YOUR SPACEFLIGHT
YOUR SAFETY

The Essential Primer for the Second Space Race

To keep up to date on the latest happenings in the second space race, check out the website accompanying this book over at

yourspaceflight.com

(or use the code below with a QR code reader)

Your Spaceflight, Your Safety

© 2018 Dr Andy Quinn

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To my lovely wife Jacqui

Thank you for your love, our life –
you are my soul satellite, I will be
lost in space without you

x

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Photo opposite by Artur Dyadchenko on Unsplash

Photo of Per Wimmer, courtesy WimmerSpace.com

FOREWORD

For an adventurer in the 21st century, space is the final frontier. Whilst the Earth and the oceans still keep many secrets and hold the potential for great scientific discoveries and personal adventures, space travel and discovery are still at a very early stage. Even more so for private individuals.

As an adventurer who has travelled to 72 countries, lived with the Indians in the Amazon, skied at 5,500 meters, dived with sharks in Fiji and travelled the world thick and thin in addition to successfully execution the world's first tandem sky dive above Mount Everest in 2008; travelling to space is for sure the next logical adventure.

Andy Quinn's book, ***Your Spaceflight, Your Safety***, provides an excellent guide to some of the key considerations, rocket providers, safety aspects and industry participants which an aspiring private astronaut would need to be aware of. I salute the author for providing such useful guidance and insight for future private astronauts.
It is fitting to paraphrase J. F. Kennedy on September 12, 1962:

"Man and his quest for knowledge and progress is determined and cannot be deterred.

The exploration of space will go ahead... We choose to go to the Moon... and do the other things, not because they are easy but because they are hard."

I personally bought my first ticket to space in 2000 - hoping to fly five to six years later (Space Adventures) - and subsequently bought another two tickets later (XCOR, Virgin Galactic).

Whilst my determination and desire to go to space is fully determined and non-negotiable and whilst the journey so far has brought me countless unique experiences and amazing people, friends, astronauts and celebrities all of whom I had never imagined meeting, the journey has not been without challenges and set backs, most notably the huge technical challenges which the engineers have persistently been working on. Yet, private enterprise, human ingenuity, engineering talent, billionaires funding and their personal ambition and admiration for space will eventually result in several private rocket options being made available at reasonable prices to the dedicated private space traveller.

This book sheds light on this journey and the options as well as important safety and training consideration and, as such, is a must read for the future private astronaut.

Enjoy!

Ad astra,

PER WIMMER
Astronaut, adventurer, financier, author and philathropist
CEO, WimmerSpace.com

Photo by Jack Cain on Unsplash

ABOUT THE AUTHOR

I've been involved in the aerospace industry for over 30 years; like you I've been inspired and excited by the suborbital spaceflight bug for the last 13 years since the Ansari X-Prize flights. To be fair this excitement has ebbed and flowed over the years with the delays and accidents, but here we are on the brink of commercial suborbital flights. So although this short primer has been brewing for some time, now more than ever does it seem appropriate to open up about the exciting flights ahead. As we know, with excitement comes risk and in this book we will discuss the risks so that you are fully informed when you sign that waiver, and you can give your informed consent.

I've worked as an aircraft engineer in the Royal Air Force and then as Flight Crew. This meant undertaking flight training and some of this is relevant to suborbital astronaut training experiences. Additionally, I've flown in a Hawk to analyse the relevance of g-force training for suborbital astronauts as part of my Thesis, as well as carrying out research in centrifuge runs; and having fun along the way.

In terms of safety, I've worked on military fast jet analysis and worked for the Civil Aviation Authority on the risk assessment of suborbital flights from the UK. I'm also working for Reaction Engines Limited on the SABRE engine and Skylon spaceplane. More recently I've provided safety and regulatory inputs for a consortium task for the UK Space Agency in relation to small satellite launchers (vertical and air-launched).

I was also the Chair of the Commercial Human Spaceflight Safety Technical Committee for the International Association for the Advancement of Space Safety and this included developing guidelines for suborbital spaceflight. During the last couple of years I have also been a member of the ICAO/UNOOSA Space Learning Group which is just starting to look at the commercial suborbital spaceflight activities.

Author preparing to take off for fast jet training.

Photo by NASA on Unsplash

INTRODUCTION

SO YOU WANT TO FLY TO SPACE?

What is it that makes us want to strap ourselves on top of a rocket and head towards the stars? Is it the need for speed? Is it the desire to drink in that once-in-a-lifetime view of the Earth? Could it be the risk and thrill of the ride?

Perhaps it's a bit of all that. Astronauts always say it's the view of the Earth; astronaut Mario Runco once said to me that the view of the Earth is

> *"...the most humbling and life-changing experience ever."*

I imagine this Earth-view would indeed be life-changing when orbiting the planet, taking in the splendour and appreciating the fragility of our planet, as Mario did. Typically, space agency missions last several months and are the culmination of years of training and study, after which your 'office' window suddenly has the best view in the solar system.

We are now on the cusp of a new era of space travel, one where space travel will be (more or less) accessible to the public. Through the efforts of private companies,

Photo courtesy Dr Carole Norberg, August 2005. Mario Runco of STS-44/STS 54 and STS 77 said to me that the view of the Earth is the most humbling and life-changing experience ever and overrides all other motives. Runco is a great ambassador for space, as are all astronauts, and after being our guest speaker on the Manned Spaceflight Course in Kiruna Sweden (2005), he was heading off to be part of a NASA team looking at Lunar Habitats. I'm sure we will see the fruits of his labour on the Moon in the 2020's – it's the only logical outcome. Live long and prosper Mario.

rather than governments, an individual can experience the wonder of space travel; albeit to suborbital heights, and for a matter of minutes, rather than months.

What moment of that journey will stand out the most? Will the brief glimspe of our planet still command the greatest reverence? Perhaps the most memorable moment will be the thrilling launch phase; or maybe pulling some serious G-Force, reaching terminal velocity during the 're-entry' phase on Virgin Galactic's *SpaceShip2* or Blue Origin's *New Shepard*.

Maybe some will recall the intense centrifuge and zero-g training sessions, or the stomach-churning twists and turns of a jet-powered G-Force training flight. Whatever moment stands out most though, in the end, I can't imagine anyone not wanting to frame their portrait, spacesuit-clad and grinning in front of the spacecraft waiting to take them to the stars.

This dream isn't for everyone though. Often, I've heard concerns that commerical spaceflight is 'too costly', 'too polluting', and most commonly: 'too dangerous'.

COST

The first private spaceflight participant was Dennis Tito, who paid $20 million to fly into space in 2001. At the time of writing, it looks like a ticket from Virgin Galactic costs around $250,000. For those of us who do want to fly to space, we'd like this cost to keep coming down! There's no denying that people are paying a premium to be part of the first wave of participants. What's important is that the commercial spaceflight industry lays the foundations for a long and prosperous ecosystem of companies that can compete fairly and bring that ticket cost down. The suborbital spaceflight market looks to be a lucrative market to the two leading companies; they need look no further than the hundreds of people (some of whom should absolutely reading this book!) who have paid for their tickets in full, before the first flights have even taken off. We can see that space is the final frontier and that we should explore the Moon, Mars and beyond (manned of course).

POLLUTION

Compared to the booming aviation and shipping industries, not to mention road traffic, the polluting effects of a limited number of space flights fall into insignificance. In the longer term, spacecraft designers are developing 'greener' systems for their spacecraft, from cleaner propulsion systems to more sustainable composite materials.

RISK

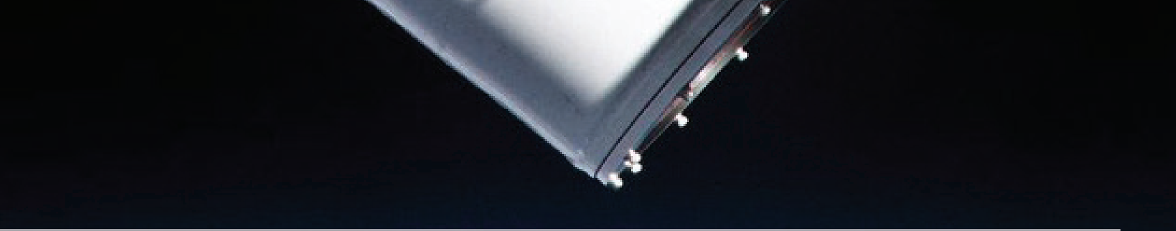
We also don't appear to mind the dangers involved in the spaceflight. Those of us who want to strap ourselves to a rocket are risk takers and pioneers with the 'right stuff'! We're also not stupid and we would expect to be informed of the level of risk, what safety measures the vehicle has, what personal protective equipment we will have and what training we will be given, especially for emergency events.

