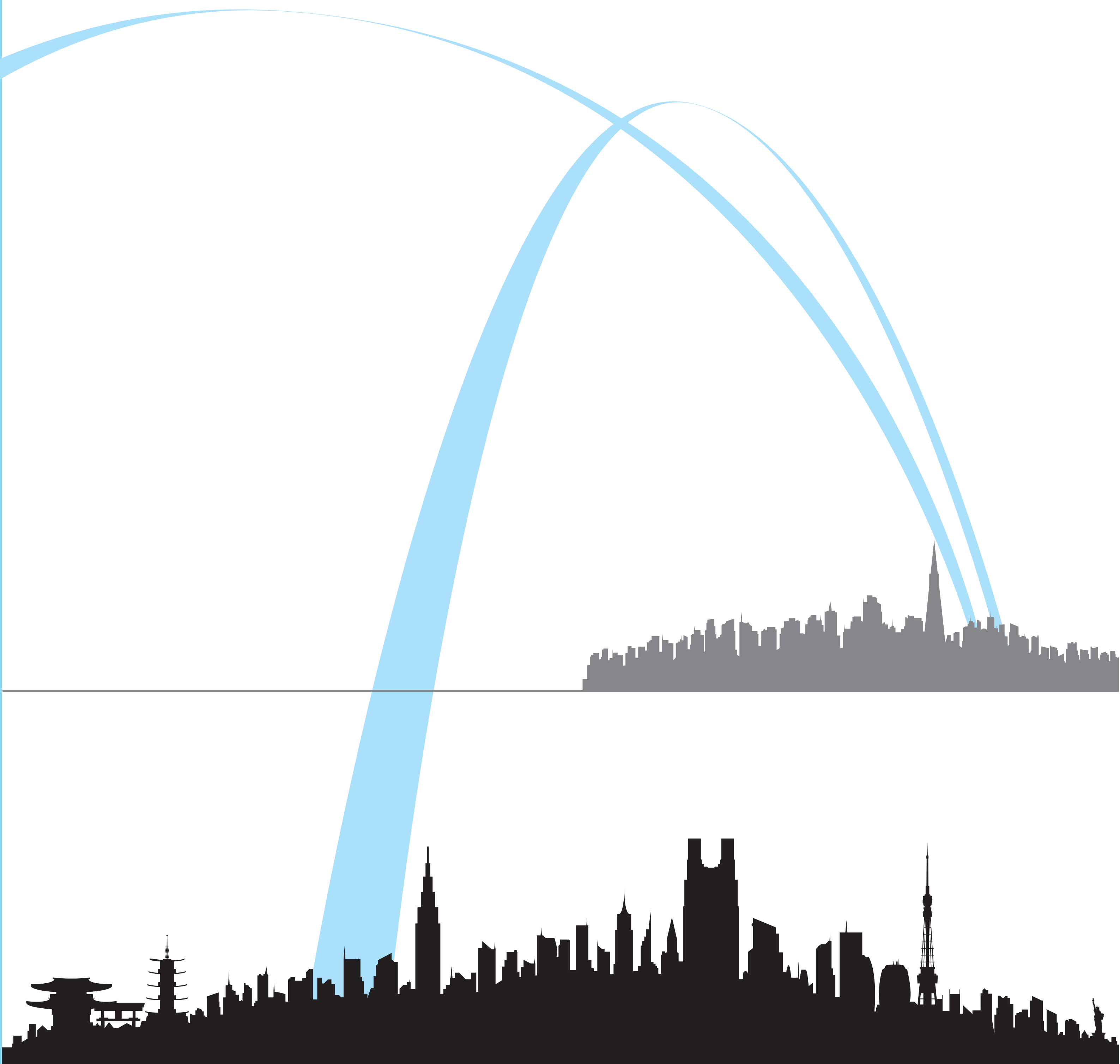
GREAT EXPECTATIONS:

An Assessment of the Potential for Suborbital Transportation



International Space University

MASTERS 2008 - EXECUTIVE SUMMARY

Introduction

Mankind has always looked to the birds with envy; their graceful mastery of the air has inspired countless dreams, and countless attempts at imitation. In recent years humanity too has mastered the skies, and space beyond, so dreams have turned to the uses to which this can be applied. The ability to travel the globe at ultra high speed is one such dream that still waits to be fulfilled.

Such high speed travel can be achieved by supersonic aircraft, as Concorde proved in over thirty years of operations, and research is ongoing into flight in the hypersonic region which lies higher than a speed of five times the speed of sound. An alternative is to propel a vehicle into space on an arc that, instead of going into orbit, returns to Earth at a final destination in less than an hour. It is this concept, suborbital point to point transportation, which this report investigates.

The technical issues involved in such an undertaking are challenging in themselves, but it would be foolish to concentrate on the technicalities at the expense of those issues which are less palpable but just as important. Consequently the report has approached suborbital point to point transportation from a multidisciplinary perspective, probing the legal, business, and operational topics as well as the technical requirements. This has resulted in a comprehensive account that is unmatched in the literature.

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Market

What is the demand?

Demand for suborbital tourism does not necessarily translate into demand for suborbital point to point transportation. Indeed, suborbital transportation may find itself in competition with other services such as supersonic civil aviation.

If the suborbital transportation routine over the long-term, the unique aspect of the space experience may not sustain passenger demand.

The success of the market is highly dependent on factors such as spaceport location, flight scheduling and passenger training.

Who is likely to fly?

Suborbital transportation is an elite service which primarily targets business people/high net worth individuals. Passengers flying between New York and Los Angeles will likely be doing so either out of necessity, availing of the luxury/prestige element or just seeking adventure.

Cargo Demand

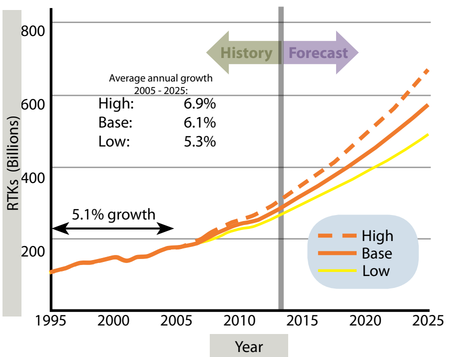
Manufacturing, assembling, and distribution of goods has established this market as one of the world's most important and dynamic industries.

World air cargo is comprised of mainly scheduled services but also on-demand (chartered). Charters are valid only if the pre and post flight processing times are kept to a minimum.

