PRIVATE HUMAN ACCESS TO SPACE
VOLUME 1: SUBORBITAL FLIGHTS

International Academy of Astronautics

The International Academy of Astronautics (IAA), a non-governmental organization recognized by the United Nations, was founded in 1960. The purposes of the IAA are to foster the development of astronautics for peaceful purposes, to recognize individuals who have distinguished themselves in areas related to astronautics, and to provide a program through which the membership can contribute to international endeavors and cooperation in the advancement of aerospace activities.

Title: Private Human Access to Space Volume 1: Suborbital Flights

Edited by Angie Bukley and Walter Peeters

Printing of this cosmic study was sponsored by IISC (Douglas, Isle of Man)

INTERNATIONAL INSTITUTE
OF SPACE COMMERCE

International Academy of Astronautics
6 rue Galilée, BP 1268-16,
75766 Paris Cedex 16, France

9 782917 761359

Cover Illustration: Silverbird II (credit: by Ondrej Doule, Space Innovations)

PRIVATE HUMAN ACCESS TO SPACE
VOLUME 1: SUBORBITAL FLIGHTS

Editors:

Angie Bukley
Walter Peeters

Table of Content

Executive Summary

Public access to space has been mentioned since many decennia by visionary authors like Tsiolkovski. Initial thoughts were clearly geared towards longer duration orbital stays in so-called space hotels. Various studies showed that launch costs of the materials required to construct such massive hotels as well as the challenges of assembly in space were not compatible with a viable business model, as well as the, then, potential technical challenges that were still primarily mastered by the space agencies.

More recently, as a first step, the potential of private suborbital flights have raised more interest. Some of the technical challenges are still considerable, but very important challenges such as re-entry into the atmosphere are less demanding for flight levels just over 100Km. Starting with the X-Prize competition, which demonstrated the feasibility of this type of project with the first flights in 2004, a number of the competitors are now working on dedicated vehicles.

Early bookings and the high indication of interest prove that a considerable market segment of the population is interested in such an experience and quite highly motivated, even though at this stage when an operational solution is not yet available. Suborbital flights in the frame of ‘adventure tourism’ therefore no doubt have a potential market.

The keys to success are the technical solutions brought forward by the different competitors of the X-Prize. A big difference in the concepts exists between the single stage approach and a two-stage approach, whereby the first stage is a conventional plane that carries the rocket boosted vehicle up to a certain altitude before releasing it for the flight up to the 100 Km barrier, which is considered ‘space’. Chapter 3 of this document refers to the system engineering and practical challenges, which are to be solved in both cases. A number of promising tests are in progress, but at this point in time a fully operational and reliable solution is not available yet.

In addition to the vehicle itself, dedicated spaceports will be required to avoid interference with commercial air traffic and to also provide an environment that is compatible with the expected level of the customers and their families and friends. The prerequisites for commercial spaceports and the present situation are described in chapter 4, including in addition to the technical prerequisites a number of entertainment oriented facilities and simulators, in order to make sure that visitors and persons accompanying spaceflight participants can also enjoy the waiting and preparation time with space-associated activities.

The interior of the vehicles will need to be adapted to the customer requirements. Several preliminary design studies have been performed on this topic with an overview of the design parameters and potential solutions are given in chapter 5. Here we need to bring in some concepts of marketing, as all provisions may not be technically necessary, but it is evident that there will be a need to provide memorabilia after each flight for the participants. Examples of such memorabilia include flight suits, mission patches, t-shirts, caps, and helmets.

Originally designed to carry paying passengers, most of the spacecraft developers have quickly realized that the vehicles could also provide an alternative for microgravity experiments by carrying scientific or commercial payloads. This rather novel idea is addressed in chapter 6. When considering suborbital vehicles for conducting microgravity experiments, on the one hand the limited flight duration and the reduced microgravity levels are a constraining factor, but on

the other hand easy access as well as the possibility for a fast repetition of an experiment are strong advantages.

No market is sustainable without a relevant demand. Therefore, in chapters 7 and 8 attention is given to the motivation of the passengers as well as on the estimates of the potential size of the market. As in every market it is evident that a reduction in price will lead to a strong increase in the potential number of customers. Although several forecast methods are open to criticism, the number of advance bookings and the strong expression of motivation as a ‘once-in-a-lifetime-experience’ give a strong indication that many customers are willing to spend a considerable percentage of their savings to such trip.

Chapters 9, 10, and 11 address the boundary conditions. The first important concern is associated with medical requirements. Whereas professional astronauts are selected via a ‘select-out’ principle, we can assume a largely above average health status of professional astronauts, hence a much lower than average risk. This is not the case for suborbital flights where the operators will work rather on a ‘select-in’ basis to attract a maximum number of customers. Selection criteria and managing medical risks are therefore of paramount importance.

Legal and regulatory issues are an additional concern. The legal regime for suborbital flights is close to the debate if Air Law or Space Law is applicable. A decision on this will have considerable consequences, also in terms of applicable regulations and standards. Moreover, as we are dealing with hi-tech developments, we surely need to consider export control regulations and ITAR issues carefully.

There are therefore a lot of strong points to be mentioned in favor of suborbital spaceflight, but there are also a number of threats and risks. Therefore, the main points from the previous chapters are mapped in a SWOT analysis, which identifies the various Strengths, Weakness, Opportunities and Threats of this new business. As a result of this analysis, a number of recommendations are made.

1. Introduction: Objectives and Scope of the Report

Many excellent books have been written in the last years about space tourism. Most of them describe well the interests of the author, as well as those of the general public, on this topic. After all of the different conquests of Humanity, there is no doubt that this one, rather in close reach, is the one probably most alive in the imagination and aspiration of the general public.

Flights of first space tourist such as Dennis Tito have indeed shown to the public that at least it is technically feasible to realize such dream. The high cost is no doubt a major obstacle, but it has to be strongly emphasized that also the first air-tickets were far out of reach for the general public.

The objective of this document is to provide an overview of the different issues associated with private suborbital spaceflight to highlight not only the opportunities, but also the barriers that must be overcome while hopefully drawing sound and actionable recommendations from this for the different entities involved in space tourism. The method chosen is a SWOT analysis, highlighting the Strengths, Weaknesses, Opportunities and Threats linked to this new space activity in the near future. In this respect the report complies with the IAA objectives as expressed on the IAA website [1-1].

To avoid creating false expectations, it must be made clear that this report will not attempt to either summarize or complement the excellent books that have already been written on the topic. For those interested in such testimonies we refer here to two excellent recent works in this field [1-2], [1-3]. It is felt also appropriate here to make a reference to a visionary work in this type of publications, already published as early as 1990 [1-4].

We will also not refer to interim steps and preparatory (training) activities that are now offered worldwide in space camps. In addition to related websites, a good overview of these activities can be found in [1-5] and [1-6]. Note that on purpose reference is also made to this non-English language work, in order to illustrate clearly that the space tourism dream is universal and not limited to one nation!

With the exclusion of these interesting works, we have to introduce here a second delimitation. One could divide the present efforts to develop personal spaceflight (a more accurate name than space tourism) basically in three broad categories.

1.1. Suborbital Space Tourism

In this case a specially designed and developed vehicle will bring passengers to a height where they can for a few minutes experience microgravity and then come back to the same location from which they started their journey. As a general rule (originated by the X-Prize competition), such vehicles will fly at a height just over 100 Km above the Earth, offering 4 to 6 minutes of microgravity before smoothly returning, most of them as a glider.

1.2. Orbital Space Tourism

As will be noted in the historical overview chapter, this was in fact the first dream of visionary developers, starting from Tsiolkovski all the way to von Braun. In a second phase, existing vehicles, such as the Russian Soyuz spacecraft, were used to bring tourists to stations in Low Earth Orbit like the MIR station and the International Space Station (ISS). One of the flights used for this purpose were the so-called taxi-flights, whereby a Russian crew brought up a new Soyuz capsule and returned with the old one, which had been attached to the ISS. Some groups are still trying to develop such orbital space stations on their own, among which the Bigelow group is certainly the most well know (see Figure 1.1) as a result of their inflatable Genesis concept. The IAA SG 3.14 will publish Volume 2 of Private Access to Space addressing orbital flights.

Figure 1.1: Genesis Orbital Space Station (Courtesy: Bigelow Aerospace)

1.3. Point-to-point Suborbital Spaceflights.

In contrast to the other two categories, with these flights we are entering the era of commercial space transport [1-7]. One could consider this, in analogy with aeronautics, as the logic next step of rapid transportation once the technological barriers are mastered. It is evident that the technical obstacles of such flight (e.g. re-entry into the atmosphere) will pose even greater challenges, which still require a lot of research and development. A typical point-to-point (P2P) flight pattern is presented in Figure 1.2. It is important to note here that this document will hereafter only emphasize the first category of space tourism activities, namely suborbital spaceflight.

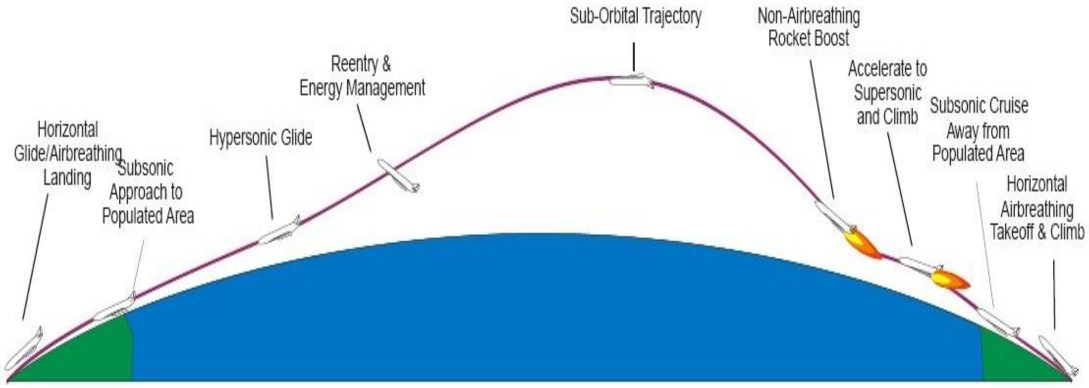


Figure 1.2: P2P Flight Pattern [1-8]

It is important to highlight the fact that this work is intended for a broad audience and is not intended to provide highly detailed technical descriptions, for which other works are much better placed. This report is intended to provide as objectively as possible an overview of the present situation and present the associated challenges, considering not only the technical and market aspects, but also the medical, legal and regulatory boundary conditions and constraints. An overview of different related aspects is given in reference [1-9], whereas the commercial and legal challenges are well described in [1-10].

One final remark on the different chapters: most chapters are written by experts on that topic and reference is made to them in the table of contents. The chapters without such reference are the responsibility my co-author and I and are based on studies done in the International Space University (ISU) and the International Institute for Space Commerce (IISC).

2.The History of Space Tourism

2.1. Space Hotels

Already from the period of the first dreams of space activities onwards, public access to space has been in the mind of space pioneers. An early example can be found as early as 1929 when Konstantin Tsiolkovski made a proposal for a 3000 meter long cylindrical habitat in space with a diameter of 3 meter and providing place for 300 families. The visionary scientist even calculated the artificial gravity via rotation and ‘gardens’ in the middle serving a closed loop life support system [2-1].

It is interesting to note here that first projects were focusing on larger Space Hotels, like the circular space habitat proposed by W. von Braun in 1952 (see Figure 2.1). There is very little early discussion on e.g. suborbital personal spaceflight.

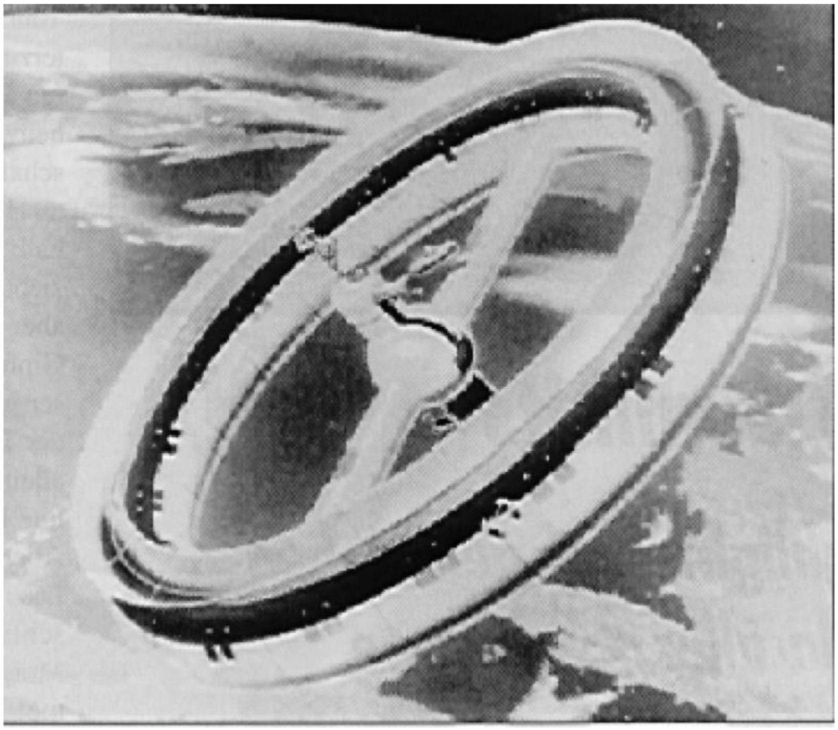


Figure 2.1: Space Hotel concept of Von Braun [2-2]

The design, which is most often found in literature, is the concept of the Shimizu Corporation of 1989 [2-3]. It is a circular design whereby the rotation is foreseen at some 3 rpm, providing for an artificial gravity of approximately 0.7g. In the outer ring, as shown in Figure 2.2, 64 guestrooms were foreseen of 7 meters in length and 4 meters diameter.

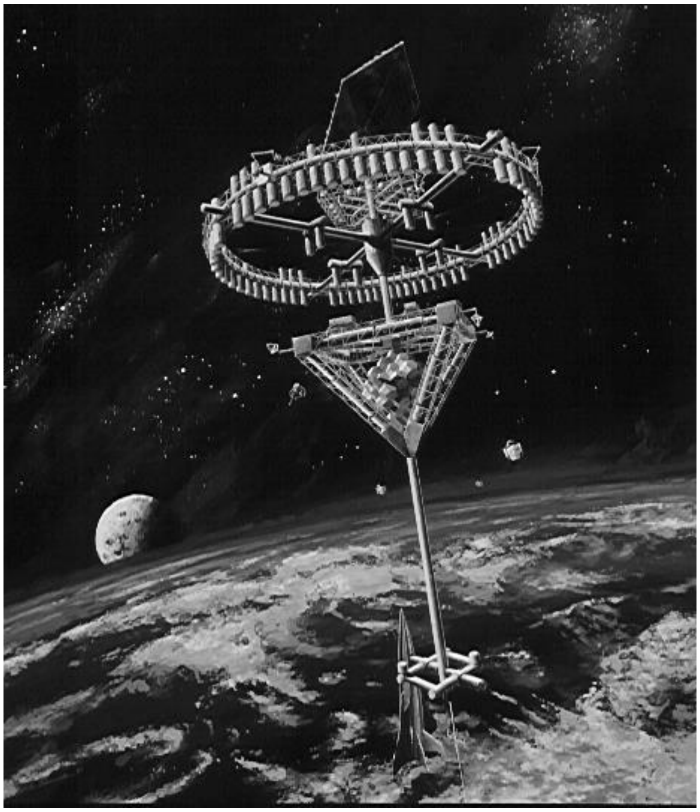


Figure 2.2: Shimizu Space Hotel project from 1989 (Courtesy: Shimitzu Corp.)

The corporation was targeting to put the hotel in operation around 2020. Taking into account a forecasted mass of 7,500 tonnes, this put a high challenge on available upload capacities (approximately 30 tonnes for the Shuttle) and made also the target date rather optimistic. Here we reach the first point of reality check. The present launch capacity and launch prizes make such projects unfeasible at this point in time.

2.2. Early (Orbital) Spaceplane concepts

As noted earlier, there are in fact less early traces of space tourism vehicles derived from spacecraft [2-4]. One of the first concepts that came to the public attention was designed by a brilliant engineer in the USA, Tsien Hsue-shen**.** The ten-passenger project was commissioned in 1949 by TWA (see Figure 2.3) but did not develop further than the concept phase (also as the designer was virtually forced to leave the country in the post-war anti-communist period and went to China, becoming the father of the Chinese space sector).

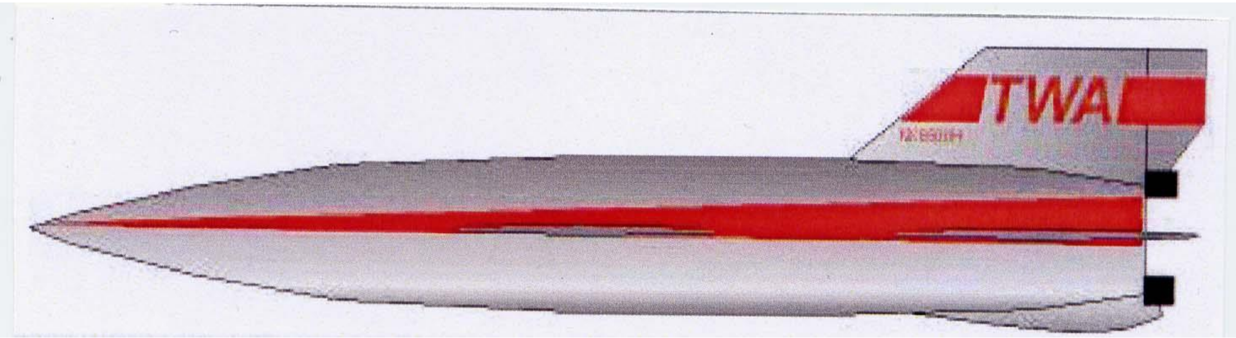


Figure 2.3: Early Space tourism concept (1949)

Later a number of government-financed designs combined both elements, such as in the very elegant Ascender design as shown in Figure 2.4. In this concept, an airplane like transport vehicle lifts off at a normal airport and at a certain height ignites additional rocket motors. The latter design is still being pursued in development and can be followed on the Bristol Spaceplanes Ltd website, www.bristolspaceplanes.com. The spaceplane is scheduled to carry three passengers and one pilot. These and derived concepts were the basis of one of the first concise books on Space tourism in 1990 [2-5].

Figure 2.4: Ascender (Courtesy: Bristol Spaceplanes)

One interesting and less known project was to transform the Shuttle cargo bay to carry 74 passengers, as shown in Figure 2.5, which was studied by NASA in 1979. The (then) estimated ticket prize of 3.4 Million dollar per seat was certainly too high to create a viable market (without windows and with very limited possibilities to move!)

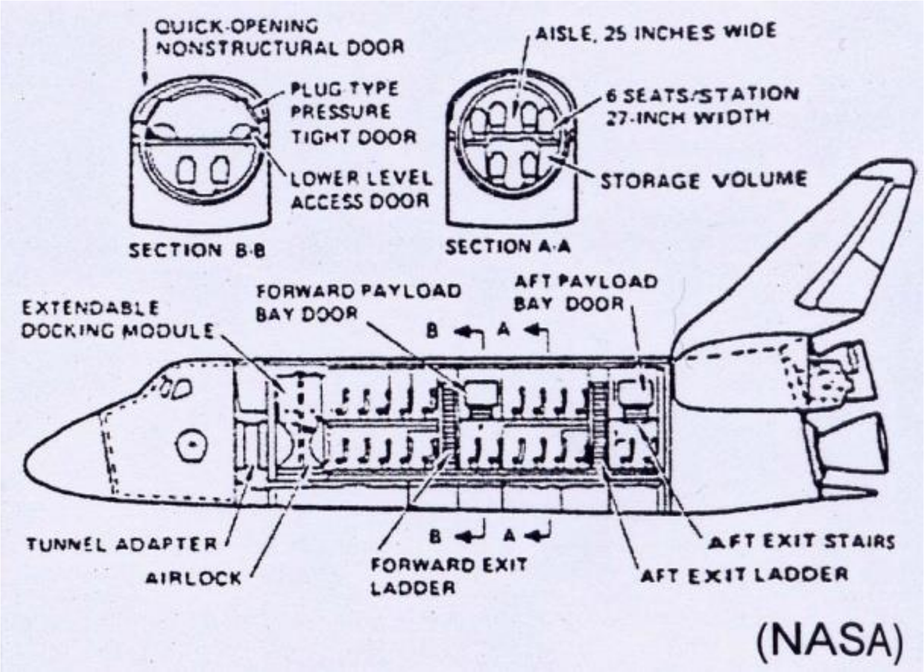


Figure 2.5: Proposed use of the Shuttle cargo bay for space tourism (Courtesy: NASA)

It is now hard to identify unambiguously with all these projects the one that introduced the complete space tourism concept first. Many indications go into the direction of the very visionary space pioneer K. Ehricke who presented a paper on this at an AAS conference in 1967 [2-6]. An overview of significant historical events in the space era with very interesting, anecdotal information can be found in [2-7], providing insights in factors leading to the public conquest of space.

2.3. The X-Prize Effect

A considerable boost in the suborbital space tourism field was provided by the very creative X-Prize competition. The competition was opened in 1996 and offered a 10 million USD prize to the company performing a space trip under following conditions [2-8]:

- The spaceship had to be privately financed and built.
- At least three adults (or the equivalent mass thereof) had to be carried to at least a 100-kilometres altitude.
- The craft had to be able to fly twice in 14 days.
- Max. 20% of the parts would be disposable.

These requirements therefore forced private designers to develop a reusable concept, putting the foundation for a feasible business plan afterwards. Approximately 28 teams competed, SpaceShipOne, shown in the photograph in Figure 2.6 won the competition in two flights on Sep 29/Oct, 4 2004. As one can see from the figure, the design is a two-stage one whereby the first stage (called White Knight) carries the second stage up to 16 km, whereas the second stage then lifts off to reach 110 km, providing 4-5 minutes of microgravity.

Figure 2.6: SpaceShipOne, winner of the X-Prize Competition (Courtesy: X-Prize)

Richard Branson, the well-known entrepreneur, took over the financing and responsibility of the further developments of this concept via a new company, Virgin Galactic. At present the company is developing a successor of SpaceShipOne, called SpaceShipTwo, which is targeted to carry six passengers. First operational flights are foreseen to carry passengers in 2014.

3. Suborbital Vehicles

Part 1: General Requirements & Blueprint for the Ideal Suborbital Vehicle

3.1. General Remarks

Personal spaceflight in the suborbital regime will have to employ newly developed vehicles. Other than in orbital space tourism, where commercial offers so far (as of June 2013) have been relying on the proven Soyuz spacecraft from the Russian space program, there is no equivalent for suborbital utilization. The last government-sponsored, crewed vehicles that flew to suborbital space in the past were the Mercury-Redstone rocket (last flown in 1961) and the X-15 experimental rocket plane (last flown in 1968), both from the US [3-1].

The successful flights of SpaceShipOne in 2004, ultimately leading to winning the X-Prize, set a precedent for a privately funded vehicle capable to go to space. Despite its proven capabilities, SpaceShipOne had never been intended to become a commercially operated vehicle; yet its design has served as a blueprint for subsequent concepts intended for routine operations. The most advanced so far is the SpaceShipTwo (see below), likely to go commercial in 2014 [3-2]. But there are also other companies pursuing such projects, making for quite some diversity in design and layout, which makes it quite different from today's commercial aviation. The latter can look back at almost 100 years of design evolution that has finally matured into the modern jet airliner. Differences between products of the few remaining manufacturers (mainly Boeing and Airbus) equal only nuances and most passengers do not care about the maker of the aircraft they are flying in, as long as air fare and on-board service are in line with their expectations or corporate travel regulations [3-3].

On the contrary, suborbital personal spaceflight is just emerging and thus still many years away from having a track record in design evolution comparable to today's commercial aviation. Due to the lack of precedents, except the aforementioned SpaceShipOne or the long-defunct X-15, manufacturers of future commercial vehicles seem to enjoy a high degree of freedom when designing future rocket ships or spaceplanes. Nevertheless, in the end the design of a commercial vehicle must serve the ultimate cause of any commercial enterprise, that is: a profitable business. Therefore, designing a craft for suborbital personal spaceflight must meet a number of high-level design criteria. Without having to go down to actual design requirements, those criteria will help to select a particular vehicle alternative. The respective criteria are listed in Table 3.1.

Table 3.1: High-level design criteria for commercial suborbital passenger vehicles

Technical	Maturity Vehicle Configuration Safety and Reliability Propellants and Emissions
Operational	Maintainability and Turnaround Durability and Lifetime Crew Training Productivity

Passenger	Mission Duration Maximum Acceleration Cabin Accommodation

These criteria may be involved in two different decision processes. The first is the decision of the builder (the Rocket Company) who decides which vehicle to design and build, in order to sell it to commercial operators [3-4]. The second is the decision of the Operator (the Spaceline) who decides which vehicle to buy from the alternative rocket companies. Each design criterion will be described in more detail in the following sections.

3.2. Technical Considerations

3.2.1. Maturity

The maturity of a vehicle design is of foremost importance to its builder. It is reflected in the technology readiness level (TRL) of the complete vehicle and its key components [3-5]. With respect to subsystems, technology readiness level ranges from the ubiquitous, commercial off-the-shelf (COTS) on one extreme (mature; TRL 9) to the very new and radical, not-proven-yet on the other (immature; TRL 1). In the public perception, space technology is often associated with a lack of maturity that brings with it the risk of unforeseen cost overruns and other ramifications. So, in the nascent market of commercial space tourism, maturity per se has to be seen as something positive.

With respect to complete vehicles, maturity equals the current state i.e. level of development. Here, the very early pre-design stage equals “immature”. Maturity increases with every stage in the design and development process and a flying and certified vehicle equals a “mature” technology.

The vehicle’s maturity directly impacts the time needed for developing technology to the level of commercial utilization – the so-called “Time to Market” (TTM). Please keep in mind that it will have taken Virgin Galactic approximately 10 years (!) from closing the deal with Scaled Composites (the builder of SpaceShipOne) to deliver a fleet of vehicles to finally flying commercially. This long time came about ***despite*** Scaled Composites having a flying craft at the time of deal closing. Imagine a competitor who had only developed slide-ware so far. How long would the TTM be? Twenty years? No investor in his right mind would want to take a stake in such a venture.

3.2.2. Vehicle Configuration

The configuration of the chosen vehicle must allow operations from a dedicated Spaceport. For space transportation systems in general, the basic decision is between a ballistic and an aerodynamic (winged) design [3-6].

Most space transportation systems in the past were vertical liftoff ballistic rockets. Launching vertically brings with it a very high rate of climb. Typically it takes less than a minute to climb to the 15 km altitude where commercial air space more or less ends. Having a ballistic vehicle launch from a regular airport would disrupt air traffic for quite some time; up to hours in case of launch aborts during ascent. In view of today’s traffic density around big airports, with take-off and landing slots only minutes apart, it seems prohibitive to even consider launching ballistic vehicles there.

Therefore, only winged vehicles are considered without disrupting air traffic. As long as it has wings, it can also land horizontally like an aircraft. Wings provide additional safety and offer an inherent engine-out capability that is not present in ballistic vehicles. A powered landing capability would be even better, as it allows touch-and-go on the runway in case of emergency. This automatically leads to a horizontal take-off, horizontal landing (HTOHL) mode for the vehicle in question.

Another important design parameter is the number of stages in a vehicle. Is it single-stage or does it need a booster stage or carrier aircraft? So far, two-stage concepts are proven (see Spaceship One) and have demonstrated technical feasibility. Single-stage concepts for suborbital applications would also be energetically feasible and promise more ease of operations, as no stages separate and have to be reintegrated. Hence, single-stage seems more desirable, but also offers a smaller performance margin [3-7].

3.2.3. Safety and Reliability

Maximum safety is a design criterion of highest priority. Safety is defined as the inverse probability of a loss of vehicle and passengers. In crewed space flight, this figure, at roughly 99%, is still far away from being acceptable for routine tourism flights. Thus, respective safety means have to be included in the design, keeping in mind those future commercial vehicles will have to be certified or licensed by aviation authorities like the FAA in the US [3-8].

Safety can be increased, for instance, by making key components redundant, such as having two engines instead of one; or by having wings for an unpowered landing in case of engine failure. Design options are numerous and will have to be reviewed thoroughly.

After safety comes reliability. Per definition, a safe, but “unsuccessful” mission is still capable to return the vehicle and its passengers either to the launch site or an alternative landing site. But what happens, if a mission that costs passengers a six-digit dollar sum cannot be accomplished as promised?

Probably, every time a mission fails (albeit vehicle, crew and passengers are unharmed), it has either to be re-flown or the paying passengers have to be reimbursed or compensated otherwise for the lack of success. “Success” in suborbital space tourism means to have definitely reached (at least) an altitude of 100 km and hence becoming eligible for the title “astronaut” (with certificate and all). To the operator, it has to be clear that every failure to provide the customers with these credentials is a failed mission.