ABOUT THIS BOOK

Part One sets the scene for suborbital flights: who are the players, where can I fly from and importantly can I actually fly? Parts of this analysis consider the unthinkable – what could go wrong? – and a further look at what we mean when we talk about 'the right stuff'. Part 1 will look at the different suborbital spacecraft (including those that don't have rockets) and look ahead to the potential of the suborbital market! Lastly, the section will help you determine the answer to a crucial question: 'am I fit to fly?'. Here we look at medical aspects and also breaking down what experiential training is essential for your spaceflight.

Part Two then provides some additional information on the management of your safety in terms of what regulations are in place and what that means for insurance. There is also further discussion on risks relating to spacecraft type to help you when making up your mind; e.g. whether to fly at all and what type of spacecraft to fly in. This will then hopefully let you know what level of risk you are willing to take. After all we do need to know how safe it is, don't we?

Part Three is your spaceflight checklist. It summarizes relevant training and medical standards and why this forms an important part of the safety measures to protect you and not forgetting the reputation and flight test performance of the operator. It includes the all-important questions to ask your operator (on top of 'where is my



spacesuit and when can I go'). The checklist is your spaceflight preparation program on your path to the final countdown – don't go to space without it!

WHO THIS BOOK IS FOR

This book is clearly aimed at you, the prospective spaceflight participant, and is intended as a general guide but with a safety slant. This is my personal perspective on the nascent suborbital industry.

The aim is not to put you off from flying with your chosen operator and the aim is not to favour one operator over another; the early forerunners will of course be the first to uncover safety or performance issues – as will all that follow. The suborbital industry has already experienced accidents during flight and ground tests.

We must never forget these accidents and never forget that space systems have inherently higher risks and that failure consequences are inevitably more spectacular. We must all learn from the past and in predicting failures, and ensure that all that is reasonably practicable is done to reduce the risks to those on board **as well as** the uninvolved public.

A good example of this practice was the response of Virgin Galactic to the unfortunate *Spaceship2* (SS2) accident on 31st October 2014. The US NTSB and vehicle designer were able to identify the causal factors of the accident due to the surviving pilot's account of events and telemetry plus on-board video. Having learned from this, Virgin Galactic are now in charge of manufacture and design for the remainder of the flight test program and have now taken appropriate measures to satisfy the NTSB recommendations – plus a few improvements of their own based on further analysis.

At the end of this short book I will have highlighted the good, the bad and the ugly of suborbital spaceflight.

If you were wondering what all the hype was about, I hope you will feel a little more informed. If you're considering buying a ticket to space, I sincerely hope this book has at the very least helped you with your decision. If you're already booked onto the first spaceship heading up, then bravo to you, hopefully you will complete the checklist at the back and take note of the questions to ask your operator.

The book is all about **you**, the spaceflight participant/space tourist. You may have notice I've not used the latter term at all yet in this book. That's because I prefer to call you suborbital astronauts – you are not a tourist.

Photo courtesy Red Bull Stratos

THE GOLDEN QUESTION

Here's a golden question to take with you through the book and we'll see where we come out at the end

If Felix Baumgartner did 10 space jumps to 'prove' his system for commercial use, would you jump on flight number 11?

When once you have tasted flight, you will forever walk the earth with your eyes turned skyward, for there you have been, and there you will always long to return

- Leonardo de Vinci

Photo by Matteo Fusco on Unsplash

Photo by Greg Rakozy on Unsplash

PART ONE: YOUR SPACEFLIGHT

THE SECOND SPACE RACE: A TIMELINE

Date	Company	Event	Comments
Sep 2004	Scaled Composites	Ansari X-Prize flight 1	103km Control issue in boost (spinning)
Oct 2004	Scaled Composites	Ansari X-Prize flight 2	112km
Aug 2005	XCOR	Oshkosh Airshow, Wisconsin	XCOR's EZ-Rocket
Jul 2007	Scaled Composites	Engine ground test accident; explosion – 3 scientists' dead	A 'cold-flow' test that was to study oxidiser flows into a 'balance chamber' without rocket motor ignition
Aug 2008	XCOR	EAA AirVenture Oshkosh Airshow, Wisconsin	XCOR's second prototype vehicle, the X-Racer competed at the Rocket Racing League flying three times
Sep 2008	Armadillo Aerospace	Northrup Grumman Lunar Lander Prize – flight 1	
Oct 2008	Armadillo Aerospace	Northrup Grumman Lunar Lander Prize – flight 2	
Jan 2013	Armadillo Aerospace	Flight Test incident	Unmanned flight test loss of control – company folded
June 2011	Copenhagen Suborbitals	Initial Flight Test	Unmanned sea-launch
Aug 2011	Blue Origin	Flight Test incident	Unmanned flight test loss of control
Jul 2012	Copenhagen Suborbitals	2nd Flight Test incident	Unmanned sea-launch partial success but nosecone came off
June 2013	Copenhagen Suborbitals	3rd Flight Test success	Unmanned sea-launch success to 8km
Oct 2014	Scaled Composites	Powered Flight Test Accident – 1 pilot dead	Break up due to inadvertent operation of the Feathering device
April 2015	Blue Origin	Pretty successful Flight Test to 93.6km	New Shepard with BE-3 engine – flight took 6 minutes. Booster separated but hydraulic failure of fin controls meant hard landing
Nov 2015	Blue Origin	Successful Flight Test	Historic return landing of Booster (100.5km)
Jan 2016	Blue Origin	Successful Flight Test	'Launch, Land, Repeat' (101.7km)
Feb 2016	Virgin Galactic	Unveiling of SSS2 VSS Unity	Will begin testing again – awaiting powered flight
Apr 2016	Blue Origin	Successful Flight Test	'Pushing the Boundaries' (103km)
June 2016	Blue Origin	Successful Flight Test	One 'Chute Out
Oct 2016	Blue Origin	Successful Flight Test	In-flight Escape Test
May/ June 2017	Virgin Galactic	Successful Flight Tests	Non-powered (glide) tests, including testing the feather system
For flight commentary and the latest events see yourspaceflight.com			

Photo by SpaceX on Unsplash

CHAPTER I
THE SECOND SPACE RACE

It's over a decade since *SpaceShipOne* was air-dropped from *WhiteKnight One* and successfully rocketed to the edge of space to win the Ansari X-Prize. This second space race seems to be more of a marathon and not a sprint! We finally appear to be entering the penultimate lap as Virgin Galactic and Blue Origin go head-to-head to win the race. This chapter looks at who's who in the suborbital space race and whether there is still a wider market for the industry.

First of all, what's been happening since that great achievement by *SpaceShip One*? On the left is a ready reckoner of significant dates since the original X-Prize and this will be updated as events happen.

The table is quite telling in that you really do need a lot of funding for a spaceflight program; okay, the suborbital industry is not in the same league as orbital flight but it still needs to have a serious multi-millionaire involved – this is no crowd-funding venture! Below is a summary of the suborbital companies in flight testing and ground testing/development mode; the early developers/newcomers get a mention, but do lack the serious funding. I've included all of the companies in the table above because despite failures for some, they certainly did give it a go.

FLIGHT TEST STATUS

Meaning that a full-scale spacecraft has started the flight test phase i.e. this includes air-drop to test aerodynamics as well as powered flight.

VIRGIN GALACTIC

www.virgingalactic.com

SpaceShip2 is air-launched from the Carrier Aircraft *WhiteKnight Two* after a 50-minute climb to 50,000ft. After release, the spacecraft then fires its hybrid rocket engine for 70 seconds travelling at Mach 3 (2500mph) to reach over 100km. The six suborbital astronauts can then experience three to five minutes of weightlessness before the unique feathering device (like a shuttlecock) ensures they descend the right way up. This vertical descent has a -6Gx profile – meaning that the g-forces are felt through the body (chest to back) and it will feel like 6 times your body weight is pressing on top of you. This experience is manageable for healthy people and will be experienced in the centrifuge as part of training. We will look at medical and training aspects later.