Type of Payload

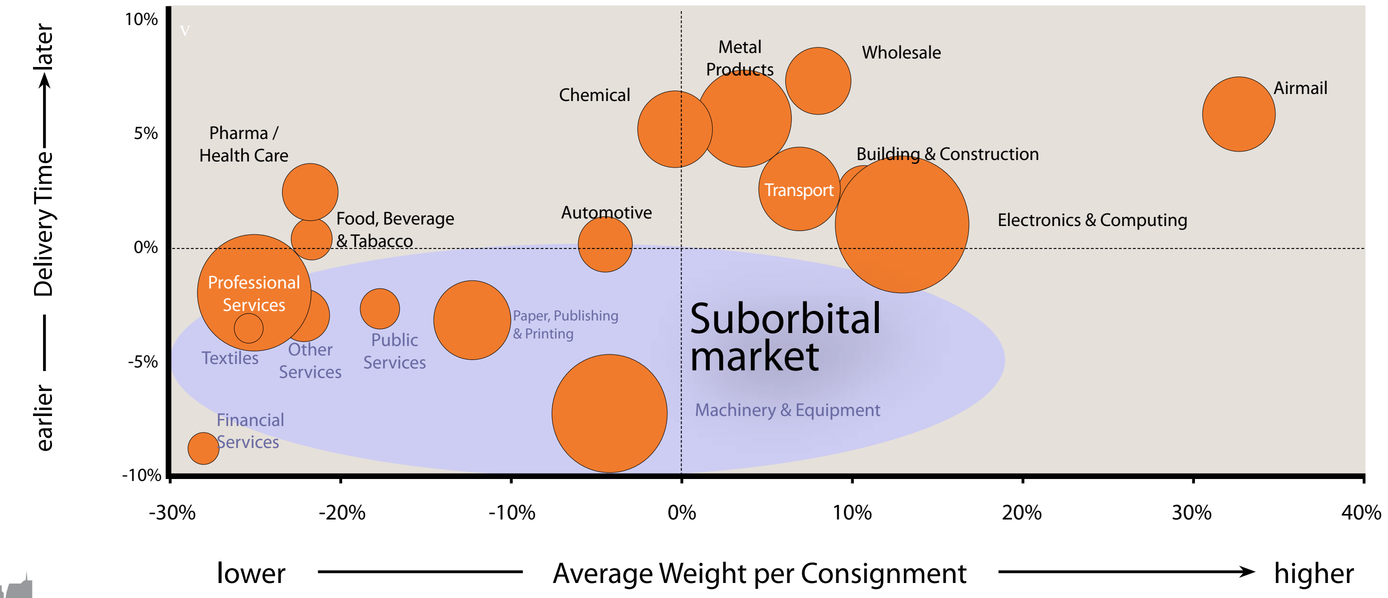
The major types of payloads are presented in the chart right.

For suborbital transportation, only payloads which need to be delivered at short notice or high weight to value ratio are considered as relevant. The development of a suborbital point-to-point transportation systems for cargo may also be driven by military demand for fast re-supply capabilities.



World air cargo forecast

"The success of the market is highly dependent on factors such as spaceport location, flight scheduling and passenger training."



Destination Analysis

Examining the current major flight routes and hubs for passengers and cargo can provide a good indication of potential future routes.

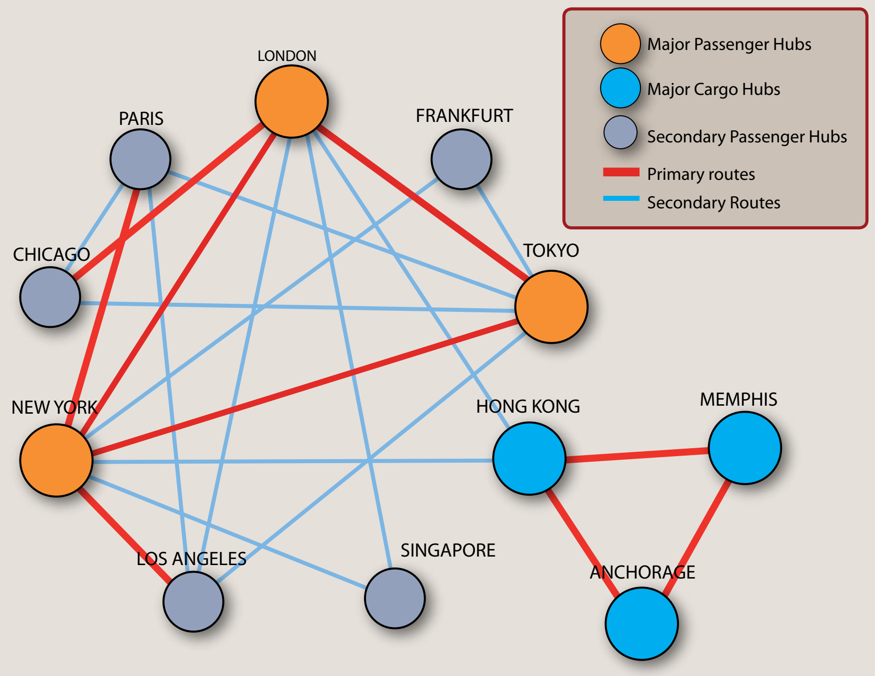
However, suborbital flight is highly dependant on distances and would not be a reasonable alternative to short-haul flights.

"Passengers flying between New York and Los Angeles will likely be doing so either out of necessity, availing of the luxury/prestige element or just seeking adventure"

Filtration Process

Using a filtering methodology based on air traffic, tourism, business, geography and other considerations, the best potential international hubs and routes for suborbital transportation were identified. Combined with analysis of population and world weath predictions, a forecast predicting the most attractive routes by 2020 was also generated.

Major international routes



The main passenger and cargo routes identified are listed below:

Passenger	Cargo
1. New York - London	1. Memphis - Hong Kong
2. London - Tokyo	2. Anchorage - Memphis
3. Tokyo - New York	3. Anchorage - Hong Kong

Door To Door Times

One of the factors that will determine the usefulness of suborbital flight is the overall door to door time. This must take into account the time it takes for check-in, taxi time on runway, take off, reentry and check-out. Analysis for typical passenger flights was carried out to compare airplane services and suborbital transportation. Time in ballistic/ricochet phase is fixed based on the distance to be covered. The assumption has been made that suborbital flights will work on a similar rapid service basis as the Concorde flights used.

Flight phase	Time(min) Airplane	Time(min) Spaceship
Boarding/Security/Preflight	90	30
Taxi/Take-off	11	11
Departure	20	15
Reentry	-	8
Descent/Approach	30	20
Landing/Taxi	11	11
Disembarking/Customs	45	20
Total Non-enroute Time	**207**	**115**

The above times included regardless of distance.

Commercial passenger jet cruise speed:
~ 900 km/hour
=> 12 hours New York to Tokyo

Suborbital flight time considerably faster:
=> 45 minutes New York to Tokyo.

Therefore, only distances greater than 3500 km are considered viable based on the fact that a suborbital vehicle would reduce the total travel time by about two thirds.

Infrastructure

What needs to be in place?

Spaceport requirements depend a great deal on the design of the spacecraft that will utilize the facility. While some designs could be operated in commercial airports with few adaptations and upgrades—such as a hybrid air and space craft—others would require a completely different spaceport infrastructure, such as a vertical takeoff and landing spacecraft.

Further, the development of spaceport infrastructure will most likely be driven by the development of the space vehicle industry. Unlike the reactive nature of developing airports, spaceports may require proactive from the private and public sectors alike—especially with regard to legal and technical challenges.

> "For a spaceport to be viable for transportation, it should be integrated with an existing commercial airport or be readily accessible to one."

The necessary infrastructures may well encompass very high costs, requiring public funding and government support. This may take place in the form of public-private partnerships with governments investing in initial infrastructure and private firms take out long-term leases as is the case for Spaceport America.

Also, for a spaceport to be viable for transportation, it should be integrated with an existing commercial airport or be readily accessible to one. The same is true for integrating with commercial air traffic.

Logistics Operations

If spaceports are located away from a metropolitan area, it must be accessible easily, such as via high-speed trains or helicopter.

Spaceports will also require special fuel and chemical storage to handle the exotic propellants used by spacecraft—this also includes specialized training for ground crews and emergency personnel.

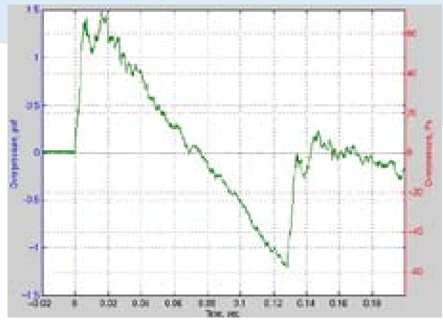
Depending on the type of spacecraft used, containment zones designed to mitigate the dangers to third parties may also be required should a catastrophic failure occur.

Environmental Concerns

The viability of suborbital transportation industry will be constrained by its environmental impacts (infrastructure impact, noise, rocket emissions in the atmosphere etc.).