Hence, maximum mission success is a matter of achieving a high degree of mission reliability. Vehicle architectures that are based on proven hardware components and have undergone a large number of tests and operational flights should be preferred. The operator may even specify a level of mission success probability to be demonstrated before buying from the builder. Mission reliability is enhanced by selecting the proper technology and will be determined to a large extent by the design features of the vehicle.

3.2.4. Propellants and Emissions

The key question with regard to the selection of propellants is: how suited is the propulsion system and its required propellants for commercial, everyday use?

There are a lot of different propellants available for space applications. As a bottom line, one can say that propellants that are easily available, well tested, proven, storable, not classified as explosives, produce little pollution and can be certified as “non-toxic” are best suited, provided that their performance is sufficient for the mission at hand [3-9].

Because there are suborbital vehicle concepts that employ all kinds of chemical propulsion systems, namely liquid, solid and hybrid propulsion, a trade-off between technical and operational merits needs to be made in every single case. For example, the combination of liquid oxygen (LOX) and liquid hydrogen (LH2), has a very high performance (specific impulse of approximately 450s), is environmentally benign (combustion products are mainly steam), but the complicated handling of the liquid hydrogen renders it unattractive for near-term space tourism applications. Some of the present designs are shown as illustration in figures 3.1 and 3.2. The Lynx by XCOR will use liquid propellants only, namely LOX and kerosene (RP-1). These are well understood and their environmental impact is similar to those of commercial airliners [3-10]. SpaceShipTwo has been foreseen for commercial operations beginning in 2014. Its throttleable hybrid rocket engine – a N2O/HTPB engine – burns hydroxyl-terminated polybutadiene (HTBP) with nitrous oxide. Its exhaust gasses are non-toxic but contain a lot of smoke particles [3-11].

Figure 3.1: Artist impression Lynx (Courtesy: XCOR)

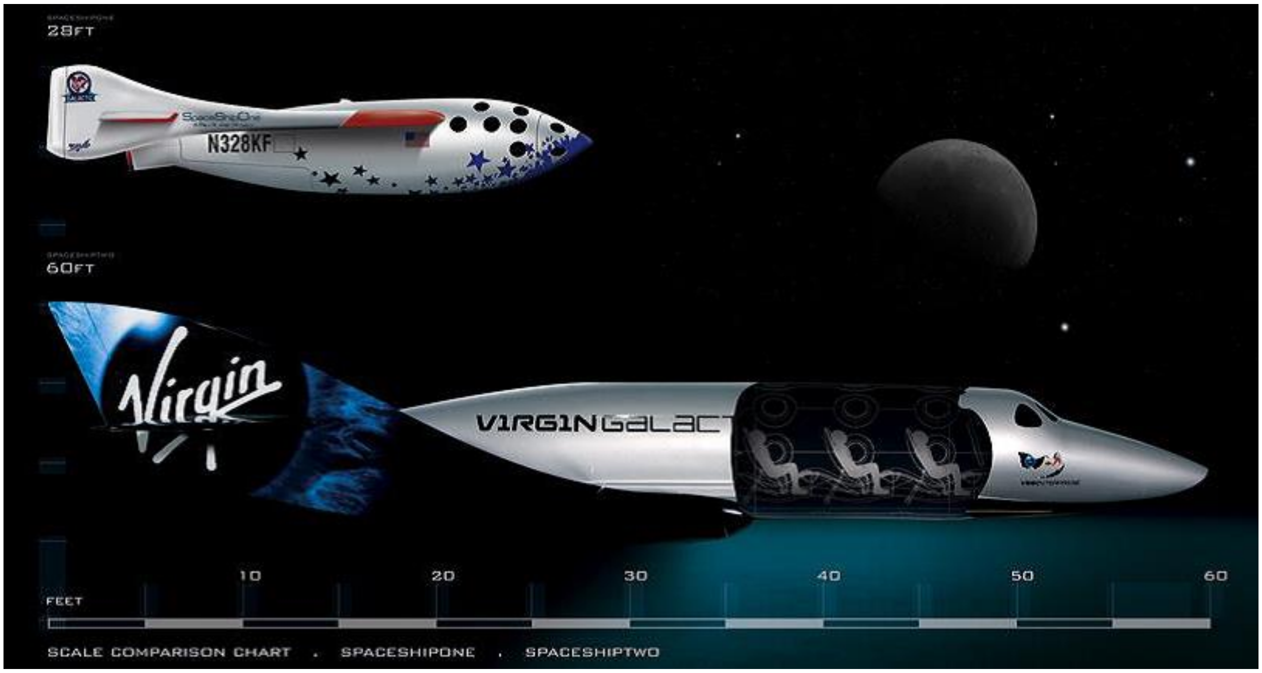


Figure 3.2: Artist impression SpaceShipTwo (Courtesy: Virgin Galactic)

3.3. Operational Aspects

The extent to which special infrastructure is needed depends on the design of the vehicle. It may require special hangars, maintenance tools, facilities, longer runways, and adapters for existing airport infrastructure, training facilities, safety equipment and more. The ideal suborbital vehicle is like a commercial airliner and can smoothly be integrated into an existing fleet of commercial air transports. Ideally, it uses the same fuel (kerosene), can be parked in the same hangars and uses the same runways and taxiways as all the other aircraft. It doesn’t need special cranes, winches, derricks and gantries, hoisting rigs , or other specialized handling equipment [3-12].

3.3.1. Maintainability and Turnaround

Low maintenance requirements is a design feature that insures short time intervals between two missions of one and the same vehicle and helps to minimize hardware cost for spares. Longer intervals for scheduled maintenance shall be preferred. Vehicle concepts that are designed in accord with this objective deserve a high rating [3-13].

3.3.2. Durability and Lifetime

The higher the expected life of key components, the better is the vehicle’s cost performance. That certainly helps the economic wellbeing of a future space tourism business. Key components with a high impact on the life-cycle cost are the vehicle structure (fuselage, tanks, wings, landing gear…), the engines and the electronics [3-14].

In several earlier studies, the engines were identified as the single most important cost driver. Consequently, the sensitivity analysis of financial performance against the (expected) engine lifetime and recurring engine costs has become good business practice in the writing of business plans for space tourism [3-15].

3.3.3. Crew and Crew Training

A vehicle layout that is similar to proven aircraft designs helps to lessen the requirements on the crew and crew training. Most experienced pilots seem to follow the rule “as long as it has stick and rudder, I can fly it”. As could be seen with Spaceship One, a major share of pilot training could be handled with a flight simulator, eliminating the requirement for a flying testbed [3-16].

3.3.4. Productivity

Vehicle operators seek high productivity [3-17]. In the case of suborbital passenger flights, it is a measure of revenue per unit of time per vehicle, e.g. $120 million per year or $600 million over the lifetime of one vehicle . Productivity is driven by ticket price, passenger capacity (number of passenger seats) and flight frequency per vehicle (a function of turnaround time). Plus, the more flights a vehicle lasts, the better its lifetime productivity. In order to achieve the same productivity in a given time, smaller capacity vehicles have to fly more often than vehicles with more seats. Usually, an increase in passenger capacity (number of seats) leads to better cost-efficiency, assuming that load factors (the percentage of seats utilized per flight) stay at 100%. On the other hand, vehicles with fewer seats tend to be smaller, thus helping technical feasibility and unit price. Currently, SpaceShipTwo (SS2) sets the benchmark with 6 passenger seats (+ 2 crew), the Lynx has only one passenger seat (+ 1 pilot). Yet, the Lynx is designed to fly 4 times per day while the flight rate for SS2 has not been determined yet; on its website Virgin Galactic only claims to “have several flights per day when regular operation starts” for an initial fleet of five SS2 [3-18]. Nevertheless, it may be assumed that there is something like an optimum number of seats for a suborbital space tourism vehicle.

3.4. Passenger Considerations

3.4.1. Mission Duration

In suborbital spaceflight, restrained by unforgiving Newtonian physics, the most interesting part of the flight (beginning with the ignition of the rocket engine) is kept down to a duration that adds up to minutes rather than hours. The microgravity phase typically lasts only two to three minutes. In that case, any additional performance which leads to higher altitudes and a longer duration of the microgravity phase of the whole mission would be highly appreciated, since it would allow the fare-paying passengers to unbuckle and float around inside the cabin. Yet, it has to be kept in mind that higher altitudes ask for a higher delta v, which in turn equals higher energy needs. As the energy and therewith the mass of propellant increases with the square of velocity at engine cut-off, there are severe limits to vehicle size and practicability [3-19].

3.4.2. Maximum Acceleration

Since the beginning of aviation medicine (and later space medicine) a lot has been written about the effects of acceleration forces on the human body. Today, it is more or less a general consensus in aerospace medicine that average, untrained humans should not be subjected to accelerations that are significantly higher than 5g (five times the Earth’s gravity), regardless of flight phase [3-20]. Therefore, a commercial space tour vehicle should be designed and configured in a way that it complies with this restriction. As a guideline, a typical expected g-load profile is illustrated in Figure 3.3.

3.4.3. Passenger Facilities

The amount of usable cabin volume per passenger as well as the number and size of windows is a very important factor for the subjective comfort level of passengers [3-21]. A large cabin volume reduces the danger of passengers getting claustrophobic. Numerous windows which should be as large as possible and face in many different directions guarantee that passengers get what they seek the most (according to market research): an uninhibited view of our home planet against the blackness of space [3-22].

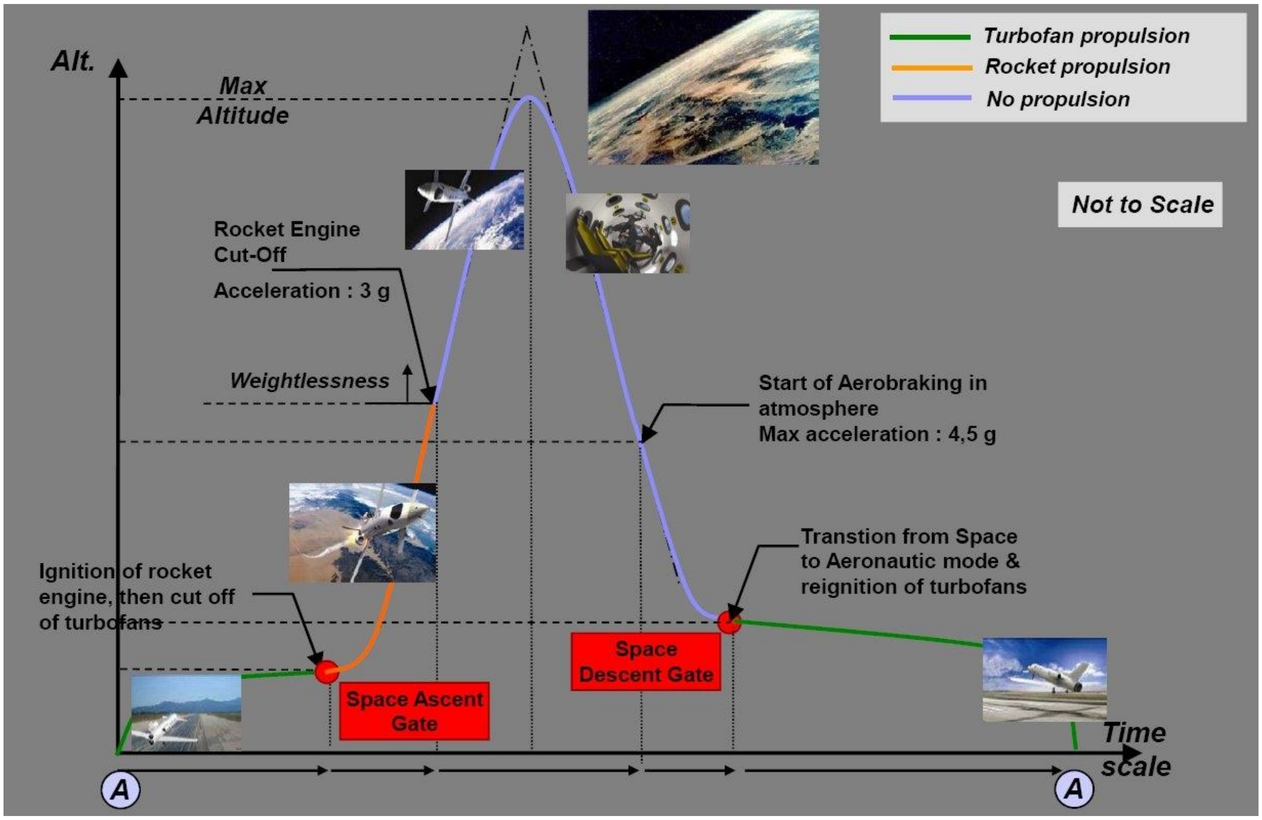


Figure 3.3 Typical flight pattern showing change in propulsion phases (Courtesy: EADS)

The history of space travel has shown that wearing a space suit simplifies life support for astronauts end enhances safety in case of emergency. Yet, if given the choice, most passengers will undoubtedly prefer to fly inside an environmentally controlled cabin that provides a shirtsleeve environment instead of being required to wear a somewhat clumsy pressure suit that restricts body movements and will inhibit the experience of freely floating in microgravity. Mainly, it is a trade-off between safety and comfort (and finally, cost), as to which solution for a life support system is best [3-23].

3.5. Regulatory Criteria

In addition to purely technical criteria as listed above, there are also some regulatory criteria that may prevent proper utilization of a vehicle. While being non-technical in nature, these may include some serious showstoppers for the technical implementation of a commercial venture. First, the vehicle has to be properly certified by the FAA (Federal Aviation Authority (US)) or a similar government agency, since experimental vehicles are off limits for commercial operations [3-8]. Second, the vehicle shall not include hardware subsystems or components that are subject to export restrictions. Third, the vehicle shall not be subject to limiting agreements with third parties, like, for instance, non-competition agreements.

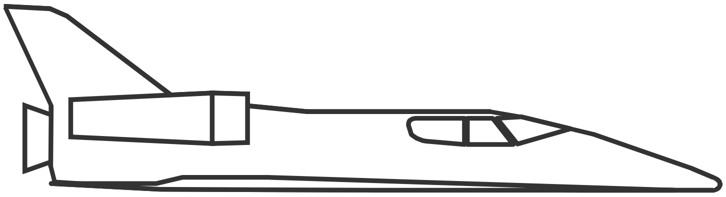
3.6. Blueprint of the Ideal Suborbital Vehicle

The experience gained from over five decades of operating human-rated space launch systems suggests that human space flight is still no routine affair. The only operational (as of late 2013) vehicle theoretically available for private space flight – destination: International Space Station (ISS) – is the Russian Soyuz. It has a "ticket price" that would have to be individually negotiated and used to run in the order of several ten million dollars in the past. The supply of such "tickets" for vacant third seats in the Soyuz is close to zero [3-24].

Suborbital tourism, on the contrary, expects annual passenger numbers running in the hundreds or even higher, making it appear closer to commercial air travel than current human spaceflight [3-12]. Turning flights to suborbital space into a viable business needs a different design approach, with vehicles aiming for "airline-like operations". This means that top priority has to be given to parameters like vehicle safety, full reusability, quick turnaround, and to the reduction of recurring costs.

The top-level design features of an "ideal suborbital vehicle for space tourism applications" are shown in Table 3.2, see also [3-24]. Note that these features are <u>not</u> binding design requirements, but express preferences as collected over roughly 20 years of space tourism research [3-12, 3-19, 3-22–25]. With suborbital personal spaceflight expected to evolve over the next decade, it is likely that over time, one design will outperform its competition. Therefore, over the long term an "industry standard" will establish itself, like the modern jet airliner did for commercial air travel.

Table 3.2: Top-level features of ideal candidate vehicle

<table>
<tr><td colspan="2">The Ideal Suborbital Vehicle (SOV) for Space Tourism Applications

(Sketch is not representative of actual design)</td></tr>
<tr><td>Technical Aspects
▪ Proven flight hardware
▪ Single Stage
▪ Horizontal take-off, horizontal landing
▪ Powered landing capability
▪ Engine-out capability
▪ Safe and non-toxic liquid propellants</td><td>Operational Aspects
▪ Independent from special infrastructure
▪ Short turnaround
▪ Minimum expendable subsystems
▪ Long average lifetime of subsystems
▪ Low crew training requirements
▪ High productivity</td></tr>
</table>

Passenger Aspects	Legal Aspects
- Long duration of "space part" of mission - Low accelerations during ascent and descent - Shirtsleeve environment - Spacious passenger cabin - Low passenger training requirements	- Export is feasible - FAA-like certification is feasible - No limiting agreements with third parties

3.7. Design Approaches

A number of different design approaches have been considered over the years to put people and payloads in space. Pelton has compiled a table that summarizes the various approaches to achieving this goal in [3-12]. The various approaches considered and the companies using each approach are presented in Table 3.3.

Table 3.3: Design approaches and the companies pursuing each [3-12]

Technical Design Approaches for US and International Commercial Space Systems (Note: Some Systems Developments Have Been Abandoned)	
Approaches for Accessing Space	**Companies Using this Particular Approach**
Lighter than Air Ascender Vehicles and Ion Engines with high altitude lift systems to provide access to LEO.	JP Aerospace (Commercial venture with volunteer support)
Balloon Launched Rockets with capsule return to ocean by parachute	Da Vinci Project, Planetspace, HARC, IL Aerospace
Vertical Takeoff Vertical Landing	Armadillo Aerospace, Blue Origin, DTI Associates, JAXA, Lockheed Martin/EADS, Masten Space
Vertical Takeoff and Horizontal Landing (spaceport)	Aera Space Tours, Bristol Space Planes, C&Space, Air Boss, Aerospace Inc., Energia, Lorrey Aerospace, Phoenix and Pre-X by EADS Space Transportation, Planetspace, SpaceDev, Space Transportation Corp., Space Exploration Technologies (SpaceX), Sub-Orbital Corp, Myasishchev Design Bureau, t/Space, TGV Rocket, Vela Technologies, Wickman Spacecraft & Propulsion.
Vertical Takeoff and Horizontal Landing (from ocean site)	Advent Launch Site, Rocketplane/Kistler (Financial Status unclear after NASA Contract cancelled)
Horizontal Takeoff and Horizontal Landing	Andrews, Scaled Composites, the Spaceship Corporation, Virgin Galactic, XCOR, and Project Enterprise by the

	TALIS Institute, DLR and Swiss Space Systems
Tow Launch and Horizontal Landing	Kelly Space & Technology Inc.
Vertical Launch to LEO from Spaceport	Alliant ATK, Inter Orbital Technologies, Rocketplane/Kistler, SpaceHab, UP Aerospace
Launch to Leo from Cargo Jet Drop	Triton Systems
Robotic Systems to LEO using Scram Jet Systems	Reaction Engines

Part 2: Design Solutions

3.8. General Principle

Reaching an altitude of 100 km or more with a manned vehicle is indeed complex; it is very similar in principle to what was done by the X-15 in the 60’s, but there was then only one test pilot, highly trained, and the flight was quite risky.

In terms of physical principle, the mission is however simple: the spacecraft shall reach a velocity at a given altitude such that the kinematic energy exchanged into potential energy allows it to reach 100 km altitude.

Theoretically, without any loss, the specific energy of a 100 km altitude mission is 1 MJ/kg, while reaching a very low orbit requires 34 MJ/kg. Considering an “injection” (engine cut-off) at 10 km altitude, the equivalent of 0.1 MJ/kg potential energy with a perfectly vertical flight path and no loss, the corresponding required velocity would be 1340 m/s, or 4830 km/h, in the range of Mach 4.3.

Such a velocity is unfortunately out of reach today with conventional turbojet engines; world altitude record is currently 37.6 km with a fighter capable of reaching nearly Mach 3, the main loss being the curvature of the velocity vector to render the trajectory vertical. Some improvement can be expected in the coming years with improved air-breathing propulsion, but there is no evidence that a vertical flight at Mach 4.3 at 10 km altitude or equivalent is within reach.

The suborbital mission to 100 km altitude therefore imposes the use of rocket propulsion, whatever the selected architecture of the vehicle; the techniques associated to Private Human Access to Space are similar to those required to go to orbit, but somehow much simpler.

3.9. Architectures

There are as many different architectures as one can dream of, as could be seen at the time of the Ansari X-Prize where some 24 different teams competed, each with its own architecture.

There is no “best” configuration, as each gives pros and cons. The main parameters are:

- The overall system, with one single or multiple elements. The spacecraft can be a spaceplane performing the complete mission with just one craft, or dual configurations where the first ascent phase is performed with a carrying plane or a balloon,

- Dual configurations with a dedicated separating carrier vehicle can be configured with the spacecraft on top of the fuselage, below the fuselage, below the wing or even below the wing between twin fuselages,
- The lift-off and landing mode, vertical or horizontal, imposes huge differences in flight profile, ground installations, abort modes… leading to very differing configurations,
- The number of passenger, including pilots, is of course a key driver to the size of the system. Ranging from 2 to 8 in the current projects, it is closely associated to the available volume for 0g operations, driving the ability of a system to perform commercial 0g experiments.

3.10. Rocket Propulsion

To achieve the required thrust to reach 100 km altitude, only 4 propulsion schemes are envisaged today

- The monopropellant engine, typically with hydrogen peroxide (H_2O_2) or hydrazine (N_2H_4) is limited in Efficiency (specific impulse, or I_{sp}) and is based on highly energetic propellants, quite dangerous due to their tendency to explode or their toxicity; they are not considered in the current proposals. An Armadillo Aerospace H_2O_2 engine firing is shown in Figure 3.4.

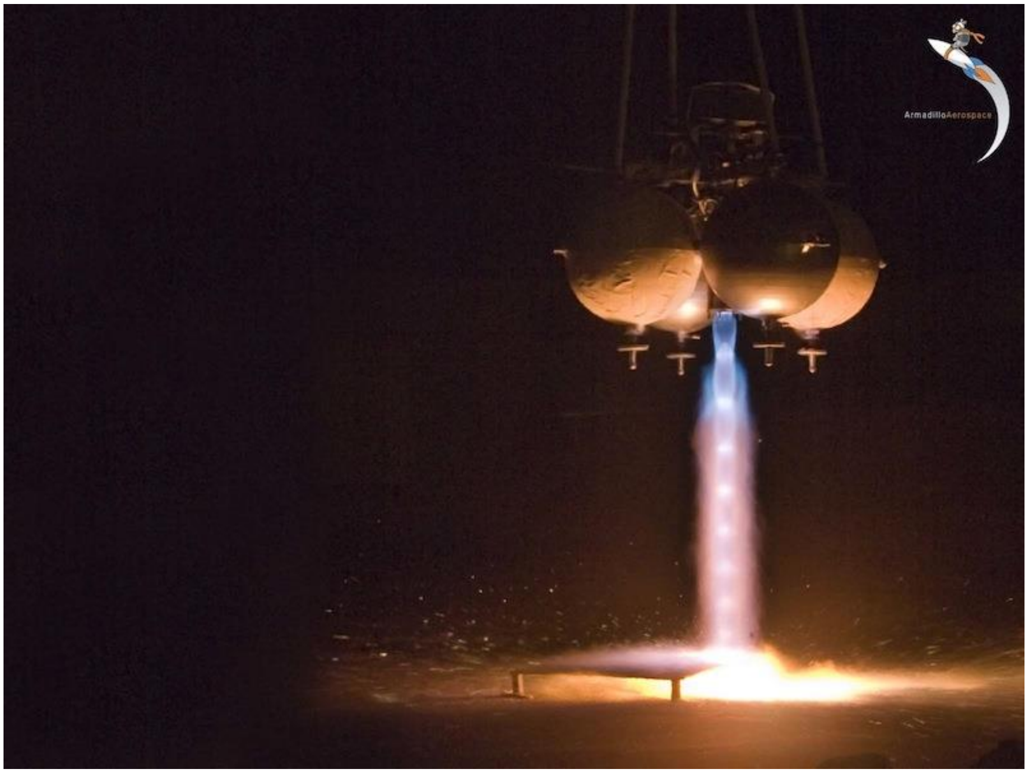


Figure 3.4: Armadillo Aerospace H2O2 engine (Courtesy: Armadillo Aerospace)

- The solid propellant engine presents a very high energy density, a moderate efficiency but more than enough for the low ΔVs that are required here, and a very high reliability. Unfortunately, in terms of safety an anomaly can be very rapidly catastrophic; also, it is hardly possible to cut a solid propulsion engine after its ignition. Such engines have been considered only in few proposals.
- The hybrid propulsion engine, mixing solid fuel and liquid oxidizer, offers plenty of advantages: it presents a relatively good efficiency, can be cut and reignited at demand leading to a good theoretical safety level, and can even adapt the thrust to the flight profile. It is unfortunately less known than conventional bi-liquid propulsion, with a lower TRL, mainly concerning the combustion process and the end of flight vibrations. The first flight test of the Virgin Galactic SpaceShipTwo hybrid engine is shown in Figure 3.5.

Figure 3.5: First flight test of the SpaceShipTwo hybrid engine (Courtesy: Virgin Galactic)

- The bi-liquid propulsion offers plenty of variants depending on the choice of oxidizer and fuel. Some are very well known, such as liquid oxygen and kerosene (LOX-Kero), some have never been used yet, such as LOX-Methane, but these couples present in general high efficiencies and good level of reusability. Numerous concepts are based on such propulsion schemes. Shown in Figures 3.6 and 3.7 are the XCOR Lynx LOX-Kero engine test and the Copenhagen Suborbitals TM65 LOX-Kero engine test, respectively.

Figure 3.6: Lynx LOX-Kero hot fire test (Courtesy: XCOR)

Figure 3.7: TM65 LOX-Kero engine test (Courtesy: Copenhagen Suborbitals)

3.11. Environmental Impact

A significant parameter to be taken into account is the environmental impact of the operations of the system. It is closely linked to the choice of the propulsion system of the spacecraft. Some generate gases with greenhouse effect while some generate soot, potentially harming the Ozone layer.

As long as there are only few flights per year, this phenomenon can of course be neglected. But if one starts considering one flight per hour, for instance, then the integral of the impact over time has to be considered: market analyses show that in twenty years' time, maybe before, some 30,000 passengers per year could enjoy a suborbital ride with one of the vehicles currently under development. Considering an average of 5 passengers per flight, this would lead to 6,000 flights per year, to be compared to the current 80 orbital flights per year; this comparison is valid, as the environmental impact is essentially linked to the atmospheric phase of the flight.

3.12. Reliability - Safety – Abort capability

The most critical topic associated to these suborbital missions is the overall question of reliability and safety. The logic follows a classical Product Assurance analysis:

- What are the credible failures and their probability of occurrence?
- What is the expected effect of one of such failures?
- What is the corresponding criticality, and acceptability?
- What are the potential recovery actions, including abort missions?
- What are the consequences on the design of the system?

In a simplified way, one can consider that the failures will essentially come from the propulsion system and from the transitory phases.

3.12.1. Propulsion

The mission of a suborbital vehicle, whatever its concept, is significantly less energetic than a classical orbital mission. It nevertheless requires rocket propulsion that raises, whatever the selected propulsion scheme, numerous potential problems associated to high pressures, high temperatures, combustion stability, vibrations, also.

It is important to keep in mind that the current best reliability of such propulsion systems is in the range of 97 to 98% [3-25], with figures nearly identical for liquid and solid propulsion (no statistics for hybrid propulsion as it has never been used operationally yet).

This means that a realistic objective, however ambitious, is a failure rate of 1%. A propulsion failure, hopefully, is not always catastrophic; it will in most cases just lead to an abort of the mission. In such case, the system shall demonstrate its ability to abort safely, whatever the instant of failure during the mission. This may be complex to do, as velocity at time of failure may prevent from an easy return to the launch site, propellant tanks may still be filled leading to controllability problems. A typical such event would be the non-ignition of the engine after drop-off from a carrier plane.

Then some failures will lead to critical conditions: as examples, consider a failure in the main propulsion system of a Vertical Take-off vehicle after 100 m ascent, or the explosion of the main engine, partly contained but tearing off a significant part of the rear fuselage. Priority shall then be given to save the passengers, often leading to complex designs such as capsule ejected after the failure and landing under parachute. These solutions shall have an operation domain which covers the complete flight domain, which is hard to design; for instance a parachute capable of saving the crew capsule after an abort 30 m above ground, or just after the injection to 100 km altitude, may be complex to design.

Last, unfortunately, some failures may lead to the loss of the crew, if for instance an engine explosion destroys part of the wings or the control surfaces of the space vehicle. This can happen, even with the best designs, as history has shown since the first manned flights.

3.12.2. Transitory Phases

The propulsion system is not the only source of potential criticality in flight; without trying to list them all exhaustively, a special attention may be given to transitory phases. Lift-off, landing, separation from a carrier plane, transition from air-breathing to rocket propulsion, wing geometry variation, closure of air-intakes… all these events which represent a sudden change in the flight environment and/or a mechanical action can induce some loss of reliability, in turn leading to failure, critical failure, recovery schemes or potentially loss of crew.

If one considers 30,000 passengers per flight in some 20 years from now, with an average of 5 passengers (including crew) per flight, there could be 6,000 flights per year of various suborbital systems.

