5: Component technology readiness

Technology	TRL	Current Status
Air breathing propulsion at hypersonic velocity, scramjet	6	Comprehensive and analysis modeling exists for hypervelocity speed up to Mach 9.6 (X-43A)
Rocket engine propulsion	9	Understanding of cylindrical space vehicle aerodynamics and propulsion up to Mach 30.
Control systems for engine and vehicle control surfaces	5	Engine-airframe control system. Full scale integration on modern hypersonic aircraft is still under development
Vehicle Health Management	4	Requires engineering development.
Communication	4	Communications in plasma are still out of reach. Requires development for communication at hypervelocity.
Manufacturing	5	Needs infrastructure and technology.

Among the technologies required, there are three that can be identified as critical. These technologies are propulsion systems, thermal protection systems, and airframe structures.

2.3.2 Propulsion

All chemical propulsion systems for air and spacecraft can be roughly divided into 5 categories:

Table 2-6: Propulsion categories

Type of propulsion	Description
Solid	Mainly used for boosters or main stage.
Liquid	Propellant in liquid form is stored in a tank and fed to the engine.
Hybrid	Uses two or more propellants in different phases, typically a liquid oxidizer and a solid fuel
Rocket-Based Combined Cycle	Air-augmented rocket system
Air-breathing	Scramjet, Ramjet, and turbojet

Hybrid engines are a combination of the two mature engine types: liquid and solid, and are characterized by having the fuel and oxidizer in different states – that is to say, the former is solid and the latter is liquid or gaseous. Fuels are usually solid materials like rubber or plastic, but can also be paraffin wax – which over the past few years has received great attention due to its high regression rate (rate of burn). The oxidizers are liquid or gaseous like O_2 or N_2O. Due to the fuels' high stability and reaction temperature, the engine must usually be ignited with a pyrotechnic charge. This small charge causes the fuel to evaporate and, together with the oxidizer, blends into a usable propellant. The hybrid system is considered safer due to the fact the oxidizer and fuel are separated, and the fuel itself is close to non-reactive when stored. With fuel grain cracking or deformation, the engine is more or less unaffected by this, as opposed to solid engines where a crack in the fuel grain could cause a major explosion due to a drastic increase in chamber pressure as a consequence of larger burn surface area. The oxidizer flow can be regulated from almost zero to full thrust—creating the desired thrust profile necessary at a given time. Hybrid engines can also handle multiple shut offs and restarts if necessary.

Liquid engines are more complex than hybrid engines, and have some benefits and drawbacks compared to the hybrid. Liquid engines are characterized by having both the fuel and oxidizer in liquid state, separated in two different tanks. Both liquid and gaseous propellants are used, but in case of liquid propellants a feeding system is required. Commonly used methods are turbo pump feeding and pressure feeding, where the former gives a very high chamber pressure and the latter a somewhat lower chamber pressure. For human-rated craft a pressure feeding system is the most attractive option due to safety. Liquid engines tend to have a high specific impulse which is a key factor in optimizing the overall vehicle. Even though the liquid engine is complex and more expensive, the higher cost could be justified due to higher propellant efficiency. This engine system has the benefit of thrust regulation, handling multiple shut-offs and restarts. The major drawback is safety. Both components of the propellant are in highly reactive states during storage and operations. Operations are more risky than with hybrid, which are important issues at air and spaceports.

Solid engines are simple, reliable engines that provide a high thrust at low cost. The propellant for this kind of engine is purely solid; it has a propellant grain with both fuel and oxidizer uniformly distributed throughout the grain and a port in the center. The shape of the port defines which thrust profile obtained. This kind of engine is often used in missiles and boosters, but somewhat rarer in exploration missions. Modern advanced solid engines have some controllability like throttling, shut off and restart, but are very limited compared to the liquid and hybrid engines. Using thrust vector control in the nozzle can achieve very accurate steering and guidance.

Air-breathing engines use air from the atmosphere to oxidize the fuel onboard the vehicle. Basic air-breathing systems include turbo jets, ram jets, scram jets and pulse jets—all based on the principle of a jet engine. A jet engine is an engine that ejects a jet or stream of gas or fluid, obtaining all or most of its thrust by reaction to the ejection (Sulocki & Cartier, 2004).

Table 2-7: Comparison between different engine types

Engine	Advantages	Disadvantages
Chemical rocket engines		
Liquid rocket engine	High I_{SP}, throttling Shut off and restart capabilities	Complex, expensive Large and heavy system
Hybrid rocket engine	Medium I_{SP} and thrust combined, easy throttling	Unstable combustion

	Shut off and restart capabilities	
Solid rocket engine	High thrust at low cost Simple design	Difficult to throttle Shut off and restart
	Air-breathing engines	
Turbojet	Simple design, efficient above Mach 2	Inefficient below Mach 2, quite noisy
Turbofan, low-bypass	More efficient than turbojet at subsonic speed	Compared to high-bypass, less efficient and more noisy
Turbofan, high-bypass	Less noisy compared to low-bypass	Complex, limited top speed
Ramjet	Few moving parts, efficient above Mach 2 (optimal at 3), lightest of all air-breathing systems, cooling is easy	Needs high initial velocity to function
Scramjet	Few moving parts, high efficiency at Mach 8 to 15	Needs initial velocity of Mach 6 to function, difficult to cool, extreme complexity
Pulsejet	Simple design	Noisy, low efficiency and not suited for lager designs

Table 2-8 summarizes the TRL levels for different propulsion systems.

Table 2-8: Propulsion system readiness

Propulsion system components	Comments	TRL
Hybrid and solid engines	Turn around time for refurbishment is long	9
Liquid engines	Reusability, able to restart. However, tank separation and residual fuel management is cumbersome, technology needs further development	9
Linear aerospike engine, Expansion Deflection nozzle	Tested for the X-33 experimental space vehicle (cancelled), but there are no major breakthroughs since it was last tested in 2001	4
Turbine, and Rocket, based Combined Cycle, pulse detonation engines	Tested in laboratory only	4
Metallic hydrogen, atomic hydrogen	On paper	1

As was discussed previously, concepts for suborbital transportation vehicles are numerous, but can be classified according to their takeoff and landing modes. The following is an examination of propulsion technologies for different hypersonic transportation concepts with some analysis of corresponding TRLs.

Vertical Takeoff, Vertical Landing (VTVL) vehicles have proven flight history for launch but soft landing on the Earth with retro engines from high altitude has not been performed. TRL 7.

The main issue during landing using aerodynamic decelerators (parachutes, air brakes, and thrust-reversal systems) is the accuracy of maneuvers. Landing accuracy depends largely on atmospheric conditions in the landing and recovery area. TRL 9.

Vertical Takeoff, Horizontal Landing (VTHL). Other than the Space Shuttle, a few vehicles have been conceptualized in VTHL category. The Space Shuttle has been a partially re-usable vehicle with costly throw away parts and laborious inspection & maintenance. With this reference VTHL vehicles can be considered at TRL 7. Figure 2-17 illustrates the resulting TRL levels for different combinations of takeoff/landing modes and number of engines.

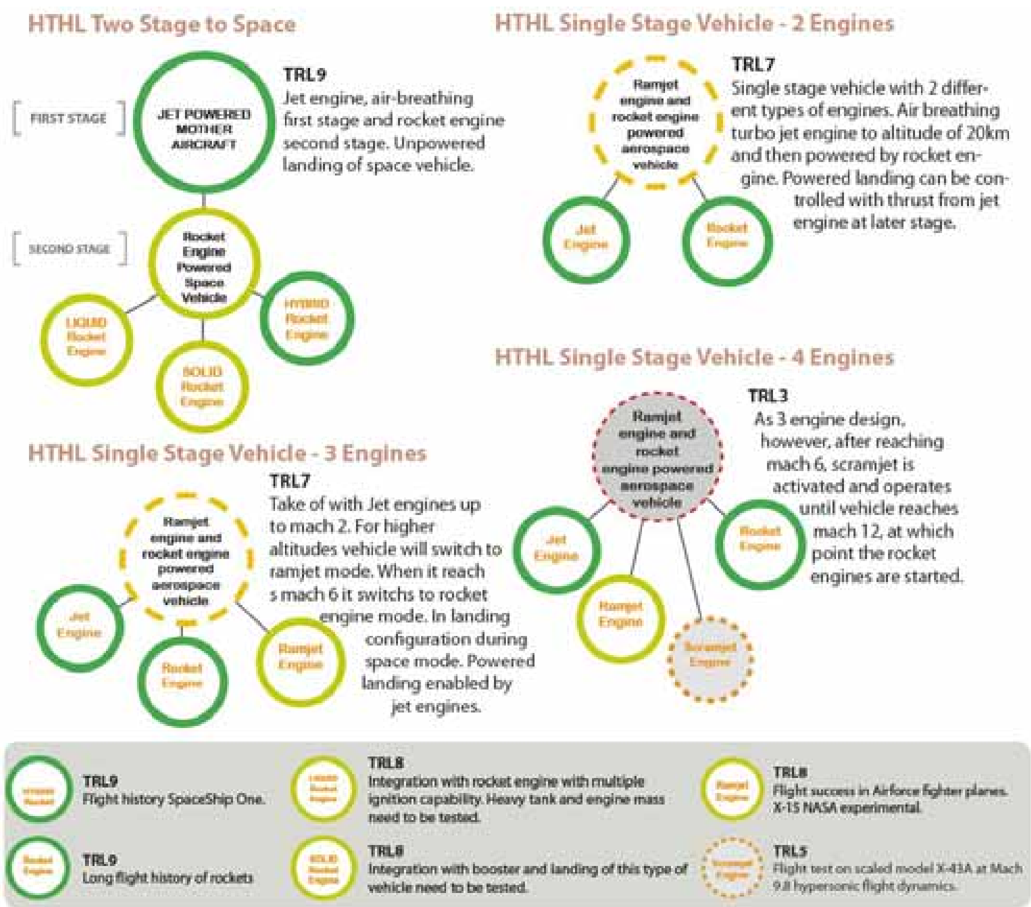

Figure 2-17: TRL levels for vehicle concepts

2.3.3 *Thermal Protection*

The thermal protection system (TPS) is a critical technology subsystem required to protect the vehicle and the payload as it travels through the atmosphere. The challenge of designing a thermal protection system for PTP suborbital vehicles is to satisfy the following requirements and constraints in the most efficient manner: operability, maintenance, durability, lifecycle costs, and integration with the vehicle structure. There are various types of thermal protection mechanisms, including: heat-sink, radiation cooling, insulation, ablation, and active cooling. Each type has its own application, advantage and disadvantages.

Withstanding the variety of forces, aerodynamic, chemical, thermal and mechanical loads, are major requirements on thermal protection materials. There is a fair understanding of reentry thermodynamics and testing facilities are well developed, however it is necessary for thermal protection systems to be proven in realistic environments. The vehicle's shape and reentry conditions play a major role. Vehicles traveling at altitude of 50 km at velocities lower than Mach 5 do not need advanced thermal protection and much of these materials are at TRL 9. For vehicles moving at higher velocities, the thermal protection needs robust material. Its integration with structure, inspection, maintenance and reliability requires more attention.

Carbon-carbon, ceramic tiles, flexible blanket, and similar materials are the typical thermal protection methods with high reusability. Carbon-carbon is used on the Space Shuttle and therefore has a high TRL but still needs more technological development for ease of maintenance and inspection. Carbon Fiber, Reinforced Silicon Carbide and metal face sheet honeycomb materials are undergoing testing in laboratories and have no flight heritage. Below is Table 2-9 summarizing the current status of various materials for TPS.

Table 2-9: Thermal protection system readiness

Carbon-Carbon composite material	TRL
Ceramic tiles: aluminum enhanced thermal barrier	9
Coatings: toughened unipiece fibrous insulation reaction cured glass	8
Tailorable advanced blanket insulation	8
Titanium multiwall concepts	7
Superalloy honeycomb sandwich panels	7
SNECMA's single concept	6
Advanced carbon/Carbon control surfaces	6
Silicon carbide/Silicon carbide	6

2.3.4 Airframe Structure Design

Besides propulsion and thermal protection systems, a third major area of technology development is vehicle structures and the materials of which they are made. The extreme challenges associated with space flight, particularly for reusable vehicles, have often led to problems in developing structural elements capable of meeting the mission requirements. A painful example of this was the failure of the composite hydrogen tanks proposed for the now-cancelled X-33, which failed during testing and were a factor in the cancellation of the program (Bergin, 2006). The X-33 suffered other structurally-related problems, including disbanding of the linear aerospike engine's copper exhaust ramps, and difficulties in the fabrication of bonded thermal protection system materials.

A key parameter in rocket design is the Mass Ratio, which is the ratio of total liftoff mass not used by propellant to the total lift off mass. The converse to this is the Mass Fraction, the fraction of total liftoff mass taken up by propellant or by components that will be discarded (such as stages). Decreasing the mass ratio increases the mass fraction and thus the performance of the vehicle; therefore, efforts to improve vehicle performance often focus on the design of lighter structures (Sutton & Biblarz, 2001).

A single stage to orbit vehicle with kerosene/liquid oxygen (LOX) propulsion requires mass fractions of about 0.94, which is to say that only 6% of the takeoff weight can be allotted to structures and payload. Contrast this to a vehicle like the X-15, which had a mass fraction of 0.55, or that of a 747, which has a mass fraction closer to 0.5, and it is evident that suborbital transports requiring near-orbital velocities will require very advanced and lightweight structures (Sarigul-Klijn & Sarigul-Klijn, 2001).

With the advent of high-performance composite materials and their increased use throughout the aerospace industry, great attention is being devoted to materials and manufacturing methods in order to maximize their benefits. Since the properties of composite materials are, by their nature, highly dependent on processing and manufacturing methods, this is a major area of research. Whereas previous vehicle development started with a design and followed with the selection of appropriate materials, advanced modern materials can be custom-designed to meet specific structural performance targets (Hammond, 2001).

TRL levels of advanced composite materials range across the spectrum from 1 to 9. At the earliest stages (TRL1), materials such as NACOMAT nanostructures exist in the lab and are forecast to be at TRL 4 by 2011. In the medium range, other new carbon fiber/SiC fiber materials are nearing the TRL 6 level. At the end of the spectrum, last generation SiC matrix materials can be found between TRL 8 and 9 (Lasalmonie, 2006).

Some of the main research areas in materials and manufacturing include:

- Lower weight – reduced structural mass leads to direct gains in vehicle performance
- Increased structural stiffness and strength
- Longer structure lifetimes – critical for highly reusable vehicles
- Higher working temperatures – needed to reduce the risks associated with atmospheric reentry and high-speed atmospheric flight (Hammond, 2001)

2.3.5 Technology Development Path & Prediction

There are four scenarios illustrating development path and costs that are depicted in Figure 2-18.

Line number 1 in depicts a scenario of a very positive environment for development: high competition, high demand, successful technology breakthroughs, and high priority funding. This could enable technology in a relatively short future.

Line number 2 depicts a scenario of a moderate environment and technology development to take place under lower competition, moderate demand, and conservative development as it exists today. Cost of development will be lower but will take longer for the technology to develop.

Line number 3 depicts a scenario of low priority development, influenced by mixed results with success and failure and a relatively low market demand. This indicates a higher cost and longer development time. Line number 4—an offshoot of line number 3, depicts a major catastrophe during development and or change of market condition which results in abandoning a development program despite considerable capital investment.

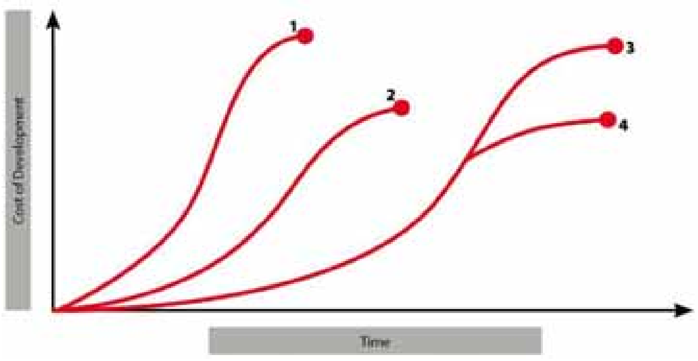

Figure 2-18: Cost of development vs. Time

Significant developments have been made in the technologies applicable to suborbital transportation, especially in the research areas of thermal systems, propulsion, and materials. There is still work to be done, but the technology has developed enough to encourage forward momentum for the industry as a whole.

2.4 Conclusions

Many design concepts exist for suborbital vehicles. The tradeoffs between these different concepts are complex and can fundamentally affect the commercial viability of a PTP suborbital transportation vehicle. Although certain vehicle concepts stand out as being better suited for commercial PTP suborbital applications, no single vehicle design obviously presents itself as the best candidate. Furthermore, the differing core competencies of individual design groups will inevitably result in different design decisions.

Once a vehicle reaches space and enters into a suborbital trajectory, many of the differences between vehicle concepts no longer matter, as the governing physics applies equally to all vehicles. This allows for a trajectory analysis that is independent of most design decisions. The results of this analysis show that for any flight distance greater than 12,000 km, the required velocity is equal to that required to enter low Earth orbit. Furthermore, if the radiation belts are to be avoided by limiting the suborbital apogee to 500 km, a velocity equivalent to LEO insertion is required for a ballistic suborbital flight of only 7,000 km. This result has important implications for suborbital vehicle design and operation, as it suggests that a practical long distance suborbital vehicle will face many of the same design challenges that exist for orbital resuseable launch vehicles (RLVs), including elevated reentry temperatures and decelerations. For long flight distances, a ricochet trajectory approach to suborbital flight is a possible alternative to direct ballistic flight. Ricochet trajectories are more energy efficient; however, they have their other associated problems, such as noise generation, multiple engine restarts, and potential passenger discomfort.

Advanced propulsion, thermal protection systems, and vehicle structures are the three key technology areas that require development. These will be necessary in order to provide the energy necessary to reach the velocities required for long-distance suborbital trajectories, withstand the high thermal loads, and make vehicles light enough to carry payloads in an economically efficient manner. While progress is being made in these areas, their future development appears to be dependent on the success achieved in the suborbital tourism and orbital industries.

3 MARKETS & DEMAND

Understanding of the potential markets and demand is key to examining the development of suborbital transportation. If there is no demand or a market cannot be developed, then there is little or no reason for commercial operators or developers of this technology to invest the capital required for such an endeavor. This chapter provides an overview of the key questions involved as well as some analysis for understanding the demand for suborbital point to point transportation. Potential routes are identified, customer demand for specific routes is questioned, and the overall marketplace is examined.

3.1 Analysis of Flight Routes

For centuries, civilizations have improved their economic position through trade. As technology has progressed, trade routes have expanded from land, to sea, and into the skies. The expansion of trade routes has been driven by the need for faster transportation to increasingly farther destinations. Suborbital commercial trade routes are potentially the next step in the evolution of global trade and transportation. While no commercial PTP suborbital routes currently exist, examining the current major flight routes and hubs for passengers and cargo can provide an indication of potential future routes.

3.1.1 Major Airline Routes and Traffic Hubs

Research performed by the Official Airline Guide has identified the busiest passenger flight routes in the world to be short regional and commuter routes. These are not appropriate for PTP suborbital transport, as significant time savings cannot be realized to justify the added expense (OAG, 2006). Of much greater interest are long-haul airline routes with high annual passenger and cargo quantities, such as those that connect airline transportation hubs.

Distribution networks commonly evolve into hub and spoke systems. Prevalent examples include the internet and postal services. Although hub-spoke architecture is not as effective a method of transport as direct PTP connections in terms of delivery time, it is a far more efficient use of limited network resources. The airline industry currently operates with a hub-spoke architecture. Major gateways, such as New York's JFK and Singapore's Changi International airports, operate as intercontinental access points to regional networks.

Although the final results are different, the analytical approach to determining major cargo destinations is very similar to that of determining major passenger destinations. The following sections will focus on primarily passenger destinations, although the final results will be presented for both cargo and passenger transportation.

Major airline transportation hubs can be easily identified by their high levels of passenger or cargo traffic, and are typically located in areas of dense human population, which further increase their value as PTP suborbital destinations. Furthermore, hub-spoke systems also allow the location of important infrastructure to be concentrated, which could be particularly important if the support cost of suborbital flight remains high.

The identification and quantification of major airline traffic hubs can be completed using airport annual reports. Determining the volume of passenger traffic that travels between specific hubs is more complex. Whereas airport annual reports typically contain information regarding total passenger throughput and category of flight, passenger density per flight route is more difficult to obtain.

Confronted with the same difficulty in accessing global information on the volume of cargo traffic per flight route, a similar approach to passenger route identification was used. Based on statistics for the total weight of cargo per airport from the Airports Council International, major cargo hubs were identified. Then, using the same process as for potential passenger route identification, potential cargo routes were determined.

3.1.2 Identifying Potential PTP Suborbital Routes

International traffic can give an indication of the number of long-haul flights originating in a city; however, it must be considered carefully, as geographic location and country size also play a major role in determining the amount of international traffic. For example, Amsterdam and Denver have similar total traffic volumes; however, their levels of international traffic are significantly different. Whereas Denver is centrally located in the US and its international traffic can be considered to be almost exclusively long-haul, The Netherlands is territorially small and has many nearby countries, which suggests that some amount of its international traffic is actually short-haul.

The distance between potential PTP destination cities is critically important. PTP suborbital flight is not a reasonable alternative to short-haul flights. Furthermore, trajectory limitations can impose restrictions on the maximum distance a PTP suborbital vehicle can travel. In order to determine the geodesic distance between potential destinations, great circle routes were calculated using an Excel spreadsheet and geographical reference data. Specifically, calculations were based on the spherical law of cosines and the haversine formula. The Earth was assumed to be perfectly spherical. These results were used to filter the potential PTP routes.

3.1.3 Minimum and Maximum Distances

As discussed in Section 2.2, certain travel distances are not appropriate for PTP suborbital flight. The Boeing 777, which is representative of the newest generation of commercial aircraft, has a maximum range which effectively allows it to connect any two points on the globe with a direct flight. From the passenger's perspective, the remaining advantage of a suborbital flight is the decreased travel time between destinations. Although suborbital vehicles are significantly faster than regular aircraft when en route, other time requirements must also be considered when comparing the overall difference between flight alternatives. Nearly all modern day jet airliners, including the Boeing 777 have a cruise speed of approximately 900 km/hr. It has been assumed that a suborbital transportation system would utilize a private check-in and customs service, similar to that which was employed by the Concorde. A significant time saving would therefore result from the shortened pre-flight and disembarking times for suborbital flight.

Table 3-1: Average duration of flight phases

(Air Canada, 2007); (RITA, 2008); (Boeing, 2007b); (Dunbar, 2007); (Clarke et al., 2006); (RITA, 2008); (GOA, 2005)

Flight Phase	Aircraft Duration (min)	Suborbital Duration (min)
Boarding/Security/Preflight	90	30
Taxi/Takeoff	11	11

Departure	20	15
Reentry	-	8
Descent/Approach	30	20
Landing/Taxi	11	11
Disembarking/Customs	45	20

By using the data presented in Figure 3-1 above it is possible to estimate the approximate amount of total travel time saved with suborbital transportation instead of a traditional commercial flight, as shown in Table 3-1. The results suggest that for any flight distance greater than 3,500 km, a suborbital vehicle will reduce the total travel time by at about two thirds, or 5 hours.

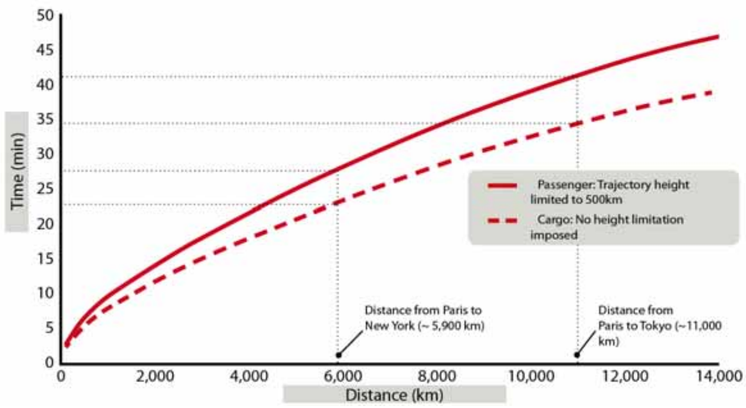

Figure 3-1: Duration of Ballistic Phase of Suborbital Flight

By using 3,500 km as a minimum required distance between destinations, several potential routes are no longer viable and will be excluded from further consideration.

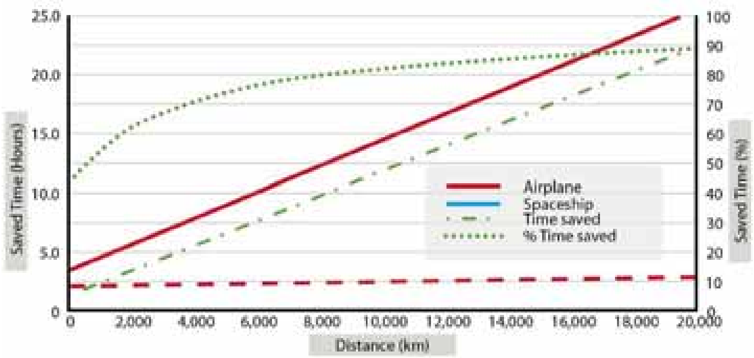

Figure 3-2: Comparison between aircraft and suborbital vehicle travel time

The maximum viable suborbital flight distance is not as easily determined. As discussed in Section 2.2, an increase in distance requires a corresponding increase in the velocity of the spacecraft during the ballistic phase of suborbital flight. This velocity increase results in the need to dissipate a larger amount of energy on reentry, which in turn leads to higher deceleration forces and temperatures. As discussed in Section 2.3.3, any PTP suborbital flight with sufficient distance will require a heat shield that is comparable in complexity to current orbital spacecraft. Furthermore, if trajectories are selected to avoid flight apogees which enter the Earth's radiation belts, then the velocity required to travel 7,000 km is the same as that which is required to enter into Low Earth Orbit (LEO). As demonstrated by Tsiolkovsky's Rocket Equation, any increase in velocity (and associated energy demands) result in decreasing payload mass ratios for a given propulsion system. In general, as travel distance increases, the technological challenges of suborbital flight become increasingly complex. These realities do not place a maximum limit on travel distances; however, the operational cost of suborbital flight increases significantly with greater distances, and may result in a situation where long distance suborbital flights are not commercially viable. As a counterpoint to this argument, Figure 3-2 demonstrates that suborbital flights provide increasing passenger utility, in terms of proportional travel time savings increase, as flight distances increase. The general conclusion can be made that long distance flights require greater economic justification than shorter routes.

3.1.4 Characterization of Worldwide Passenger Traffic Flow

Research performed by the Globalization and World Cities Research Network (GaWC), has identified the relative magnitude of passenger traffic between major international cities (Witlox et al., 2004). This was accomplished by analyzing partial booking information contained in a Marketing Information Data Transfer database. Although this database does not represent the complete worldwide passenger market, it is large enough to statistically represent overall traffic trends, which are portrayed in Figure 3-3.

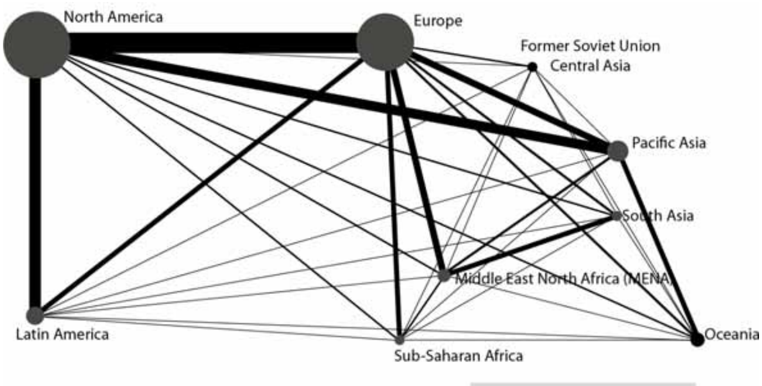

Figure 3-3: Traffic flow between world regions

(GaWC, 2008)

The results contained in GaWC bulletin #157 have been further used by this report to calculate the regional and inter-regional passenger traffic volumes as a percentage of total worldwide traffic. The results of this analysis are presented in Table 3-2. This representation of passenger traffic flow is particularly useful, as it is solely based on traffic start and end points. By excluding connections and transfers, passenger travel demands are more clearly understood.

Table 3-2: Regional and inter-regional traffic flow

	Europe	N. America	Latin America	Pacific Asia	S. Asia	Middle East / N. Africa	Sub-Saharan Africa	Oceania	USSR Cent. Asia
Europe	24.83%	8.03%	1.87%	2.61%	0.77%	2.55%	1.26%	0.51%	0.70%
N. America		24.32%	4.90%	3.83%	0.61%	0.77%	0.27%	0.38%	0.16%
Latin America			3.98%	0.09%	0.01%	0.04%	0.03%	0.03%	0.01%
Pacific Asia				6.44%	0.79%	0.49%	0.11%	1.17%	0.06%

S. Asia					0.97%	1.38%	0.08%	0.05%	0.02%
Middle East/N. Africa						2.02%	0.21%	0.05%	0.04%
Sub-Saharan Africa							1.27%	0.06%	0.01%
Oceania								2.18%	0.00%
USSR/Cent. Asia									0.08%

According to Airports Council International, a total of 4.4 billion passengers were served by airports in 2006 (ACI, 2007). Unlike the data contained in GaWC bulletin #157, this value represents the total of all passenger movements within airports, including transfers and connections. The passenger traffic levels identified in Appendix A also include transfer and connection traffic. By comparing these values with the total traffic flow experienced by the region in which each city is located, it is possible to estimate the total number of flights each city receives from a specific region, provided one makes the assumption that inter-regional traffic is equally divided amongst all regional airports. In reality, major airports typically account for a great percentage of international traffic, therefore, this assumption can be assumed to underestimate the real inter-regional traffic experienced by the suborbital destination cities. The results of this analysis are presented in Table 3-3.

Table 3-3: Regional and inter-regional passenger traffic to major cities, 2007

City	2007 Traffic (millions of people)	Regional Traffic	Europe	N. America	Latin America	Pacific Asia	South Asia	Middle East/N. Africa
London	126.2	8.4%	92.2	14.9	3.5	4.8	1.4	4.7
New York	105.1	7.1%	12.5	75.7	7.6	6.0	0.9	1.2
Tokyo	101.1	20.9%	12.0	17.6	0.4	59.1	3.6	2.3
Paris	86.4	5.8%	63.1	10.2	2.4	3.3	1.0	3.2
Chicago	76.6	5.2%	9.1	55.1	5.6	4.3	0.7	0.9
Los Angeles	61.5	4.1%	7.3	44.2	4.5	3.5	0.6	0.7
Frankfurt	52.8	3.5%	38.6	6.2	1.5	2.0	0.6	2.0
Beijing	48.7	10.0%	5.8	8.5	0.2	28.5	1.7	1.1
Hong Kong	46.0	9.5%	5.5	8.0	0.2	26.9	1.6	1.0
Singapore	35.1	7.2%	4.2	6.1	0.1	20.5	1.3	0.8

The regional and inter-regional traffic flows presented above can be further analyzed to determine the specific traffic flow between cities.

3.1.5 Destination Analysis

Once the preliminary shortlist obtained by down-selecting to the routes with the highest traffic volume, a final analysis of the remaining routes and destinations was performed.

Amsterdam is major international airline hub; however, it is in close proximity to both Paris and London, which each serve an even larger passenger base. It is unlikely that three PTP suborbital routes can coexist in such a small geographic area during the early stages of market development, therefore all routes which include Amsterdam have been eliminated. Similarly, other cities in close proximity to better potential hubs were eliminated. Also eliminated were cities which are relatively far from other urban centers and do not have a large extended population and business in their immediate vicinity from which to draw additional passengers, as well as cities with low median incomes.

