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Manned systems for Suborbital flight and related operating scenarios and ground infrastructures analysis

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1 Abstract

With Space Shuttle retirement in 2011, [1] worldwide aerospace industry focused on new technologies aimed at develop of an innovative new line of reusable Space Vehicles. Furthermore, on the wake of the new NASA strategies, commercial companies start to heavily be involved, aiming at easier and cheaper access to space.
In particular, in the perspective of a future space tourism era, the category of spaceplanes is the most interesting to analyse. However, since spaceplanes can be used not only in sub-orbital flight, but also in LEO missions, a preliminary study will be executed in order to stress these differences. As we will see in the next chapter, missions using spaceplanes are not addressed only to future space tourists but also to carry cargo, scientific payloads and crew to the ISS or, more in general, in LEO platforms. Special focus of this work is the sub-orbital flight missions with a spaceplane: different concepts will be identified and compared.
After a general overview, as this kind of flight is at an early stage, identifying and analysing all the critical issues involved in this activity, both for the vehicle but, more importantly, for the human body is paramount. The purpose in this part, once detected the main issues, will be to suggest possible mitigation solutions.
As important as the vehicle itself is the ground segment, which has the role to support the mission and make sure that all safety requirements are addressed. Consideration on this part will be made, as Italy is seeking a significant role in future Sub-orbital initiatives and capabilities. In fact, thanks to a memorandum of cooperation recently signed between Italian industries and Virgin Galactic to evaluate the possibility of establishment of a suborbital flight initiative in Italy, this country will hold the first spaceport in Europe. Also, in 2018, the airport of Grottaglie was designated as national spaceport for sub-orbital needs.
Furthermore, some other aspects strongly connected to sub orbital flight can be looked in depth, like hybrid rocket propulsion and its related issues, as it still isn't widely used; and Air-Launch, as it is, as demonstrated by Virgin Galactic, more than a possibility to launch a spaceplane: advantages and drawbacks will be discussed.
Special thanks to Altec with whom I developed this thesis, in particular to Eng.Francesco Santoro, and to my colleague and friend Riccardo Mollo.

Con il ritiro dello Space Shuttle nel 2011, l'industria aerospaziale mondiale ha iniziato a focalizzarsi su nuove techologie atte allo sviluppo di una nuova innovativa linea di veicoli spaziali riutilizzabili. Inoltre, sull'onde delle nuove strategie della NASA, compagnie commerciali private hanno iniziato ad essere coinvolte in modo sostanziale, con l'obiettivo di permettere in futuro un più facile e più economico acceso allo spazio.
In particolare, nella prospettiva di una futura imminente era del turismo spaziale, la categoria degli spazioplani risulta la più interessante da analizzare. Tuttavia, dal momento che gli spazioplani possono essere utilizzati non solo per voli suborbitali, ma anche per missioni in orbita bassa (LEO), verrà eseguito uno studio preliminare per sottolineare le differenze dei diversi concept di missione. Come vedremo nel capitolo seguente, le missioni che utilizzano spazioplani non sono indirizzate solo ai futuri turisti spaziali ma anche per il trasporto di cargo, payload scientifici ed equipaggio verso la Stazione Spaziale Internazionale o, più in generale, su piattaforme LEO. In questo lavoro ci focalizzeremo specialmente su missioni suborbitali eseguite con spazioplani: diverse configurazioni verranno identificate e confrontate.
Dopo una panoramica generale, dal momento che questo tipo di volo è ancora ad una fase iniziale, è fondamentale identificare e analizzare tutte le criticità in gioco in questa attività, sia per il veicolo ma soprattutto per il corpo umano. Lo scopo in questa parte sarà, una volta identificate le problematiche, quello di suggerire possibili soluzioni di mitigazione.
Della stessa importanza del veicolo è il segmento terra, che ha il ruolo di supportare la missione e assicurarsi che tutto proceda nel rispetto dei requisiti di sicurezza. Alcune considerazioni verranno fatte in merito, dal momento che l'Italia sta cercando di acquisire un ruolo significativo nel futuro delle iniziative e capacità di volo suborbitale in Europa. Infatti, grazie ad un accordo recentemente stipulato dall'industria aerospaziale italiana e la Virgin Galactic per valutare la possibilità di stabilire una iniziative di volo suborbitale su suolo italiano, il nostro paese ospiterà il primo spazioporto in Europa. Inoltre, nel 2018, l'aeroporto di Grottaglie è stato scelto come spazioporto nazionale per le future iniziative di volo suborbitale.
In questo lavoro verranno approfonditi altri aspetti fortemente legati alla tematica del volo suborbitale, come la propulsione ibrida e le sue criticità, che la rendono ad oggi non largamente utilizzata; e l'aviolancio, che rappresenta, come dimostrato dalla Virgin Galactic, più di una possibilità per il lancio di uno spazioplano: in merito verranno discussi i principali vantaggi e problematiche.
Ringraziamenti speciali vanno ad Altec, con la quale ho collaborato alla realizzazione di questo lavoro, in particolare all'Ing. Francesco Santoro, e al mio collega e amico Riccardo Mollo.

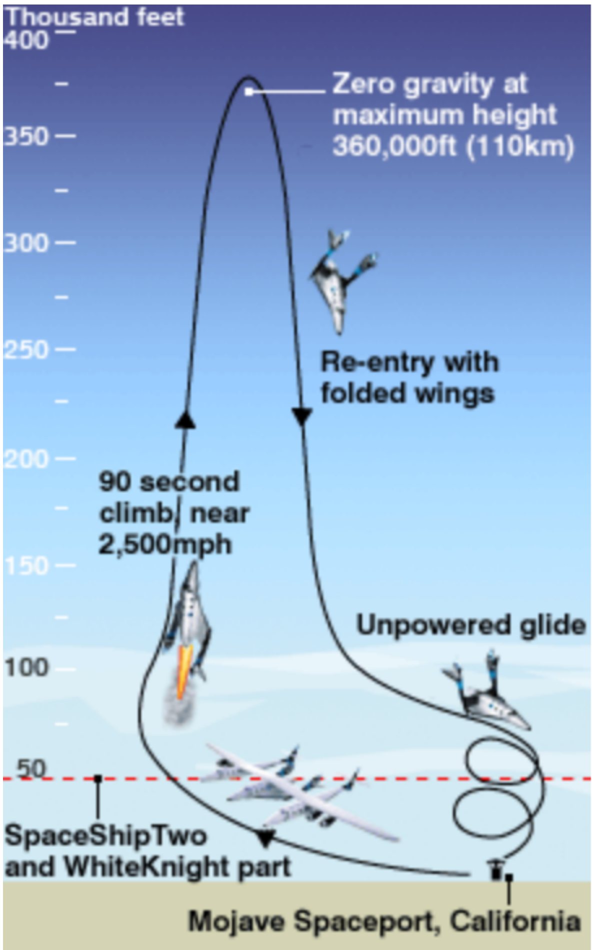


Figure 1: A typical Sub-Orbital mission profile [Credits: Virgin Galactic]

2 Suborbital flight: an overview and industrial trends

Currently in Aerospace Industry there is a great interest in this kind of activity, especially due to the presence of numerous private companies, which aim to make space accessible to tourists. A kind of vehicle that makes possible a sub orbital flight is called Spaceplane: its peculiarity is the capability to operate in different scenarios, fly trough the atmosphere, reach a low orbit or at least an apogee high enough to be considered in space, then re-entry on the Earth and potentially gliding to land on a runway like a conventional aircraft. Actually, as we will see, from an operational standpoint, for this vehicle there are different mission concepts:

- LEO operations to carry cargo on the ISS (unmanned mission);
- LEO operations to carry Astronauts on the ISS or in LEO platforms(manned mission);
- Tourist (or scientific) sub-orbital flight to experience some minutes in microgravity;
- Point to point sub-orbital flight to connect two different spaceports on the Earth.

In this chapter, we're going to give an overview of what have been the main initiatives in sub-orbital flight in the last decades, stressing the differences and the common aspects. We're going to detect the key enabling technologies and then to find out what are the most important critical issues in this kind of activity.
In particular, for the vehicle itself, we have severe structural and thermal solicitations, the last ones especially during the re-entry phase; but more importantly for the human body, as it is subjected to significant loads due to accelerations, and he has to survive in the harsh environment of space and high atmosphere.
It's important to point out suborbital flight is strongly related to Hypersonic flight. This one is characterized by a Mach number above 5. Physically, it means that physical properties of the air, like dissociation and ionization, cannot be neglected anymore.

2.1 Spaceplanes: recent concepts

2.1.1 SpaceShipTwo

It represents the second attempt made by the American Company *Virgin Galactic* in designing a spaceplane (the previous was SpaceShipOne in 2004). The ultimate purpose of this vehicle is to carry space tourist in a sub-orbital trajectory, in order to make them appreciate some minutes in microgravity, floating in the cabin. Alternately another concept of operation is to install a scientific payload, carrying a Specialist able to execute scheduled experiments [2] [3].

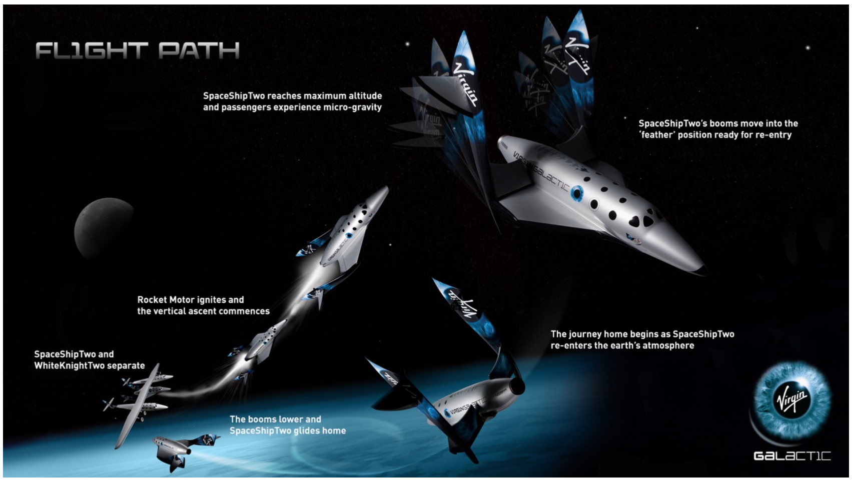


Figure 2: SpaceShipTwo Mission Profile [Credits: Virgin Galactic]

Therefore, the current Virgin Spaceplane is expected to accomplish only sub-orbital flights (not reaching LEO), landing at departure spaceport.
Take off is carried out by a Carrier called WhiteKnight to whom the SpaceShip is anchored on the bottom side (air-launch captive on bottom). This carrier is a particular aircraft with 2 fuselages, powered by 4 turbojets, able to carry the SpaceShip up to 15200 m.
Arrived at this altitude the Ship is undocked from the Carrier and, after a certain delay, lights up its Hybrid rocket propeller. This is the climbing phase in which the Ship increases its pitch angle up to 90°, for an almost vertical ascent. The ignition lasts approximately 60 seconds, followed by a *coast phase*, at the end of which it has reach 100 km of altitude, the conventional boundary between atmosphere and space.
After some minutes in microgravity the Ship assumes a particular attitude configuration, called *fethered*, which consists in lifting aerodynamic tail surfaces

Figure 3: SpaceShip with its Carrier WhiteKnight, take off configuration [Credits: Virgin Galactic]

to create an increase in drag in order to let a rapid descent. Once reached an altitude of 70000 *ft* the initial attitude is restored, letting the Spaceplane to glide to get to the spaceport on a usual landing on a runway.

2.1.2 Dream Chaser

Designed by the American private company Sierra Nevada Corporation, it's a vehicle capable of autonomous landing on runway by gliding [4]. In this is similar to the SpaceShip (even if the last one has two pilots on board); but actually it presents some differences: first of all, it's designed to reach the low Earth orbit (LEO), in particular docking at the ISS. Therefore a greater amount of thrust at launch is required, and the innovative *air-launch* is replaced by a more regular ground launch, placing the ship in the fairing of the rocket.

Figure 4: Burning phase [Credits: Virgin Galactic]

Figure 5: Dream Chaser launching configuration [Credits: Sierra Nevada Corporation]

Initially the Dream Chaser is composed by two modules: the ship itself, the only part that is supposed to re-entry, and a cargo module, anchored to the back of the ship, equipped with solar panels in order to provide current to the payload.
Once undocked from the ISS, the ship can perform an automatic re-entry in atmosphere and land without engine.

Figure 6: Dream Chaser [Credits: Sierra Nevada Corporation]

The main goal of this vehicle to su carry supplies to the ISS, in an unmanned configuration. However, in the near future, it will be able also to carry astronauts to the Space Station, in a manned configuration.

2.1.3 IXV

Short name for *Intermediate eXperimental Vehicle*, it was a demonstrative spacecraft designed by ESA [5]; its mission consisted in verify the capability of performing a automatic controlled atmospheric re-entry from LEO. It was equipped whth a guidance, navigation and control system, and used e thermal shield made of ceramic material to protect the bottom side and the nose during re-entry. The last one is slightly rounded compared to the one of the Spaceship because of the hypersonic (instead of supersonic) velocity profile.
For the launching phase, Vega rocket can be used, in a configuration similar to the Dream Chaser, in order to reach LEO.
However, once back on Earth, being unprovided of a landing gear, it executed a more classical *splash-down*.
Since it was a technological demonstrator, it didn't carry any payload. Nevertheless it open up the path to future development: in fact european industry is engineering e new vehicle called *Space Rider*. It will be launched by a Vega rocket, and it will perform various activities depending on the mission: carrying scientific payload to conduct experiments in microgravity, robotic demonstrator, Earth observation, telecommunication.

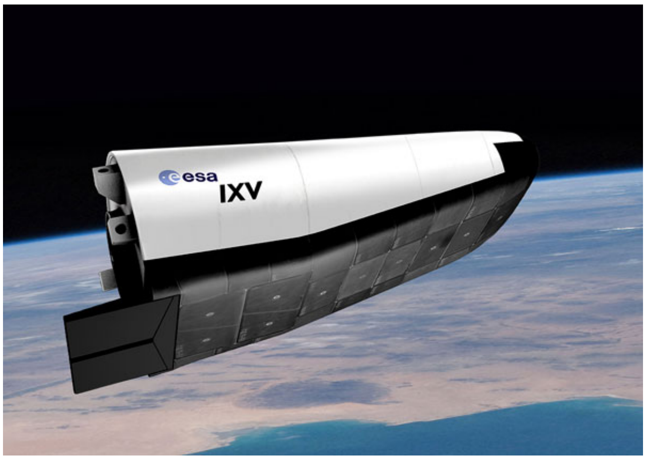


Figure 7: IXV operating in LEO [Credits: ESA]

2.1.4 Airbus Defence and Space Spaceplane

Its a concept of Spacplane developed in the last decade, similar for some aspects to the SpaceShip, in fact it was intended for tourist sub orbital flight, with the possibility of carrying up to 4 tourists with a pilot.
The peculiarity of this vehicle is that it's supposed to perform every phase of the mission independently, in fact it's a concept of SSTO, single stage to orbit. It's equipped with 4 turbofan engines per atmospheric propulsion, which let the vehicle to get to 12 km of altitude. At this point we have the ignition of a liquid rocket engine with LOX and Methane, which is the start of a steep ascending phase, exceeding Mach 3, reaching, at the end of a 90 seconds burning, an altitude of 60 km. Afterwards, the vehicle keeps climbing till reaching 100 km, letting weightlessness to be experienced [6] [7].
Re-entry phase should happen at high angle of attack in order to the Space-Plane to dissipate as much velocity as possibile in the atmosphere till getting to 15 km of altitude, where conventional turbofans are re-activated to allow a classic landing like an airline aircraft. However this is only a concept, not event in developing at the present time.

2.1.5 XCOR Lynx

Also this vehicle was never able to fly, essentially due to its producer company bankruptcy, XCOR Aerospace. It's able of an horizontal take off and landing, carrying a pilot with a passenger or a scientific payload [8].
It's only equipped with a liquid rocket engine (LOX - Kerosene), so it should be placed on the runway threshold, as it's not able of autonomous ground movement.

Figure 8: Airbus SpacePlane taking off [Credits: Airbus]

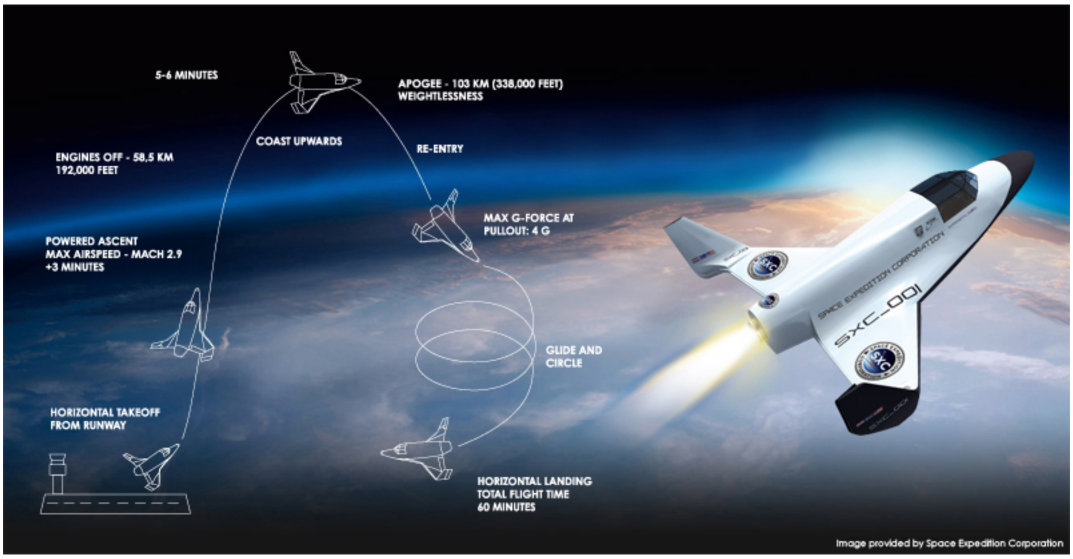


Figure 9: XCOR Lynx Flightpath [Credits: XCOR]

The propulsion system allows the vehicle to clim till 42 km at Mach 2; afterwards the climbing goes on until the apogee, at 60 km, is reached, allowing 4 minutes in weightlessness. Gliding it lands on a runway.