If we summarize the figures given in the previous lines, we should reasonably consider a propulsion or mechanical system failure with a probability of 1%; then among these failures, 10% can be critical, leading to a complex passenger safety scheme; last, out of these critical failures, 10% may lead to the loss of the crew. The reader can of course consider its own figure to do the exercise, but it leads to 3 deaths per year in average.

Such a high figure is of course not acceptable. Which figure would be? Of course, ideally, one shall have a design enabling zero failure, and everyone aims at this goal. But reality is different, and even with a progressive improvement thanks to high reusability levels and perfect safety features it is hard to conceive a system 10 times better. Probability of failure would then have to be 0.1%, and even with such figure, we would witness one death in average every 3 years…

So, what are the real objectives? Most probably a factor 100 has to be gained in reliability compared to today's figures, aiming at 99.99% instead of 99% (which is already optimistic). But what could be the technical solutions to gain such a factor 100, for instance concerning the design of a combustion chamber, of a separation system or a wing sweeping mechanism?
The answer is still unknown today.

4. Spaceports

Some progress has been made in the provision of ground infrastructures for private human access to space, although much of it, at least outside of the USA, remains in the conceptual stage. To some degree, there need not be much difference between a spaceport and an airport, but the differences that do exist are significant. So, it is worth describing the main functions of a spaceport, and perhaps underlining the differences with regard to both a standard airport and also to a traditional launch site.

4.1. Space Tourism and the General Public

4.1.1. Comparison with an Airport

At least initially, spaceports will not handle as much traffic as a traditional airport. Spacecraft will not be taking off and landing every few minutes. While a typical airport runway may be able to handle some kinds of space tourism vehicle, in some cases spaceports will also need to be able to handle vertical launches and landings. Customs facilities will not be needed at spaceports, at least initially, and probably a less intrusive baggage security system could be employed. Unlike airports, a spaceport will need to allocate space to significantly more general public than the relatively few space tourists who will be flying from the location (which incidentally was also the case in the early years of airline travel). Refueling at a spaceport will need to take place more remotely than currently takes place at an airport, because of the nature of the fuel and oxidizers used. Figure 4.1 shows a conceptual layout for a typical spaceport.

4.1.2. Comparison with a Launch Site

There are about 35 operational traditional launch sites globally, and they are generally all government or even military facilities. A spaceport designed specifically for commercial private human access to space will need to be much more inviting to the general public, in order to generate revenues from terrestrial tourism. Visitors will need to be encouraged, not discouraged. Most of the traditional launch sites have been located to enable orbital launches to take place, and so they are often located at a coastline. For suborbital private human access to space, the trajectory is generally straight up above the spaceport with a return to the same spaceport, and so this can take place from an inland spaceport. If it ever becomes economically viable to provide point-to-point suborbital space transportation from one spaceport to another, then it may be necessary to reconsider the location of the spaceport because of safety requirements below the flight corridor.

Figure 4.1: Dubai Spaceport Project (Courtesy: Space Adventures)

4.2. Spaceports: Selection Criteria

There are a number of technical and business factors, listed below, to be considered in deciding whether a potential site is suitable for a commercial spaceport for suborbital space tourism, and at this early stage of the growth of the industry it is not entirely certain how much weight should be given to each of them. Tax incentives and liability limitation regimes are provided by some states in the USA as additional factors.

4.2.1. Altitude and Geographic/Scenic Values

It is helpful to site a spaceport at a high elevation, and from a competitive perspective it is important to ensure that from apogee at 100km above the spaceport the private space travelers have an interesting view (1000km in all directions). Coastlines and islands are particularly good in this regard.

4.2.2. Accessibility vs. Remoteness

There is an inherent conflict in determining the location of a commercial spaceport between, on the one hand, having a location near to large population centers (source of terrestrial tourism revenues) and, on the other hand, needing to be remote enough to satisfy the regulatory safety requirements which are concerned about low populations under the flight corridors at various azimuths. A solution may be to have a remote site but with efficient access methods such as tour coaches that include training facilities to take visitors to the spaceport.

4.2.3. Safety

There is also an inherent conflict between the wish to encourage the public to enjoy all aspects of the working spaceport, whilst having to recognize the need to keep them safe. The spaceport design should ideally reach a compromise whereby the public can see almost everything that is happening, whilst being kept behind safety glass.

4.2.4. Constraints Associated with Air Traffic Control

One major problem in the reuse of an existing airport as a commercial spaceport is the need to ensure that there are no Air Traffic Control conflicts in the operation of the spaceport. During the period when space tourism demand is initially low, it may be possible to simply allocate time slots to the suborbital space tourism flights when air traffic is excluded from the airspace above the spaceport. However, this can only be a short-term solution: once growth in demand takes place, there will be a need to develop a better coordination arrangement between the spaceport and Air Traffic Control. It should also be taken into account in this context that many of the spacecraft returning from space and descending through the normal flight regimes will be doing so as gliders, and therefore will not be able to respond to traditional requests from ATC concerning e.g. maintaining altitude.

4.2.5. Meteorological Constraints

For someone to pay $200,000 to go into space and look at the view from above the atmosphere, only to find that the entire Earth within the 1000km in each direction is covered in clouds might be a matter for some concern. Perhaps even more important from the point of view of the commercial viability of the spaceport is the need to choose a location where on most days in the year flying is possible. Frequent heavy winds, rain, thunder and lightning are meteorological constraints to a successful commercial spaceport venture.

4.3. Main Functions and Facilities of a Commercial Spaceport

Each spaceport will have a different combination of features that will be the means whereby the spaceport management can differentiate their venue in a competitive environment. However, most spaceports will require a combination of the facilities and functions listed below.

- Training facilities. These may include simulators for use of the potential space tourists, which might also be used by the general public as revenue generators for the spaceport operators.
- Medical facilities. These will include the ability to conduct health screening for space tourist candidates, but also emergency facilities. A keep fit gym may be part of this area.
- Launch and landing of spacecraft. This is obviously the main purpose of the spaceport, so it will be essential for the public visitors to have good viewing arrangements for these phases of the flights, probably including large flat screen television screens and viewing platforms behind the control room.
- Maintenance facilities. For this industry to be commercially viable, it is essential that the spacecraft are truly reusable and engineers will need to be able to refurbish the engine and turn the craft around within an hour or so.

- Fuel storage and handling, and engine test stands. Depending on the design of the spacecraft using the spaceport as their base, a spaceport will need to have facilities for handling all or some of the following: solid propellants, liquid propellants, hybrid propellants, cryogenic propellants and oxidizers.
- Control facilities. It is still not very clear what kind of special facilities will be needed for ground control of suborbital space tourism operations. However, for marketing reasons it will be important that the day-visitors be able to have access to the control room via a visitors' gallery.
- Emergency response teams. This will be similar to the teams available at regular airports, excepting that they will require additional HAZMAT training to handle the fuel and oxidizers used by the spacecraft operators.
- Hangar Space. This will be required for the spacecraft and mother planes, where applicable.
- Payload processing facilities. An area will be required in cases where the suborbital space flights are being used by academic researchers who have special equipment for conducting zero-g experiments.
- Communications. This will be important between the spacecraft pilots and the ground, but possibly also between the space tourists and their families back at the spaceport. It will be very important to have a good public address system to keep the public day-visitors aware of the spaceport activities. In addition there will be the normal communications of a civilian airport involving traffic movements, security, emergency and other required services.
- Weather forecast services. This will be needed as with aircrews at a normal airport, with the additional needs to be able to include high altitude wind data and space weather information.
- Lodging and restaurants for staff, tourists, relatives and visitors. This will be particularly important at spaceport locations that are geographically remote.
- Entertainment for terrestrial tourists, many of them revenue-generating. There is a need to attract significant numbers of day visitors in order for a commercial spaceport to be viable, as a destination in and of itself, because there will not be enough space tourists (even including their families and friends) to take full advantage of the facilities. This aspect will probably become a big competitive differentiator between spaceports. Some will provide a full space-related theme park experience, and others will provide IMAX movie theatres, some will provide an educational tour.
- Showcase for the operator. Clearly, the spaceport will become an important part of the marketing of the space tourism experience, and therefore the space tourism operator will be very involved in the way in which the spaceport presents the venue.
- Employment and economic returns. Underlying almost everything else on this list is the need for the spaceport to generate revenues and hire staff, and become self-supporting with even a tax contribution to the host state. Until the first suborbital space tourism flights begin to operate (not before 2014 at the earliest) it is not clear just how effective

will be spaceports at generating wealth and employment opportunities for the general public; it is however recognized that this will be a very important test of the long-term viability of private human access to space. At a time of general financial malaise, it will be important to demonstrate that space tourism does not only benefit those who can afford the ticket prices.

4.4. Current Examples

With regard to spaceports for commercial private human access to space, specifically for suborbital space tourism, currently only one has so far demonstrated its operational capability, and that is Mojave Spaceport in the USA. All of the others summarized below are either conceptual, or are still in process of construction in order to become operational, although Spaceport America in New Mexico, USA is very close to completion for first flights.

- Mojave Spaceport – California, USA, 35.0 deg N latitude. This desert facility was used in 2004 for the spaceflights of SpaceShipOne, and is currently being used for development testing of SpaceShipTwo and the XCOR Lynx spacecraft.
- Spaceport America – New Mexico, USA, 32.8 deg N latitude (see Figure 4.2). This remote facility has been designed and built as an inland spaceport specifically for the anchor tenant Virgin Galactic operations. Almost complete.

Figure 4.2 Artist impression of Spaceport America, home of Virgin Galactic (Courtesy: URS/Foster + Partners)

- Oklahoma Spaceport, USA, 35.5 deg N latitude. This is an existing but disused airport with long and broad runways, which was intended for use by Rocketplane, before that company went bankrupt. Currently no new suborbital space tourism operator has expressed interest in using the facility.
- Mid Atlantic Regional Spaceport – Virginia, USA, 37.5 deg N latitude. This spaceport, formerly known as the NASA Wallops launch site, is within easy reach of the Washington DC urban area, and is going to be used by Orbital to fly their Cygnus spacecraft to the International Space Station. Currently no suborbital space tourism operator has registered an interest in using the facility.
- Florida Spaceport and Cecil Field, USA, 28.5 deg N latitude. An attempt is being made by the Kennedy Space Center to open up its facilities for space tourism purposes, and initially some Zero-G flights have been conducted from their Space Shuttle runway. Cecil Field is further up the coast and is an existing airfield.
- Hawaii Spaceport, USA, 16.5 deg N latitude. Conceptual only. Sites were investigated by Rocketplane before bankruptcy.
- Spaceport Sweden – Kiruna, 68.0 deg N latitude. An existing ESA sounding rocket facility with access to Aurora Borealis, being considered by Virgin Galactic as a possible site for European operations.
- Spaceport France – Montpellier, 43.3 deg N latitude. Conceptual only.
- Spaceport Spain – Barcelona, 41.2 deg N latitude. Conceptual only.
- Spaceport Netherlands – Lelystad, 53.3 deg N latitude. Under consideration by Rocketplane.
- Spaceport Caribbean (Curacao), 12.1 deg N latitude. Memorandum of Agreement with XCOR for operational lease of Lynx suborbital space tourism vehicle.
- Asian and Middle Eastern Spaceports. UAE at 24.0 deg N latitude (being considered by Virgin Galactic as a possible site for operations), Singapore at 1 deg N latitude, Japan at latitudes between 30 and 37 deg N latitude, all conceptual at present.

5. Suborbital Vehicle Interior Design

5.1. Boundary Conditions

Whereas the word space tourism has two components, namely ‘space’ and ‘tourism’, often the first component has been dominating the design criteria.

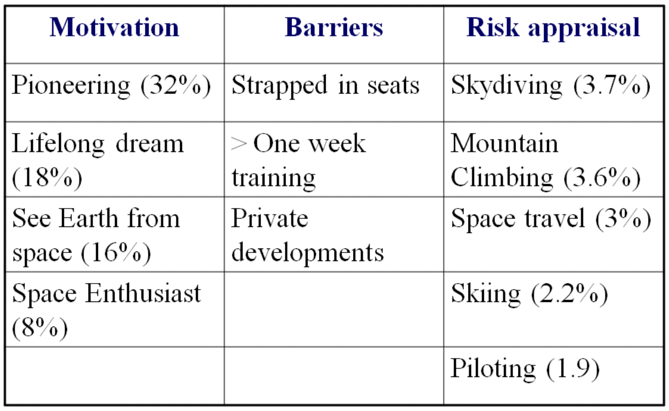
Ignoring the customer requirements has very often led to commercial failures. Recently, the space sector has become increasingly aware of the necessity of this and, in particular under impulse from very customer oriented companies such as Richard Branson’s Virgin Galactic, we note increased emphasis in the design phase of commercial oriented spacecraft.

From a tourism perspective, space tourism belongs to the category of ‘adventure tourism’. The importance of this lays in the risk appraisal aspect. Often the argument has been used that space tourism has a considerable risk factor. Whereas this cannot be ignored, this risk factor is equally present in other adventure tourism disciplines such as mountaineering and parasailing, even to a certain extent in bungee jumping.

It is interesting that, asked about perceived risks, many respondents did not even consider space tourism as one of the most risky disciplines, as can be seen from table 5.1 [5-1]. The table represents responses of the target group (with percentages of answers in brackets) on 3 questions:

- What is your highest motivation to book a flight?
- Which are the barriers that make you reluctant?
- Compare space tourism with other activities in terms of risk.

Table 5.1: Motivation and Risk perception of the space tourism target group.



Motivation	**Barriers**	**Risk appraisal**
Pioneering (32%)	Strapped in seats	Skydiving (3.7%)
Lifelong dream (18%)	> One week training	Mountain Climbing (3.6%)
See Earth from space (16%)	Private developments	Space travel (3%)
Space Enthusiast (8%)		Skiing (2.2%)
		Piloting (1.9)

The potential size of the market for public space travel will depend, in part, upon the attractive features that designers of spaceflight experiences incorporate into their spacecraft and related operations. Until recently, the question had not been asked ‘what do passengers require and how can we adapt our planes to these desiderata?’

Several market surveys have been undertaken and several opinions presented [5-1], [5-2]. In general, the expectations of future space passengers include:

- Viewing space and the earth
- Experiencing weightlessness and being able to float freely in zero gravity
- Experiencing astronaut training and other sensations
- Communicating from space
- Being able to discuss the adventure in an informed way
- Having astronaut-like documentation and memorabilia.

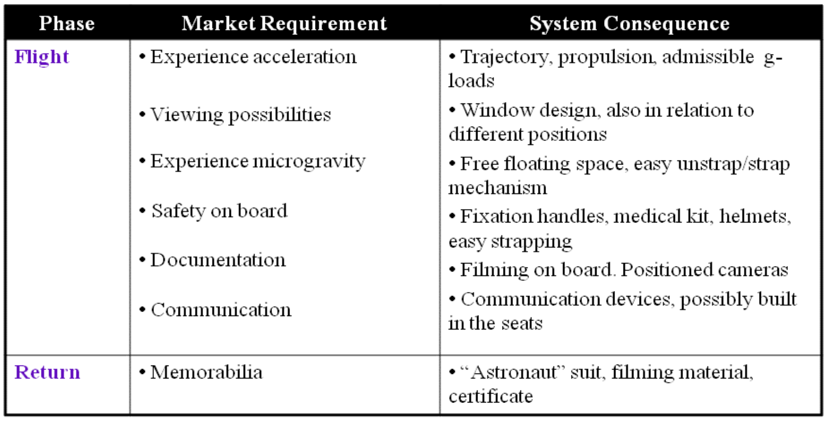
These objectives need to be combined with sometimes conflicting constraints such as

- Guaranteed safe return
- Limited training time
- Minimal medical restrictions

5.2. Interior Design Requirements

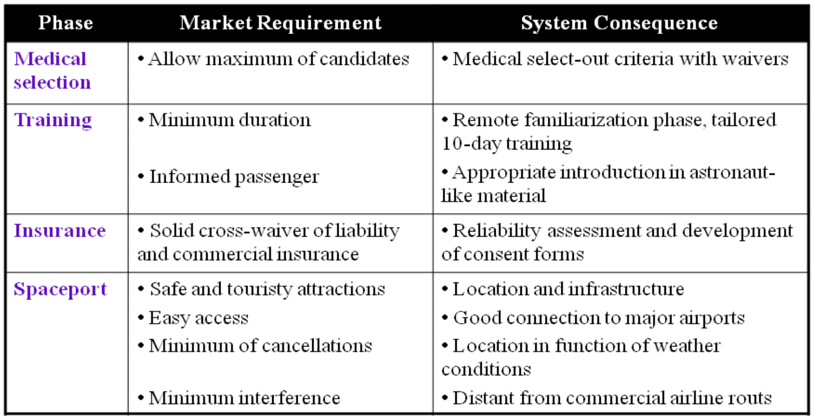
This tentatively leads to a number of technical design requirements as per table 5.2, as well as a number of operational requirements as per table 5.3 [5-3].

Table 5.2: Design requirements for suborbital vehicles.



Phase	Market Requirement	System Consequence
Flight	• Experience acceleration	• Trajectory, propulsion, admissible g-loads
	• Viewing possibilities	• Window design, also in relation to different positions
	• Experience microgravity	• Free floating space, easy unstrap/strap mechanism
	• Safety on board	• Fixation handles, medical kit, helmets, easy strapping
	• Documentation	• Filming on board. Positioned cameras
	• Communication	• Communication devices, possibly built in the seats
Return	• Memorabilia	• "Astronaut" suit, filming material, certificate

Table 5.3: Operational requirements for suborbital space tourism.



Phase	Market Requirement	System Consequence
Medical selection	• Allow maximum of candidates	• Medical select-out criteria with waivers
Training	• Minimum duration • Informed passenger	• Remote familiarization phase, tailored 10-day training • Appropriate introduction in astronaut-like material
Insurance	• Solid cross-waiver of liability and commercial insurance	• Reliability assessment and development of consent forms
Spaceport	• Safe and touristy attractions • Easy access • Minimum of cancellations • Minimum interference	• Location and infrastructure • Good connection to major airports • Location in function of weather conditions • Distant from commercial airline routs

The first group of objectives requires adapted interior design but also some additional features. Figure 5.1 shows some of the potential solutions as envisaged at ISU [5-4] whereby we note:

- The chairs are designed to adapt/move in accordance with different g-loads in the different phases of travel
- Windows are foreseen to ensure visibility at all phases and seating positions
- A safety bar is designed to assist passengers back into chairs before re-entry
- Communication devices are built into the individual seats
- Cameras on board, to be operated by the co-pilot, to record the different phases
- Wearing of astronaut-type suits and helmets to minimize potential injury.

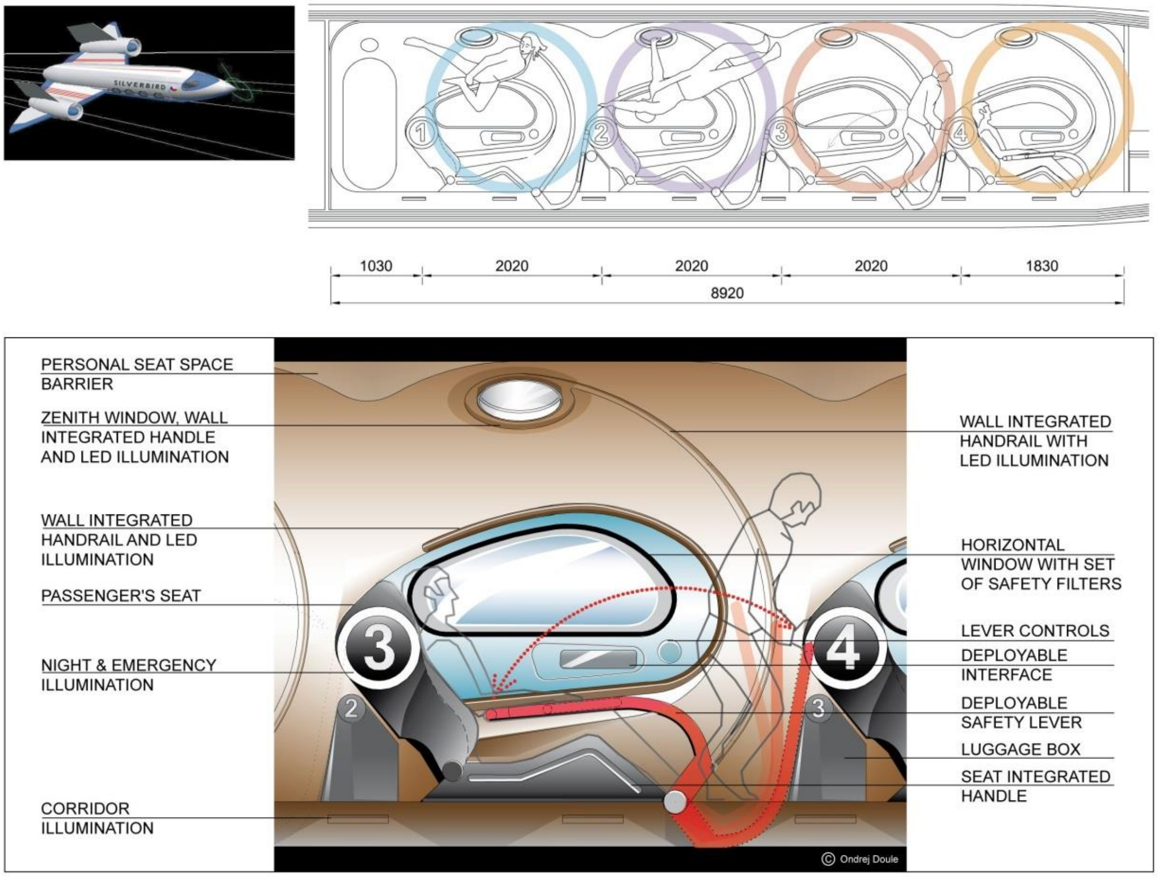


Figure 5.1: Interior design proposal (Doule, ISU)

4.3. Interior facilities and operational aspects

Medical considerations are particularly important. Whereas the traditional astronaut-selection philosophy was based upon ‘select-in’ principles, a paradigm shift will be needed to concentrate on ‘select-out’ approaches (since all selection criteria will influence the eligible market). This has influence on, amongst others [5-5]:

- The pre-medical check, to be concentrated on select-out criteria (whereby psychological issues will play a paramount role), as covered by the FAA guidelines [5-6]
- The medical facilities on board, such as an adapted medical kit
- In view of the necessity of an astronaut like suit (mainly for marketing reasons), this could be combined with built-in medical (and GPS) sensors.

Also in the case of training for the participants, the technical aspects of the training are not the only consideration. Spaceflight participants will also wish to be fully informed. The educational dimensions of the experience will therefore be important as well.

A number of these assumptions have been studied in detail in ISU and evidently can be contested by other approaches. Just to highlight a few of these items:

- Astronaut suits and helmets are suggested not only as memorabilia but also to add safety related equipment as well as to reduce chances for injuries (helmets)
- From a liability point of view substantial training is suggested emphasizing on safety aspects such as egress under different emergency conditions. Moreover this period may be used for medical examinations and observation as well as the necessary familiarization with the spaceflight and plane (responding to the requirement of candidates to be well informed participants, not only passengers)
- The short flight will reduce the need for extensive medical aid on board, but for injuries and emergency situations, a limited small medical kit is proposed for use by the co-pilot, trained to handle medical emergencies.

Undoubtedly we touch here upon an area where close cooperation between the space and the traditional aeronautical sector, with its considerable experience in meeting customer requirements, will be necessary.

6. Payload Flight Opportunities

6.1. Introduction

A number of studies have been executed over the last decades to evaluate the different knowledge steps needed before safely undertaking a deep space human spaceflight mission far beyond the moon. Indeed, even if possibilities for return from the moon were not evident in case of life-threatening incidents, they were not fully impossible, as demonstrated during the Apollo 13 mission. Increasing the distance traveled will exponentially increase the probability for the requirement of such intervention. Not only the distance, but also communication delays will make any rescue attempt quasi-impossible.

As a consequence, all technology elements onboard an exploration spaceship, in particular those associated with the ECLSS, need to be based upon proven and validated systems, or to express it in terms of system design, in TRL levels greater than 8. Many of the technologies that are required have not yet reached that level; some are quite far from reaching that mark. Therefore, study groups have developed very detailed roadmaps describing how to push the technology maturity to the levels required to support space exploration class missions. All of these studies have proposed such a roadmap. The best known of these is the one produced by the COSPAR Panel on Exploration (PEX). An excellent summary of this document can be found in [6-1]. No doubt the most technologically oriented program has been developed by NASA's Exploration Team (NEXT) [6-2]. The relationship between the development of new technologies and the possible mass savings was analyzed, as illustrated in Figure 6.1 for the case of a mission to Mars.

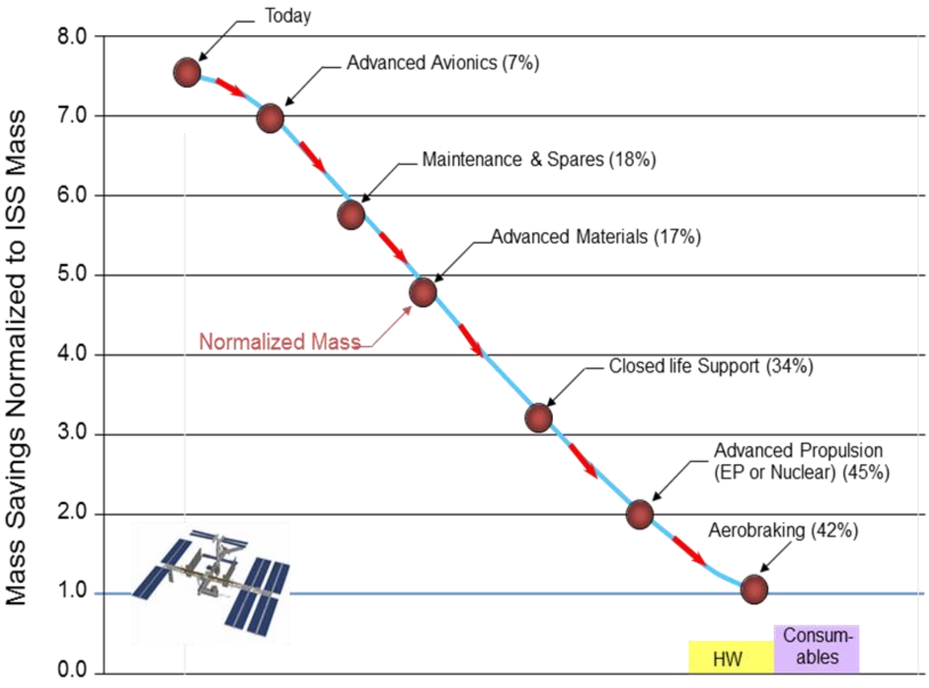


Figure 6.1: Assumed mass saving versus new technologies (Courtesy: NEXT/NASA)

All of the exploration roadmaps have one element in common, namely that the use of new technologies and materials requirements to be validated in incremental steps. There is no doubt that an ultimate verification on board, for example, the ISS will have the highest reliability. However, there are major factors that considerably hinder such testing, namely

- The limited number of flight opportunities
- The down mass capacity of the present transfer vehicles
- The limited chance for repetition at short time intervals, and
- The high costs.

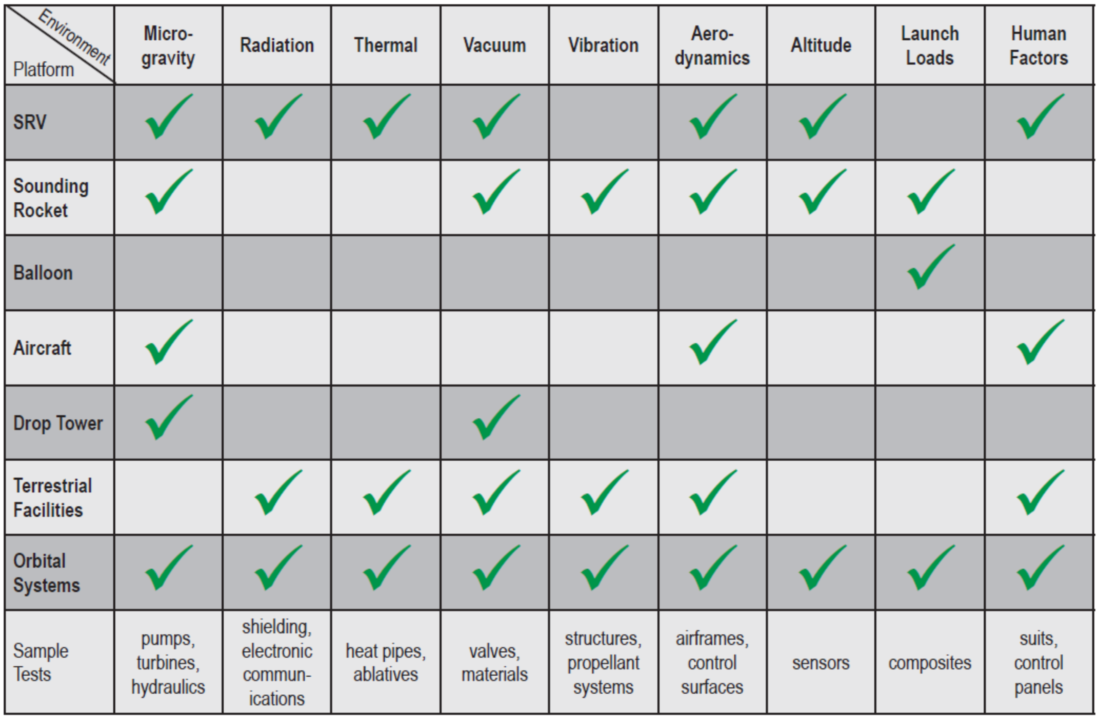
Suborbital flights can partially assist in this dilemma, as will be explained in next section.