After careful consideration, it was decided that Bangkok, Madrid, and Moscow are not sufficiently global cities to be considered for the initial set of suborbital routes; however, these cities are developing rapidly on the world stage, and may be front runners in an expanded network of suborbital routes (Taylor, 1999, 2005). Some potential niche markets were considered, such as Las Vegas. Las Vegas should be considered a strong potential candidate for route expansion due to the large volume of passenger traffic, provided suborbital flight can be made commercially viable based purely on image, prestige, and excitement, as opposed to saved travel time.

The final result of the destination filtering process has produced the recommended PTP suborbital routes listed in Table 3-4.

Table 3-4: Recommended PTP suborbital passenger routes

Rank	Route		
1	Los Angeles	→	New York
2	New York	→	London
3	Tokyo	→	New York
4	Tokyo	→	London
5	Chicago	→	Tokyo
6	Chicago	→	London
7	Los Angeles	→	Tokyo
8	Paris	→	New York
9	Paris	→	Tokyo
10	Los Angeles	→	London
11	Beijing	→	New York
12	Hong Kong	→	New York
13	Chicago	→	Paris
14	Beijing	→	London
15	Hong Kong	→	London
16	Frankfurt	→	New York
17	Singapore	→	New York
18	Frankfurt	→	Tokyo
19	Los Angeles	→	Paris
20	Singapore	→	London

This analysis has identified New York – Los Angeles as the most promising route, in terms of passenger volume. Furthermore, the comparatively short route distance allows for operational cost savings and simplified vehicle design that can potentially result in a lower ticket price than that of other, longer flight routes. Additionally, this route occurs entirely within national borders, which greatly simplifies regulation. Finally, although not an intercontinental flight, the Los Angeles – New York flight still connects two major cities on the Atlantic and Pacific coasts; therefore, a certain level of prestige exists. Since international routes are major candidates for initial PTP suborbital flights, the top three international routes are also very important. It is clear that the major international routes are those linking New York, London, and Tokyo.

Once the destination select-out process was completed, the remaining destinations were subjected to a final cross check. Major tourist and economic hubs were identified and listed in Table 3-5, alongside passenger traffic information. By combining these three key indicators, it was possible to identify locations that have the best potential to be a suborbital hub. The choice of the criteria is based on the assumption that terrestrial tourism and business are the two main reasons for travel. Note that in the case of tourism, there was no available information on cities, but on a national basis only.

Table 3-5: Comparative ranking of major global cities

(ACI, 2008); (UNTWO, 2007); (Democratic investments, 2008)

Rank	Air Traffic (2007 passengers)	Tourism (2007 visitors)	Stock Exchange (2007 capitalization)
1	*London*	*France*	*New York*
2	*New York*	Spain	Tokyo
3	Tokyo	*USA*	*Paris*
4	*Paris*	China	NASDAQ
5	Atlanta	Italy	*London*
6	Chicago	*United Kingdom*	Shanghai
7	Los Angeles	*Germany*	Hong Kong
8	Dallas	Mexico	Toronto
9	*Frankfurt*	Austria	*Frankfurt*
10	Madrid	Russia	Bombay

The four locations that reoccur in every column are italicized. Sorted by order of importance according to the sum of their rank for each criteria (the lowest score corresponding to the highest rank), these four cities are: New York, Paris, London, Frankfurt. This cross-check matches well with the route analysis for international routes, and the combination of these hubs give us three major candidate international routes: New York – Paris, New York – London, and New York – Frankfurt. Due to the proximity of the cities, flights between Frankfurt, London, and Paris are not a possibility. It is not surprising that the two best potential international routes for suborbital transportation coincide with the two only sustainable routes that Concorde ever linked.

A similar analysis has been performed by the GaWC network. Summaries of their findings are presented in Figure 3-4 (GaWC, 2008). The fact that both the GaWC research and the analysis performed on airline hubs identified similar cities lends support to the overall results presented here.

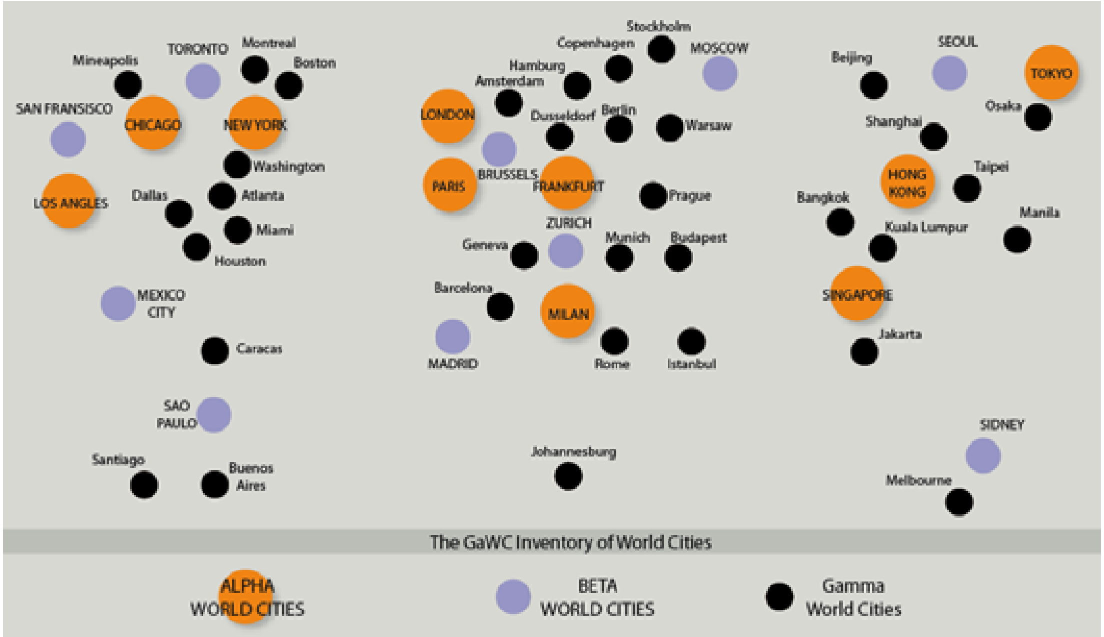

Figure 3-4: Classification of major global cities

(GaWC, 2008)

In summary, the major international routes identified are those linking New York, London, and Tokyo, while New York to Los Angeles emerges as the most promising domestic route. The traffic flow on international routes between London, New York, and Tokyo, and the national route between New York and Los Angeles is presented in Figure 3-5.

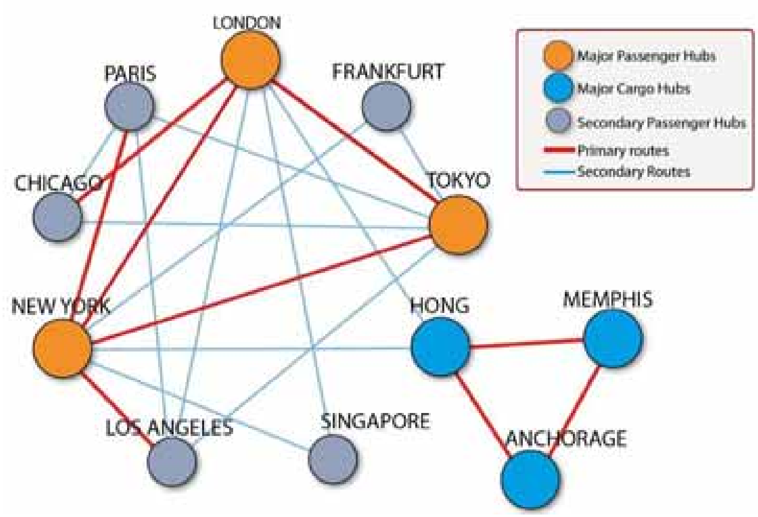

Figure 3-5: Major routes between primary international hubs

3.1.6 Cargo Routes

A similar analysis to that presented for passenger routes was also performed for cargo routes. Unlike passenger hubs, cargo hubs are primarily located in areas that offer geographic advantages, as opposed to areas with high human density. The results are presented in Table 3-6. For example, Anchorage, Alaska, is one of the largest cargo hubs in the world, as its relative proximity to the Asian market made it an excellent cold war era landing site for aircraft with limited flight range. Memphis, Tennessee is the world's largest cargo destination due to the fact that FedEx has chosen this site to be their major North American distribution hub. One of the factors that influenced this decision was Memphis' relatively central location with respect to most major North American destinations. As a result the three major hubs are Hong Kong, Memphis, and Anchorage. Cargo traffic to and from Asia is predicted to continue growing significantly (China Contact, 2000) (FedEx, 2007). Cargo companies have identified a need for Asian intercontinental express routes and are currently developing them. Recently, DHL-Sinotrans has created the 'Europe First' service, which delivers packages between Asia and Europe in an average of 2.2 days.

Table 3-6: Recommended PTP suborbital cargo routes

(ACI, 2008); (Infoplease, 2008)

Route	AVG Cargo (t)	Distance (km)
Hong Kong/Memphis	3,806,624	13,130
Tokyo/Memphis	3,472,390	10,600
Anchorage/Memphis	3,333,537	5,050
Anchorage/Hong Kong	3,299,586	8,150
Seoul/Memphis	3,198,078	11,080
Shanghai/Memphis	3,167,691	11,940
Paris/Memphis	3,069,235	7,310
Frankfurt/Memphis	3,004,800	7,650
Anchorage/Tokyo	2,965,352	5,560
Louisville/Hong Kong	2,925,482	12,970

The recommended routes identified in Table 3-4 and Table 3-6 were determined using the most accurate data currently available; however, the results do not take into account any expected future changes in the global economy or predicted growth rates. In addition to the previously discussed cities of Bangkok, Dallas, Las Vegas, Madrid, and Moscow, several other cities should be seriously considered as potential PTP suborbital destinations in the near future. In particular, Mumbai, Sao Paulo, and Shanghai are cities which need to be carefully watched, as they are the economic centers of countries that are experiencing incredible economic development and are expected to be important hubs of international commerce. Dubai is also a very interesting city to consider, as it is regional hub of the Middle East, and has an enormous amount of expendable capital due to oil proceeds.

3.1.7 Concorde

Amongst the many various types of air transportation that have existed, supersonic transportation aboard Concorde is the service which is most similar to suborbital transportation, as it is the fastest means, to date, for long distance commercial travel. It was also an elite service, and was therefore limited to high traffic flight routes. Because of the similarities between these two transportation services, it is useful to identify the major flight routes used by the Concorde and compare them to the recommended suborbital routes identified above.

The Concorde was operated by British Airways and Air France for 27 years. During this time, the Concorde flew primarily on transatlantic routes such as Paris - New York/ Washington, and

London - New York / Washington. Auxiliary routes were also temporary utilized, such as Paris - Dakar - Rio, Washington - Dallas (AeroWeb-fr, undated) and even London - Bahrain – Singapore; however, the latter was more likely the result of political links existing between the United Kingdom and its historical colony (Concordesst, 2003).

Even if the choice of the Concorde's routes was influenced by politics, these routes still needed to be economically viable. The cost of supersonic transportation limited the number of eligible passengers; however, sufficient demand must still have existed to be able to operate such an elite service on these routes. From 1976 to 2003, the Concorde carried about 2.5 million passengers, most of them traveling between Europe and the US (Concordesst, 2003).

The Concorde's historical operations confirm that the major international route for suborbital transportation would be a transatlantic route between the US and Europe (most likely New York to Paris or London). Since the Concorde was barred from flying over the continental US, it cannot be compared to the potential suborbital New York – Los Angeles route. The Concorde's history also suggests that other candidate routes might be interesting to consider between Europe and Asia, as well as between Europe and South America, especially when one considers that certain parts of Asia and South America both have high rates of economic development. The near-complete absence of data on the use of supersonic planes for cargo transportation suggests the lack of a market for this particular application. In total, 15 Concorde aircraft were built and commercially operated, but none of them appears to have been used exclusively for cargo transportation. Therefore, the Concorde routes discussed above are only good indicators of potential passenger suborbital routes, and not necessarily cargo routes (Air France, 1997).

3.2 Passenger Demand

3.2.1 Forecasting Future Passenger Traffic Flow

The traffic volumes that can be estimated for the routes identified in Table 3-6 are based on present day (2006) data, however PTP suborbital flight is not yet ready to compete in the transportation market and will not be ready for several years to come. In order to give a more realistic description of the potential PTP suborbital market, these traffic volumes should be forecasted into the future. The year 2020 has been selected as the earliest realistic potential date for operational commercial suborbital transportation based on current trends.

Current and predicted world population values were obtained from the US Census Bureau, and are presented in Figure 3-6. According to these values, world population is expected to increase 13.8% by the year 2020 (USCB, 2008). In addition to world population growth, the global economy is also expected to increase. The current Gross World Product (World GDP) is estimated to be USD 65.8 trillion (CIA, 2008). According to the Economist Intelligence Unit (EIU), the average World GDP is expected to grow by 3.5% per year, for an overall increase of about two thirds by the year 2020 (EIU, 2005). This growth is also presented in Figure 3-6. EIU also predicts that the growth rate of China and India will be significantly greater that the world average, which supports the conclusions regarding emerging PTP suborbital destinations in these particular countries. It is important to note that both population and economic growth are subject to many unpredictable forces which result in uneven growth rates. These factors make accurate prediction of future population and World GDP difficult.

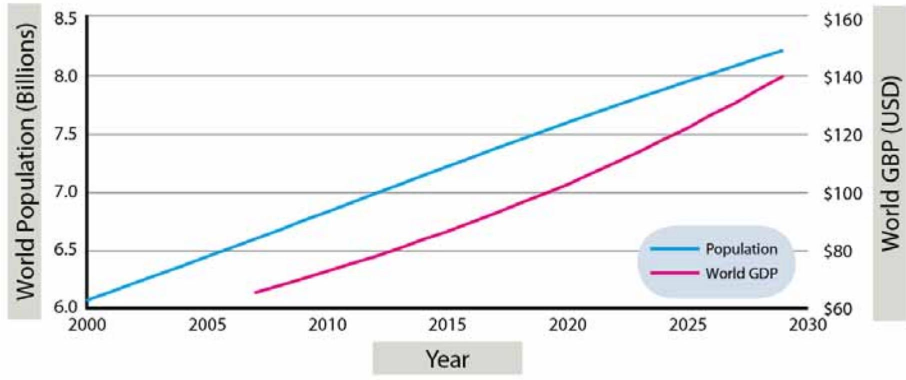

Figure 3-6: Predicted world population and economic growth

(USCB, 2008); (EIU, 2005)

PTP suborbital transportation is an elite form of transportation which caters primarily to a target market of High Net Worth Individuals (HNWI). According to the 2007 World Wealth Report, nearly 95,000 people currently have at net worth of over 30 million dollars (Capgemini, 2007). Furthermore, world wealth is consolidating in this growing elite group, which increased in size by more than 10% in each of the last two years. This is a positive trend from the standpoint of suborbital transportation, as it suggests a growing market. By using the population and World GDP estimated growth values discussed above, it is possible to adjust the wealth demographics contained in the 2007 World Wealth Report to reflect the year 2020. This forecast is presented in Figure 3-7 and assumes that wealth distribution will maintain the current proportional distribution.

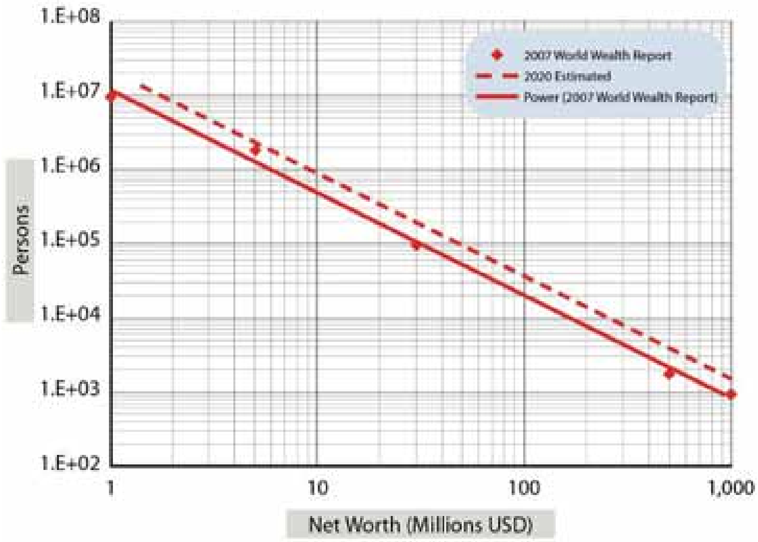

Figure 3-7: World wealth distribution

(Capgemini, 2007)

The results produced by forecasting world wealth distribution suggest that the number of people currently possessing a specified net worth will increase approximately 85% by the year 2020. Provided one accepts the assumption that demand is limited to those who can afford the current ticket price of air flight, then one can expect a similar overall increase in air travel as additional people become sufficiently wealthy to afford ticket purchases. It is acknowledged that this is a significant simplification of a complex and volatile market; however the state of the global economy is one of the main influences on the health of the world transportation market.

These results can then be combined with the previously determined forecasted growth rate to predict the 2020 passenger traffic volume that will flow along the potential PTP suborbital routes identified Table 3-7.

Table 3-7: Total passenger traffic on potential PTP suborbital routes

Rank	Route	Distance (km)	2006 Total Traffic (millions of people)	2020 Estimated Total Traffic (millions of people)
1	Los Angeles/New York	3,940	3.13	5.77
2	New York/London	5,566	1.05	1.94
3	Tokyo/New York	10,845	1.04	1.92
4	Tokyo/London	9,561	1.01	1.86
5	Chicago/Tokyo	10,144	0.91	1.67
6	Chicago/London	6,358	0.77	1.42
7	Los Angeles/Tokyo	8,814	0.73	1.34
8	Paris/New York	5,832	0.72	1.33
9	Paris/Tokyo	9,724	0.69	1.27
10	Los Angeles/London	8,758	0.62	1.14
11	Beijing/New York	10,982	0.60	1.10
12	Hong Kong/New York	12,948	0.56	1.04
13	Chicago/Paris	6,656	0.53	0.97
14	Beijing/London	8,137	0.49	0.90
15	Hong Kong/London	9,620	0.46	0.85
16	Frankfurt/New York	6,196	0.44	0.81
17	Singapore/New York	15,341	0.43	0.79
18	Frankfurt/Tokyo	9,338	0.42	0.78
19	Los Angeles/Paris	9,091	0.42	0.78
20	Singapore/London	10,863	0.35	0.65

3.2.2 Passenger Market Demand

In order to estimate the percentage of the total market that might reasonably be captured by PTP suborbital flight, various ticket price / passenger volume pairs were analyzed for the New York - Paris flight route. This route was chosen because it was flown by the Concorde, and also due to the relative abundance of data. The supersonic Concorde is perhaps the most analogous transportation model to suborbital flight. When in operation, it catered primarily to elite travelers who could justify the ticket price by the time-savings and prestige enjoyed. The approximate ticket price for a one way flight onboard the Concorde was USD 5,550. Annual passenger traffic for the Concorde from 1982 to 1995 is shown in Figure 3-8 and suggests an average of approximately 42,500 passengers per year.

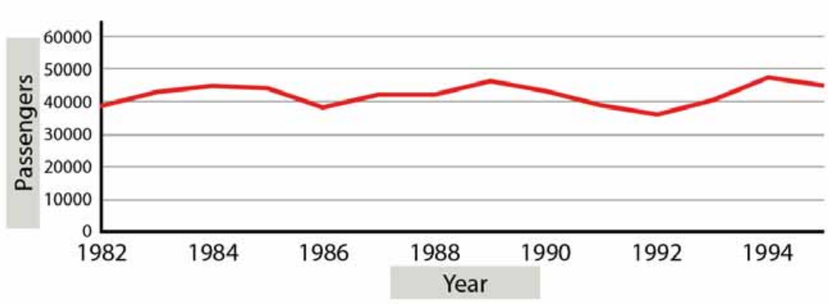

Figure 3-8: Concorde passenger demand

(Air France, 1997)

As discussed above, the approximate passenger traffic between New York and Paris has been previously calculated. According to the International Air Transport Association (IATA), premium (first and business classes) traffic accounts for between 14-15% of total traffic on long-haul business class routes (IATA, 2006). This allows us to estimate the total number of passengers who bought premium and economy class tickets in 2006. IATA has also identified the average 2006 price of a one-way ticket for the New York – Paris route to be USD 405 for economy class and USD 2,375 for premium class (IATA, 2007).

This information, combined with that of the Concorde, provides three ticket price-passenger volume pairs that can be used to extrapolate the number of passengers that could be expected at a specific ticket price. The results of this analysis are shown in Figure 3-9, and show a very high level of correlation. It important to note that the price points being used to predict demand are at least an order of magnitude smaller than the expected ticket prices for suborbital flight. It is possible that the relationship between the identified ticket price-passenger volume pairs does not hold at these higher price levels. It is also important to remember that a suborbital flight experience is significantly different than a regular airplane flight. A greater number of customers may be willing to pay a higher premium than the table suggests in order to enjoy both the experience of space flight, as well as the reduced travel time that suborbital flights offer.

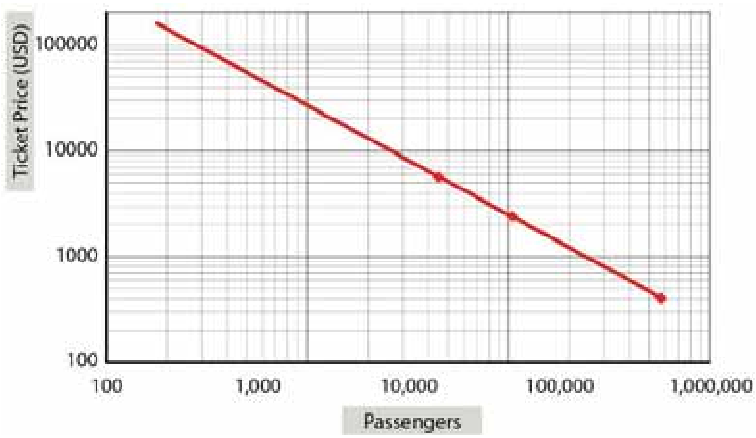

Figure 3-9: New York -Paris passenger class regression

By applying the trend determined in Figure 3-9 to the total forecasted traffic flows identified in Table 3-7, it is possible to predict the level of demand that can be expected for PTP suborbital transportation between various destinations at different ticket prices. Figure 3-10 presents the predicted traffic volumes graphically.

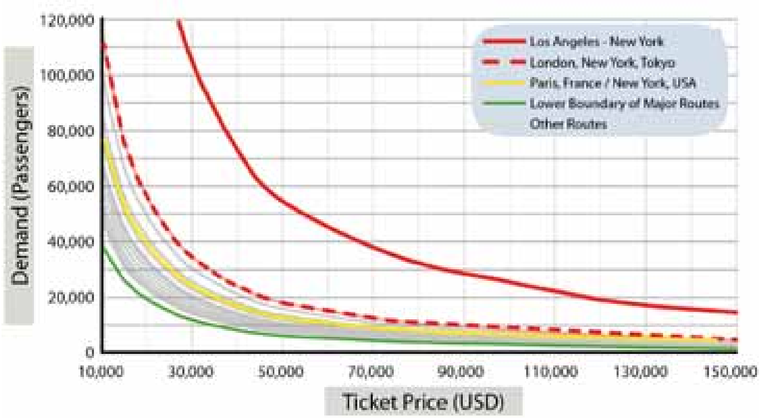

Figure 3-10: Effect of ticket price on PTP suborbital demand

As determined earlier, the flight route between Los Angeles and New York is an obvious outlier. The real traffic volume for this route is likely to be lower, as the route itself is significantly shorter than the others, and therefore provides a reduced time saving advantage. While this is the most promising intra-national route, the major international route triangle between London, New York, and Tokyo is the next most important set of routes, with an estimated daily traffic of approximately 50 passengers at a ticket price of USD 50,000. The lower bound of traffic volume for the major routes selected in this report is only 17 passengers a day at the same ticket price. Gross revenue continues to increase as ticket price decreases.

3.2.3 Passenger Profile

Based on the demand for suborbital transportation discussed above, daily traffic is expected to range from 15 and 150 passengers, depending on the specific route and the ticket price. If PTP suborbital transportation is realized, both the profiles of these passengers, as well as their motivation to travel, will likely be substantially different from those of current would-be suborbital tourists. The 2006 Futron report entitled Suborbital Space Tourism Demand Revisited has identified the following characteristics of a typical suborbital tourism passenger:

- Average Age: 55 years
- Gender: 72% male, 28% female
- Fitness level: 46% above average
- Vacations: 48% take at least one month of vacation per year
- Employment status: 41% full time, 23% retired

Futron (2006) also determined that based on the willingness of potential passengers to spend no more than 1.5% of their net worth on vacation expenses, the market is limited to those with a net worth of greater than USD 7 million. Clearly, the suborbital market in the space tourism industry has been targeted initially to HNWIs that can afford the USD 200,000 price tag for a ticket that offers them four minutes of microgravity. As the market develops, however, the price of the ticket will fall and demand will increase, opening the flights to a larger population.

Determining the profile of a PTP suborbital passenger is complicated by several factors that made it infeasible to conduct an extensive survey of potential passengers for this report. First, the number of passengers willing to pay USD 50,000 for a flight between New York and London is estimated at 50 people per day. These individuals can be segmented into three categories:

- Passengers conducting time-sensitive business (ticket may be purchased by individual or corporation)
- Passengers not conducting time-sensitive business, but that can afford the price and perceive the high-speed nature of the flight as a luxury
- Passengers seeking a thrill or adventure (i.e., tourists)

The estimated demand value does not account for the possible substitutes or alternatives the customer may utilize for a lower price. Video teleconferencing enables virtual meetings to take place without requiring the parties involved to be in the same location. Customers considering suborbital transportation for time-sensitive purposes are not likely to accept a level of personal risk that is significantly higher than regular commercial air flight, as the perceived pay-off is only several hours of saved time. .

The cost of the ticket may not result in overall cost savings for a business; however, some passengers may wish to fly on a PTP suborbital flight for the sake of prestige. The "prestige effect" can be defined as a cognitive thought process of the consumer that is intangible, yet affects demand significantly among certain markets. Simply put, this effect involves a consumer's desire to pay a premium for a product or service because it is new, exclusive, and affords them the notion of escalation in a societal context among his or her peers. There are several factors that may be significant in determining whether a market will be impacted by the prestige effect. One could also consider the 'Ulysses factor' (cf., the hero of Homer's Odyssey); it is the need for exploration and adventure, involving an exciting and even (according to the individual's perception) risky action. It is a physical and intellectual need related to knowledge and curiosity (Peeters, 2007c).

The Ulysses factor can be found in extreme tourism activities such as climbing Mount Everest, trekking through Antarctica, and other similarly risky and exotic tours. Forecasting this effect is simple enough if it the activity encompasses the characteristics mentioned above. The one downside to this phenomenon is once the activity is no longer novel and becomes routine, it is no longer considered "risky", leading to the possibility for the effect to wear off. The prestige effect can also weaken, for example take the glamour and prestige of flying commercial aviation in the 1950s, which has given away to the practical economics of getting from "point A" to "point B".

3.3 Cargo Demand

Over time, cargo delivery has continued to become faster and farther-reaching as technologies continue to emerge, improve, and evolve. This evolution of technology serves the ever-increasing global demand for shorter delivery times. Achieving this performance is the priority of the international players such as Federal Express (FedEx) and United Parcel Service (UPS).

But will the future world air cargo market develop a need for PTP suborbital transport? And if so, what type of goods would be delivered via PTP suborbital transport? The following sections investigate possible answers to these questions.

3.3.1 World Air Cargo Market

Along with telecommunications, internet, and broadcasting services, the air cargo market can be considered as an element of globalization. Distribution of goods and resources has established the air cargo market as one of the world’s most important and dynamic industries. The potential market for suborbital delivery of these goods can be examined from both a military and commercial standpoint.

Military Market

The development of air cargo transportation systems was initially driven by World War II. By analogy, the development of a suborbital point-to-point transportation system for cargo may be driven by military demand to re-supply a mobile isolated army unit. (Dinerman, 2008). The global mobility of cargo aircraft is a strategic factor for military forces; the US Air force, for example, spent USD 1.4 billion in 2007 on cargo aircraft to improve global mobility (Faykes, 2007). Suborbital vehicles will have appeal for the military as they will be capable of reaching great distances in a short amount of time. This could serve to move equipment efficiently to personnel in the field. However, this would not match well with passenger routes, since the requirements to deploy people or cargo to battlefields are likely to be far different from those for linking major cities on commercial routes.

Commercial Market

Based on the Boeing world air cargo transportation report for the next 20 years, air freight is expected to grow at a rate of 6.1 % through 2025 (Boeing, 2007a). Growth rates are calculated using revenue tonne-kilometers (RTKs), which refers to the revenue per tonne transported per one kilometer. In 2005, revenues were calculated to be 178.1 billion. Revenues are predicted to increase to 582.8 billion in 2025 (Boeing, 2007a); a 30% increase. The air cargo market is predicted to become increasingly profitable and promising, which will support the possible emergence of suborbital point-to-point delivery systems. Although feasibility of applications has not appeared yet, suborbital cargo delivery is a realistic business possibility that is worth examination.

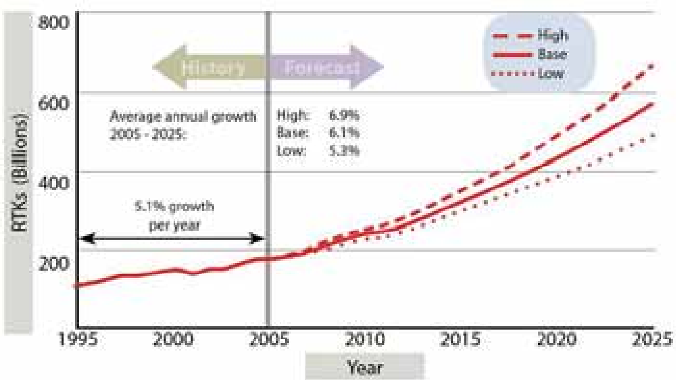

Figure 3-11: World air cargo forecast 2006-2007

(Boeing, 2007a)

The world air cargo is comprised of scheduled services and on-demand services (charter). The normal trend for air cargo is scheduled service.

The development of a fast transportation means such as a suborbital point to point transportation system can drastically reduce the travel time; however, the benefit of this reduction is valid only if pre- and post-flight processing times are minimal. Unlike passenger transportation, scheduled transportation cannot be a market for the suborbital transportation system because pre- and post- flight processing is longer for packages than passengers (Martin

& Law, 2002). Therefore, it is more suitable to look into for an on-demand (charter) service rather than a scheduled service. Nevertheless, the charter market segment is very small in comparison with scheduled market. The world's air charter market in 2005 was only 9% of the total air cargo market, but it is continuing to grow stronger as a result of military action in the Middle East and overall worldwide air cargo demand (Boeing, 2007a).

The growing demand for air express service is global, due to the increase of worldwide economic trade and the development of multinational corporations. China has been identified as the fastest growing market for express delivery (FedEx, 2007), and this market is expected to double in the next five years (China Contact, 2000).

3.3.2 Cargo Profile

For the current world air cargo market, many types of freight are transported including documents, computers, automotive parts, apparel, food products, and machinery. The current major commodities shipped by air around the world are shown in Table 3-8.

For PTP suborbital transportation, only payloads that need to be delivered rapidly and/or have a high value for their weight are considered as relevant. The cost of using a suborbital transportation system is exorbitant; in the case study given later in this report, cargo costs were estimated to be as high as USD 2.6 million per metric ton. A reasonable transportation cost is expected to be 3% to 6% of the total value of the cargo, which means that the total value of the cargo, per metric ton, would be approximately USD 43 - 87 million. At these cost levels, the potential market is extremely limited. The time saved using suborbital transportation versus other methods of transport has value as well. For example, if a critical component fails on an Intel assembly line and needs to be replaced, losses of up to USD 200,000 per hour are induced (Boeing, 2007a). Reducing delivery time can reduce downtime and financial losses to companies.