2.1.6 Skylon

It's a vehicle designed by UK based reaction engines in partnership with UK Space Agency. It's a SSTO, able to reach LEO. It's equipped with an innovative engine, called SABRE (Synergistic Air - Breathing Rocket Engine), which works with LOX and liquid Hydrogen [9].

Figure 10: Skylon taking off [Credits: UK BRE and UK Space Agency]

However the engine is characterized by two operative modes:

- Airbreathing mode: the engine “takes” air from the outside atmosphere and then strongly compressed, while fuel for combustion is the tanks contained Hydrogen;
- Rocket mode: once reached an altitude of 26 Km, at Mach 5, this mode is activated; Oxygen is no longer taken from the atmosphere but from on board tanks, in order to reach the orbit.

Both take off and landing are horizontal on runway. Currently it’s only a concept, for payload transport, but future development expects also to carry up to 40 passengers.

2.1.7 Space Liner

It’s a DLR (German Space Agency) project, currently stopped for lack of funds. It’s a concept of a point-to-point tourists transport, alternatively a cargo transport vehicle for LEO. In both cases, it’s reusable.
It consists in two stages, with a vertical take off and horizontal landing, with the presence of a booster for launch phase connected to the actual spaceplane, able to accommodate up to 50 passengers, with two pilots [10].

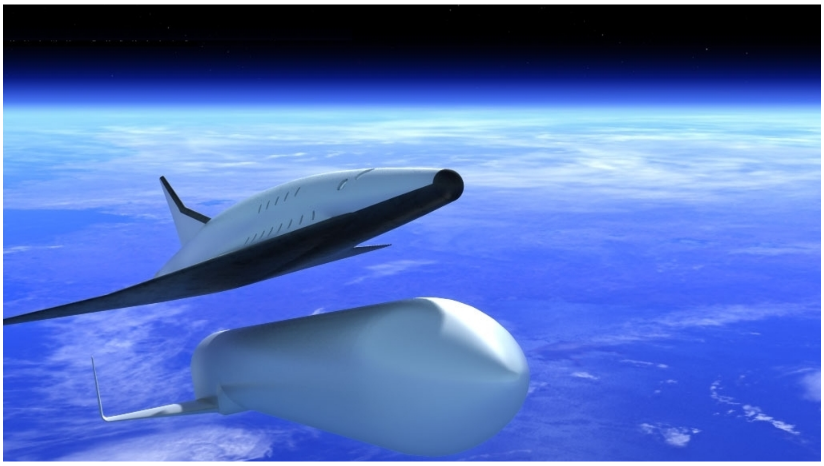


Figure 11: Spaceliner detachment from booster [Credits: German Space Agency]

Propulsion system consists in 11 liquid rocket engines (9 for the booster w 2 for the ship), which employ LOX and liquid hydrogen.
After an initial ascending phase and booster separation, spaceplane engines shutdown occurs, at an altitude of 80 Km. At this point the ship can glide over very long distances, reaching a speed of many Mach numbers.
Maximum loads of acceleration occur during the propulsive phase, without exceeding 2,5 g.

2.1.8 Boeing X-37

It's an unmanned vehicle initially developed by NASA. Then the project moved to the Defence Department and the vehicle now operated by USAF in partnership with NASA [11] [12].

Figure 12: Boeing X-37 during descending [Credits: Boeing]

The vehicle has already performed five long-duration missions in LEO, being used as a technological demonstrator.
For the ascending phase, it utilises a launch vehicle (Atlas V, Falcon 9), of which it constitutes the payload. It can re-enter independently landing on a runway.

2.1.9 SOAR

It's a spaceplane concept developed by the Swiss Space Agency for satellites releasing in sub-orbital trajectories or in LEO. For ascending phase a captive on top air-launch it's expected, utilising an Airbus A300 [13] [14].

Figure 13: SOAR spaceplane on top of an Aibus A300 [Credits: Swiss Space Agency]

At undock altitude, the Ship detaches from the aircraft and ignites its NK-39 engines with LOX and liquid Hydrogen.
Once the apogee at 80 Km is reached, the vehicle can execute e gliding re-entry e then land on a runway.
Another mission concept for SOAR was releasing payload in LEO thanks to a second stage .
Unfortunately the project has been dismissed for lack of funds.

2.2 Considerations

Spaceplane	Flight	Mission	Take off	Landing	Status	Propulsion
SpaceShipTwo	Suborbital	Commercial Tourist	Airlaunch (Carrier)	Horizontal on Runway	Test	Hybrid (HTPB/N2O)
Dream Chaser	Orbital (LEO)	Payload & Crew to ISS	Vertical (Launcher)	Horizontal on Runway	Test	Liquid (Propane/N2O)
IXV	Orbital (LEO)	Tech. Demonstrator	Vertical (Vega)	Splash – Down	Flown in 2015	Liquid (Hydrazine)
ADSS	Suborbital	Commercial Tourist	Horizontal (SSTO)	Horizontal on Runway	Concept	TF + Liquid (LOX/Methane)
XCOR Lynx	Suborbital	Com. Tourist & Payload	Horizontal (SSTO)	Horizontal on Runway	Concept	Liquid (LOX//Kerosene)
Skylon	Orbital (LEO)	Com. Tourist & Payload	Horizontal (SSTO)	Horizontal on Runway	Concept	SABRE
Space Liner	SO (Point to Point)	Commercial Tourist	Vertical (Launcher)	Horizontal on Runway	Concept	Liquid (LOX/Liquid H2)
Boeing X-37	Orbital (LEO)	Tech. Demonstrator	Vertical (Launcher)	Horizontal on Runway	5 missions	Hypergolic Nitrogen-Tetroxide/Hydrazine
SOAR	SO & LEO	Payload	Airlaunch (A300)	Horizontal on Runway	Concept	Liquid (LOX/Liquid H2)

Figure 14: Recent concepts comparison

At the end of this overview, some comments are desirable: of course we took into account different typologies of spaceplanes with different purposes; but the intention was to give a wide vision only considering the kind of vehicle.
First of all, we saw different solutions for launch and ascent to orbit or sub-orbital trajectory. Among them, two are the most indicated: using air-launching or staging with a rocket. A deepening on which are positive or negative aspects for both of these solutions will be executed in the next chapter. For now we can surely say that staging is a more *traditional* option while air-launching brings some innovations. A possible third solution is the SSTO like Airbus SpacePlane or Skylon: of course the ultimate goal in the future will be to make this option the best possible choice, but, at the present time, technology is not mature enough for industry to sustain development costs for something so innovative and cutting-edge.
We saw how, for almost every spaceplane, propulsion system is based on liquid propellants: this is due to the reliability and controllability of liquid rockets; however Virgin Galactic employs and Hybrid rocket bringing innovation. Further consideration will be made later.
In the following, we're going to focus only on a typical sub-orbital mission, assuming a tourist flight.

3 Mission concept trade off for Sub-orbital flight with Spaceplanes

In the previous section we did a literature review, looking for the most recent concepts for suborbital flight, stressing the major aspects and focusing con main differences.
The next step in this work is to find out, through a logical process, what could be the most convenient and optimal concept for such a mission, in terms of staging and propulsion strategy, TO and Landing possibilities. Before doing so, it is important to have clear in mind what our mission goal is, what is the main objective that has to be accomplished: what we have to do is to determine a *Mission Statement*:

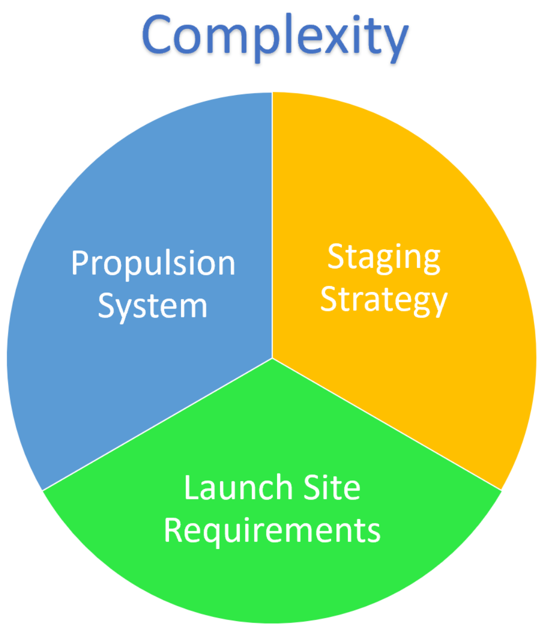
Take untrained people (tourists) into suborbital flight to let them experience and enjoy few minutes in microgravity. Alternatively provide opportunities for microgravity experimentation. This shall be accomplished by a spaceplane, with one or more stages, able to land safely on a runway.

Of course the main goal is to take tourists into space; to make this possible we use a *spaceplane*. But, since we're talking about *untrained people*, it's important that this vehicle is able to land on a runway, in order to have an as soft as possible landing. Actually tourist will not be completely untrained, from the moment that a very short training period is expected in order to them to get familiar with some procedures and equipment. The difference is that they are not professionals like real astronauts.
In the context of a scientific mission, suborbital spaceflight it's a great opportunity for its longer exposure to microgravity time compared to parabolic flight: 4-5 minutes against 25 seconds. So there is a concrete chance to validate and experiment payloads for future long duration flight in space. The number of stages we may employ, so the staging strategy, as well as take off and propulsion choices will be assessed ad hoc basing upon the specific mission requirements and constraints.
To determine them a trade off process is required.
So, as regards staging and take off strategies, for a spaceplane with horizontal landing we can think of three possible concepts:

- Single Stage to Orbit spaceplane (SSTO), so with only one stage which is the spaceplane itself;
- Employ a launcher to give the spaceplane an important initial boost;
- Take the spaceplane to a certain altitude and then release it using a carrier aircraft.

Figure 15: Take off and Staging Strategies

Among this possibilities, the best one is chosen by mean of a trade off process, in which three different *figure of merit* are analysed for each case: safety, cost and complexity. By figure of merit we mean a characteristic that has to be quantified in order to assess the performance of the system or method, in relation to its alternatives.
In particular for each FoM the following aspects will be explored:



Also advantages and drawbacks of each configuration are discussed.

3.1 Single Stage to Orbit configuration

Probably this is the most fascinating concept, due to the fact that we have only one, completely reusable stage. It should be able to take off and land horizontally on a runway. So the main advantage is the full reusability. A lower number of stages implies a less complex vehicle, as it's not required to design interfaces between stages, there will not be any separation event during flight (typically one of the most dangerous phases of a space mission). The possibility to take off horizontally like a conventional aircraft represents a benefit when it comes to a tourist mission, as it avoids strong rocket-like accelerations. Besides, from a psychological standpoint, a potential client will be more comfortable with an horizontal take off. So, in terms of safety and complexity, theoretically SSTO could be the most indicate configuration.
Problems rise for practical reasons, from the moment that this is not a proven technology but currently under development; this could led to safety issues that have to be proper addressed for a tourist mission.
As regards costs, in a future perspective they will be cut down, especially thanks to the fully reusability of the vehicle but, at the moment, substantial development costs have to be sustained.
Finally, main advantages and drawbacks may be summarized as follows:

Advantages

- Completely Reausable Single Stage
- Less Complex Configuration
- No separation Event
- Horizontal Landing/Take Off

Drawbacks

- Not proven technology (safety issues)
- High Development costs

It's worth it to say something more about maybe the most evoluted concept of SSTO currently under development: the Skylon, focusing in particular on its innovative engine.

3.1.1 Skylon's SABRE engine

To overcome the greater problem of SSTO concepts, that is featuring the vehicle with an engine capable of both operating from sea level to space, many ideas have been studied but most of them have numerous practical issues. As regards Skylon Spaceplane engine, it's called SABRE which stands for *Synergistic Air-Breathing Rocket Engine*. It's an evolution of LACE (*Liqui Air Cycle Engine*) concept, which attempts to increase its efficiency by gathering part of its oxidizer from the atmosphere. To liquefy the oxidizer liquid Hydrogen fuel is used.

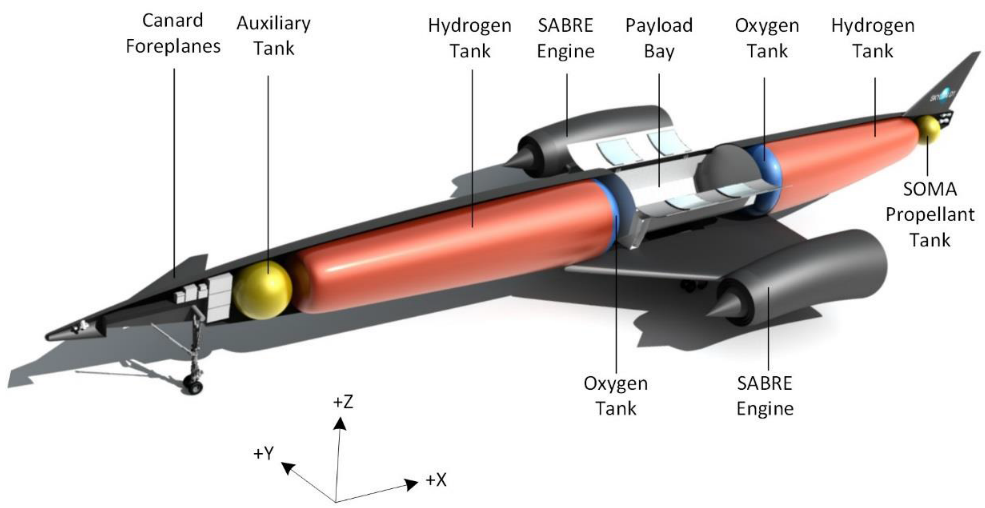


Figure 16: Skylon diagram [Credits: UK BRE and UK Space Agency]

Main differences with respect to LACE design are:

- The air is precooled but not liquefied. After cooling air is compressed with a very high pressure ratio (about 200);
- A closed-loop Helium cycle is added in order to exploit air/LH2 temperature differences to produce power, which is used to drive air and Helium compressors;
- Compressed air is used in a combustion chamber (rocket like);
- The engine is equipped with auxiliary ramjets to burn excess air during off design operations. Since most of the oxidizer comes from outer atmosphere, huge tanks for liquid hydrogen (also used in precooling process) are needed, while smaller ones for liquid oxygen.

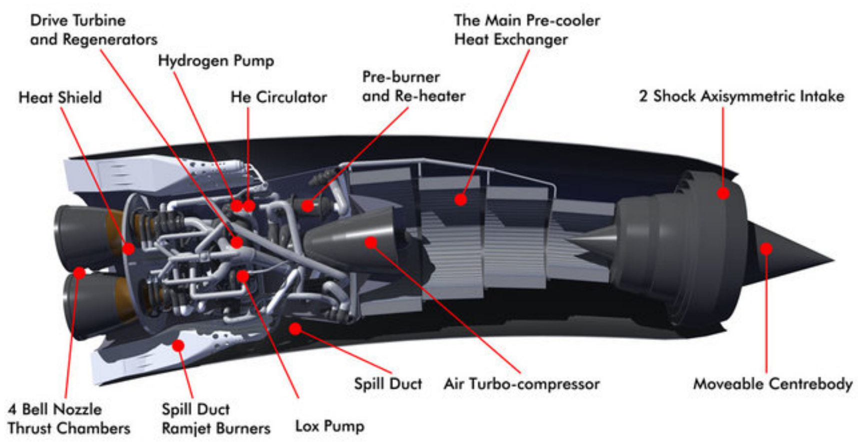


Figure 17: SABRE main components [Credits: UK BRE and UK Space Agency]

SABRE engine is characterized by different operative modes: the Airbreathing mode for Mach 0-5: the oxidizer is taken from the atmosphere. At Mach 5 all the air captured by the intake enters the main engine after passing into the precooler (design point). At lower Mach numbers engine requires less air than air captured by the intakes, then some air is bypassed into auxiliary ramjets. After Mach 5 oxygen is taken from on board tanks since the engine operates at very high altitudes (Rocket Mode).