Spaceports will have to comply with international / national law and regulation, but they also need to obtain the support of the general public. Careful selection of the site and education of the local population will be of paramount importance.

Noise is a potential *showstopper* for suborbital transportation,



and should be mitigated according to these options:

- Reduce the spacecraft sound profile by modifying the design
- Operate from coastal airport
- Adapt the existing noise regulations

Solutions should be sought out to minimize the environmental impact of spacecraft—both on Earth and in space.

LEGAL CONSIDERATION

INTERNATIONAL LEGAL CONFLICT
AIR LAW vs. SPACE LAW

Air Law: Based on the air law principle of sovereignty of national airspace, permission is needed to transit through foreign airspace.

Space Law: Due to the principal of non-appropriation and freedom of access to outer space, no such permission is needed. The Issue: There is currently no international agreement on where "air" ends and "space" begins—therefore international suborbital activities fall into a conflict of legal status.

The Solution: Initially bilateral agreements between affected states will suffice—however an international agreement will be necessary if the industry grows.

Air & Space Traffic Management

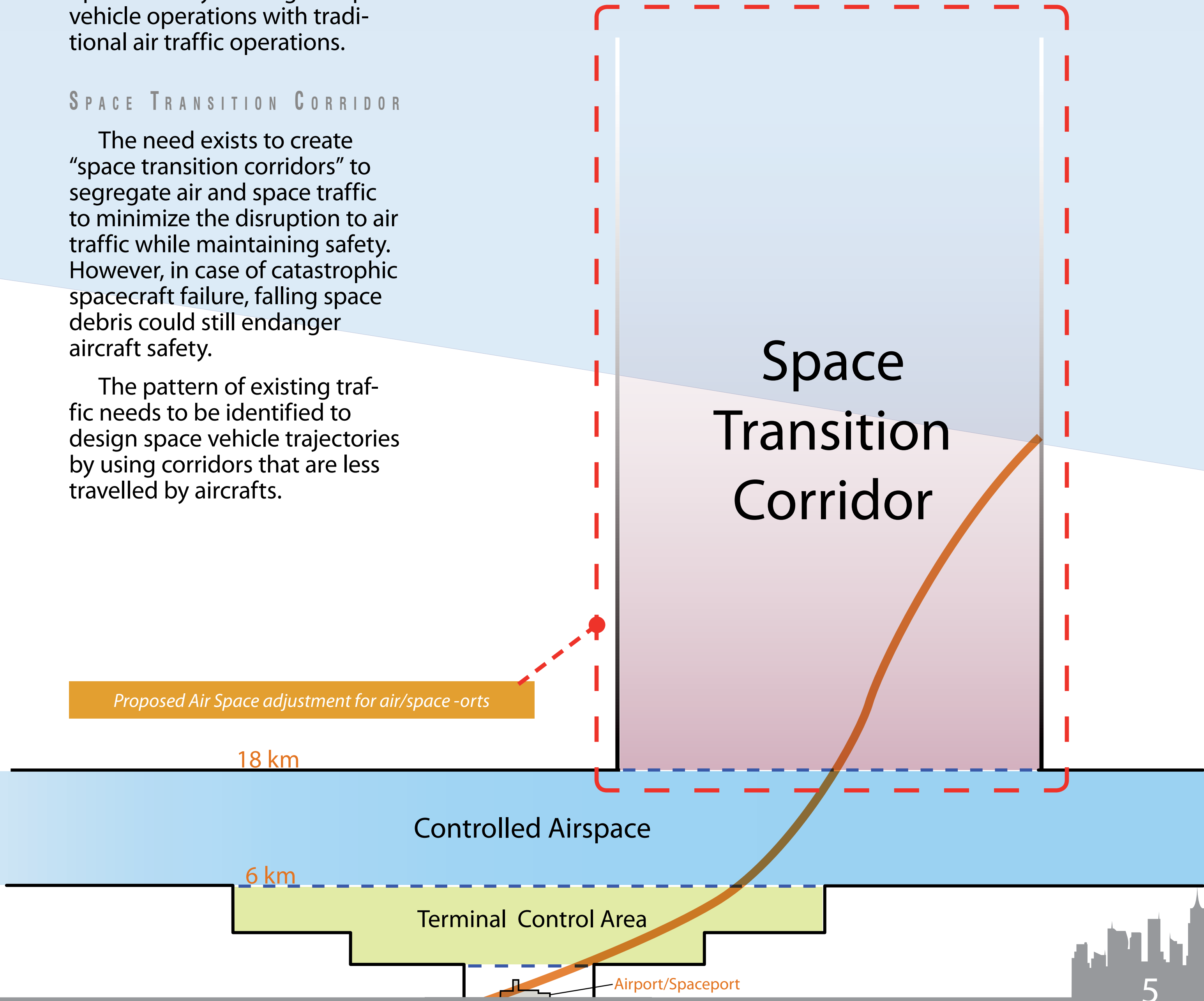
Before this industry can launch, concepts and standards of operation have to be developed in a way to integrate space vehicle operations with traditional air traffic operations.

> "Concepts and standards of operation have to be developed in a way to integrate space vehicle operations with traditional air traffic operations."

Space Transition Corridor

The need exists to create "space transition corridors" to segregate air and space traffic to minimize the disruption to air traffic while maintaining safety. However, in case of catastrophic spacecraft failure, falling space debris could still endanger aircraft safety.

The pattern of existing traffic needs to be identified to design space vehicle trajectories by using corridors that are less travelled by aircrafts.



Technical

How does it work?

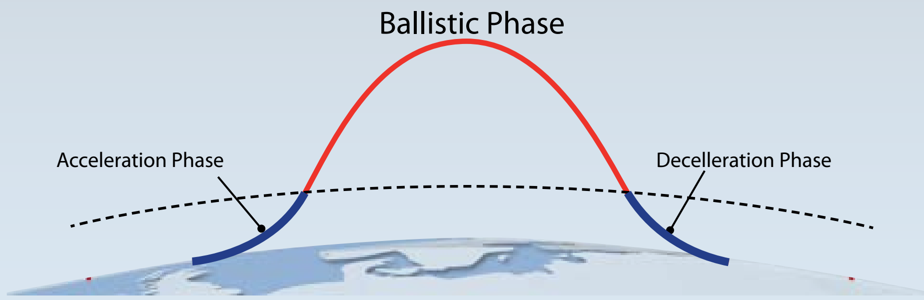
The maximum ground distance to be covered by any suborbital trajectory considered is 20,000 km (half the circumference of the earth). This allows complete coverage of the earth from any point.

> " Re-entry velocity determines G-loads and thermal loads, and has then to be the lowest possible "

Passenger flights (or piloted flights) will also be subjected to a height limitation of 500 km (the approximate height of the lower limit of the inner Van Allen radiation belt) , imposed to avoid any radiation related issues.

Two types of trajectories are therefore considered for suborbital transportation systems, namely:

- Ballistic trajectories
- Ricochet trajectories



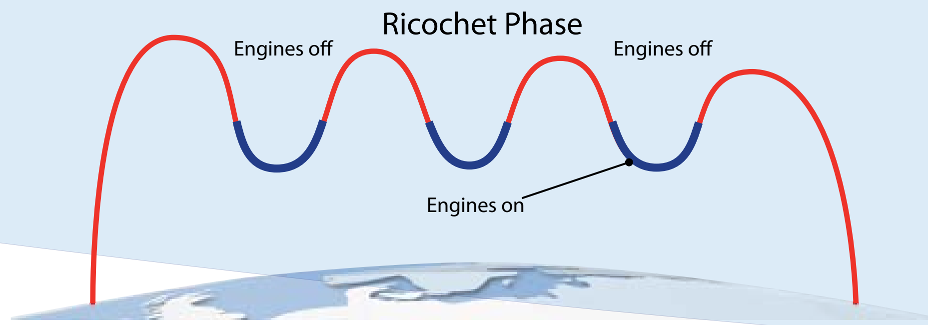
Ballistic Trajectory

The Acceleration phase is where a velocity gradient (Delta-V) is needed to achieve ballistic phase. The Ballistic phase is the elliptical part of the trajectory that remains un-powered.