Table 3-8: Major commodities shipped by air

(Boeing, 2007)

	North America to Latin America		Europe to Latin America		Europe to N. America		Asia to N. America		Asia to Europe	
Westbound	Small packages	14%	Auto parts	21%	Industrial machinery	11%	Office machines or		Apparel	16%
	Data processing		Electrical Machinery	16%	Documents and small		computers	21%	Misc. manufactured	
	machines	11%	Transport equipment	9%	packages	9%	Electrical machinery	9%	items	14%
	Electrical machinery	7%	Industrial machinery	9%	Misc. manufactured	8%	Telecommunication	8%	Electrical machinery	10%
	Industrial machinery	6%	Manufactured Metal	8%	items		equipment		Documents and small	
	Telecom equipment	5%	Other	47%	Electrical machinery	7%	Misc. manufactured	7%	packages	9%
	Other	57%			Scientific equipment	5%	items	5%	Office machines	8%
					Other	60%	Other	37%	Other	43%
	Latin America to North America		**Latin America to Europe**		**N. America to Europe**		**N. America to Asia**		**Europe to Asia**	
Eastbound	Small packages	9%	Machinery	16%	Documents and		Documents and		Misc. manufactured	
	Vegetables/Fruit	11%	Auto parts	11%	small packages	13%	small packages	11%	items	21%
	Fish	22%	Leather	10%	Machinery	12%	Machinery	14%	Machinery	16%
	Other	57%	Other	61%	Scientific equipment	5%	Misc. manufactured	6%	Small packages	8%
					Other	70%	items	5%	Other	62%
							Other	64%		

Non-Biological Items

The Chinese market shows promise for express delivery; therefore, results from a study done on the Chinese express delivery market were extrapolated to the global express delivery market for this report (Booz Allen Hamilton, 2007). As shown in Figure 3-12, this analysis classifies parcel types as a function of their average weight and average delivery time.

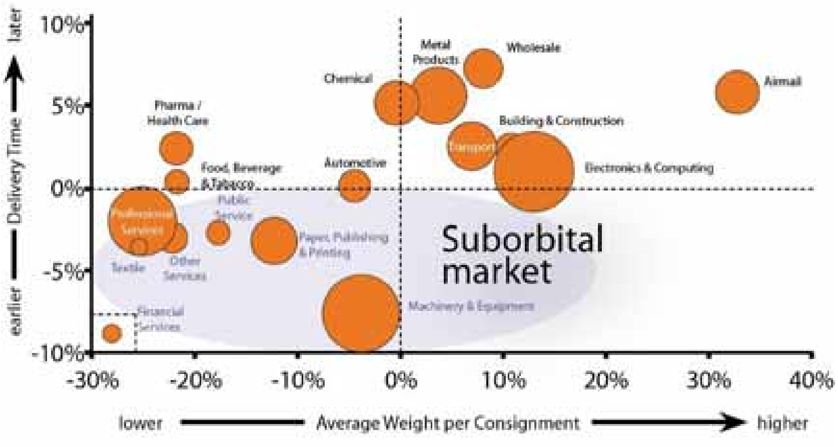

Figure 3-12: Comparison of economic express delivery models across industries

(Booz Allen Hamilton, 2007)

Organ Transplants and Biological Elements

The transportation of human organs for transplant is one potential market for suborbital transportation. This market exists because of time limits of organ survival outside of the human body, which range from 2 – 48 hours, depending on the organ. About 7 percent of people waiting for a heart or lung transplant in the US die before an organ becomes available, totalling approximately 200 people annually (UNOS, 2008). Suborbital transportation would allow organs to be transported quickly and to more distant destinations, increasing the opportunities for successful transplants to waiting patients.

Note that success of this market would be highly dependent on total travel time. While the flight time would be reduced, time-savings could potentially be lost due to spaceports located in remote locations and the requirement for additional travel time to reach the final destination. Additionally, the fragility of the organs adds to the complexity of the transport due to the g-loads experienced during the suborbital flight. Special packaging would likely be required for transport, adding to the total delivery time.

Furthermore, the nature of the transplant "market" needs to be taken into account. Demand for organs far outstrips supply, often by a large percentage. A search of the International Registry of Organ Donation and Transplantation, (TPM, 2008) indicates that no nation has a surplus of donors in any category. In these circumstances, any available organ will almost certainly find a suitable recipient locally or regionally; it would be an unusual case for an organ to find its nearest potential recipient at distances that would make a suborbital flight a realistic proposal.

3.3.3 Comparison of Different Means of Transport for Cargo

For a given type of cargo, the mode of the transport is essentially chosen based upon the volume and weight of the cargo, price and efficiency of the transport method, and the reliability of delivery.

Volume and Weight

High volume parcels (>10 m^3) are unlikely to be transported using a suborbital transportation system. Table 3-9 gives a comparison of volumes and weights that can be transported by air, sea, and on a suborbital vehicle which is currently under development. From the table, it can be seen that there will be limited capability to transport items with large volume and weight on suborbital vehicles the near-term. This will put limitations on the type of cargo that can be carried using point to point suborbital transportation.

Table 3-9: Volume and weight comparison

(S.Jones Containerservices, 2006, Startupboeing, 2008, and Linehan, 2008)

	Sea container	Express air freight aircraft (MD-11F)	Space Ship Two
Volume	9.28 to 66.83 m^3	447 m^3	<20 m^3
Weight	0.95 to 3.35 metric tons	91.2 metric tons	<900 kg

Speed

Express air freight delivery currently averages about 1.5 days for transatlantic transport, but this duration could be reduced to a few hours or less with suborbital transportation. Table 3-10 shows the delivery duration for several modes of transport.

Table 3-10: Comparison of travel time for cargo

(Airbus, 2007)

	Europe to US
Bulk sea	14 days
Sea Containers	11 days
General air freight	9 days
Express air freight	36 hours
Suborbital flight duration	1 hour

Price

In the research of package transportation prices, the assumption was made that the item is machinery or an electronic component with dimensions of 45x45x45 cm.

The shipping rate of a package for international priority services is not dependent on value if it is between USD 10,000 and 100,000, or dependent on weight if a package is less than 68 kg (150 lbs). The shipping rate also includes tracking, pickup, and handling fees. For heavyweight items between 68 kg and 1,000 kg, the price of shipping is approximately USD 13 to 16 per kg (FedEx, 2008).

For suborbital point-to-point transportation of cargo, a similar approach to FedEx for international priority services may be appropriate. This would imply a fixed price for items under 68kg, and set price per kg for cargo over 68kg. The prices for suborbital transport service, however, would be much higher than those used currently for air transport delivery services such as FedEx or UPS.

Reliability

Customers using suborbital transport for cargo will pay high prices, and consequently will expect the safe delivery of their high-value cargo. The confidence level in suborbital transport services will need to be established, eventually leading to higher demand for such services. This, however, cannot occur until vehicles are developed and flown on a fairly regular basis to prove the reliability of the technologies involved.

3.4 Competition

Though there seems to be an existing demand for suborbital tourism (Futron, 2006), this does not necessarily translate into demand for PTP suborbital transportation. Indeed, the demand for PTP suborbital transport may be difficult to predict; many external factors have to be taken into account, such as personal buying power, fuel prices, national economics, and the competition of potential market substitutes.

Suborbital transportation could potentially evolve into long-distance, fast-transportation service, putting it in competition with civil aviation, and more specifically, supersonic civil aviation. With regard to passengers, suborbital transportation could also be defined as a very elite method of transport, putting it in competition with first-class commercial carrier transportation, charter aircraft, and business jets.

By entering this market, suborbital transportation will be in competition with alternative methods of long-distance transportation, but also will be a differentiated service as it will be the fastest transportation means on the market and a unique service of space transportation. The demand elasticity will depend on how suborbital transportation will differentiate itself from its substitutes (Duffy, 1993). The "prestige factor" of traveling using rapid suborbital transport should also not be discounted.

A SWOT analysis has been conducted and presented in Table 3-11:

Table 3-11: SWOT Analysis

Strengths	**Weaknesses**
• Confidence in suborbital technology after success of SpaceShipOne • More environmentally-friendly than conventional air transportation • *Faster* transportation method than conventional air transportation • "Prestige Effect" and lure of "Space" • Attractive and differentiated service • Ability to have breakfast in Los Angeles, lunch in Paris, and dinner in Tokyo—all in one day	• Development costs are very high • Initial ticket prices are projected to be very expensive and non-competitive with conventional air transport • Loss of credibility if there is a catastrophic loss • Lack of existing spaceport infrastructure and spacecraft that will result in real "time-savings" • Possible health restrictions on passengers may constrain demand
Opportunities	**Threats**
• Lack of *fast* trans-oceanic/continental transportation • Legislation in favor of developing this technology is growing • Worldwide growth (8%) in HNWIs who are likely to be among the first commercial passengers • Worldwide growth in business-class	• Time-to-market may be too late along the development cycle • A supersonic or hypersonic "Concord successor" may evolve and diminish the "time-savings" achieved over conventional air transportation. • Lack of consensus with regard to the International Legal Framework

airfares over the last decade • Market is open and yet to be exploited • High level of investors interested in entrepreneurial venture	• Airspace deconfliction • Exotic and volatile fuels and propellants may limit locations of operations • National security concerns may create roadblocks to international use of technologies

The two main competitive advantages of suborbital transportation over its potential substitutes are the uniqueness of a space experience including microgravity and the view of Earth, and secondly, very high-speed transportation capability.

The first advantage is not relevant to the cargo function; it could even be considered a disadvantage in the sense that the material transported would require a better packing to avoid any movement or shock during the microgravity phase and the transition phases (acceleration, deceleration). With regard to passengers, the space tourism aspect may help to initiate the market but not be able to justify a long-term demand. As with current air transport, people will not buy a plane ticket with the goal of observing the Earth from the sky; the real market is obviously based upon transportation.

The second advantage, high-speed transport, is the only long-term competitive advantage of suborbital transportation. This is highly dependent on factors such as spaceport location, flight scheduling, and the level of training required for passenger transportation. The total travel time is important when considering competition with other forms of transit. For example, passenger transportation via train can be more efficient than an airplane between relatively short distances, such as Paris to Strasbourg (about 450 km). An airplane is a faster vehicle, but the total trip length may be longer due to check-in, luggage claim, and ground transport to and from the airport. In the case of the Paris-Strasbourg route, the train takes 140 minutes to carry passengers directly between city centers; total travel time by aircraft would take longer than this.

A direct threat for suborbital transportation is the commercialization of a new civil supersonic airplane, such as a successor to Concorde. This type of aircraft would have the advantage of utilizing existing airport infrastructure, rather than pursuing the expensive endeavor of constructing new spaceports. Concorde flew from Paris to New York in 3.5 hours, directly from Charles de Gaulle airport to John F Kennedy airport (AeroWeb-fr, Undated). For comparison we estimate a transatlantic suborbital flight would take less than an hour, but if the spaceports are located far from major destinations and cities, suborbital transportation would not be competitive with supersonic transport methods.

3.5 Conclusions

Although suborbital trajectories can be theoretically used to connect any two points on the Earth, there are a limited number of routes that should be realistically considered. The elevated cost associated with suborbital flight requires the existence of wealthy potential markets to justify frequent scheduled flights. Furthermore, these markets must be located at distances from each other that justify the use of suborbital flight over other means of transportation. An analysis of airport traffic, city globalization, tourism, and economic importance has identified several candidate routes for passenger and cargo traffic. The most promising of these routes is Los Angeles to New York, but the most promising international routes connect New York, London, and Tokyo.

A widely held opinion is that PTP suborbital transport will likely evolve from the space tourism industry. However, the successful emergence of this market is dependent on a large number of factors, including the emergence of competitive substitutes such as a supersonic or hypersonic transport vehicle, or the location of spaceports in relation to major cities worldwide. PTP suborbital transportation will have some advantages over the existing competition, such as travel time-savings over long distances and the allure of "space". Due to the estimated high price of such a service, however, the market is predicted to be relatively narrow from both a passenger and cargo perspective. It should also be noted that the analysis of future market demand for PTP suborbital transportation required many assumptions to be made, as the technologies required for this mode of transport are still under development. The potential passengers for PTP suborbital transport include those on time-sensitive business, those traveling for luxury or adventure, and military personnel, although troop deployment to remote areas is vastly different from commercial passenger services. Initial analysis shows that at USD 50,000 per ticket, a future market of about 50 passengers per day could exist in the major routes between New York, London, and Tokyo.

The identified possible market for cargo is very limited and would be restricted to items that are have a per-kilogram value approximately 20 times their transport cost. In one possible scenario, the price of transportation is estimated to be as much as USD 2.6 million per metric ton of cargo; implying that the total value of cargo transported would be approximately USD 43 million per metric ton. Clearly, due to the high value of the items that would be transported, the cargo market is unlikely to develop until concrete travel time-savings are proven and reliability of the transport service is established.

4 FINANCE & GROWTH

The viability of a suborbital transportation industry is uncertain. Objective examination of the industry's feasibility remains difficult at best—with as many possible outcomes as there are opinions. Nevertheless, this chapter of the study pursues an objective overview of the financial aspects of PTP suborbital transportation with regard to costs, funding, and examines the seemingly logical growth from suborbital tourism.

4.1 Parametric Cost Estimation

How much will suborbital transportation cost? Cost estimation is carried out in different ways throughout a design cycle. When sufficient data is available for a particular design, “bottom-up” costing is performed based on costing of subsystems and individual parts. However, in the early, conceptual phases of development—when little specific data is available—parametric costing is the most accepted means of estimating the cost of the system (Koelle, 1998). This section provides a cost estimate for an example PTP suborbital transportation system for comparison to estimates of the price the market is willing to bear. This forms the basis for preliminary analysis of whether or not PTP suborbital transportation is commercially feasible at the present time.

4.1.1 Cost Estimation Scenario

For this scenario, one of the three major candidate routes identified earlier in this study, the London-Tokyo route, was selected based on two factors: (1) it was the second-best candidate route identified, and (2) it presented a difficult challenge from the perspective of ΔV. In this sense, the route may be regarded as conservative, as it is based on a highly traveled passenger route with fairly more stringent technical requirements than other possible routes. The distance between London and Tokyo is approximately 9,561 km.

From the results of Market Demand section of this study, it is evident that the future market for PTP suborbital transportation is highly speculative at this time and may have substantial price elasticity. However, a passenger estimate for early systems may be on the order of thousands annually. To start, a baseline of 5,000 passengers per year has been chosen, as this is within the order of magnitude specified for early suborbital transportation markets at a price point between USD 50,000 and 100,000 per ticket each way. This is still a wide range, but since significant uncertainty applies to this market, more detailed estimates may not exist for some time. It is also assumed that each passenger purchases a roundtrip ticket, leading to 10,000 actual tickets per year.

Flight frequency is highly dependent on the technical capabilities of the vehicle. However, since one of the perceived advantages to the system is the ability to literally go “around the world and back” in a single day, it is likely that passengers may be interested in having at least two flight opportunities a day to each destination. Four flights per day are specified as the minimum number needed—a morning flight and an evening flight in each direction, leading to a total of 1,460 flights per year.

Based on a total number of 1,460 flights per year and 10,000 tickets, the number of passengers per flight is calculated to be 6.8 and is rounded up to seven for this study. To serve these passengers on a short-duration flight, a crew of two was assumed, a pilot and co-pilot (no flight attendants given the short flight time). To satisfy this demand, and assuming a one-day turnaround time, four vehicles are required, and a fifth is included as a spare during downtime for maintenance (this is not typical in airlines, but may be required if maintenance downtime is high).

The study examines whether or not a transportation system can be developed with a ticket price not greater than USD 50,000 to 100,000 per passenger.

4.1.2 Assumptions

In addition to the assumption above that passengers purchase a roundtrip set of tickets, the following assumptions have been made for the study.

Based on FAA estimates, passenger weight is assumed to be 86 kg (190 lb) plus 14 kg for checked baggage (Wald, 2003), for a total of 100 kg. With a crew member mass of 86 kg with minimal baggage, the total mass of crew plus passengers with baggage is 872 kg. It is assumed that the vehicle conservatively can carry only 1 % of its total Gross Lift-off Weight (GLOW) as payload, a total GLOW of 87,200 kg is specified—substantially less than that of a Boeing 757 medium-range airliner (Boeing, 2007b).

Based on the trajectory methods described earlier in the study, a vehicle traveling from London to Tokyo is assumed to have the following trajectory characteristics:

- Trajectory type: ricochet
- Distance: 9,560 km
- Number of hops: 3
- Maximum velocity: 5.9 km/s
- Total ΔV: 7.7 km/s
- Flight duration: 35-90 minutes—depending on takeoff and landing methods

Additionally, it is assumed the vehicle uses relatively conventional, bi-propellant chemical propulsion with a specific impulse of 350 s, equating to an effective exhaust velocity of about 3,433 m/s, roughly on the order achieved by a LOX/RP-1 combination such as an RD120 (Sutton & Biblarz, 2001).

Based on the ΔV requirement of 6.6 km/s, the rocket equation can be used to calculate final overall mass based on a GLOW of 87,200 kg. The rocket equation yields a final dry mass of about 9,250 kg, of which 872 kg is payload, leaving approximately 8,380 kg for structural mass, or 9.6% of GLOW. This is within the range for single stage vehicles with known materials (Sutton & Biblarz, 2001).

4.1.3 Parametric Costing Methods

Parametric cost estimates are based on relationships between various cost-affecting parameters, and by comparing the system under consideration to previous similar designs. Of critical importance are the use of a dataset that encompasses the most relevant previous work, and the development of appropriate relationships from this dataset by which future cost estimates can be extrapolated.

To date, no successful PTP suborbital vehicles have been developed; this necessitates the use of data from other development programs. The TRANSCOST Model, developed by Dietrich

Koelle and revised several times, uses data from National Air and Space Administration (NASA) and European Space Agency (ESA) space vehicle programs performed over the past 30 years and has been used extensively for parametric cost estimation (Goehlich, 2002). However, it is primarily concerned with orbital vehicles, which may have different requirements than suborbital vehicles. Therefore, a derivation of this model called SUBORB-TRANSCOST was developed by Robert Goehlich for use in estimating suborbital vehicle costs. For this study, the primary focus was limited to main relationships and was performed using Microsoft Excel.

Primary factors in the SUBORB-TRANSCOST model are the use of mass-based cost relationships and the application of various assessment factors to account for variances in team experience, engineering methods, and other areas. While the mass relationships are based on historical data, the assessment factors are primarily up to knowledge and experience of the person using the model (Koelle, 2003).

While parametric cost methods are often used in the aerospace industry, it is important to note some of their main features and limitations:

- The method assumes programs are run in a similar manner to traditional government aerospace programs, rather than commercial development
- The method produce rough estimates, rather than specific predictions: typically, within about +/- 25% (Goehlich, 2002)

The last point is probably the most important when considering the development of suborbital transportation vehicles. They represent an entirely new capability for a novel market, rather than evolution within an existing area of endeavor. Life cycle cost estimates for suborbital transportation are limited by their comparison to costs in different aerospace markets. As Max Hunter, a famous US aerospace engineer once said:

> "If you are promoting a revolution, you can't do it with life-cycle costing... If Douglas Aircraft Corporation in 1933 had used only life-cycle costing, there would never have been a DC-3" (Spencer, 2008).

4.1.4 Cost Estimation by Phase

Development Costs

Development cost includes the costs associated with design and testing of the new system. Due to the high-level nature of the method, costs such as tooling, prototyping and the like are not specifically estimated; instead, the development cost is taken as the sum of vehicle development plus propulsion development costs:

$$C_D = C_{D,R} + D_{D,J} + C_{D,B} + C_{D,W}$$

Equation 1. Sum of Vehicle and Propulsion Development Costs

Where C_D, $C_{D,R}$, $C_{D,J}$, $C_{D,B}$, and $C_{D,W}$ are the total development cost, rocket engine development cost, jet engine development cost, ballistic vehicle development cost—with engines, and winged vehicle development cost—without engines, respectively.

Values for each of the constituents of the total development cost were estimated using mass-based relationships. Of particular note is that, for a single stage suborbital vehicle, only one of either the ballistic vehicle development cost or the winged vehicle development costs would be considered, depending on whether the vehicle was winged or not.

Rocket engine development cost assumes liquid propellant engines and may be less applicable for solid or hybrid systems. A major factor in this variable is the desired reliability of the engine, which relates to the number of tests (and therefore development costs) required. Jet engine development costs are based on a large body of previous work and can be considered fairly reliable.

Ballistic vehicle development costs are less reliable, and Goehlich himself states that "it is not yet possible to define an accurate cost estimation relationship for the ballistic vehicle development cost" (Goehlich, 2002).

Reusable winged vehicle development costs are dependent on many factors, among which is the technical quality factor, which itself is based on the vehicle maximum velocity, increasing in a logarithmic fashion as design velocity increases.

For the example cost analysis, a winged vehicle was chosen due to the higher accuracy of estimates for winged vehicles and for the additional utility of wings in providing a lift-to-drag ratio suitable for the ricochet trajectory needed for the chosen route.

Several assessment factors were required for the study. These included:

Table 4-1: Rocket engine, jet engine, and winged vehicle development parameters

Rocket engine development parameters		
Assessment Factor	**Value**	**Explanation**
Rocket engine vacuum thrust (each) (kN)	1,711	Assumes thrust-to-weight ratio of 2 on launch
Project system engineering factor	1.05	Assumes lean development approach
Rocket engine technical development factor	0.9	Assumes rocket engine is evolved from previous designs
Rocket engine technical quality factor	1.3	Assumes engine reliability around 0.998
Rocket engine team experience factor	0.7	Assumes team with significant relevant experience
Rocket engine commercial development factor	0.2	Assumes lowest-cost processes used
Jet engine development parameters		
Assessment Factor	**Value**	**Explanation**
Jet engine thrust at sea level (each) (kN)	29	Assumes small jet engines operated briefly at landing
Jet engine project system engineering factor	1.05	Assumes lean development approach
Jet engine technical development factor	0.5	Assumes existing engines with minor modifications
Jet engine team experience factor	0.7	Assumes team with significant relevant experience
Jet engine commercial development factor	1	Given in reference

Winged vehicle development parameters		
Assessment Factor	**Value**	**Explanation**
Winged vehicle dry mass (Mg)	8.4	Based on estimate
Number of rocket engines	1	Assumed
Number of jet engines	2	Assumed
Project system engineering factor	1.05	Assumes lean development approach
Winged vehicle technical development factor	1	Assumes new design with existing approach
Maximum design speed (Mach)	17.35	Used for calculating technical quality factor
Winged vehicle team experience factor	0.7	Assumes team with significant relevant experience gained from suborbital tourism
Winged vehicle commercial development factor	0.5	Given in reference

Based on this, development cost is estimated to be USD 4.3 billion. If it is assumed that the jet engines do not require a new development program, their development cost can be removed; leaving a total of USD 3.7 billion in 2008 values.

Production Costs

Production cost estimation covers the cost to produce a completed vehicle and is modeled similar to development cost. Factors common to both development and production cost are not listed a second time.

Table 4-2: Rocket engine, jet engine, and winged vehicle production parameters

Rocket engine production parameters		
Assessment Factor	**Value**	**Explanation**
Number of rocket engines (per vehicle)	1	assume 5 vehicles, 1 engine per vehicle
Number of produced rocket engines (fleet total)	50	based on number of reuses and years of operations
Integration factor	1.02	assume simple integration due to experience
Number of vehicle stages	1	Assumed
Number of launches per year (fleet total)	1460	Assumed
Number of years of operations (fleet total)	10	Assumed
Number of rocket engine reuses	1460	Assumed
Rocket engine commercial production factor	0.2	given in reference
Jet engine production parameters		
Assessment Factor	**Value**	**Explanation**
Jet engine commercial development factor	1	Assumed
Number of jet engines (per vehicle)	2	2 engines per vehicle, 5 vehicles total
Number of produced jet engines (fleet total)	10	assume simple integration due to experience

Integration factor	1.02	assumed
Number of vehicle stages	1	assumed
Jet engine commercial production factor	1	given in reference
Number of launches per year (fleet total)	1460	assumed
Number of years of operations (fleet total)	10	assumed
Number of jet engine reuses	14600	assume jet engines reusable for entire lifetime

Winged vehicle production parameters

Assessment Factor	Value	Explanation
Number of produced winged vehicles (total fleet)	5	assumed
Number of launches per year (total fleet)	1460	assumed
Number of years of operating (total fleet)	10	assumed
Number of vehicle reuses	14600	assumed
Integration factor	1.02	assume simple integration due to experience gained from suborbital tourism
Number of vehicle stages	1	assumed
Winged vehicle commercial production factor	0.5	given in reference

Based on the parameters above, the total production cost for each vehicle is USD 680 million.

Operating Costs

Total operating cost is comprised of three major components: variable direct operating costs, fixed direct operating costs, and indirect operating costs. For the purpose of this study, abolition costs were ignored on the assumption that vehicles will operate for the entire useful life. Insurance costs were also ignored. Lastly, the propellant prices were updated to 2008 figures. Factors for the operations costs estimates are summarized in the table below.

Table 4-3: Operating cost factors

Assessment Factor	Value	Explanation
Boil-off factor	1	given by reference
Propellant mass [Mg]	78	calculated
Propellant manufacturer price [MY/Mg]	0.01	assumed, based on high price increases
Interest rate	0.2	assumed
Years of interest rate	5	assumed
Repayment rate	0.25	assumed
Years of repayment rate	5	assumed

Based on these inputs, operating costs are estimated to be USD 3.7 million per launch.

4.1.5 Cost Sensitivity Factors

Given an estimated cost-per-launch of USD 3.7 million and 7 passengers, ticket prices would need to exceed USD 525,000 per passenger. This is clearly not in the established range of USD 50,000 to 100,000, so the prospects for a viable business are questionable in this case study. However, it may be possible to lower the estimated cost by changing the assumptions and input parameters.

One important factor is sizing the vehicle appropriately for the market. For instance, if the case study vehicle is scaled for 14 passengers and 2 crew members, the cost per passenger is lowered to about USD 355,000 per person. At high numbers, such as a 100-passenger transport, costs are in the range of around USD 145,000 per passenger. It is clear that based on this methodology, cost-per-passenger soon reaches an asymptotic lower limit above USD 100,000 per passenger, as shown in the graph below.

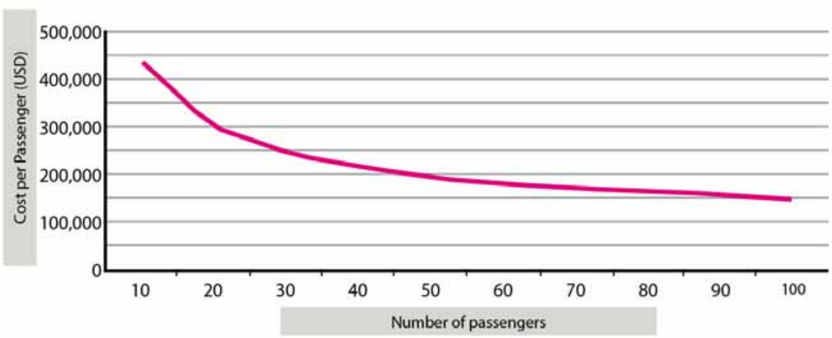

Figure 4-1: Number of passengers vs. Cost per passenger

Improvements in structural efficiency can only play a limited role. Assuming that the vehicle dry structural mass can be reduced by 1% of GLOW, the payload could be increased by 1% of GLOW, allowing more passengers to be carried. The results of continuing to substitute vehicle structural mass for payload are shown in the table below, down to a relatively low vehicle structural mass fraction of around 6.6% GLOW. Both rocket engines and jet engines were resized to maintain similar thrust-to-weight ratios. In this scenario, cost per passenger still tends toward an asymptotic minimum and still remains well above USD 200,000 per passenger.

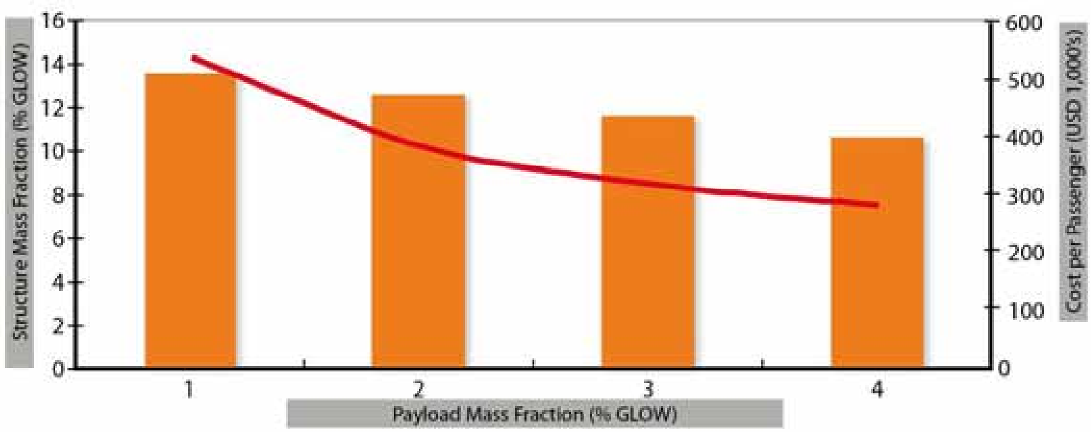

Figure 4-2: Payload fraction vs. Cost per passenger

A third factor is the mass of the passengers and their baggage. The case study above assumed that each 86 kg passenger would require approximately 14 kg of additional mass for baggage, as is the case for current airliners. However, if this amount is reduced or eliminated, some cost savings can be realized due to lower payload requirements. In the case study, reducing the baggage requirement entirely lowers cost per passenger by about USD 20,000; a notable amount, although not enough to close the business case.

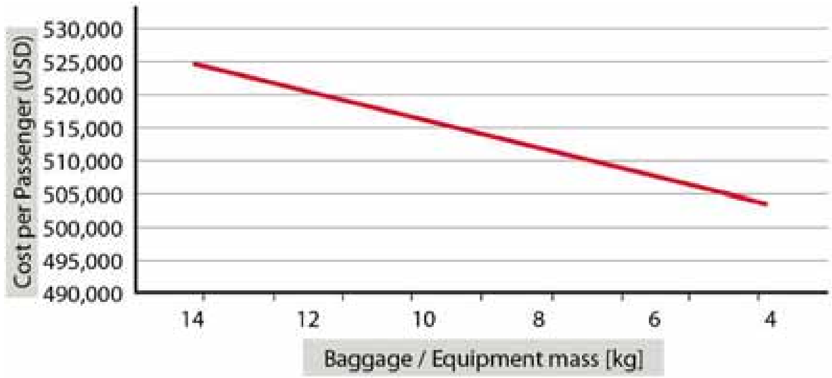

Figure 4-3: Cost per passenger vs. Baggage mass

Finally, another notable cost driver is the maintenance work required between flights. The parametric model is based on previous projects that involved high labor and materials costs for vehicles that were of limited reusability; future suborbital vehicles will only be successful if they can be operated with a minimum of maintenance between flights. While data for maintenance costs associated with current suborbital tourist vehicles is scarce, the parametric model can be used to investigate the cost implications of reducing maintenance requirements. The graph below shows cost per passenger for the baseline study as it varies with maintenance effort, beginning with the maintenance costs calculated by the model and incrementally reducing these costs by 10% to show the impact on overall cost.