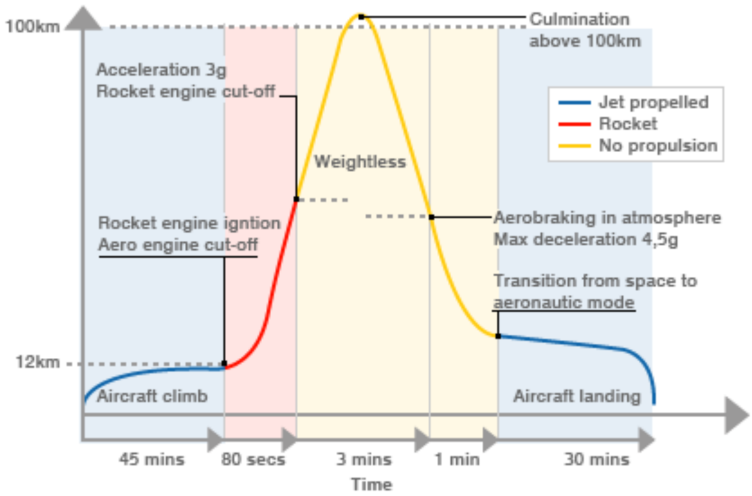


Figure 18: Skylon mission profile [Credits: UK BRE and UK Space Agency]

Such an innovative but at the same time complex engine of course requires time to be employed, as it does exploit cutting-edge technology. The most difficult part is to manage three different cycles (Air/Oxygen, Helium, Hydrogen) and different operative modes in only one engine. The greater advantage is being capable of reaching space departing from ground level with a single vehicle, by switching operative mode at certain altitudes or Mach numbers.

3.2 Launcher and Spaceplane Configuration

In this case we have an actual rocket whose payload is the spaceplane itself. Or, from an another perspective, we can consider the whole vehicle as composed by two stages: the first is the launcher rocket while the second it's the actual spaceplane. This is the concept adopted for the Dream Chaser mission design. Since most of the ΔV is provided by the rocket, less fuel will be needed for the spaceplane to reach space, since it will ignite its engines at very high altitude. Besides, the reliability of this configuration, given by the fact that it represents the commonest way of leaving the atmosphere, it can be considered a positive factor for a tourist mission.

Figure 19: Atlas V with Dream Chaser configuration [Credits: Sierra Nevada Corporation]

However, putting some untrained people on top of a giant rocket could not represent an ideal situation; both in terms of safety reasons, since a rocket is essentially a controlled bomb, and acceleration profile, with the necessity of coping to several numbers of g for some minutes.
Furthermore, the whole vehicle couldn't be fully reusable. Nowadays only few kind of launchers are completely reusable like Falcon 9 by SpaceX. For example in the case of Dream Chaser Spaceplane, Altas V launcher is used which is expendable. For this reason, from the moment that several launches per month are expected, cost and operating schedule impact are not negligible.
Besides, compared to a SSTO, utilizing a two stages vehicle is a drawback in terms of complexity: interfaces between the stages will be designed, as well as we'll have separation event. Finally, employing a rocket, we assume to take off vertically (and land horizontally with the spaceplane). Speaking of a tourist mission, a *softer* take off (horizontal) in terms of acceleration would be desirable. So, major advantages and drawback may be summarized in the following chart:

Advantages

- Can allow to diminish the spacecraft mass (less fuel required for the spaceplane
- Proven Technology

Drawbacks

- High risk for flight participants
- High cost and operating schedule impact
- Two stages
- Vertical take off/horizontal landing

3.3 Carrier and Spaceplane configuration

This is the concept adopted by Virgin Galactic for SpaceShipTwo. Of course it's a two stages configuration: the first one is a modified aircraft (special built vehicle by Virgin) while the second is the actual spaceplane. The carrier employs common turbofan engines to reach a certain release altitude (15 Km for SpaceShipTwo); this means that ground personnel and facilities are less conditioned by launch event.
Another major aspect of this configuration is the set of advantages deriving from *airlaunch*, embodied by this concept of design. Details about airlaunch will be discussed later, comparing it with conventional *ground launch*.

Figure 20: WhiteKnight carrier with [Credits: Virgin Galactic]

Of course in this configuration we have both horizontal take off and landing (HTHL), more suitable for a tourist mission. Compared to the rocket configuration, in this case the spaceplane will have to carry more fuel, since the second stage will give large part of necessary ΔV; this could mean less payload capacity.
Compared to the SSTO having two stages approach results in an increase of complexity. In addition complexity is given by the interface between stages, as well as the release mechanism which has to be strongly reliable.
From one hand, costs are reduced for the almost full reusability of the vehicle, a precious aspect to guarantee numerous flights during a month; from the other hand, development costs to design and build an appropriate carrier for the spaceplane have to be sustained at the beginning.
To summarize we can use the following chart:

Advantages

- Increased flexibility in achieving appropriate safety levels for on ground infrastructures and personnel
- Airlaunch advantages
- Horizontal take off/landing

Drawbacks

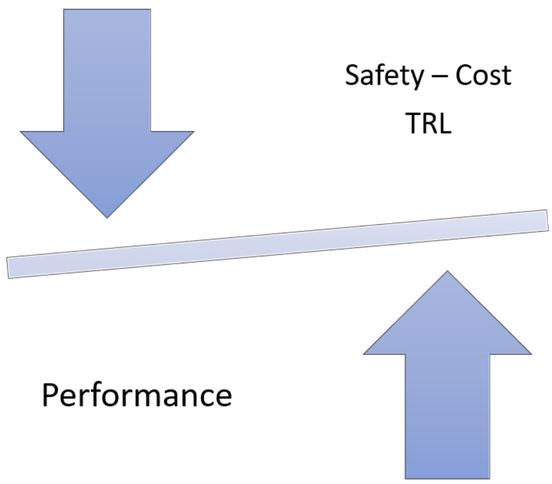
- Not great payload capacity (compared to rocket concept)
- Two stages
- Carrier development costs
- Complexity of the release mechanism

After analysing the possible configurations now we can move on with choosing what is the most suitable one for our mission.

3.4 Trade off process

To identify the best option all the advantages and drawbacks have to be compared. As a start, we can think about what are the most important features requested for the mission, in order to perform an initial screening of the various configurations.

3.4.1 SSTO issues



As regards SSTO we may say that from a performance standpoint could be the best choice, because it assures a relatively less complex vehicle (one stage) and fully reusability. Besides, for a tourist mission, HTHL concept is preferable.
Though, evaluating today's technology, we can state TRL (*technology readiness level*) does not allow a safe and sustainable flight program with a SSTO spaceplane. Safe because for this mission concept a more consolidated flight technology is desirable. Sustainable because high development cost for a new technology must be considered; costs will be cut down only in a long term perspective. On the other hand, two stages configurations, carrier and launcher, are both validated technologies to get to space (especially the latter).
Once we rule out SSTO solution, there are two possibilities left. To understand which is more indicated a deeper analysis should be done. What we know so far is that a two stages configuration will be chosen. Now we can think of doing a confrontation between take off strategies to pick the most indicated.

3.4.2 Air Launch & Ground Launch Comparison

For a launcher configuration we'll have a common *Ground Launch*; while with a Carrier configuration we talk of *AirLaunch*. Since the first typology is the most used to get to space, it could be useful for the purpose of the present study to identify valid reasons for choosing the second.
First of all, Air Launching provides mobility and deployment advantages over surface launching [15] [16]. It's possible to fly over or around launch constraining weather. With this strategy, we have minimum launch site requirement and we may have reduced range safety concerns. Besides, air launching significantly reduces the acoustic energy from the engine since there is no reflection from the ground and air density is lower.
Another important rational is about losses. In fact, reaching space, the vehicle copes to different losses, which the change of velocity has to overcome. In fact the amount of acceleration that it is provided to the spacecraft consist in the ΔV, which is the maximum change of velocity of the vehicle considering no external forces acting on it, plus the losses. The first contribute can be expressed using the Tsiolkovsky equation, also known as *rocket equation*:

$$\Delta V = c \ln \frac{m_i}{m_f}$$

in which appear:

- The effective exhaust velocity c which depends on propulsion characteristics;
- The natural logarithm of initial out final mass ratio, which substantially is related to the amount of on board propellant mass.

Gravity losses arises because part of the launch vehicle's energy is wasted in holding it against the pull of Earth's gravity. It is given by:

$$\int g \ \sin\gamma \ dt$$

with integration carried from ignition to burnout. Flying a trajectory that zeros out the flight path angle (γ) between the vehicle velocity vector and the local horizontal as soon as possible minimizes gravity loss.
Drag loss shall also factored in, which is caused by the friction between the launch vehicle and the atmosphere. It's given by:

$$\int D/m \ dt$$

where both the drag force D, and the mass of the launch vehicle, m, are continuously changing. Drag force is given by:

$$D = \frac{1}{2}\rho V^2 C_d S$$

in which the mass flow density, the flow velocity relative to the object, the reference area and drag coefficient appear. Drag losses can be minimized by flying a vertical trajectory to clear the atmosphere as soon as possible, in order to reach quickly a low density zone. Also important is to design a low drag vehicle, as drag depends on surface area.
So a compromise trajectory has to be determined to minimize losses. A vertical trajectory that would minimize drag losses increases gravity losses while a trajectory that pitches early to the horizontal would decrease gravity losses while increasing drag losses.
In the end ΔV depends on launch location, in particular on launch site latitude and launch direction: these parameters could be more flexible in case of air launching.

Therefore air launching can reduce required ΔV: launch at altitude can decrease gravity and drag losses as well increasing engine efficiency due to a better thrust expansion in the engine nozzle and due to using a large area ratio nozzle properly sized for the launch altitude.
The initial part of the flight of a conventional ground launched vehicle takes place in the most dense layers of the atmosphere, this causes inefficiencies related to drag loss.

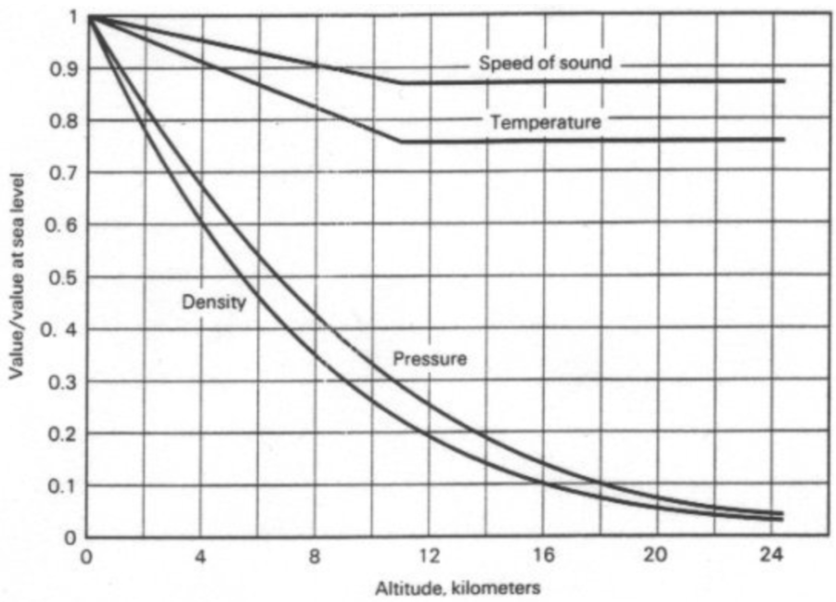


Figure 21: Atmospheric density, pressure and temperature behaviour with altitude

A significant portion of the vehicle's propellant is already consumed before it reaches the launch altitude for an air launched vehicle. Of course the effect of drag on the vehicle diminishes as the atmosphere thins during the ascent. At about 10 Km altitude, the density of the atmosphere is only 25 % of the density at sea level. Beginning the flight at that altitude will drastically reduce the drag loss. In addition, air launch will limit the gravity loss because of the time that an air launched vehicle needs for ascent (excluding initial carrier phase) will be shorter than for a ground launched vehicle.
Besides a more efficient nozzle design can be utilized for an air launched vehicle because of the lower ambient pressure at launch altitude. In fact every rocket engine is designed for a certain altitude, the so-called design altitude, at which the ambient pressure equals the exit pressure of the nozzle with ideal expansion. The first stage nozzle of any ground launched vehicle is typically a compromise due to the range of altitudes it will experience during ascent. The nozzle design of an air launched vehicle needs less compromise, since it operates over a smaller range of pressures.

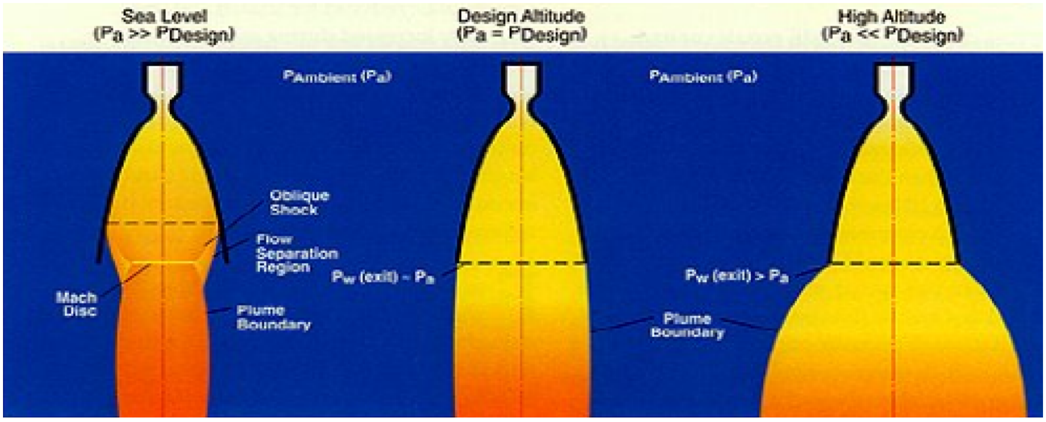


Figure 22: Nozzle expansion behaviour in relation to external pressure [Credits: reference n]

Air Launch also reduces the aerodynamic loads on the launch vehicle. As the launcher accelerates it passes through a point at which the maximum dynamic pressure occurs. The dynamic pressure depends on the atmospheric density and velocity of the vehicle according to the relation:

$$q = \frac{1}{2}\,\rho V^2$$

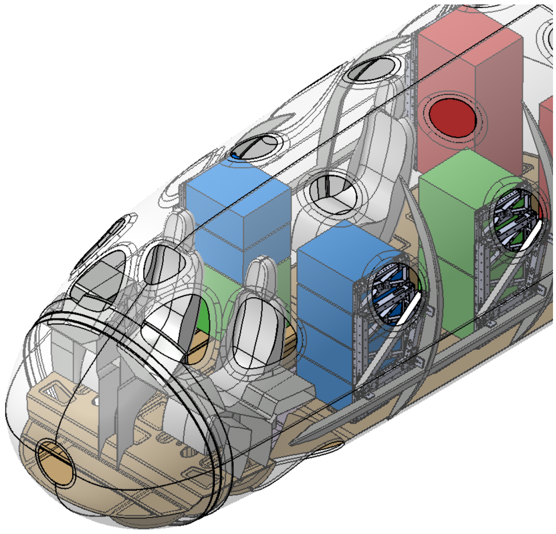
As the density is reduced the loads acting on the vehicle are lessened and structural design can be simplified. This advantage is diminished if the launch is executed at very low altitude with high velocity. Last performance advantage of air launch is a reduction in acoustic loads compared with ground launch. Acoustic reflection from the ground can damage the vehicle and ofter requires additional strucutural reinforcements for the launch vehicle; besides, noise for on ground personnel will be minimized.

Of course, gross take-off weight (GTOW) and the geometry of an air launched vehicle are restricted by the limitations of the carrier aircraft. Therefore some consideration can be made about mass fraction. The initial mass of a spacecraft can be defined as:

$$m_i = m_u + m_p + m_s$$

in which we have the sum of three contributes: payload mass, propellant mass and structure mass. In order to get to space a sizable portion of a launch vehicle's mass must be propellant. The mass of the propellant, m_p, relative to the mass dry mass fraction also includes the crew, escape systems and life support systems.
In a launcher configuration most of the ΔV will be provided by the rocket, so

the stage embodied by the spaceplane will carry less propellant: more room will be available for payload. That's also why such configuration is the most indicated to carry mass to LEO. Instead in a carrier configuration spaceplane ignites at a relatively low altitude so it has to be equipped with an engine capable to provide the necessary ΔV to get to space: more propellant will be needed on the spaceplane compared to the ground launch; as a consequence we have a lower payload capacity. For example Dream Chaser payload capacity is 5000 Kg (with launcher) while SpaceShipTwo's is 450 Kg.