Entry must happen above 50 km high, and Exit below 90 km high.

The Deceleration Phase is the re-entry phase. Re-entry velocity determines G-loads and thermal loads, and has then to be the lowest possible. Un-powered re-entry constitutes the worst scenario.

Orbital velocity is reached for distances over 12,000 km without height constrain, whereas it is reduced to 7,000 km with a height limit of 500 km. Under these conditions, the London - New York distance can be covered in 28 minutes and the New York - Tokyo distance in 42 minutes



Ricochet Trajectory

The idea is to skip on the atmosphere, which enables to significantly decrease the maximum height compared to ballistic trajectory.

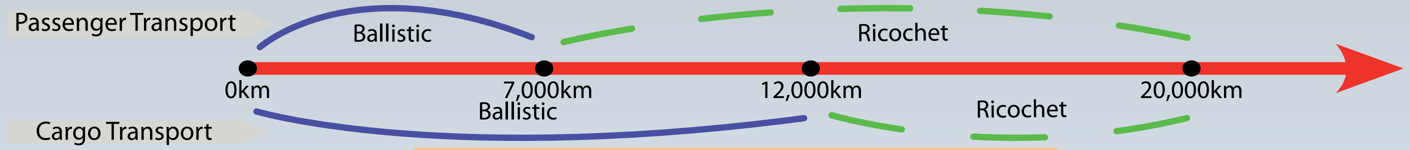
In a ricochet trajectory, insertion velocities remains below the orbital velocity for any distance until 20,000 km, and re-entry velocity are reduced. Increasing the number of hops can reduce the delta-V required.

The big disadvantage of the method is the probable negative effects of hops on the human body, as 40% of the population would already experience unpleasant feeling with a simple parabolic flight.

> " The London - New York distance can be covered in 28 minutes and the New York - Tokyo distance in 42 minutes"

Acheiving Total Earth Coverage

Covering the entire earths surface requires a combination of ballistic and ricochet trajectories. Although technically possibe, it makes no sense to use a ballistic trajectory for distances over 12,000 km (7,000 km when a 500 km altitude limitation is applied) due to orbital velecity being reached. Therefore, depending on the application, complete earth coverage will required a mix of trajectories as seen in the diagram below.

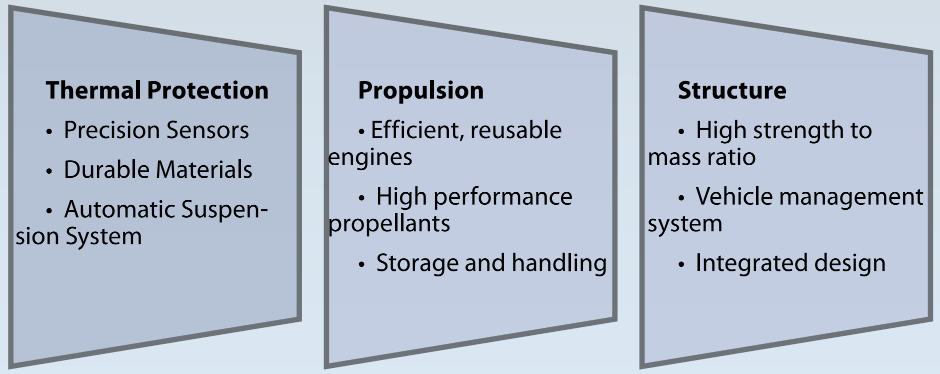


Achieving maximum distance for Cargo and Passenger

Technology Development

Identifying the critical technologies and their development path aids in understanding the level of industry readiness regarding suborbital transportation.

The most important technological areas of development are shown to the right.

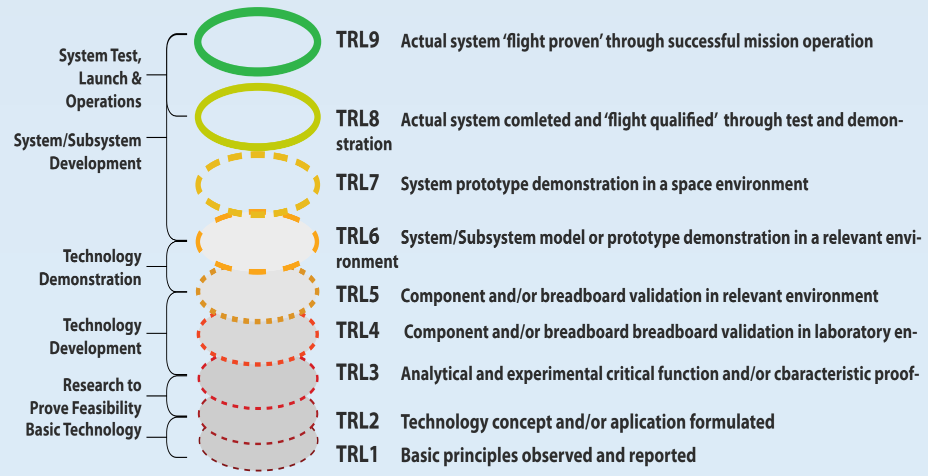


Main technology development requirements

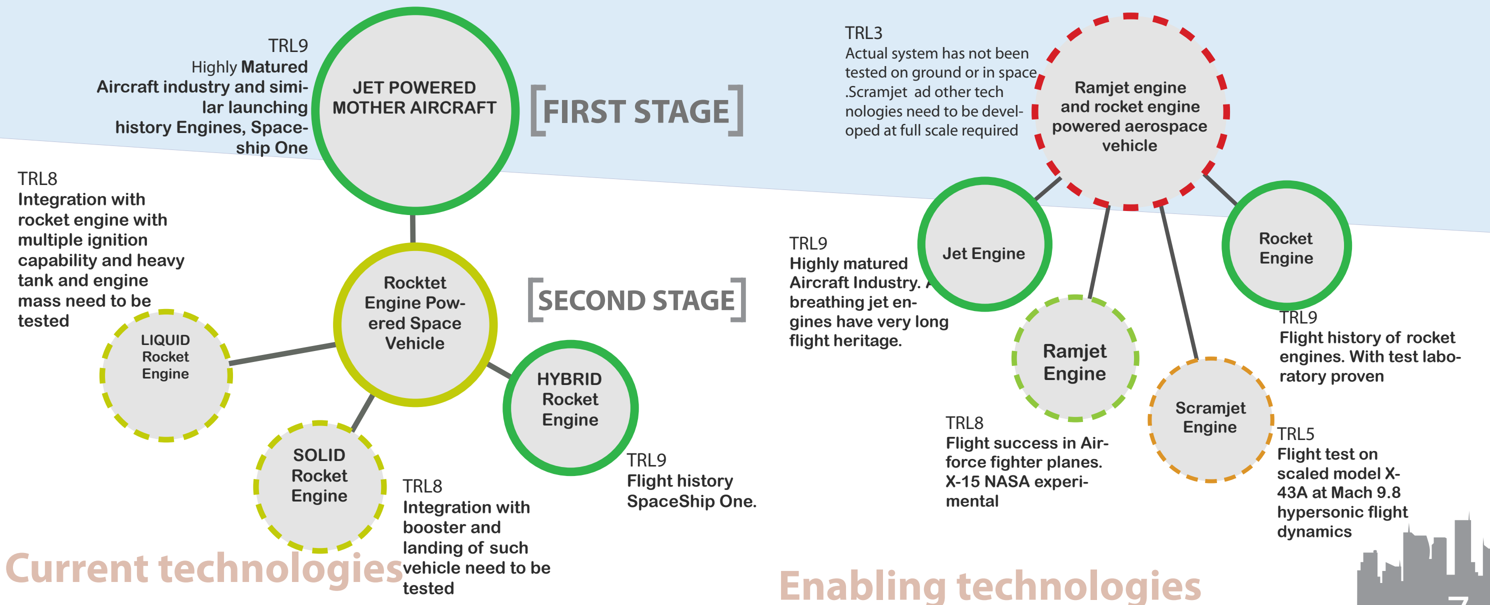
Technology Readiness

Using NASA's technology readiness guidelines the key propulsion technologies required to are demonstrated here. Current technologies are based on the 'flight proven' SpaceShipOne style spacecraft which is not suitable for long haul point to point flight.