6.2. The use of Suborbital Vehicles as Payload Carriers

Suborbital Vehicles (SOV) currently under development, some in the advanced testing stage, are planned to fly frequently and are expected to be easily accessible at reasonable costs. In this respect they compensate for a number of drawbacks associated with the aforementioned ISS flights. On the other hand, the microgravity levels will be of limited quality and the short duration of the flight is yet another constraining factor. Still, many experiments and technology demonstrations could be executed using these platforms, in particular when human presence or an operator is required. In the article cited in reference [6-3], a number of possible experiments are outlined, such as

- Protein Crystal Growth (Pharmaceuticals)
- Cell function and Electrophoresis (Biology)
- Development of New Materials (Materials Sciences)
- Semiconductor Production (Materials Processing)
- Fluid Physics
- Combustion Science
- Component Research and Testing.

Recent interest in flying payloads onboard an SOV has been increasing. The recent Tauri report on suborbital reusable vehicles [6-4] lists a number of application areas where Suborbital flights (in the report called SRV’s, or Suborbital Reusable Vehicles) can be of help in relation to other microgravity platforms, as depicted in Figure 6.2 below.



Environment / Platform	Micro-gravity	Radiation	Thermal	Vacuum	Vibration	Aero-dynamics	Altitude	Launch Loads	Human Factors
SRV	✓	✓	✓	✓		✓	✓		✓
Sounding Rocket	✓			✓	✓	✓	✓	✓	
Balloon								✓	
Aircraft	✓					✓			✓
Drop Tower	✓			✓					
Terrestrial Facilities		✓	✓	✓	✓	✓			✓
Orbital Systems	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sample Tests	pumps, turbines, hydraulics	shielding, electronic commun-ications	heat pipes, ablatives	valves, materials	structures, propellant systems	airframes, control surfaces	sensors	composites	suits, control panels

Figure 6.2: Comparison of microgravity platforms (The Tauri Group, 2012)

As a logical consequence, the report considers payloads on board of Suborbital Vehicles as a considerable future market for the private operators. The first proof of this is NASA's Flight Opportunities Program (FOP) [6-5]. NASA has booked a number of flights already with Virgin Galactic and XCOR. Examples of preselected experiments are listed on the NASA Flight Opportunities Program (FOP) (see https://flightopportunities.nasa.gov). Note also that the proposal to use spaceflight participants for life science experiments has been suggested, based upon the broader medical selection criteria of space tourists versus professional astronauts from an health level perspective [6-6].

6.3. Opportunities from the Future SOV Operators

As a preamble to this section, note that part of this article is based on *pro bono* work done at ISU on the behalf of a SOV developer and operator. However, the work was not published and was mainly performed by Mr. Benoit Hérin, a researcher at ISU. In this section, two suborbital vehicles, initially designed for the transport of space tourists, are examined amongst others for accepting payloads.

6.3.1. The Virgin Galactic SpaceShipTwo (SS2)

Probably the most well known of the suborbital vehicles currently under development is SpaceShipTwo (SS2) [6-7] shown in Figure 6.3, the precursor for which won the X-Prize (see SS1 in Figure 2.6). The main characteristics are provided below.

- Means of transportation: SS2
- Duration of microgravity: 3 to 5 minutes
- Duration of flight: 80 – 110 minutes
- Maximum accelerations: 5.5G N_x
- Quality of microgravity: high (not announced yet)
- Safety level: high - dedicated to tourism activities
- Frequency of flight: frequent and responsive
- Seat price: from $200,000 (now) to $50,000 (progressive estimate)

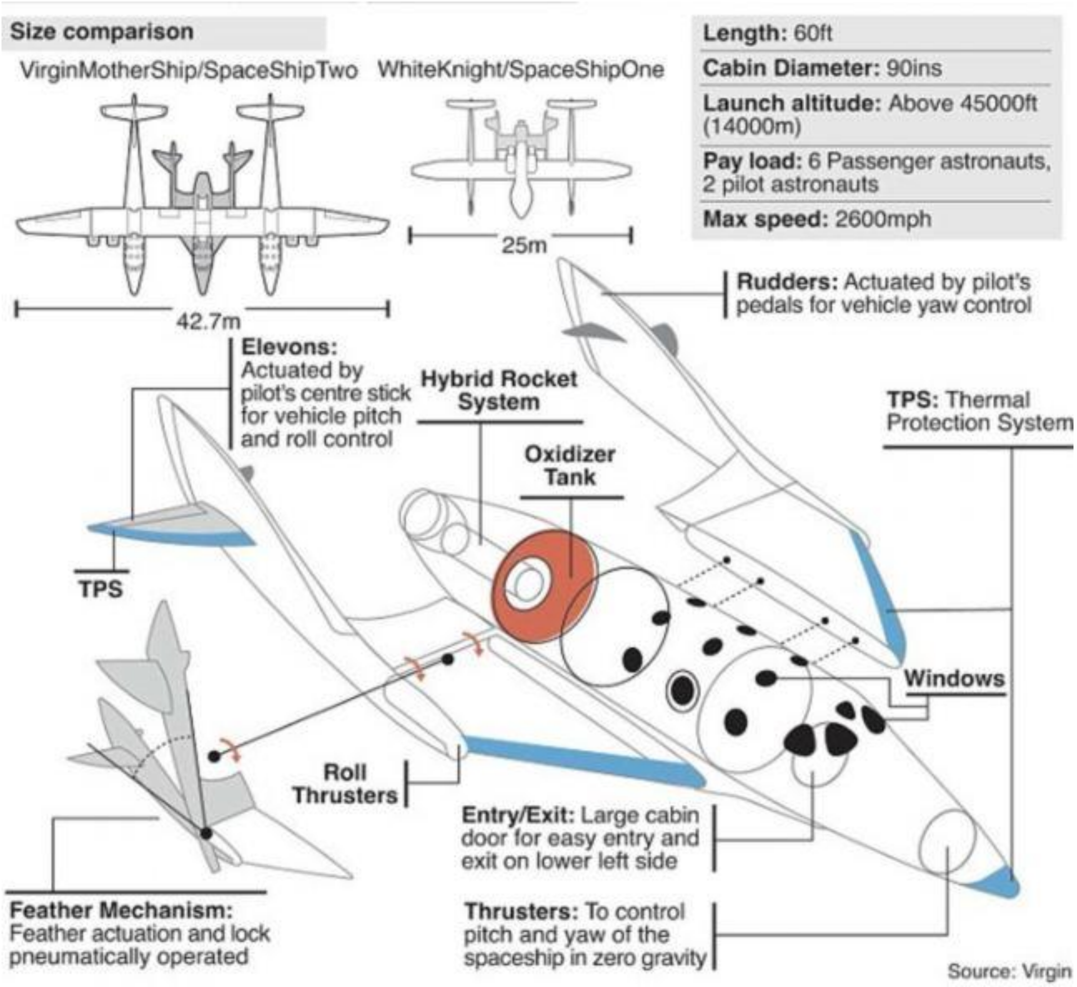


Figure 6.3: Schematic of Virgin Galactic SS2 (Courtesy: Virgin Galactic)

Clearly the limited microgravity duration will significantly constrain the number of possible experiments as well as the types of technology demonstrations that can be executed to the level required to reach the desired TRLs to support human exploration. In addition, the expected microgravity levels have not yet been communicated. Virgin Galactic has proposed a number of possible size and weight options for experiment payloads, as show in Table 6.1. An important element to consider is the mixing researcher investigators with space tourists on the same flight. For this reason, serious researchers are giving most of their consideration to dedicated payload flights, which allow for the installation of experiment racks as shown in Figure 6.4. Dedicated flights would provide an opportunity to conduct microgravity experiments in an environment that will be significantly quieter than that provided when tourists are free floating and potentially running into the onboard experiments during the flights.

Table 6.1: Payload size and weight options for SS2 [6-7]

Type	Dimensions	Volume (MLEs)	Max Weight* (lbm)
Standard Payload	18.50" W x 46.50" H x 21.50" D	4	120
Small Payload	18.50" W x 23.00" H x 21.50" D	2	60
Mini Payload	18.50" W x 11.25" H x 21.50" D	1	30

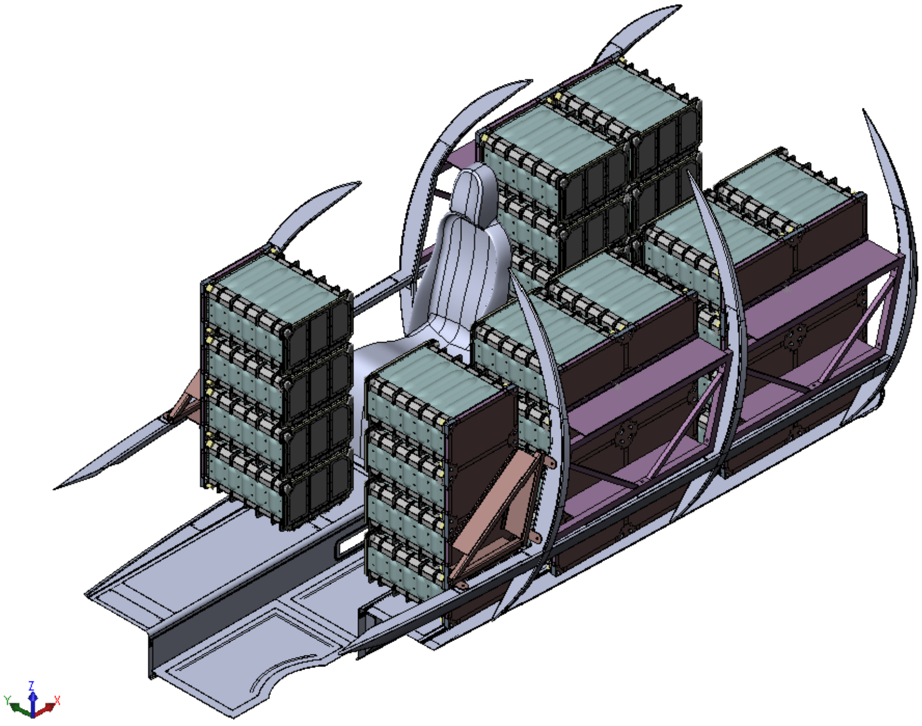


Figure 6.4: Planned experiment setups inside SpaceShipTwo [6-7]

6.3.2. The XCOR Lynx

Lynx, a suborbital flight vehicle under development at XCOR, is a different concept whereby basically there will be the pilot and only one passenger for each flight. The main characteristics of the vehicle are provided below [6-8].

- Means of transportation: Lynx
- Duration of microgravity: 3 to 5 minutes
- Duration of flight: 25-30 minutes
- Maximum accelerations: 4G N_x
- Quality of microgravity: high (not announced yet)
- Safety level: high - dedicated to tourism activities
- Frequency of flight: frequent and responsive
- Seat price: from $99,000 (now)

The maximum payload mass is estimated to be on the order of 650kg using the dorsal pod container configuration on the back of the Lynx as shown in Figure 6.5 below. Payloads in the dorsal pod fairing can remain in place or be launched by the pilot at the appropriate altitude and trajectory. Figure 6.6 shows all of the Lynx payload location options, including volume and mass information.

Figure 6.5: Payload compartment on top of the Lynx (Courtesy: XCOR)

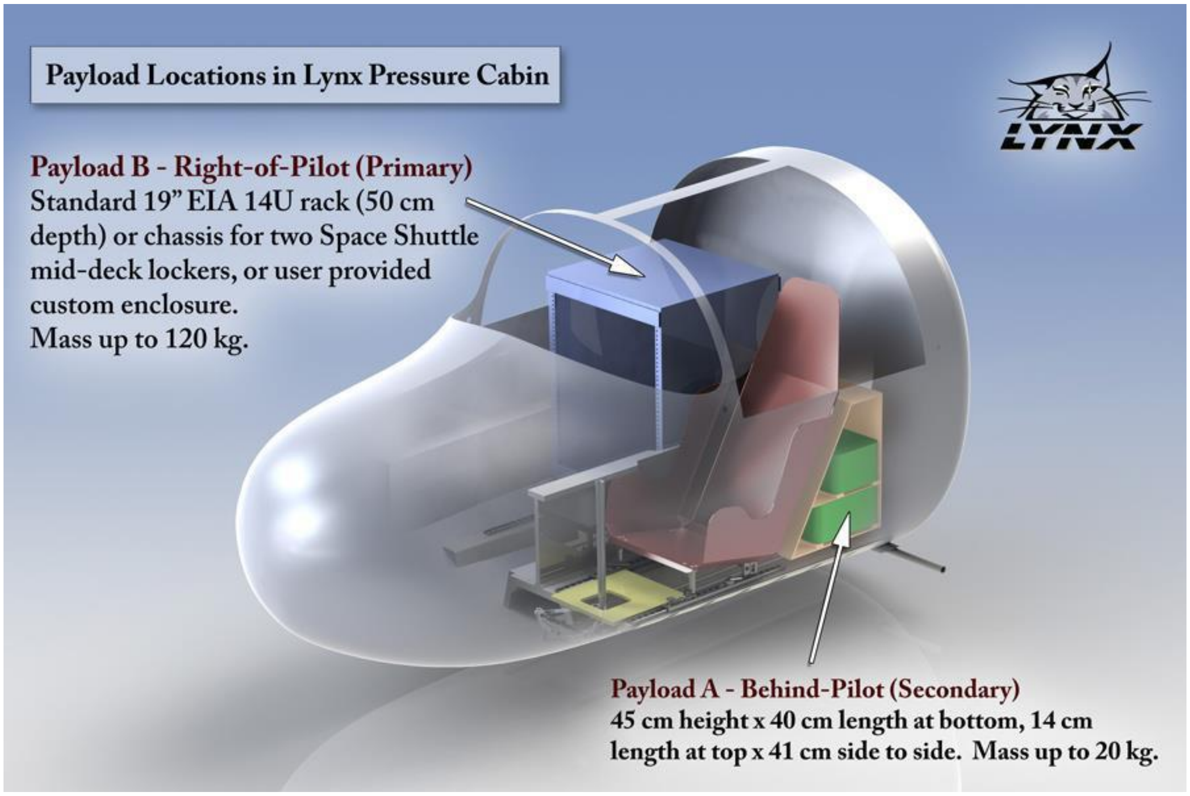


Figure 6.6: Lynx Payload location options [6-8]

6.4. Comparison of the Different Platforms for Microgravity Research

6.4.1. Choice of Flight Modes

Currently, investigators have two options between which they can choose to perform experiments, in particular those requiring human participation. The options are *parabolic flights* and the *International Space Station*. *Suborbital spaceflights* will provide yet another alternative with some advantages as well as inconveniences as compared to the other two. The factors that must be taken into account to assess the most suitable option are:

- Price
- Duration of µg
- Quality of µg
- Size and Mass of the payload
- Potential level of automation of the experiment – access to human services
    - Fully automated
    - Possibility to control it remotely (telemetry)
    - Need to have a human test subject
    - Need to have a person to handle it
- Legal Restrictions
- Repeatability of the experiment (different subjects, several time the same task)
- Delay between submission and moment of realization
- Acceptable risk on board (potentially dangerous experiments)
- Access to a source of energy, data transfer, full autonomy.

The major drivers in selecting the appropriate platform are the duration and the quality of microgravity required for the experiment and the size and the mass of the payload. There are then others that will have an impact on the decision only for specific experiments.

There are two aspects that will make the use of SOV’s scientifically interesting. The first one is the duration of continuous microgravity (3 to 5 minutes), and the second one is the flexibility and access to the service. While using the ISS offers longer microgravity duration (as long as necessary), parabolic flights offer only about 22 seconds of microgravity [6-6]. At the opposite end, the flexibility of parabolic flights is similar to suborbital spaceflights, while access to the ISS is much less flexible and even restricted in some cases. Based on that fact, suborbital spaceflight seems to be a good compromise, particularly when the duration of the experiment must be longer than 22 seconds and can be shorter than 3-5 minutes. This also applies when human participation is required as either a test subject or to handle the experiment. Major questions to be resolved include:

- What is the demand for 4-6 minute microgravity experiments and is this long enough to get results significantly different from what can be obtained during parabolic flights and to justify the extra cost?
- What will be the quality level of microgravity? So far it has been announced that it will be high quality, but still it will have to be compared with what can be obtained on board of parabolic flights and the ISS as it might be restrictive, particularly if it is a lower quality than expected.

If we now consider the cost aspects, we can observe the following. Based on the data we currently have, we know that the price for a seat on board SS2 will be $200,000 at the beginning and should decrease to $50,000 after several years. The price for a seat on the XCOR Lynx is currently advertised at $99,000. There was also information released that allows us to extrapolate the payload price per kg. NASA will pay $1.5M to fly up to 600kg of payload as part of the NASA's flight opportunities program [6-5]. From that we can estimate that the price per kg of payload will be around $2,500. This type of approximation can be tricky as this is what a space agency is paying in this case, and it is for a flight dedicated only to automated payloads. However, this at least gives us an order of magnitude. Interestingly, the first commercial contract to fly scientists for the purpose of conducting research experiments was signed with the Southwest Research Institute (SwRI) at a price of $1.6M for eight seats [6-9]. That equates to $200,000 per seat with experiments. Based on this information, it looks like at this stage the price for having a scientist and a payload on board would be similar to the price for a tourist seat, maybe with some level of constraint on the size and mass of the payload, but we are still missing key information to go further in our assessment. It is easy to imagine that the price will be case dependent.

The main advantage is the enhancement of some technologies in the TRL scale.

The disadvantages are mainly

- The relatively short duration of microgravity (4 to 6 minutes)
- The relatively low microgravity levels (specific levels have not yet been published).

This will obviously reduce the number of possible applications that could be provided by suborbital vehicles.

6.5.Conclusion

The use of suborbital space tourism is evidently no ‘cure for all pain’. The limited microgravity duration and likely limited microgravity levels will significantly restrain the number of possible payload operations. Nevertheless, there are a number of distinct advantages, such as the regular availability of the flights, the reduced preparation times, and potentially reduced costs that might be required to demonstrate higher TRLs.

It is therefore suggested here to consider suborbital space tourism vehicles as one of the platforms to prepare exploration flights, similar as has been done in the NASA FOP program.

7. Societal Motivations for Personal Spaceflight

7.1. The Stakeholders

It would be too simplistic to consider only one class of people: the explorers. To make it brief one can at least identify the tourists, the flight hardware manufacturers, the ground segment manufacturers, the operators, the ones who are the driving force and last but not least those who are going to finance all that! Some pertaining the above list may share common views, but definitely not all of them.

7.2. Why is Space Tourism Gaining Speed Recently?

Space tourism can be looked at something independent from the time, since it has been dreamed of in nearly the last hundred years. So why is it appearing now? It results probably from the conjunction of several factors: the maturity of the orbital space transportation (though the style of production is still very much that of a cottage industry), the successful performance of manned orbital flights and maybe the fact that nothing really new appears to be expected in orbital flight.

7.3. The "Common Man" Aspirations for Suborbital Tourism

One must be conscious that the attractiveness of going orbital is probably far more important than the one for going suborbital for the common man in the street. The exploration dream to Viewing the Earth from space and experiencing weightlessness has never left the aspiration of humans as well as going on other planets. But, as it is stated it is a dream that out of reach for the quasi totality of the population. If more than 500 people went to space so far, only a dozen were tourists. The cost of access to space is definitely a barrier that prevents ordinary people to go to space. Suborbital tourism, one or two degrees of magnitude cheaper is probably a stopgap measure, though still an attractive one.

In addition to the view from above and 0g there are other factors such as the thrill of danger and its adrenalin shot, clearly identified as in other classes of "adventure tourism" defined as [7-1]:

> *A variety of self-initiated activities utilizing an interaction with the natural environment that contains elements of real or apparent danger, in which the outcome, while uncertain, can be influenced by the participant and circumstance.*

However it must be noted that the space tourist differs from these high-risk adventure tourists since he is in relatively passive mode (a happy payload?). One new motivation may appear: to transition from the space tourist status to the one of pilot, more pro active.

Though as already stated suborbital flight is a kind of downgraded orbital tourism, it won't prevent the passengers to feel as an astronaut and, maybe also important, to appear as such for their neighbors and their family.

In many cases there is a wish to appear and feel as exceptional. This raises an interesting question: when suborbital tourism will be mature with prices drop and more and more people having flown will space tourism remain as attractive?

The idea for the space tourists to be part of a step in the “natural” continuation of humankind’s evolutionary process, i.e. “to see what’s behind the next hill” is not objectively valid, but it won’t probably prevent the space tourist to believe it.

7.4. The Other People’s Aspirations for Suborbital Tourism

They may appear as numerous as the variety of stakeholders. For the few ones who had the idea (Bezos, Branson, Bigelow, etc.) and who managed to translate in reality their wishes it must be exceptionally exciting since they can truly consider themselves as pioneers and to be part of these rare people who have marked their times with new technical progress.

Along this line the technical designers are also part of the same move. However for those who are comparing suborbital tourism with the first years of aviation they probably have noticed that the designers are not the pilots, nor the ones who are putting their money in the adventure and that is not a unique activity for them.

Between the two last main categories of stakeholders are the investors. Apparently they have various motivations. There is a genuine enthusiasm for this new field of activity, but also for the image benefit they can take for their other activities.

Last but not least are the space and aircraft manufacturers who cannot ignore this segment, since too close to their core business. The hopes of reaping benefits are always present. Another feature is also worth mentioning: the side effect on recruitment for young graduates. Up to the mid 90’s space was considered as a high tech field, attracting the best engineers because of the technologies and the last frontier image. This image is not true anymore, the technical jobs having been overtaken by the internet/software/telecoms offers then by finance. A company such as Astrium has been surprised to see the number of unsolicited job applications they received after announcing their involvement in a suborbital spaceplane.

7.5. Suborbital Tourism as a Vector of Outreach for Youngsters

The above remark about job applications underlined the attractiveness of the topic for youngsters, but it would be preposterous to believe that suborbital tourism is an important vector for the outreach. Nevertheless some specific initiatives such as ACE, with its dozen of work packages, its continuing stream of students from different teams, can be noted but there was probably less enthusiasm for such project than for the Lunar Google X prize which appeared more reachable.

7.6. The Philosophical Dimension

Humans are born explorers. Since the *homo sapiens* were able to cover large distances by walking upright (and this way carrying supplies and children), they were confronted with rivers they learned to cross and mountains they learned to surpass. The problem became more complex when seas were reached. In this case physical abilities were not sufficient to surpass this difficulty and special tools, ocean-fairing ships, had to be built. This required a level of engineering skills and ingenuity and an iterative process.

A paper comparing the exploration at sea and in space was highlighting the similarities between both endeavors and clearly demonstrates the incremental approach of Henry the Navigator in improving his ships step by step, going further and further in his expositions [7-2]. As an interesting comparison the paper demonstrates the fact that the approach taken was balancing the different objectives (compared to other maritime exploration approaches) was the basis of its success, as can be noted from Figure 7.1 on the next page. This figure plots different approaches in function of classical strategic plotting, as extensively explained in aforementioned reference [7-2].

If we continue our voyage, the next major obstacle for humans was … the sky. People saw birds flying and tried to imitate this, not always with the expected success though.

At the end of the 19th Century a breakthrough took place with first attempts of Clement Ader in 1897 and the memorable on 17 December 1903 in Kitty Hawk, by the Wright Brothers. From then on the development of aeronautical transport evolved rapidly. From 1919 onwards (hence only 16 years later) pilots took passengers with them frequently on short air trips. It is evident that such ‘air tourism’ bears a considerable resemblance with present ‘suborbital space tourism’ as a next step in human exploration. Admittedly, the considerable number of planes freely available after the First World War and the availability of a large number of very experienced (military) pilots facilitated this rapid process, which is not the case for suborbital space tourism.

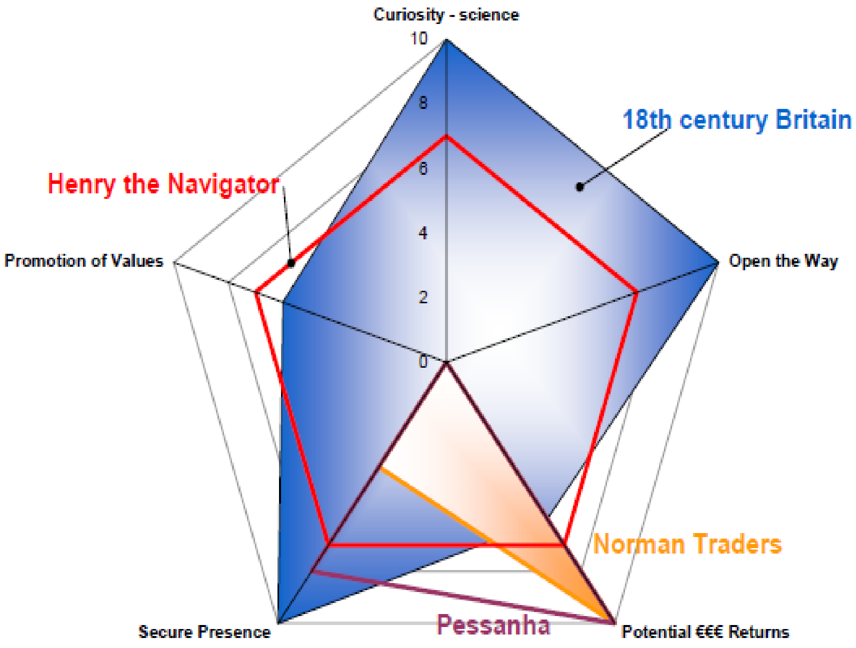


Figure 7.1: Comparison of Maritime Exploration programs and Henry the Navigator’s rationale [7-2].

Still, the exploration dream to view the Earth from space and experience weightlessness has never left the aspiration of humans and regularly hope arose that this would become soon possible. For different reasons we know that the step was not an easy one to take and it took 40 years, after the first flight of Y. Gagarin in 1961, before first passenger, Dennis Tito, was able to experience a spaceflight privately financed.

A DLR organized workshop, gathering scientists and philosophers, already as early as 1991 explained this drive as follows [7-3].

> *Exploration of the Universe is a logic further conquest of frontiers, typical of the universality of man and in line with his sense of responsibility.*

Interesting research in this field has been done in the frame of “historical anthropology” whereby space exploration is described as a “natural” continuation of humankind’s evolutionary process, i.e. “to see what’s behind the next hill” [7-4], [7-5].

In a recent work, J. Arnould has also developed the balance between the different risks which need to be mastered, but should not be a major showstopper for humanity to continue to explore [7-6].

Often the aspect of risk has been mentioned in relation to space exploration. Historically risk has never stopped people to explore poles, mountains or deep sea.

We have witnessed the development of skydiving, bungee jumping, river rafting and many more adventure tourism elements over the last few decades. There is no reason to assume that suborbital space tourism will not be an integral part of this in the next few years!

8. Market Demand

There is no doubt that business can only flourish if there is a realistic market demand. It is known in marketing that this aspect is very difficult to measure in the market of New Products, where reference figures or analogue statistical data are not available [8-1], [8-2].

In order to estimate the size of the market initially a number of telephone interviews were made in different countries. The first approach was made by P. Collins [8-3] in Japan in the early 1990's. In order to make the results currency and purchasing power independent the questions were asked in terms of how many months of salary would people be willing to spend on such suborbital space trip. The questionnaire was repeated in a similar way in North America, Germany, UK and many other countries [8-4], [8-5] leading to very high numbers of potential participants, in the order of nearly 10% of the respondents were indeed willing to spend a year's salary. This type of market research was heavily criticized mainly as

- There was no commitment linked to it
- Only desire was measured
- The target population was not adequate.

The billionaire Richard Branson (Virgin Group) established a company 'Virgin Galactic Airways' in April 1999, targeting at a 200,000 people market willing to pay up 100,000 $ for a trip [8-6]. Evidently, as his own money is at stake, he was more conservative in his assumptions.

Later, tourism experts [8-7] used the income of people worldwide and assumes that only 0.56% of them are interested in a space trip (taking into account physical fitness and adventure tourism interest), This way they came to a more conservative market potential of over 40,000 people willing (and able) to pay a $100,000 ticket price.

One of the best-known approaches was then executed by Futron (D. Webber) and was based upon a more tangible and objective logic [8-8].

1) It was noted that high Net Worth Individuals (HNWI) were regularly spending 1.5% of their free capital on one single trip
2) Based upon a $100,000 USD ticket price, therefore only persons with a net wealth of more than $7 million USD were considered
3) A survey was made of 450 individuals *within that group*:
4) 28% showed an Interest in space flight
5) 86% were physically fit enough to do such trip.