So far, having undertaken 57 hot-fire ground tests (Scaled Composites up to October 2014), 36 airdrop unpowered tests (to date at time of writing, including *VSS Unity*) and three successful powered flight tests, Virgin Galactic are practically neck-and-neck with Blue Origin in this space race and arguably could already have been operating commercially had it not been for setbacks. In 2007 their engine catastrophically exploded during cold-flow injector ground tests killing three scientists[1]. The hybrid engine is fueled with hydroxyl-terminated polybutadiene (HTPB) and nitrous oxide (N2O) providing 60,000 pounds-force (270 kN). Since the accident the project has moved on and so have key personnel. The ambition is to get the engine to reliably and safely power *SpaceShip2* to the edge of space for commercial flights.

Back in 2014, Virgin Galactic signed up their 700th & 701st customers – the Winklevoss twins (the film *Social Network*) with thousands more waiting in the wings.

On 31st October 2014 during the 4th powered flight test *SpaceShip2* suffered a catastrophic accident, a short time after firing the rocket, whereby the vehicle structurally broke-up. A sad day indeed with one pilot fatality and one survival (thanks to a parachute).

On 20th February 2016, Virgin Galactic unveiled *SS2 Unity*. Stephen Hawking was proud to be part of the unveiling and looks forward to his spaceflight in the not too distant future. Virgin Galactic will now continue with the vehicle development and will use their own (fast-jet/astronaut based) test pilots, ably led by Dave Mackay. *SS2 Unity* has carried out successful air-drop tests and will commence powered flights soon in 2018.

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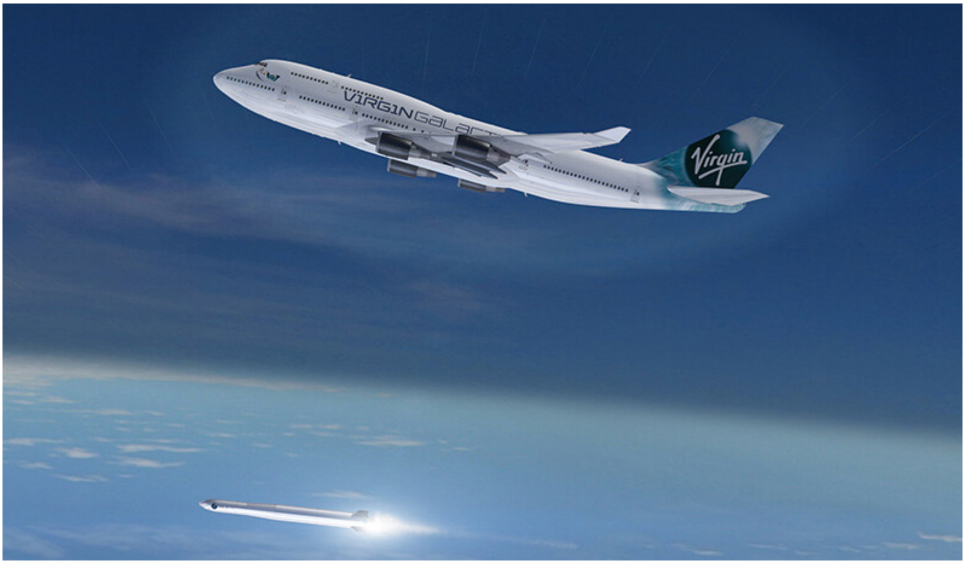
1 Cal/OSHA Accident investigation. Inspection No: 310821103, July 26, 2007

Credit: Virgin Galactic. View of SpaceShip2's *rocket firing after being air-dropped from* WhiteKnight Two

The company have set up 'Virgin Orbit' and are developing *LauncherOne* which is a custom-designed spacecraft to provide an affordable, dedicated path to orbit for smaller payloads. The typical configuration will be capable of delivering on the order of 500lb (225kg) payloads (satellites) to low earth orbit (LEO) and 225lb (100kg) to higher altitude, Sun-Synchronous LEO.

U.S. equipment developers are subject to International Traffic in Arms, or ITAR, regulations which exists to restrict the distribution of arms and proliferation of weapons systems. The regulations can range from a tin of army-coloured 'olive' paint to aircraft parts and in particular (and more appropriate) rocket engines, as well as the technical data associated with them. The point is really about the potential 'dual-use' under the Wassnaar Arrangement and the 'fear' is that the suborbital technology could be used as a weapon system against the U.S. as the originators of the technology; hence suborbital vehicles being on the U.S. Munitions List.

Although Virgin is a UK-registered brand, Scaled Composites (now Virgin Galactic – The Spaceship Company) are the design organisation and it is their design that is subject to ITAR.. There are two aspects to consider in my view. Firstly it's about flying in the U.S. at Spaceport America with suborbital astronauts from all over the world (or that's what should be allowed). However due to the FAA-AST requirements of informing 'participants' of the risks and allowing them to ask questions (See Chapter 10) then clearly people from those countries that are 'banned' by ITAR cannot fly in the U.S. vehicles. Secondly it is the aspiration of Virgin Galactic to operate in other countries such as Sweden, the UK and the UAE (see Spaceports in Chapter 2). So here is a potential bigger issue than flying with people in the U.S. that are not allowed by ITAR. If the U.S. government does not relax the export controls, then U.S. companies like Virgin Galactic may be not be permitted to operate outside of the U.S. potentially inhibiting growth for those companies. Virgin Galactic stated the following in relation



Credit: Virgin Galactic. Impression of Launcher One *rocket firing after being air-dropped from the 747 Carrier Aircraft,* Cosmic Girl

to the first case of people flying on board in the U.S. on a U.S.-developed vehicle:

> *"Virgin Galactic's space system is controlled under the ITAR by the U.S. government. The U.S. government has determined that the spaceflight customer experience falls under EAR99, a distinct category under the jurisdiction of the Commerce Department. Virgin Galactic adheres to both the spirit and the letter of U.S. export controls and has for now chosen not to accept deposits from countries subject to U.S. export and other regulatory restrictions," and Virgin Galactic further stated that "The U.S. government is giving focused attention to these and related issues, and as those considerations continue, Virgin Galactic may adapt its policies in consultation with appropriate regulators, legislators and other stakeholders..."*

We shall have to see whether the U.S. government relax the regulatory restrictions for suborbital flight or whether Virgin Galactic adapts its policies, whilst sticking within the rules, to allow people, say from China, to fly.

BLUE ORIGIN

www.blueorigin.com

Having developed the New Shepard vertical launch/vertical landing vehicle in the shadow of the Virgin Galactic, Blue Origin are now looking like strong competitors to Sir Richard Branson's company. As with Virgin Galactic the development has not been without incident. During flight tests in 2011 the New Shepard suffered an 'instability' resulting in thrust termination and destruction of the vehicle – the vehicle being unmanned for test flights.

Credit: Blue Origin

The company are also focusing their efforts on the orbital development program as part of the partnership with NASA on the Commercial Crew Development Program. In November 2013 test fired their B-3 Liquid Hydrogen-Liquid Oxygen engine for two and a half minutes (to mimic an orbital launch with 110,000 lbs of thrust). Blue Origin's approach is developing a reusable first stage launcher that descends to perform a powered vertical landing – so building on the suborbital model but with extra thrust! Their flight profile may also include landing at sea on a platform (Space-X have shown how difficult this is). The development of the engine has continued since 2013 and is at version BE-3 (suborbital version) and BE-4 (orbital version). The capsule then will separate and spend up to 1 minute in weightlessness before falling back into the discernible atmosphere for a parachute descent.

"New Shepard is designed to carry three or more astronauts up to sub-orbital space", Blue Origin President Rob Meyerson told reporters[2]. "We say 'three or more' because there are combinations of astronauts and science payloads. We believe the science payload market is going to be a big one as well".