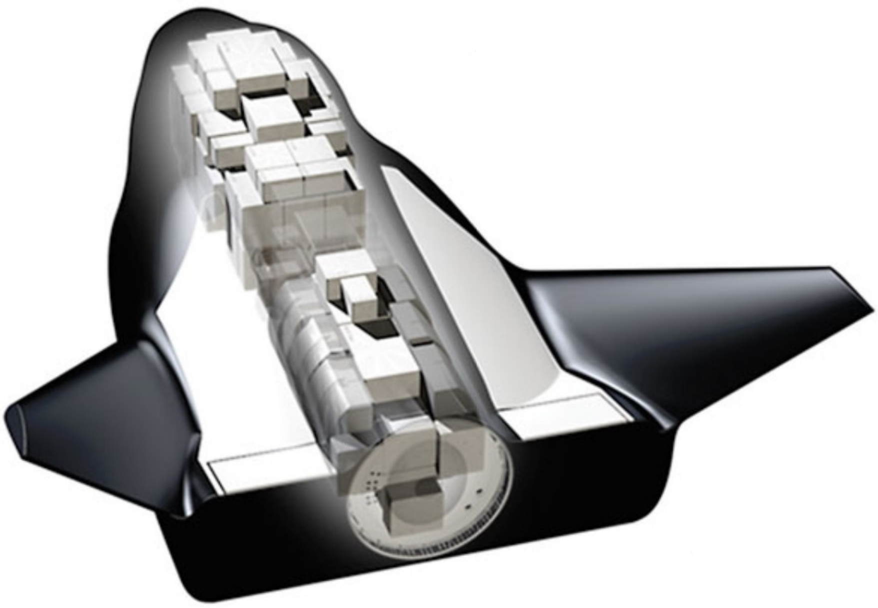


Figure 23: Payload configurations [Credits: Virgin Galactic, Sierra Nevada Corp.]

After these consideration, we can say that for the mission we want to accomplish air launch is the most indicated strategy, since we don't need large ΔV and we don't want to carry large size payload (neither reach the orbit) but take tourists (up to six) on a sub-orbit: all the advantages just discussed can be exploited.

Advantages

- Mobility and deployement advantages
- Minimum launch site requirements
- Potentially reduced environmental impact
- Reduced deltaV to reach the orbit
- Initial altitude and velocity
- Reduced aerodynamic loads on the launch vehicle
- Reduced gravity and drag losses

Drawbacks

- Modification on existing aircraft or development of a new carrier aircraft costs
- Ideal only for small payloads
- Separation event of the launch vehicle from the carrier

Now that we figured out the best take off strategy, me move on in choosing which typology of air launch use. We can identify two kinds: captive on top or captive on bottom. The first one main peculiarities are:

- Possibility to carry a large launch vehicle on top of the carrier aircraft;
- It requires extensive modifications to the carrier aircraft;
- The carried vehicle should have active controls at release from the aircraft and its wings must to be large enough to support it at separation from the carrier aircraft;

As regards instead captive on bottom configuration characteristics:

- Proven and easy separation from carrier aircraft;
- Limits to vehicle size due to under the carrier aircraft clearance limitations and the high cost of carrier modification; alternatively, a new carrier aircraft would eliminate clearance limitations (costs may be greater).

For safety reasons, speaking of a tourists mission, due to the more reliable and simpler release technique of captive on bottom over captive on top, the first is chosen for our mission concept. Other advantages over the captive on top concept are a greater aerodynamic efficiency and an easier accessibility for both crew and tourist as well as on ground personnel for maintenance tasks. Next and final step of this trade off process will be identify the best propulsion strategy for our case of study.

3.4.3 Propulsion Strategy

Hybrid Proposal

The standard rocket propulsion options, the technologies around which all launch systems in use today have been designed, comprise two well defined categories: solid and liquids rocket engines.
Solids tend to be easily stored for considerable periods of time, are less expensive to develop, always available to use. However the great limit is that they cannot be turned off once ignited until they have completed propellant burnout.
On the contrary, liquids allow stop, start, restart and most importantly throttling capability, so they are the most used for launch vehicle main engines. But another kind of propulsion is possible, with intermediate characteristics between solid and liquid propellants; that's why it is called hybrid propulsion. In the following part, we're going to understand why hybrid hasn't been used so far in large number of applications and instead why should be used for our mission concept; analysing and discussing major pros and cons. Essentially a Hybrid rocket engine can be schematized as follows:

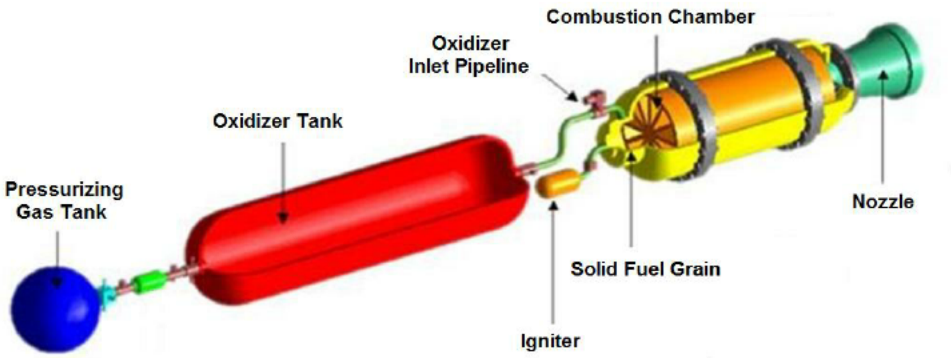


Figure 24: Hybrid Rocket propulsion system scheme

The first difference compared to other systems is the nature of oxidizer and fuel: the first is liquid while the second is solid. Typically we have tank containing the liquid oxidizer, the combustion chamber which is the also the container of the grain solid propellant. A valve regulates oxidizer flow through the chamber. Before reacting with solid propellant, oxidizer is vaporized. So

the total volume of the hybrid motor will be intermediate between a solid and a liquid designed to produce the same total impulse; in fact only the oxidizer needs to be moved to the combustion chamber during operation reducing the number of moving parts compared to an all liquid system.
Generally the liquid propellant is the oxidizer while the solid propellant is the fuel because solid oxidizers are extremely dangerous and lower performing than liquid oxidizers.
The governing equation for hybrid rocket combustion which describes the regression rate law con be expressed as follows:

$$\dot{r} = a_o G_o^n$$

in which appear:

- $\dot{r}$ that is the averaged regression rate;
- The coefficient a_o and the exponent n are propellant dependent constants that are determined experimentally. a_o is the regression rate coefficient, and contains information about grain length; instead n is the regression rate exponent;
- G_o represents the oxidizer mass flux rate.

Comparison with Liquids and Solids engines
Hybrids, in the form of a solid fuel burned with fluid oxygen, embody many of the advantages of solids [17]. In fact these are: lower cost via relatively easy design and fabrication; relative simple compared to all liquid propulsion systems, since half of the pumping and piping as well as the engine have been eliminated. Hybrids are more advantageous than solids in that they are less costly to handle and process since they are not energetic (fuel and oxidizer are mixed long before flight and held together by some sort of rubbery binder material). From a pollution standpoint, hybrid fuels are advantageous because they can easily be formulated to contain only carbon hydrogen, oxygen and nitrogen (just like liquid fuels) and thus produce primarily water, oxides of carbon, hydrogen, nitrogen and so relatively benign species during operation [18] [19]. Instead liquid propellant systems consist of fuel and oxidizer which are stored and handled separately until they reach the combustion chamber in the rocket engine. Because they are stored and handled separately, liquid are less hazardous than solids. The most common liquid fuels are hydrocarbons, while the most common liquid oxidizer is oxygen, which is normally handled as a cryogenic fluid to maximize its density and to limit weight of the tank required to hold it. The explosive hazard for liquid systems is generally lower than that for solids as neither the fuel nor the oxidizer can explode by itself.

The primary combustion products formed during engine operation are water, hydrogen, carbon dioxide, and carbon monoxide. Since the fuel and oxidizer are held separately in the rocket, liquid systems utilize pumps to move the liquids into the engine which consist of the inlets, injector, combustion chamber and nozzle. Starting, stopping and throttling are controlled primarily by varying the pumping rates. There are a large number of moving parts, many moving at very high speeds.

After this overview we can state that hybrids are inherently safer than other rocket designs. In fact, storing the oxidizer as a liquid and the fuel as a solid, contributes to create a design that is less susceptible to chemical explosion than conventional solid and bi-propellant liquid designs. The fuel is contained within the rocket combustion chamber in the form of a cylinder with a circular channel called port hallowed out along its axis. Compared to solids propellant we have some advantages: first of all the fuel can be fabricated at any conventional commercial site and even at the launch complex with no danger of explosion; that's thanks to the non-explosive character of the fuel, which led to safety in both operation and manufacture. Since the beginning of our study, we stressed the importance of safety among all other aspects for a tourist space mission. Thus a large cost saving could be realized both in manufacture and launch operation. Additional advantages over the solid rocket: better specific impulse, throttle-ability to optimize trajectory and the ability to thrust terminate on demand. Besides the products of combustion are environmentally benign unlike conventional solids that produce acid forming gases such as hydrogen chloride.
Compared to liquid rockets, hybrids require one rather than two liquid containment and delivery systems. The complexity is further reduced by omission of a regenerative cooling system for both the chamber and nozzle. Throttling control is simpler because relative to only one propellant stream. In the case of liquid rockets with liquid hydrogen and oxygen we have also hypergolic combustion, that means that substances react instantly.
The theoretical specific impulse of a hybrid rocket is more appropriately compared to a bi-propellant liquid than a solid. The oxidizer can be any of the oxidizers used with liquid bi-propellant engines, N_2O is the most used. In this case, an autopressurized blowdown system is employed, with no need for a pressurizing gas. Furthermore N_2O is not cryogenic as LOX, and so easier to handle and store. Typically, the solid fuel is a polymeric hydrocarbon such as hydroxyl-terminated-poly-butadiene (HTPB), a common solid propellant binder with an energy density comparable to kerosene.
The main drawback of the hybrid is that the combustion process relies on a relatively slow mechanism of fuel melting, evaporation and mixing. In the solid

rocket, the flame is much closer to the fuel surface and the regression rate is typically an order of magnitude larger. As a rough comparison, the regression rate in a solid rocket at a typical chamber pressure can be on the order of 1.0 cm/sec, whereas a typical hybrid using HTPB may have a regression rate on the order of 0.1 cm/sec. To compensate for the low regression rate, a solution can be increasing the burning area. In fact propellant flow rate in the nozzle depends on the burning area of the grain and e regression rate according to the relation:

$$\dot{m}_p = \rho \dot{r} A_b$$

This is accomplished by using a multi-port fuel grain.

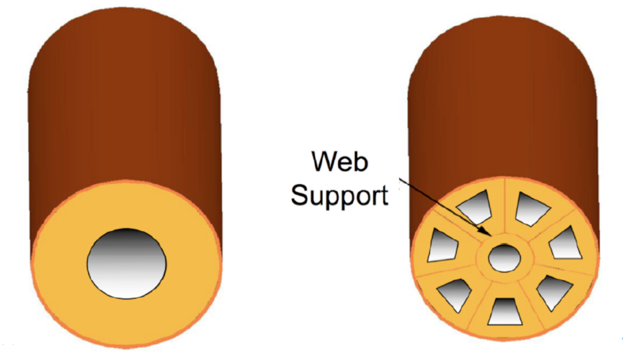


Figure 25: Single and multi-port grain configuration [Credits: Reference n]

The most obvious problem with the multi-port design is that the amount of fuel that can be loaded into a given volume is reduced. Another problem is that it is very difficult to get each port to burn at the same rate. If one burns slightly faster than another, then the oxidizer will tend to follow the path of least resistance leading to further disparity in the oxidizer flow rate variation from port to port.

Used Propellants

As regards hybrid propellants we can do some considerations. The most common fuel is HTPB, that is a synthetic rubber. Excellent mechanical properties enables HTPB to use as a hybrid fuel. Hybrid fuel may contain the addition of metal powder in order to improve performance; the most common is aluminium.

Hydrocarbons might be also used as hybrid fuels; for example paraffin which is solid even in the ambient temperature which simplifies the storage process.

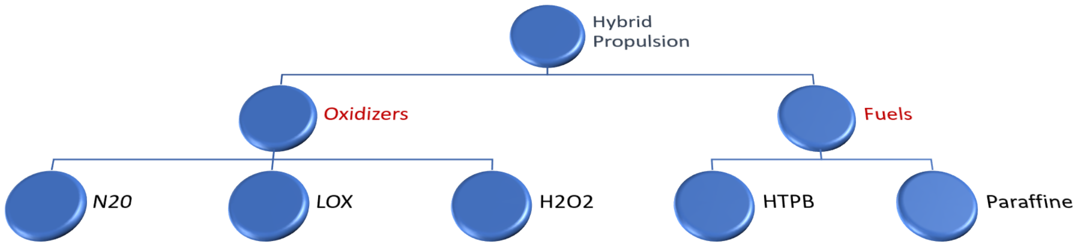


Figure 26: Most used propellants in Hybrid rocket propulsion

The most commonly used liquid oxidizer is liquid oxygen; this applies for liquid rockets but also for hybrids. However liquid oxygen has several disadvantages for hybrid application. First of all, it is cryogenic. Furthermore, a pyrotechnic ignition device is required. The igniter can be used only once; it means that in this case a hybrid motor cannot be restartable (but throttling is possible). But there is an alternative that is gaseous ignition. In this case liquid oxygen should be vaporised before the mixture forms. In this case we have incomplete oxygen vaporisation before the combustion port that causes low-frequency combustion instabilities.
The alternative for liquid oxygen is nitrous oxide (N_2O). Technically it is cryogenic too; but its critical temperature equals $36,6°C$ that allows to store nitrous oxide in liquid phase at the ambient pressure. Besides at $20°C$ the N_2O vapour pressure is 5,85 MPa. This makes possible to eliminate additional pressurization devices in the oxidizer feed system.
Another very interesting oxidizer for hybrid application is hydrogen peroxide (H_2O_2). This propellant decomposes both catalytically and thermally on water vapour and oxygen. The decomposition adiabatic temperature ranges from 900 to 1100 K, depending on concentration (commonly used 80-98%). These values are highly above ignition temperatures of polymeric hybrid fuels. It means that utilization of hydrogen peroxide makes possible to eliminate additional ignition devices. Furthermore, hydrogen peroxide itself as well as its decomposition products are environmentally friendly.

Oxidizer	Fuel	O/F	Specific Impulse [m/s]
LOX	RP-1	2,5	3450
H2O2 98%	HTPB	6,6	3200
LOX	HTPB	2,5	3450
N2O	HTPB	8,5	3050

Figure 27: Different combinations characteristics

At the end of this paragraph it's possible to summarize what we said in a chart, in order to have a clear glance of main characteristics of hybrid propulsion:

Advantages

- For the oxidizer (N2O) an autopressurized blowdown system is used, turbopumps are not needed
- Combustion chamber is the solid fuel tank itself
- N2O not cryogenic as LOX
- Throttling available like in liquid rockets
- Green combustion
- Safer than liquid propulsion (not hypergolic propellants) and than solid ones

Drawbacks

- Limited burning due to limited regression rate (not really a problem in suborbital mission)
- Less performant than liquid rockets
- Combustion instability issues

As we can observe, there are many advantages for utilising hybrid propellant rockets: in particular regarding safety, complexity and performance matters. For a sub-orbital flight with tourists, hybrid propulsion is the most suitable choice. It's possible to save weight, have throttling and have satisfying performances for a mission that has not to reach the orbit (single port design is used for fuel grain). Another approach would have been used for a mission departing from ground and which had to go into orbit; in that case, burning phase would have last several minutes (in our case maximum 60 seconds). In this scenario, regression rate and combustion stability issues must be taken into consideration.
In conclusion, main physical and chemical properties of both oxidizer and fuel for hybrid propulsion are reported:

Property	HTPB	N2O
Physical state	Liquid	Gas
Appearance	Viscous	Liquid Gas
Color	Colorless to light yellow	Colorless
Melting Point	NA	-90,81°C
Boiling Point	>300°C	-88,3°C
Flash Point	>205°C	NA
Relative density	0,9	1,226
Viscosity dynamic	5000 mPa.s	0,014 mPa.s

Figure 28: Oxidizer and fuel properties

3.4.4 Figures of Merit Evaluation

We discussed about three different figures of merit for each configuration: safety, cost and complexity. To identify in a more formal way the best concept we can conduct a trade off based on weight factors assigned for each FoM [20]. As regards safety the following relation is used:

$$Safety = S_b + \left(\sum_{i=1}^{n_{stages}} k_{ei} e_i \right) - k_{t1} \left(\sum_{i=1}^{n_{stages}} t_i \right)$$

in which there are:

- S_b is the basic level of safety (equal to 1);
- n_{stages} is the overall number of stages of the configuration;
- i is the index representing each single stage;
- e_i is a variable that indicates the presence of the propulsive system in the i-esim stage: it's equal to 1 if the i-esim stage hosts a propulsion system, it's equal to 0 otherwise;
- t_i is a variable that indicates the presence of the propellant system in i-esim stage: it's equal to 1 id the i-esim stage hosts a propellant system, it's equal to 0 otherwise;
- k_{ei} is a weighting factor that shows the impact of the propulsive system of each stage on the safety FoM;
- k_{t1} is a weighting factor that shows the impact of the propellant system on the safety FoM.

The same thing applies for cost and complexity, with analogous relations. For cost we have:

$$Cost = C_{b2} n_{stages} \cdot \left[1 - (1 - j) \left(\frac{1}{n_{stages}} \right) \right] + k_e \left(\sum_{i=1}^{n_{stages}} e_i \right) + k_{t1} \left(\sum_{i=1}^{n_{stages}} t_i \right)$$

where:

- C_{b2} is the basic level of cost (equal to 1);
- k_e is a weighting factor that shows the impact of the propulsive system on the cost FoM;

- k_{t1} is a weighting factor that shows the impact of the propellant system on the cost FoM;
- j is a *switching* variable that indicates the presence of already developed stages: equal to 1 if all stages have to be properly designed and developed, 0 is the first stage is already existing;
- n_{stages}, i, e_i and t_i have the same meaning.