On the basis of these data an S-curve distribution of the target market was constructed as shown in Figure 8.1. This curve is filled in terms of years and therefore can not be directly related to Figure 8.2.

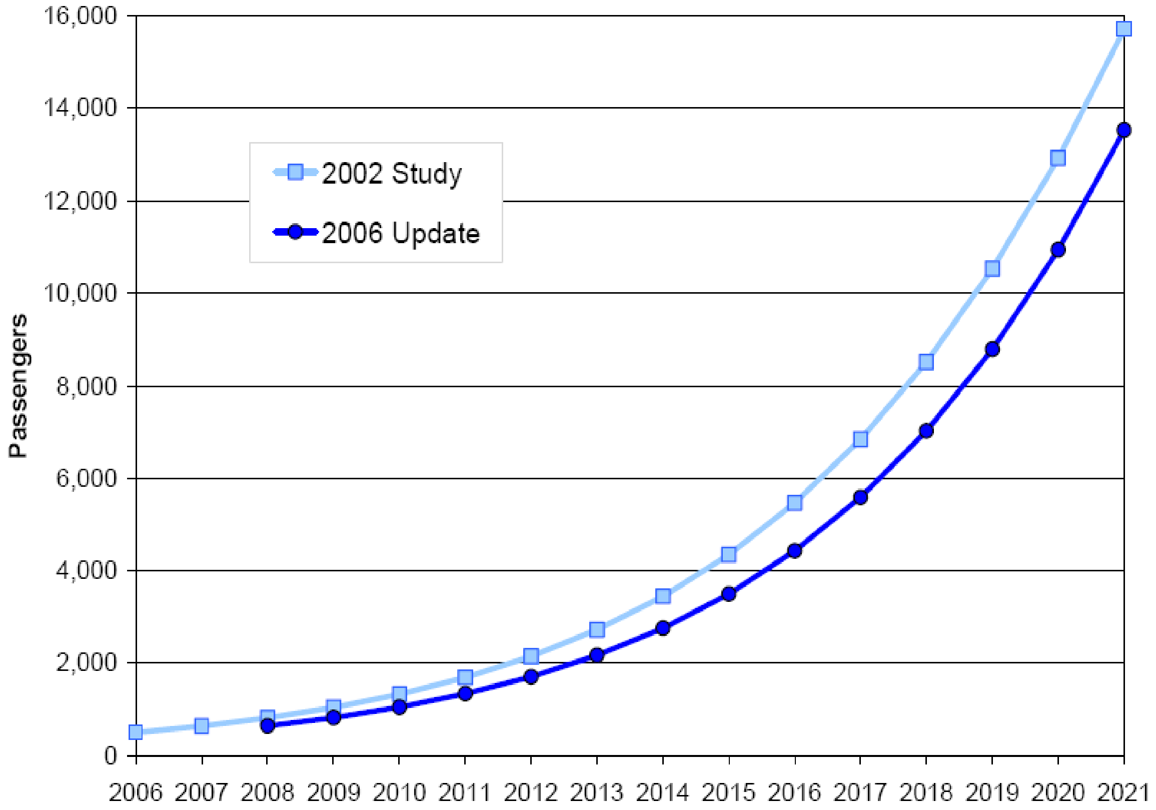


Figure 8.1: Plot of Futron forecast studies [8-8], [8-9]

Note that:

- Also the revised 2006 study is plotted in Figure 8.1, which took into account slippage of the start of operational activities and a ticket price of $200,000 USD instead of the original $100,000 USD
- In the new study the pioneering effect was considered. Only first customers are assumed to be willing to pay the high amounts and it is expected that prices will drop due to competition as per Figure 8.2.

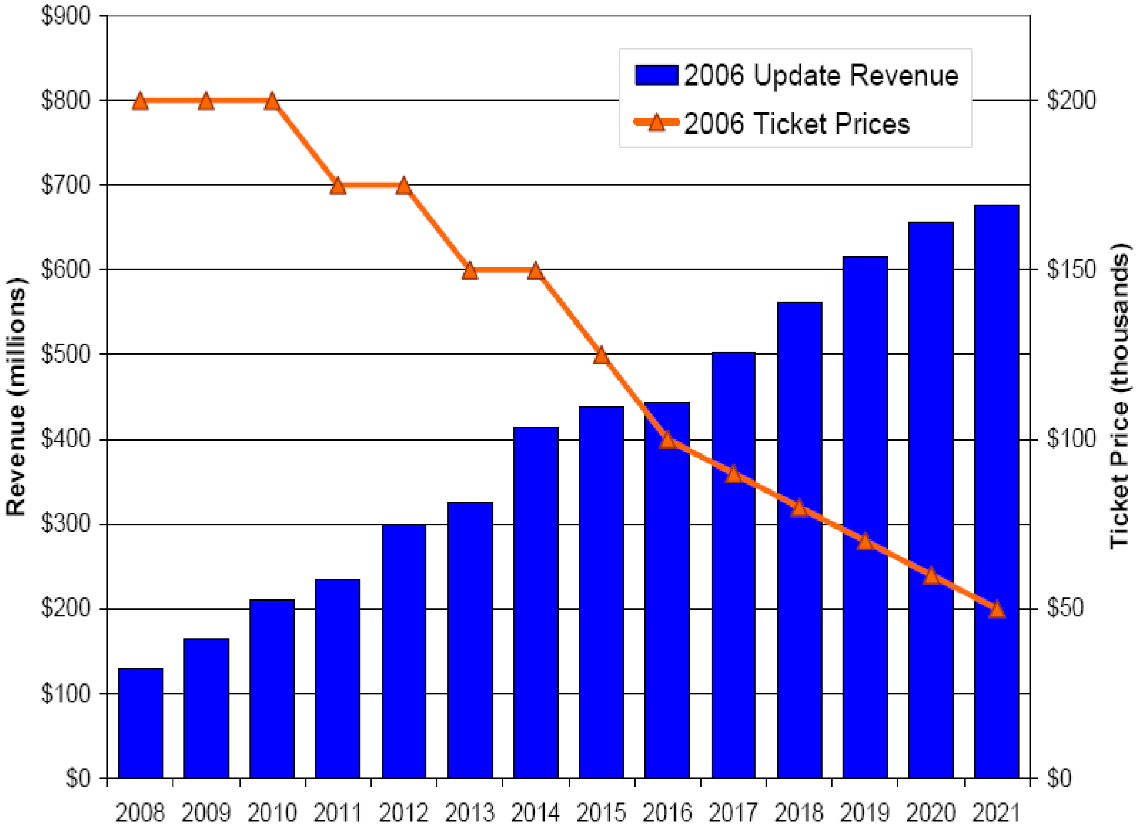


Figure 8.2: Plot of digressive ticket prices due to pioneering effect [8-9]

Estimates from this type of analysis are indicating a potential market of some 13,000 passengers yearly, confirmed by EADS studies that also estimate the market at steady state conditions at 15,000 passengers/year. A special feature of a recent approach, the so-called Tauri study [8-10], is that a wider variety of potential markets are considered as shown in Figure 8.3

A number of points need to be emphasized here:

- There is a considerable shift of wealth towards Asian countries where the affinity for hi-tech events is higher. Indeed, according to Forbes in 2012
  - More than 10 million people worldwide have more that 1 million USD free capital (beyond real estate etc.)
  - More than 30% of them live in Asia.

COMMERCIAL HUMAN SPACEFLIGHT

Human spaceflight experiences for tourism or training

Individuals
Corporate
Contests and promotions
In-space personnel training

BASIC AND APPLIED RESEARCH

Basic and applied research in a number of disciplines, leveraging the unique properties of and access to the space environment and microgravity

Biological and physical research
Earth science
Space science
Human research

AEROSPACE TECHNOLOGY TEST AND DEMONSTRATION

Aerospace engineering to advance technology maturity or achieve space demonstration, qualification, or certification

Demonstrations requiring space/launch environment
Hardware qualification and test

MEDIA AND PUBLIC RELATIONS

Using space to promote products, increase brand awareness, or film space-related content

Film and television
Media, advertising, and sponsorship
Public relations and outreach
Space novelties and memorabilia

EDUCATION

Providing opportunities to K-12 schools, colleges, and universities to increase access to and awareness of space

K-12 education
University educational missions

SATELLITE DEPLOYMENT

The use of SRVs to launch small payloads into orbit

Very small satellite launch

REMOTE SENSING

Acquisition of imagery of the Earth and Earth systems for commercial, civil government, or military applications

Commercial Earth imagery
Civil Earth imagery
Military surveillance

POINT-TO-POINT TRANSPORTATION

Future transportation of cargo or humans between different locations

Fast package delivery
High-speed passenger transportation (civil)
High-speed troop transportation (military)

Figure 8.3: Overview of different markets as considered in the Tauri report of 2012 [8-10]

Note that the reference to Point-to-Point (P2P) transport refers to a progressive character in this summary. There seems no doubt that many of the technologies validated during the operational phases of suborbital flights will benefit the development of future P2P vehicles. However, it has also clearly to be considered that P2P vehicles will be a next generation development of spacecraft. Already re-entry technologies and thermal protection, just to mention a few aspects, will drive a completely new design concept.

A considerable number of bookings are based upon incentive travels. Bookings are known from Oracle, IBM, Pepsi Cola, Volkswagen and undoubtedly many more companies that want to remain anonymous.

Doubts are often expressed if people are willing to spend large amounts to very expensive and short duration activities. We can illustrate this statement by a few present examples.

- The rental price of the yacht ‘Alysia’ is presently 661,500 € per week
- An exclusive island in the Caribbean van be rented for $1,000,000 USD weekly
- The luxury yacht ‘Eclipse’ can be rented for $1,420,000 USD weekly (including a crew of 70 persons)

It certainly belongs to an overview report of this nature to also represent a picture of a space pioneer, W. Inden, who graphically tried to show that space tourism is certainly not to be considered as extremely exotic, compared to the spending for cruises or the purchase of ultra-expensive cars, as shown in Figure 8.4 [8-11].

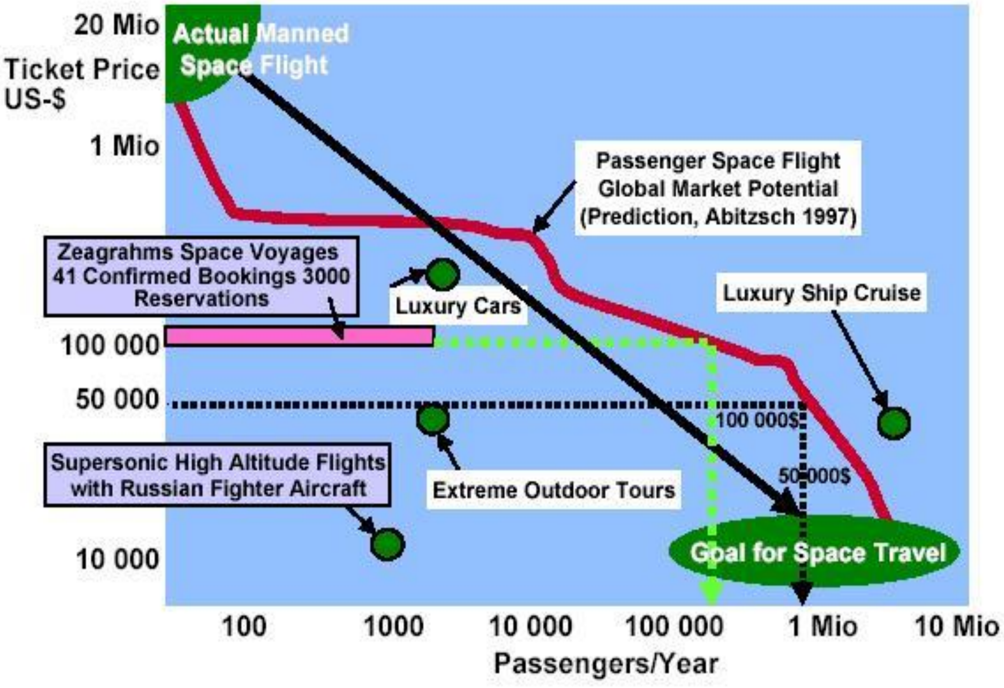


Figure 8.4: Space tourism in comparison to other luxury goods (Courtesy: W. Inden)

The future will prove if these forecasts are realistic.

When writing this report the number of reservations is estimated in the order of 950, divided as follows (all figures on the basis of operator statements).

- Virgin Galactic: > 550 customers, and > 60 million USD paid
- Armadillo: > 200 bookings
- XCOR: > 175 bookings

It appears evident that such figures, before any operational flight took place, give at least a strong indicator of the potential market interest in suborbital space tourism.

9. Medical Aspects of Suborbital Space Tourism

9.1. Introduction

The goal of Space Medicine is to study the physiological, psychological, environmental and operational stress factors that affect humans during space flights, and to assess the potentially adverse consequences (acute and chronic) of exposure to such stress factors on their health and safety. Because crewmembers are directly responsible for the safety of space flight operations, the main challenge for space medicine practitioners is to ensure the medical fitness and performance readiness of generally "normal" individuals, who work in "abnormal" space environments. In other words, the primary role of space medicine practitioners is to prevent the occurrence of sudden in-flight medical incapacitation or performance impairment of space crews while they operate space vehicles. Regarding passengers, Space Medicine's primary role has been to ensure that all individuals, whose health status may vary from clinically normal to diseased, will not die or experience in-flight medical emergencies, and will safely reach their final destination.

9.2. Background

Most of the accumulated space medicine knowledge and experience to date has been obtained from professional astronauts and cosmonauts (career space crews) between the ages of 35 and 50 years old. Most of the biomedical data (medical, physiological, psychological) collected to date are based on the effects of space flight (short and long) on generally healthy career space crews. Because of medical privacy laws and individual space career considerations, individual biomedical data from career space crews is not readily available for scientific study. There is a limited amount of medical information on pathologies occurred among career space crews during: 1) Ground medical events, 2) Short-duration space shuttle flights, 3) Long-duration MIR space station flights, 4) Long-duration MIR/NASA flights. Limited biomedical information has also been collected and analyzed from 7 private space passengers who participated in short-duration (up to 2 weeks) orbital flights arranged through a commercial space company. Furthermore, available biomedical information from space travelers who have moderate-to-severe pathology is also very limited (quantitatively and qualitatively). Such an insufficient level of overall medical knowledge and experience represents a significant challenge to those space medicine practitioners who, are or will be, responsible for the medical assessment of prospective commercial space passengers who have a wide range of health and fitness levels. Therefore, several medical screening approaches have been proposed by government and professional groups such as the U.S. Federal Aviation Administration (FAA), the Aerospace Medical Association (AsMA), the Center of Excellence for Commercial Space Transportation (COECST), and the International Academy of Astronautics (IAA) to preserve the health and promote medical safety of passengers who intend to participate in commercial suborbital flights and short-duration orbital flights (up to 4 weeks).

9.3. U.S. Federal Aviation Administration Recommendations

The FAA report on "Guidance for Medical Screening of Commercial Aerospace Passengers" contains general guidance for the manned commercial space industry (suborbital and orbital) in the medical assessment of prospective passengers (Ref 3). This guidance is designed to identify individuals who have medical conditions that could result in an in-flight medical emergency or in-flight death, or could compromise in any other way the health and safety of any occupants onboard a commercial space vehicle. Space flight exposes individuals (healthy or unhealthy) to an environment that is far more hazardous than what is experienced by occupants during routine airline flights. During suborbital flights, existing medical conditions can be aggravated or exacerbated by exposure to a variety of environmental and operational risk factors. Such risk factors include in-flight acceleration (vehicle flight profile), impact deceleration (hard landing or crash), decreased barometric pressure (cabin pressure, pressure suits), ionizing and non-ionizing radiation, temperature extremes, breathable air composition and quality, microgravity, noise, vibration, etc. Due to the various technological approaches that are been pursued to design and operate manned commercial space vehicles, the FAA medical guidance applies differently to two categories of passengers: 1) Passengers participating in suborbital space flights (or exposed to an acceleration of up to +3Gz during any phase of the flight), and 2) Passengers participating in orbital space flights (or exposed to an acceleration exceeding +3Gz during any phase of the flight). The FAA report discusses medical conditions that may contraindicate passenger participation in space flights (suborbital or orbital) and the recommended disposition of these passengers.

9.4. Aerospace Medical Association Recommendations

The AsMA Task Force on Space Travel developed "Medical Guidelines for Space Passengers – Parts I and II" [9-1, 9-2]. The first report contained lists of medical conditions that would disqualify individuals from participating in orbital flights of 1 to 7 days in duration. The second report provided medical screening recommendations for short-duration suborbital space flights based on the following five assumptions: 1) The space vehicle interior will be small and confining with a capacity for four to six passengers, 2) The flight will be suborbital of 1 to 3 hours duration including approximately 4 to 6 minutes in microgravity, 3) The cabin will be pressurized to sea level (760 mm Hg) with an 80% nitrogen and 20% oxygen atmosphere; no life-support equipment will be necessary for nominal flight, 4) Acceleration will range between 2 and 4.5 $+G_z$ or G_x, depending on the space vehicle (training may be executed in a human rated centrifuge as in Figure 9.1), and 5) There will be different emergency egress procedures (depending on the space vehicle). This report also addressed other considerations, including space motion sickness, pregnancy, sudden incapacitation, and age. The final recommendations contained broad guidelines for obtaining medical histories at the time of flight application, and again immediately pre-flight, and the performance of a physical examination and diagnostic studies by a physician trained in aerospace medicine, the content of which depends on the information found in the medical histories.

Figure 9.1: Human Rated centrifuge (Courtesy: US Air Force)

9.5. Center of Excellence for Commercial Space Transportation (COECST) Recommendations

The COECST developed a report on “Flight Crew Medical Standards and Spaceflight Participant Medical Acceptance Guidelines for Commercial Space Flight” [9-7]. This report provides: 1) A consolidated set of recommendation for crew medical standards that will be useful to the FAA in its regulatory responsibility for crew medical standards and safety, and 2) A consensus set of spaceflight participant (SFP) acceptance guidelines that can serve as advice to commercial operators as they develop their own medical programs. Commercial companies will have the opportunity to incorporate these guidelines into their operations and adjust them as appropriate to meet their individual flight parameters, safety standards and risk profiles. Companies currently are required to inform spaceflight participants about the mission-related risk, but the specific risk of certain medical conditions has yet to be determined. The crew medical standards and SFP guidelines included in this report are considered the minimum recommended and governmental agencies and operators have the option for additional medical and operational constraints. On Phase I of this study the COECST collected and reviewed existing documents addressing orbital and suborbital crew member medical certification, spaceflight participant (SFP) medical evaluation and acceptance guidelines, and developed recommendations for medically–related testing and training for both crew members and SFPs. On Phase II the COECST prepared a preliminary document incorporating the various guidelines and recommendations as previously outlined and obtained input and comment from those involved in the commercial space flight industry, NASA, and the FAA. The COECST convened a working group of experts in aerospace medicine and physiology, operations, training, safety, government, and the public to consider the comments from Phase II. On Phase III the COECST prepared a consolidated set of recommendations for the medical certification of crewmembers, medical acceptance guidelines for SFPs, and recommended appropriate training procedures for both suborbital and orbital commercial space flights. Although the FAA sponsored this project, it neither endorsed nor rejected the finding of this research. The presentation of this information is in the interest of invoking technical community comment on the results and conclusions of the research.

9.6. International Academy of Astronautics Recommendations

The IAA report on "Medical Safety and Liability Issues for Short-Duration Commercial Orbital Space Flights" identifies and prioritizes medical screening considerations in order to preserve the health and promote the safety of paying passengers who intend to participate in short-duration flights (up to 4 weeks) onboard commercial orbital space vehicles [9-5]. The IAA recommendations are generic in scope and are based on current analysis of physiological and pathological changes that may occur as a result of human exposure to operational and environmental risk factors present during orbital space flight. This approach includes the identification of pre-existing medical conditions that could be aggravated or exacerbated by exposure to the environmental and operational risk factors encountered during launch, in-flight and landing. The IAA report outlines recommendations on the medical history assessment, physical examination and medical tests of orbital space passengers, as well as the recommended additional medical assessment and disposition of passengers who have medical conditions that may preclude their participation in space flight.

9.7. Recommendations for the Implementation of a Medical Safety Management System for Suborbital Commercial Human Spaceflight Operations

The principles of an effective and efficient Safety Management System (SMS) in aviation are: Safety Policy, Safety Risk Management, Safety Assurance, and Safety Promotion [9-8,9-9]. These same principles can be applied to the implementation of a Medical SMS (MSMS) for Suborbital Commercial Human Spaceflight Operations (SCHSO).

9.7.1. Medical Safety Policy

The main goal of a Medical Safety Policy in support of SCHSO should be to promote the preservation of life and health of all space vehicle occupants (crews and passengers) during space flight. Methods and processes to support this medical safety policy should include pre-flight medical screening, medical monitoring during pre-flight training, in-flight biomedical monitoring, and post-flight medical evaluation of all space vehicle occupants.

This medical safety policy should include a clear organizational commitment to:

1) Continual improvement in the level of medical safety
2) Management of medical safety risks
3) Full compliance with applicable regulatory requirements
4) Encouraging employees to report medical safety issues without reprisal
5) Establishing clear standards for acceptable behavior

6) Providing management guidance for setting safety objectives
7) Providing management guidance for reviewing safety objectives
8) Maintaining MSMS program documentation
9) Communicating the policy to all employees and responsible parties
10) Reviewing the policy periodically to ensure it remains relevant and appropriate to the organization
11) Identifying responsibility of management and employees with respect to safety performance.

Senior leadership must demonstrate a real commitment to continuous improvement of medical support programs and emphasize their relevance to the operator's success. Furthermore, senior leadership must communicate the operator's expectation of a workforce safety culture that promotes the preservation of life and health of all space vehicle occupants.

9.7.2. Medical Safety Risk Management

The implementation of a Medical Safety Risk Management approach includes:

1) Description of the System of Interest – Identify medical conditions that may contraindicate crew and passenger participation in commercial space flights, including any deformities (congenital or acquired), diseases, illnesses, injuries, infections, tumors, treatments (pharmacological, surgical, prosthetic, or other), or other physiological or pathological conditions that may: a) result in an in-flight death, b) result in an in-flight medical emergency, c) interfere with the proper use (don and doff) and operation of personal protective equipment, d) interfere with in-flight emergency procedures or emergency evacuation, and/or e) compromise the health and safety of the passenger or other space vehicle occupants, and/or the safety of the flight. Some medical conditions may be cleared for space flight following special medical assessments in simulated spaceflight environments including the use of a zero-G aircraft, a high performance aircraft, a hypobaric (altitude) chamber, or a human rated centrifuge (see Figures 9.1 and 9.2). Using a flexible approach that applies current aerospace medicine knowledge and experience-based medical risk analysis, it may be possible to permit special medical accommodations for prospective participants who have certain pathologies (including disabilities).
2) Identify the Safety Risks - It is essential to identify all risk factors (actual and potential) that could compromise the health and safety of all commercial space vehicle occupants, including exposure to in-flight acceleration (vehicle flight profile), impact deceleration (hard landing or crash), decreased barometric pressure (cabin pressure, pressure suits), ionizing and non-ionizing radiation, temperature extremes, breathable air composition and quality, microgravity, noise, vibration, etc.
3) Analyze the Safety Risks – It is critical to implement safety risk controls to ensure human tolerance to in-flight acceleration, protect occupants against impact deceleration, control barometric pressure within human tolerance limits, protect occupants against exposure to ionizing and non-ionizing radiation, protect occupants against extreme temperatures, control the composition and quality of breathable air, ensure human tolerance to the adverse physiological effects of exposure to microgravity, protect occupants against exposure to

noise and vibration, etc. Individual contributing factors must be identified, including pre-existing medical conditions and fitness status, use of medications (prescribed or over-the-counter), individual variability in physiological tolerance limits, self-imposes stress factors (fatigue, nicotine addiction, alcohol & drug use, obesity, dehydration, psychological stress, scuba diving before flying, etc.). It is necessary to estimate the likelihood and severity of adverse health and operational safety outcomes based on expected level of exposure to identified hazards, use of all available safety risk controls, and the presence of contributing factors.

4) Assess the Safety Risk - Determine the commercial space operator's levels of acceptability and unacceptability of adverse health and operational safety outcomes. The operator shall define levels of management that can make safety risk acceptance decisions.

5) Control the Safety Risk - Safety risk control/mitigation plans must be defined for those adverse health and operational safety outcomes that are considered unacceptable. Safety risk controls shall be clearly described, evaluated to ensure that the requirements have been met, ready to be used in the operational environment for which they are intended, and documented.

Figure 9.2: Preparation of candidate for centrifuge testing (Courtesy: US Air Force)

9.7.3. Medical Safety Assurance Process

The next step is to implement a Medical Safety Assurance Process to continually monitor adverse health and operational safety outcomes to identify new hazards or the need to change risk controls or other risk management responses.

The safety assurance process should include:

1) Information Acquisition - Medical information collected from space vehicle occupants (especially those with medical waivers) will be extremely important to establish operator-owned prospective medical databases. Medical databases may include the results of pre-flight medical screening, medical monitoring during pre-flight training, in-flight biomedical monitoring, and post-flight medical evaluation. Operator-owned medical databases will be of critical importance (medical & legal) to the safety and health of subsequent space vehicle occupants. The operator should also establish criteria for the collection of relevant medical/human factors data from the investigation of unexpected incidents and accidents that resulted in injuries and/or fatalities among space vehicle occupants. All medical information collected and archived in databases should be protected to ensure individual medical-legal privacy rights. The operator should establish a process to self-assess compliance with existing regulatory requirements regarding medical support programs and risk controls to preserve the life and health of space vehicle occupants. The operator should monitor operational data to assess conformity with safety risk controls, to measure the effectiveness of safety risk controls, to assess system performance, and to identify new hazards.
2) Data Analysis - Provides the space medicine community with an opportunity to gain critical experience with non-career astronauts who have certain medical abnormalities to demonstrate that they could fly safely. Enables the revision of medical screening criteria used by commercial space transportation companies to accommodate individuals with certain medical abnormalities, optimize their pre-flight treatment, and observe their effectiveness during space flight. Data analysis benefits other individuals who may have similar medical conditions and wish to safely fly in space. Data analysis can be used to demonstrate that individuals and their physicians can evaluate and accept some medical risks for pre-flight training and actual space flight. Through data analysis, commercial space transportation companies shall identify where improvements can be made to their medical safety management system.
3) System Assessment - The collection and analysis of medical data will be used to document conformity or non-conformity with the medical support programs and risk controls designed to preserve the life and health of space vehicle occupants. The assessment will also help identify new potential hazards and the need for changes to existing medical support programs and risk controls.
4) Development of Preventive or Corrective Actions - Actions must be implemented to address any non-conformities with medical support programs and risk controls that compromise the preservation of life and health of space vehicle occupants. Records should be kept of the disposition and status of preventive and corrective actions. Senior leadership must constantly review the effectiveness of medical support programs and risk controls to assess and support the need for changes.

9.7.4. Medical Safety Promotion

The final step is the implementation of a Medical Safety Promotion process through the establishment of a medical safety culture characterized by an appropriate knowledge base, competency, resources, communications, training and information sharing that is actively promoted by senior management. Operator employees acknowledge their accountability and act on their individual responsibility to promote the preservation of life and health of space vehicle occupants.

Senior management shall promote the growth of a positive safety culture through:

1) The publication of their stated commitment to medical safety of space vehicle occupants.
2) Visible demonstration with actions of their commitment to the Medical Safety Management System.
3) Communication of the medical safety responsibilities for the organization's personnel.
4) Clear and regular communication of medical safety policy, goals, objectives, standards, and performance to all employees of the organization.
5) An effective employee safety feedback system that provides confidentiality as is necessary.
6) Use of a safety information system that provides an accessible efficient means to retrieve information.
7) Allocation of the resources required to implement and maintain the Medical Safety Management System.
8) Development of medical safety lessons learned that should be used to promote continuous improvement of medical safety.

9.8. Other Recommendations

Recommendation 1: An important consideration is that the first generation of commercial suborbital space vehicles may not have any emergency medical intervention capabilities onboard (medical equipment, supplies, and medically trained personnel), and it would be very difficult to change the pre-planned flight profile of a space vehicle (especially an orbital vehicle) to initiate an emergency landing in order to seek life-saving medical care for passengers at medical facilities [9-6]. Therefore, prospective space passengers with significant medical conditions will have to undergo a very comprehensive medical waiver process before allowing them to participate in space flights in order to preclude the need for in-flight medical care.

Recommendation 2: It is highly recommended that suborbital commercial space operators implement non-invasive biomedical monitoring of space passengers prior to launch, during the entire flight, and in the immediate post-landing period [9-6]. It is a fact that professional astronauts/cosmonauts are characterized by a high degree of physiological and psychological fitness that is not representative of the general commercial space flight participant population. There is limited knowledge about the effects of space flight on the general public. Biomedical monitoring preflight, in-flight and post-flight will be used to assist with defining the medical and biological effects experienced by spaceflight participants during suborbital commercial space flight operations [9-10]. The basic physiological parameters to be monitored may include body temperature, heart rate, blood pressure, ambulatory electrocardiography, respiratory rate, transcutaneous arterial oxygen saturation (PSaO2) and carbon dioxide partial pressure (PaCO2). It is recommended that such a monitoring system be fully portable, light and compact, self-powered, non-invasive, minimally intrusive on the wearer, and with a built-in automated data collection and storage capability.