Enabling technologies and their combined technolgies readiness levels are indicated on the bottom right.



NASA's Technology Readiness Guide



A Tale of Two Cities

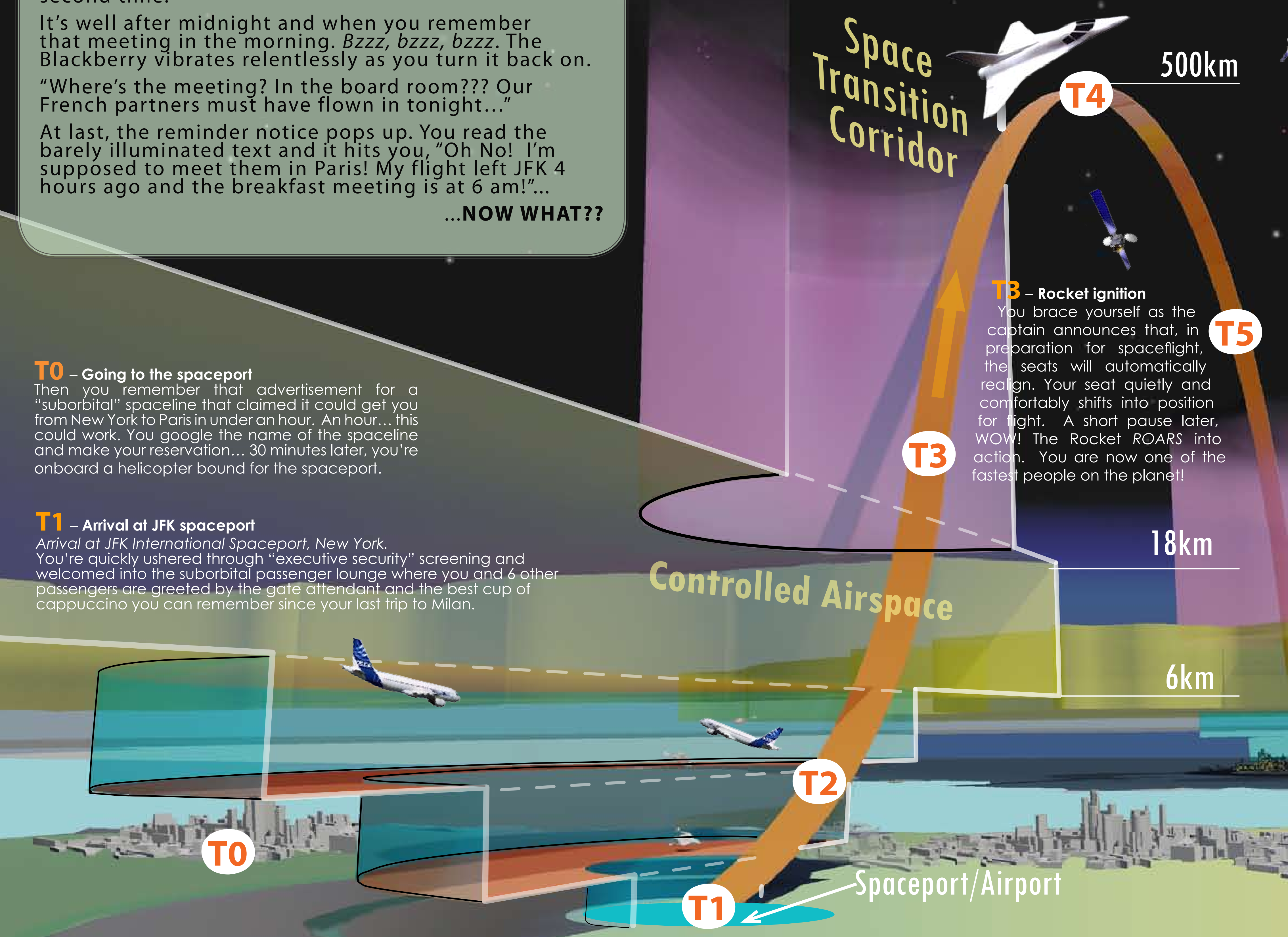
Late Thursday evening — and it's been a long week. It's been tough staying ahead of the curve with all the meetings, office calls, and the like. That incessant Blackberry constantly reminding you of where you should have been an hour ago to meet with someone you can't remember. You finally switched it off after it interrupted your 4pm board meeting for a second time.

It's well after midnight and when you remember that meeting in the morning. *Bzzz, bzzz, bzzz*. The Blackberry vibrates relentlessly as you turn it back on.

"Where's the meeting? In the board room??? Our French partners must have flown in tonight..."

At last, the reminder notice pops up. You read the barely illuminated text and it hits you, "Oh No! I'm supposed to meet them in Paris! My flight left JFK 4 hours ago and the breakfast meeting is at 6 am!"...

...NOW WHAT??



T0 – Going to the spaceport
Then you remember that advertisement for a "suborbital" spaceline that claimed it could get you from New York to Paris in under an hour. An hour... this could work. You google the name of the spaceline and make your reservation... 30 minutes later, you're onboard a helicopter bound for the spaceport.

T1 – Arrival at JFK spaceport
Arrival at JFK International Spaceport, New York.
You're quickly ushered through "executive security" screening and welcomed into the suborbital passenger lounge where you and 6 other passengers are greeted by the gate attendant and the best cup of cappuccino you can remember since your last trip to Milan.

T2 – Take off
As you begin to relax in a very space-aged cabin, you hear turbine engines start to wind - a familiar sound. The LCD screen in front of you begins a short video on the safety features of the spacecraft, emergency procedures, and interesting facts bout the spaceflight you are about to embark on - wow, this is cool. The captain informs the passengers that, though it is raining now in New York, skies are clear in Paris—where you will be landing in approximately 45 minutes time!

T3 – Rocket ignition
You brace yourself as the captain announces that, in preparation for spaceflight, the seats will automatically realign. Your seat quietly and comfortably shifts into position for flight. A short pause later, WOW! The Rocket *ROARS* into action. You are now one of the fastest people on the planet!

T4 – Welcome to Suborbia
The rockets turn off. The captain informs you that you can feel free to "float about the cabin" for the next 20 minutes. The view from the window is spectacular. You think to yourself that forgetting your scheduled flight to Paris was the best mistake you've ever made. The world looks different from here... places seem closer, there are no borders - this is why your company went global!. Then you notice magazine floating away and consider—for the first time—that you are actually in space. The captain announces a stellar view of the International Space Station out the left window.

T5 – Reentry
After your weightless floating about the cabin, the captain announces that passengers must now return to their seats for reentry. Your seat realigns again. Nice! Your heart races—you're coming back down to Earth.

T6 – Approach and landing
You hear the turbine engines being to wind up—the last 25 minutes or so seemed unnaturally quiet—the engines instill your confidence in the eager craft. The sun is just dawning in the horizon, and you appreciate the silhouette of the Eiffel Tower as you touchdown at Charles de Gaulle.