Blue Origin development has progressed rapidly and on 29th April 2015 successfully launched to 307,000ft. The booster separated perfectly though had hydraulic issues on the control system (as it is supposed to power down to Earth – see diagram). The main capsule returned to Earth with parachute deployment per schedule and it landed with a gentle-ish 24ft per second touch-down (surely some airbags would help). Their second test flight in November was even better with the Booster successfully returning to carry out a vertical landing – a great historic day (and beating their orbital counterpart, Space-X). They continued this success during the third test flight; their motto 'launch, land, repeat' certainly seems to stack up! The fourth test verified the 'one-parachute out' on the crew pod, with the launcher providing a perfect launch, return and land.

On 5th October 2016, the fifth flight test demonstrated a successful 'abort' whereby the capsule fired its own mini-rockets to separate from the booster; this test objective was a major milestone in a seemingly well-structured test campaign.

2 Spaceflight Now, 9 April 2015

Credit: Copenhagen Suborbitals – yes this is a sea-launched vehicle so I hope you have your swimwear to hand

New Shepard flew again for the seventh time on 12th December 2017, from Blue Origin's West Texas Launch Site. Known as Mission 7 (M7), the mission featured the next-generation booster and the first flight of Crew Capsule 2.0. Crew Capsule 2.0 features large windows, measuring 2.4 feet wide, 3.6 feet tall. M7 also included 12 commercial, research and education payloads onboard. Crew Capsule 2.0 reached an apogee of 322,405 feet. Also on board, Blue's instrumented test dummy "Mannequin Skywalker".

COPENHAGEN SUBORBITALS

copenhagensuborbitals.com

Not having a boss such as Branson or Bezos, Copenhagen Suborbitals have done extremely well to design and build a vertical launch vehicle and then to test it – from the sea! The company have been going for over seven years and are progressing with the designs of their engines, the capsules, GPS guidance system and spacesuits.

Copenhagen Suborbitals (CopSub) have a definite mind-set in their build-fly-fix programs. They want to show that you can develop spacecraft within a smaller team at vastly reduced costs to typical governmental-controlled programs (or without the Branson-Bezos backing). As with the other suborbital developers in flight test, their launch of the capsule *Beautiful Betty* (previously *Tycho Deep Space*) in 2012 resulted in a 'mishap' when the nose cone broke off the Smaragd-1's launcher and the vehicle span out of control. CopSub have continued with their progress and had a successful flight up to 8km in 2013. They have continued testing their BMP-2 Engine with hot-fires in May 2015. Since then the company have developed a smaller 'Nexø I' rocket and eventually intend to develop a manned rocket, *Spica*. The company website states:

"The Nexø II rocket will be the most advanced rocket build and launched by CS so far. The Nexø rocket class is a technology demonstrator in advance of building the significantly bigger Spica rocket that will take our astronaut to space. Thus, Nexø is an important part of the Spica roadmap and the technology developed and used in the Nexø class will be used in the Spica rocket".

The sea-launch is a unique business model that has great potential for world-wide operations. This does however come with trade-offs in terms of risk during launch, re-entry and landing.

ARMADILLO AEROSPACE

An article in 2013 stated that the founder John Carmack has revealed that the company is now in 'hibernation'.

The transition from contract work to vehicle building just didn't pan out, he says. Having more full-time staff backfired, as workers were bogged down in planning and reviews; the team also repeated many of NASA's mistakes in material choices, limiting its production capacity. As Carmack isn't prepared to invest more of his personal funds to keep Armadillo going, the firm will likely remain on ice until there's a new investor who's ready to pay.

This is such a shame for those prospective space-diving 'junkies' who probably saw this vehicle as the answer to their prayers (see Chapter 8). It is included here because they were part of the X-Prize and did get their prototype vehicle off the ground!

Credit: Armadillo Aerospace. Single seat Reusable Launch Vehicle going straight up – what a ride that would have been!

GROUND TEST STATUS

XCOR

www.xcor.com

Author's Note: *XCOR filed for bankruptcy in November 2017. This section is retained just in case somebody takes up the mantle...*

The Lynx production spacecraft (Mark II) is single pilot, single suborbital astronaut vehicle (or Reusable Launch Vehicle [RLV] in U.S. terminology) that fires its four XR-5K18 rockets on the runway and then climbs up to a suborbital height of 100km. The whole flight is about 30 minutes. The suborbital astronaut will remain strapped into the seat but feel like they have literally piloted the spacecraft as they will be sitting virtually alongside the pilot. XCOR are developing a prototype vehicle (the Mark I) that will fly to 62km as part of the experimental license. There are already plans in place to develop the Mark II vehicle into a Mark III that features an external dorsal pod with either a payload experiment or upper stage capable of launching a small satellite into LEO.

Having a sound but steady development schedule, XCOR have been busy testing their cryogenic pumps for their Lynx rocket engine. The impressive facet is that the engine is 'throttleable' and can be restarted. This builds on the EZ-Rocket demonstrator vehicle using regeneratively-cooled liquid-fuelled rocket engines. The first flight was in 2001 and by 2008 the EZ-Rocket (second prototype Mark-I X-Racer) fantastically did circuits at the Oshkosh Air-show demonstrating the controllability of the vehicle but more importantly that the engine could be shut down and restarted. Overall the EZ-Rocket flew 26 times and the X-Racer 40 times showing great experience for Lynx development. In 2013 XCOR demonstrated a 67-second pump fed engine run and so continue their progressive development approach. This will provide great confidence that their vehicle is designed around a reliable engine with good safety features which will be needed to cope with the intended operating schedule of four flights a day. In December 2014 XCOR managed to 'close the loop' on their testing and so seem to be progressing well with the airframe taking shape.

Also XCOR have been expanding their engine acumen towards the orbital field. United Launch Alliance have sub-contracted XCOR to develop a Liquid Hydrogen engine which will incorporated XCOR's unique piston pumps. XCOR are confident that the vehicle is safe and that they are developing best practices for the emerging industry, starting with a very successful rocket engine development program.

XCOR have partnered with various Spaceports and operators to keep the Lynx development on track and the successful engine tests can only fuel confidence for the partners. The latest Spaceport MoU with Prestwick Spaceport was signed at the Farnborough 2016 Airshow.

Artist impression of the Lynx Reusable Launch Vehicle. Photo Courtesy of XCOR.

As with Virgin Galactic, ITAR is a bridge to be crossed in gaining approval to, in the first instance, fly people from say China and secondly in gaining approval to take their vehicle to operate outside of the U.S. In relation to ITAR XCOR doesn't see an issue in that the level of detail that participants will be told is 'what is necessary to discuss the general risks and detailing what is available on-line already – XCOR are not going to tell the participants on how the cryogenic pumps work for instance' (and indeed that is absolutely right – no need to go into engineering detail, but simply the vehicle type, profile, operating aspects concerning drills, specific hazards and so forth – see Chapter 10).

XCOR (SXC) announced that work had stopped due to lack of funding. Having achieved so much in the development, the company owners are still looking to continue this exciting project.

EARLY DEVELOPMENT STATUS

Meaning that the company has (or had) some funding and progressed to 'Phase B' of the design lifecycle (analysing the System Requirements and following on to a Preliminary Design Review).

AIRBUS SPACE AND DEFENCE

www.space-airbusds.com/en/dossiers-ea0/the-spaceplane-rocketing-into-the-future.html

Airbus Defence & Space (formerly EADS-Astrium) are developing a spaceplane based on a business-jet style vehicle with aero-engines to be able to operate from any airport (Spaceport) prior to the rocket engine phase. The term 'spaceplane' is not used in the U.S., however the UK CAA's report on Commercial Spaceflight [*www.caa.co.uk/cap1189*] have defined this as – 'a winged vehicle that acts as an aircraft while in the atmosphere and as a spacecraft while in space'.

The spaceplane will carry four suborbital astronauts to the edge of space. Currently Airbus are developing a prototype which is then to be further developed with the Singapore government and industry (the spaceplane will operate out of Singapore when certified).

The cabin is planned with you, the suborbital astronaut, in mind and therefore this bodes well in terms of designers thinking about your safety within their analysis. The seats have been designed like a pendulum therefore allowing the acceleration to be perpendicular to your backs when the vehicle pulls +3Gz transiting to the climb phase. They could have squeezed 6 seats in by the look of the diagram below but they clearly wish you to have more room.