Recommendation 3: Biomedical information collected from suborbital space passengers (especially those who are granted medical waivers) should be used to establish medical databases to be used for epidemiological studies [9-6]. It is recommended that medical databases include the results of the initial medical screening and pre-flight medical evaluations, the results of any in-flight biomedical monitoring, as well as any post-flight medical findings. Post-flight medical debriefs are highly recommended to collect critical medical data and to resolve and/or follow up any health issues resulting from space flight. A post-flight medical debrief will aid in establishing a reliable and comprehensive evidence base for continual improvement of health risk management techniques [9-4]. All medical information archived in databases should be protected to ensure the individual medical-legal privacy rights of space passengers. Space operator-owned medical databases would be of critical importance (medical & legal) to the success of the manned commercial space transportation industry, and, more importantly, to the health and safety of subsequent space passengers.

9.9. Conclusions

Human commercial space transportation is generating a unique set of medical and human factors issues that must be effectively managed in order to protect the health and safety of those directly involved in space flights. In the very near future, the general public will be able to participate in suborbital commercial space flights and this new industry will show rapid growth. Therefore, space medicine practitioners must be prepared to meet their obligations and responsibilities in support of manned commercial space transportation.

The ultimate success of the emerging commercial human space flight industry will depend (to a great extent) upon their organizational actions to demonstrate a firm commitment to prevent the occurrence of adverse health and medical safety outcomes among paying space passengers.

The timely and effective application of a Medical SMS to manage the medical risks associated with spaceflight will significantly impact the successful initiation and continued viability of the emerging commercial human spaceflight industry.

10. Legal Aspects of Suborbital Personal Spaceflight

10.1. Introduction

Recent technological and entrepreneurial developments indicate that routine personal suborbital flights for ordinary people with emerging aerospace transportation systems might start in 2013. Richard Branson’s Virgin Galactic Company is, undoubtedly, the world’s leader in private aerospace transport, but there are other companies in various countries that are active in this race. Virgin Galactic will begin operational personal suborbital flights using a combination of its two vehicles, which are WhiteKnightTwo and SpaceShipTwo. A custom-made transport aircraft WhiteKnightTwo (‘mother ship’), with SpaceShipTwo on board, will take off from an airport. When both these vehicles reach an altitude of about 15 kilometers, SpaceShipTwo will fire its rocket engine for a vertical rise to reach an altitude of about 105 kilometers to be in outer space. SpaceShipTwo, its pilot and about six passengers (tourists), will remain for a few minutes in space before returning to land horizontally at a designated airport like a glider (an aircraft). In addition to people, Virgin Galactic will also carry small payloads. Virgin Galactic will have competition from companies like California-based XCOR Corporation that is building—and will soon be operating—a spaceplane called Lynx, a simpler single vehicle, for half-hour suborbital flights for humans and payloads.

> *Like an aircraft, Lynx is a horizontal takeoff and horizontal landing vehicle, but instead of a jet or piston engine, Lynx uses its own fully reusable rocket propulsion system to depart a runway and return safely [10-1].*

Undoubtedly, different technologies will be developed and tested initially and finally the safest vehicles, providing the most cost-effective, comfortable, reliable and regular suborbital transportation, will prevail. This new mode of aerospace transport will be an important stepping-stone for orbital flights, as well as point-to-point journeys on the surface of the Earth, through outer space, for transporting people and freight.

It is expected that like aircraft, aerospace vehicles most likely would be developed and manufactured by a small group of countries. By constructing and operating appropriate ground facilities (aerospace ports, navigational aids, etc.), other countries would make the most of this newest mode of transport and benefit from space commercialization. Aerospace vehicles will soon be ‘flying’ not only domestically but also on international routes from and to different countries around the world. Will it be possible for people and goods to go via such flights from Montreal to Tokyo in two hours by 2020? Yes, most probably.

However, for some time to come, there will remain numerous technological challenges, particularly in making aerospace flights significantly safe. Economic realities will dictate to reduce cost significantly to make affordable for masses. Perhaps, the most important and difficult challenge relates to legal and regulatory issues both in air law and space law. In other words, to a large extent, the future of such transport will essentially be determined on the basis of applicable international and national legal regimes.

Aerospace vehicles for suborbital trips could be considered both as aircraft and space objects at the same time. This duality of identity and classification of aerospace vehicles raises several important legal questions and unprecedented challenges related to the safety of both aviation and space transportation, navigational and communication services, airworthiness and space worthiness, personal training and certification, use of aerodromes and spaceports, traffic rights, liability for damage and injury, scope of jurisdiction of international organizations such as the International Civil Aviation Organization (ICAO) as well as national regulatory authorities, only to mention a few.

In this brief chapter, only the applicability or non-applicability of current regulatory regimes will be discussed, rather than analyzing in detail their precise and appropriate rules, particularly with respect to (a) right to fly over or into airspace of foreign countries, (b) liability for damage, personal injury and death caused during suborbital flights and (c) national regulatory restrictions in the form of export controls.

10.2. Application of Air Law or Space Law Treaties?

Because the trajectory to be followed by an aerospace vehicle for suborbital flights will normally cut through portions of airspace and outer space, it would be subject to different international legal regimes depending upon where it is located on the trajectory at any point in time. Thus, an aerospace vehicle could be considered to be an aircraft while flying in the airspace. The same vehicle could also be considered to be a space object when passing through outer space. Depending upon its location, such an aerospace vehicle would be subject to two very different international legal regimes, that is space law and air law. Space law comprises of several international treaties, the two most relevant of which are the *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies*, entered into force on 10 October 1967(hereinafter referred to as the 1967 Outer Space Treaty) and the *Convention on International Liability for Damage Caused by Space Objects*, entered into force on 1 September 1972 (hereinafter referred to as the 1972 Liability Convention). The 1967 Outer Space Treaty established the right of freedom of use of outer space by all countries and their private entities. Such use is carried out with rockets (launch vehicles), which are space objects or spacecraft.

On the contrary, air law consists of numerous international treaties, the most significant of which is the *Convention on International Civil Aviation*, signed at Chicago on 7 December 1944 (hereinafter referred to as the Chicago Convention). Article 1 of this Convention categorically recognizes that “every State has complete and exclusive sovereignty over the airspace above its territory.” This provision is understood broadly to mean that each State controls its airspace strictly and allows entry of any foreign aircraft or any other vehicle only pursuant to its own discretion or its commitment under any applicable multilateral (e.g. the Chicago Convention) or bilateral treaty and that too only for those purposes and under those conditions that are specified therein. For example, the Convention does not apply to State aircraft (e.g. aircraft engaged in military, customs and police services), which cannot fly over the territory of another State or land thereon without authorization by special agreement or otherwise and in accordance with the terms thereof. No scheduled international air service may be operated over or into the territory of a State, except with the special permission or other authorization of that State, and in accordance with the terms of such permission or authorization. States allow foreign aircrafts to fly over their territories pursuant to the obligations they have accepted under the *International Air Services*

Transit Agreement, signed at Chicago on 7 December 1944. They reserve their right to (a) specify the routes to be followed and the airports to be used within their territories by foreign aircrafts and (b) revoke an authorization to foreign aircraft, *inter alia*, in cases of failure of foreign aircraft to comply with the laws of the State flown over. Therefore, a State may choose not to allow passage over or entry into its airspace, without its agreement, by foreign aircrafts and suborbital vehicles, which it considers not to be aircrafts.

The Chicago Convention does not directly define "aircraft", but according to Annex 1 to the Convention, the aircraft is as "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." Thus, if a vehicle for suborbital flight is to be considered as an aircraft, it ought to be essentially deriving "support in the atmosphere from the reactions of the air" and consequently will be subject to air law regime that imposes strict restrictions on the vehicle's entry into or flying over the national airspace of other countries.

On the other hand, if a vehicle for suborbital flight is considered to be a spacecraft then it will be governed by space law regime, entitling it to the right of freedom of use of outer space. However, a question arises: does a vehicle for suborbital flight as a spacecraft has the right of (innocent) passage through or 'fly' into the airspace of foreign States for the purpose of providing international services? The Council of ICAO is of the opinion that aright of passage of spacecraft for a suborbital flight through the foreign sovereign airspace does not exist under the present international law. Therefore, it appears that a suborbital flight would need special permission of foreign States to passage through or 'fly' into their airspaces or territories.

Applying the definition specified in the above-mentioned Annex 1 to the Chicago Convention, one can say that WhiteKnight is an aircraft and SpaceShip largely meets the criteria for an aircraft since it lands at an airport as an aircraft. It is important to keep in mind that from the moment it takes off from WhiteKnight using its rocket propulsion thrust and while in outer space, SpaceShip is also a space object. Similarly, Lynx spaceplane should be considered as a spacecraft on its ascending journey for suborbital flight as it will use rocket propulsion system when departing a runway. But on its descending journey, it is believed, that it will return to an airport like an aircraft. Therefore, at least these two aerospace vehicles for suborbital flights will be subject to two different legal regimes and, in practice, it might be difficult to determine which set of international rules (i.e. air law or space law) apply to them at what stage.

10.3. Airspace Traffic Management

National airspaces as well as international airspace over the high seas are increasingly becoming crowded as aviation expands exponentially. Aerospace vehicles for suborbital trips will also use these environments. However, if these vehicles are classified differently from aircraft (i.e. if they are spacecraft), they will not be subject to international and national rules governing air navigation or air traffic management. Figure 10.1 depicts a future scenario.

Under the Chicago Convention, each State is obliged to provide, in its territory, air navigation facilities in accordance with the Standards and Recommended Practices (SARP's) in the form of Annexes established pursuant to this Convention. Consequently, the ICAO has adopted SARP's governing air navigation in national airspaces, under Annex 9 on Facilitation, which applies to all categories of aircraft operation. Under this Annex, States are obligated to "adopt appropriate measures for the clearance of aircraft arriving from or departing to another" State. Similarly, Annex 2 to the Chicago Convention, which contains rules of air navigation over the high seas (i.e. international airspace) applicable to all aircraft of the States parties to the Convention. In Canada, a private company NAV CANADA is authorized and required to provide aviation navigation services. Its "mandate is to provide safe, effective and efficient air navigation services to aircraft operating in Canadian domestic airspace and in international airspace assigned to Canadian control [10-2]". National air traffic management authorities, like NAV CANADA, will not be legally required or entitled to provide air navigation services to the operation of aerospace vehicles if they are considered not to be aircraft, as discussed above. Consequently, aerospace vehicles for suborbital flights not being governed by air navigational standards and practices, or if regulated by different set of traffic management rules, could endanger the safety of both aviation and suborbital flights.

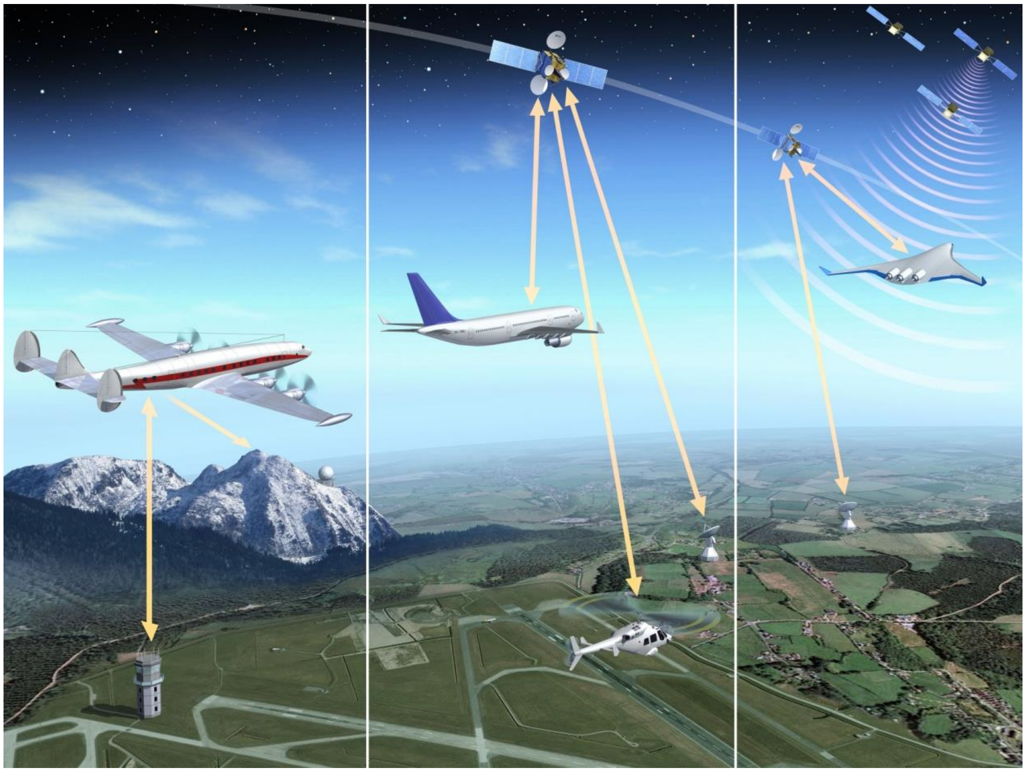


Figure 10.1: Example of future Air Traffic management System IRIS (Courtesy: ESA)

It is, therefore, imperative that taking into considerable similarities between the operational aspects of aviation and aerospace transport for suborbital trips, both these modes of transportation should be regulated under a uniform international legal regime governing navigation [10-3]. Aerospace vehicles should come within the jurisdiction of ICAO. A logical extension of this international body's powers and responsibilities is based primarily on the necessity for uniform, international and strict safety standards not only for aviation but also for aerospace vehicles for suborbital flights. In a recent statement to the UN COPUOS, the ICAO expressed its views on the "Concept of Suborbital Flights", stating that if "foreign airspace(s) be traversed [by suborbital flights], and should it be eventually determined that suborbital flights would be subject to international air law, pertinent Annexes to the Chicago Convention would in principle be amenable to their regulation [10-4].”

10.4. Legal Status of Aerospace Vehicles

Since legal status of aerospace vehicles for suborbital flights is not fully settled at international level, some efforts are being made to define these vehicles at regional and national levels. For example, according to the proposed regulatory approach of the European Aviation Safety Agency (EASA), suborbital vehicles ought to be classified or designated as aircraft [10-5]. Therefore, the designers and operators of such vehicles will have to be fully certified in respect of matters such as safety, operations, flight crew licensing, and airworthiness before the commencement of their first commercial flight. Most of the current rules and standards applicable to aviation and aircraft are readily available for these purposes. On the other hand, under the US law, including the Federal Aviation Administration (FAA) rules, the position is different. In April 2004, the US FAA (Office of the Associate Administrator for Commercial Space Transportation-AST) issued a launch license to Scaled Composites for their SpaceShip flight under the US *Commercial Space Launch Act* (as amended) [10-6]. The Act governs commercial launches of orbital and suborbital rockets. This implies that SpaceShip has been categorized as a spacecraft (space object) subject to space law of the US. Similarly, Lynx is expected, according to XCOR website, to “operate as an FAA AST-licensed suborbital reusable launch vehicle. XCOR already has successfully passed the AST licensing process with an earlier vehicle concept [10-1].” Such categorization and status of SpaceShip and Lynx are determined by the US law and are applicable only in the US. However, Virgin Galactic and XCOR (and eventually other aerospace transport operators) will be using White Knight, SpaceShip and Lynx vehicles for international flights as well as domestic flights in other countries. The US law will not be applicable in determining their legal status outside the US. For domestic flights, in countries other than the US, the legal status of White Knight and SpaceShip vehicles will be determined according to their respective laws, which could be similar to, or different from, those of the US. However, in absence of such laws, the logical assumption should be that these vehicles are aircraft in accordance with ICAO regulations and respective national laws applicable to aviation. For international suborbital flights, it would be appropriate to consider WhiteKnight, SpaceShip and Lynx vehicles as aircraft in order to achieve maximum safety of aviation and aerospace vehicles for suborbital flights.

10.5. Liability Issues

The liability regime for aerospace transport for suborbital flights largely depends upon the legal status of the vehicle involved in such transport. The dual legal status of aerospace vehicles, as indicated above, and consequent application of two different legal regimes would cause confusion as to how to determine liability in case of damage, injury or death caused during aerospace transportation for suborbital flights. Aerospace transport gives rise to two main types of liabilities, which is third party liability and passenger liability.

The third party liability arises when damage, injury or death is caused by a space object or aircraft. Briefly, if damage, injury or death is caused by a space object, the matter is essentially governed by a space treaty, that is the 1972 Liability Convention. This Convention imposes absolute and unlimited liability on the launching State (not the service provider) if the damage, injury or death is caused on the surface of the Earth. However, if the damage, injury or death is caused in outer space, such liability is mainly determined on the basis of the fault of the launching State or the person for whom it is responsible. On the other hand, if damage, injury or death is caused by an aircraft, the matter is governed by the *Convention on Damage Caused by Foreign Aircraft to Third Parties on the Surface*, signed at Rome, on 7 October 1952 (hereinafter referred to as the 1952 Rome Convention), which has so far been ratified by only a few States. Under the Convention, a person who suffers damage is entitled to compensation, without proving the fault of the operator of the aircraft, but if he can prove that the damage was caused by an aircraft in flight. The amount of damages that can be recovered is determined on the basis of the weight of the aircraft concerned. In order to modernize the Rome Convention, two other international treaties on third-party liability were adopted in 2009; i.e. the *Convention on Compensation for Damage Caused by Aircraft to Third Parties*, and the *Convention on Compensation for Damage to Third Parties, Resulting from Acts of Unlawful Interference Involving Aircraft.* The first one deals with third-party liability arising from general risks inherent in civil aviation (e.g., aviation accidents), and the second deals with liability arising from acts of unlawful interference with aircraft (e.g., terrorist attacks or hijacking). Both Conventions provide for strict liability of the operator for third-party damages up to a maximum of 700 million International Monetary Fund (IMF) Special Drawing Rights (SDRs) per event to be determined on the basis of the take-off mass of the aircraft involved. In addition, there is a provision for establishing an International CACF to pay compensation for third-party damages.

The passenger liability could result from contractual relationship between a passenger and an aerospace transport operator carrying on suborbital flights. Passenger liability for injury or death caused during aerospace transport may be determined in accordance with applicable national law and/or international law. The US is the only State that has adopted specific national legal regime relating to passenger liability in aerospace transport. The US *Commercial Space Launch Act (*as amended in 2004) considers travelers in vehicles like SpaceShip as “space flight participants” (SFPs). This categorization implies that SFPs are not ‘passengers’ using the services of a transport common carrier. This approach has been adopted to shift the liability risk from spaceflight operators to the SFPs and, thereby, to provide incentive to spaceflight operators by eliminating, or at least minimizing, passenger liability risks. Since SFPs are considered to be active participants in the spaceflight, they may incur liability for “third party claims arising from their involvement in space travel [10-7].” It may, therefore, be advisable for the SFPs to procure insurance not only against their own injury or death but also against possible third party claims.

Secondly, and more importantly, the US law includes a provision regarding a waiver of compensation claim by a SFP, thereby excluding liability of the space flight operator. In order to take advantage of such waiver, spaceflight operators are required by law to inform the spaceflight participants of the risks of their launch activities. Before making an agreement to fly a space flight participant, a space flight operator must inform each space flight participant in writing about the risks of the launch and reentry, *inter alia* that: (a) participation in space flight may result in death or serious injury, or total or partial loss of physical or mental function; (b) the United States Government has not certified the launch vehicle and any reentry vehicle as safe for carrying crew or space flight participants. In addition, a space flight operator must seek from each space flight participant a written, signed and dated consent (“informed consent”) stating that he/she understands the risk, and his or her presence on board the launch vehicle is voluntary. However, legal validly of such «informed consent” is questionable in various countries and several states of the US.

As noted earlier, the US law will not be applicable in determining the validity of a passenger's waiver excluding the liability of the aerospace transport operators involved in international flights as well as national flights in other countries. In such cases, the issue of passenger liability will be governed by applicable international treaties and/or foreign law. For example: (a) the *Convention for the Unification of Certain Rules Relating to International Carriage by Air,* signed at Warsaw on 12 October 1929, (as amended; hereinafter referred to as the Warsaw Convention) and the *Convention for the Unification of Certain Rules for International Carriage by Air*, signed at Montreal on 28 May 1999 (herein after referred to as the 1999 Montreal Convention), which has replaced the Warsaw Convention, or (b) the 1972 Liability Convention that applies to aerospace vehicles using rocket propulsion (space object, including launch vehicle).

In case of aircraft passenger injury or death, the Warsaw Convention provides limited liability, while the 1999 Montreal Convention provides for unlimited liability, of operators. The 1999 Montreal Convention applies only to "international carriage of persons" by aircraft. Therefore, neither the 1927 Warsaw Convention nor the 1999 Montreal Convention will be applicable to aerospace vehicles for suborbital flights using rocket propulsion since they will not be considered to be 'aircraft'.

If an aerospace vehicle involved in international transport is considered to be a space object, it will trigger the application of international space law, particularly the 1972 Liability Convention. The Convention imposes absolute unlimited liability on the "launching State", but not on an operator, of a space object, for death or personal injury if caused by the space object on the surface of the Earth. On the other hand, fault-based unlimited liability is imposed on a "launching State", if death or personal injury is caused elsewhere than on the surface of the Earth. However, this Convention does not impose liability for death of, or injury to, the passenger's onboard space objects involved in suborbital flights.

10.6. Export Control Issues

Several countries have promulgated their national laws and regulations in order to prevent international proliferation of missiles and other defense-related technologies. The most significant, rigid and extensive export controls rules are the American *International Traffic in Arms Regulations* (ITAR) [10-8] that have been promulgated by the US Department of Defense under the *Arms Export Control Act* [10-9]. All 'defense articles' and 'defense services' on the United States Munitions List (USML) are subject to export controls. A defense article includes any item or technical data, which is information in the form of blueprints, drawings, photographs, plans, instructions or documentation. Any person, who intends to export a defense article, including information, must obtain the approval of the DOD's Directorate of Defense Trade Controls (DDTC) prior to the export.

ITAR (see Figure 10.2 for logo) has not been popular with foreign countries (that started manufacturing their on ITAR-free products) and the American private space sector that has been losing significant business and expressing its consistent opposition to ITAR. ITAR adversely affect companies that are entering into commercial suborbital flights business. The situation is well described by Brian Feeney, who succinctly states that, "the ITAR control will slow and would limit exports of the flight hardware. All of the New Space Companies in the US, including Virgin Galactic (Scaled Composites), XCOR, SpaceX etc., do not allow non-US citizens as employees for the opposite reasons of excess cost due to ITAR should they have a non-US citizen on staff. Further, export controls are so tight that XCOR is only able to do wet leases on its suborbital flight hardware to foreign companies with only XCOR employees allowed to service and fly the spacecraft. A further example of ITAR restrictions can be seen with Virgin Galactic not being allowed to sell flight seats on its suborbital spacecraft to Chinese citizens as they may be able to see ITAR controlled hardware, subsystems [10-10].”

The ITAR applies when a corporation or business intends to export items from the US. Export, under *inter alia*, includes “disclosing (including oral or visual disclosure) or transferring technical data to a foreign person, whether in the United States or abroad.” As noted above, in order to seek “informed consent” the suborbital flight operator “must provide each space flight participant an opportunity to ask questions orally to acquire a better understanding of the hazards and risks of the mission…[and must train the participant] on how to respond to emergency situations, including smoke, fire, loss of cabin pressure, and emergency exit.” There is a possibility of occurrence of violation of ITAR when a spaceflight operator engages in the United States in providing the above-mentioned information (i.e. technical data) to SFPs who are foreign citizens.

Compliant International Traffic in Arms Regulations

ITAR

Figure 10.2: ITAR logo

In view of long standing concerns of the America space companies, the Obama administration has recently adopted an amendment to the ITAR whereby the President would have the authority to remove satellites from the USML; consequently no license will be required for the export of satellites. This is a small but a significant move in the right direction and has been applauded by the Commercial Spaceflight Federation (CSF). The Federation hopes that “progress in this area will encourage the removal of manned suborbital spaceflight systems from the U.S. Munitions List [10-11].” It should be noted that outside of the US, other national export control regulations might influence suborbital space tourism.

10.7. Conclusion

Personal suborbital flights are fast becoming a reality and orbital flights will soon follow as technologies are being developed and entrepreneurial competition is building. However, existing international air law and space law as well as laws of almost all countries are either deficient or contain inadequate or inconsistent provisions for appropriately regulating aerospace transport for suborbital flights. The US national law in this regard is, perhaps, the most developed but the application of ITAR would become a major barrier for the expansion of personal suborbital flights by non-Americans and in foreign counties.

The legal status of suborbital flights is not settled at international level. In order to encourage the emerging industry, particularly internationally, for personal suborbital flights it is imperative that important international legal issues must be resolved as soon as possible. Taking into considerable similarities between aviation and aerospace vehicle for suborbital flights, they should be regulated under a uniform international legal regime under the jurisdiction of ICAO, particularly with respect to safety and navigation. Since, absolute and unlimited liability applicable to space objects under space law could deter private investment and thus retard the development of this industry, all aerospace vehicles for personal suborbital flights should be classified as aircraft subject to aviation laws both at national and international levels, at least till aerospace transport becomes a mature industry.

11. International Commercial Space Industry Regulation

11.1. The Boundary Conditions

The international commercial space industry represents a huge regulatory challenge from almost every perspective. First, the technical approaches that are currently being developed around the world are radically different. Effective regulation may be difficult until there is more coherence in the various systems that are being developed in what is now almost a chaotic development environment that is akin to the very first days of aviation. Initially the European and U.S. approaches were quite different as to how to proceed to develop regulatory approaches for commercial space transportation. It clearly made no sense to have in Europe a structured regulatory process aimed toward safety certification related to winged vehicles but not to have a parallel approach to rocket based launches. Currently there is a more common approach, both in Europe and the US, of using experimental case-by-case licensing of all types of commercial launches whether the vehicles are winged or involve rocket systems. Clearly the great diversity of technical and operation approach remains a problem for effective and consistent regulation around the world, as shown in Table 11.1, which provides a summary of some of the many approaches now under consideration [11-1].

Secondly, the technology, safety concerns, and approaches associated with commercially-operated suborbital flights for so-called space tourism suborbital parabolic flights are dramatically different from those associated with development of commercial systems seeking to deliver cargo and ultimately humans to low earth orbit. Table 11.2 also identifies some of these important differences [11-1].

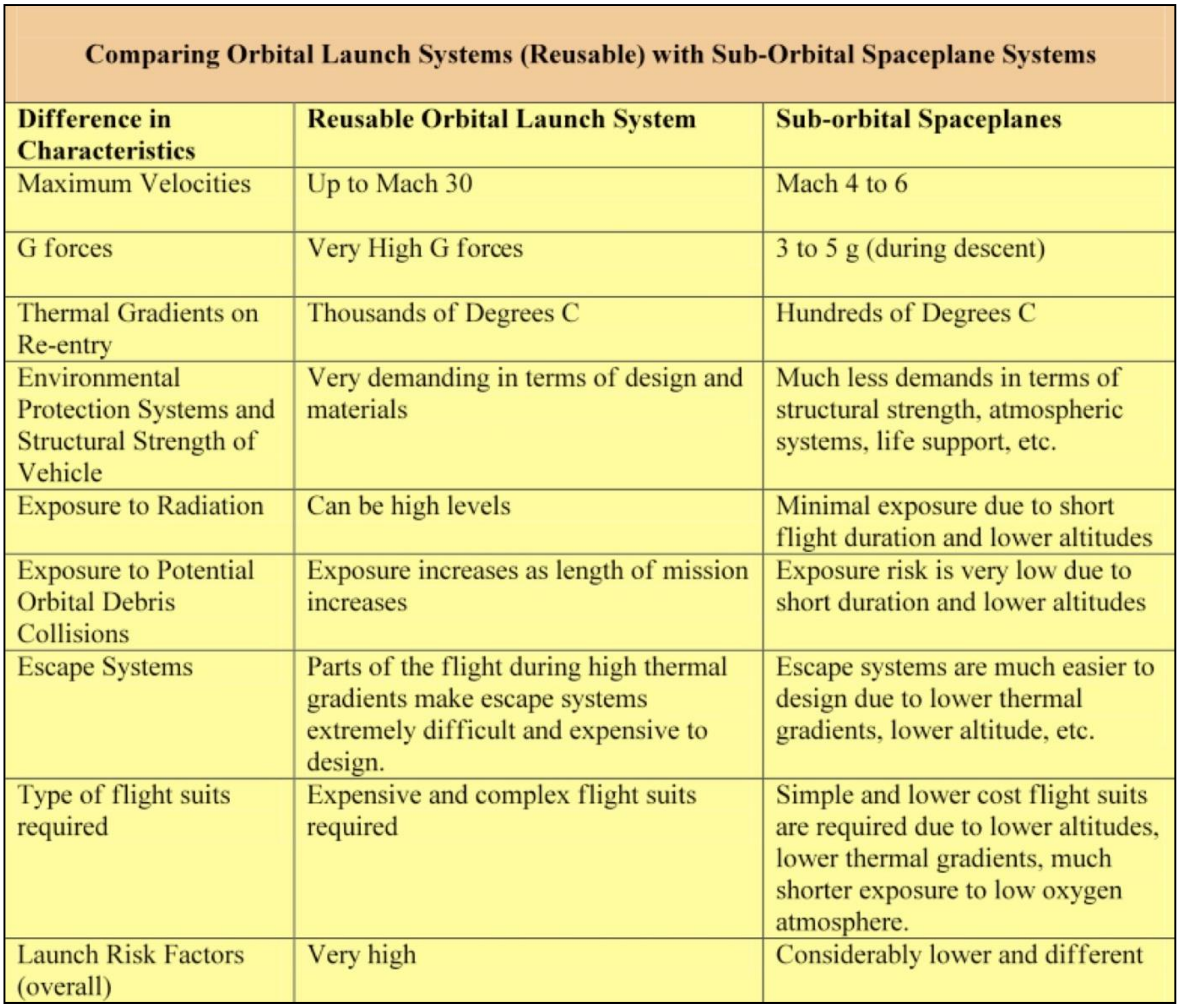
Thirdly, although there has been nearly $3 billion (U.S.) investment in various aspects of the so-called suborbital space tourism business, yet the total amount of collected revenues and reservation fees total only about $600 million (U.S.). This largely includes the flights to the International Space Station booked by Space Adventures, bookings by Virgin Galactic and XCOR. There is thus no certainty that this industry will prove economically viable even if appropriate longer-term safety and environmental regulations are developed for such enterprises.