Finally, for complexity FoM, the relation is:

$$Complexity = C_{b1} n_{stages} \cdot \left[1-(i-j)\left(\frac{1}{n_{stages}}\right)\right] + k_e \left(\sum_{i=1}^{n_{stages}} j_i e_i\right) + k_{t1} \left(\sum_{i=1}^{n_{stages}} t_i\right) + j k_{t2} \prod_{i=1}^{n_{stages}} t_i$$

where:

- C_{b1} is the basic level of complexity (equal to 1)
- k_e is a weighting factor that shows the impact of the propulsive system on the complexity FoM;
- k_{t1} is a weighting factor that shows the impact of the propellant system on the complexity FoM;
- k_{t2} is a weighting factor that shows the impact of the presence of cross-feed on the complexity FoM (not present in our configurations);
- j_i is a *switching* variable that indicates the development status of propulsion systems in already developed stages: j_2 is always equal to 1 meaning that the second stage propulsion system should be ad-hoc developed, while j_1 is equal to 1 if the propulsion system is related to a first stage that should be developed, equal to 0 if the first stage is already existing;
- n_{stages}, i, e_i and t_i have the same meaning.

Safety, cost and complexity indexes are evaluated for each configuration, then a final Trade-off value index is calculated with a relation that takes into account each FoM:

$$T.O = \frac{K_1 \cdot safety}{K_2 \cdot complexity + K_3 \cdot cost}$$

where K_1, K_2, K_3 are weighting factors for every FoM.
Varying these factors we decide which FoM are the most important, and different trade off indexes are obtained. Therefore it's possible to rank them and

pick the configuration with the highest index value.
First we have to choose appropriate weighting factors for each FoM relation: they will have different values depending on the configuration. They will range from a maximum value of 0,75 for a high impact, to 0,25 for a low impact.

	SSTO	Launcher	Carrier
Safety	Ke = 0,75	Ke1 = 0,75	Ke1 = 0,5
	Kt1 = 0,75	Ke2 = 0,25	Ke2 = 0,75
		Kt1 = 0,5	Kt1 = 0,33
Cost	Ke = 0,75	Ke = 0,5	Ke = 0,25
	Kt = 0,75	Kt = 0,5	Kt = 0,25
Complexity	Ke = 0,75	Ke = 0,75	Ke = 0,25
	Kt1 = 0,75	Kt1 = 0,75	Kt1 = 0,25
	Kt2 = 0	Kt2 = 0	Kt2 = 0

Figure 29: Weighting factors for each FoM

On the base of the considerations we did previously we selected appropriate values for each weighting factor. Speaking of safety we have highest values for SSTO configuration, as its propulsion system is still in developing phase and so it can led to safety issues for participants; in the case of launcher he have high impact for the first stage, while for carrier configuration the spaceplane itself hosts an important propulsion system, right where the occupants are.
As regards cost, mostly we have high impact on the SSTO configuration for development cost related to the propulsion and propellant systems.
In the end, for complexity FoM, the lowest values are for the carrier configuration, as it employs common turbofan engines for the first stage and an hybrid rocket system for the second one. No cross feed system is expected in each configuration, so the factor K_{t2} is equal to zero.
Using the relations we explained before, FoM index for every configurations can be calculated:

	SSTO	Launcher	Carrier
Safety	1	3	2,91
Cost	2,5	3	3
Complexity	2,5	3,25	3

Figure 30: FoM index for each configuration

The final step is to evaluate the trade off index for each configuration: varying the Ks coefficients we can decide what importance to attribute to the single FoM, and see as a consequence what is the most suitable for our purposes.

	K1	K2	K3	SSTO	Launcher	Carrier
Case 1	0,33	0,33	0,33	0,20	0,480	0,485
Case 2	0,5	0,25	0,25	0,40	0,960	0,970
Case 3	0,25	0,5	0,25	0,1330	0,3158	0,3233
Case 4	0,25	0,25	0,5	0,1330	0,3243	0,3233

Figure 31: Trade off indexes for different cases

As we can see in almost every case of study the best configuration is the Carrier and Spaceplane. This happens attributing same value for every FoM, but also giving more importance to safety (which is the best choice for a tourist mission) and in second place to complexity, as in carrier configuration we employ a relatively simpler propulsion and propellant system.
Launcher is the best solution but only attributing more importance to cost: that's why in this case while launcher is an already existing and consolidated technology, carrier has to be developed for this specific mission.
As we consider safety the main driver in this trade off, carrier configuration is selected.

3.4.5 Case of study: chosen configuration

After this trade-off it's possible to focus on our case of study that will be our reference in the following chapters. We chose, through a logical process the best staging, take off and propulsion strategy:

- Two stage configuration;
- Air-Launching Strategy captive on bottom;
- Hybrid Propellant Rocket propulsion system.

Of course this concept is currently reflected in the Virgin Galactic SpaceShipTwo. Now that we have selected it as our ideal concept, it's appropriate to identify main subsystems for spaceplane segment, that represents the second stage of the vehicle, by doing a product breakdown structure.

Figure 32: SpaceShipTwo main components [Credits: Virgin Galactic]

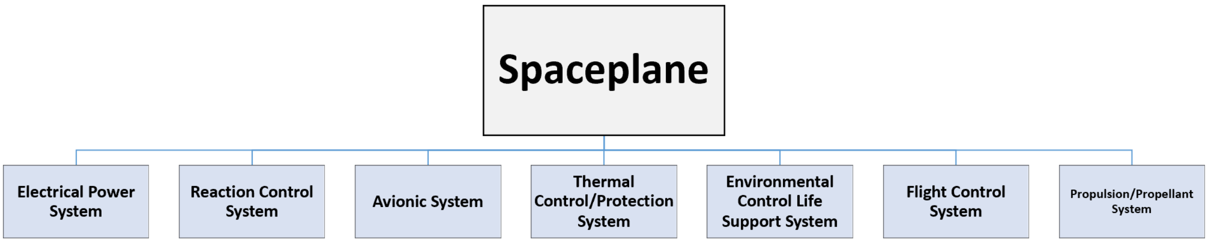


Figure 33: Spaceplane systems breakdown structure

It can be useful describe the main tasks of each system:

- *Electrical power system* (EPS) for energy storage, energy conversion from some source into electrical power (batteries), power regulation, distribution and control throughout the spaceplane. The obvious functions of a spacecraft power system are to generate and store electric power for use by other spacecraft subsystems. Power system must control, condition, and process the power received from the primary source to comply with the needs of the spacecraft systems. It also must provide protection to other subsystems against reasonably likely failures. During normal operations, the power system must accept commands from on board sources and provide telemetry data;

- *Reaction Control System* that uses thrusters to provide attitude control, and sometimes translation. Used to provide stable attitude control. An RCS is capable of providing small amounts of thrust in any desired direction or combination of directions. An RCS is also capable of providing torque to allow control of rotation (roll, pitch, and yaw). Typical use in suborbital flight is at trajectory apogee to point the cabin towards the Earth for better view;

- *Avionic System* for command and data handling functions. The first means that ObC receives, validates, decodes and distributes *commands* to other spacecraft systems; in the second place it gathers, processes and formats spacecraft housekeeping and mission date for downlink. Its task are also on-board communications and to/from ground segment as well. It shall also provide exchange of telemetry data with the ground;;

- *Thermal Control System*(TCS), which has to function to guarantee both an acceptable global energy balance and local thermal properties, and also to maintain all spacecraft and payload components and subsystems within their required temperature limits for each mission phase;

- *Thermal Protection System* that provides defence for the spacecraft by shielding it from extreme heat sources, typically referring to the atmospheric re-entry heat generation. The main task is to protect the spacecraft's structure and interior, in particular the crew compartment.

- *Environmental Control and Life support system* has the function of keeping the crew alive, providing a physiologically acceptable environment for the spacecraft. For a suborbital mission essentially it provides atmosphere monitoring: it controls pressure, temperature and humidity, it removes CO_2 and traces contaminants; it ventilates and monitors the atmosphere condition. Optionally it can provide water for drinking; food (it has to be stored and prepared), and provide waste collection and processing.

- *Flight Control System* which purpose is to convert pilot commands into movement of control surfaces in order to control the spacecraft along and around three axes. In this particular configuration, release mechanism for separation from the carrier aircraft can be considered part of this system. In the end, in the SpaceShipTwo concept another important element is the feathering system which is activated at the apogee of the trajectory, acting as an aero brake in order to start re-entry phase.

- *Propulsion System/Propellant System*, diffusively analysed in the previous paragraph, its main task is to provide the necessary ΔV to reach the expected altitude.

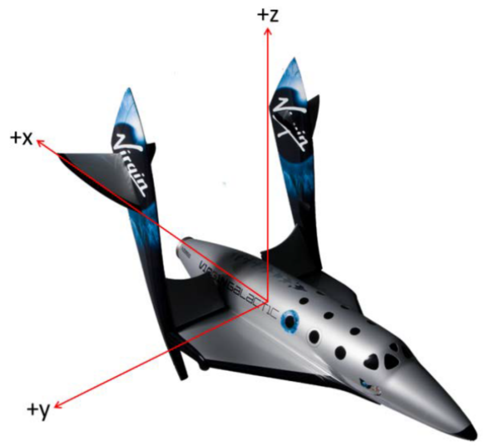
3.5 Alternative mission concept: Scientific Payload

In the previous part we focused only on a tourist mission, and it was a driver for the trade-off process. Alternatively, we can think about sub-orbital flight as a potential platform to perform scientific experiments in unusual condition: in fact, during the flight, up to 5 minutes in microgravity can be experienced. So, it would be useful to test and validate scientific equipment and payload, in anticipation of long duration mission on board the ISS [21].
However, as we saw with mass fraction considerations, the chosen configuration may be the best solution for tourism, but for scientific purposes it results in some way limited by payload size mass limitation for payload experimentation. Anyway there are several advantages in using such a vehicle: in particular we refer to SpaceShipTwo in the following considerations. One of the key performance attributes could be the possibility to have frequent and responsive flight access, allowing maximum flexibility and series measurements taken on several flights in rapid succession. Besides, quick recovery of payloads is guaranteed, with pre-flight and post-flight access within hours of a launch.
Affordability is demonstrated by prices that are highly competitive with parabolic flights and sounding rockets, and certainly much cheaper than orbital flights. There is also the possibility to conduct observation of the upper atmosphere through large windows to which experiments can be mounted.
Especially compared to sounding rockets, g-loading is dramatically gentler. Being designed to carry human beings into space, gravity loading on board are quite gentle compared to other launch vehicles.

Platform	Microgravity Time	Microgravity Quality (g)	Maximum g-load	Flight Frequency
Drop Towers	2–10 sec	10^{-6}	65	Daily
Parabolic Aircraft	~20 sec	10^{-2}	2	~ 50 per year
Sounding Rockets	5–20 min	~10^{-5}	21	~ 20 per year
SpaceShipTwo	***3-4 min***	***10^{-3}-10^{-5}***	***~5***	***Daily***

Figure 34: Comparison of Microgravity Research Platform [Credits: Virgin Galactic]

It may be important to differentiate between *flight and ultimate acceleration.* The first are defined as the maximum expected flight loads during all phases of flight.



Axis	+	-
N_x	+2.8 g	-2.6 g
N_y	+1.9 g	-1.9 g
N_z	+8.1 g	-2.0 g

Figure 35: SpaceShipTwo Flight Accelerations [Credits: Virgin Galactic]

Instead ultimate acceleration are defined as the maximum expected flight loads during a vehicle emergency or crash landing scenario. These loads are:

Axis	+	-
N_x	+4.2 g	-9.0 g
N_y	+3.3 g	-3.3 g
N_z	+14.6 g	-3.0 g

Figure 36: SpaceShipTwo Ultimate Accelerations [Credits: Virgin Galactic]

A standard SpaceShipTwo payload flight will fly a total of five payload racks with a single seat for a Payload Specialist. His duty are to monitor payload systems, interact with payloads as required and handle payload emergencies.

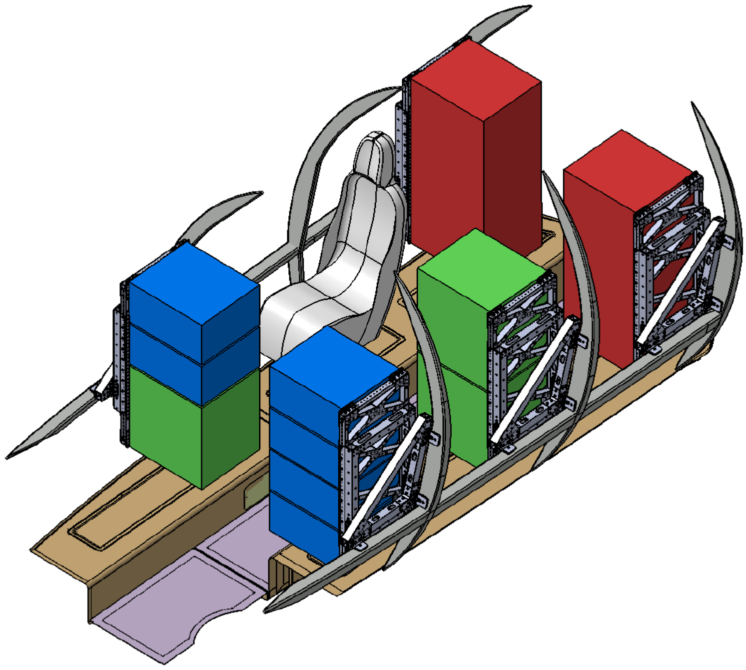


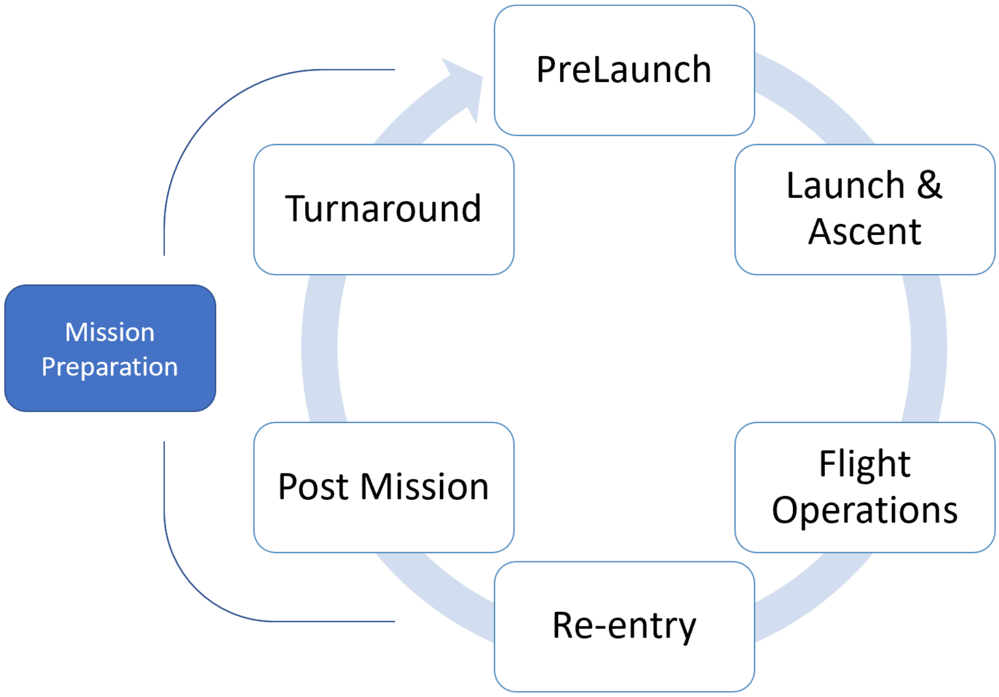
Figure 37: Cabin Interior for a Scientific Mission [Credits: Virgin Galactic]

3.6 Suborbital Mission Overview

We obtained a specific configuration through a trade off process. At the end of this chapter it's appropriate to better define the mission concept; in particular for our suborbital mission the following capabilities have to be established:

- transporting passengers for touristic purposes safely to an altitude of at least 100 Km over a parabolic flight to let them experience microgravity environment;
- HTHL capabilities that do not rely on rocket propulsion for take off and landing;
- alternatively exploit the suborbital platform to perform scientific experiments in microgravity installing payload on board instead of carrying tourist.

Mission concept can be described as a closed loop process in which all the main phases are considered:



The Mission Preparation phase can be considered as the first part of the mission and it includes:

- Postflight inspection and checkout (from previous flight)

- Vehicle configuration preparation, if tourist or scientific;
- Eventual Payload preparation and integration;
- Ground segment configuration preparation;
- Crew and ground personnel training (including nominal and contingency missions simulation) as well as passengers;
- Completion of process verification and certification for flight readiness;
- Functional test are conducted.

Afterwards there is the Pre Launch phase which includes:

- All the activities required to prepare the vehicle and the ground segment for flight;
- A preflight checkout to verify the correct behaviour of all the subsystems and equipment (for flight and for ground as well);
- Preflight runway operations;
- Vehicle fuelling;
- Depending on the mission, if scientific or tourist, experiments have to be installed or passengers boarded, as well as crew members.