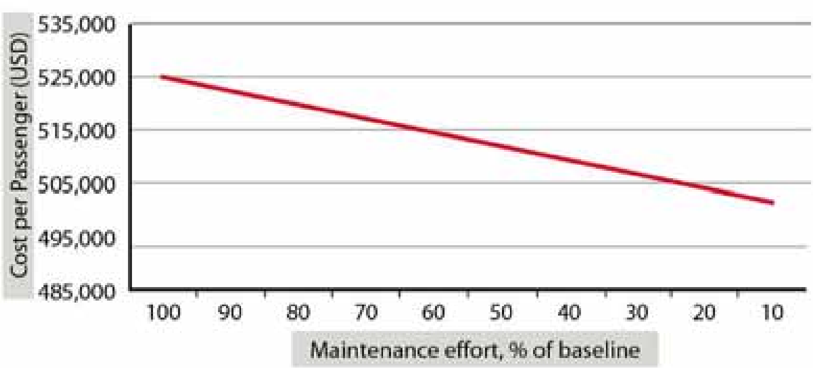

Figure 4-4: Cost per passenger vs. Maintenance effort

However, other factors may play a larger role in lowering the cost per launch to one that the market can bear. Primary among these is the development and operation process used to design and test new vehicles; as the parametric methods described above are based on government programs, they may tend to overestimate costs when compared to leaner private developments. An example of this is the discrepancy in overall program cost between the X-15 and SpaceShipTwo programs. The X-15 flight test program operated 27 flights in 1964 at an average cost of about USD 602,000 per flight (Love & Young, 1966), or approximately USD 4,000,000 per flight at present-day value (Friedman, 2008). SpaceShipTwo, to be operated by Virgin

Galactic, is designed to reach altitudes and speeds similar to that of the X-15 while carrying 6 passengers at a price of USD 200,000 each, or USD 1,200,000 of revenue per flight (NewScientistSpace, 2008). This suggests that SpaceShipTwo per-flight costs will be less than 30% of those for the X-15 program, which may show that there is hope for similar cost reductions in future programs.

If the 30% cost-per-flight ratio was applied to the SUBORB-TRANSCOST model for the case study, it would result in a cost-per-passenger of approximately USD 150,000.

Moreover, another more advanced vehicle may be viable if it were designed with the following characteristics, and would yield a per-passenger cost of approximately USD 75,000:

- 7 passengers and 2 crew members
- Payload fraction of 4%
- Maintenance effort of 10% of the baseline
- No passenger baggage
- "30% X-15/SpaceShipTwo reduction factor"

4.1.6 Cost-Driven Segmentation

As can be seen in the previous section on cost sensitivity, many factors related to vehicle design and operation can affect costs. However, another major factor in both the development and cost-effectiveness of vehicle development is the amortization of development costs.

Using the SUBORB-TRANSCOT model, total development costs for the case study vehicle were calculated to be approximately USD 4.3 billion. Even if private industry can reduce this by a large margin, development costs will likely still be in the billions. Coupled with this could be a relatively high cost of capital, as suborbital vehicle development is perceived as a high-risk investment and requires high amounts of capital.

This situation may lead to a segmentation of the market between vehicle developers and vehicle operators, as is currently the case in the airline industry. The benefit for vehicle developers would be the ability to quickly recoup development expenses by selling vehicles upfront for full price, rather than slowly paying off their production and development via flight revenues. It would also lower the barriers of entry for potential vehicle operators, as they would only require enough capital to purchase vehicles (rather than develop them), allowing a greater number of vehicles to be purchased and operated. Additionally, once a vehicle for suborbital transport has been developed, it is likely that market perception of the risk will decrease, allowing operators to borrow capital for purchasing vehicles at lower rates than those for vehicle development.

Separating the vehicle developers and operators could lower costs by eliminating the need to amortize development costs through flight revenues, but this would depend on the cost of capital for financing the purchase of vehicles. The SUBORB-TRANSCOST model was modified to take this into account by:

- Eliminating the development amortization cost from cost-per-flight
- Adding a margin of 10% to the per-vehicle production cost to account for vehicle developer/manufacturer profit margin
- Reducing the interest rate on vehicle financing from 20% to 10% (assume lower perceived risk since vehicle has already been developed)

The new cost per passenger is calculated at roughly USD 480,000, only a small reduction in cost.

While segmentation may not lead to significant cost-per-passenger reductions, it may significantly lower the barriers to procuring the capital necessary to develop and operate suborbital transports.

4.2 Funding

In the examination of viable PTP suborbital transportation, funding the cost of developing spacecraft and infrastructure is identified as one of the greatest challenges. Some members of the "New Space" industry feel that most spacecraft development is powered by "dot com" batteries that will eventually run out (Witt, 2008). There are several distinct sources of funding and involve different motivations, risks, return, and impacts. This section provides a cursory examination of funding methods for developing PTP suborbital transportation as well as a discussion on risk, return on investment (ROI), and the cost of capital (CoC).

4.2.1 Current Developments

At the moment, funding for PTP remains limited at best. Most of the recent breakthroughs in technology have been funded by entrepreneurs and Angel Investors. SpaceShipOne, the first privately funded suborbital spacecraft was funded largely by former Microsoft chairman, Paul Allen. Other reusable space technologies are being pioneered by other entrepreneurs such as PayPal founder, Elon Musk. Public funding sources for suborbital transportation are scarce at best, currently limited to paper studies in the United States. It is possible, however, that as the technology and business models mature, that other funding sources will become available, though this may not be in the near term.

4.2.2 Cost of Capital

The 6% annual rate of return used by many finance models use is generally unrealistic because this rate can only be obtained from a government-backed loan (Eilingsfeld & Schaetzler, 2002). Space ventures are considered to have very high risks due to long project development cycles and break even estimates that may not occur before the actual product reaches the end of its lifecycle. Motorola's Iridium communications satellite constellation is one well known example of a financially unsuccessful venture which was forced to compete with less expensive and far-reaching terrestrial networks by the time the constellation was deployed (Peeters, 2007a). Values for CoC and ROI vary widely across the spread of funding sources. The table below provides estimates for several funding sources:

Table 4-4: Cost of capital
(Eilingsfeld & Schaetzler, 2002)

Source of Funding	Cost of Capital
Government-backed Loan	6%
Private Debt	8 – 10%
Junk Bonds	~15%
Common Stock	15 – 18%
Venture Capital	~40%

4.2.3 Sources

The potential funding sources to support the development of PTP suborbital vehicles, operations, and infrastructure are explored in this section. The sources range from private to public funds, and the size, interestingly enough, crosses the spectrum of individuals to large governments.

Venture Capital and Angel Investors

Venture capital (VC) is a form of private equity that comes from either individual investors, sometimes referred to as "Angel Investors", or from venture capital funds which are professionally managed funds of investment capital from a pool of investors. One of the better known "Angels" is Paul Allen, who solely funded the development of SpaceShipOne. This type of funding source is an important factor for new, high growth, high risk, and high return start-ups. Typical investments from a venture capitalist, fund, or "angel" consist of direct cash for a startup business, during the early growth phase, in exchange for shares of the company. Because of the high-risk nature of new aerospace companies, for example a new suborbital spacecraft manufacturer, the traditional capital markets and debt issue methods of raising funds is usually unavailable. One important issue with VC is that a firm may have to yield some control of the company to the venture capitalist or fund manager with respect to management of the firm. Another important point to consider with VC funding is that the investor typically "gets in early" and "gets out early"—meaning they will have an exit strategy to ensure a high return on their investment. The emergence of the Space Angel's Network as a consortium connecting aerospace start-ups with potential venture capitalists which illustrates a trend for venture capital for a potential suborbital company. The Space Angels Network was created to address the "major chronic structural gap in seed-stage funding for space-related companies" (Lee, 2007).

Prize Model

Prizes have long been a mechanism in aerospace and technology developments. In the first quarter of the 20th century, there were literally hundreds of prizes in the fledgling aviation sector. The most notable of these prizes was the Orteig Prize, a USD 25,000 award put forth by hotelier Raymond Orteig for the first person to fly non-stop between New York and Paris. Charles Lindberg won this prize, and worldwide fame, in 1927. Today, with the successful winning of the Ansari X PRIZE, and the advent of the new V-Prize challenge, incentive now exists for competition. It should be noted that the prizes themselves are most likely not a method or source of funding. In fact, more than USD 400,000 was spent in the research, development, and execution of wining that original USD 25,000 Orteig Prize. The winning spacecraft that took the USD 10 million Ansari X PRIZE was estimated to cost more than USD 25 million to develop. It should be noted, however, that in the case of Charles Lindberg and SpaceShipOne, the winning of their prizes led to commercial contracts afterwards that more than justified the expense. Winning a prize can be considered a gateway to alternative sources of funding.

Private Equity

A more recent source of funding is the private equity market. Private equity firms play a major role in supporting new businesses likely to yield high returns; firms including Carlyle, Blackstone, and KKR have been closely observing the "new space" market for the past decade. Private equity partners enter the funding cycle late in the project timeline, after venture capital and investment returns have financially sustain the firm. Any potential company will have to demonstrate the execution of a successful business plan before private equity partners are willing to provide funding for a project. Private equity partners generally fall between managed public funds and venture capital with their level of risk aversion, and as promising contenders in the PTP suborbital transportation arena move to market, a buyout or mezzanine opportunity from one of the major private equity players is likely (Peeters, 2007b).

Partnerships

Public-Private Partnerships and Multinational Public-Private Partnerships (MP3s) are effective mechanisms for funding large-scale projects, such as transportation systems and infrastructure, educational institutions, and space projects by sharing the cost, risk, and technology between public entities and private companies. Funding for these partnerships exists on an "enormous scale", due to the large amount of capital available to governments (Pritchard & MacPherson, 2003). The alliance established between Great Britain and France to develop the Concorde is a particularly relevant example of MP3 funding for a fundamentally new type of vehicle. Japan and France have also formed a MP3 to develop the next generation of supersonic transport, although funding for this project is currently limited due to its early, investigative phase (Sucher, 2005). Finally, ESA's current efforts to spur rapid transportation have led to public funding of private research efforts, including Reaction Engine UK's LAPCAT A2 design for a hypersonic passenger vehicle (ESA, 2008a).

Military

The defense sector may provide a source of funding for PTP suborbital transportation; the military applications have sparked the interest of many officials in the upper echelons of governments and militaries around the world. In the US, the Department of Defense established the Office of Operationally Responsive Space in May 2007 to address the need for rapid development and deployment of space assets (Rupp, 2007). Additionally, the US National Security Space Office has been examining the feasibility of a spacecraft capable of inserting 13 US Marines to any location in the world within a few hours (Damphousse, 2007). Though this particular study is limited both by practicality and funding, it alludes to the fact that the US government is interested in the rapid transportation of troops and potentially cargo. Perhaps the most promising application will be the transport of time-critical of spare parts. Funding for such projects may become a reality in the future.

4.2.4 Conclusion

For the most part, the means to fund a PTP suborbital transportation system remain limited. As industry moves forward with this effort, risks will lessen, and the number of sources of funding will likely increase. In spite of this seemingly dire funding situation, there are still resources to be tapped, just as there is no limit to the human ingenuity to enable this mode of transportation and delivery. The risk-taking acts of VCs, angel investors, and the government will lay the monetary foundation of this "New Space" venture.

4.3 Evolution from Suborbital Tourism

When Scaled Composites successfully flew a private vehicle to the 100 km altitude mark and back twice within two weeks, it was considered no small feat of engineering innovation and technical expertise. Mojave Aerospace Ventures (a venture between the project's financier Paul Allen and Scaled Composites) walked away with the USD 10 million prize and international recognition. The realization of this type of flight also led to a corporate partnership between Virgin Galactic and Scaled Composites to create the first suborbital space tourism business venture, intended to take passengers to the edge of space for a ticket price of USD 200,000.

The Ansari X PRIZE was not the first cash incentive offered to push the technological envelope, taking inspiration from the Orteig prize awarded to Charles Lindbergh in 1927 for completing the first nonstop flight between New York and Paris. This incredible feat of its time opened the skies to the possibility of air travel between the US and Europe, and in the same vein, the skies have been opened to a private presence in space, initially through suborbital joyrides. Studies have shown the market for suborbital space tourism is potentially lucrative, and several other companies have started to develop space vehicles for similar tourism flights. This market, however, will not sustain itself indefinitely, and single point suborbital trajectories may evolve into PTP routes across the globe.

From tourism to transportation: The V-PRIZE has been established to award a cash prize to the first vehicle to make a flight from Virginia to Paris in less than one hour. In this section, the question of whether or not a growth path exists from single point suborbital space tourism to PTP suborbital transportation is addressed, including an analysis of the likely steps.

4.3.1 Development of the Space Tourism Industry

The space tourism industry is defined by physical limitations and market forces. The physical limitations include: trajectory limits, the thermal environment, and the force of g-loads on the vehicle and payload. The viability of trajectories may ultimately direct the development of future suborbital tourist flights. As this industry matures, the trajectories may increase in altitude and range. This evolution will likely drive technology development. Market forces are inherent in commercial technology growth, as they define the climate in which a technology develops. For example, increased demand for better views of the Earth (Futron, 2002) may encourage a move to higher altitudes or larger viewing windows. These characteristics of the flight and vehicle have implications on spacecraft design and performance, which would likely accelerate the development of more advanced subsystems.

Technical Drivers

The current model for space tourism flights revolves around vertical single point trajectories. From a technical point of view, for the same orbital energy, a vertical trajectory with a greater peak altitude will provide passengers with more time in the microgravity environment and an expanded view of the Earth as compared to a trajectory with greater range and smaller peak altitude that does not return to the same starting point. These trajectory characteristics are two factors driving the suborbital space tourism industry. Once competition exists in this market, space tourists will be able to select a provider based on the experience. The overall experience is shaped by several variables, and the trajectory of the flight is a key element. Table 4-5 below compares the advantages and disadvantages of vertical and horizontal trajectory profiles in terms of passenger experience.

Table 4-5: Passenger experiences

Variable	Vertical Trajectory	Horizontal Trajectory
Duration of flight	Longer duration than horizontal trajectory profile with the same orbital energy	Reduced time of flight for same orbital energy; may be advantage for transportation
Duration of microgravity	Longer duration of microgravity than horizontal flight profile with the same orbital energy May impact design of fluid management systems May require more complex guidance, navigation and control subsystems for reentry May require more robust TPS for reentry at higher velocities May require increased shielding from radiation and space debris	Reduced microgravity may be detrimental to the tourism experience
View of Earth	Expanded view of the Earth at higher altitudes, however, visibility is still limited at low altitudes	Portion of Earth visible to passengers is altitude dependent
Range	No range dimension covered; vehicle returns to launch site	Greater distance covered than vertical trajectory Vehicle lands at a different site than the launch site
Infrastructure	Requires a single spaceport for launch and landing	Requires separate takeoff and landing facilities
Legal implications	Same legal jurisdiction over launch and landing sites	Launch and landing sites may be located in different legal jurisdictions

G-loading is of particular significance as it depends on the choice of trajectory, and humans have limits to the level of g-force they can endure. The maximum g-forces experienced during the SpaceShipOne flight was 5 g's over less than ten seconds (Handwerk, 2004). This level of force is extreme and pushes the limit of what passengers can tolerate. From studies conducted by Chambers (1963) and Fraser (1966), it is recommended that passengers should not be subjected to g-loads greater than 3.0 +Gx and 2.0 +Gz, and the duration of the maximum g-load should not exceed 30 minutes. The constraint imposed by g-tolerance is an indicator that mission concepts for suborbital tourism will increase in range if there is an increase in the altitude of the trajectory profile to meet customer demand for an enhanced experience.

Market Drivers

The initial phase of suborbital space tourism flights is already generating significant interest, despite the hefty ticket price. The demand for this type of flight is expected to increase over the next decade, and the price is predicted to fall with increasing demand (Futron, 2006). Laing and Crouch (2004) acknowledge that the motivation to pay for this activity has not been studied with depth; however, several sources (Celsi et al., 1993; Shoham et al., 1998; Jones et al., 2000) have cited the risk as being a motivation for tourism experiences. Others have suggested market drivers include the desire to be the first (Smith, 2000), the novelty of the experience (Bello & Etzel, 1985), and prestige (Riley, 1995), which was discussed in Section 3.2.3.

The question of how long interest in suborbital space tourism flights will endure remains unanswered, though there have been forecasts as to the duration over which the market is sustained. Futron has used 40 years as a baseline timeframe for the market to reach maturity, but they have also modeled a 35- and 45-year maturation periods for comparison as shown in Figure 4-5 below:

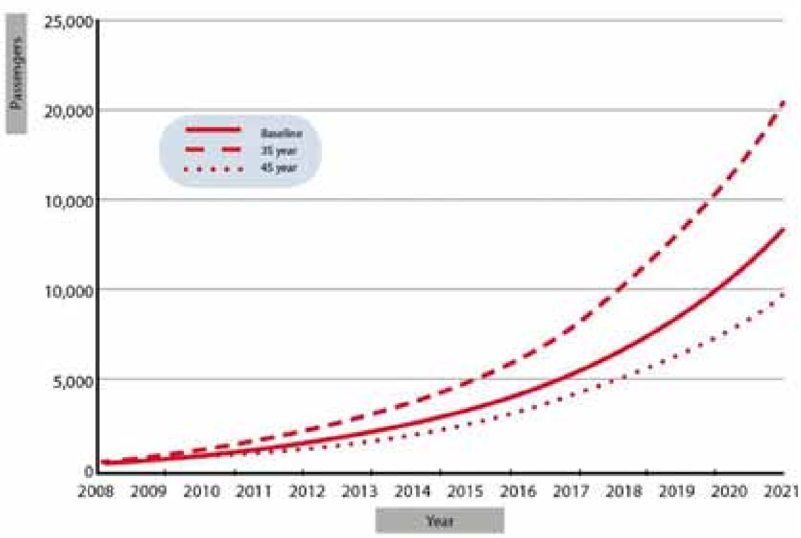

Figure 4-5: Passenger demand forecast using different market maturation

(Futron, 2006)

Once the suborbital tourism market reaches maturity, as indicated by the peak labeled 'Tourism plateau' in Figure 4-6, a new market is required to sustain the industry, and PTP suborbital transportation has been suggested as a possible next step (Peeters, 2007c).

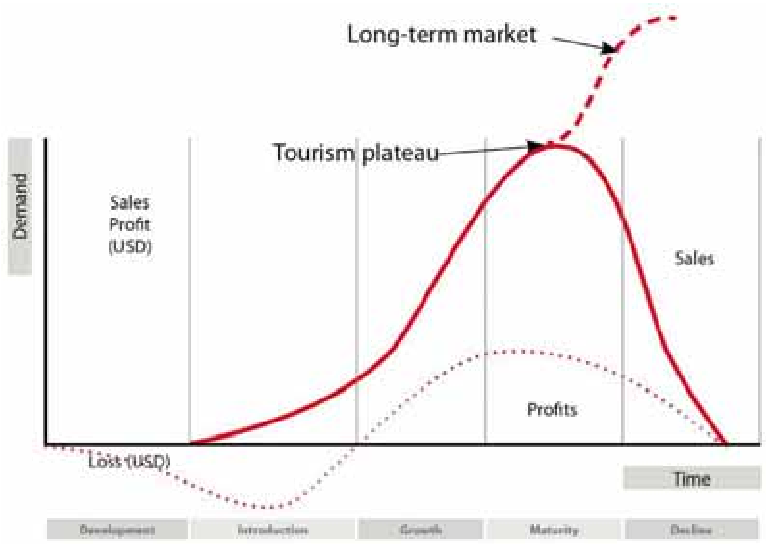

Figure 4-6: Evolution of suborbital tourism industry

(Peeters, 2007c).

4.3.2 Growth of Passenger & Cargo Suborbital Transportation

It is unlikely that passenger and cargo vehicles will develop independently of each other for PTP suborbital transportation; large, civil aircraft have historically been designed as multi-purpose vehicles with the ability to carry both passengers and cargo. The question of which payload may be transported first goes beyond the technical requirements. While the requirements for carrying cargo may differ than those for carrying a human, there are other factors to determine what will be transported first. Market demand is a significant indicator of the timeframe for providing a passenger, cargo, or mixed-payload transportation service, and the infrastructure into which these services should fit must be accounted for as well. The technology development is discussed in 2.3, demand is discussed in Chap 3, and infrastructure is discussed in Chap 5.

PTP suborbital passenger flights have a precedent in the industry of high speed travel with the Concorde supersonic transport. The Concorde passenger market increased from a total of 60,000 passengers per year in the first ten years to a sustained 110,000 passengers per year during the remainder of its lifetime. Current high speed transportation markets are experiencing positive growth with possible supersonic options operating in the future. Throughout this report, there are examples of restrictions that apply to passenger vehicles, which do not exist for cargo. Across the various disciplines, there are differences in trajectories and spaceports, markets, legal requirements, safety and environmental issues. Perhaps the biggest difference between the two is in terms of allowable trajectories. This comes primarily from radiation requirements for passengers, but also as a result of allowable g-forces. The Van-Allen belt starts at approximately 550 km altitude and varies at different times of years and on different parts of the planet. Capped trajectories come at hefty energy costs but also have the advantage of yielding less g-force due to the lower inclination of the reentry angle through the Earth's atmosphere.

Much of the technology required to deliver cargo does already exists; sounding rockets and Intercontinental Ballistic Missiles (ICBMs) are versatile and may be capable of delivering payloads over long distances, with minor modification. Conversely, current suborbital tourism vehicles are not capable of transporting cargo over intercontinental distances, and in fact, the industry is aiming to provide passenger satisfaction through single point joyrides. Although high safety standards are required for cargo vehicles, they do not necessarily need to be as stringent as passenger vehicles. Higher g-forces are viable for most types of cargo and a pressurized fuselage is generally not required, though in aircraft they are generally provided for economic reasons stemming from standardization.

An examination of the growth path of the aviation industry would indicate that transportation of cargo was conceived by the German military in World War II in order to give them a logistical advantage over Allied forces. Cargo transportation was not considered an option for the private sector until FedEx started delivering packages worldwide, and now their infrastructure has been developed and refined to support the transportation of cargo using a network of vehicles. This well-established infrastructure will not go away anytime soon, and the FAA (2005) predict that using suborbital vehicles to transport cargo will only be successful if the vehicles can integrate into existing infrastructure.

4.3.3 Technology Development from Suborbital Tourism

The technology gap between single point and PTP designs is large. The most mature single point design is SpaceShipOne. Although the design concept was innovative as a prototype and proved a technology path, there are a number of challenges that will prevent the immediate leap to PTP suborbital transportation.

One of the greatest challenges from the SpaceShipOne concept is the lack of independent non – rocket powered flight capability to allow the vehicle to carry itself high enough for an air launch using separate jet engines. This capability, more importantly, means that the vehicle is capable of a powered landing; likely to be a requirement for all air traffic-controlled areas. There are advantages of having jet engines, even for tourism vehicles; they enhance safety, reduce the amount of restricted airspace required, allow operations in a wider range of localities (such as over the sea), and give the spacecraft a self-ferry capability. These advantages have led to at least two potential suborbital tourism designs, Rocketplane XP, and an unnamed EADS Astrium design, being equipped with conventional jet engines. It is reasonable to assume that this design feature will become well developed, if not standard.

The ΔV requirement for SpaceShipOne was estimated to be approximately 1.5 km/s. From the analysis in Chapter 2, a transatlantic crossing requires a ΔV of approximately 7 km/s. This increase in ΔV requires a higher performance propulsion system. For suborbital tourism operators, once able to reach an adequate altitude, there may be no strong motivation to increase the performance of their rocket engines. It may be that their development effort is directed at increasing the reliability and reusability of their rocket engines instead. It is likely that a similar situation will arise with regards to thermal protection. It is realistic to argue, as Hoerr (2008) has, that propulsion and thermal protection for PTP transportation will arrive via orbital vehicles, rather than from the space tourism industry.

4.3.4 Summary

As it stands today, the growth path from suborbital tourism to suborbital transportation is unclear. Suborbital tourism is initially most likely to follow a demand for better and better passenger experiences. Leisure customers may begin to seek new thrills in the form of crossing the day/night terminator, passing through the northern lights or partially traversing the globe with a continental or oceanic crossing. Development in this direction will depend on an existing demand for the space adventure experience. Higher and higher altitudes may not be enough to satisfy the market and a variety of original options and fresh ideas will be required. If this is the case, there is a likely possibility that longer hops will push along the technology to make PTP transportation more and more within reach.

Advanced propulsion and thermal protections systems are two of the areas that require development. Unfortunately the suborbital tourism industry may not be willing to fund any development beyond what is required to achieve a tourism flight. It may be that this technology will need to be obtained from elsewhere.

In the early days of aviation, no one ever dreamt that airplanes were much more than a risky, but thrilling, ride in the air, yet we now live in a world were we take commercial aviation for granted. One driving factor that should not be forgotten is human perception. If the suborbital tourism industry takes off, the notion of transporting passengers and goods on ballistic trajectories may also gain higher acceptability from the public than would otherwise be the case.

4.4 Conclusions

The results of the parametric cost estimation performed for this study indicate that the cost per passenger on a seven passenger vehicle may be in excess of USD 525,000 each, with a lower limit approaching no less than USD 100,000 per passenger. In equivalent terms of cargo, the costs could be as large as USD 2.6 million per metric ton. The cost sensitivity analysis reveals that the cost is driven by technology development to achieve higher technological efficiency and the maintenance required between flights. The involvement of the private sector also indicates a reduction of costs, as was seen with the comparison of the cost-per-flight between SpaceShipTwo and the X-15 program. Funding this type of project is indeed difficult due to technology risks and uncertainty of a potentially niche market. As the vehicles demonstrate their reliability through extensive flight testing, funding sources are likely to increase. For the present, suborbital tourism is primarily funded by angel investors with the desire to support an extraordinary feat. The V-PRIZE is an encouraging example of the prize model; however, the requirements for this competition are still under development. The evolution from suborbital tourism to PTP suborbital transportation is not entirely clear. As the suborbital tourism industry matures, it is likely that operators will continue to increase the quality of the service provided. The extension into new and fresh ideas for suborbital tourism may lead to initial PTP trajectories to meet this demand, as well as the development of required technologies.

5 INFRASTRUCTURE & ENVIRONMENT

The infrastructure required for a viable PTP suborbital transportation network is a significant part of the challenge facing the development of this industry. Key considerations are the requirements for spaceports, the required ground infrastructure, development of suitable air and space traffic management systems, and the impact of these elements on other areas of human activity and on the environment. This section will discuss these issues and present the challenges, some potential solutions, and conditions that must be met if the industry is to be viable.

5.1 Spaceports

Just as conventional airplanes cannot operate without airports, spacecraft that may one day provide PTP suborbital transportation will require a similar infrastructure of spaceports. Many spaceport requirements depend upon the particular design of the spacecraft utilizing the facility. For example, a spacecraft based on the SpaceShipOne (SS1) flight profile, which involves un-powered gliding during reentry and landing, would probably not be able to fly into a commercial airport without causing major interruptions to regular air traffic. In the case of SS1, the Mojave Air & Space Port had to close for 90 minutes to allow for recovery of the spacecraft, that is, the landing of a glider (Witt, 2008). A 90 minute interruption at any major commercial airport would not be feasible and therefore, an SS1 type flight profile would have to use a separate spaceport outside congested airspace.

Figure 5-1: URS/Foster+Partners' Design for Spaceport America

An example of a spaceport being developed to handle traffic like SS1 and its successor, SS2, is Spaceport America, as pictured in Figure 5-1 above. However, if the spacecraft were similar to the EADS Astrium design and shared a powered takeoff and landing flight profile, it may be possible to use major commercial airports with only some modifications, upgrades, and additional ground crew training.

5.1.1 Development of Spaceport Infrastructure

Following the first successful flight of an airplane in 1903, the focus of the aviation industry was on research and development of aircraft technology, not on the development of airfields. A rudimentary set of airfields was established during World War I, but the significant development of airfields in the United States was driven by commerce, such as the need for airmail flights to have refueling and mail drop off sites in various locations. The aviation industry began growing rapidly in the late 1920's, which then drove the need for improved infrastructure and regulatory frameworks, including licensing. As passenger travel became more commonplace and high capacity aircraft emerged (such as the Boeing 747), the construction of larger airports became a requirement as well as the expansion and improvement of existing airports. This was expensive and required a great deal of government support. Some key dates and events in the development of the airport infrastructure in the United States are presented below in Table 5-1.

Table 5-1: Timeline for the development of US airports

Year	Development
1903	First flight at Kitty Hawk: Afterwards, R&D focused on aircraft technology, not so much on airports. First airfields have very basic infrastructure.
1914 –1918	World War I: Development of some of the first airports, but still quite basic – just infrastructure for aircraft maintenance and refueling.
1918	US airmail service begins: First route is between New York and Washington DC. Many areas in the US see the opportunity to become connected to the rest of the country and construct local airports. 145 airports by 1920 form the basis of the national airport system.
1926	Air Commerce Act: Created to manage a fledging (but rapidly growing) aviation industry. Helped to establish airfields, facilities, and navigation aids. Also helped develop the regulatory framework for the new industry (including licensing and the use of airspace).
1938 –1945	World War II: Government funds were used to construct and improve national airports for defense purposes.
1944	National Airport Plan: Established for airport system planning. Provided federal funding for airport improvement and construction.
1950's	A national travel boom overwhelms the airport system. Carriers expand their fleets, and need arises for an improved air traffic management system.
1960's	Emergence of the Boeing 747: Air transportation again reached critical levels.
1970	The Airport and Airway Development Act: Invested federal money into airport improvements and also imposed taxes on those who used the aviation system to pay some of the cost for these improvements.
1976 & 1978	Deregulation Acts: Resulted in hub-and-spoke model of airports that is presently observed.

It is important to note that the overall development of the airport system in the United States was largely reactive, rather than proactive. This was particularly true in the technical and legal regimes. Similarly, spaceport development will likely be driven by the development of the space vehicle industry; however, the additional challenge of integrating spacecraft traffic and infrastructure requirements with that of existing air traffic and infrastructure exists. This will be particularly important for the development of PTP transportation, and unlike the history of airport development, the development and integration of spaceports may require proactive initiatives with regard to legal and technical challenges.

The costs of developing the infrastructure to support a growing space industry, particularly that of a PTP suborbital industry, may also have some parallels to early airport development. With respect to demand and public safety, additional construction and improvement of the airport infrastructure was required as the aviation industry evolved. Such improvements were quite expensive and therefore required government support, such as the U.S. Airport and Airway Development Act. Similarly, spaceport construction and infrastructure costs are high, and such ventures often require support from the government. Many spaceports are already supported at least in part by public funding. A selection of spaceports currently under development for suborbital space tourism, their estimated development costs, and sources of funding are shown in Table 5-2 below:

Table 5-2: Spaceport development costs and sources of funding
(David, 2006; Space Adventures, 2006; Spaceport Singapore, 2006)

	Development Cost (USD)	**Sources of Funding**
Spaceport America	USD 225 million	New Mexico state government
United Arab Emirates Spaceport	USD 265 million	UAE government and private companies
Mid-Atlantic Regional Spaceport	USD 30 million in upgrade to existing spaceport	State support from Virginia and Maryland government
Spaceport Singapore	USD 115 million	Government and private companies

As the example of Spaceport America has shown recently, garnering public support and funds can be a challenge (Medina, 2008). Development of a network of spaceports, or integration into the existing airport system, will be an expensive and challenging endeavor. Some savings may be made by using existing facilities, such as decommissioned military bases, and their runways, or by using existing rocket range facilities. Europe in particular, has large numbers of long runways left over from the cold war which would be capable of supporting some suborbital concepts. It may be viable to develop a purpose built spaceport without public funding, especially if it is designed for tourism purposes other than PTP transportation. This is the case with the joint ventures creating the tourism infrastructure for Spaceport Sweden in Kiruna (Spaceport Sweden, 2008).

5.1.2 Accessibility

Spaceports will likely begin to materialize on a large scale when a demand for services from suborbital vehicles arises. Point to point suborbital transportation, in particular, may drive the proliferation of spaceports, as the vehicles will require facilities worldwide for takeoffs, landings, and maintenance. A key point to consider in the early phases of PTP suborbital transportation, however, is where the initial spaceport facilities will be located. A primary goal of PTP transportation is to significantly reduce the amount of time that it takes cargo and passengers to reach long distance destinations. If a spaceport is located in a remote location, as some of those currently under development are, then the transportation time from the spaceport to the final destination must also be considered. Once this is factored in, for some spaceports, the total transit time of cargo or passengers may not be significantly less than that of an aircraft that flies directly to a destination for a lower cost. Table 5-3 lists the status, location, and proximity of some current or proposed spaceports that may be setup to support the fledgling space tourism industry.