Like most other suborbital designers there is an aspiration to be able to launch satellites and with this sort of aircraft-based design either a dorsal fin style fairing would have to be designed in or 'bomb-bay' fairings underneath could be an option. These decisions need to be made early in the design stages and as yet there is no further news of which option they are going for.

Recently however, Airbus D&S seem to have gone rather quiet about this project with fears that their bosses don't believe in the 'suborbital' market. Let's hope they change their mind with the success of the others.

Credit: Airbus Defence & Space – Artists impression of the Spaceplane based on a business jet design

Credit: Airbus Defence & Space

Credit: Swiss Space Systems

SWISS SPACE SYSTEMS (S3)

www.S-3.ch/en/home

S3 were developing a suborbital aircraft reusable (SOAR). S3 seemed to be doing well, but have suffered a setback in funding. As I said, this is an expensive undertaking and secure funding is key. Another sad setback.

POSSIBLE NEWCOMER STATUS

Meaning they have (or had) initial investment to start development i.e. concept phase.

This final group of prospective suborbital operators (illustrated on the right) have interesting looking designs and some have undertaken design studies proving their system is sound and ready for major investment.

Some of these companies have (or had) initial seed funding to get them to the next phase and some are trying to raise funding through donations and/or investments from the general public though crowd-funding. Examples of the latter category include Bristol Spaceplanes, Copenhagen Suborbitals and We Are Spaceship. Others in this category have been around for many years with sound business models but have not quite secured the big investment to take them to the next phase, despite having well-known consortium members ready to be part of their dream. I hope these companies get the investment they need once the forerunners commence operations. wallets.

Once that suborbital flight is a success potential investors may be more inclined to open their wallets. Indeed Rocketplane XP have been given a lifeline – a new contract to develop a vehicle for satellite launch; here's hoping that the vehicle will carry suborbital astronauts and launch satellites (though not on the same flight).

Good luck Chuck Lauer and team!

Bristol Spaceplanes (UK)
bristolspaceplanes.com

We Are SpaceShip (Germany):
www.wearespaceship.com

Credit: We are Spaceship

RocketPlane (USA):
www.rocketplane.com

Credit: Rocketplane

Ship In Space (UK)
shipinspace.com

EARL (UK)
www.spacefleet.co.uk

THE MORE SERENE SUBORBITAL EXPERIENCE

Space Balloons may seem a strange conception but they have been in existence for decades. The early 'high altitude' balloons were used for weather data gathering and later were developed to carry humans prior to the Russian success in sending a human into space using rocket-power. Since then there have a only been a few high altitude balloon flights with humans on board; in particular the *Excelsior III* balloon used for his third and record-breaking high-altitude 'jump' by Colonel Joseph Kittinger on 16th August 1960 from a height of 31.3km[3].

The FAA definition is

> *a balloon is a lighter-than-air aircraft that is not engine driven, and that sustains flight through the use of either gas buoyancy or an airborne heater[4].*

Zero2Infinity are a new company developing a 'near space' balloon (BLOON) with the goal of attaining a height of 36km for their two- to three-hour flight. The vehicle will be able to accommodate four passengers and two pilots. The sail is basically a balloon filled with inert helium. It bears the whole system through the atmosphere, with no fuel or propellant, no noise and no discomfort. Of note, they have recently developed and flight tested a very small satellite launcher system called BLOOSTAR. This uses the same principle of the balloon ascending to 30km altitude to air-launch the satellite – a great and simple idea.

The World View vehicle is different to the BLOON vehicle in that the Parafoil is already deployed and hence this is one less failure mode i.e. 'fails to deploy' but of course there is always the other side of the argument that may say the parafoil could get damaged on the ascent.

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3 http://en.wikipedia.org/wiki/Joseph_Kittinger
4 http://www.faa-aircraft-certification.com/faa-definitions.html

Credit: World View

So surely these near-space balloons are much safer than their rocket-powered competitors? We will look at the safety aspects in Part 2.

Is 36km actually 'near-space' and will you get your suborbital astronaut wings? If you are sitting in a cosy pod sipping champagne and taking in the view then perhaps it is a bit un-astronaut like; whereas if you are wearing a similar spacesuit/pressure suit to that of the rocket-powered vehicles and with the addition of an emergency parachute in case of parafoil failure then perhaps you may earn your wings. Let's see what the operators provide in terms of protection and training…

Credit: Zero2Infinity

THE MORE THE MERRIER

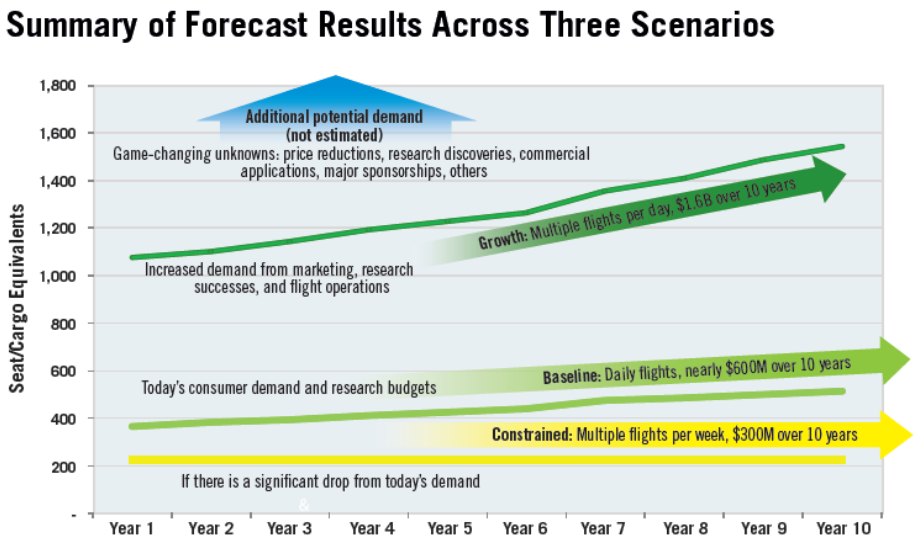
So there are lots of companies in various stages of development and all are wishing Virgin Galactic and Blue Origin successful commercial ventures to prove that suborbital flight is achievable. This then will unlock investment for their projects and so provide greater competition and in turn bring down the seat prices and increase the market.

There have been many market studies since the original Futron study in 2002. All of the studies have analysed High-Net-Worth Individuals with disposable income available for suborbital flights. In regards to the suborbital market projections, the updated 2006 Futron/Zogby report suggests that up to 13,000 people per year could be undertaking suborbital flights by 2021.

In a more recent contrasting study by the European Space Research and Technology Centre[5] the number is estimated at 15,000 people per year; the report suggests that the industry could move towards a classical aeronautical business model as soon as there would be a sufficient number of spacecraft manufacturers to cater for demand. The report further suggests that the 'luxury travel market' represents a unique chance for space tourism to get off the ground and reach the critical mass that will enable a significant ticket price decrease.

An even more recent market study was undertaken by the Tauri Group for the

5 Ve. Ziliotto. *Relevance of the Futron/Zogby survey conclusions to the current space tourism*, Acta Astronautica (2009)



Credit: Tauri Group

FAA-AST showing a 10-year forecast based on current seat prices. The results don't include additional potential demand if the prices were reduced, though clearly doing so would open up the spaceflights to a much wider populous.

THE IMPORTANCE OF SCIENCE

As well as suborbital astronaut flights and satellite launchers, the vehicles described above are capable of undertaking microgravity and other space-related research for the benefit of mankind. Access to suborbital environments means that research can be carried out in microgravity, (limited) radiation, vacuum and other fields.

Although the actual time in 'space' conditions may be small compared to orbital flights the suborbital flight increases the access to space conditions for a greater number of scientists and academia alike. The space time is short and so the cost is vastly reduced and another factor is the turnaround time of the vehicles (and numbers of operators over the next few years) which means more availability.

Photo by Alejandro Benet on Unsplash

CHAPTER 2
SUBORBITAL SPACEPORTS

An important aspect of your spaceflight, in addition to who you want to fly with, is where you can fly from.