Launch-Ascent operations consist in:

- Acquisition and assessment of external condition and weather condition to allow go for launch within the system performances and safety constraints;
- Continuous monitoring of the vehicle telemetry before and during launch, as well as during ascent, in order to assess performances and safety conditions;
- Continuous tracking of the vehicle;
- Monitoring crew/flight participants conditions and continuous voice coordination with the crew;

Flight Operations phase follows the shutdown of the rockets with consequent start of the ballistic part of the flight; it includes:

- Continuous monitoring of the telemetry to assess the status of the vehicle;

- Continuous tracking and monitoring of the trajectory and its propagation for re-entry assessment;
- For a scientific mission: experiment execution and relative telemetry acquisition, monitoring and control;
- Passengers microgravity experience, monitoring of passengers and crew conditions.

Reentry operations foresee:

- Continuous monitoring of the telemetry to assess the status of the vehicle;
- Continuous assessment and forecast of the vehicle trajectory, also in case of planned controlled re-entry abort;
- After landing, make sure that the vehicle is safe;
- Continuous monitoring of the crew and passengers condition and their exiting after landing.

Post Mission Operations include:

- Transportation of the vehicle in the turn-around area;
- Storage and consolidation of the collected data;
- For scientific flight: experiment removal from the vehicle;
- Download crew and passengers items;
- Mission performance assessment.

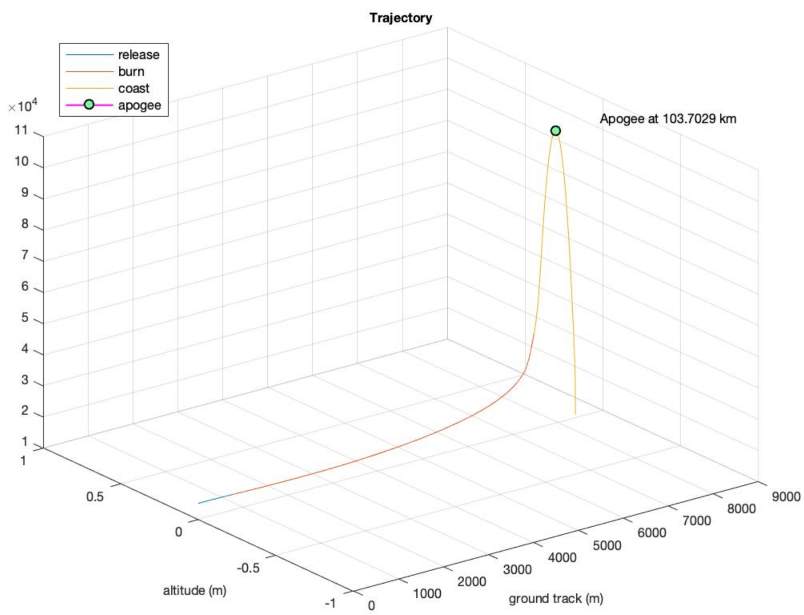
In the end the turnaround phase consists in:

- Vehicle physical inspection;
- Maintenance activities execution;
- Vehicle specific checkout;
- Substitution and retest of critical components (as landing pad and nozzle)
- Final preparation for next flight.

To conclude the chapter we can now think of a possible mission profile, both for a tourist and scientific suborbital flight. Simulations are conducted assuming appropriate values for performance and geometry parameters: trajectory obtained is a good approximation of real models.
For a tourist mission the following values are assumed:

Tourist Mission Profile	
Mass	13000 Kg
Release Altitude	15200 m
Carrier velocity at release	128,61 m/s
Release duration	6 s
Burn duration	60 s
Maximum value of thrust	378 kN
Minimum value of thrust	222 kN
Fuel mass	6800 kg
Apogee	103,70 Km
Perc. of Maximum Thrust	80%

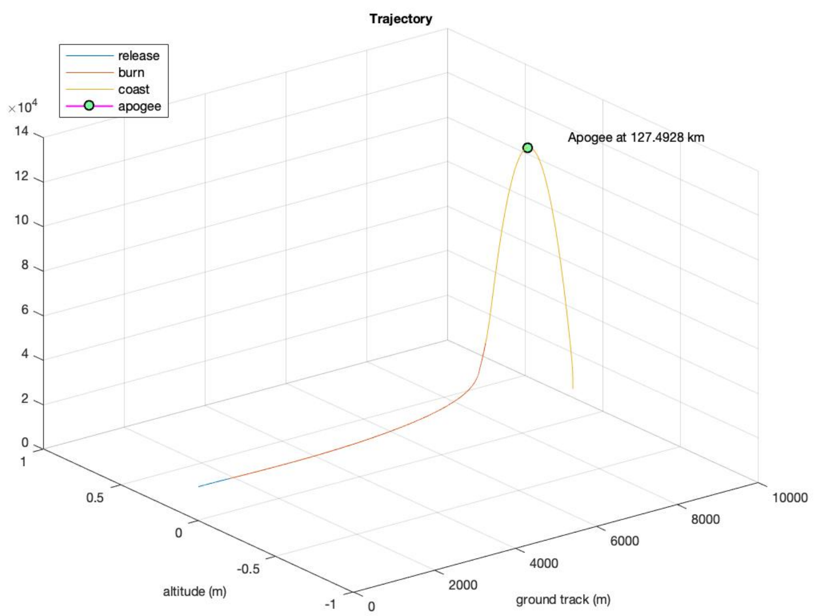
Figure 38: Suborbital tourist mission profile and data



While for a scientific mission the only parameter changing is the percentage of maximum thrust used during the burning phase, in order to get to an higher altitude and take advantage of a longer time in microgravity:

Scientific Mission Profile	
Mass	13000 Kg
Release Altitude	15200 m
Carrier velocity at release	128,61 m/s
Release duration	6 s
Burn duration	60 s
Maximum value of thrust	378 kN
Minimum value of thrust	222 kN
Fuel mass	6800 kg
Apogee	127,49 Km
Perc. of Maximum Thrust	90%

Figure 39: Suborbital scientific mission profile and data



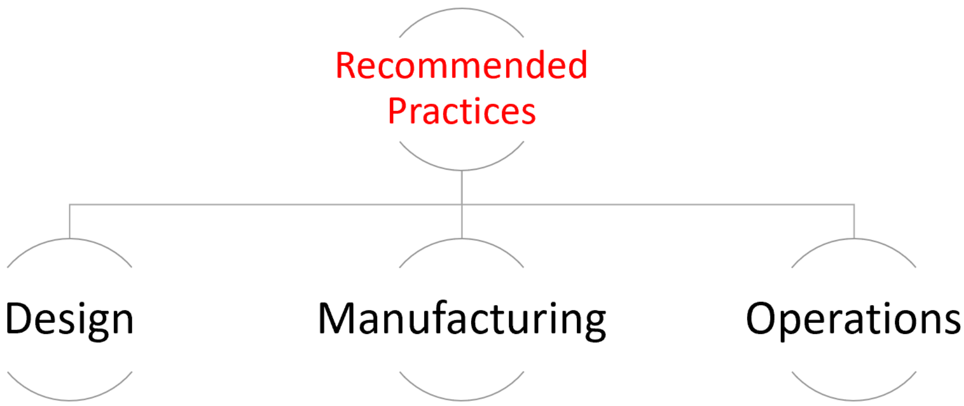
4 Flight occupants safety: impact on design and training

Until now we've been focusing on finding the most suitable configuration for a tourist suborbital mission, starting from the definition of a mission statement, then employing a trade off process based on advantages and drawbacks of different concepts and comparison between them.
The configuration we chose, a carrier and spaceplane, is the one that Virgin Galactic will employ to take tourists in the next decade. As we're talking of a totally new kind of transportation, as space is opening its doors to regular people and not professional astronauts, a careful safety assessment is compulsory. In the next years this experience will be available not only in the United States, but also in Europe and maybe in other continents, as space tourism market will be *more accessible* and tickets to space *more affordable.* In particular, in the South-East of Italy, Grottaglie Airport has been selected as a future national Spaceport for aerospace experimentation and suborbital launch.
Therefore Italy is enabling the possibility of establish suborbital initiatives based on a designated spaceport. However Italy is currently lacking of a regulatory system to allow such activities. As American initiatives for suborbital flight are based on the FAA (Federal Aviation Administration) regulatory system, a first approach can be evaluating the differences compared to the Italian context. For instance, while Nex Mexico (where currently Virgin Galactic Spaceport is) is a mostly desert country, with a low population density, in Italy is quite the opposite.
One of the major differences is that the FAA suborbital regulatory system does not deal with safety of occupants but has only released a set of recommendations. Instead the Italian approach is to regulate also the safety of occupants. This chapter is an initial attempt of screening such regulation and try to incorporate them within the selected suborbital flight systems and operations.

4.1 FAA Recommended Practices for Human Space Flight Occupant Safety

This document is a set of practices that the Federal Aviation Administration (FAA) Office of Commercial Space Transportation believes are important and recommends for commercial human space flight occupant safety [22]. They are meant for suborbital and orbital launch and reentry vehicles. Flight occupants in a space flight include flight crew and space flight participants.
THe application of these recommended practices will ensure that occupant safety is considered throughout the life cycle of a space flight system, and that occupants are not exposed to avoidable risks.

In the document, three levels of care are addressed. First, the occupants of commercial human space flight vehicles should not experience an environment that would cause a serious injury or fatality, from the time they are exposed to vehicle hazards prior to flight until after landing when they are no longer exposed to vehicle hazards. Second, the level of care for flight crew when performing safety-critical operation should be at the level necessary to perform those operations. It is assumed that each member of the flight crew is safety-critical, and that space flight participants may be called upon to perform limited safety critical tasks, such as emergency egress and restraining themselves in their seats. In the end, the third level applies to emergencies, during which occupants should have a reasonable chance of survival.
The document deals with three main subjects: Design, Manufacturing and Operations related to the space flight. Mostly we're going to focus on the first part, in which important aspects for our purposes are explored: Human needs and accommodations, human protection and his integration with the vehicle, system safety. The last block relative to operation is also important to us as it gives some useful indications and considerations about Medical conditions and training.



From the list of practices we picked the most interesting ones from a regulatory standpoint in relation to flight participants to a suborbital spaceflight. Considerations will be done about each practice.

4.1.1 Design Related Practices

Atmospheric Conditions
The importance of a breathable and habitable atmosphere inside the cabin is paramount for a tourist flight. About this subject the practices say that:

- The vehicle should provide atmospheric condition to all occupants adequate to protect them from serious injury and allow safety-critical operation to be performed;
- The flight crew or ground controllers should be able to monitor and control the atmospheric conditions such as the composition of the atmosphere, its pressure, temperature and humidity, possible presence of contaminants like particulates, guarantee ventilation and circulation.

It is important to keep into account all this things: in fact occupants may become ill or incapacitated if the habitable environment is either contaminated or otherwise degraded. Furthermore, an ill or incapacitated occupant may divert the flight crew's attention from the performance of safety-critical operations, thus endangering occupant safety. Problems can rise for example due to a low oxygen partial pressure, hazardous concentrations of contaminants of high humidity. Therefore, the capability to monitor and control these atmospheric conditions is necessary to protect occupants from harm.

Human Protection and Human/Vehicle Integration: Physical Considerations
In this section is discussed how to prevent injuries to crew or flight participants related to: accelerations, vibration, radiation, noise exposure. Another document, named *Medical Issues for Occupant Safety* regarding all these aspects with a deeper approach, will be discussed later.

Medical Equipment and Supplies
The vehicle should have first aid and medical equipment and supplies for treatment of injuries or medical emergencies that might occur during flight, consistent with the mission and the number of occupants. In the case of suborbital mission, a flight operator may be able to very quickly provide medical assistance due to the very short duration of flight. However, in the case of Virgin Galactic mission, an on board doctor or medical operator is not expected; so basic training for flight participants will include also first-aid techniques and procedures.

Fire Event Detection and Suppression
Of course one of the most dangerous event that could happen in space is a fire. About this FAA recommends that:

- the system should have the ability to detect a fire event within the habitable volume and alert the occupants;
- the vehicle or an occupant should have the ability to extinguish a fire in the habitable volume.

In fact, in enclosed spaces, fire significantly threatens occupant safety; and alerting them to the presence of fire allows for quick action to mitigate the hazardous effect. Automatic detection is desirable, for example with smoke detectors. As regards fire suppression an integrated system can be used, or at least portable fire extinguishers.

Emergency Response to Cantaminated Atmosphere
In order to respond to a contaminated atmosphere, the vehicle should provide equipment and provisions to limit occupant exposure to the contaminated atmosphere such that occupants are protected from serious injuries and safety-critical operation can be performed successfully. A good strategy would be to employ self-contained breathing apparatus to protect occupants from the hazard and allow the flight crew to manage the emergency.

Emergency Response to Loss of Cabin Pressure Integrity
In the event cabin pressure integrity is lost, the vehicle should be properly equipped to prevent incapacitation of flight crew and serious injury of occupants by providing:

- Enough pressurant gases to maintain cabin pressure, or
- A pressure suit or other equivalent system that makes available environmental control and life support capability for the occupants.

As we know Space is an harsh environment, characterized by extremely low pressures and wide ranging temperatures; that's why protection is needed for life in the cabin to be sustained. With an improved, reliable and redundant environmental control and life support system, the use of emergency systems such as pressure suits may not always be required. In the case of SpaceShipTwo, cabin atmospheric condition are the equivalent of 2000 m of altitude, a choice similar to the one done on conventional aircraft. Nevertheless, pressure suits and breathe masks with oxygen supply for flight participant are desirable on board and ready to use in emergency situations or in the most critical phases of the mission such as burning and reentry phases.

Manuel Override of Automatic Functions
The system should allow the flight crew or ground controllers to manually override any automatic safety-critical function, provided the override of the function will not directly cause a catastrophic event. To goal is to prevent that automatic functions could have undesirable effect and result in serious injury to the occupants. Allocation of specific override capability to the flight crew, ground controllers, or both, can depend on the vehicle design and operations. For a suborbital mission profile, where different phases follow each

other in a relatively short time, override capability allocation to the flight crew is preferable.

Protection From Inadverted Actions

No single inadvertent flight crew or ground controller action should result in an event causing serious injuries to occupants.

Inadvertent actions or errant switch activation could occur due to a number of factors such as limited crew experience, ambiguous procedures, the flight environment, a stressed operational environment, and inadvertent bumping of controls.

To stress the importance of this recommendation, it's worth to quote e recent episode in which SpaceShipTwo was involved in 2014. During a flight test the vehicle experienced an anomaly 13 seconds after release during burning phase that resulted in the destruction of the vehicle and the death of the copilot, while the pilot survived after successfully parachuting to the ground. The main objective of the mission was to test the feathered re-entry system under supersonic conditions [23]. In the feather down position a pair of feather lock hooks were engaged at the leading edge of the boom to provide the structural integrity required during the transonic region (conventionally from 0.8 to 1.2 Mach), in which large up loads on the tail during powered flight would otherwise overpower the actuators and cause the feather system to extend without any additional pilot action.

Normal extension of the feather system requires a two step sequence of crew actions:

- Feather Lock Handles on UNLOCK position: to disengage the feather lock hooks from the tail booms and enable rotation of the system. When accomplished at 1.4 Mach or greater, the feather system remains retracted due to a sufficient closing pre-load from the feather actuators and tail-down aerodynamic loads;

- Feather Handle on EXTEND position: to command the feather system into extended position. According to the checklist this step has to occur after rocket motor burn out while the vehicle is in space, just prior the apogee.

The probable cause of the accident was the copilot's unlocking of feather locks at 0.92 Mach, before reaching 1.4 Mach. At this speed, after unlocking the system, lift from the horizontal tails well exceeds the feather actuator's ability to prevent a rapid aerodynamic extension of the feather system. These forces caused the feather to rapidly extend without executing the second step of nominal extension.

Figure 40: Feather unlock system

This premature extension imparted over 9g's of pitch up acceleration forces on the spaceship, resulting in its in-flight breakup.
One of the contributing causes was identified in the fact that the Feather Lock system did not have an automatic mechanical inhibit to prevent premature movement of the feather system.
As a result a recommendation by Virgin Galactic after this accident was the implementation (already accomplished) of an automatic mechanical inhibit to prevent unlocking or locking the feather locks during safety-critical phases of flight.

Emergency Survival Equipment for over water Flight
The vehicle should include emergency survival equipment that provide reasonable chance of survival of all occupants for post landing emergencies. Since over water flight is expected, it should include: first aid tools, floatation device, signaling equipment, navigation and survival tools.

Recommendation	Implementation Status	Comments
Control & Monitor Atmospheric condition	Unknown	Composition, pressure, temperature, humidity, cantaminants, provide ventilation
Protection against cantaminated atmosphere	Unknown	Self-contained breathing apparatus can be used
Acceleration, vibration, radiation & noise protection	Implemented	Check Medical issues for Suborbital spaceflight
Medical assistance	Not Impl.	On board doctor not expected
Fire detection & Suppression	Unknown	Smoke detectors and integrated fire suppression system are desirable (or at least portable fire estinguishers)
Cabin pressure integrity redundance	Not Impl.	Pressure suits & breathe masks with Oxygen supply for flight participants are desirable
Manual Override & Protection from inadverted actions	Implemented	After 2014 accident
Emergency Survival Equipment for over water Flight	Unkown	First aid, floatation device, signaling and navigation equipment

Figure 41: Design related recommandations

4.2 Medical Issues for Suborbital Flight Occupants

In this section we will define some medical standards for suborbital space flight participants and suborbital crew members, describing the environment during a suborbital space flight and then discussing some mitigation strategies to lower medical risks. Issues deriving from suborbital flight are mainly related to: acceleration, microgravity, cabin environment, vibration, radiation and noise [24].