T7 – Getting to the point
As you disembark from the spacecraft, you're welcomed to the Suborbital Passenger Lounge where you clear customs and immigration—and finish another delicious cappuccino before being whisked off to an awaiting helicopter to bring you well inside the périphérique of Paris. You still have an hour and half to prepare for the breakfast meeting and negotiations that will follow.

Safety

What are the risks?

Safety may become the defining issue for the industry's success or failure. Spaceflight is seen as a risky endeavor but high risks may not be acceptable for suborbital transportation.

RELIABILITY

It is difficult to forecast the reliability level of a suborbital transport systems. Evidence of

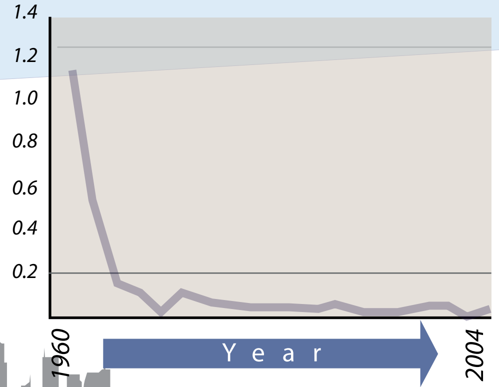
" the radiation dose an equivalent commercial aircraft flight would receive during a flight of the same distance "

this can be seen from the US Space Shuttle – with a reliability level still subject to contention. Any vehicle failure or accident, especially at the early stages of the industry, may lead to the total collapse of the sector.

Commercial aircraft safety rules aim for a reliability up to 0.999 at 95% confidence interval but rocket technology is not as proven as jet propulsion.

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.

Fatal US Airline Accidents per 100,000 Departures

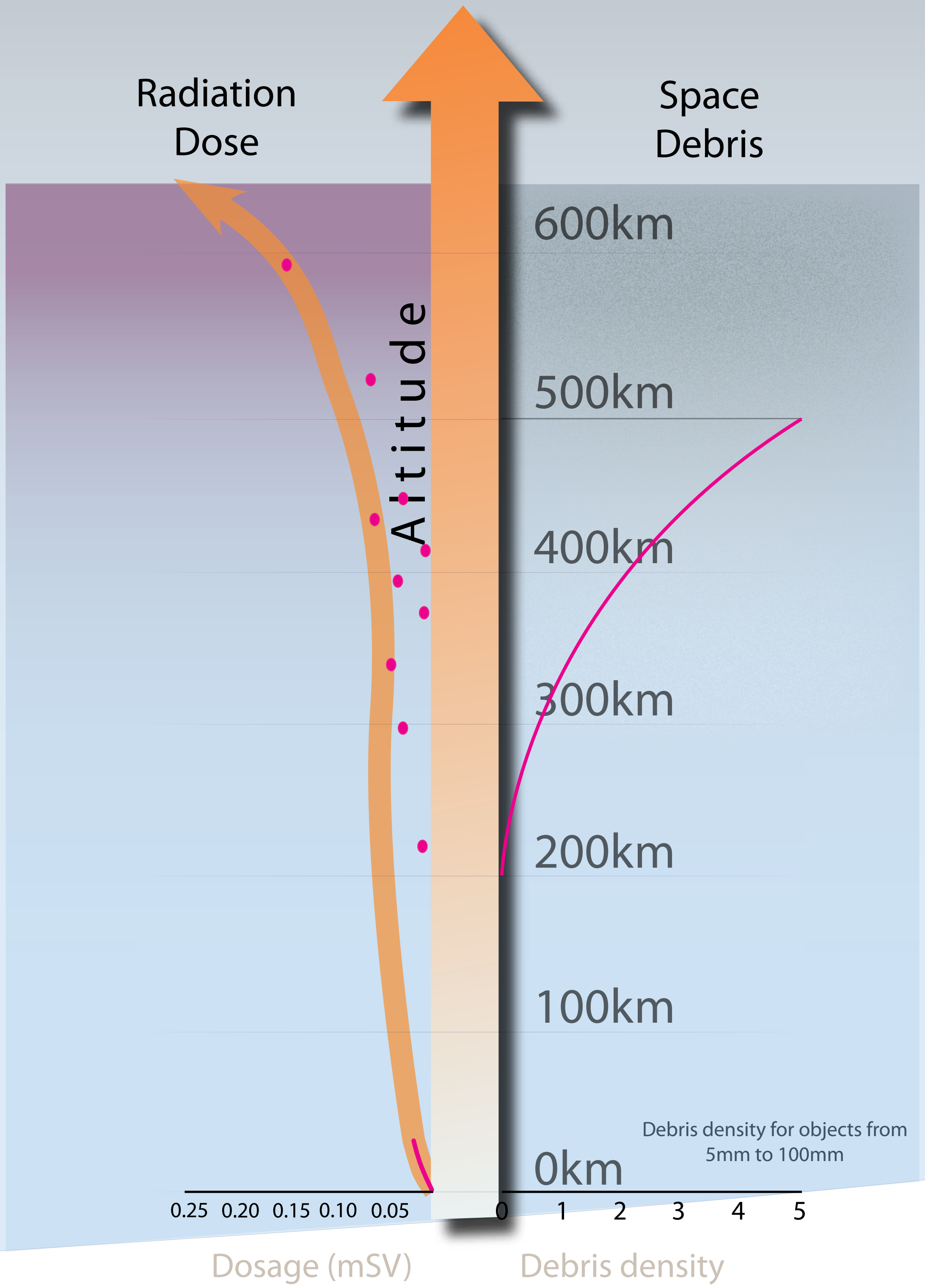


RADIATION

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 solar particle events would increase doses dramatically.

" Passengers must be made fully aware and consent to elevated risks but waivers of liability can not be relied upon. "



LEGAL CONSIDERATION

- Acceptable levels of safety and reliability must be reached to ensure access to insurance and sustainability of the industry in the event of accident.

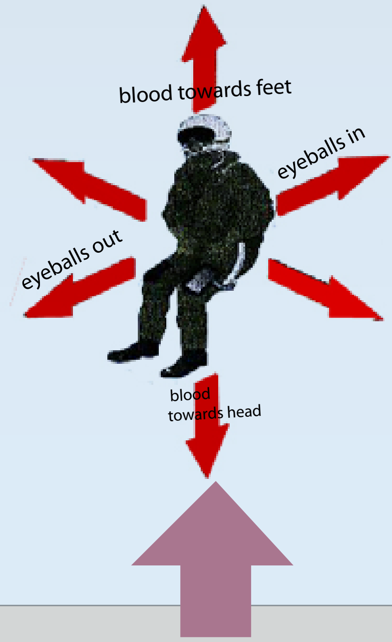
SPACE DEBRIS

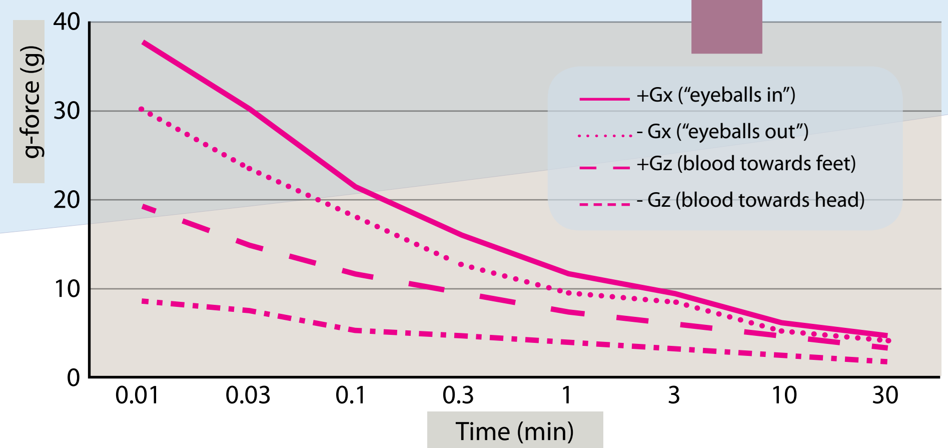
" a collision with a object greater than 5 cm that would be likely to destroy the space vehicle. "

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 a velocity of about 7 km/s. 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 10cm can be tracked and avoided, but smaller pieces remain a hazard.