Table 11.1: Suborbital Space Tourism approach summary (extracted from J. Pelton and P. Marshall, Launching into Commercial Space, (2013) AIAA, Reston, Virginia).

The Space Tourism Leaders				
Company Name	**Vehicle**	**Technical Approach**	**Concerns**	**Start of Service**
Armadillo Aerospace	Black Armadillo	1 stage. LOX/ethanol engine. (Limited capital investment). Vertical Takeoff and land. (Like the Delta Clipper design.)	New system. Limited tests	2014-15?
Blue Origin	Initially will depend on start-up Spaceship 2 fleet. Followed by New Shepherd launch system	Reusable Launch Vehicle. Hydrogen Peroxide and Kerosene fuel. Abort system.	New Shepherd is a developmental system. Limited tests	2014-15?

Space Adventures (with XCOR Corp)	XCOR vehicle	Lynx (Sub-orbital space) (HTHL) Isopropyl alcohol/LOX	New system. Limited tests	2014-15?
Space Adventures (with Myasishchev Design Bureau)	Explorer Space Plane (C-21) lifted to high altitude by the MX-55 High Altitude launcher plane (HTHL)	Liquid fuel motors. Horizontal Takeoff and Horizontal Landing (HTHL) (lifting body with parachute landing)	Based on extension of Russian systems but still this is a new system	2014-15?
Space Dev (now part of Sierra Nevada Corp.)	Dreamchaser	Single Hybrid Engine. (Neoprene and $N0_2$) for sub-orbit. Launch of spaceplane on the side of 3 large hybrid boosters to reach LEO orbit & ISS.	Both sub-orbital and orbital system derive from SpaceShip 1 but still a new system.	2014-15?
Spaceship Corp.	SpaceShipTwo (upgraded version of SpaceShipOne with increased cabin size),	Hybrid Engine. (Neoprene and $N0_2$) for sub-orbit) Flown to high altitude on a jet based launcher system.	Undergoing testing program – will be the operational system for Virgin Galactic and others.	2014
Space X	Dragon capsule and Falcon 9 to low earth orbit	Both systems based on Falcon rocket technology. Liquid-fueled systems	Both spaceplane and rockets based on liquid-fueled Falcon system. Both require extensive tests.	2013
Virgin Galactic	Fleet of SpaceShipTwo.	See also Spaceship Corp. above.	As first system will require extensive tests.	2014

Table 11.2: Systems Comparison (extracted from J. Pelton and P. Marshall, Launching into Commercial Space, (2013) AIAA, Reston, Virginia).



Comparing Orbital Launch Systems (Reusable) with Sub-Orbital Spaceplane Systems

Difference in Characteristics	**Reusable Orbital Launch System**	**Sub-orbital Spaceplanes**
Maximum Velocities	Up to Mach 30	Mach 4 to 6
G forces	Very High G forces	3 to 5 g (during descent)
Thermal Gradients on Re-entry	Thousands of Degrees C	Hundreds of Degrees C
Environmental Protection Systems and Structural Strength of Vehicle	Very demanding in terms of design and materials	Much less demands in terms of structural strength, atmospheric systems, life support, etc.
Exposure to Radiation	Can be high levels	Minimal exposure due to short flight duration and lower altitudes
Exposure to Potential Orbital Debris Collisions	Exposure increases as length of mission increases	Exposure risk is very low due to short duration and lower altitudes
Escape Systems	Parts of the flight during high thermal gradients make escape systems extremely difficult and expensive to design.	Escape systems are much easier to design due to lower thermal gradients, lower altitude, etc.
Type of flight suits required	Expensive and complex flight suits required	Simple and lower cost flight suits are required due to lower altitudes, lower thermal gradients, much shorter exposure to low oxygen atmosphere.
Launch Risk Factors (overall)	Very high	Considerably lower and different

The recent FAA and Space Florida-sponsored market study projected traffic levels about 5% of the similar market study conducted in 2006 raises serious market concerns in this regard [11-2].

These types of market studies of the suborbital “space tourism” industry suggest that the true major market may be commercial supersonic and hypersonic transportation--of which space tourism might be considered only a minor subset. In short it would seem that perhaps the prime objective for international discussions with regard commercial space flight must be the longer-term regulation of commercial supersonic and hypersonic flight. It also needs to be considered that this will involve not only the upper altitudes but also perhaps the area between commercial air space and outer space sometimes referred to as “protospace” or “sub-space”. This regulatory concern will not only involve safety and the regulatory domain usually associated with the International Civil Aviation Organization (ICAO), but also environmental pollution and the World Meteorological Organization and the UN Environmental Program.

Figure 11.1: Docking of private capsule DRAGON to ISS [11-2]

Fourthly, the development of commercial space transportation systems by SpaceX (see Figure 11.1), Sierra Nevada, Boeing, EADS, Reaction Engines and Orbital Sciences, among others also suggests that regulatory focus must be increasingly address the issue of Space Traffic Management. In particular this discussion will first need to consider which national, regional and international bodies will address this issue.

The increasing number of commercial national and international air carrier flights around the globe, the advent in 2013-2014 of space tourism flights (see Figure 11.2), and the increasing likelihood of commercial launch to low-earth orbit by a range of new carriers, as well as suborbital flight systems that may involve carrier aircraft and towing vehicles, balloon-based launches, and even lighter-than-air ascents to “dark sky stations”, all combine to suggest the importance of Space Traffic Management (at the national, regional and international scale). The workshop hosted by the McGill Air and Space Law Institute and the International Civil Aviation Organization (ICAO) 24-26 May 2013 will focus on the many regulatory and safety issues that this increasing complex air and spaceflight interface now gives rise to in terms of safety, collision avoidance, environmental concerns and even space debris and sustainability of space issues. There have been well reasoned articles that suggest that the Chicago Convention under which ICAO operates (i.e. by the Convention referring to “vehicles” rather than aircraft) could actually already have the authority to assume at least some responsibilities for some of the Space Traffic Management (STM) responsibilities [11-3], [11-4].

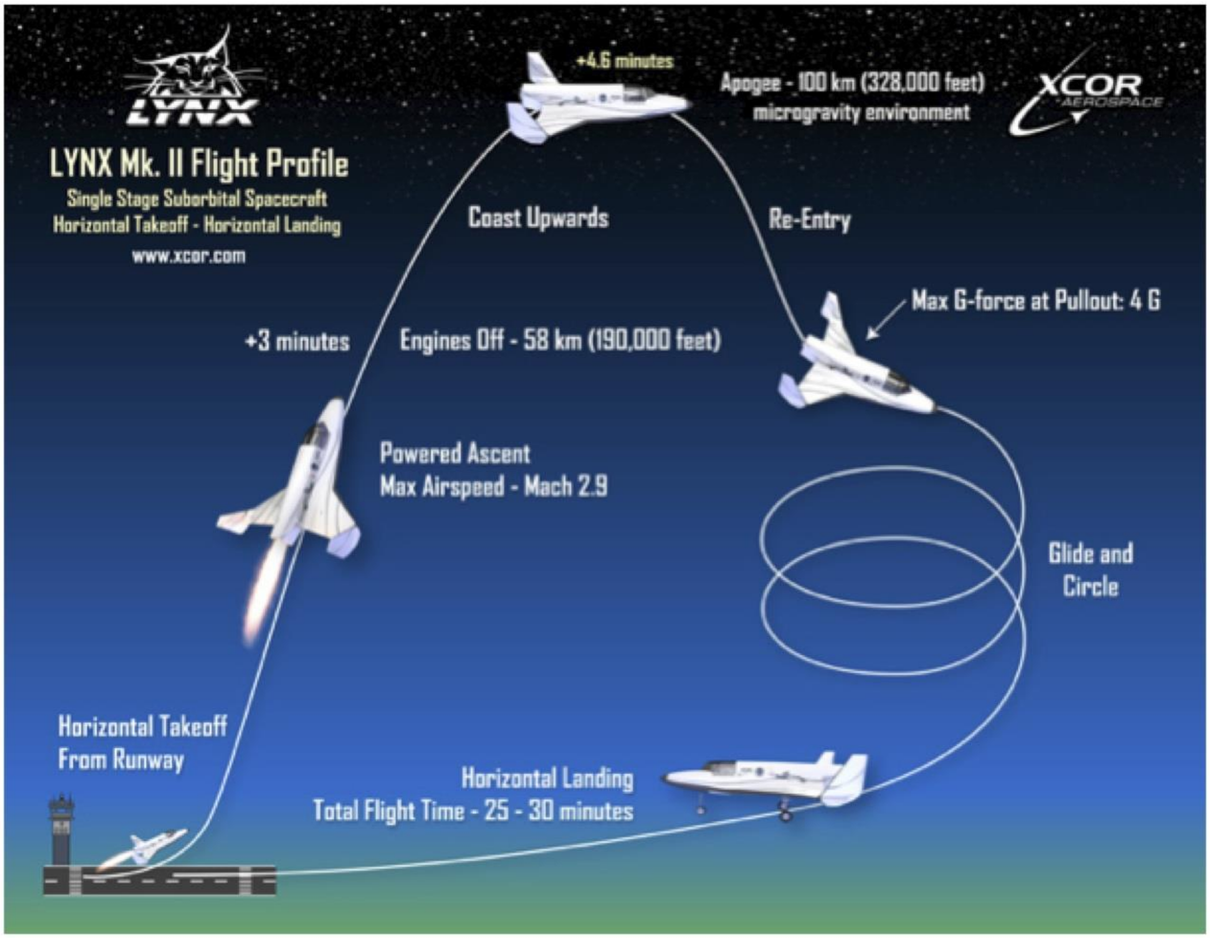


Figure 11.2: Flight pattern of Lynx (Courtesy: XCOR)

11.2. Remedial Actions

The complexity of the issues may suggest to some that safety and regulatory concerns are almost out of control. This is simply not the case. Steps that seem prudent and advisable include the following:

1) National regulatory bodies such as the Federal Aviation Administration (FAA) and NASA in the United States, the European Aviation Safety Agency (EASA), ESA and the EU in Europe should continue regular meetings and exchanges of information concerning a common approach to the regulation of commercial suborbital flights. It is important that these consultative processes continuously keep U.N. entities such as ICAO, WMO, UNEP and COPUOS advised of these exchanges and also include entities such as the Inter-Agency Debris Consultative Committee (IADC) and the Space Data Association informed as well. Other interested regulatory entities from around the world with an interest in the safety and regulation of commercial space vehicles and spaceports should over time be added to this consultative process.

2) Efforts to develop common guidelines and regulations around the world should include winged and rocket based systems as well as vehicles that are launched by carrier

vehicles, balloon or parachute launch, etc. In short all types of commercial space vehicles should be included in the international discussions and safety and environmental regulatory guidelines. Environmental standards would involve higher altitude emissions, sonic boom mitigation and other related matters. Further spaceports for commercial transportation systems should be integrated into this process. These discussions should address what standards should be set to certify such facilities, how often they should be recertified, etc. Common approaches among all countries involved in commercial space transportation systems need to be involved so as to address such issues as levels of liability coverage, the statutory responsibility of range safety officers, etc. Prime objectives should be to discuss and agree the evolution of international standards for spaceport safety as well as commercial space vehicles. This process should help consider how evolving safety and environmental standards for suborbital and orbital commercial space vehicles might perhaps in time be overseen by an agreed international enforcement body.

3) Serious thought needs to be given to the concept of Space Traffic Management (STM) with a sense of urgency rather than waiting for a major air-space interface disaster. Discussion of STM should at least include the entire domain from the Earth's surface to low-Earth orbit. This international discussion process should include other related issues such as the problem of increasing levels of orbital debris, common command and control frequencies, the regulatory provisions related to controlled de-orbit of satellites (including small satellites), the regulation of "proto-space", etc.

4) While it is premature to address such issues as the safety certification of suborbital space planes, the collection of metadata on all of these systems in a systematic way (as recommended by U.S. Congressionally mandated study of commercial space transportation) would be prudent [11-5]. This should particularly include an attempt to work toward standards and certification processes for key subsystems for space planes and commercial space vehicles launching to and returning from low earth orbit. This is a useful and practical step that could be taken now. Some of the systems that might be standardized and certified as subsystems are listed below.

    - Environmental control and life support system
    - Main propulsion system and fuels
    - Guidance
    - Navigation and control system
    - Avionics and software
    - Main structural system
    - Thermal protection system
    - Thermal control system
    - Health monitoring system
    - Electrical power system

- Mechanical systems
- Flight safety system, and crew system

In a recent article FAA experts describe the drawbacks of a full certification approach and conclude that licensing procedures may be the only realistic way to support private human spaceflight enterprises [11-6].

11.3. Conclusions

It is time for detailed and even urgent international consultation on a number of key issues related to commercial space transportation systems. These issues, among others include: (i) future safety standards and processes that might be used beyond the interim system of case-by-case experimental licensing of commercial spaceplane flights, especially for the post-2015 time period; (ii) consideration of possible international standards and certification for subsystems for commercial space planes, (iii) standards and possible certification procedures for new forms of supersonic and hypersonic transportation now under development (including environmental concerns); (iv) international inspection and certification procedures for spaceport safety standards, inspections and certification: (v) coordinated international approaches related to space traffic management and control, and related issues of sustainability of space as now being developed by the UN Committee on the Peaceful Uses of Outer Space. Only focused international discussions and evolving levels of understanding and agreement (sometimes characterized as “soft law”) will move things forward in the near term. In the longer term international agreements and assignment of functions to international agencies with regulatory authority and enforcement powers will be needed. A good deal has been written on these subjects that should be carefully considered. The various relevant articles in the Space Safety Magazine, the publications of the International Association for the Advancement of Space Safety (IAASS) such as “An ICAO for Space?” and the Conference Proceedings of the IAASS Conferences are helpful reference materials to be considered.

12. SWOT Analysis

12.1. Introduction

At this point the different aspects of personal spaceflight have been discussed in detail from different view angels. Each specialist has pointed out that personal spaceflight, often popularly referred to as space tourism, has much potential but also drawbacks. Table 12.1 below maps these aspects in the four so-called SWOT categories along with the origin of the factor. A description of each also follows.

S: Strengths are those elements under own control which facilitate the success of the product

W: Weaknesses are inherent issues which need to be considered and can harm the business plan considerably

O: Opportunities are perceived chances to enhance the business concept, but are partially beyond control of the originator

T: Threats can considerably hinder the business but are not fully controllable by the entrepreneur; at best they can be influenced.

Table 12.1: Overview SWOT table

	Helpful to Achieving the Objective	**Harmful** to Achieving the Objective
Internal Origin Attributes of the Organization	➢ Potential demonstrated market ➢ Tourism Sector in search of new adventure tourism products ➢ Attracts business angels as financiers ➢ Relatively off-the-shelf technologies ➢ New activities and employment effects (in particular spaceports)	➢ Increasing Time To Market (TTM) ➢ Accidents during the first flights ➢ Emergency landings/rescue actions away from spaceport ➢ Unexpected medical risks and claims ➢ Liability issues with consent forms ➢ Respect of safety standards
External Origin Attributes of the Environment	➢ Possible support from Agencies (payloads) ➢ Incentive trips (Axe) ➢ New Space trend (e.g., SpaceX) ➢ Interest in medical experience ➢ Experimenting with green propulsion ➢ May create innovative approaches and spin-offs	➢ Lack of clear regulations ➢ Export Control influences ➢ Lack of experience with medical support for passengers of average health ➢ Loss of motivation after pioneering effect subsides ➢ Market competition and price wars

12.2. Description of the respective components

The various items are described in more detail here:

12.2.1. Strengths

1) Potential demonstrated market

Reference is made to the chapter in this position paper that describes the different demand forecasts. Even if a number of them are obviously too high there is no doubt that there is a real demand. The size of it may be discussed; the principle is beyond any doubt.

The fact that some 950 persons have made down payments before any operational flight seems to be the ultimate demonstration of this demand.

2) Tourism sector in search of new adventure tourism products

There are various studies that the tourism sector is urgently looking for new products, now that club formulas and the other products of the 2nd half of the 20th century have reached a saturation point.

Adventure tourism and a change in traveler behavior are two factors under discussion. The tourism sector, accounting for more than 10% of the world's overall GDP, is less aware of space tourism yet but will no doubt strongly support it once there are first operational flights available.

3) Attracts business angels as financers

Virtually each space tourism project is backed up by a business angel, as can be noted from table 12.2 [12-1].

Table 12.2: Present space entrepreneurs

Name	Wealth source	Project supported
Paul Allen	Microsoft	SpaceShipOne
Jeff Bezos	Amazon.com	Blue Origin
Robert Bigelow	Hotel/Real Estate	Bigelow Aerospace
John Carmack	Computer games	Armadillo Aerospace
Ellon Musk	PayPal	SpaceX
Jeff Greason	Intel	XCOR Aerospace

Business Angels are not only attracted by the profitability of a project but even more by a visionary aspect thereof. Each of the aforementioned Business Angels has access to 2-20 Billion USD and can therefore support the initial investment for suborbital project development.

4) Relatively off-the-shelf technologies

The fact that the last phase of the flight is merely limited to a smooth transfer over 100Km and low energy reentry avoids in this case a number of critical technologies like thermal resistant shielding. In fact most project are using relatively traditional propulsion systems, whereas also the Life Support systems only have to provide for a good environment during a very limited period (compared to flights on board of space stations).

By no means is it pretended here that all technologies are readily available, but the number of critical technologies without existing high TRL levels is visible.

5) New activities and employment effect (in particular spaceports)

Each new activity is applauded at present at times where economy is weak and unemployment a major concern.

Suborbital space tourism will require spaceports out of flight routes (see Chapter 3). It is not only the space tourist but also the whole environment that benefits, spectators, services (taxis), hotels, local tourism, restaurants, memorabilia sales etc.

As an example, for the New Mexico Spaceport a study was made leading to the conclusion that 7500 jobs could be created in and around the spaceport (many evidently in the newly to build high-class hotels) with an estimated yearly turnover for the economy of $400 million USD [12-2].

12.2.3. Weaknesses

1) Increasing TTM (Time To Market)

There are plenty of examples whereby a wrong assessment of the time needed to become operational has been leading to considerable problems for enterprises. An example of this is the CargoLifter project that had an excellent start in 1996. Equity capital of 320 M€ was found rapidly, but as the operations did not start in 2000 as foreseen, financers backed out leading to bankruptcy in 2002.

Another aspect to be taken into account is that pre-financers may lose interest or may claim their advance payments back.

2) Accidents during first flights

This is no doubt one of the most feared issues of the operators. Although approximately 15 people are dying each year attempting to climb Mount Everest, this is an “accepted” activity with a long history. In particular due to the high visibility, early accidents could lead to a strong public reaction in the case of space tourism.

In order to increase safety and avoid such early accidents, additional efforts will be needed to study escape possibilities during the different flight phases.

3) Emergency landings/ rescue actions away from spaceport

In most of the business models it is assumed that the vehicle will return back to the base and land on the dedicated landing strip. In case of a serious deviation an emergency landing in a less suited environment might become problematic, also as the landing gears under design are less suited for landings on (rougher) grounds

4) Unexpected medical risks and claims

Contrary to present spaceflight where a ‘select-out’ principle is used, operators will try to optimize their seat occupation and give easier waivers. The effect of such flights on certain diseases or disorders is unknown and waivers are assumed, but not tested.

5) Liability issues with consent forms

Normally a lot of legal liability issues can be solved by an informed consent form. This, however, assumes to have a good knowledge of the possible risks and full information thereof. In case of an unforeseen risk, the sense of the consent form may be endangered.

6) Respect of safety standards

Agencies and large contractors have strict product assurance philosophies. It is not sure that such a system will also be maintained by smaller companies that have limited investment money available.

12.2.3. Opportunities

1) Possible support from Agencies (payloads)

Many endeavors have benefitted from indirect Agency support in terms of early commitments, improving cash-flow situations. As discussed in the payload related Chapter 5, early bookings from NASA are already confirmed. Besides the financial side effect this also adds to the credibility of these projects with the general public.

2) Incentive trips

Already now a number of trips are booked by companies to e.g. reward employees. Known examples are Oracle, Pepsi Cola, Volkswagen, but evidently many others are discreet about this and have already booked trips. Another category of trips is booked for prizes or contests, such as AXE (see Figure 12.1). In fact Unilever announced recently that they have bought 22 flights from XCOR to promote the AXE campaign [12-3]. It is assumed that such incentive trips may become an important part of the potential ticket sales.

Figure 12.1: Example of incentive trip opportunity

3) New Space trend (cfr. SpaceX)

Similar skepticism was expressed a decade ago when SpaceX announced its Dragon plans, and very similar comments were expressed on technical complexity and safety standards. In the meanwhile this project has proven its reliability and feasibility.

This could become, as a precedent, a catalyst to increase the interest in private suborbital flights. Indeed, there is no doubt that the orbital docking to ISS now executed by the private sector is no doubt much more challenging than from a technical point of view than suborbital flights, hence the New Space entrepreneurs have proven their capabilities.

A logical extension of the early suborbital flights is Point-to-Point flights, possibly initially only with cargo [12-1]. A number of technologies will no doubt be validated during operational suborbital flights that, in parallel with the aircraft sector, are likely to develop into commercial transport.

4) Interest in medical experience

Present knowledge of experience with humans in space is limited to well-selected and very healthy individuals (mainly professional astronauts). If we want to expand space travel to the general public, like e.g. regular point-to-point travel, we need more knowledge about space medicine effects on the general public. Although no present interest is expressed there is an obvious potential that may develop

5) Experimenting with green propulsion

Contrary to governmental operators, commercial operators are aware about the needs to comply with increasingly more stringent environmental constraints. They have therefore a higher motivation to experiment with alternative propellants (e.g. oxidated rubber) in order to ensure sustainability. This might become an interesting catalyst for the whole industry.

6) May create innovative approaches and spin-offs

Although not the prime objective there is a high probability that particular procedures or technologies will evolve from this sector applicable, as spin-offs, to other sectors. Examples may be compact ECLSS systems, MMI, power supplies etc. that could have spinoff possibilities in the automotive and aircraft sectors.

12.2.4. Threats

1) Lack of clear regulations

Investors do not like uncertainty and risks that are beyond their influence. A lot of regulations, e.g. in the area of certification and Flight Airworthiness are presently not fully known. Even the debate if Air law or Space law is applicable has a considerable number of consequences.

This regulatory unclear framework may not only scare off investors but may also become an operational threat if introduced a posteriori influencing the costs for certification or licensing.

2) Export Control influences

As recalled in the legal chapter, export control could play a paramount role when operators intend to penetrate international markets. In particular US technology, subject to ITAR, may be considered to fall under this topic. As long as flights are taking place from US territory there is no major obstacle, but in view of the different spaceport projects in e.g. Singapore, Dubai, Spain and Sweden, this may become a limiting factor, in particular if crafts will be maintained there.

3) Technology transfer from agencies

Agencies have an inherent reluctance to cooperate in the space tourism industry. This stems from the fear that initially the sector is related to wealthy individuals, whereas agencies are more geared towards benefits to society in general.

Nevertheless, even if creative, many of the operators may lack knowledge about certain technologies or do not have the necessary level of TRL maturity, which may house in agencies. If such technologies would be required to be transferred from agencies, there might be the aforementioned hesitance and even reluctance.

4) Lack of experience with medical support for average health passengers

Until now astronauts have been selected according to the select-out principle. The number of candidates has been so important that very rigid medical criteria could be maintained, whereas waivers were only given to experienced astronauts.

Space tourism operators will work with select-in criteria to try to reach out to a maximum market. In order to do so, they will try to give a maximum number of waivers. Some of these waivers, in particular in case of existing diseases, will be given without previous experience data as e.g. there is no experience with astronauts with diabetes, in view of the selection criteria.

A number of these waivers may be safely assumed, but a marginal risk remains which probably cannot be fully covered by a liability waiver.

5) Loss of motivation after pioneering effect decreases

The high number of early candidates and bookings may indicate that there is a considerable market. Nevertheless we shall not ignore that this market, composed mainly of wealthy people, is also a high-demanding one.

There is no doubt that the ‘wow-factor’ of being able to be in space attracts such people, who in general have already tried another set of adventure tourism experiences. If this effect will continue remains to be seen and is hard to predict. An ISU study based upon economic theories indicates that a saturation and even decline may be reached after some seven years of operations [12-4].

6) Market competition and price war

Many competitors are working on similar products, be it with different emphasis. Moreover, new competitors may learn from early mistakes and come quickly on the market once profit margins are becoming evident. They may come up with novel concepts that could hamper the expansion of the early market developers. The structure of the market and its complexity has been recently analyzed in [12-5] and underlines such threat. Different aspects influencing this market can be found in a recent work on commercial space, compiled by the International Institute of Space Commerce [12-6].

The risk here is a clear ticket price war, as assumed in the Futron study [12-7]. There will be a point where the prices are decreasing to an extent that profit margins will disappear or become marginal.

13. Conclusions and Recommendations

13.1. Conclusions

In this document we have provided an overview of the different issues and challenges associated with private suborbital spaceflight. An historical perspective was provided to set the stage for addressing the technical challenges still to be overcome. The various elements required for the business of space tourism, including spaceports, vehicle design, to include interior considerations, were addressed. An assessment of what motivates people towards personal spaceflight as well as the medical requirements that might be imposed were also detailed. Indeed, there is still much to do on the legal side of things as this new enterprise seeks to identify the appropriate legal framework in which to operate. Finally, the market demand, including that for potential payload opportunities, was analyzed and the current international commercial regulations have been presented to provide a complete picture of this emerging business area. A SWOT analysis, highlighting the Strengths, Weaknesses, Opportunities and Threats associated with space tourism captures the essential elements under consideration and is the basis for the following recommendations.

13.2. Recommendations

The recommendations derived from this thorough treatment of the topic of space tourism are now presented. There has been no attempt made to measure the relative importance of each of the recommendations. In order to distinguish between general recommendations and those for which concrete actions are proposed, two categories have been created.

13.2.1 General Recommendations

1) Recommendation 1: Follow-on products will need to be considered

   It is relatively clear that the market may have a limited lifetime. From this perspective, it may be of a strong advantage to take into account already in the design phase that follow-on products may have to be later developed. This could e.g. be the case for point-to-point commercial spaceflight.

   This recommendation is also linked to the observation that the suborbital flights as presently schedules will have a relatively short Product Life Cycle, hence the need to prepare already early new products.

2) Recommendation 2: More emphasis on markets other than tourism

   In a previous chapter the aspect of payloads and the use of suborbital flights for short microgravity experiments have been highlighted. This would not only expand the market, but also increase acceptability of suborbital flights.

The Tauri report has also pointed towards completely new markets such as

- Publicity
- Filming industry
- Marketing of products
- Scientific research.

Approaching these markets will require different strategies and different distribution channels, probably even different marketing departments and dedicated vehicles.

3) Recommendation 3: Feedback on customer demand to be taken into account

The paying customers belong a priori to a high demand public, which is used to paying a good price but only for a product matching their expectations. Considerations like

- Interior design
- Memorabilia
- Spaceport infrastructure,

just to quote a few, are considered but will evolve in the course of operations. This feedback must be taken into consideration when (re)designing the client oriented offering.

4) Recommendation 4: Communication on start date of operations

The operators have for several reasons been too optimistic in their Time To Market (TTM) previsions. Whereas the cash-flow issues are their internal issue, the constant slippage of the start of operations is leading to a lack of credibility of this new sector.