Table 5-3: Proximity of typical spaceports to major cities

Spaceport	Location	Distance from Nearest Major City (km)	Travel Time (by ground transport)	Estimated Completion Date
Spaceport America	72 km north of Las Cruces, New Mexico, United States	160 km to El Paso, Texas / 286 km to Albuquerque, New Mexico	2.5 hours to El Paso, Texas / 3.5 hours to Albuquerque, New Mexico	2009/early 2010
Mojave Air & Space Port	Mojave, California, United States	154 km to Los Angeles, California	1.5 hours to Los Angeles, California	Complete
Mid-Atlantic Regional Spaceport	Wallops Island, Virginia, United States	290 km to Richmond / 273 km to Washington, DC	3.5 hours to Richmond / 3.5 hours to Washington, DC	Complete
Spaceport Singapore	Singapore	0 km	~30 min to Singapore city center	2009
Ras Al-Khaimah Spaceport	United Arab Emirates	< 150 km to Dubai	1 hour drive to Dubai	Proposed
Spaceport Sweden	Kiruna, Sweden	390 km to Tromsø, Norway	5.5 hours drive to Tromsø	Completed, but being modified for tourism by Virgin Galactic (2012)

Spaceports could utilize various other transportation means to reduce transit times from the spaceport to the nearest major city, such as high speed trains, helicopters, or aircraft. This may require additional infrastructure and lead to a higher cost for the spaceport. When suborbital vehicle safety and reliability has been adequately demonstrated, it would be a great advantage to the industry to integrate into the existing airport system. This would significantly reduce infrastructure costs, as airports would only need to be retrofitted to support new vehicles, rather than the building of entirely new facilities. Some spaceports are co-locating with airports already, such as Spaceport Singapore or the Mojave Spaceport (Witt, 2008).

5.1.3 Emergencies & Technical Facilities

In the event of an emergency, the ground crews and staff at any spaceport must be prepared to act. Preparations will take the form of everything from evacuation planning, hazardous material containment and recovery, to medical facilities, and several other procedural mechanisms. If an in-flight emergency occurs, ground crews will have to be ready to deploy quickly in case the spacecraft cannot land according to normal procedures. If there is a medical emergency during a flight, the same requirements for an airport would apply. Currently spaceports that handle manned flights have appropriate evacuation and emergency procedures in place that are designed for the unique vehicle characteristics. Airports tend to have general emergency facilities that are scaled according to the type of aircraft that operates at the airport. Any spaceport that handles more than one type of vehicle or a combined air/spaceport would probably have to adopt general emergency facilities like an airport rather than bespoke procedures like current spaceports. Commonality of elements of spacecraft design can assist in this process.

A key piece of the infrastructure at any spaceport will be storage and handling of fuels and chemicals unique to spacecraft. Though airports around the world already deal with hazardous materials for servicing regular aircraft, the requirements for spacecraft could be different depending on their unique requirements. The importance of this issue is highlighted by the fact that, in late 2007, the Mojave Air and Space Port was in danger of losing its FAA "launch site operator" license to operate as a spaceport due to an accident involving a rocket propellant fuel that led to the deaths of three workers at Scaled Composites (Gatlin, 2007).

5.1.4 Passenger & Immigration Facilities

As with any airport, the conveyance of international passengers at a spaceport will require mechanisms for dealing with passport control, customs and immigration, and security. How this is addressed will depend upon the type of spaceport and whether or not it is combined with a commercial airport. Some challenges may exist if the spaceport is a standalone facility that may not have the passenger throughput to justify having full time immigration and customs officials. The logical conclusion is that integrating with an existing airport that already has these protocols in place is the easiest approach. Another aspect not to be overlooked is passenger service. If passengers are paying a high premium for PTP suborbital flights, then lounges that can compete with the finest first class lounges in airports around the world would be essential.

5.1.5 Use of Existing Airport Facilities

As mentioned in the introduction, one of the major challenges for spaceport development is that most are designed to meet specific requirements of spacecraft that are to be the first tenants of the spaceport, as noted by Brown et al. (2004) "Facility and infrastructure accommodations for a new architecture tend to take considerable time, on the order of several years. This characteristic precludes the sharing of facilities and infrastructure when a new architecture arises without significant ground infrastructure investment because of incompatibilities." Is it possible, then to integrate spaceport operations into an existing airport? One example, the Mojave Air and Space Port, could serve as a model as this facility has accomplished just that in 2004 with the award of a launch site operator license from the FAA. However, it should be noted that Mojave does not facilitate the traffic and international passengers that nearby Los Angeles International Airport (LAX) can. On average, Mojave has 300 aircraft movements a day (Witt, 2008) whereas LAX can top 3000 aircraft movements in a single day (LAX, 2008). This is an issue for certain spacecraft designs, for example, in each of the three launches of SpaceShipOne, the Mojave Air and Space Port was required by regulators to close all aircraft movements and operations for 90 minutes (Witt, 2008). Some commercial airports in Europe have been temporarily provided with enhanced facilities by NASA to support spaceflight operations under the Space Shuttle's Transatlantic Abort Landing (TAL) abort scenarios.

5.2 Space & Air Traffic Management

The introduction of commercial space operations, along with the expected doubling of air traffic in the US in the next decade will place large demands on the US national airspace system, consequently, the FAA has developed a concept of operations for a future Space and Air Traffic Management System (SATMS). The purpose of the SATMS is to integrate space vehicles operations with traditional air traffic operations in a seamless manner. This will require new space and air traffic management tools as well as enhanced communications, navigation, and surveillance services (FAA, 2006a). Other countries face similar air traffic issues although none have gone as far as the FAA in dealing with space and air traffic management in such an integrated form.

5.2.1 Air Traffic Management

Typically airspace is divided into two types, controlled and uncontrolled. Controlled airspace normally requires vehicles to gain permission to enter and to be in contact with air traffic control (ATC) while in the airspace. In controlled airspace air traffic management is highly procedural and aircraft are required to follow ATC instructions. Over the years, international standards have been developed to separate aircraft in flight which describe the minimum altitudes and lateral distances to be maintained between aircraft to avoid collision and hazardous conditions. Uncontrolled airspace comprises the remainder of a country's airspace. Most countries have a band of controlled airspace at high levels over their entire country, typically between 6 km and 20 km altitude, although the altitude varies from country to country. Above this band, airspace is uncontrolled. Restricted airspace is a special class of airspace which can be established by national authorities and is often used to separate normal air traffic from activities such as military or test operations. Restricted airspace can be permanent or activated on a temporary basis and can extend to an unlimited altitude. With the exception of geostationary orbital positions, similar separation standards are yet to be developed between spacecraft or between spacecraft and aircraft.

5.2.2 Spacecraft Operations

The current procedure for separating aircraft from spacecraft during spacecraft operations is the use of restricted airspace that is prohibited for aircraft to enter. In some cases, such as in shuttle operations additional airspace, in a buffer zone around the permanent restricted airspace, is made temporarily restricted during launch and recovery operations. However, this procedure is not sustainable in an environment with high air traffic, and regular space activities. A more efficient method will therefore be required to minimize the impact on air traffic while maintaining safety. For spacecraft having a powered aircraft-like mode then controlled airspace can be utilized in the same manner as a conventional aircraft, including during rocket flight. In this case the restricted airspace can be limited to the uncontrolled airspace above the controlled band providing, on reentry, the vehicle can start its conventional engines, make contact with air traffic control, and gain their permission to enter the controlled airspace prior to descending into the controlled band. Figure 5-2 illustrates two scenarios; on the left, a control procedure relying on restricted areas, in this case the airspace around Kennedy Space Center, and on the right, a procedure that a vehicle with powered aircraft-like characteristics could use. The restricted airspace concept is particularly relevant during the early stages of the PTP suborbital flights when the vehicle technology has not matured and the level of reliability is still relatively low. Once the vehicle technology has matured and reliability level is high enough, a more regular flight schedule is to be expected. The viability of traffic management options will be based largely on the ability of the vehicle to comply with ATC clearances.

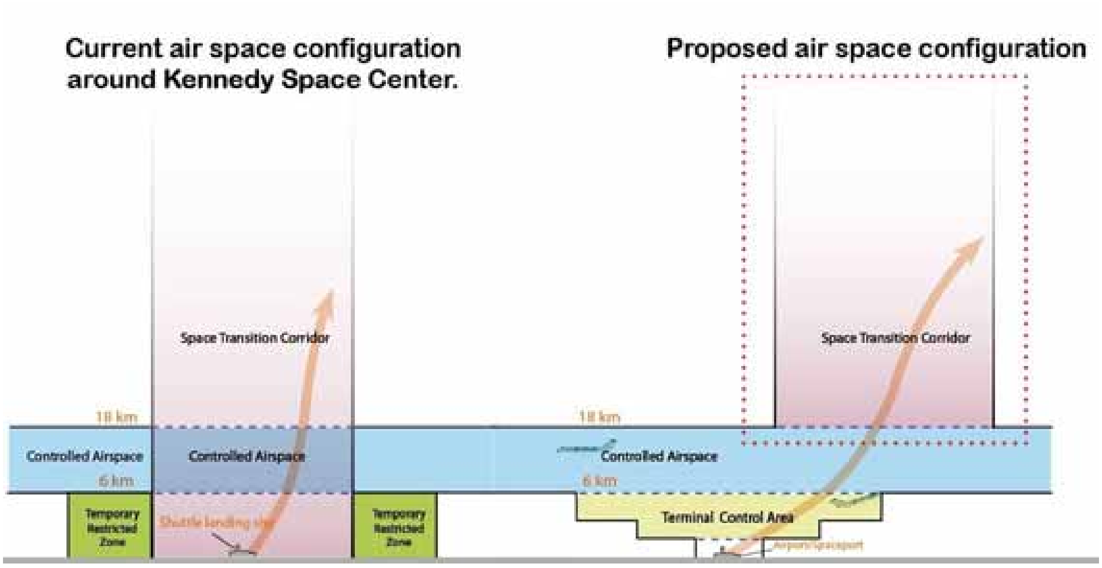

Figure 5-2: Two air traffic control scenarios

5.2.3 Space Traffic Management

Space Traffic Management (STM) deals with objects in orbit and at a high enough altitude to conflict with orbital objects. Although this includes debris the practical limitation of management is those objects that can be tracked, which is a size of above 10cm in low Earth orbit. As of 2006 there were 1,100 objects of this size in orbit below 500km, 32 of which are operational satellites. This figure does not include satellites on elliptical orbits that enter this region for part of their orbits. One of the objects (the ISS) is permanently manned. (ISU, 2007)

Objects are tracked, for strategic purposes, by the US, Russia and increasingly by other countries, and the US releases basic two line elements (TLEs) for tracked objects. According to Boyce (2004) these TLEs are of an accuracy of 1-5km, and do not contain information on highly classified US satellites. Importantly, except for a small number of objects, such as the ISS, objects are not tracked continuously so their orbits may only be checked every few days.

The key to safe suborbital travel in this part of space is to predict or track orbital objects, and choose trajectories and travel times that avoid the objects. US launch licenses make it an obligation to conduct such an assessment in conjunction with US Strategic Command, and also prohibit spaceflight within 200 km of another manned spacecraft. Operators from other countries may have to rely on published data, or on their own country's space surveillance capabilities if available. In both cases, the accuracy of the data may not be enough for large scale use. Internationally, space surveillance is being mooted as a method of providing transparency of activities in space, treaty compliance, and as a component of space debris management, so it may be that current space surveillance systems evolve into a more open, accurate capability available to all (Nardon, 2007).

5.2.4 Terminal Operations

Terminal operations are those that take place in the immediate vicinity of a spaceport, such as taking off and landing. For ground launched concepts, the launch would also be considered a terminal operation. One of the conditions for a ground launch placed on traditional spaceports by various regulating authorities around the world is exclusion and containment zones during rocket launch operations. These zones are designed to mitigate the dangers to the general public and third parties should a catastrophic failure occur. This may prove impossible to integrate with current airports. How integration will be addressed in the future depends largely on the launch technologies employed, since one can safely assume that regulations will not allow public safety to be compromised. Understanding the importance of the integration of spaceports and airports may drive development of spacecraft design. Spacecraft like the EADS Astrium concept, which has jet engines, will be able to easily integrate into airport operations. One crucial issue will be runway allocations. Indeed, some proposed spacecraft designs will not require a runway, such as Blue Origin's New Shepard vehicle, due to its vertical takeoff and landing profile (FAA, 2005). Moreover, regulators have required multiple axis runways for some spacecraft that require glider recovery operations, such as SpaceShipOne at Mojave Air and Space Port (Witt, 2008).

Landing operations may take the form of sequencing a spacecraft into the landing pattern of regular aircraft, or conversely, stopping commercial aircraft operations for the duration of the landing and recovery operation, such as at Mojave Air and Spaceport. However, if the spaceport is to be a standalone facility that caters only for spacecraft, the operations may be quite different. Some landing operations of Spaceport America, for instance, may closely resemble the operations of a sailplane or glider airpark. Then again, there are other designs such as Blue Origin that utilize vertical take off and landing operations, which could require a completely different approach to landing operations, involving securing the airspace and ensuring public safety on the ground.

5.3 Environmental Impact

The environmental impacts of a suborbital transportation industry are one of the key issues associated with its viability. Major impact drivers include spaceport and infrastructure impacts, noise, and the effects of rocket emissions on the atmosphere. This section investigates each area and provides an explanation of the challenges involved.

5.3.1 Spaceports & Ground Infrastructure

Thoughtful consideration must be given to a spaceport's impact on the environment. Whether the spaceport is co-located with an existing airport or is located separately on undeveloped land, stringent environmental restrictions will most certainly apply. Though the vast majority of requirements may be based on national environmental laws, they may be derived from international agreements as well. In the US, in order to obtain a permit to construct a large infrastructure project such as a spaceport, a detailed Environmental Impact Assessment (EIA) must be submitted to regulators before any major construction begins. This is mandated by the National Environmental Policy (Title 42 USC, 1969). Many other countries (and individual states within the US) also levy requirements for similar Environmental Impact Statements (EIS) as well.

Potential impacts of the spaceport exist on every foreseeable resource, including but not limited to "air quality, airspace, biological resources, cultural resources, geology and soils, hazardous materials and hazardous waste management, health and safety, land use, noise, socio-economic impacts and environmental justice, traffic and transportation, visual and aesthetic resources, and water resources" (FAA, Unpublished, 2006). The findings of the experts on the EIA are then subjected to a public review, essentially to solicit the opinion of the local population as well as other stakeholder views on the establishment of the spaceport. Failure to meet the requirements or expectations of even one of these elements may lead to the withholding of the permit to establish and construct the spaceport.

One example of this issue arising was the setback faced by Spaceport America in January 2008 because of a faulty EIS (Airport Technology, 2008). Indeed, planners must exercise extreme diligence when it comes to environmental concerns. Careful selection of the site and an education and outreach campaign to reach the local populace are of paramount importance. An increase in the number and frequency of suborbital flights is sure to have an environmental impact that could precipitate the creation of new legislation. The extent of the environmental impact is currently subject to speculation and debate. This is so because attention for now is mostly focused on the technological and financial challenges of suborbital transportation. Not surprisingly, there are those who believe that increased suborbital flights will further compound the environmental problems facing the Earth. It is apparent that the environmental impact of suborbital flights is dependent upon the type of propulsion used by the launch vehicle. It can therefore be argued that the need to satisfy environmental concerns will be one of the drivers of the technology that will result in the transport system(s) that will ultimately be used for suborbital flights.

5.3.2 Noise

Noise generated in the atmosphere during flight is potentially a problem for suborbital transportation. The speed required produces a sonic boom for the part of the flight during which the vehicle is still in the atmosphere. Since this portion of the flight may occur near population centers, it is a serious issue for the viability of suborbital transport. The boom is created as a result of the system of shock waves that develop around the airframe of the vehicle, particularly at the tail and nose of the craft, during supersonic flight. The audible boom is the sound of the release of pressure accumulated on the shock wave. The noise generated travels along the flight path, creating a continuous boom. From the perspective of someone on the ground, the sound would be very brief, similar to thunder. The intensity of a sonic boom depends on the speed and altitude of the vehicle, the weight of the vehicle, and its design. With increasing altitude the sonic boom attenuates according to an inverse square law, but covers a correspondingly larger area. Temporary variations in the sonic boom can occur due to meteorological effects, even to the point where booms do not reach the ground, or vehicle maneuvers. (NASA, 2008b)

Current noise regulations are too strict to allow for regular supersonic flight due to sonic boom propagation. It is probable that efforts at easing regulations to allow sonic booms over land will be met with great resistance. In studies on noise tolerance, frequent exposure to sonic booms has been found to be more distressing than standard airport noise (Peterson, 1995). The Concorde supersonic jet program was in many ways actually detrimental to the development of high speed commercial flight, since the sonic booms produced by the Concorde, and the ensuing public complaints, led to a ban on civil supersonic flight over inhabited land in the United States (Henne, 2005). The Concorde exceeded noise limits on more than 75% of its takeoffs, and remains the loudest commercial airliner ever built (Gillman, 1977).

There may be flexibility on the US air speed restrictions if the problem of sonic booms can be appropriately mitigated. The National Academy of Science's Commission on Engineering and Technical Systems' (NAS, 1992) study of high speed civil transport recommended that NASA conduct an "aggressive program to define acceptable sonic boom levels and should continue its program to investigate approaches to meeting those levels." If an acceptable level of noise could be determined, it may be possible to allow supersonic flight over land, without significant public outcry.

It is important to note that relaxing noise limits in order to allow a louder noise profile will be difficult. Moreover, shifting suborbital transportation away from urban centers in order to mitigate noise concerns will most likely have an adverse effect of diminishing the utility of the technology, by forcing long commutes from the landing area to the final destination. The approach to this problem must therefore involve a vehicle design that reduces the sound profile of the vehicle and can conduct demonstration flights that show that the vehicle is capable of flight at speeds greater than Mach 1 without creating noise in excess of conventional airline noise. This may lead to a waiver or repeal on the ban of supersonic flight over land. Trying to solve this problem by lobbying for a higher tolerance in noise regulations will most likely end in disappointment. The only viable way forward is to develop technologies and operational schemes that can effectively reduce the noise associated with suborbital transportation (Peterson, 1995).

There has been extensive work done on noise suppression for supersonic flight, though no system is in production as of yet. The Quiet Spike effort by Gulfstream has demonstrated an ability to dampen sonic booms (Henne, 2005). By altering the configuration of the body of the aircraft as it accelerates to supersonic speed, the Gulfstream Quiet Supersonic Jet (QSJ) proposes to shift the frequency of the sonic boom to a range inaudible to human ears. The Japanese space agency is also studying the problem via its Supersonic Transport Team. The team has also focused on changing fuselage geometry rather than engine noise to reduce the booms (Wahlin, 2006). Northrop Grumman and NASA have done similar work with the Shaped Sonic Boom Demonstration project, which showed that sonic booms can be shaped or even aimed by altering the shape of the aircraft (Warwick, 2000). These developments suggest that the problem of sonic boom propagation may be sufficiently mitigated to allow for supersonic flight over land during the atmospheric portion of the suborbital vehicle's flight. Reducing the intensity of booms to a level acceptable to the general public will eliminate a major barrier to easing the speed limit. It would seem that much of the concern for overland speed limits centers on noise, rather than actual speed. Successful implementation of noise abatement techniques represents the best method of allaying those concerns. Even if these concerns cannot be fully addressed, it would be possible to operate from coastal spaceports with a subsonic cruise away from the spaceport followed by acceleration to suborbital velocities at an appropriate distance.

5.3.3 Ozone Depletion

One of the main environmental concerns of PTP suborbital transportation system is its potential contribution to the depletion of ozone in the atmosphere. Ozone occurs naturally in the stratosphere. About 90% of atmospheric ozone is found within this layer which starts at about 10 – 16 km, depending on latitude, and extends up to about 50 km.

The bulk of the ozone is concentrated around 15 to 30 kilometers above the surface. This layer of the stratosphere is therefore often referred to as the "ozone layer" (Aftergood, 1991, Fahey, 2006). The ozone levels in the atmosphere are represented in Figure 5-3 below. The ozone layer absorbs the bands of ultraviolet radiation that can induce skin cancer and decrease photosynthesis in plants (Aftergood, 1991); hence its depletion in the atmosphere is of great concern. The amount of ozone in the stratosphere is maintained by a delicate balance of continuous production, transport and destruction of ozone molecules. This balance can be easily disturbed with the introduction of even very small quantity of active chemical compounds such as those produced by rocket engines (Ross & Zittel, 2000)

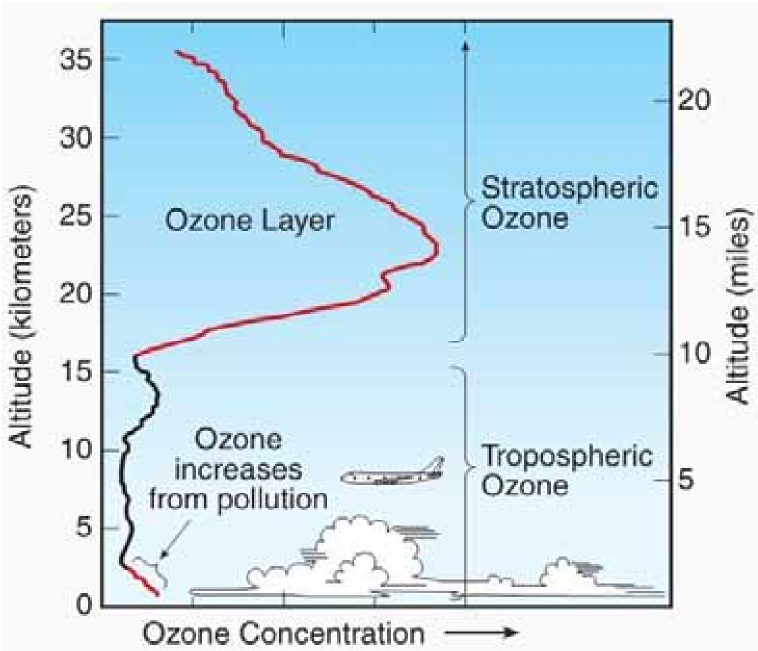

Figure 5-3: Ozone in the atmosphere

(Aftergood, 1991; Fahey, 2006)

The nature and extent of the contribution of rocket plumes to ozone depletion depends on the type of propellants used. The most damaging, yet most commonly used in traditional rocketry, are solid rocket propellants. The main ingredients of the most widely used solid propellant are powdered aluminum (the fuel) and ammonium perchlorate (the oxidizer). The concentration of exhaust products released by this mixture varies according to the altitude. Of the exhaust products, hydrogen chloride and aluminum oxide cause the most environmental damage on the ground. At higher altitudes the hydrogen chloride breaks down in the atmosphere releasing free chlorine atoms, which act as a catalyst for a continuous cycle of ozone destruction.

Effects of rocket emissions on ozone are both short and long term. After a launch, changes in atmospheric composition arising from chemical reactions between the exhaust and the air are noticeable along the flight path of the rocket. The concentration of free chlorine in the exhaust can be up to a thousand times higher than elsewhere in the stratosphere and the consequent loss of ozone within this area is equally remarkable. Long term effects occur as the emissions disperse throughout the whole stratosphere and are accumulated over time. Aftergood (1991) believes that Solid Rocket Motor emissions currently add less than 1 percent to the ozone depleting chlorine produced by industrial chlorofluorocarbons in the stratosphere. However, when compared to most other individual industrial activities, a single solid rocket launch is a considerable source of pollution and, collectively, rocket launches can have a significant effect.

As solid propellant rockets seem to be less environmentally and politically acceptable, two categories of rocket propellants that produce greatly reduced levels of pollutants are being considered. These are liquid propellants and alternative solid propellants. The cleanest burning rocket propellant is composed of liquid oxygen and liquid hydrogen. Its primary exhaust products are about 95 percent water vapor and about 5 percent molecular hydrogen. As Aftergood (1991) noted, even these relatively clean propellants are not absolutely clean as far as the atmosphere is concerned. Water vapor and molecular hydrogen, which are also natural components of the upper atmosphere, can be activated to form hydroxyl radicals and atomic hydrogen. These can act as catalysts in the destruction of ozone, albeit far less efficiently than free chlorine atoms.

Other common liquid propellants, such as liquid oxygen and kerosene, produce carbon dioxide and carbon monoxide as well as water vapor. This makes them less environmentally attractive, although the low cost of kerosene and the fact that it can be stored at ambient temperatures are advantages. According to Ross & Zittel (2000), the US Air Force is trying to develop cleaner solid propellants. The principal environmental objective is to eliminate the production of hydrogen chloride, which can be achieved, for example, by replacing the ammonium perchlorate oxidizer with ammonium nitrate. They noted, however, that there are two main drawbacks with this substitution. The revised mixture yields less energy on combustion and releases nitrate radicals that, though less harmful to the ozone layer than chlorine radicals, are still an atmospheric pollutant.

The way forward ultimately may be the development of new and more environmentally friendly propellants. These are so-called green or bio fuels. Virgin Galactic has announced the intention to develop a new fuel, Butanol, which, according to Will Whitehorn (2007), freezes at a lower temperature than ethanol and can be produced from biomass. Some, like Ashford (2007) have also opined that suborbital flights will most likely be the first sector to use liquid hydrogen fuel in large quantities. This, he contends, will invariably spread the use of hydrogen technology to the aviation sector as well as ground transport, and that suborbital flights may ultimately be quite advantageous and beneficial to the Earth in the long run.

5.3.4 Carbon Footprint

A carbon footprint is a "measure of the impact human activities have on the environment in terms of the amount of green house gases … (water vapor, carbon dioxide, methane, nitrous oxide, ozone and Chlorofluorocarbons)… produced, measured in units of carbon dioxide" (Carbon Footprint, 2008). A number of carbon footprint calculators have been devised and are available; however, those available (for example the EPA carbon footprint calculator) are optimized for estimating carbon produced by individual and business activities. It would be useful to explore the possibility of devising a carbon footprint calculator for suborbital transport system, as is available for air travels. One possibility is to carry out a Life Cycle Assessment of the suborbital transport system. This would involve the detailed study of the impact of suborbital transport systems on the environment. The concept is often used to verify the environmental compliance level of a single product or a company. Some of the parameters examined include ozone layer depletion, acidification and global warming. The availability of a calculator with the same functional unit as that used in the air travel sector at the design or early stage of suborbital transport development would help in improving the design and performance characteristics of PTP suborbital transport systems. It may also present the industry in good light as an environmentally conscious and proactive industry.

5.3.5 Environmental Laws

As is often said, laws follow technology. Understandably, there are currently no environmental laws directly regulating suborbital transportation since the technology is still developing. However, it can be expected that if a suborbital transport system is to be used for passenger transport, at the minimum, existing environmental regulations relating to air travel will be applicable. These may then be further developed as the sector matures. Currently, the most important environmental law relating to aircraft operation is the International Civil Aviation Organization Annex 16, which sets the standards for Aircraft Engine Emissions for different aircraft type (ICAO, 1997). This can be expected to be extended to PTP suborbital transportation, perhaps with some amendments or additional clauses.

Another set of environmental laws that may be relevant to the industry are national environmental protection laws of states that may become destination points for the PTP suborbital transport system. Many of these laws are in tandem with international standards like the International Civil Aviation Organization (ICAO) standards. Others may include the requirement to carry out detailed environmental impact assessment relating to the establishment and construction of spaceports. The suggestion made by Lozino-Lozinsky and Plokhikh (Lozino-Lozinsky et al. 1990, cited in Aftergood, 1991) to use only liquid propellants between the altitudes of "12 and 20 kilometers, where most of the ozone layer lies" could become a basis of international agreements. This could also include the outright prohibition of the use of solid rocket propellants. The industry will therefore be best served if it takes these issues into consideration while developing PTP suborbital transportation systems.

5.4 Conclusions

Accessibility is a must for PTP suborbital transportation: the major benefit of this means of transport is the time savings involved. If it takes two hours to get from a spaceport to any other destination, or to a connecting flight at a conventional airport, then the time savings will be diminished. Integrating major commercial airports with spaceports is therefore the logical conclusion. For this to occur, spacecraft will have to be designed in such a way that makes them easily integrated into conventional commercial airspace and with other air traffic. Ground infrastructure upgrades will be crucial as will crew training to accommodate the arrival of advanced technologies and exotic, more volatile, fuels and propellants.

The question then remains: will private investment and pubic-private partnerships be enough to create the infrastructure required for viable PTP suborbital transportation? Only time will tell, but if history is any indication, it will take significant public funding to develop the network of spaceports that would function similar to the world's current network of airports. Moreover, the ability to use the existing airport infrastructure could be a key in developing PTP suborbital travel, but will be limited to specific spacecraft designs that are suitable to existing airport infrastructure.

For the industry to be sustainable there will be the need to integrate space vehicle operations with traditional air traffic operations in a seamless manner. The FAA proposed concept of operations for Space and Air Traffic Management System is a step in the right direction. Although its provisions as currently stated will be insufficient to handle full fledged PTP suborbital transportation (as it appears to be more geared towards traditional space operations and space tourism), it will nonetheless be very useful at the nascent stage of the industry when the reliability levels of the vehicles are yet to be fully ascertained. The rules and procedures to be adopted will depend on the characteristics of the vehicle with respect to ATC clearances. It is hoped, however, that the ultimate vehicle will be one that will be more responsive to ATC clearance (notably, horizontal take off and powered reentry and landing). STM as a means of tracking objects in space would be necessary to ensure a safe flight path for the vehicles. This would have to depend on national or international arrangements to provide space surveillance capability which at present is possessed by only a few nations.

Numerous environmental issues must be dealt with if the suborbital transport industry is to be viable. Among these are the impact of spaceports on the environment, the carbon footprint of the vehicles themselves, ozone depletion, noise, and all relevant environmental laws. It seems likely that noise requirements will play a major factor in limiting operations, and that minimization of noise during these stages of flight will be a design factor. The impacts of propulsion choice on ozone depletion and generation of greenhouse gases will be a major driver in propulsion system selection, and currently point the way toward "green" propellants.

6 SAFETY & RELIABILITY

Safety and reliability are of paramount importance to any transportation industry, but for PTP suborbital transportation, they may become the defining issues of the industry's success or failure. Space flight is seen as a risky endeavor, and the Challenger and Columbia tragedies reinforced the association of space with danger in the minds of a public that will not distinguish between orbital and suborbital flight. For orbital space flight and the suborbital tourism market, risk is accepted to a certain extent, but this will not be the case for suborbital transportation. People may well be prepared to risk their life to get to space; they will not do so to get to Paris.

6.1 Reliability

Reliability is sought after for many reasons; it reduces maintenance costs, provides confidence to customers that the service will be delivered, and is a key element in safety. It is this last characteristic that this chapter will focus on. It is difficult to forecast the reliability level of any future design, more so a complex system such as a suborbital transport system. Evidence of this fact can be seen from the only comparable system, the Shuttle, whose reliability level is still subject to contention even a few years before its retirement. According to (US, 1986), while the Shuttle engineers believed the probability of a failure with loss of vehicle and of human life to be 1 in 100, NASA management quotes a probability of 1 in 100,000. The future suborbital transport vehicles will have to do better than this for two reasons. Firstly, to satisfy certification requirements, that are expected to be as stringent as for commercial air travel; and secondly, for the survival of the industry. It was possible to investigate the Shuttle accidents, rectify identified problems and continue operations mainly because it is a government program. The suborbital transport industry will not have this luxury as any vehicle failure or accident, especially at the early stage of the industry may lead to the total collapse of the sector. The contribution of the Concorde accident to the ultimate retirement of the aircraft comes to mind.