As regards accelerations, medical concern exist with the application of sustained gravitoinertial forces to the human body as a consequence of space launch. Common consequences of such an event are neurovestibular, cardiovascular and musculoskeletal problems. Exposure to either +Gx or +Gz can have an impact on pulmonary function resulting in hypoxemia, airway closure and atelectasis. To avoid the potential for compromising cardiovascular and neurological function, acceleration forces are preferably applied in the +Gx direction, as an individual is more tolerant to +Gx acceleration, and with the heart and brain located at approximately the same level within the acceleration field there is less risk for acceleration induced loss of consciousness (G-LOC).

That's why the vehicle should be designed to limit occupant exposure to transient and sustained linear and angular acceleration such that occupants are protected from serious injuries and safety-critical operations can be performed successfully.
To have some numerical limitation we may refer to the acceleration envelope recommended by the IAA for commercial aerospace vehicles: it says that we should not exceed +3Gz (-2Gz), ±6Gx and ±1Gy. These levels are well tolerated by the human body if experienced gradually. To compare this numbers with real values, SpaceShipTwo acceleration peak during engine boost is 3.8 +Gx, with a brief spike up to +3.8 Gz as the vehicle rotates to a nose high attitude. On reentry phase, +Gz will experienced by the crew members, while flight for flight participants it can be converted along the Gx axis thanks to the possibility of tilting back the seats. Not important consequences related to microgravity exposure will be noticed, as it will last only few minutes for a suborbital fligh. The same thing applies for cardiovascular effects.

Suborbital flight vehicles will operate at such high altitudes that there is a potential risk for an inflight decompression to very low or even absent atmospheric pressures. Such an exposure could result in hypoxia or even death among the occupants. So pressure suits could be used as an additional safety option to cope to a possible depressurization hazard. This is very important for a tourist mission because otherwise the crew would be completely reliant on cabin integrity being mantained as there is no redundancy and depressurization would certainly be a catastrophic event.
The cabin atmospheric composition (O_2 and CO_2) will also need to be controlled. In particular fire detection and suppression system will limit the maximum O_2 concentration. A redundant backup O_2 supply will probably be available. Besides air circulation must avoid CO_2 accumulation.

Suborbital mission profile usually reaches a peak altitude of 350000 ft (116 km). As we still have some protection by the atmosphere, radiation levels at this altitude should be less than 15 microSv/hr, for a total duration of less than 30 minutes of exposure. The occupational exposure limit recommended by the International Commission on Radiological Protection (ICRP) for commercial aircrews is 20 mSv per year, averaged over 5 years with a maximum in any one year of 50 mSv.
For the most part, there is no concern regarding the acute effect of ionizing radiation because of the short duration of the flight and the fact that launch can be controlled depending upon atmospheric condition (avoiding for example

periods with intensive radioactive activity). However all flight crew members are recommended to wear personal dosimeters to track an individual's accumulated dose.

On a suborbital flight noise is mostly generated by the propulsion system, which is then transmitted through the whole vehicle. As a spacecraft is an enclosed space, the noise is reflected multiple times off the walls, floor and ceiling. These noise levels are of short duration but can also be quite intense, causing reduced visual acuity, vertigo, nausea, disorientation, ear pain, headache and of course degradation in pilot performance. Noise can also interfere with normal conversation, making difficult to understand verbal communication. Also, it can be a distraction and can increase the number of errors. That's why NASA set a maximum noise level of 105 dB. Auditory protection is required during a suborbital flight launch at least by the crew, in order to prevent sensorineural hearing loss and to facilitate communication. Another countermeasure would be to cover the cabin with a soundproofing material panel.

As regards vibrations, they are mostly associated with launch and aerodynamic loading. Symptoms commonly elicited to vibrations include general discomfort, fatigue, headache, and back pain. Manual tracking errors increase in the 2-16 Hz range causing impaired psychomotor coordination. As a reference SpaceShipOne experienced thrust oscillations at 5-10 Hz which generated an impressive amount of vibration. It's important to dampen these vibration due to the propulsion system to be out of the indicated range.

Limitation	Comments
Max. Acceleration Commercial Aerospace Vehicles • ***+ 3 Gz (-2 Gz)*** • ***± 6 Gx*** • ***± 1 Gy*** • ***Increments of less than 0,25 G/sec***	SpaceShipTwo acceleration peaks are: • + 3,8 Gx • + 3,8 Gz (very short time) • + 6 Gz during reentry The last one can be directed along X axis by tilting back passengers seats
Microgravity exposure	4 to 6 minutes, not an issue for suborbital flight
Cardiovascular effects	Negligible
Inflight decompression	Pressure suits &/or breathe masks should be used
Ionizing radiation: max 350000 ft of altitude dose of 15 microSv/hr flight of less than 30 minutes	• No acute effects, launch time can be controlled • Individual dosimeters are desirable
Noise: for the most due to propulsion system: ***- Limit set by NASA: 105 dB***	Auditory protection required for the crew. Noise isolation for the cabin
Vibration: due to launch and aerodynamic loads • ***Minimum tolerance between 4-8 Hz*** • ***Impaired phychomotor coordination 2-16 Hz***	Reference: SpaceShipOne thrust oscillations 5-10 Hz. Damping desirable

Figure 42: Medical issues for occupants

4.3 Training and medical evaluation for flight occupants

In this paragraph we're going to make a distinction between the crew and flight participants, as both constitute the flight occupants category. To be certified for sub-orbital flight, flight participants must undergo a medical evaluation and learn some basic skills and operations for their upcoming flight. So, although not being professional astronauts, training is required also for participants. Instead for crew members, same rules of professional astronauts apply. For the following informations, we refer to the FAA document as well as the one reporting main medical issues for occupants.
Starting with the medical assessment, in case of crew member it should be done within 12 months before a suborbital flight. The crew member will be judged *not able* to fly if any medical condition or physiological change is reported, as well as if he's receiving any medical treatment. Besides it is very important that any crew member should be able to demonstrate the ability to withstand space flight stresses, that we discussed in the previous paragraph.
As regards flight participants, assessment consist in a medical consultation that has to take place 12 months before flight with a physician experienced in aerospace medicine, in order to ascertain the medical risk of spaceflight.

Talking about training the analysed documents put emphasis only on few aspects, without claiming of being an exhaustive index of how the training should be. For crew members training should include practice on emergency egress and also a physiological training to learn how to recognize sign and symptoms associated with decompression.
As regards flight participants particularly important parts of the training should be: identification of human hazards, the interaction with the vehicle and other occupants during all phases of flight; to learn notions of aerospace physiology and in the end how to respond to an emergency situation, in particular: use and location of survival equipment as well as fire detection and suppression equipment; how emergency egress should take place.
Training for flight participants will be *part of the package*, included in the ticket price for a suborbital flight. Besides this kind of training should be repeated every defined number of mission and conducted only by certified trainers.

Personnel	Medical Evaluation	Training
Crew	• Medical examination within 12 months before a suborbital flight • NOT able to fly if there is a medical condition or physiological change • NOT able to fly if receaving medical treatment • Should be able to demonstrate the ability to withstand spaceflight stresses (acc/dec, vibrations)	• Emergency egress • Physiologic training to learn how to recognize signs and symptoms associated with decompression
Flight Participants	• 12 months before flight medical consultation with a physician experienced in aerospace medicine, to ascertain the medical risk of spaceflight	• Identification of human hazards interaction with the vehicle and other occupants during all phases of flight • Aerospace physiology • How to respond to an emergency situation: 1. Use and location of survival equipment 2. Use and location of fire detection and suppression equipment 3. Egress

Figure 43: Training and medical evaluation

5 Ground Segment

A fundamental part in a Space mission is represented by the ground segment, which also in a suborbital flight has the duty to provide all the functionalities and capabilities required to support tracking and monitoring of the flight, as well as associated ground infrastructure required to properly support mission preparation and execution. This means that proper communications and tracking capabilities shall be implemented: this task can be accomplished by defining, implementing and testing proper space to ground interfaces. A proper ground station should be able of:

- Telemetry (TM) monitoring;
- Flight segment tracking;
- Telecommand (TC) capability;
- Voice link with flight segment;
- Access to payload data;

For this suborbital mission a Control Center facility is required, which has to provide:

- Controlling and managing launch activities;
- Controlling the flight segment;
- Access for monitoring and commanding payload;
- Coordination of all activities during mission execution;
- Managing safety and mission rules during flights;
- Interfacing with external entities during nominal and contingency conditions.

Another important step is to identify the ground links necessary to secure exchange of data between various facilities composing the ground segment. Proper ground segment facilities and tools have to be defined with the purpose of:

- Supporting operations and logistics at the spaceport;
- Supporting and managing mission preparation activities and mission configuration tasks;
- Supporting launch activities.

All mentioned elements compose the ground segment for a suborbital mission with a spaceplane.

5.1 Ground Station Operating Scenario

The definition and following development of a proper Ground Segment for a space mission in the first place depends on the definition of the reference mission, in our case a suborbital flight space mission accomplished with a spaceplane. Further development of this kind of vehicle may led to different mission concepts like point-to-point flights and, consequently, to different support scenarios to be identified.
In particular for suborbital flights the monitoring and tracking of the vehicle needs to be precise and accurate, with the main goal of ensuring safety to passengers as well as the vehicle itself and the ground equipment. Therefore accurate tracking functionalities are required, as well as adequate space to ground communications capabilities, in order to keep an active link with the vehicle for telemetry reception, data provision and tracking.
Other factors to be considered during the development of a concept for the ground segment are the safety constraints and requirements imposed by mission definition and existing safety regulation (from FAA or national regulation where existing). In particular, since a regulatory approach to suborbital flight should be established, it's important to understand which Ground Station telemetry and tracking services should interface with local air traffic control authorities.
We have to distinguish between a tourist and scientific mission. In the second case other elements have to be considered like the possible needs of controlling and monitoring payloads on board the spaceplane. Usually payloads' developers have ad hoc control facilities, as the experiments could require a real time control. In this scenario there are two possible options: either forwarding payload data to the specific payload control center, or bringing payload ground support equipment within the Spaceplane Control Center.

Recalling the mission operations flow and different phases described at the end of the third chapter, it is now appropriate to see which role the ground segment plays in evert part of the mission. In fact spaceplane ground segment shall support all phases and operations foreseen for flight preparation.
The fist phase is *mission preparation*, which consists of all activities and support equipment required for definition of mission profile and related requirements. During this period training and simulation activities for customer and operators shall be carried out and supported. As a result, certification of flight readiness for the people involved in the mission shall be achieved, with particular attention to safety and contingency procedures that have to be executed and tested, in order to guarantee customers and operators awareness and readiness to overcome and handle potential issues that might arise during flight. Ground segment shall also support vehicle configuration and prepara-

tion, in particular for the provision of all ground support equipment needed to configure and perform maintenance properly.
In case of scientific mission, these activities cover also payload configuration and preparation for on-board accommodation and flight readiness certification. Proper interfaces with the vehicle shall be implemented if required for payload installation: particular attention shall be posed in performing mechanical, electrical and electronic connections; verifying and validating that all the required functionalities are in place and operational.
It is needed to take into account all the logistics aspects that concur to complete mission preparation and achieve flight readiness. This include managing spare parts, the inventory and handling of replacement units as well as refurbishing parts that shall be carried out and supported with proper tools. All storage and configurations shall be kept under control; in particular the handling of hazardous material shall be performed after proper training and certifications have been obtained by the relevant operators, in order to conduct all the operations safely and with no hazard to people, environment, vehicle and ground equipment.
Lastly, during this phase, all the processes for mission authorization shall be carried out, also contacting relevant authorities for flight authorization. This is a delicate procedure as it can be a show stopper or introducing severe delays in flight schedules.

After preparation we have the *pre-launch phase*: in order to carry it out properly all the required support equipment shall be identified and procured. Also final activities for preparation of flight and ground segment shall be carried out and track of all performed activities kept.
Specific checkout procedures shall be performed in order to certify that everything is set and ready to support the actual mission. Activities to be performed can be: payload accommodation, vehicle status verification and assembly status (in case of failed parts replacement for example), verification of nominal condition of operation for all critical on-board equipment and control computers. If any non-conformances are encountered, they shall be handled and managed properly, in order to check if the safety can still be guaranteed, with associated risks level evaluation, if decisions are taken to still proceed with flight.
Launch pad operations and all relevant activities related to launch preparation shall be carried out with proper equipment that will have to be identified and procured. This includes re-fuelling activities and fuel handling, to be performed only by trained and authorized people, which shall operate the fuelling tools and handling devices.
In the end another operation that shall be supported and taken care by ground

segment operators and equipment is the passengers boarding and safe buckling them onto seats for launch preparation.

During the *launch-ascent phase* all external condition and weather forecasts on the various sites involved in the mission shall be checked out in order to provide final decision for launch go-ahead. In order to do so proper equipment shall be identified and deployed all over the area interested by the suborbital flight. During launch sequence all ground and launch pad systems will have to be monitored with proper tools, and operators shall be trained and qualified in order to verify that safety is ensured. In particular, in case of potential mission abort, the operators shall be well trained to spot possible hazardous situations and to issue the launch abort sequence as expected.
During ascent phase the ground segment shall support the acquisition of data from the spaceplane, providing at the same time all equipment and tools required for assessment of such data. Moreover, positioning the ground station(s) throughout the suborbital flight area will allow to have a full coverage and visibility of the vehicle during the mission.
This phase is particularly important because all procedures, processes and tools have to be available and ready to support operations: for instance in case of contingencies or issues during the launch or during the ascent the control team has to be ready to trigger the emergency procedures (if needed and planned), as well as the flight abort process. This also means that all the relevant emergency authorities shall be alerted and rescue teams have to be ready for recovery and damage containment.

The central part of the mission is the *flight operations phase*, which encompasses the continuous monitoring of vehicle telemetry in order to maintain under control the status of the spaceplane. It is also expected a continuous tracking and monitoring of the trajectory and telemetry of the vehicle.
Another important aspect to monitor is customers health status, while approaching and experiencing micro gravity. After that we get close to re-entry phase, so it is very important that all procedures aboard the vehicle are correctly followed and performed by the crew in order to get back people safely sit and buckled up on their seats while approaching the descent.
In case of scientific mission active payload are embarked, and during this phase the data is received and transmitted to payload control center for its monitoring and exploitation.

As we approach the end of the mission, we have the *re-entry operations phase*, during which the telemetry of the vehicle has to be continuously monitored, in order to keep under control the vehicle status. This covers also the condi-

tion of re-entry abort situations where both the unplanned re-entry trajectory as well as the coordination with local rescue and safety authorities shall be maintained. Flight crew conditions shall be kept under control as the forces experienced by passengers might be very high, even during nominal descent.
Once the vehicle is landed its status shall be assessed and indications for safing the vehicle provided to ground operators. Then, once the vehicle is declared as landed the crew members and passengers can be disembarked with help of ground operators.
In case of emergency situations as landing on waters, proper provisions will allow quick rescue operations for the safety of the crew and passengers.

Mission is not over even after landing, as there are some *post-mission operations* to perform. During this phase, the vehicle shall be transported in to proper area for maintenance and status assessment. All data produced during the flight shall be retrieved and downloaded for later post-processing, with the final goal of improving mission quality and passengers' experiences.

5.2 Control Center

For a suborbital mission, Control Center main duties are to provide infrastructures, systems, tools and applications to be used during flight execution for telemetry monitoring, storage, processing, displaying as well as detailed trajectory and re-entry activities support, management of Ground Station operations, meteorological forecast data of the launch, landing and flight area. During a suborbital mission the support and control of the vehicle from the control center must be continuative, in order to guarantee passengers' and environment's safety.
The Control Center shall provide equipment needed for monitoring, controlling, coordinating ans assessing the status of the overall Ground Segment. This means that the Control Center shall be equipped with monitoring console, weather forecast analysis tools and trajectory prediction tools.
The Control Center will have to coordinate all pre-launch activities, performing checkout procedures and both vehicle and weather assessment status, in order to provide the go-ahead for the flight. The launch phase will be closely monitored by the control center verifying that the flight area is clear and, if needed, communicating with authorities about mission trajectory and expected take off and reentry times. During ascent phase the control center will continuously monitor the vehicle condition; moreover all vehicle parameters will be kept under control to be ready to declare an emergency and to start the launch abort procedure with all the relevant operations. Finally during the flight and re-entry phases the activities performed on board the spaceplane

will be monitored by the control center, in order to verify the safety status of the flight.
Furthermore the control center can coordinate through voice links with other sites the activities performed for the suborbital flight. It is possible to identify different voice links:

- Control Center with ground operators during pre-launch activities;
- Control Center with Ground Station operators for systems status check and for real time mission coverage;
- Control Center with the spacaplane during all the phases, for coordinating launch readiness, for providing report to vehicle crew on system status, for supporting crew during re-entry phase;
- Control Center with flight and rescue authorities to communicate flight plans, launch readiness, launch execution and for coordinating activities and providing required information in case of emergencies;
- Control Center with Payload Center in case of scientific mission;

During the mission various activities are performed and they need proper support throughout their execution: this means that adequate hosting facilities, room and storage areas shall be foreseen. The control center shall provide the training and simulation areas, activities that shall be carried out for both flight operators, flight participants and ground operators. Simulations are very useful as they give to mission operators more confidence with typical flight conditions and in order to get familiar with procedures.
A preliminary configuration of consoles provided within the Control Center should be:

- Flight Directory: has full responsibility over the flight and takes final decisions;
- Medical: its main duty is to keep under control the healt and status of people on-board the vehicle; moreover it can call mission abort in case of particular conditions where health of people on board is threatened;
- Vehicle Manager: technical responsible of the vehicle system and supported by sub-systems specialists;
- Ground Manager: technical responsible for the ground equipment and communication; supported by the ground team;
- Flight participants referent: reference engineer for passengers, talks with the crew on the vehicle.