G-LOADS

One of the most important medical issues is dealing with the g-forces expected 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 average passenger should not be subjected to G loads greater than 3+Gx and 2+Gz, and that the period of exposure to these 'maximum' G loads should not exceed thirty minutes.





" The core risk drivers for the suborbital transport system will be the propulsion systems during the ascent and the thermal system during the descent. . "

Growth

How will it develop?

Whether or not suborbital point to point transportation is feasible depends on many factors such as cost, funding, technological development, and growth of existing suborbital markets.

Parametric costing

A parametric costing model was created that illustrated the cost sensitivity for development, production, and operations of suborbital spacecraft. The SUB-ORB-TRANSCOST model developed for this project is based on specific scenarios only and do not cover all suborbital flights.

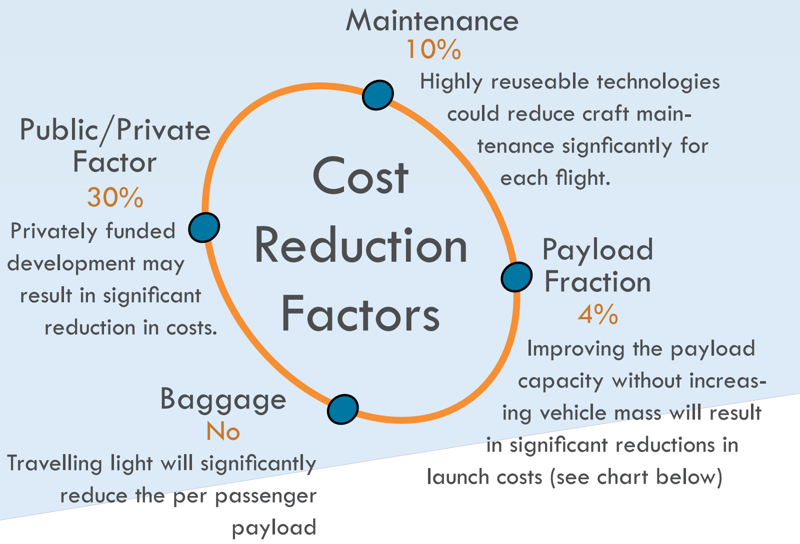
Based on a seven passenger aircraft capable of transatlantic voyages, the variance in costs resulted in ticket prices ranging from USD 70,000 to USD 525,000 for a seven passenger spacecraft. The variances illustrates just how sensitive to the this industry is to key cost drivers. Small adjustments to cost factors resulted in large variance in ticket price.

Cost Reduction Factors

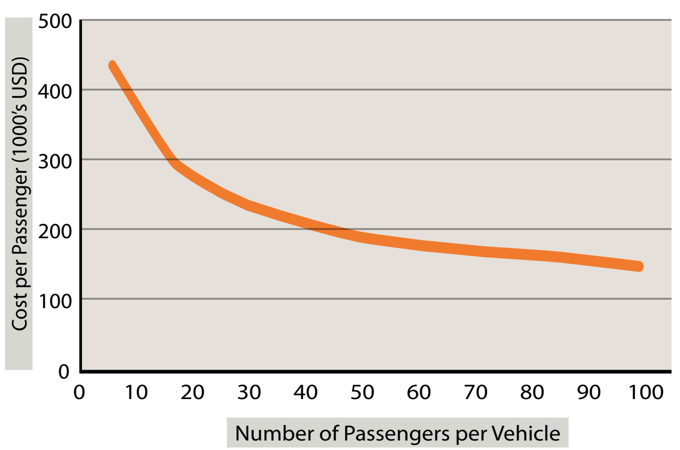
Significant reductions of the cost are possible by making optimistic assumptions about key factors in the model. Using the same model and adjusting the values for key factors including maintenance, payload fraction, baggage and source of funding the ticket price is reduced to USD 70,000.

Market Segmentation

Although market segmentation between vehicle developers and vehicle operators would reduce the cost per passenger by only a few percent, it may significantly lower the barriers to procuring the capital necessary to develop and operate suborbital transport systems.



> "Due to the high risks and long project development cycles, traditional capital markets and debt issue methods of fundraising is unavailable."



LEGAL CONSIDERATION

To aid in the sustainable development of the industry, designs and operations should mirror — to the fullest extent possible — those standards that have been set for the aviation industry.

> "Prizes, such as the X-Prize, remain a valuable means for achieving aerospace and technology development."

Funding

Due to the high risks and long project development cycles, traditional capital markets and debt issue methods of fund-raising is unavailable.

The risk-taking acts of venture capitalists, space angels, and the government could very well lay the monetary foundation of this 'New Space' venture.

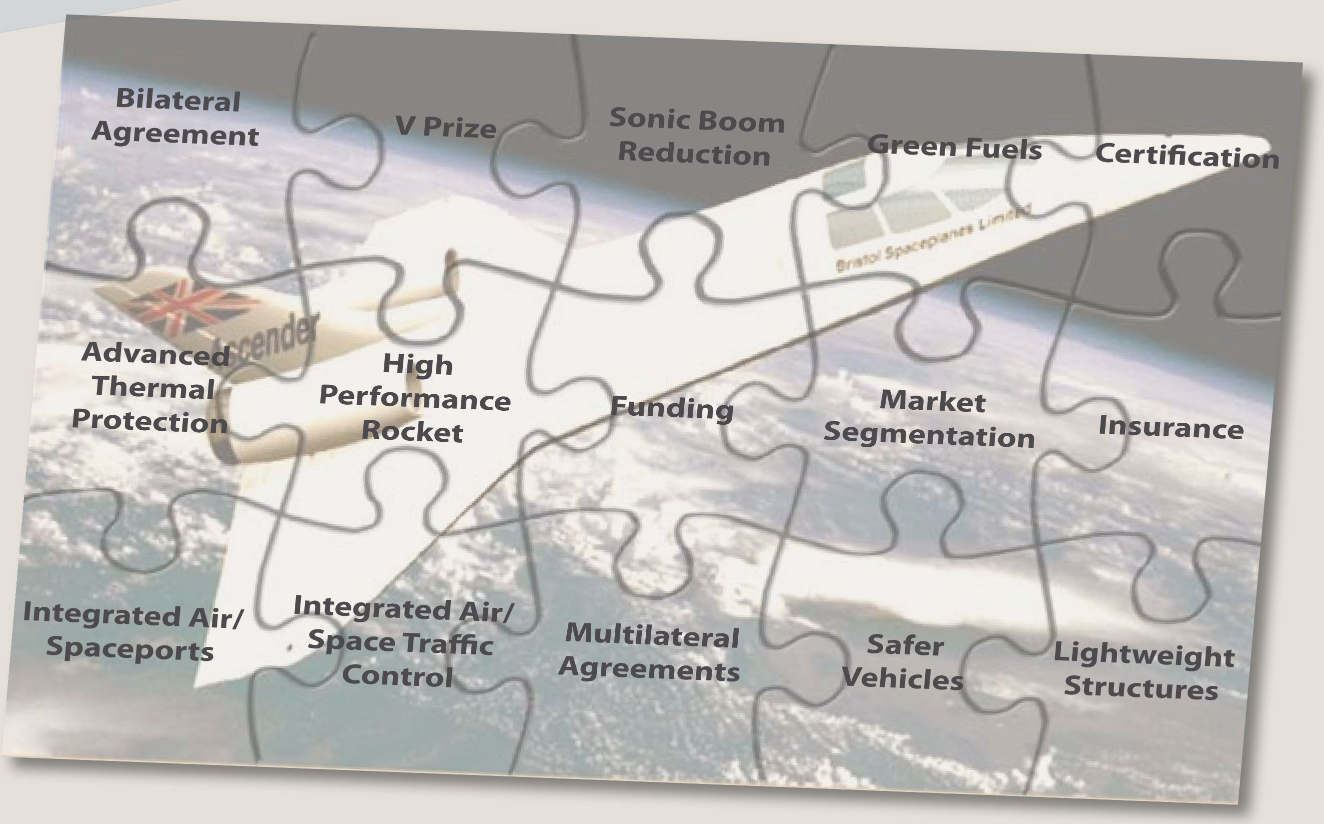
Prizes, such as the X-Prize, remain a valuable means for achieving aerospace and technology development. They can also serve as a gateway to alternative sources of funding.