6.1.1 Reliability Standards

Aircraft safety rules aim for a reliability up to 0.999 at 95% confidence interval in critical systems of commercial aircraft, but the technology is not proven in rocketry as it is in jet propulsion, therefore it will be difficult to make any rocket system as reliable as conventional jet propulsion systems. Rockets have a reputation for unreliability and danger; especially catastrophic failures. Contrary to this reputation, carefully designed rockets can also be reliable. In military use, suborbital ICBMs are not considered unreliable. However, one of the main non-military uses of rockets is for orbital launch. In this application, the premium is on minimum weight, and it is difficult to achieve high reliability and low weight simultaneously. The current failure rate of launchers is about 5% and is unlikely to change unless rocket engines are operated at higher design margins.

Notwithstanding whatever design will be used, there is always some heritage to new designs. Although new designs can increase overall reliability it is unlikely to eliminate the main risk drivers as long as the same physical principles are used. This will therefore mean that, unless totally different launch physics are used, the core risk drivers for the suborbital transport system will be the propulsion systems during the ascent and the thermal system during the descent. The new design will have to include features that are intended to reduce the risk contribution of these drivers. It should be noted that the more revolutionary the design features, the more the probability that the risks will be reduced, but with correspondingly more uncertainty in its performance because of its deviation from the existing knowledge base (Fragola, 2000).

6.2 In-Flight Safety

The study of the effects of space environment on spacecraft is of particular interest to the space community, as the lifetime and mission performance of satellites and spacecraft are impacted by the dynamic space environment. Several industry groups have been established to monitor and predict what is referred to as "space weather", to the level of accuracy that is currently demanded of terrestrial weather forecasting, so as to better anticipate the effects on a space vehicle throughout the duration of its mission. Space environment effects are classified into five generally accepted categories: vacuum, neutral, plasma, radiation, and micrometeoroid/orbital debris (MMOD). The impact on the overall mission can be explored from both the vehicle and human perspectives, and the effect of the space environment on spacecraft missions has been observed ever since Explorer 1 discovered the Van Allen radiation belts. This has led to the development of spacecraft components that withstand the radiation effects, guided material selections and thicknesses for protection against radiation and MMOD, and motivated mission planners to coordinate their timelines with the solar cycle. The impact on human health is a naturally significant question, and there exists no empirical data for suborbital passengers to assess the primary risk of radiation hazard, however, an interesting comparison of radiation exposure to pilots, airline crews, and astronauts will be made in the subsequent section. The increasing trend of orbital debris will also be considered.

6.2.1 The Atmosphere

Suborbital transport systems have to be designed to cope with a wide range of environmental conditions, from launch through the atmosphere into the relative vacuum of space, to reentry and landing. Knowledge of the environment is vital for design decisions. The real atmosphere is not homogenous; however, models of the atmosphere have been created that describe the average change in main parameters with altitude and latitude. The best known of these models is the International Standard Atmosphere (ISA), which is heavily used by the aviation industry (ISO, 1975). Unfortunately the ISA only describes the atmosphere up to 80km so for flight above this altitude another model is needed such as the NRLMSISE-00 model (NRL, 2000) which covers the altitudes expected to be traversed by suborbital vehicles.

The models show that the ambient temperature varies from 15°C at the surface to about -103°C at 90 km after which it increases exponentially with altitude. The density of the atmosphere reduces exponentially with height to a density of approximately 1.00 x 10^{-10} g/cm^3 at 100 km. It should be noted that this is a model and the actual conditions will vary. The atmosphere is divided into a number of layers, mainly demarcated by the temperature profile.

The troposphere is the lowest part of the atmosphere and contains about 95% of all earth's air. A typical feature of the troposphere is a constant vertical temperature gradient. Nearly all weather phenomena occur in this lowest part of the atmosphere. The troposphere occupies the vertical space from the ground to 8 km in the Polar Regions, increasing to 18 km near the equator.

The next layer above the troposphere is called the stratosphere. There is a roughly constant temperature of -56°C in the whole range of altitudes up to about 50km. The stratosphere consists of clear and dry air. Up until recently there was not considered to be any weather in the stratosphere but now a variety of weather phenomena have been acknowledged to occur in the upper stratosphere. Collectively known as Transient Luminous Events (TLEs), Very little is known about these phenomena and especially their effects on vehicles. At the present time there are about 100 rocket launches per annum so the odds of a spacecraft passing through a TLE are extremely small.

Above about 50km the temperature starts to decrease with altitude. This is the mesosphere and extends to 80 – 85 km after which the temperature increases with height in the region known as the thermosphere. The thermosphere extends to over 600 km, at which point the atmospheric density is vanishingly small.

6.2.2 Space Radiation

Space radiation comes from three main sources: solar particle events (SPEs), Galactic Cosmic Rays (GCRs), and particles trapped in the Earth's magnetic field.

Solar particle events consist of high energy particles, mainly protons and electrons that are created in energetic events in the Sun. Because of their high energy they are particularly dangerous and can lead to life threatening doses of ionizing radiation for astronauts conducting spacewalks in Low Earth Orbit (LEO). Galactic cosmic rays originate from outside the solar system and are constant. The atmosphere attenuates them and the Earth's magnetic field tends to concentrate them at the poles so their density increases with altitude and latitude. Trapped particles exist in a torus around the Earth known as the Van Allen belts after their discoverer. There is both an outer belt and an inner belt, which extends down to approximately 200 km, however at this low altitude the particle energies are low and unlikely to penetrate any spacecraft skin. The distribution is not even over the Earth, with a higher density at the poles and in a region known as the South Atlantic Anomaly. The eleven year solar cycle has an effect on all three types of radiation. When the Sun's activity is at its maximum the atmosphere expands and the density of galactic cosmic rays and trapped particles reduces for any given altitude and latitude but, due to a more energetic Sun, the likelihood of a Solar particle event increases (NASA, 2008a).

Since 1996 European legislation has treated natural sources of ionizing radiation as an occupational hazard, compelling employers to provide suitable protection. As a result European airlines are required to monitor the exposure of their employees to natural radiation, and take appropriate action, such as re-rostering, to ensure air crew are not exposed to more than the allowed effective dose which should not be higher than 100 mSv over five years with a maximum of 50 mSv for a given year, with lower limits for pregnant crew members. This is general health and safety legislation and would apply to any European suborbital transport operator. (Council Directive (EC), 1996). In the US recommendations on occupational exposure for aircrew are made by the FAA. The dose levels are a 5-year average effective dose of 20 mSv per year with no more than 50 mSv in a single year, again with lower limits for pregnant crew members. (FAA, 1994) The limits for astronauts are the same at NASA, ESA, and the Japanese Space Agency at 500 mSv/yr with career levels varying with age.

Models have been developed to estimate the radiation dose imparted on a vehicle at various altitudes, and are routinely used by the aviation and space industries. However the intermediate altitudes are poorly modeled since aviation models, such as CARI-6 (2004) and EPCARD Ver.sion 3.2 (2002), do not have data above 25 km, and Space models such as NASA's AE-

8/AP-8 (1990) are unreliable below 300 km. Radiation from GCRs and particles trapped in the Earth's magnetic field has been well modeled as the dose from GCRs is relatively constant, while the dose from electrons and protons in the Earth's magnetic field correlate to solar activity and the 11-year solar cycle. SPEs cannot be reliably predicted.

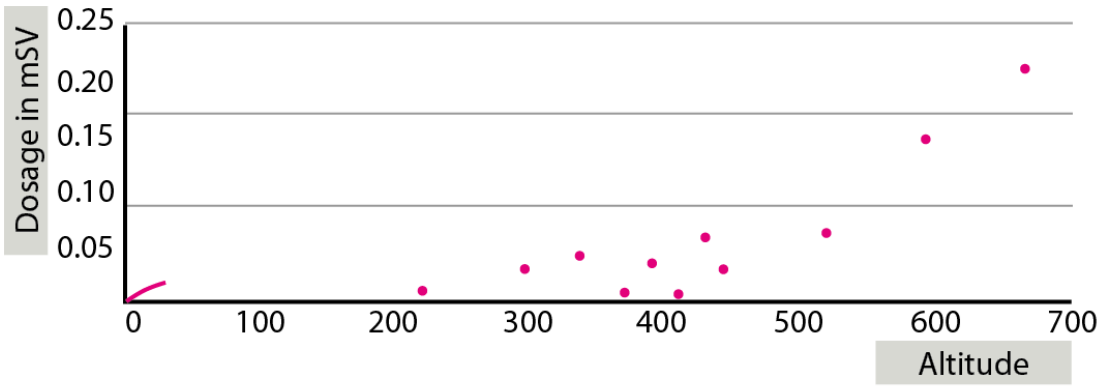

Figure 6-1: Equivalent dose at various altitudes
(CARI-6, 2004), (Bottollier-Depois et al, 1996), (Axelsson, 2006), (Gautam & Badhwar, 1999), (Akopova et al, 2005)

Figure 6-1 shows the radiation dose at a variety of altitudes. At around 500 km the dose is around 0.05 mSv/hr which suggests that a pilot could conduct about 800 flights per year of 30 minutes each before exceeding the occupational dose, but at 700 km a pilot could only fly 200 times a year. It is important to note that solar particle events, which occur about ten times in a year, could increase these figures dramatically. Importantly the dose for a suborbital flight below 500 km are below the dose an equivalent commercial aircraft flight would receive during a flight of the same distance, due to the large difference in flight time. Flights above 500 km that penetrate the inner Van Allen belt, and flights during SPEs would increase doses dramatically.

Table 6-1: A comparison of doses on aircraft and suborbital transportation systems

Route	Aircraft Flight Time	Equivalent Dose	Suborbital Flight Time	Equivalent Dose
London - New York	7 hours	0.042 mSv	28 min	0.023 mSv
New York - Tokyo	14 hours	0.083 mSv	42 min	0.035 mSv

During periods of elevated solar activity The US National Oceanic and Atmospheric Administration (NOAA) issues a Solar Radiation Alert; this identifies certain routes and altitudes to be precluded from scheduling, in order to limit radiation exposure to humans, and communication interference. Last minute forecasting, however, leads to scheduling inefficiencies and reduced revenues.

6.2.3 Space Debris

Space debris is the term for non-functional man-made objects that exist in space. It ranges from entire defunct satellites to tiny flakes of paint, all of which travel at a velocity of approximately 7 km/s. The atmosphere imparts drag on slow-orbiting debris and forces the debris to reenter so that the debris density changes with altitude. There are also particular orbits that, due to various historical events, have a higher debris density than normal. The effects of a collision with a piece of space debris vary between sub-millimeter debris that will cause some damage, to a collision with a object greater than 5 cm that would be likely to destroy the space vehicle. Currently space debris greater than 10 cm can be tracked and avoided, but smaller pieces remain a hazard. Although not strictly debris, micrometeorites impact Earth's atmosphere in substantial numbers and they are normally taken into account in any density calculations.

Several short and long term models exist to predict the trends of space debris. NASA has developed an engineering model called the Orbital Debris Engineering Model. ORDEM 2000, however, is not the optimal tool for predicting future debris patterns. To address the development of debris over time, NASA has created the one-dimensional orbital debris evolution model, EVOLVE, and the three-dimensional LEO-to-GEO Environment Debris model, LEGEND. These models take into account historical launches, explosions, and collisions. The models can profile altitudes and estimate probabilities of collisions. ESA has developed the Meteoroid and Space Debris Terrestrial Environment Reference (MASTER) reference model to characterize space debris. Figure 6-2 shows a graph of space debris density for all objects that are large enough to do significant damage, but too small to be tracked, in a cubic kilometer for a one hour period that has been calculated by MASTER. It should be noted that space debris is currently increasing, and all models show that it continues to do so over the next decades.

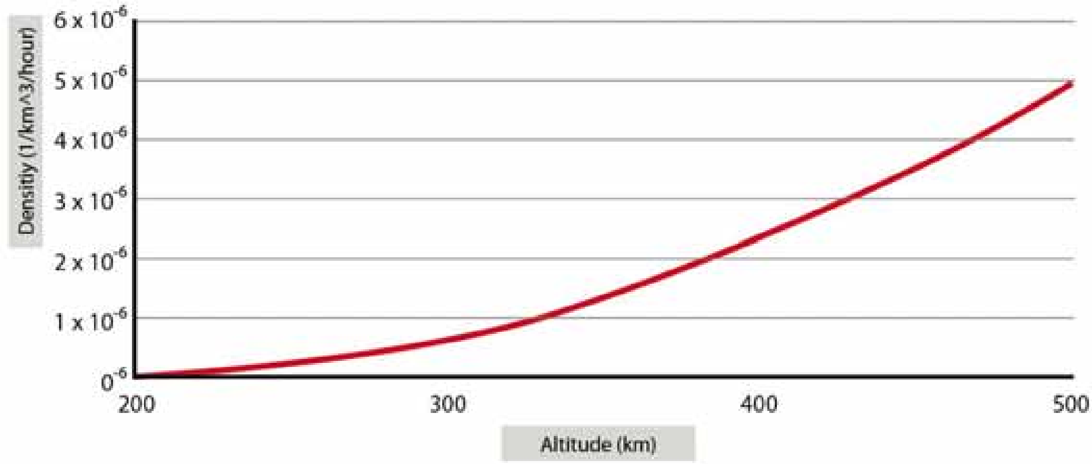

Figure 6-2: Density of debris between 5 mm and 10 cm

Currently space debris tracking capabilities are not widespread, and are primarily under military control. They exist in the US, Russia and lately in Europe and China. Operators will have to ensure that they have an adequate source of up to date information from models and from active tracking. In the US, a launch licensee is required to consult with US Strategic Command, who track debris, about their trajectory if they intend to go higher than 150 km.

6.3 Passenger Safety

The task of assuring the in-flight safety of passengers begins long before the actual flight. It starts right from the conception of each mission, and in this case each flight is considered as a separate mission, to the post-flight phase. Important considerations include the design of the spacecraft and ground operations, the potential screening, selection and training of crew and passengers, choice of flight profile, and other factors that would have a bearing on the physical and mental readiness of all individuals involved in the mission to cope with real and potential hazards of spaceflight.

6.3.1 Medical Requirements

The passenger requirements should be the same as any other commercial flight in terms of qualification and health. Depending on the main trajectory parameters, the seat placements, the attachment systems, the emergency masks or pressurized suits and the cabin hygiene systems will be lighter or more complex. Good spacecraft design, and low g-forces, could allow the operator to avoid the medical screening and testing required for suborbital tourism flights. Section 7.2.4 covers liability in greater depth, but it is unlikely that waivers and informed consent would be acceptable for a transportation service. As can be seen below if these systems are in place and applied then the operator will have difficulty attracting customers.

In many respects, based on adopted regulatory standards, it is expected that a number of the aircraft safety requirements for transatlantic flights would be similar to what would obtain in these PTP flights. However, considering the possibility of different flight profiles, it is necessary to ensure that the aircraft and passengers are fully prepared to go through the associated stresses of PTP flights. Thus the following is expected:

- A healthy and well-trained crew
- Passengers that are fit enough to cope with the stresses associated with the flight
- Sufficient onboard and ground medical capability to cope with emergencies

Should these flights be operated under current FAA requirements, including the informed consent system, medical screening is not required for passengers; however, medical screening may become necessary if the flight profile dictates that passengers would be exposed to risky G loads during flight. Selected passengers however may not be tested prior to every flight. In this case it would be sufficient to have the passengers produce some sort of recent (up to 6 months) medical fitness report as part of the informed consent to be obtained from them before they embark on the flights. The necessary requirements for such a report and details of the informed consent procedure could be made available routinely and as early as possible as part of the booking procedure. The risk due to radiation should also be clearly stated in these forms. Thus, the operators should ensure that they have a detailed list of conditions that would restrict a passenger from flying, clearly stated in a waiver of liability and/or consent form to which a passenger is expected to agree to, after having read it with the opportunity of asking questions from the operator. This should serve as a means of screening the passengers and also aid in relieving the operator of liability if something goes amiss. The expected duration of exposure to microgravity is not likely to be long enough to pose any major difficulty. Table 6-2 below, modified from Adebola (2008) suggests details that could be integrated into the informed consent form to cover for the medical and emergency care implications of suborbital flight.

Guidelines for selection could be based on the Aerospace Medical Association (AsMA, 2001) guidelines and other relevant research like Dr Karim's (Karim, 2005). These are meant to serve as guidelines having covered in detail the different requirements from the medical perspective. They offer 'select-out' criteria based on likely medical conditions or physiological and psychological problems that could pose a threat to the passenger and others during the flight.

Table 6-2: Information for passengers and consents to be obtained before flight (Adebola, 2008)

Organization	Information to be given and consent to be obtained
Federal Aviation Administration	Known risk for injury, death, disability total or partial loss of physical and mental function, and existence of unknown risk
	Existence of unknown hazards
	U.S. government's non-certification of vehicle safety (if not certified)
	Safety record of all launch and reentry vehicles for humans
	Safety record of operator's launch vehicle
	Right to request additional information about human space flight
	Right to ask questions orally before giving written consent
Emergency Medical Care	State of available medical care facilities onboard, on ground and of specialist care within the vicinity of the 'spaceport'
	Legal and cost implications of disqualification if the passenger is found to be unfit before the main flight, even if flight has been booked, and consent to emergency care for the passenger in such situations.
	Quality of medical personnel and telemedicine infrastructure attached to the mission
	Consent to carry out any emergency procedure deemed necessary
	All possible emergency procedures, their attendant risks and possible complications.
	Consent to transfer to any medical facility
	Consent to allow any medical personnel at the spaceport and at any other facility to which passenger may be transferred to treat them
	Consent to have any medical intervention carried out on them by any medical personnel at such facilities.
	Passengers should state the individual(s) who will be responsible for making decisions for them if they become legally unfit to do so
	If there is no designated person, or the person cannot be reached consent be given to the operator to make all necessary decisions
	All costs for emergency medical care and all other complications will be borne by the passengers or his family, unless due to gross negligence or intentional harmful action on the part of the operator.

6.3.2 On-Board Medical Facilities

It is appropriate to state that what is required is that the medical support for such paying passengers on space flights should be sufficient to satisfy the requirements for a safe and sound space trip. So apart from what is described in the Environmental Conditioning and Life Support System (ECLSS) below, it would be necessary to ensure that there is a capable medical infrastructure which would serve to handle any medical emergencies that may occur onboard. It should also be deemed necessary for flight operators to ensure that they have standard onboard and ground medical capability as much as is deemed to be commensurate with the estimated risk of the flight to passenger and crew safety. This may require, if necessary, the presence of a trained paramedic on board. There may not be a need for direct physiological monitoring of passengers yet there should be the option of being able to communicate directly with an in-flight attendant or voice communication with medical personnel on ground (Adebola, 2008). In 2004, the FAA in the US recommended an enhanced emergency medical kit (FAA, 2004), the contents of which were clearly stated, be mandated to be carried aboard all flights on which a flight attendant is required, and without which no one should operate an airplane. Moreover, these kits are already in commercial production and a customized medical kit has likewise been proposed for suborbital flight, taking into consideration the relatively short duration of the flights and the mass constraints of rocket-launched spacecraft. It might also be necessary to have vomit bags available for those who are likely to react during the flight (Adebola, 2008). Considering the fact that a selection process was not carried out in getting passengers, it would be necessary to make the investment of having an up to date medical kit on board to cater for any emergency medical event in spaceflight. However in view of the fact that the medical requirements for airlines differ from country to country, it might be required that this issue also be considered when making agreements and regulations for the international operation of PTP suborbital flights.

6.3.3 G-force Tolerance

One of the most important medical issues is that of dealing with the g-forces expected to be present on a suborbital flight. Suborbital tourism operators expect g-forces of +3g at the start of the ballistic phase and up to +6g during reentry. These levels of g-force require comprehensive selection and training regimes that would be unacceptable for a transportation business. It is therefore imperative to employ methods to keep g-forces low. The tolerance of a healthy individual to the level of g-forces, and their duration, is given in Figure 6-3 below. It contains data for positive and negative g-forces in both the head to foot (Gz) and back to front (Gx) directions. It is important to note that "tolerance" is interpreted as any condition short of unconsciousness, involuntary convulsions, or extreme pain (Chambers, 1963).

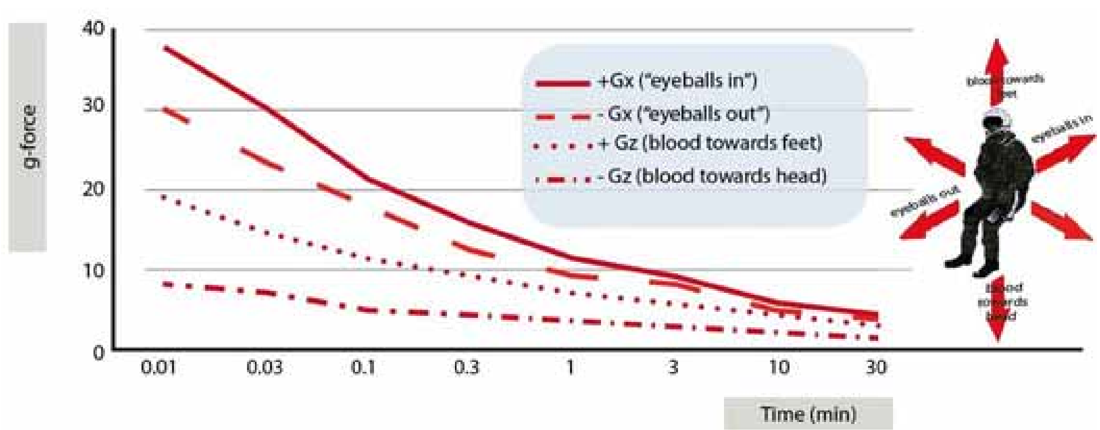

Figure 6-3: Average g-tolerance in four vectors of sustained acceleration

(Chambers, 1963)

A description from Fraser (1966) gives a flavor of the conditions expected at 4.5 – 6.0 Gz – "Diminution of vision, progressive to blackout after about 5 seconds; hearing and then consciousness lost if exposure continued". The same document indicates that 2.0 Gx is tolerable to at least 24 hours and 2.0 Gz is described as "Increase in weight, increased pressure on buttocks, drooping of face and soft body tissues" which suggests a reasonably tolerable experience.

From these studies it seems reasonable to suggest that the average passenger should not be subjected to g-loads greater than 3.0 +Gx and 2.0 +Gz, and that the period of exposure to these maximum g-loads should not exceed thirty minutes. It is assumed that the increased g-loads would occur during ascent and reentry, in which case the levels and duration should be limited to ensure that the range of exposure remains within the acceptable limits for the average population, and as close to routine commercial air transport as possible. As g-tolerance is greater when the forces act in the Back to Front (Gx) direction it is also a useful suggestion to have seats that would automatically adjust the posture of the occupants to compensate for the effect of the g-forces.

6.3.4 Training

Training can range from lengthy training as required by orbital tourists to the briefings given by airlines to their passengers (how to use seat belts, lifejackets etc). Suborbital tourism companies plan to include a 2-5 day training program. The main drivers that increase training are: being able to un-strap in microgravity, the levels and duration of g-forces, and the concept chosen for the suborbital vehicle. Other features that would reduce any training requirement further are the provision of cabin crew and good design of the cabin, life support systems, and emergency systems.

If passengers are to be allowed to free-float during the microgravity phase then they must be adequately trained for it; specifically, in particular they must be capable of returning to their seats prior to reentry. If g-forces are high enough passengers must be trained in the anti-g straining maneuver and possibly pressure breathing techniques. They would also require undergoing a selection procedure. If this is impossible to avoid then some form of training certificate, indicating that training has been completed and how long ago it was conducted, should be developed.

However, considering that the primary benefit of PTP suborbital transportation is the reduction in travel time over a large distance, this characteristic will likely preclude customers from undergoing a significant training process to shorten time from door-to-door. In fact, any training requirements should be limited to pre-departure airline style briefings. This necessarily eliminates free movement about the cabin during the period of microgravity. Increasing the mobility of the passengers during flight will only increase the required amount of training and overall trip duration.

A jet powered takeoff and landing concept with low reentry g-loads, in which passengers were not allowed to un-strap during microgravity would probably only require airline style briefings to ensure adequate passenger safety.

6.3.5 Environmental Control & Life Support Systems

The nature and the complexity of the ECLSS for human space flight are determined by the nature and duration of the mission. However for ultra-short space flights like PTP flights that are expected not to last longer than a couple of hours, it is expected that the specifications would be determined largely by the biological requirements of the passengers, the flight environment and the flight profile. Aircraft life support systems are open loop systems utilizing hot, high pressure, air bled from the jet engine compressors that is then cooled using turbines and atmospheric air to the appropriate temperature. The conditioned air is then fed to the cabin where it provides temperature control. The conditioned air is at high pressure which allows pressure control to be conducted simply by venting excess pressure through special valves to the outside. Water and emergency oxygen are stored on board and used as required, and waste is stored until landing. This system relies on the presence of the atmosphere to function.

ECLSS systems on early short duration space flights, such as Mercury and Gemini, used an open loop system that provided oxygen and water, and removed carbon dioxide. All the requirements and the waste products were stored on board. The Mercury system had two sub systems; the suit system which, controlled temperature, humidity, and the astronaut's oxygen supply but in normal use was not pressurized in flight, and the cabin system, which controlled cabin ventilation, temperature and pressure. Waste was extracted through an umbilical cord and stored on board. (NASA, 1994)

Some crucial aspects that would require attention in designing the ECLSS for a suborbital transportation system include:

- Thermal control
- Pressure regulation
- Humidity control
- Air/Oxygen provision and Carbon Dioxide removal

Standard aircraft systems can be used during the conventional phase of flight, including toilet facilities but during the suborbital phase, when no atmospheric replenishment can occur, the ECLSS system will have to rely on resources stored on on-board. Emergency equipment has to be as light as possible since the price per kg of payload will be much higher than for commercial aircraft. All safety devices can be minimalist and lighter since the flight time is shorter, for example a one hour flight may not require toilets or a galley.

6.4 Vehicle Safety

It is obvious that no space vehicle can ever be 100% safe; however it is expected that the level of safety of these vehicles would be as close as possible to what presently applies to airlines. To accomplish this, both national and international standards, discussed here, have been put in place to aid in the certification of these vehicles. Issues of survivability are also to be given proper attention to properly cope with emergencies. The interior design aspects also contribute to in-flight safety and survivability and thus also require particular attention.

6.4.1 Vehicle Certification

Certification, in terms of transportation, is the process of confirming that a vehicle conforms to a standard. In civil aviation, certification of an aircraft's design by a national aviation authority is a requirement for that aircraft to conduct international flights and the certification process has developed into a robust mechanism to ensure safety. For state aircraft and spacecraft, certification is not required under international law but invariably some form of certification process is applied. An alternative to certification is licensing, which is permission from a competent authority to conduct an activity.

Currently, in the US, most civil space vehicles, including suborbital Reusable Launch Vehicles (RLVs) are regulated through the FAA's licensing regime. The one exception is the Space Shuttle, which has a certification process set to a NASA standard and which is re-certified for each flight. Most aircraft are certified in one of a number of categories, for example Transport, Acrobatic and Utility categories. For the suborbital tourism industry the current licensing regime provides a less costly alternative to certification. For example, Burt Rutan, in an interview to

Aviation Week, (Dornheim, 2003) estimated that it would cost USD 100M to USD 300M to gain a certification for SS1 to carry passengers. Transportation operations are required to bear less risk than adventure travel so certification may be the appropriate safety mechanism. For international travel certification is likely to be a requirement.

For the Concorde, a special certification regime was developed by France and UK for the flying airworthiness certification which included the most extensive test program for any civil aircraft, carried out two years of ground testing and over six years of flight testing. For PTP suborbital transportation it is possible to create a separate certification category, but in any case the testing required to support certification is time consuming and costly.

The aircraft certification and testing process must be progressive and suitable for the technologies used in the vehicle. Even though there is currently no certification legislation for suborbital vehicles, the certification procedure should include test and verification of the activities listed in Figure 6-4.

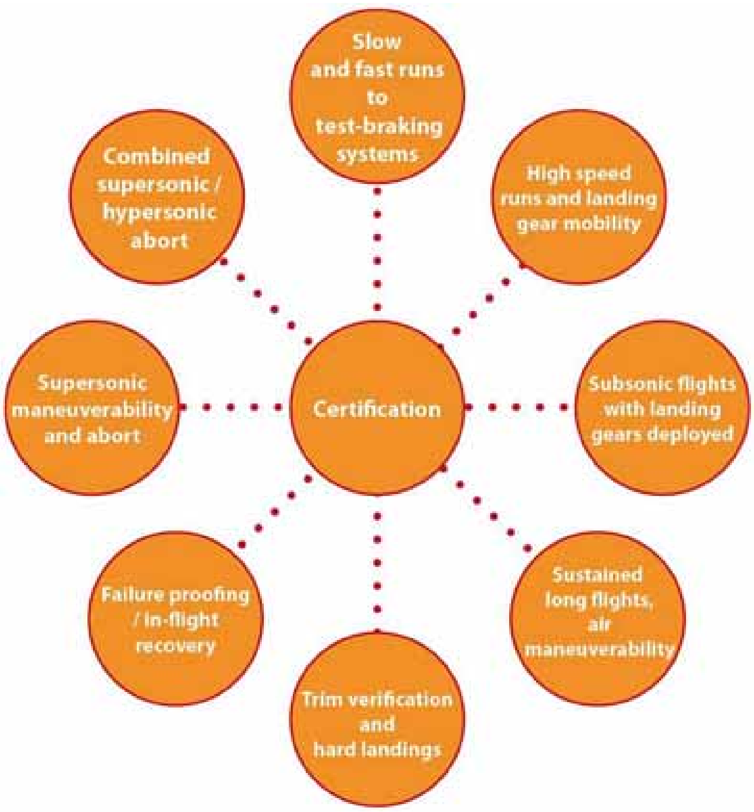

Figure 6-4: Vehicle certification

For international aviation, standards are mostly interchangeable, with the two major certification agencies, the FAA and the European Aviation Safety Agency (EASA) publishing standards that are almost identical. Other nations will normally follow these two standards when publishing their own certification standards. With the exception of some joint and international standards, manned spacecraft standards are normally set by the agency conducting the flight. The US regime for RLVs uses licensing to provide safety for the uninvolved public but currently does not provide safety standards to protect the passengers, although they benefit from the measures put in place for the uninvolved public.

Table 6-3: International safety standards for aviation and space activities
Sources indicated in table

	Air	Space	US Licensing Regime
Primary Document	Chicago Convention, 1944	Outer Space Treaty, 1967	Title 49, United States Code, Chap 701
International Requirements	Certification Required under Annex 8 of the Convention on Civil Aviation (does not apply to state aircraft). Certified aircraft can fly in other states airspace under the convention.	No International Mandatory Safety Standards	Applies to Launches from US territory and by US persons anywhere in world. Currently interim legislation until 2012
National Requirements	National Authorities publish certification standards for aircraft registered in their territory. Numerous agreements for states to recognize other states certifications.	Normally National authorities issue launch licenses that incorporate certain standards. For unmanned vehicles these standards protect the uninvolved public	Launch site and launch operations require licensing. This can be for a series of launches. The current legislation only protects the uninvolved public
Other Standards	State (normally military) aircraft have unique certification standards, a variety of permits, licenses, and experimental permits cover aircraft not intending to fly outside of the state	International Standards Organization (ISO) 14620 Space Systems standard covers system safety, launch site operations, and flight safety systems. European Cooperation for Space Standardization has published standards. Joint standards have been developed for the International Space Station	Permits allow for testing and crew training but cannot be used for revenue generating flights. Space Shuttle and military launches have different certification standards Unguided suborbital rockets have reduced requirements.