As Industry Leaders, Virgin Galactic are currently based at Mojave Air & Spaceport for the development and test phases for their vehicles. For commercial operations they will need to move on and suborbital spaceports are popping up all over the world to receive them and the new boys on the block.

Next stop Spaceport America! Situated in New Mexico, Spaceport America will provide the facilities for the first commercial launch of this second space race as Virgin Galactic close in on the finishing line.

America has a lot of other spaceports such as Spaceport Florida, Oklahoma Spaceport, West Texas Spaceport and the Caribbean Spaceport to name a few.

Clearly for Blue Origin, who may yet win the suborbital space race, they will launch from the West Texas Launch Site (Spaceport) and no doubt be looking for other suitable locations for vertical launches in the US, such as Florida, and abroad.

In Europe, Spaceport Sweden have all the basic attributes for beginning commercial

Credit: Spaceport America

spaceflight operations apart from establishing and implementing operator requirements such as propellant handling and storage; these attributes will no doubt progress when they have a customer. There are spaceflight experiences available for everyone whilst the Spaceport waits for Virgin Galactic or Blue Origin in the future. Spaceport Sweden have teamed up with AirZero-G (France) to provide Zero-G flights and QinetiQ to provide centrifuge and hypobaric experiences and training at the Swedish Flight Physiological Centre at Linköping.

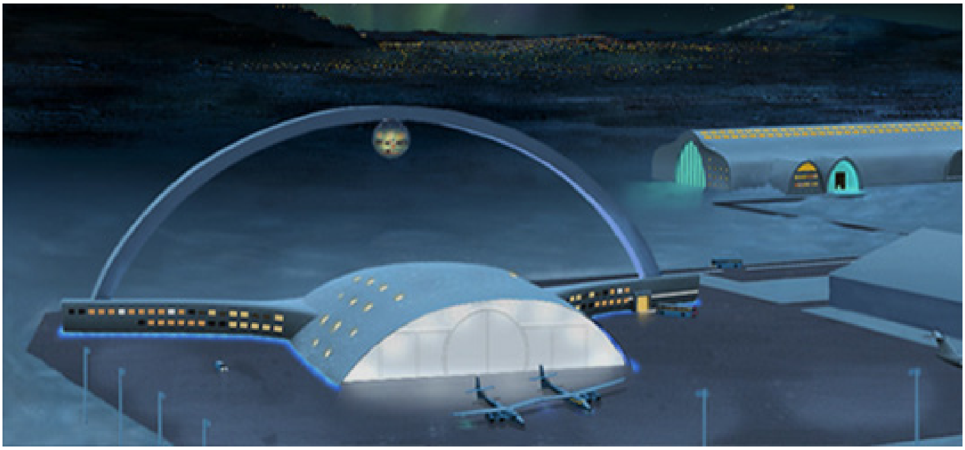
Elsewhere in Europe the UK Government have announced their intention of establishing a Spaceport by 2020 as detailed in the UK CAA's report on Commercial Spaceflight (CAP 1189) and as announced at the February 2017 LaunchUK event. CAP1189 is based on the CAA's review of existing commercial spaceflight regulations and also taking note of potential operator's requirements. The next phase of the UK Government sponsored task is to derive a suitable framework based on the report and this started with the Draft UK Spaceflight Bill (Primary Legislation). Then next steps are to derive the more detailed Secondary Legislation and guidance material. This will then allow any of the prospective UK Spaceports to apply for a launch license (all are coastal locations). The CAA have also provided a definition of a spaceport – 'a launch site for space operations' which includes suborbital spaceflight.

There are also opportunities in the Middle East due to the remote locations and funding. Virgin Galactic have an agreement to fly from Abu Dhabi having received funding from Aabar and more recently from Saudi Arabia. Asia are also gearing up to welcome spaceflight operators and Spaceport Malaysia have agreements to operate spaceplanes as well as their Zero-G flights.

Other Spaceports popping up in Asia include Spaceport Singapore who have an agreement with Airbus Defence & Space (formerly EADS Astrium) to develop a spaceplane; this seems to be on hold currently whilst the company focuses on engine development and perhaps due to lack of funding from Singapore's Government and private sector.

Rocketplane also intend to operate from Japan at Hokkaido - if successful with funding from their current satellite launcher programme.

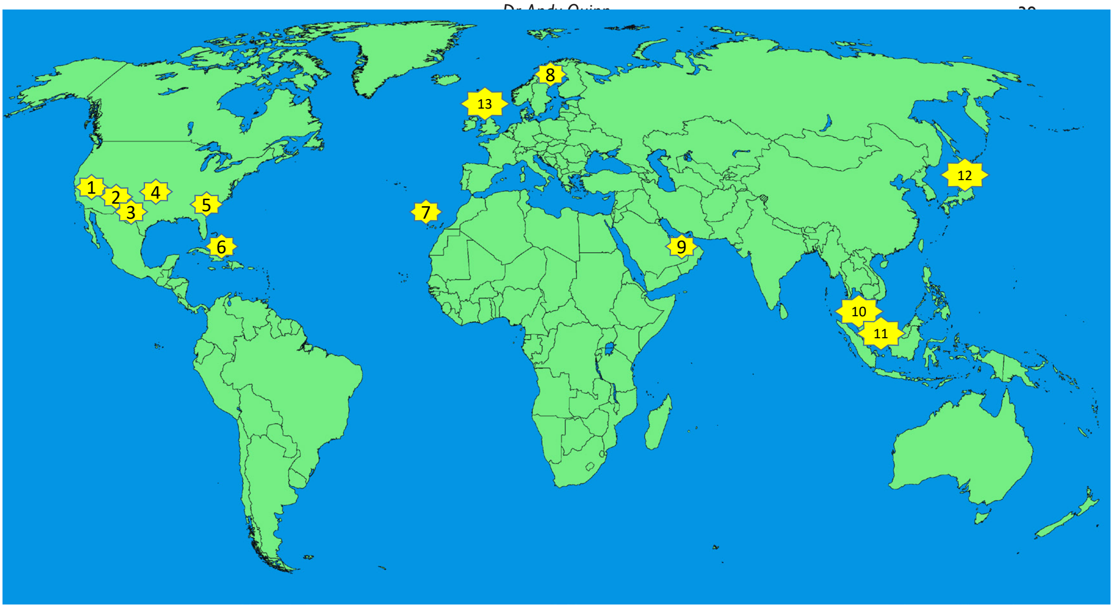
Credit: Spaceport Sweden



Spaceports have generally been associated with orbital launchers such as Kennedy Spaceport and Kourou Spaceport in French Guyana. These are remotely located with safe distances designed to protect the public (and for launching orbital vehicles). Suborbital spaceflight is different. What we have is different designs of the vehicle and together with the rocket, these factors make a big difference in the selection of a suitable spaceport. On the one hand an air-launched operator such as Virgin Galactic could take off from a 'normal' airport (that has been upgraded to a Spaceport – see further below) because the Carrier Aircraft will have been certified to do so. The Carrier Aircraft then flies to the approved exclusion zone or air corridor to release the spacecraft for its rocket phase. Then the spacecraft will glide back to the Spaceport after filing a 'Notice to Airmen' through the Air Traffic Management system which ensures other aircraft are aware that the corridor is active and that the approach path to the 'airport' is clear.

Next we have the horizontal take-off vehicles. These are further split into two types and have different Spaceport requirements. Firstly, the Rocketplane XP spacecraft design has two conventional engines for the take-off. This means that it can operate from a normal airport (that has been upgraded and approved to Spaceport standards) and then glide back under Air Traffic Control (with the potential to relight its main engines for landing or diverion). On the other hand, any future spacecraft (like the XCOR's Lynx vehicle design) would fire its rocket on the runway, then take-off like a fighter plane and would climb up to 80-100km. It would then glides back to the runway under Air Traffic Control. Any rocket fired on the runway would be very noisy and the noise thresholds would need to be checked within the Environmental Assessment for the spaceport; in most cases this type of spacecraft would either operate from a remote Spaceport or operate from a Spaceport that accepts noise (with limited exposure) such as Spaceport Florida. On top of the noise there is also the issue of safe distance in cases of rocket explosion. The primary concern here is to protect the un-involved public i.e. mainly those watching the launches/take-offs or even watching the test runs.