Whereas this may be considered as a problem for the sector, such a general lack of credibility could affect the space sector in general.

5) Recommendation 5: Global response preparation in the event of an early failure

There is no doubt that each operator has developed an individual communication strategy in case of failure. What might be useful is a global response to the market, taking into account the effects of such unfortunate event on regulatory frameworks, insurance and public opinion. Whereas Agencies have taken such role in the past, a different coordination mechanism may be needed.

13.2.2. Recommendations with Specific Actions

1) Recommendation 6: Increase relation between the New Space entrepreneurs and the traditional space sector

It is clear that technically there is possibility for synergies.

The traditional space sector, via the exploration and human flight programs, has considerable experience with spaceflight having higher demands than suborbital ones. The same goes for safety requirements and e.g. escape and emergency landing systems. On the other hand, the New Space entrepreneurs are aware they must respect environmental issues and other commercial issues. From this perspective they experiment with greener propellants that may be of interest to agencies. An exchange of technologies and experience will no doubt be beneficial for both communities.

As an example we can refer to

- The SpaceX Dragon capsule, a close cooperation between NASA and industry
- The Flight Opportunities Program (FOP), offering to scientists to host payloads on board of commercial platforms under development like XCor and Virgin Galactic offerings.

Action suggested: IAA to initiate a working group allowing Space Agencies to propose technologies to New Space Entrepreneurs and vice versa, with emphasis on TRL improvement. Such action could reduce the risk of duplication of effort and development.

2) Recommendation 7: Study the use of Suborbital vehicles for scientific research

Suborbital vehicles certainly have limitations, such as the duration microgravity of the microgravity phase of the flight and disturbances. On the other hand they also have strong advantages such as paid access and the possibility for frequent and fast repetition of the experiments.

Action suggested: IAA to initiate a study to determine what class of experiments could be successfully executed using suborbital vehicles in full coordination with the designers, the space agencies, and interested industry partners.

3) Recommendation 8: More research in medical selection criteria and follow-up

The issue has been highlighted before. We have no experience about the effect of microgravity and acceleration on particular diseases, as until now only extremely fit and trained persons have participated in spaceflight.

With short training times and waivers, the situation is rather different and asks for more research, including the psychological aspects (e.g. hidden claustrophobia). These considerations may also lead to reflections on countermeasures and on-board medical kits.

Action suggested: IAA to organize a working group on medical issues associated with suborbital flight, including potential medical and pharmaceutical experiments

4) Recommendation 9: More integrated studies on legal and regulatory issues

In view of the strong interrelation a more generic recommendation is preferred. Indeed the lack of a clear regulatory framework, the questions on a legal framework and the liability issues, at their turn influenced by informed consent forms and medical risks, cannot be treated in isolation. It is also in the interest of the space sector in general to have these findings examined by a non-partisan group of experts, also in view of the safety issues. Also the aforementioned global response in case of early failures could be part of this mission.

Action suggested: Create a dedicated IAA working group, preferably funded by the interested parties, leading to the formulation of recommendations to international regulatory bodies.

14. References

1. Introduction : Objectives and Scope of the Report

[1-1] IAA Website, www.iaaweb.org (consulted 29 March 2013).
[1-2] Gibson, D., Commercial Space Tourism: Impediments to Industrial Development and Strategic Communication Solutions, EBook: eISBN: 978-1-60805-239-4, 2012.
[1-3] Pelton, J. And Marshall, P., License to Orbit. The Future of Commercial Space Travel, Apogee Books, Ontario, 2009.
[1-4] Ashford, D. and Collins, P., Your Spaceflight Manual, Eddison Sad, London, 1990.
[1-5] Kohn, M., Handbuch Weltraum Tourismus, Ehrenwirth, 2009.
[1-6] Van Pelt, M., Space Tourism, Copernicus, New York, 2005.
[1-7] Peeters, W., From suborbital space tourism to commercial personal spaceflight. Acta Astronautica 66, 2010, 1625–1632.
[1-8] ISU, Great Expectations, Team Project MSc 2008, ISU, 2008.
[1-9] Pelton, J. and Bukley, A., The Farthest Shore, Apogee Books, 2010.
[1-10] Solomon, L., The Privatization of Space Tourism, Transaction Publishers, New Brunswick, 2008.

2. The History of Space Tourism

[2-1] Tsiolkovsky, K., The Purpose of Space Exploration (in Russian), (Kaluga, 1929)
[2-2] Von Braun, Space Frontier, (Holt, Rhinehart and Winston, 1971)
[2-3] Matsumoto, S. et al., Feasibility of Space Tourism. Proc. of the 17th Symposium on Space Technology and Science. (Tokyo, 1990) pp. 2301-2308.
[2-4] Peeters, W., From suborbital space tourism to commercial personal spaceflight. Acta Astronautica 66 (2010) pp. 1625-1632.
[2-5] Ashford, D. and Collins, P., Your Spaceflight Manual (Eddison Sad, London, 1990)
[2-6] Ehricke, K., Space Tourism, AAS67-127, AAS Annual Meeting, Dallas (1967)
[2-7] Webber, D., The Wright Stuff - The Century of Effort Behind Your Ticket to Space (Apogee Books, Canada, 2010)
[2-8] Peeters, W. Space Marketing, chapter 9 : Space Tourism (Kluwer, Dordrecht, 2000)

3. Suborbital Vehicles

[3-1] Evans, M., The X-15 Rocket Plane: Flying the First Wings into Space, University of Nebraska, Lincoln, 2013, p.252.
[3-2] Bizony, P., How to Build Your Own Spaceship, Plume, New York, 2009, p. 63.
[3-3] Holloway, S., Straight and Level: Practical Airline Economics, 3rd Edition, Ashgate, Aldershot, 2008, pp. 14–15.
[3-4] Stiennon, P. and Hoerr, D., The Rocket Company, AIAA, Reston, 2005.
[3-5] Larson, W. and Pranke, L., Human Spaceflight, McGraw-Hill, New York, 2000, pp. 948.
[3-6] Kuczera, H. and Sacher, P., Reusable Space Transportation Systems, Springer, Berlin, 2011, pp. 17–31.
[3-7] Bentley, M., Spaceplanes. From Airport to Spaceport, Springer, New York, 2009, pp. 116–123.

[3-8] Jakhu, R. Et al, The Need for an Integrated Regulatory Regime for Aviation and Space, Springer, Wien, 2011.

[3-9] Bentley, M., Spaceplanes. From Airport to Spaceport, Springer, New York, 2009, pp. 144–145.

[3-10] Bizony, P., How to Build Your Own Spaceship, Plume, New York, 2009, p. 66.

[3-11] Bizony, P., How to Build Your Own Spaceship, Plume, New York, 2009, p. 62.

[3-12] Pelton, J, License to Orbit: The Future of Commercial Space Travel, Apogee Books, Burlington, Canada, 2009.

[3-13] Kuczera, H. and Sacher, P., Reusable Space Transportation Systems, Springer, Berlin, 2011, p. 190.

[3-14] Koelle, D., Handbook of Cost Engineering and Design of Space Transportation Systems, Revision 4, TCS, Ottobrunn, 2013, pp. 164–169.

[3-15] Kuczera, H. and Sacher, P., Reusable Space Transportation Systems, Springer, Berlin, 2011, pp. 187.

[3-16] Kuczera, H. and Sacher, P., Reusable Space Transportation Systems, Springer, Berlin, 2011, pp. 143–144.

[3-17] Holloway, S., Straight and Level: Practical Airline Economics, 3rd Edition, Ashgate, Aldershot, 2008, pp. 334–338.

[3-18] http://gantdaily.com/2013/04/30/virgin-galactic-spaceshiptwo-for-space-tourists-in-successful-test-flight/ (accessed 15 May 2013)

[3-19] Pelton, J. And Bukley, A., The Farthest Shore, The Rise of Space Tourism, Apogee Books, 2010, pp. 106-113.

[3-20] Clement, G., Fundamentals of Space Medicine – Second Edition, Springer, New York, 2011.

[3-21] Larson, W. And Pranke, L., Human Spaceflight, McGraw-Hill, 2000, pp. 761-795.

[3-22] ISU, Great Expectations: An Assessment of the potential for Suborbital Transportation, MS08 Team Project, ISU, Strasbourg, 2008, available under http://www.isunet.edu.

[3-23] Häuplik-Meusburger, S., Architecture for Astronauts. An Activity-based Approach, Springer, Berlin, 2011, pp. 276–289.

[3-24] ISU, Space Tourism, From Dream to Reality, SSP, ISU, Strasbourg, 2000, available under http://www.isunet.edu

[3-25] Guery, Jean-François, et al., Solid propulsion for space applications: An updated roadmap, Acta Astronautica 66 (2010) 201-219.

4. Spaceports

[4-1] Webber, D., "Horses for Courses - Spaceport Types", International Space Development Conference, Washington DC, May 2005.

[4-2] Webber, D., "The Changing Role of Spaceports", Chapter 26 of Beyond Earth - The Future of Humans in Space, Edited by Krone, B, Apogee Books, 2006

[4-3] Webber, D., "Tourism's Latest Sector - Private Spaceflight", Chapter 7 of Tourism and Developments, Issues and Challenges, Edited by Mihalic and Gartner, Nova Science Publishers, 2013

[4-4] ISU, FUTURIST, SSP09 Team Project, (ISU, 2009), available under http://www.isunet.edu

5. Suborbital Vehicle Interior Design

[5-1] Futron Corporation, Suborbital Space Tourism Demand Revisited, (Futron, Bethesda, 2006)

[5-2] Crouch, G. and Laing, J. Space Tourism Attributes and Implications for Consumer Choice, Conference on Cutting Edge Research in Tourism – New Directions, Challenges and Applications, University of Surrey, UK, June 6-9, 2006, ISBN 1-84469-012-1.

[5-3] Peeters, W., From suborbital space tourism to commercial personal spaceflight. Acta Astronautica 66 (2010) 1625–1632.

[5-4] Doule, O., Passenger Safety on Personal Spaceflight – Spacecraft Interior Concept Design (IAC, Glasgow, 2008, IAC-08-B3.2-D2.7.5).

[5-5] Adebola, S., Emergency Medicine for Human Suborbital Flight (Personal Assignment, ISU, 2008), available under www.iisc.im

[5-6] FAA, Guidance for Medical Screening of Commercial Aerospace Passengers. Federal Aviation Administration, report DOT/FAA/AM-61/1 (January 2006).

6. Payload Flight Opportunities

[6-1] Ehrenfreund, P. et al., COSPAR Panel on Exploration Report (2010), Toward a global exploration program: A stepping stone approach, COSPAR, Paris, June 2010.

[6-2] NASA Exploration Team (NEXT) Design Reference Missions Summary, available under http://history.nasa.gov/DPT/Architectures/NExT%20DRM%20Summaries%20Jul_02%20%28Advanced%20Draft%29.pdf, July 2002.

[6-3] Martin J.C. and Law G.W., Suborbital Reusable Launch Vehicles and Applicable Markets, prepared by the Aerospace Corporation for the U.S. Department of Commerce, Office of Space Commercialization, October 2002.

[6-4] The Tauri Group, Suborbital Reusable Vehicles: A 10-Year Forecast of Market Demand, study published in 2012, funded by FAA and Space Florida, and available under http://www.taurigroup.com/files/Suborbital_Reusable_Vehicles_A_10_Year_Forecast_of_Market_Demand.pdf, 2012.

[6-5] NASA, Flight Opportunities Program, https://flightopportunities.nasa.gov), consulted on 15 Nov. 2012

[6-6] Wagner EB, Charles JB, Cuttino CM. Opportunities for research in space life sciences aboard commercial suborbital flights. Aviat. Space Environ Med 2009; 80: 984.

[6-7] VIRGIN GALACTIC, Payload Users Guide. Ref: WEB003, January 3, 2013.

[6-8] XCOR, Lynx Payload Users Guide, September 28, 2012.

[6-9] VIRGIN GALACTIC, Virgin Galactic to Fly Scientists to Space, available under www.virgingalactic.com/news, February 28, 2011.

[6-10] SPACE.COM, NASA Buys Flights on Virgin Galactic's Private Spaceship, available under www.space.com, October 14, 2011.

7. Societal Motivations for Personal Spaceflight

[7-1] Naisbitt, J., Global Paradox (Avon, New York, 1994) p.163

[7-2] Sandrone, S. and Wagner, A., Henry the Navigator and the Moon. Paper IAC-07-D3.1.04, (IAC, 2007).

[7-3] SAPHIR, Dokumentation des Workshops am 3. Juli 1991 bei der DLR, Cologne, September 1991.

[7-4] Kerner, M., Der mensch in der Geschichte, in Sahm, P. and Thiele, G., Der Mensch in Kosmos, OPA, Amsterdam, 1998, p.9.

[7-5] Zabusky, S., Launching Europe: An Ethnography of European Cooperation in Space, Princeton University Press, Princeton New Jersey, 1995.

[7-6] Arnould, J., Icarus' Second Chance, Springer, 2011.

8. Market Demand

[8-1] Peeters W., Space marketing, chapter 9, Kluwer, Dordrecht, 2000.

[8-2] Abitzsch, S., Global Market Scenario of a Space Tourist Enterprise. Paper presented at the International Symposium on Space Tourism, Bremen, March 20-22, 1997.

[8-3] Collins, P. et al., Commercial Implications of Market Research on Space Tourism. Proc. of the 19th Symposium on Space technology and Science, Yokohama, May 1994.

[8-4] Dasch, P., Space Tourism: Getting Beyond the Giggle Factor. Ad Astra Magazine, March/April 1996, p. 40.

[8-5] Barrett, O., An evaluation of the potential demand for Space Tourism within the United Kingdom, Bournemouth University, Dorset, England, 1999.

[8-6] Berger, B., Billionaire Shops for Space Tourism Vehicle. Space News, May 10th, 1999, p.6.

[8-7] Crouch, G., The Market for Space Tourism: Early Indications. Journal of Travel research. (40, Nov. 2001) pp. 213-219.

[8-8] Futron, Suborbital Space Tourism Demand, 2002.

[8-9] Futron, Suborbital Space Tourism Demand Revisited, 2006.

[8-10] Tauri Group, Tauri Report, 2012.

[8-11] Inden, W., Tourist Space Flights. A Vision for 2020 and its Challenges for Today. Proceedings of the International Symposium on Impact of Space Technology Innovation on Economic Development, Shanghai, April 2001, pp. 222-233.

9. Medical Aspects of Suborbital Space Tourism

[9-1] AsMA Task Force on Space Travel. Medical Guidelines for Space Passengers. Aviat. Space Environ. Med. Journal 72:948-950. 2001.

[9-2] AsMA Task Force on Space Travel. Medical Guidelines for Space Passengers II. Aviat. Space Environ. Med. Journal 73:1132-1134. 2002.

[9-3] Antuñano, M.J., Baisden, D.L., Davis, J., Hastings, J.D., Jennings, R., Jones, D., Jordan, J.L., Mohler, S.R., Ruehle, C., Salazar, G.J., Silberman, W.S., Scarpa, P., Tilton, F.E., and Whinnery, J.E. “Guidance for Medical Screening of Commercial Aerospace Passengers” Technical Report No. DOT-FAA-AM-06-1. Federal Aviation Administration, Office of Aerospace Medicine, Washington, D.C. 2006.

[9-4] Antuñano, M.J., Vanderploeg, J.M., Jennings, R.T., Richard, E.E. and McDonald, P.V. Chapter 30 - Commercial Human Space Flight. Fundamentals of Aerospace Medicine, 4th Edition, 2008.

[9-5] Antuñano, M.J., Hobe, S. Gerzer, R. (Editors). Medical Safety and Liability Issues for Short-Duration Commercial Orbital Space Flights. Position Paper. International Academy of Astronautics. 2009.

[9-6] Antuñano, M.J. Manned Commercial Space Flights: A New Challenge for Aerospace Medicine. Italian Journal of Aerospace Medicine. No. 3, July 2010, pages 3-10.

[9-7] Jennings, R., Vanderploeg, J., Antu?ano, M.J., Davis, J. Flight Crew Medical Standards and Spaceflight Participant Medical Acceptance Guidelines for Commercial Space Flight. FAA Center of Excellence for Commercial Space Transportation. June 30, 2012.

[9-8] International Civil Aviation Organization (ICAO) Safety Management Manual, Doc 9859 AN/460

[9-9] Federal Aviation Administration (FAA) Advisory Circular AC No: 120-92. Safety Management Systems for Aviation Safety Providers. August 12, 2010.

[9-10] Vernon, P., Vanderploeg, J.M., Smart, K., Hamilton, D. AST Commercial Human Space Flight Participant Biomedical Data Collection. Final Report DOT Volpe Center Contract DTRT57-05-D-30103, Task Order # 6, Subcontract 10153943 from The Aerospace Corporation. Wyle Laboratories, Inc. Technical Report # LS-09-2006-001. February 2007.

10. Legal Aspects of Suborbital Personal Spaceflight

[10-1] http://www.xcor.com/products/vehicles/lynx_suborbital.html (last accessed: 2 May 2013).

[10-2] http://www.navcanada.ca/NavCanada.asp?Language=en&Content= ContentDefinitionFiles %5CServices%5Cdefault.xml (last accessed: 2 May 2013).

[10-3] Jakhu, Ram, et al, (eds.), The Need for an Integrated Regulatory Regime for Aviation and Space: ICAO for Space?, Springer, 2011.

[10-4] UN Committee on Peaceful Uses of Outer Space, document: A/AC.105/C.2/2010/CRP.9 of 19 March 2010.

[10-5] Jean-Bruno Marciacq, et al, “Accommodating Sub-Orbital Flights into the EASA Regulatory System,” in Joseph N. Pelton and Ram S. Jakhu (eds.), Space Safety Regulations and Standards, 2010, Elsevier, pp. 187, et seq.

[10-6] 51 United States Code, Ch. 509, §§ 50901-23 (2011).

[10-7] Timothy Robert Hughes and Esta Rosenberg, “Space Travel Law (and Politics): The Evolution of the Commercial Space Launch Amendments Act of 2004,” 31, Journal of Space Law, (2005), p. 1, at p. 35.

[10-8] 22 Code of Federal Regulations §§ 120-130.

[10-9] 22 United States Code § 2778.

[10-10] Brian Feeney, “Canadian Aerospace Flight Test Area and Runway Needs -- for Higher Risk Commercial Experimental Aircraft and Spacecraft Development”, http://aerospacereview.ca/eic/site/060.nsf/vwapj/DreamSpaceGroup.pdf/$file/DreamSpaceGroup.pdf (last accessed: 2 May 2013).

[10-11] SBANDALA, “Commercial Spaceflight Federation Applauds the Passage of ITAR Reform Provision,” published 21 December 2012; and available under http://www.commercialspaceflight.org/2012/12/commercial-spaceflight-federation-applauds-the-passage-of-itar-reform-provision/ (last accessed: 2 May 2013).

11. International Commercial Space Industry Regulation

[11-1] Pelton, J. and Marshall, P., Launching into Commercial Space, (2013) AIAA, Reston, Virginia

[11-2] Tauri Group, “Suborbital Reusable Vehicles: A Ten Year Forecast of Market Demand” http://www.faa.gov/about/office_org/headquarters_offices/ast/media/Suborbital_Reusable

_Vehicles_Report_Full.pdf and see also Futron Corporation, Passenger Demand Forecast Using Different Market Maturation Periods, 2006

[11-3] Dempsey P. and Mineiro M., "The ICAO's Legal Authority to Regulate Aerospace Vehicles", in Joseph N. Pelton and Ram S. Jakhu Space Safety Regulations and Standards, (2010) Elsevier Press, Amsterdam, Netherlands

[11-4] Seibold R.W., J.A. Vedda, J.P. Penn, S.E. Barr, J.F. Kephart, G. W. Law, G. G. Richardson, Aerospace Corporation, Joseph N. Pelton, H.R. Hertzfeld, and J. M. Logsdon, George Washington University and Jeff A. Hoffman, M.E. Leybovich, M.I.T., Analysis of Human Space flight Safety-Report to Congress: Independent Study Mandated by the Commercial Space Launch Amendments Act of 2004 (Public Law 108-492), 11 November 2008.

[11-5] Yehia, J.A. and Schrogl, K.U., European regulation for private human spaceflight in the context of space management. Acta Astronautica 66 (2010) 1618-1624.

[11-6] Nield, G. et al., Certification Versus Licensing for Human Spaceflight in Commercial Space Transportation. New Space, Vol (1)1, pp.46-50.

12. SWOT Analysis

[12-1] Peeters, W., From suborbital space tourism to commercial personal spaceflight. Acta Astronautica 66 (2010) 1625–1632

[12-2] Futron, New Mexico Commercial Spaceport Economic Impact Study, Futron, Bethesda, 2005.

[12-3] XCOR 2013 [Online], Unilever Buys 22 Flights on XCOR Aerospace's Lynx Suborbital Spacecraft For Global AXE Campaign, available under http://www.xcor.com/press-releases/2013/13-01-11_unilever_buys_22_flights_on_lynx.html [accessed 02/06/2013].

[12-4] MacLeod, J., Estimating Suborbital Market Structure (Personal Assignment, ISU, 2008), available under www.iisc.im

[12-5] Davidian, K. and Conrad, C., Industry Structural Analysis of the Commercial Suborbital Research Market. New Space, Vol (1), 2013, pp. 10-20.

[12-6] Morris, L. and Cox, K. (eds.) Space Commerce, ASTWG, IISC, 2010.

[12-7] Futron Corporation, Suborbital Space Tourism Demand Revisited, Futron, Bethesda, 2006.

15. Appendices

15.1. Contributors

Antuñano, Melchor J.	Chapter 9
Bonnal, Christophe	Chapter 3 (Part 2)
Bukley, Angelia P.	Chapter 1, 6, and 13
Calabro, Max	
Couston, Mireille	
Crowther, Richard	
Droneau, Philippe	
Eilingsfeld, Fabian	Chapter 3 (Part 1)
Eymar, Patrick	Chapter 7
Gerzer, Rupert	Chapter 9
Jakhu, Ram	Chapter 10
Peeters, Walter	Chapters 1, 2, 5, 8, 12, and 13
Pelton, Joseph N.	Chapter 11
Romero, Manola	
Salt, Dave	
Smith, Garrett	
Webber, Derek	Chapter 4
Winisdoerfer, Francis	

15.2. Acronyms

AAS: American Astronomical Society
ACE: Astronaute Club Européen
AIAA: American Institute of Aeronautics and Astronautics
AsMA: Aerospace Medical Association
ATC: Air Traffic Control
CHSO: Commercial Human Spaceflight Operations
COESCT: Center of Excellence for Commercial Space Transportation
COPUOS: (United Nations) Committee on the Peaceful Uses of Outer Space
COSPAR: International Council for Science Committee on Space Research
COTS: Commercial OFF-THE-SHELF (hardware)
CSF: Commercial Spaceflight Federation
EASA: European Aviation Safety Agency
EADS: European Aeronautic, Defense and Space Company
ECLSS: Environmental Control and Life Support System
FAA: U.S. Federal Aviation Administration
FOP: Flight Opportunity Program
g: Earth gravity (force)
GDP: Gross Domestic Product
GPS: Global Positioning System (navigation)
G_x: g-load in X-axis
G_z: g-load in Z-axis
HAZMAT: Hazardous Material (handling)
HNWI: High Net Worth Individual
HTBP: Hydroxyl-terminated PolyButadieen (propellant)
HTOHL: Horizontal Take-off, Horizontal Landing
IAA: International Academy of Astronautics
IAASS: International Association for the Advancement of Space Safety
IADC: Inter-Agency Debris Consultative Committee

ICAO: International Civil Aviation Organization

IISC: International Institute of Space Commerce

IMF: International Monetary Fund

ISS: International Space Station

ISU: International Space University

ITAR: International Traffic in Arms Regulations

LCC: Life Cycle Cost

LEO: Low Earth Orbit

LH2: Liquid Hydrogen

LOX: Liquid Oxygen

MJ: Mega Joules (propulsion energy)

MLE: Middeck Locker Equivalent

MMI: Man-Machine Interfaces

N2H4: Hydrazine (propellant)

NEXT: NASA Exploration Team

N_x: X-axis force

OST: Outer Space Treaty

P2P: Point to Point (flight)

PEX: Panel on Exploration (COSPAR)

SDR: Special Drawing Rights

SFP: Space Flight Participant

SOV: Suborbital Vehicle

SMS: Safety Management System

STM: Space Traffic Management

SS2: SpaceShipTwo (Virgin Galactic)

SRV: Suborbital Reusable Vehicle

SWOT: Strengths, Weaknesses, Opportunities and Threats (analysis)

SWRI: Southwest Research Institute

TRL: Technology Readiness Level

UN: United Nations

USD: United States Dollars

USML: United States Munitions List

15.3. IAA in Brief

International Academy of Astronautics

A Brief Description

Founded:

16 August 1960, Stockholm, Sweden, by Theodore Von Karman. Independent non-governmental organization recognized by the United Nations in 1996.

Aims:

Foster the development of astronautics for peaceful purposes; Recognize individuals who have distinguished themselves in space science or technology; Provide a program through which members may contribute to international endeavors; Promote international cooperation in the advancement of aerospace science.

Structure:

Regular Meeting; Board of Trustees consisting of: President; four Vice-Presidents and twenty-eight Trustees, seven from each Section: Basic Sciences, Engineering Sciences, Life Sciences and Social Sciences. Current President: Dr Madhavan G. Nair, Past-President: Prof. Edward C. Stone, USA, Vice-Presidents: Mr. Yannick d'Escatha, France; Prof Liu Jiyuan, China; Dr. Hiroki Matsuo, Japan; Prof. Anatoly Perminov, Russia, Secretary General Dr. Jean-Michel Contant, France.

Activities:

Encourage international scientific cooperation through symposia and meetings in the area of: space sciences, space life sciences, space technology & system development, space systems operations & utilization, space policy, law & economy, space & society, culture & education; Publish cosmic studies dealing with a wide variety of topics including space exploration, space debris, small satellites, space traffic management, natural disaster, climate change, etc.

Cooperation with other Academies:

Establish cooperation with Royal Swedish Academy of Sciences (1985), Austrian Academy of Sciences (1986, 1993), Academy of Sciences of France (1988, 2001), Academy of Finland (1988), Indian Academy of Sciences (1990, 2007), Royal Spanish Academy of Sciences (1989), German Academy of Sciences (1990), Kingdom of Netherlands (1990), Academies of Arts, Humanities & Sciences of Canada (1991), U.S. Academy of Sciences (1992, 2002), U.S. Academy of Engineering (1992, 2002), Israel Academy of Sciences and Humanities (1994), Norwegian

Academy of Science and Letters (1995), Chinese Academy of Sciences (1996, 2013), Academy of Sciences of Turin (1997), Australian Academy of Sciences (1998), Royal Netherlands Academy of Arts and Sciences (1999), Brazilian Academy of Sciences (2000), U.S. Institute of Medicine (2002), Academy of Sciences of Ukraine (2010, 2012), Academy of Sciences of South Africa (2011), Royal Society of South Africa (2011), Pontifical Academy of Sciences (2012).

Publications:

Publish the journal of the International Academy of Astronautics ACTA ASTRONAUTICA ranked 4th in the world; Yearbook, Dictionaries and CD-ROM in 24 languages (last languages Afrikaner and Swahili); Book Series on small satellite, conference proceedings, remote sensing and history. All publications available at https://shop.iaaweb.org.

Membership:

Active members 1124 in 83 countries in four Trustee Sections; Honorary members (3):

- Africa: Algeria, Burkina Faso, Cameroon, Egypt, Ethiopia, Ivory Coast, Kenya, Libya, Morocco, Nigeria, Senegal, South Africa, Tunisia.
- Americas: Argentina, Bolivia, Brazil, Canada, Chile, Columbia, Cuba, Guatemala, Mexico, Peru, Uruguay, USA, Venezuela.
- Asia: Bahrain, Burma, China, India, Indonesia, Irak, Israel, Japan, Kazakhstan, Korea, Kuwait, Kyrgyz Republic, Malaysia, Mongolia, Pakistan, Saudi Arabia, Singapore, Sri Lanka, Syria, Thailand, Turkey, Vietnam.
- Europe: Armenia, Austria, Belarus, Belgium, Bulgaria, Croatia, Czech Rep., Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Macedonia, Netherlands, Norway, Poland, Portugal, Romania, Russia, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom, Ukraine.
- Oceania: Australia, New Zealand.

IAA Office:

Office 6 rue Galilée, Po Box 1268-16, 75766 Paris Cedex 16, France; IAA Office Branches in Bangalore (India) and in Beijing (China) for its Study Center; Regional offices in Abuja (Nigeria), Tunis (Tunisia), Buea (Cameroon) and Nairobi (Kenya).

Mailing Address: IAA, PO Box 1268-16, F-75766 Paris Cedex 16, France

Telephone: 33 1 47 23 82 15, Fax: 33 1 47 23 82 16, email sgeneral@iaamail.org

Web Site: http://www.iaaweb.org https://shop.iaaweb.org/