6.4.2 Abort Procedures

The ability to intentionally terminate a flight in a safe manner is important. Although a vehicle can conduct an abort in the absence of any failure, due to weather, for example, in public air transport much emphasis is placed on engine failures and the general requirement is that the aircraft can make a safe landing if an engine completely fails. This is primarily done through redundancy, by using more than one engine, and through operational procedures, for example by prohibiting lengthy flights over water. As aircraft engines have improved their reliability, procedures have changed, for example prior to 1964, transatlantic flights required four-engine aircraft, and required three engines up to 1985, whereas nowadays the vast majority of transatlantic flights are conducted with twin engine aircraft. This has been made possible by the improvement in engine failure rates to less than 2 failures in 100,000 hours.

The early years of manned space flight abort procedures have been primarily concerned with a launch pad explosion, with the preferred procedure being to use a launch escape system to separate the crew capsule from the launcher. Ejection seats have also been used on some designs. Medium level aborts result in a parachute descent to an unprepared site. The Space Shuttle has no launch abort capability but its maneuverability allows for a medium level abort either returning to its launch site or to a pre-designated transatlantic landing site. In the event that the Shuttle cannot make a runway, the crew can, in theory, manually bail out.

Abort procedures for air-launched suborbital spacecraft can consist of a return to base while still in captive carry or, in the case of a rocket failure, a glide abort. During its test program SpaceShipOne returned to base in captive carry flight on one occasion after a glide test was abandoned. The X-15 program conducted numerous captive carry and glide aborts for a variety of technical reasons including situations in which unused fuel was jettisoned prior to a glide landing (Jenkins, 2000).

Table 6-4: Abort Procedures for various suborbital concepts

	Vertical Launched Parachute Landing	**Horizontal Launch Powered Landing**	**Air-Launched Glide Landing**
Captive Carry	N/A	N/A	Return under captive carry, or release and conduct glide abort to prepared site
Rocket Explosion	Launch Escape System	Possible catastrophic damage, otherwise return under conventional power, possibly after a short ballistic phase	Possible catastrophic damage, otherwise glide abort, possibly after a short ballistic phase
Rocket ignition Failure	Crew egress on launch pad	Return under conventional power	Glide abort to prepared site
Rocket stops early	Abort to unprepared site (or ocean) under parachute	Some ability to return under conventional power if fuel available	Abort to unprepared site (or ocean) with a glide landing
Ballistic Phase ends with spacecraft off course	Abort to unprepared site (or ocean) under parachute	Some ability to abort under conventional power if fuel available	Abort to unprepared site (or ocean) with a glide landing
Destination site not available due to weather	Parachute descent into unsuitable weather conditions	Conventional abort to a pre-prepared alternative site	Some capability to glide abort to a pre-prepared alternative site

6.4.3 Interior Design Considerations

The interior layout of the vehicle must be planned with the safety of the passenger foremost in the mind of the designers. Very little data exists on the optimal configuration of the interior, but a recent study by Doule (2008) was conducted on this subject. Table 6-5 contains a summary of Doule's design considerations across several interior environment factors.

Table 6-5: Vehicle interior design considerations
(Doule, 2008)

Microgravity
Principles for releasing and restraining of the passengers
Interior arrangement to allow or restrain movement of passengers in microgravity
Placement of lightweight bags for personal needs should be considered
Soft materials should be used for interior coating
Interior safety
Six or four point seat belts for higher security (shown in Figure 6-5)
Acceleration sickness has to be taken into account due to the possible high g-load
Control of all the allowed floating objects should be considered
Noise & Vibration
SoftRide vibration isolation systems using UniFlex Isolators
ShockRings
Dash-Zero suspension gravity systems
Airborne Stabilization/Vibration Isolation Systems
Noise cancellation device
G-loading
Musculoskeletal problems can be avoided if the position of the passenger's body is stabilized during acceleration or deceleration
Head, neck and spine should stay in a fixed position during high Gx exposure and supported by the rigid structure of the seat
Passenger well-being
General preference of dark and quiet space can be supported by adjustable environment of passenger seat
Motion sickness can be mitigated by fixing the head in one position
Recommended restraint system is composed of two shoulder belts and a lap belt
Seat design
Rigid contour body support system
Slight contouring to support body position
Dimensions that accommodate large variations in body size
Padding against vibration and impacts

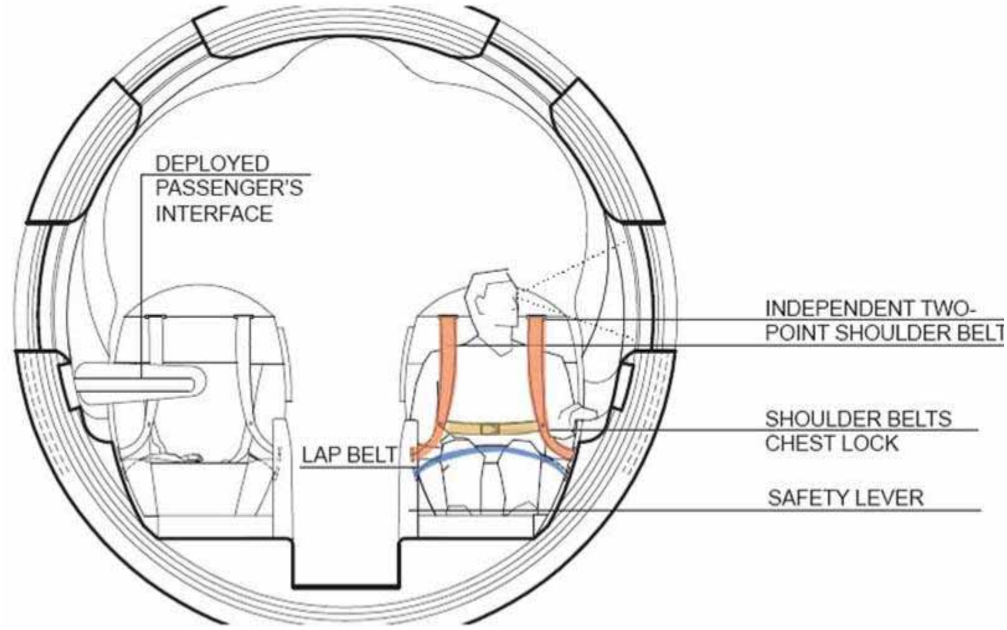

Figure 6-5: Six-point concept for seat restraining system
(Doule, 2008)

6.5 Conclusions

Historically, the main reliability issues are with the propulsion systems and thermal protection both of which can be overcome by increasing the margins under which they operate. Further improvements will be possible through the experience gathered if there are high flight rates and many launches. It will be challenging to create the 0.999 reliability that is required for air transportation, and probably impossible without more design heritage from other reusable vehicles, perhaps from suborbital tourism or orbital flights.

The ability to accurately characterize potential in-flight hazards will enable optimization of operations in many areas. Accurate information will guide the design of spacecraft, scheduling of flights and assessment of future risks and other criteria. Knowledge of the space environment is an important factor to enabling spacecraft designs that will reduce operational difficulties. Apart from the weather problems that all flying vehicles have to deal with, suborbital vehicles have two additional issues, radiation and space debris. While radiation doses on suborbital flights will be less than a journey of the same distance on an aircraft flight, suborbital flights are much more vulnerable to SPEs than commercial jet flights. Operators must obtain proper warning of hazardous events, perhaps through a service such as NOAA's Space Weather Alert. The monitoring of radiation on-board, and prediction of crew doses, will also be a regulatory requirement. Space debris is a hazard that exists in low levels at the altitudes expected to be used, but for the debris that are less than 10cm and cannot be tracked the only mitigation is in the vehicle structure. For larger debris, tracking capability will need to be utilized to ensure safe operation. As space debris is continuing to increase it is important to take this into account as there may well come a time when there is too much debris to contemplate large scale passenger suborbital operations.

Passenger safety is important and it is unlikely that a transportation service would be considered suitable for a system of waivers and informed consent. Consequently the vehicle has to be designed to allow the greatest range of passengers to safely travel. This can be accomplished by minimizing the g-forces passengers will be subject to and good design of on board safety systems. If additional requirements are forced on passengers then a system of carrying out early paperwork at the moment of booking, and "frequent flyer" status can mitigate the pre flight procedures.

Any mechanism short of full certification is unlikely to be acceptable for routine intercontinental flights. Neither the passengers nor the States are likely to accept an uncertified passenger spacecraft. The certification process will probably involve the creation of a new category in the aviation certification system and will be a lengthy, expensive procedure. Abort capability is essential for the safety of the passengers and will depend on the choice of concept. A system that uses its own power to takeoff and land can support the greatest range of abort scenarios across the phases of flight.

7 LAW & POLICY

Legal and political considerations are fundamental to the establishment of any emerging industry. Without governmental support and the necessary regulatory authority, even the most innovative of ideas rarely develop to commercial levels, particularly those involving new technology or hazardous activity. This chapter aims to assess the role government can play in starting or stimulating the development of PTP suborbital transportation and assess whether or not the industry will benefit from concerted international effort.

7.1 Role of the Government

The role of the government in the establishment of a new industry is to help its private sector to develop and encourage the growth of domestic economies. Consequently it is necessary to create the proper environment nationally and foster relations internationally to achieve the economic objectives. With regard to the aviation industry, the government's role has been mainly directed towards developing rules for the creation of the sector, for national and bilateral policies to avoid the monopoly of the market, and for safety and environmental issues (Den Braven, 1998). The space industry, however, has not optimized its pace of commercial growth. Though a government's role includes legal responsibility for authorizing and supervising private space activities, the government is often slow to promote development within the private sector. This conservatism may be derived from history, as space exploration has traditionally been conducted as a public activity, and States are internationally responsible and liable in the event of damage. Issues of national security are also drivers for policy decisions as a State places the protection of its citizens as one of its highest priorities. Consequently, restrictions may be instituted that, as a secondary effect, hinder industry development.

7.1.1 Example of International Cooperation: Concorde

Concorde provides an example of international cooperation intended to support domestic economies. The French and UK governments issued an intergovernmental agreement in 1962 with the purpose of developing and manufacturing a supersonic aircraft. One year later, Concorde was introduced to the market as a French-British aircraft. The next step for the two countries was not only to obtain support from other governments but to persuade domestic companies to continue the project. The UK government established regulations and financially supported the construction of Concorde. The government was concerned with critical technical details, including: landing distance, engine development, subsonic performance, payload capacity, and range (Owen, 2001), while requirements on the operation of the Concorde were left to the private sector.

7.1.2 Application to PTP Suborbital Transportation

The role of government on national and international levels with respect to PTP suborbital transportation includes (Freeland, 2004):

- Ongoing Governmental Support
- Analysis of the international political and economic environment
- Improvements to the aviation industry
- Promote private sector initiatives

- Create an appropriate governing authority to license and regulate
- Create adequate rules and regulations to provide: clarification of the status of vehicle and activity, reasonable safety protection and qualifications for passengers and crew, and reasonable liability and insurance protection for passengers, crew, and third parties
- Enter into, or promote, strategic alliances and cooperation for: vehicle or technology development and negotiation of viable routes

It is clear from aviation history and national perspectives that the style of regulation ranges from extreme governmental involvement to the liberalization of the industry. Typically, a balance is made between the protection of the public, and the ability of industry to innovate.

Based on the reciprocity principle, bilateral agreements are conceived on the notion that mutual benefits are achieved on both sides. Typically, States jealously guard their space launch technology, however, as landing rights in another state must be granted, joint vehicle development may be attractive. This is a serious issue, particularly for the US where the issue of export controls is an almost insurmountable challenge. An exception can be observed in the Technical Assistance Agreement reached between Virgin Galactic (UK) and Scaled Composites (US) to establish the SS2 concept; cooperation is possible, though Adlen (2006) argues that this agreement was approved to promote a US objective to corner the fledging space tourism industry.

7.2 Legal Framework

Point to point suborbital transportation is still a conceptual activity without a regulatory history, and deliberation on the basis of a legal framework is necessary before the flights can commence. The main difficulty with respect to a legal regime for PTP suborbital transportation is that no consensus exists as to the classification of suborbital flight or the status of the vehicle that will conduct it. As there is currently no internationally accepted demarcation point between airspace and outer space, the classification of the vehicle as an air transport or a space transport remains in question and is fundamentally a matter of policy. A functional approach to the demarcation issue would suggest that this is air travel as outer space is simply used as a transit area in between two points on the Earth's surface, while a spatial approach would argue that the nature of travel is by air in the airspace and by space in outer space. Other views are either arbitrary or based on technological factors such as vehicle design, launch and landing configuration, and utilization of a conventional runway, which may generate a greater bias to air travel or space travel (Diederiks-Verschoor, 1999). As the boundary between airspace and outer space, if ever defined, would mark the limit of a States' sovereignty it is likely that any demarcation decision would be taken on political grounds.

It is therefore necessary to analyze both Air and Space Law regimes, assess the suitability or each regime and its applicability to PTP suborbital transportation, and determine if the Air Law regime, Space Law regime, a combination of both, or a completely new regime is needed to ensure that operations can unfold without legal ambiguity.

7.2.1 General Principles

In order to establish a PTP suborbital transportation legal model, it is natural to start with the general principles. Table 7-1 and Table 7-2 summarize the main relevant points and definitions that exist under Air Law and Space Law. This figure is followed by a description of the US regime, which can potentially serve as a baseline for a PTP suborbital transportation legal framework, and the Swedish regime.

Table 7-1: General principles of space law
Sources indicated in table

Principle	Information
Legal basis	Outer Space Treaty, 1967. Applicable to space objects
Definition of space object	Includes component parts of a space object, as well as its launch vehicle (Art. 2, Liability Convention, 1972)
Fundamental principles	Freedom of access implies the right of innocent passage to enter and exit space, though some States oppose this notion (COPUOS, 2005) Exploration and use of outer space for the benefit and in the interest of all countries No international regulatory standards
Responsibility and liability	States are responsible for national space activities and liable for damage caused by space objects under their jurisdiction. Private entities are subject to authorization and supervision of the State (Liability Convention, 1972)
Landing Rights	In case of unintended landing, the landing state must ensure protection and return of astronauts and space objects back to their national territory (Rescue Agreement, 1968)

Table 7-2: General principles of air law
Sources indicated in table

Principle	Information
Legal basis	Chicago Convention, 1944. Applying only to civil aircraft
Definition of Aircraft	Any machine that can derive support in the atmosphere from the reactions of the air other than the reactions of the air against the Earth's surface (Annex 7, Chicago Convention, 1944)
Fundamental Principles	Supreme and exclusive sovereignty of States in the airspace above their territory. Right of innocent passage applies to civil non-scheduled flights only. States may require such flights to land International Air Services Transit Agreement (IASTA, 1944) extends innocent passage to scheduled flights International Air Transport Agreement (IATA, 1944) Allows aircraft to embark and disembark passengers Bilateral negotiations for countries that have not ratified the IASTA or IATA International Standards and Recommended Practices applicable to all States
Responsibility and Liability	Contractual liability for damage to passengers and cargo owners (Warsaw Convention, 1929. Montreal Convention, 1999). Non-contractual third party liability on the ground (Rome Convention, 1952)

US Regime

The Commercial Space Launch Amendments Act (CSLAA) of 2004 made amendments to Title 49 U.S.C. Subtitle IX, Chapter 701, Commercial Space Launch Activities, to promote the emerging human spaceflight industry, clarify the FAA's regulatory authority, and establish the "informed consent" regime. Suborbital vehicles under the provisions are classified as launch vehicle and not an aircraft, so that they can be regulated separately. The CSLAA requires a phased approach to regulating commercial human space flight as regulatory standards should be dynamic to support the evolving industry. The following FAA rulemaking has amended US regulations in order to support commercial human space flight activities:

- Final Rule on Experimental Permits for Reusable Suborbital Rockets (April 6, 2007)
- Safety Approval Final Rule (September 14, 2006)
- Final Rule on Human Space Flight Requirements for Crew and Space Flight Participants (Feb 13, 2007)

The salient points of the US legal regime include:

- Definition of the terms: Space Flight Participant (SFP), flight crew, suborbital rocket, and suborbital trajectory
- Experimental vehicle permits in lieu of licensing to streamline approvals for the flight testing of new vehicles
- SFPs fly at their own risk and must sign reciprocal waivers of liability with the US Government and the FAA. Passengers must also provide written informed consent before the flight
- The FAA is prohibited from issuing regulations designed to protect SFPs unless a design feature, or operating practices, result in a human space flight incident, fatality, or serious injury to space flight participants during an FAA authorized flight. This restriction is in effect until December 23, 2012

Swedish Regime

Under the Ministry of Industry, Employment, and Communication, the Swedish National Board is responsible for licensing space activities in Sweden. In support of establishing a sustainable space tourism industry, analogous to the effort spearheaded by Virgin Galactic, Sweden is currently creating a regulatory environment similar to the US system in order to encourage commercial human space flight from its territory. Sweden seeks to classify suborbital vehicles as sounding rockets and apply the tax advantages of hot air balloon flights to the regime. There already exists a regulatory regime to cover Third Party Liability (TPL), which could apply to Virgin Galactic operations. It is still unclear, however, if European or Swedish regulations will apply to space tourism from Swedish territory, in light of the trend towards a more unified Europe (Spelding, 2008).

Application to PTP Suborbital Transportation

Upon analysis of State opinions and the current legal frameworks for Air Law and Space Law, there is no consensus as to how suborbital vehicles should be classified and how the activity of suborbital transportation should be regulated. It is a policy decision for States to determine the nature of the activity and identify the relevant departments responsible for regulating the activity. It is likely that interested States will initially develop their regime at the national level and—if the market demands it—evolve to an international model. The most advanced regime for suborbital transportation currently exists in the US and will likely lead the way to establishing an international model for the regulation of PTP suborbital transportation. It is unclear what the next phase for regulation will be after 2012, when new regulations can be enacted on the various aspects of this industry. Much of the regulation is dependent on how the vehicles develop. Sweden is taking steps to develop its regulatory regime for suborbital tourism.

7.2.2 Licensing & Certification

The certification and licensing procedures are interpreted by States to varying degrees due to their own national laws. The procedures for the certification and licensing of aircraft are outlined under the Chicago Convention; for spacecraft under the international space treaties; and for suborbital vehicles under the US special regime.

Certification is a process where details of a system are compared against a set standard. It is a costly and cumbersome process to certify a vehicle, but once it is done, the vehicle can be produced without recourse to further regulatory hurdles (ISU, 2007). Licensing differs from certification in that it is a permission to operate the system. This does not have to be in line with a set standard, thus it is not an entirely uniform process for each licensee. There will normally be regulations and guidelines, but these will not have the comprehensive detail required in certification standards (Foust, 2003). To determine the standard, it is necessary to asses the purpose of the vehicle and the role that safety plays. In the case of PTP suborbital transportation, the likelihood and probability of reaching the destination to deliver the payload must be acceptable. "Creating intelligent transport systems involves the use of advanced technologies to increase the efficiency and safety of transport operations"; transportation systems that can not guarantee a minimum standard of safety should perhaps not be classified as such a system (Black, 2003). A summary of these requirements is provided below.

Table 7-3: Certification requirements
Sources indicated in table

Air	Space	US Special Regime
Certificate of Airworthiness—Requirements under Article 30 of the Chicago Convention Minimum level of Airworthiness—Annex 8 of the Chicago Convention Certification applies to: airlines, airports, airmen, and noise	No international requirement for certification of spacecraft National Example—Russia has certification requirements for space objects, space infrastructure facilities, equipment for development, and use of technical space equipment Roskosmos-accredited agencies certify the equipment to ISO 9000 standards (Karizsky, undated) Preliminary quality estimate Organization and quality checkout and estimate Certified quality inspection checkout	No initial requirement for vehicle certification Unofficial report states that "Virgin Galactic will perform several test flights this summer and will need to be certified by the FAA" before official dates are made public (Spelding, 2008) Certification applies to: FAA second-class airman medical certificate, pilots, spaceports

Table 7-4: Licensing requirements
Sources indicated in table

Air	Space	US Special Regime
Crew and personnel license is required—Annex 1 of the Chicago Convention	Activities of non-governmental entities in outer space shall require authorization and supervision by the appropriate state—OST, Article VI National licensing and regulatory legislation for states who partake in space activities States with national licensing and regulation for private activities: Australia, Brazil, Belgium, Hong Kong, Norway, South Africa, Russia, Sweden, UK, Ukraine, and US	Launch- or reentry-specific license authorizes a specified number of launches or reentries with the same operational parameters of one type of launch or reentry vehicle operating at one launch or reentry site A launch or reentry operator license will allow an operator to perform multiple launches or reentries of the same or similar type of vehicle over a specified time period of up to five years A launch site operator license allows the holder to operate a facility from which spaceflights are made Experimental permits issued for research and development of new design concepts, new equipment, or new operating techniques; showing compliance with requirements as part of the process for obtaining a license; or crew training prior to obtaining a license for a launch or reentry using the intended design of the rocket

Application to PTP Suborbital Transportation

At this stage, the preferred system under US law is to grant experimental permits for vehicles undergoing flight testing. This commendable provision enables companies to test their vehicles with less stringent criteria and build up a flight history without risk to passengers. The provision goes to the heart of the development process as it encourages flight testing of the vehicle and could serve the basis for safety of PTP suborbital systems. The regulatory approach is modeled on the FAA approach to issue Experimental Airworthiness Certificates for experimental aircraft. The EAC reduces the regulatory burdens imposed by the launch license process by granting permits faster and with fewer requirements. The most viable way for vehicles to be used for PTP suborbital transportation is through certification. The Russian system of certification as outlined in Table 7-3 may serve as an initial model.

7.2.3 Right of Transit & Traffic

Under Air Law

Transit rights refer to the right of aircraft from one State to fly over or to make a technical stop in another State on the way to its final destination, which is granted to civil non-scheduled flights under the Chicago Convention. On first sight this right appears to make a ballistic overflight legal, however, the over-flown State is given the right to require the vehicle to land, which is impossible for a ballistic vehicle to comply with. Traffic rights refer to the right of aircraft to land and pick up or drop off passengers and cargo. States must agree bilaterally or multilaterally to exchange these traffic rights for the purpose of international air transportation. The Chicago Convention has established bilateral and multilateral rules of the road for air transportation.

The conditions for the traffic rights are agreed upon on a bilateral basis through intergovernmental instruments. These instruments are usually in the form of Air Services Agreements which covers the basic framework to grant airlines economic bilateral rights to fly between two countries. Operational issues including frequency and capacity are normally covered by Memorandums of Understanding (Haanappel, 2003).

Under Space Law

Current International Space Law does not include regulations for commercial traffic in or through space except as far as it relates to astronauts and space exploration. It also does not specifically regulate the intentional return of space objects, through national or foreign airspace, except as provided for under the Liability Convention and Rescue Agreement texts, which suppose that "Only cases of accident, distress, emergency or unintended passage may constitute circumstances that preclude the wrongfulness of such passage" (COPUOS, 2005).

It has been argued that because most launches take place over the high seas or within national territory, there exists a customary right of innocent passage to and from space. It is contended, however, that States are not in agreement that this right automatically exists, and, up to the present, it has not been a significant issue (COPUOS, 2005).

Consultations & Notification

Security and safety concerns are a potential stumbling block to the multilateral acceptance of the innocent passage of PTP suborbital vehicles. States are becoming more protective of their skies, due to the fears spurred by 2001 terrorist attacks on the World Trade Center. The Russian space shuttle, Buran, flew just once in 1988 and deorbited over South America, flew over North Africa, and possibly reentered over Turkey before landing at the Baikonur Cosmodrome. It seems that no prior consent was sought or notification given to Turkey. Despite the apparent existence of a right of innocent passage, it is suggested that notification should be given if there is a possibility of entering foreign airspace to support diplomatic relations and ease concerns of national security.

In March 1990, the US communicated to the former USSR information regarding final flight stage of the Space Shuttle Atlantis. The information contained general flight and technical data. This action was performed out of courtesy a few hours before the event, and while this event did not establish precedent, it may serve as a basis for notification requirements (COPUOS, 2005).

Examples of Transit & Overflight Provisions

These examples of provisions can be useful in the creation of transit provisions for PTP suborbital vehicles.

- Under the Baikonur Rental Intergovernmental Agreement, the Main Principles and Conditions for Utilization of the Baikonur Launch Site contain provisions for transit rights of Russian vehicles (Omorova & Omorova, 2006).
- The Russian Federation has stated that a space object of a foreign State may make a single innocent passage through the airspace of the Russian Federation for the purpose entry into Earth orbit and outer space. The vehicle may also be permitted to make an innocent passage through the Russian Federation on its return to Earth, provided sufficient advance notice was given about the time, location, and path of such a flight (COPUOS, 2005)
- Article 20 of the Civil International Space Station Agreement Implementation Act has a provision for transit through the airspace of cooperating States

Bilateral Space Agreements

As under Air Law, it is proposed that traffic rights will need to be agreed upon bilaterally or multilaterally. This has never been established for commercial purposes, but below are examples of provisions that allow for bilateral landing rights between foreign jurisdictions:

Under Division 5, Sections 42 and 43 of the Australian Space Activities Act 1998, if a space object is proposed to be launched from a facility outside Australia and returned to a location within Australia, the Minister may give written permission authorizing the return of the space object to a specified location in Australia. This may be applied to a series of such returns that may be authorized by a single permission. This authorization may be granted subject to specified criteria and to any conditions that the Minister determines, including:

- The competency of the applicant
- Satisfaction of insurance/financial requirements
- Low probability of harm to the public
- National security and foreign policy
- Assumption of liability and indemnification for damage from foreign country
- Subject to provisions under agreement between the country

With regard to the US Space Shuttle, NASA has Transatlantic Abort Landing (TAL) Agreements that establish augmented landing sites in foreign jurisdictions, should the Shuttle fail to reach orbit. A transatlantic abort has never occurred, but would essentially be a PTP suborbital flight, with takeoff from and landing in separate jurisdictions. NASA currently has three active TAL sites, two in Spain at Moron and Zaragoza, and one in the south of France at Istres. The sites are strategically placed within gliding range of a Space Shuttle launched along NASA's standard trajectories. Figure 7-1 below shows current and historical TAL sites and a selection of launch trajectories.

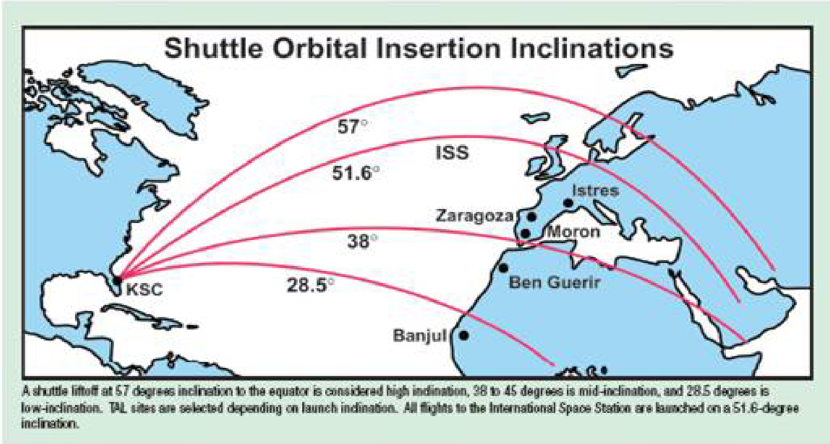

Figure 7-1: Space Shuttle TAL sites and typical trajectories
(NASA)

The Shuttle TAL procedure was incorporated into existing passenger airports in Chile, Gambia, Senegal, and Cologne/Bonn, proving that provisions can be made for space vehicles within existing aviation infrastructure. (Nakatani, 1997)

Application to PTP Suborbital Transportation

It is proposed that PTP suborbital transportation will likely develop on a limited bilateral basis, where individual countries or blocks of countries will enter into agreements to allow launches and landings. Worthy consideration should be made for the long term, towards the establishment of an international system to avoid a web of bilateral agreements.

It is also proposed that the US could negotiate with these TAL site countries for PTP suborbital transportation services to be integrated into their airports, as experience has already been gained in negotiating operational aspects of receiving a space vehicle. Interesting to note that there is no mutual gain in the current agreements between the US and developing countries, which would not be the case in commercial negotiation (Nakatani, 1997).

Under the Air Law regime, the ICAO Template Air Services Agreements can be accessed at http://www.icao.int/icao/en/atb/epm/Ecp/Tasa.htm which contains a comprehensive framework for air services agreements, including provisions based on the traditional, transitional, and liberal approaches to various elements of the agreement as discussed above. Such provisions could be analyzed alongside provisions of the TAL agreement as a basis for PTP suborbital transportation.

7.2.4 Liability

Liability rules are among the most fundamental concerns with respect to commercial activity because all parties must be aware of what their obligations, rights, and remedies are before engaging in an activity. Clarification is even more important when the risk of damage occurring increases.

Under Air & Space Law

The standard of liability can either be fault based, strict, or absolute. Strict, or absolute, liability refers to an activity where proof of damage as a result of the activity is enough for culpability and there is no need to establish fault. Fault based liability means the claimant must prove that the damage caused was due to the defendant's negligence or committal of a wrong. The level of liability can be classified as limited or unlimited, which refers to the existence, or otherwise, of a cap on the amount of damage that can be paid. State Liability refers to compensation for a State's breach of its international obligations vis-à-vis liability of private entities to compensate for damage caused by their activity. An ideal liability regime for damage applicable to suborbital transportation vehicles carrying passengers and cargo must account for the following situations outlined in Table 7-5:

Table 7-5: Air and space liability regimes
Sources indicated in table

International Air Law Liability Regime	International Space Law Liability Regime
Scenario 1: Damage caused by collisions	
No direct provisions for collision of aircrafts with other aircrafts Likely to be based on fault under national law	Treated under OST, Article II Unlimited fault-based liability for collisions with other space objects Unlimited absolute liability for collisions with aircraft in flight No claims
Scenario 2: Damage caused to third parties on the Earth's surface	
Treated under the Rome Convention 1952 & Protocol 1978	Treated under Liability Convention, Article II
Applicable to liability caused by foreign aircraft to third parties on the ground Limited liability depending on size of vehicle Unlimited liability for damage caused by deliberate act, omission with intent, or unlawful flight Strict liability standard No compensation if damage is not a direct consequence or results from fact of passage of the aircraft Low history of third party damage claims National law will apply if damage is caused by a national aircraft	Applicable for liability of the launching State The term "launching State" means: (i) a State which launches or procures the launching of a space object; (ii) a State from whose territory or facility a space object is launched (Article I) Unlimited liability and absolute liability: no need for fault No liability if: a launching state establishes that the damage as resulted from gross negligence or from an act or omission with intent on the part of the claimant state (Article VI) Low history of third party damage claims Not applicable to nationals of the launching state or foreign national participants. (Article VII)

International Air Law Liability Regime	International Space Law Liability Regime
Scenario 3 – Damage caused to passengers	
Treated under the Warsaw System & Montreal Convention	Treated under Article III Liability Convention
Limited liability (low levels) Based on fault and reversed burden of proof Unlimited Liability for willful misconduct and absence of ticket Not liable if: all necessary measures were taken to avoid damage, or if damage is caused by negligence of the Plaintiff Elimination of liability ceilings A two-tier liability system	Liability for damage sustained to passengers while inside the space object is not covered Only if caused by another space object Unlimited fault-based liability (Article III) Not applicable to nationals of the launching state or foreign national participants (Article VII)

The US Model: Informed Consent & Liability Waivers

The US regulations primarily aim to protect the uninvolved public and the US Government. The regulations are very detailed with respect to crew, but lack content with respect to the Space Flight Participants (SFPs). In an elaborate set of regulations dealing with "liability cross-waivers", the crew and SFPs will have to execute a reciprocal waiver agreeing not to sue the US government. (FAA, 2007) Passengers must be at least 18 years old because of the understanding required to be informed. The regulations provide for the following information requirements:

- SFP must be informed about risks, including: safety history of all manned space vehicles, detailed safety briefing specific to the vehicle, and instructions to passengers regarding safety and emergencies onboard the vehicle
- Knowledge that the FAA has not certified the vehicle as safe
- SFPs must be given the opportunity to ask questions

In the event of an accident, it will be important to determine whether such a waiver of the claim is void as a matter of public policy, or whether the waiver was the product of truly informed consent. It is proposed that operators must maintain accurate, understandable data and keep adequate records of information provided throughout of the chain of activities pertaining to the flight. To limit the impact of an error in the information, US States may enact State liability laws to protect the operators. The States of Florida and Virginia have recently drafted legislation for both immunity to the operators and informed consent for the passengers.