Credit: Spaceport Malaysia



Author Derived: Suborbital Spaceports: 1. Mojave Air & Spaceport 2. Spaceport America 3. West Texas Spaceport 4. Oklahoma Spaceport 5. Spaceport Florida 6. Caribbean Spaceport 7. Gran Canarias Spaceport 8. Spaceport Sweden 9. Abu Dhabi Spaceport 10. Spaceport Malaysia 11. Spaceport Singapore 12. Spaceport Hokkaido 13. UK Spaceport.Others not on the map but in contention – Lleida Spain, Lelystad Netherlands, Baltic Sea (for Copenhagen Suborbitals).

AIRPORT TO SPACEPORT

Transforming the normal airport into a Spaceport requires additional Safety Management and part of that activity is a risk assessment to ensure the safety of the uninvolved public on the ground (the Expected Casualty [E_C] analysis) AND to ensure the safety of those on board the vehicle and to ensure the safety of the uninvolved third parties in other aircraft.

In relation to safety at the Spaceport, the main consideration is safety of the uninvolved public. Clearly there is an existing risk of an aircraft crash for people who live next to or near airports (remember Concorde), though they may not think in those terms and instead may be more concerned with noise and pollution. Regulators and suborbital operators will have undertaken the E_C analysis to determine whether the risk of suborbital flight is below the safety threshold (target) to ensure that a 'reasonable' level of safety is maintained: note this cannot be equivalent to the risks posed by aircraft as they have been certified based on millions of flight-hour experience, whereas suborbital flight is novel with virtually no experience and hence is more 'risky'. The explosive siting plan for the spaceport provides appropriate safety distances to protect the uninvolved public for the storage of propellants and oxidizers and also for the 'loaded' vehicle on the runway (included mated spacecraft with the Carrier Aircraft). The safety distance to Inhabited Buildings is 1250ft (381m) and 750ft (229m) to Public Traffic Routes. These distances are based on the blast over-pressure with fragments from the explosion and the likelihood of resulting in casualties.

After take-off/launch the current E_C target is one in 10,000 per mission (collective risk of death/severe injury to the uninvolved public).

For the flight portion, E_C calculations take into account the following:

- Probability of failure of the vehicle (or indeed due to pilot error – or rather they should do considering the immaturity of suborbital vehicle operations)
- Likelihood of a debris fragments of the vehicle (or whole vehicle) will impact with the uninvolved public
- The casualty area
- The population density (which is the number of people in an area divided by the population area – usually in kilometres squared)

Should the E_C safety target be met, then the Regulators and the Spaceport can still provide further mitigation in reducing the residual risk (as there is always residual risk) such as limiting the flight profile to avoid overflight of heavily populated areas, limiting flights in the event of strong winds (which can adversely affect any debris trajectory, in the event of a vehicle break up for instance). Also the Authorities will be limiting the flight profile to a restricted airspace 'box' to prevent the likelihood of a mid-air collision with aircraft (and have a time limit for the restriction to minimize disruption to other airspace users) – the target threshold E_C for (other) aircraft is one in one million per mission. Another aspect (for coastal Spaceports and overflight of the sea) is a target threshold E_C of one in 100,000 per mission of a vehicle break-up (piece of debris) hitting a boat and killing the occupants.

The safety analysis will also derive explosive safe distances depending on type and amount of propellants in use and also determine acceptable noise levels. The Air Traffic integration needs to be proportionate to the location's airspace management with approved air corridors and exclusion zones for the rocket phase and glide phase (normal aircraft can 'go-around' if there is a problem on the runway or there is wind-shear for instance, as the engines are operable at all times – the suborbital spaceplanes mostly glide back). The airspace required will likely be segregated special use airspace (segregated-SUA) similar to unmanned aircraft systems (UAS) though more 'dynamic' and flexible solutions may be adopted so as not to inconvenience existing airspace users.

So some vehicles that take-off (launch) using rocket propulsion from the ground cannot simply operate from any Spaceport (due to the uninvolved public safety threshold not being met for instance) and thus must generally operate from 'remote' Spaceports. The key to successful operations is to provide an operational framework that does not impinge on existing airspace users (too much) and for suborbital operators to plan their flights accordingly; and of course, to get the suborbital vehicle reliability rates (and confidence levels) up to an acceptable level during development and early operations.

Credit: NASTAR. Jim Vandenberg from NASTAR/Virgin Galactic 'hooked' up to monitor his vital functions for centrifuge rides as part of medical and training.

CHAPTER 3
THE MEDICAL; AM I FIT TO FLY?

Not all people will be able to fly to the edge of space – this is no carnival fair ride. Yes, for those of us whom are fit and healthy and have experienced acceleration forces in the centrifuge or in fast jets, then the suborbital flight will be thrilling and fun and wondrous. So are you fit to fly? Well let's see how fit and healthy you should be.

The Federal Aviation Administration's Office of Commercial Space Transportation (FAA-ST) state the following in relation to spaceflight participants:

> *"Each space flight participant should provide his or her medical history to a physician experienced or trained in the concepts of aerospace medicine. The physician should determine whether the space flight participant should undergo an appropriate physical examination."*

Does this statement mean that you don't undergo a medical if your medical history shows a 'clean bill of health'? No - the Aerospace Physician will do a medical examination before you fly. The operator has a duty of care to you and would need to demonstrate this in the event of a death. The assessment will examine your medical history and current fitness level to determine whether you can cope with the training and the spaceflight and then carry out the medical assessment.

The goal of the operators will be to be as 'inclusive' as possible but in the early days some people may be told they are not fit to fly.

Let's look at **why** you may not be fit to fly at that point in time – why some conditions may contraindicate a prospective suborbital astronaut from his or her dream.

- *Not Fit Ever*
  Not many people will fall in to this bracket I imagine but some will be excluded due to certain medical conditions (yet to be determined).

- *Not Fit for the Moment*
  For example, you have a recent injury, or you have a medical condition that is 'borderline' and there is simply not enough data (for suborbital flights) to say yes or no – hence wait until we have more flights under our belt and then we may let you fly.

- *Not Fit For This Flight Only*
  Perhaps you're either not well or during the pre-flight training (in the centrifuge or on a zero-g flight) you can't cope and need more experiential training to desensitize you (which would be good to do much earlier in the schedule than just two days before the spaceflight – the FAA-AST guidelines say this should be within six months of the flight).

At the end of the day, it's about being fit enough so that you do not have an inflight death, or inflight medical emergency, or have a medical issue that comprises yourself or your other suborbital astronauts and most of all so that you do not compromise the flight crew's ability to pilot the vehicle. Also in the event of an inflight emergency that you can follow the emergency drills and not compromise others.

Some of the medical issues that could be encountered during the flight include the following:

- *Neurovestibular* – changes in the body's sensory systems; this is most likely in the +Gz or 'eyeballs down' acceleration (more of in the next Chapter); hence seat design should be angled back so that the person feels the acceleration more in the +Gx axis (chest to back) as the body can generally withstand a higher level of 'G' as the heart and brain are approximately at the same level. These acceleration forces, coupled with noise and vibration may also induce motion sickness.

- *Musculoskeletal* – neck injuries are most likely when experiencing high G-forces.

- *Cardiovascular* – changes in cardiac rate and function.

- *Pulmonary Function issues* – difficulty with breathing due to airway closure or pressure on the lungs.

From the above medical hazards/conditions, the outcome could range from a minor nuisance factor, through serious condition to death. This is why you really do need the GP medical assessment followed by the operator Aerospace Medical assessment before being decreed 'fit for training' in the first instance and then 'fit for flight'.

If you have an existing medical condition or are recovering from an operation or injury, then the suborbital spaceflight environment could aggravate or exacerbate these issues; hence the operator's aerospace physician will make an assessment of you and this may include recommendation for controlled and gradual g-force runs in the centrifuge.