Public-Private Partnerships are effective mechanisms for funding large-scale (space) projects.

The defense sector may also provide a source of funding borne of its own interests.

Putting All The Pieces Together

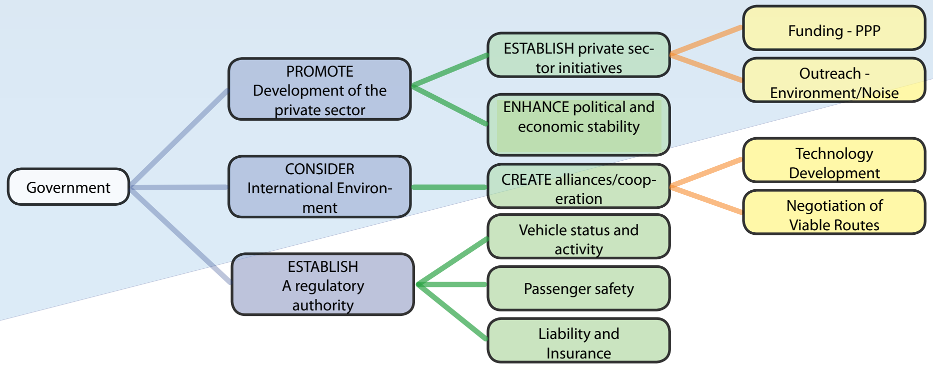
In order for there to be a viable suborbital point to point industry, a myriad of factors will be required.



Law & Policy

What role does government play?

The Role of the Government in the establishment of a viable suborbital point to point transportation industry is vital. Not only to encourage the growth of the industry through economic incentives but also through provision of necessary infrastructre and fostering international cooperation. Government involvement is summarised in the figure to the right.



Agreements

Interested States should enter into bilateral agreements to authorise the entrance of suborbital transportation vehicles in national airspace bearing in mind the principle of exclusive soverignty of national airspace enshrined in the Chicago Convention 1944. As the number of actors increases, multilateral agreements will be necessary to prevent a web of bilateral agreements.

International Space Flight Organisation	New Department under ICAO
• Proposed by FAA • Clarity of law and process • Specialised in suborbital/orbital activities • Would need an International treaty to establish it • International Governmental forum - issue of funding	• Benefit from the learning curve of air regualtion • International Forum known to all • Requires only an amendement of the Chicago Convention • Air/spacetraffic integration and management

As a result of multilateralism, the establishment of a hybrid law is recommended under a new governing authority or a new subdivision under the International Civil Aviation Organisation

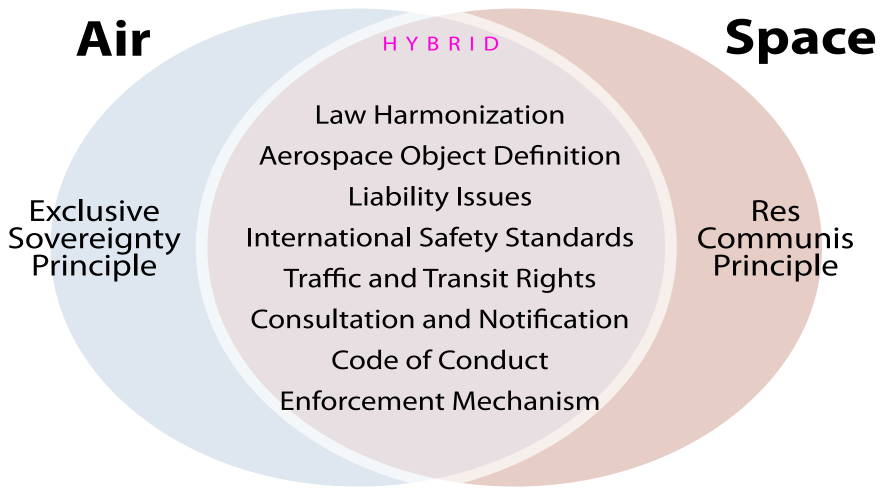
Legal Framework

There is no legal framework regulating suborbital activity. A legal regime for point to point suborbital transportation must account for the following:

- Rules for classification regulation of vehicles and the activity
- Traffic rights and overflight rights between States
- Rules for liability in the event of damage
- Permissible interation between operations and passengers

Conclusion

Current regulations do not provide for suborbital point to point transportation systems. There is no law that prevents such activity, dependent on policy decision to accept overflight or landing of suborbital vehicles on foreign territory. Through the establishment of hyrid legal framework, an international body should be developed as the industry grows. The main function of the body will be to ensure clarity of law and process in some of the areas shown below.



Conclusions

When preparing this report, a neutral position was adopted, neither przomoting the notion of suborbital point to point transportation nor seeking to put forward a negative prognosis simply because challenges exist. Those who dream of global travel at many times the speed of sound will be glad to hear that no insurmountable obstacles have been found.

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.

A significant theme, through all disciplines, is the desirability of a vehicle with aircraft-like characteristics. In fact aviation, with its comprehensive legal regime, well developed safety systems, and extensive infrastructure can act as both an example, and a support, to suborbital transportation.

With the technical, business, and route constraints that have been identified, it is probable that only a small number of routes will be viable. Coupled with a niche demand, it will be difficult for a vehicle program that is dedicated to suborbital point to point 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.

Key Findings

- There are only two relevant trajectories: Ballistic and Ricochet
- Distances over 12,000km (or 7,000km when 500km passenger height limitation is used) are in excess of orbital velocity.
- Typical travel times for the ballistic phase are less than an hour over any reachable distance on earth.
- Ricochet trajectories are the most suitable for distances greater than 7,000km
- Ricochet trajectories will probably be too uncomfortable for most passengers
- Suborbital routes should only be considered for distances beyond 3,500km
- The best potential international hubs are: London – New York – Tokyo
- New York – Los Angeles is a potential national route
- A Concorde successor will be a commercial threat to suborbital transportation
- Passenger and cargo transportation will be niche markets
- Prizes may be useful ways of opening up additional funding
- Spaceports will have to be easily accessible to the passengers
- The integration of spaceports with airports is preferable to dedicated spaceports
- Spaceports will have to satisfy rigorous environmental assessment
- Suborbital vehicles will have to be integrated with traditional air traffic control
- A vehicle with a horizontal powered takeoff and landing would be desirable
- Sonic boom reduction is needed
- Solid fuels are likely to be unacceptable. Green fuels will need to be developed
- Vehicles will have to withstand space hazards as well as traditional aviation hazards
- The ability of passengers to tolerate the G-loads is an important constraint.
- Orbital debris less than 10cm cannot be tracked and will pose a hazard
- Solar Particle Events will be hazardous to passengers
- Modifying aviation law is the most promising regime for suborbital transportation
- Space law, which is more flexible, may be useful in the early stages of development
- Bilateral agreements on landing rights could be the first legal regimes created
- Technology transfer limitations may impede progress

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