An important area consist in the Mission Control Room, where all monitoring and controlling activities of the spaceplane are conducted. In particular it has to be equipped with consoles to allow TM monitoring and control, as well as trajectory monitoring, vehicle tracking and re-entry trajectory prediction. Every console has to be equipped with voiceloop systems in order to enable intercommunication within the Control Center as well as with other sites and the vehicle itself.
This represents only an initial configuration, derived from Space missions know how: over several missions will be possible to have a solid knowledge base to better understand which elements are more important; therefore control center configuration could be ri-modulated over time.

5.3 Ground Station

Ground station shall provide space to ground communication with the spaceplane. It is important to considered which areas are interested by the sub-orbital flight in order to identify a proper position for the station in such a way that the monitoring of the entire flight can be guaranteed. More than one station can be foreseen if necessary. However, in this case one station should be enough, in particular it shall be placed near the take off and landing area of the spaceplane. To study the positioning of the Ground Station the preliminary reference trajectory shall be analysed:

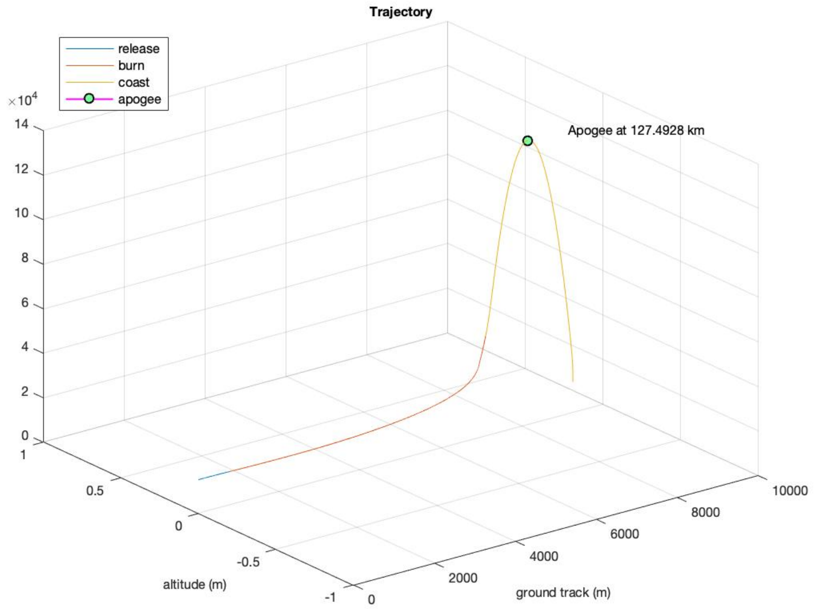


Figure 44: Scientific mission trajectory [Credits Riccardo Mollo]

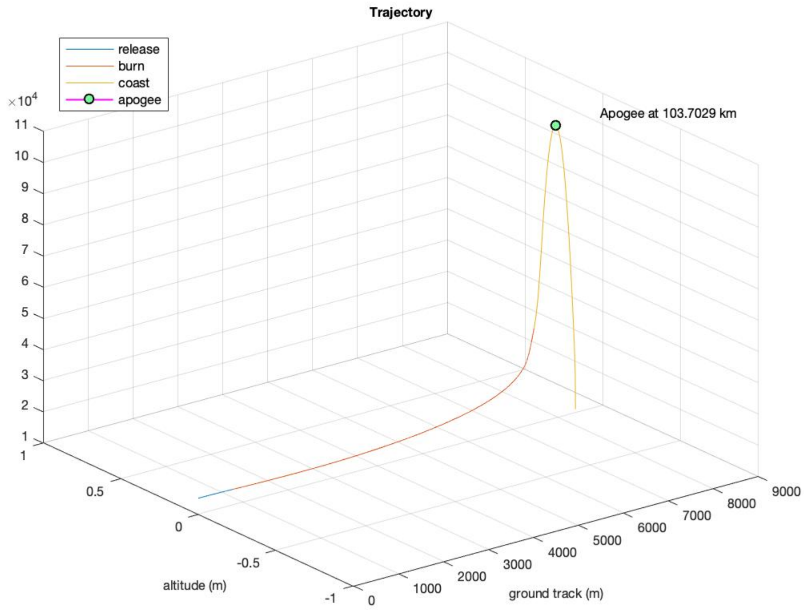


Figure 45: Touristic mission trajectory [Credits Riccardo Mollo]

Differences between two trajectories consist in the amount of maximum thrust used during burning phase: in a scientific mission full thrust is employed for a longer time, that's why we have a more elevated apogee. This choice comes from the necessity of having a longer microgravity phase in order to better perform scientific experiments.
We have two possible trajectories depending on the purpose of the mission: tourist or scientific. Considering these trajectories a feasibility analysis can be conducted to verify that one ground station can be sufficient for tracking the spaceplane. As a first assumption we may say that a unique antenna could be able to track the full spacecraft trajectory, assuming that the horizon masking of the Ground Station site does note affect the Line of Sight from the antenna to the Spaceplane, in particular at low degrees of elevation. The final location of the antenna has to avoid the presence of obstacles in the surrounding intercepting the Line of Sight, in particular at low elevation angles.
Generally studying spacecraft trajectory it's possible to determine the required coverage angle which allows communication between the vehicle and the ground station. For example, for a satellite on orbit around the Earth, the scheme can be:

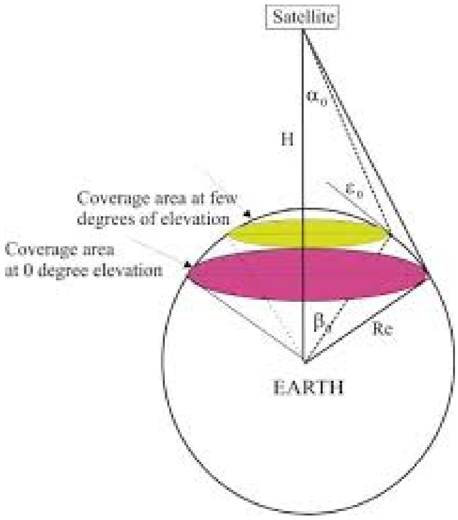


Figure 46: Coverage angle defines the acquisition area by intercepting Earth sphere

In particular coverage angle β depends on spacecraft altitude and elevation angle according to the relation:

$$\beta = -s + acos\left[\frac{R_E}{R_E + h}cos(s)\right]$$

The equation can be described with the following graph, in which different curves are obtained varying the altitude and the elevation angle (between 5 and 30 degrees):

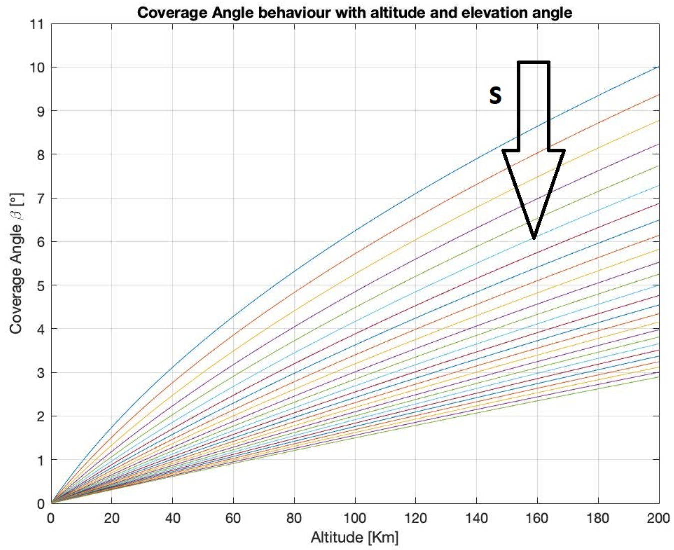


Figure 47: Coverage angle behaviour for different values of altitude and elevation angle

We can observe that for $h \to \infty$ we have $\beta = -s + 90°$, while keeping h = cost, for greater elevation angle the coverage angle is reduced. In order to have elevated visibility time an high altitude is desirable; but this is applicable for a spacecraft on orbit. For a suborbital flight we expect low altitudes, while for elevation angle it could range between low and high values depending on the position of the spaceplane during the various phases of the mission with respect to the ground station.

5.4 Emergency Recovery

Emergency recovery has to be coordinated from the Control Center and operated either by a team which is part of the mission or by local authorities; in alternative a combination of the two might be considered. It is important that from the control center are provided dedicated procedures, known and validated by the operators, in order to react as promptly as possible in case of contingency. Such procedures have also the role of determining what information have to be disclosed and at what level. These procedures should also clearly cover how to escalate in case of contingency, and who has the role to give final decision.
Simulations of emergency condition and recovery with local authorities and/or the mission recovery team should also be conducted, in order to increase confidence and reactivity in these situations.

5.5 Oxidizer and Fuel Safety Data Sheet for Ground Segment

One of the most critical activity for on ground personnel is to deal with dangerous substances, as chemicals can be in some situations; that's why precise instruction should be given to ground operators on how to handle and manage fuel and oxidizer for spaceplane engine, and more importantly on how to act in case of emergencies. To do so, already available safety data sheets have to be analysed. In particular we are going to focus on fire-fighting measures and handling and storage. For more information it is suggested to check full data sheets at the end of the document [25] [26].

5.5.1 N_2O Safety Data Sheet

Fire-Fighting Measures

- *General Fire risks*: heat can cause tanks explosion;
- *Fire Fighting*: splashes of water, dry powder, foam, carbon dioxide;
- *Dangerous combustion products*: thermal decomposition that can generate nitrogen monoxide, nitrogen dioxide;
- *Special Procedures*: in the event of fire, block the leak if there is no danger. Sprinkle with water until the container is cooled. Use extinguishers, isolate the source of fire;
- *Special protection devices*: workers must use flame-retardant overalls, helmet with protective visor, gloves, rubber boots, self-contained breathing apparatus.

Handling and Storage

- *Safe Handling pracautions*: under pressure gases can be handled only by trained and experienced people. The substance must be handled in accordance with industrial good hygiene procedures and safety. Containers must be protected from physical damages: do NOT drag, roll, slide or let fall. When handling the cylinders, even for short distances, use an equipment suitable for the transport. Always fix the cylinders in vertical position, close all the valves if not used. Provide ventilation. Do not allow the backflow of the gas into the container, as well as the water, acids and alkalis. Keep containers under $50°C$ of temperature. Do not use direct flames of electric heating devices to increase container pressure. Close container valve after each use as well as when it is empty. Do not ever attempt to transfer gases from one container to another one;

- *Conditions for safe storage*: containers must not be stored in conditions that may encourage corrosion. Stored containers should be checked periodically in order to evaluate general conditions and leaks. Store containers in places free from fire risks and far from heat sources. Keep away from combustible substances. Avoid asphalted areas for storage and usage (fire risk in the event of a leak). Keep separated from other gases and other inflammable materials.

Stability and reactivity

- *Reactivity*: no reactivity danger outward others described in the following points;
- *Chemical Stability*: stable under normal conditions; Over 575 ° C, N2O decomposes under normal pressure condition into nitrogen and oxygen. If N_2O is pressurized it can be decompose also at temperature above 300 ° C.
- *Possibility of dangerous chemical reactions*: it oxidizes organic materials violently. It can react violently with inflammables as well as with reducing agents;
- *Conditions to avoid*: Heat;
- *Incompatible materials*: combustible materials, catalysts;
- *Dangerous decomposition products*: thermal decomposition generate toxic products that can be corrosive in presence of humidity. Under normal storing conditions and use, these products are not expected to form. In case of fire, for thermal decomposition, nitrogen oxides can be generated.

5.5.2 HTPB Safety Data Sheet

Fire-Fighting Measures

- *Extinguishing media*: Water spray or fog, carbon dioxide, foam, dry chemical, dry powder, sand.
- *Unsuitable exinguishing media*: Use of heavy stream of water may spread fire;
- *Fire hazard arising from the chemical*: Heat from fire can generate flammable vapor; when mixed with air and exposed to ignition source, can burn in open air or explode if confined;
- *Firefighting instructions*: Fight fire from safe distance and protected location. Avoid direct personal contact with liquid even after fire is out. Use water or fog for cooling exposed containers. Heat may build pressure, rupturing closed containers, spreading fire and increasing risk of burns and injuries. Prevent fire-fighting water from entering environment;
- *Protection during firefighting*: Do not attempt to take action without suitable protective equipment. Complete protecting clothing and self contained breathing apparatus are required;
- *Other informations*: fires are typically very smoky.

Handling and Storage

- *Precaution for safe handling*: Ensure ventilation of the work station. Wear personal protective equipment. Avoid contact with elevated temperature or molten product to prevent burns. Use only non-sparking tools.
- *Hygiene measures*: do not eat, drink or smoke when using this product. Always wash hands after handling the product;
- *Technical measures for storage*: electrical equipment should conform to the national electric code. Containers which are opened should be properly resealed and kept upright to prevent leakage;
- *Storage conditions*: Keep container tightly closed. Stor in a dry, cool area. Purge open drums with nitrogen before resealing.

Exposure controls/personal protection

- *Appropriate engineering controls*: ensure good ventilation of the work station;

- *Hand protection*: protective gloves. Do not use natural rubber gloves, but wear thick (¿ 0.5 mm) nitrile gloves. Replace gloves immediately when torn or any change in appearance is noticed;
- *Eye protection*: safety glasses;
- *Skin and body protection*: wear suitable protective clothing;
- *Respiratory protection*: in case of insufficient ventilation, wear suitable respiratory equipment.

Stability ad Reactivity

- *Reactivity*: no dangerous reactions known under normal condition of use;
- *Chemical stability*: stable under use and storage condition as recommended previously;
- *Possibility of hazardous reactions*: Cracks into gaseous and liquid products above 426 ° C. Decomposes by polymerization above 204 ° C. Once initiated, the reaction generates enough heat to continue spontaneously;
- *Condition to avoid*: Heat, direct sunlight, high temperature;
- *Incompatible material*: Strong oxidizing agents, strong reducing agents, strong acids, free radical initiators/peroxides;
- *Hazardous decomposition products*: Under normal condition of storage and use, hazardous decomposition products should not be produced.

6 Conclusions and future works

6.1 Conclusions

The study in this work has shown that airlaunch system approach is the most suitable configuration to achieve suborbital flight and it captures the emerging market opportunities, in terms of space tourism, microgravity experience and astronauts/pilots training. Suborbital flights guarantee a few minutes of high quality microgravity at around 100 Km of altitude to be exploited in many perspectives.
A trade off process was carried out to asses the main advantages and drawbacks for different configurations in relation to take off strategies, propulsion and staging. The trade off process was based on a mathematical approach that proposed Figure of Merit Analysis. This lead to a reference configuration which features two stages, air launch and hybrid propulsion, properly matching the operative scenarios. An initial characterization of the main subsystem for this configuration has been conducted.
Suborbital flight initiative preparation and its related spaceport is based on a series of different operative scenarios that have to take into account the system configuration and also all the spaceport operative and safety requirements and constraints. A suborbital space flight regulatory system is currently under development in Italy, which emphasizes the occupants safety: with this purpose this work proposed a re-adaptation to the Italian context of some FAA guidelines.
A significant input to this work was given by trajectory simulations, conducted by my colleague Riccardo in his thesis.
An outline of suborbital flight Ground Station was performed to properly accomplish mission tasks and to collect and process telemetry data. Our considerations are mostly theoretical and cannot be fully validated until the number of flights grows: the effort for the ground segment development will be greater at the beginning but it will get easier over time by acquiring a knowledge base and and a fixed commercial profile activity.

6.2 Future Works

As a prosecution of this work of great interest may be more detailed studies and developments conducted to assess the technology readiness level of the airlaunch method and eventually introduce new ones. Also other configurations different from a Spaceplane, for example Capsule approach used by Blue Origin, should be considered to have a wider set of possibilities. Further, as a future development it is recommended to carry out different trade off methodologies and refine the relevant approach. Another interesting study may be to

find customized reference configuration for different operative needs.
Further developments may include also a deepen reference spaceport analysis in order to assess its compliance with all the requirements and the following definition of all the activities that have to be conducted, in particular referring to trajectory tracking methodologies for engineering purposes and possible integration with air traffic control authorities.
Another possibility may be extending this kind of work to a point-to-point like mission concept, and assess which technology and operative concepts should further be investigated and developed.

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