Product Liability

Product liability refers to the duty that a manufacturer has to ensure that he delivers a reasonably safe product and liability for the totality of the product on breach of the following duties as stated in Table 7-6.

Table 7-6: Product liability duties
Sources indicated in table

Duty	Conditions	
Design a safe product	Refers to safety at time of production	No liability for development risk—defense is 'state of the art': absence of the knowledge or ability to eliminate a danger
Manufacture a safe product		
To warn against dangers of using the product	Continuous duty that applies throughout the normal life of a product	

Manufacturers may be protected from product liability claims during the development phase, but must be aware of the duty to provide a safe product once in the market. In the US, the crashworthiness doctrine applies whereby a product, even if not defective, must provide a sufficient degree of protection to the users. Legal considerations for the defective and dangerous aeronautical products constitute a major concern due to the large number of accidents resulting from them. It is proposed that future liability for an aeronautical product in the Space Law regime will follow much of the same path (Haanappel, 2003).

Application to PTP Suborbital Transportation

The issue of liability must be considered in the design of the vehicle and operational concepts for PTP suborbital transportation. To create a sustainable industry, these concepts must mirror, as far as is possible, the standards set by the aviation industry. The hazardous nature of activity determines the standard of liability, absolute vs. fault based. PTP suborbital vehicles have no heritage, so the liability would presumably be absolute, particularly with respect to third parties. Fault-based liability is appropriate where the activity of each party involved is subject to the same degree of risk, such as collisions between vehicles or other space objects (Masson-Zwann, 1992).

The issue remains as to the level of liability and whether or not the liability of operators and third parties should be limited. The original Warsaw convention was adopted to protect the young fledging airline industry from potentially ruinous liability claims. Bearing in mind that PTP suborbital systems are not yet established, entrants to the industry would benefit from a limited liability system similar to Warsaw (Wassenburg, 1997). In light of the trend of liberalization of the aviation industry, and considering trends in consumer protection laws, it may be unacceptable to have limits with no equitable benefit to claimants (Gimblett, 1997). It is worth noting that the imposition of limits to liability often motivates claimants to sue aircraft manufacturers instead of attempting to obtain a higher level of compensation because the manufacturer's liability is rarely limited (Shaw, 2003). It is proposed that manufacturers of suborbital transportation systems must be aware of their obligations with respect to liability once out of the development phase (Haanappel, 2003). This also highlights the important role that insurance will play in the development of the industry.

Waivers of liability may continue to be applicable between parties of equal bargaining power, but it will be wise to monitor the development of product liability law and international safety standards for manufacture and design. As these standards are adopted, it is less likely that responsibility in case of negligence can be waived. With regard to TPL, the Air and Space Law regimes are similar and provide for strict unlimited liability. It is proposed that the Rome

Convention is more likely to be applicable (Farand, 2007).

With respect to minimum age, medical consent, and training, operators must determine if eligibility requirements will exist and to what level. The US system requires the participants to be able to understand the risks involved; however, with "conventional" modes of transportation, it is not generally required to know any more than the basic emergency and safety procedures. It is proposed that if safety and reliability standards can be attained, then anyone can travel on a PTP suborbital flight. The US regulations do not discuss the physical condition of SFPs and do not require medical clearance before flying. No amount of "best practices" can insulate the industry against a SFP that becomes ill, injured, or otherwise damaged during a "nominal" flight (Dunstan, 2007).

From an operator's perspective, it is nearly inevitable that an accident will occur, and companies will be sued. Griffith (2008) suggests that occasional lawsuits do not need to destroy the industry "if companies develop a culture of safety with… sufficient documentation of such an all-out safety effort to convince a jury that it existed". The jurisdiction of the operating state, responsible public relations after an accident, and liability insurance are all factors to limit the effect of liability claims on the industry.

7.2.5 Insurance

Securing affordable insurance is a fundamental necessity for the PTP suborbital transportation industry because passengers will accept risks through informed consent. Personal accident liability of the operator appears to be one of the greatest concerns because the stature of passengers on a flight may increase the operator's legal exposure should an accident occur (Leatherwood, 2008). Lloyd's of London is the world's major space insurer and underwrote the first space risk in 1965. It is their view that the risk associated with commercial spaceflight will enter the aviation insurance market, but until vehicle designs are finalized, insurers will be reluctant give ratings on risks (Lloyd's, 2007).

In rating premiums for airlines, insurers consider a number of factors, including (Margo, 2000):

- Airline's loss history (previous accidents and claims)
- Airline's operating conditions
- Airline reputation
- Qualification of crew members,
- Airports served
- Condition and age of equipment including maintenance levels
- Type of passenger carried and legal exposure in the event of a loss

The main difference between underwriting of risk for aviation and for PTP suborbital transportation vehicles is the lack of flight heritage, with no operational vehicle to make an adequate assessment.

Application to PTP Suborbital Transportation

Despite assertions to the contrary, it is stressed that insurance will be available for this mode of transportation, and policies for suborbital tourism vehicles have already been written (Dunstan, 2008). The price of the premium and its level of impact to the industry remain in question. Alton (2008) suggests that PTP suborbital transportation will be insurable depending on several factors, including:

- Management team
- Technology platform
- Testing
- Established training standards for: maintenance, personnel, crew including pilots, flight attendants (if any), and passengers' training for emergencies and physiological events

When premiums are established, Alton (2008) also proposes that companies will need:

- Basic property and casualty insurance
- Professional liability for the corporation
- Aerospace related insurance: aviation, passenger, launch, third party, and hull liability

Lloyd's (2006) suggests that the price to cover the hull of a vehicle will depend on the safety and reliability of the venture established through its testing phase.

7.3 International Scenarios

Government legislations are largely driven by domestic interests; however, policies also evolve to embrace bilateral or multilateral cooperation (Peterson, 2005). In order to establish a common guideline for PTP suborbital transportation, governments must primarily address the following factors: location of landing site and environmental guidelines to minimize pollution and noise. These factors may have international implications. The three dominant actors that will take part in future international negotiations for PTP suborbital transportation activities based on their current space activities and interest in this industry are: the US, Europe, and Asia. Within this section potential decision-making scenarios are analyzed for the willingness of these countries to negotiate based on their respective foreign policies.

7.3.1 Multilateralism

The possible willingness of the three actors to cooperate in a multilateral agreement is analyzed in Table 7-7 below, accounting for the risks, national concerns, and interests of each.

Table 7-7: National factors for decision making in a multilateral regime

Factors	US	Europe	China-Asia
National security	Terrorism and security clearance	Immigration concern	Core interests safekept by research institutes (Scobell & Wortzel, 2005)
Economic policy	Liberalism-free market	Liberalism-free market Concorde antecedents	Protectionism. Most strict and active governmental role in the private sector.
Technology transfer	Strict policy, with extraterritorial effects Subjective scope Not a discussion topic in negotiations NASA-mission oriented	Flexible policy ESA charter-space programs are geared to industrial development. Willing	Chinese government has emphasized the need for Foreign Direct Investment (Bennett et al.., 2001)

Factors	US	Europe	China-Asia
	Spin-off oriented and secondary goal of space investments (Hertsfeld, 2002)	to cooperate with other nations. Stimulate the transfer process, particularly procurement policy (Hertsfeld, 2002)	Willing to acquire foreign technology
Use of soil and airspace (status quo)	Open Skies policy	Open Skies policy	Status quo view; State controlled Preconditions can be settled (Scobell & Wortzel, 2005)
Environmental legislation	Regulations are established to avoid supersonic sound and noise pollution. Environmentalists have a strong influence in the government	Concorde experience Environmental law in accordance to all European countries and its allies	Not well developed yet; considered as tool in international diplomacy (Edmonds, 1999)
Suborbital aviation safety	Regulations developed	Not developed	Not developed
Risks to cooperate	Economic threat in allowing technology import	Need to agree as a block Terrorism and increase in security governmental constrain	Allow landing and surpass its national skies More strict regulation will be needed in clearance

USA

It can be observed that ITAR is not present in the negotiation table, and the US will continue to make arguments for sustaining its ITAR legislation. The threat of terrorism is another main concern. Security is extremely important, and regulations of US spaceport activities and clearance of passengers onto US soil will be imperative. Environmental issues and noise pollution will also be a significant issue in the public negotiations. The US may find a way to establish such treaties as binding, which differs from the current way in which treaties are accepted—the bona fides status.

Europe (EU)

Immigration and security are the main issues Europe will negotiate to get establish regulations in a multilateral agreement. Safety standards are also a concern, and Europe is willing to harmonize their standards with others (EU, 2007).

Space traffic management should be considered as a starting point in negotiations for a multilateral agreement, as it is important to establish possible routes and define sensitive zones.

China—Asia

China is a country characterized by a strong governmental presence. China may be willing to open its markets if the contribution of the industry is clearly described. China's plan for achieving PTP suborbital transportation is not well-developed, and they may be willing to apply the international framework of another country—such as the US—or participate in a creation of new international law.

7.3.2 Bilateralism

The primary difference between bilateral and multilateral negotiations is the complexity of the negotiation (Dellios, 2001). Bilateral negotiations can be less complex depending on the actors, interests involved, political situation, and actual scenario.

Table 7-8 below characterizes the advantages of having a bilateral agreement, and the difficulties encountered without one regarding national issues for PTP suborbital transportation activities.

Table 7-8: Comparison of effects of the presence and absence of a bilateral agreement
Sources indicated in table

Bilateral Treaty Present	Bilateral Treaty Absent	Policy drivers
Use of State's legal framework as a base for suborbital transportation regime	Safety standards regulated according to national policies; lack of harmonization if a treaty is not reached	Safety standards
Negotiation of framework of bilateral law with State's own perspectives (Peterson, 2005)	Different national regulations for vehicles and suborbital flights	Terrorism
New resources for domestic economies	Different criteria for licensing in US and Europe (Haanappel, 2003)	Space traffic management
A block can be formed	Industry negatively impacted by lack of treaty	Liability
Revenues and taxes may increase if government invests in companies	Increased vulnerability to possible terrorist attacks	Environment
Harmonized safety standards for suborbital flights	Infrastructure costly	Immigration
Gain prestige and allies in a future negotiation	Possible illegal immigration between States	National security
	Space object information for space traffic management required, which may	

compromise national security
Penalties must be defined for parties in violation of the law
Different environmental standards

Recommendations

The US government is the only State to assign a governmental body to regulate a commercial space transportation industry. Additionally, the US national security concerns may hinder the growth of the industry. The US must address its national security concerns with more flexibility or establish bilateral cooperation to obtain an assurance of security.

Within Europe national legislations require collaboration between the space agencies and the governments. Considering Europe as a block, the regulatory bodies that could play a role in suborbital flights include:

1. EASA—this new authority is currently responsible for the certification of aircraft and is in the process of developing its framework. Looking into the future, EASA will extend its influence over the safety regulation of airports and Air Navigation Service Providers. The EU Parliament and European Commission have provided four years, starting from April 2008 for the transition, in which EASA's priorities will be the licensing of flight crews and establishing a new management system based on the International Civil Aviation Organization's (ICAO) recommended standards (IAASS, 2008).

2. Joint Aviation Authorities (JAA)—associated body of the European Civil Aviation Conference It is proposed that EASA will absorb many of its functions (Adlen, 2006).

The fastest ways to harmonize the regulations is to follow the framework of the most developed country, or use the Australian law as a model (see Australian Case) and choose the best regulations according to the main interests. A final option is to create a pattern of law in cooperation with US and invite other nations to follow once the framework has been consolidated by the governments involved.

China perceives regulation as an indispensable element of national security, and to this effect, Chinese regulation can be strict and severe. Despite this, China will increasingly face deregulation of its airspace in line with other Asian countries, including Singapore and Japan. The latter countries already support an open economy without strong interference from the government. China may be more willing to open its territory and enter into a bilateral agreement for future PTP suborbital landings, as the industry increasingly deregulates.

7.4 Technology Transfer

ITAR could be perceived as an obstacle to the development of commercial space activity due to the peculiarity of its effect on international business. In the case of PTP suborbital transportation, items such as the design of a propulsion subsystem, are classified in the Munitions List as Aircraft & Associated Equipment and subject to ITAR. This classification of the suborbital vehicles will need to be amended or made inapplicable because the final use of the vehicle will be civil and commercial (Title 22 USC, 1992).

Passengers are also involved in the ITAR regulations through access to potentially classified information, which may be a requirement for safety reasons and informed consent. It is proposed that this problem can be solved by developing a passenger briefing that contains ITAR-compliant information. Crews will require technical information to conduct their duties to an extent that will make it difficult to avoid the provisions of ITAR.

Landing a suborbital vehicle on foreign territory may be classified as an export, depending on the interpretation of transit provisions. The Export Administration Act has two types of licenses. Most non-military commodities and technical data are exported under a General License (GL) or Individual Validated License. The GL is a broad authorization to export goods and technical data without case-by-case government review (Meessen, 1992). It is proposed that a policy decision should be made to create a special license for commercial private space vehicles so they will not be considered dual use and subject to ITAR.

7.5 International Cooperation

It is proposed that interested States begin to work towards an international agreement, an example of which is the Open Skies policy. To achieve this goal, one must ask, will there need to be an international dimension in the form of an international governing authority congruous to ICAO for air activity, and COPUOS for space activity, to regulate PTP suborbital transportation?

A new international legal framework will be needed in order to better regulate the PTP suborbital activities. A new legal regime is needed with a hybrid law developed by the most proactive States and supported by other nations who may have concerns regarding their national airspace sovereignty. In Figure 7-2 below, the legal aspects that may require the development of a hybrid law regime are illustrated.

Figure 7-2. Hybrid Air and Space Law Regime

7.5.1 The ICAO View

ICAO establishes international standards and recommended procedures for the airspace activities of member states. One of its strengths is the creation of the Universal Safety Audit Program under ICAO Assembly Resolution A32-11 1998, which subjects all contracting States to regular, mandatory, systematic and harmonized safety audits. This program has been designed to determine the status of States' implementation of the critical elements of a safety oversight system.

The ICAO view regarding the regulation of vehicles is: "certificates and licenses issued or rendered valid, under national regulations, by the Contracting State in which the aircraft is registered shall be recognized by the other Contracting States for the purpose of flight over their territories, including landings and takeoffs" (ICAO, 2005). The effect of the provision is that if a State classifies a suborbital transportation vehicle as an aircraft, it may fall within the ambit of ICAO.

The importance of ICAO for PTP suborbital transportation is driven by the need to implement an international safety regulation guideline for this industry. It is proposed to create a division within ICAO to harmonize regulations and standards for PTP suborbital flights, using the safety audit program as an international means to fill the gaps. This division, which will benefit from the learning curve that exists within the aviation sector, can be streamlined to provide States a fast track to developing policies without bureaucracy. Additionally, forming this division under ICAO, and not a new international organization, will minimize the cost to do so.

7.5.2 The COPUOS View

The main function of COPUOS is to promote the international cooperation and peaceful use of outer space. It operates on the principle of consensus, but is flawed by its inability to make decisions that have an impact, considering that COPUOS works on a good faith basis. Essentially, the demarcation issue and uncertainty caused by lack of consensus (Christol, 1981) has contributed to the confusion to determine how suborbital flights should be regulated. Another issue still debated is how to identify aerospace objects on the basis of design factors, technological capabilities, or function. States argue that a legal regime for aerospace objects may be difficult to establish, as requirements for a vehicle may differ according to location, nature of activity, destination, function, or purpose (COPUOS, 2005).

7.5.3 International Space Flight Organization (ISFO) Proposal

If ICAO and COPUOS cannot independently develop a special regime or improve existing frameworks to regulate PTP suborbital flights and address the issues of identification of an object, legal status of the crew, passengers' and vehicle liability, traffic control, innocent passage, and takeoff and landing procedures, another international regime is needed (Benko & Kai-Uwe, 1993). It has been proposed by the US that an ISFO organization should be established to regulate international aspects (Sgobba, 2007). The establishment of a new entity would go far in providing clarity, as well as providing the opportunity to create a regulatory environment specifically tailored to maximizing the potential of the industry. Some of the following factors listed in Table 7-9 must be taken into consideration for the development of such an organization.

States, guided by their governments, can choose the best way to develop a hybrid international space flight law bearing in mind that non-contracting States will be affected, through the establishment of new legal principles and economic order.

Table 7-9: Factors that can lead to a creation of an international organization

Funding	International cooperation	Structure and mission	Outreach
States, non-governmental, and governmental organizations shall contribute financial resources	States must address to the ICAO or UN assembly to start in settle a convention or treaty to create an international body Liability and a proper regulatory framework shall be agreed by consensus States must agree suborbital space activities and vehicles should always be for peaceful uses Needed to guide set of principles for specific rules Cooperation with dominant actors and non-dominant must be held as well	States must explain through a resolution the main objectives, goals missions and structure of the organization A solution of disputes mechanism must be addressed To give binding power	Society must support its government for the creation of this new body that regulates according to national interest, such as following environmental rules Non-governmental organizations should balance governmental power

7.6 Conclusions

The General Air and Space Law Regimes applicable to spacecraft currently do not directly apply to suborbital vehicles. ICAO suggests that suborbital flights can be accommodated under the existing system, if a policy decision is made to classify these vehicles as aircraft. The benefit to regulating this activity as an air activity, in line with the functionalist approach, is that there is already an established body of law, which can be amended to fit the peculiarities of suborbital flight.

The current Space Law regime is inadequate for commercial passenger carrying PTP suborbital transportation. The regime does benefit from its flexibility to establish the regulations and procedures required for the more stringent aviation industry, as evidenced by the US classification of suborbital vehicles as launch vehicles. Additionally, as evidenced by Australian law, States can easily enter into bilateral agreements under similar terms. Multilateral acceptance of the transit or right of innocent passage may need approval to prevent opposition from outside States.

There is no certification procedure for PTP suborbital transportation systems, and the current technological environment is not advanced enough to request that vehicles are certified before they are flown. In that respect, it is recommended that in line with the US view, States should allow a period of unlimited experimental testing of these vehicles. For the transport of passengers to be viable, vehicles will eventually have to be certified, as it is likely that permission will not be granted to fly over foreign territory if vehicles have not met a minimum standard.

It is proposed that interested States enter into agreements to permit suborbital systems to enter their territory on a bilateral basis. It is contended that as States move more towards an Open Skies system of freedom of the air, there will inevitably be inherent difficulties in establishing universal acceptance of PTP suborbital transportation. Bearing in mind the national security concerns of States, the most viable routes from this perspective are those that fly over the high seas, such as from the US to Europe. This would prevent the likelihood of protest from States against the initialization of the activity and also minimize third party liability risk. From the perspective of future markets, though China and Asia appear to be viable destination points, it is clear that air transportation must be fully liberalized before deliberation can be made on this issue.

Liability regimes are moving towards a rejection of liability limitations, particularly between parties of unequal bargaining power. Based on this, it may be difficult to justify a system of limited liability at an international level. Operators and manufacturers will have to ensure that the appropriate levels of safety and reliability are met to prevent liability claims in excess of the capacity to handle them. To this end, the ability to acquire insurance is an important factor in determining the viability of this industry. It is expected that insurance will be available, and if the environment supports the testing of vehicles to demonstrate their safety, the market will certainly be there.

It is suggested that the US may be the first State with a conductive atmosphere for PTP suborbital transportation. Sweden is intending to establish a regulatory system similar to that of the FAA-AST in the US and act as a second base for Virgin Galactic suborbital flights. If Sweden establishes a regime in line with US and gains support from Europe, a potential bilateral regulatory environment may be more easily developed. Other jurisdictions that may be good candidates for bilateral agreements include those countries that current provide TAL sites for the Space Shuttle, including France and Germany.

8 CONCLUSIONS & RECOMMENDATIONS

When preparing this report, a neutral position was adopted, neither promoting the notion of point to point suborbital transportation nor seeking to put forward a negative prognosis simply because challenges exist. Those who dream of rapid global transportation will be happy to hear that no insurmountable obstacles have been found. And others, with a more pessimistic approach, will approve as well; challenges exist in abundance.

8.1 Study Findings

The conclusions of this report span the entire interdisciplinary arena, and taken as a whole, represent the most comprehensive account of point to point suborbital transportation available. Readers should be aware that the conclusions presented here are developed from research described in detail in the corresponding chapters.

8.1.1 Technologies & Trajectories

From the various competing designs, this report finds a strong case for the adoption of a vehicle equipped with secondary jet engines for point to point suborbital transportation. The two relevant trajectories investigated are ballistic and ricochet profiles. Ballistic trajectories enable flights up to 12,000 km before requirements equal those of an orbital vehicle. Even with an altitude limit of 500 km imposed to avoid excessive radiation exposure at the lower bound of the Van Allen radiation belts, 7,000 km remains achievable before the change in velocity required is equivalent to that of an orbital flight. Ricochet trajectories consist of a number of short ballistic arcs joined by short periods of flight through the Earth's atmosphere. Ricochet profiles allow flights to all corners of the Earth's surface at a lower velocity requirement than for an orbital flight that de-orbits to return to the Earth. A notable disadvantage is the nauseous environment created by the required maneuvering.

8.1.2 Markets & Demand

Choosing to consider only routes with distances greater than 3,500 km, data was gathered on the patterns of world passenger and cargo travel. Analysis provided a list of probable routes of which three were identified as potential international passenger hubs: London, New York, and Tokyo. A national route between New York and Los Angeles was also identified as potentially suitable for this market. For cargo traffic, routes between Memphis, Anchorage, and Hong Kong were identified in a similar exercise. The passenger and cargo markets are predicted to be niche markets, due to the high price of the service. Preliminary analysis forecasts up to 50 passengers per day at USD 50,000 per ticket for the major routes between New York, London, and Tokyo. Passenger traffic should be even higher for the routes between Los Angeles and New York. From the cargo perspective, possible payloads include: documents, equipment, precious stones, electronics, and other items of high value. The cost is estimated to be as high as USD 2.6 million per metric ton. Since supersonic transport aircraft would also offer significant time savings at lower cost, they are a potential competitor in this market.

8.1.3 Finance & Growth

Parametric modeling of development, production, and operations illustrated that the very first suborbital vehicles may exceed USD 525,000 per passenger on small 7 passenger spacecraft. Manipulation of the parametric cost model suggests that increasing the passenger number only leads to an asymptotic lower limit near USD 100,000 per passenger. In this scenario, cargo cost could be as high as USD 2.6 million per metric ton. Adjusting cost sensitivity factors revealed that prices per ticket are largely dependent on the efficiencies of private industry and continued progress with technology development.

For the most part, the means to fund a point to point suborbital transportation system currently remains limited. In spite of this seemingly dire funding situation, there are still resources to be tapped. The risk taking acts of venture capitalists, angel investors, and the government could very well lay the monetary foundation of this "New Space" venture.

The point to point suborbital transportation industry will only be feasible with continued growth in technology development; a realistic understanding of the costs associated with developing, producing, and operating suborbital spacecraft; allocations of funding from various sources; and leveraging the experience gained from suborbital tourism.

8.1.4 Infrastructure & Environment

Spaceports will have to be easily accessible if the major benefit of point to point suborbital transportation, significant time savings, is to be realized. This leads to the conclusion that spaceports should be co-located with current airports. Since spaceport requirements and vehicle design are co-dependent, vehicle design will be driven to be compatible with airports. If spaceports must be located in remote areas, a means of rapid transport between the spaceport and population center will be required.

For the point to point suborbital transportation sector to be sustainable, space vehicle operations must be integrated with traditional air traffic operations in a seamless manner. A vehicle that is responsive to air traffic control clearance, such as a horizontal takeoff concept with powered landings, will be easy to integrate with air traffic.

One of the environmental challenges to overcome is the noise generated by the sonic boom of the suborbital vehicle. Other environmental issues that must be dealt with include the impact of spaceports on the environment (which will face rigorous environmental assessment), the carbon footprint of the vehicles themselves and the probable contribution of the vehicle's operation to ozone depletion. This will be a major driver in selecting propulsion system, and already it is clear that solid fuels will be unacceptable. Increasingly, "greener" propellants appear to be the way to go. Not only must the vehicle's design, manufacture and operation be environmentally friendly, it must also be widely perceived and accepted as being so.

8.1.5 Safety & Reliability

Point to point suborbital transportation pushes the envelope of current technologies, and it will be difficult at best to achieve the 0.999 reliability demanded by the air transportation industry without increased design heritage, that may be derived from suborbital tourism flights or reusable launch vehicle testing. The vehicle will be exposed to environmental effects both within and outside the atmosphere, including terrestrial weather, radiation, and orbital debris. The passengers on a point to point suborbital flight, however, are exposed to less radiation than on the same route in an aircraft, but they will nevertheless be extremely vulnerable to Solar Particle Events during periods of increased solar activity. Orbital debris will pose a challenging problem as debris smaller than 10 cm is not within current tracking capabilities. Passengers and States will probably not accept anything less than full certification before the vehicle can be used.

8.1.6 Law & Policy

In order to adequately regulate this industry, States should, at the least, create an oversight authority and classify the vehicle (or activity). An international body, such as International Civil Aviation Organization (ICAO), or a new body, may be able to harmonize safety standards on an international level, with amendments for characteristics about the vehicle that differ from an aircraft. The US already has experience in a similar regime to establish international landing sites for the Space Shuttle in the event of an abort. Limited liability may become a thing of the past for the industry, which will require operators and manufacturers to ensure accepted levels of safety and reliability can be reached. Insurance is likely to be available, provided the vehicle manufacturers can perform the flight testing required to increase vehicle reliability without legal barriers.

8.2 Recommendations

This study gives the opportunity to make recommendations that are useful to industry, government, and other stakeholders. The recommendations do not cover every challenge implied by point to point suborbital transportation, but offer a guide to the major conditions that need to be taken into account for a sustainable point to point suborbital transportation industry.

A significant theme through all disciplines is the desire for a vehicle with aircraft-like characteristics. Aviation, with its comprehensive legal regime, well-developed safety systems, and extensive infrastructure can act as both an example, and a support, to a fledgling suborbital transportation industry.

With the technical, business, and route constraints that have been identified, it is probable that only a small number of routes will ever be viable. Coupled with a niche demand, it will be difficult for a vehicle program that is dedicated to point to point suborbital transportation to raise funds. Far more likely is a vehicle that is developed in combination with a reusable orbital transportation, suborbital tourism, or military program.

The main recommendations are:

- The international routes identified are New York to London/Paris, London/Paris to Tokyo, and Tokyo to New York.
- Trip times will be approximately 90 minutes or less.
- Suborbital routes should only be considered for distances beyond 3,500 km. Ballistic trajectories are feasible for distances up to 7,000 km, but beyond this range, ricochet trajectories should be utilized if possible.
- Radiation exposure and the likely public perception that vehicles should avoid flight in the Van Allen radiation belts, limit flight apogees to below 500 km.
- The cargo market will be limited to only those items that have specific values of millions of dollars per ton, or for which the time value is high.

- Passenger transportation should be the primary focus of early suborbital transport.
- The size of the passenger market is highly dependent on price and may be on the order of 50 passengers per day at ticket prices of USD 50,000 each way.
- Traditional development methods would lead to high costs. Leaner development may be possible, and would likely have significant reductions in overall cost.
- Operation of suborbital vehicles from existing airports is highly desirable.
- Space traffic management systems must be developed and integrated with existing air traffic management.
- Vehicle developers and vehicle operators should be independently operated to reduce the financing challenges.
- Further technology development should be focused on propulsion, durable thermal protection, and lightweight structures.
- “Green” propulsion technology is essential for continued viability in the face of increasingly stringent environmental regulation.
- Due to increased awareness of environmental issues and skepticism towards the space industry, attention must be focused on convincing the populace of the environmental sustainability of point to point suborbital transport.
- Noise-suppressing designs or operations that only generate sonic booms away from cities will be required. Waivers for the ban on supersonic flight over land are not likely to be granted without demonstrations of quiet flight.
- The growth path from suborbital tourism to point to point suborbital transport is not clear; however, experience gained from suborbital tourism will help to lower the barriers to a viable point to point industry.
- Vehicles must be certified by a government agency for safety.
- Point to point suborbital vehicles will require reliability levels similar to commercial aviation. This implies significant flight testing.
- Vehicles should be designed to reduce the g-loads on passengers
- States will need to develop bilateral or multilateral agreements to permit international flights of point to point suborbital vehicles.

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APPENDIX A: PASSENGER VOLUME FOR MAJOR AIRPORT HUBS

City, Country	Total Passengers	Int'l Passengers	Sources
London, UK	126,201,345	114,440,189	ACI, 2008; Infoplease, 2008; BAA Stansted, 2008.
New York, USA	105,105,434	32,558,744	ACI, 2008; Infoplease, 2008; The Port Authority of NY and NJ, 2008.
Tokyo, Japan	101,076,731	34,302,493	ACI, 2008; Infoplease, 2008; Narita Airport, 2008.
Paris, France	86,400,000	69,100,000	ACI, 2008; Infoplease, 2008; Aéroports de Paris, 2008.
Atlanta, USA	84,846,639	8,897,291	ACI, 2008; Infoplease, 2008; Hartsfield-Jackson Atlanta Int. Airport, 2008.
Chicago, Ill.	76,605,080	11,911,353	ACI, 2008; Infoplease, 2008; Chicago Airport System, 2008.
Los Angeles, USA	61,468,571	17,154,640	ACI, 2008; Infoplease, 2008; LAX Los Angeles World Airports, 2008.
Dallas, USA	60,006,307	5,550,429	ACI, 2008; Infoplease, 2008; Dallas/Fort Worth International Airport, 2008.
Frankfurt, Germany	52,816,231	47,087,699	ACI, 2008; Infoplease, 2008; Frankfurt Airport, 2008.
Madrid, Spain	48,822,222	29,339,784	ACI, 2008; Infoplease, 2008; AENA, 2008.
Beijing, China	48,654,770	11,120,099	ACI, 2008; Infoplease, 2008; BCIA, 2008.
Denver, USA	48,594,184	2,190,063	ACI, 2008; Infoplease, 2008; Denver International Airport, 2008.
Amsterdam, Netherlands	48,248,860	47,677,570	ACI, 2008; Infoplease, 2008; Schiphol Group, 2008.
Las Vegas, USA	46,960,872	2,244,574	ACI, 2008; Infoplease, 2008; McCarran International Airport, 2008.
Hong Kong, China	45,973,969	45,973,969	ACI, 2008; Infoplease, 2008; Hong Kong International Airport, 2008.
Bangkok, Thailand	42,799,532	31,632,716	ACI, 2008; Infoplease, 2008;
Houston, USA	42,764,820	7,722,990	ACI, 2008; Infoplease, 2008; Houston Airport System, 2008.
Phoenix, USA	41,810,456	1,749,433	ACI, 2008; Infoplease, 2008; Phoenix Sky Harbor International Airport, 2008.
Moscow, Russia	39,584,098	23,827,662	Infoplease, 2008; NGA, 2008; Domodedovo International Airport, 2008.
Rome, Italy	38,300,000	19,023,729	ACI, 2008; Infoplease, 2008; ADR, 2008.
Detroit, USA	35,979,270	2,947,545	ACI, 2008; Infoplease, 2008; Detroit Metro Airport, 2008.
Minneapolis, USA	35,384,728	2,012,000	ACI, 2008; Infoplease, 2008; MSP, 2008.
Singapore, Singapore	35,080,113	35,080,113	ACI, 2008; Infoplease, 2008; Changi Airport Singapore, 2008.
Orlando, USA	34,411,699	2,295,938	ACI, 2008; Infoplease, 2008;
San Francisco, USA	33,574,807	8,962,965	ACI, 2008; Infoplease, 2008; SFO, 2008.

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