The more medical data gathered during both training activities and flights the better; after which the aerospace medical experts can then start to provide more accurate lists for contraindicating conditions. Whilst undertaking training and for the actual flight you will have a physiological monitor to check on your vital functions. 'Astronauts-4-Hire'[6] are testing such a device – the ViSi MobileTM System from Sotera Wireless. The device has the capability to reliably capture critical physiological metrics such as continuous non-invasive blood pressure, arterial oxygen saturation, heart rate, respiratory rate, skin temperature and multi-lead electrocardiogram. Additional data from integrated accelerometers and a display will be used to remotely view, control, and assess physiologic response. As can be seen below this is worn on the wrist and it remains to be seen how this will be integrated to a spacesuit for instance. Another way of achieving the same results would be a 'smart' bio-vest which could easily fit underneath the spacesuit.

The key point about the physiological monitoring is that it also integrates with the spacecraft's telemetry such that during the flight the operator's aerospace physician can monitor the suborbital astronauts (as well as the crew).

MEDICAL CONSENT?

As well as informed consent to fly (see Chapter 9) in terms of knowing and accepting the risks (from the hazards) consideration should be given about your medical consent. What I mean here is that should you have a medical incident or emergency then somebody on board (or ground-crew/support staff 'first to the scene') may try and save your life in difficult circumstances. Now I'm not saying we are a litigious society, but we are and I'm sure your lawyers are all over this spaceflight.

Part 3 contains a checklist for your spaceflight including a medical section for you to complete as part of your preparation program.

PILOT MEDICAL REQUIREMENTS

As well as being interested in your own health you will no doubt be wondering about the medical status of your pilots (I'm going to call these suborbital astronaut (crew) – though will here forth still call them pilots). The FAA-AST requires a pilot **only** to have a *Class II Aerospace Medical Certificate*. What this means is a thorough medical examination to strict standards for blood pressure, neurologic aspects, Electrocardiograph (ECG) (which measures electrical impulses through the heart), Lung Function Test (spirometry/peak flow) which tests your ability to breathe deeply and to expel

6 www.astronauts4hire.org/2012/02/press-release-astronauts4hire-and-vital.html

(Credit: Astronauts4Hire/Sotera Wireless)

air from your lungs and so on. However, the medical experts in the industry, including the International Association for the Advancement of Space Safety (IAASS) Suborbital Safety Technical Committee, say that pilots of suborbital vehicles should have the most stringent standard i.e. the *Class I Aerospace Medical Certificate*. The main additional assessment is the Electroencephalogram (EEG) which records the brain's spontaneous electrical activity. The IAASS Suborbital Safety Guidance Manual states the reason being that these high performance spaceplanes need to be handled by high performance pilots i.e. fast jet test pilots (in the first instance) and hence these category of skilled pilots have Class I medicals and have also been subjected to high g-forces within the centrifuge. The Aerospace Medical Association (AsMA) also have a similar view to this.

So don't worry – these pilots do (generally) have the 'right stuff' not only in relation to performance but also in terms of medical fitness (including medical history). In my view pilots of suborbital vehicles should not only have Class I Medical Clearance, but originate from the test school cadre (or be the crème-de-la-crème of fast jet pilots). Why? – because they are able to cope with high g-forces, fast speeds, and emergencies **better** than any other pilot. No disrespect to airline pilots (that are not in this category – there are some airline pilots who were previously in this category) but during certain parts of the suborbital flight you really do need to have the best-of-the-best; otherwise pilots will make mistakes and cause accidents. I'm not saying the best-of-the-best fast jet pilots do not make mistakes but they certainly can cope with a lot more than their non-test pilot counterparts and make less vital mistakes in the critical phases. I have no facts or proof of this, I just know this is right having flown with fast jet pilots and airline-type pilots (in the RAF, who are now airline pilots).

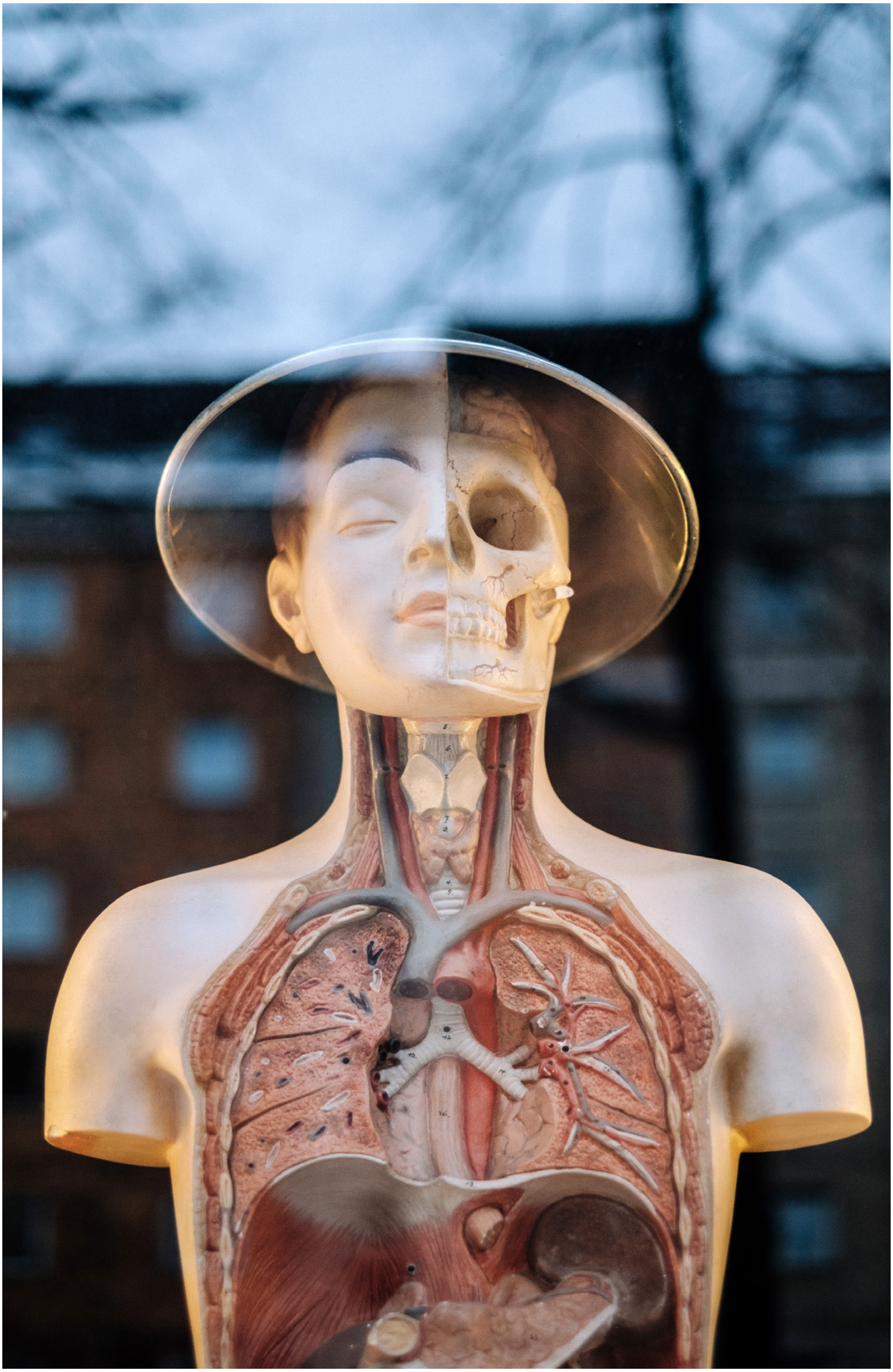


Photo by Samuel Zeller on Unsplash

TRAINING AND FITNESS

One of the key questions many prospective suborbital astronauts will have is: am I fit enough to go? Fortunately, this is one factor where you can make a difference. I'll hand over to Alex Quinn, fitness coach and personal trainer, who offers the following advice on how to get the most out of your spaceflight experience.

ALEX QUINN

coachquinny.co.uk

I began my research into the physical training side of Suborbital Spaceflight specifically for normal folk over ten years ago. My dissertation within my Degree in Exercise and Sport Science at the University of Exeter was titled *The Effects of Strength Training on the Ability to Perform the Anti-G Straining Maneuver.* I was specifically looking at how improvements in a few areas including muscular strength, core strength and breathing capabilities could improve one's ability to perform the AGSM, a technique used when experiencing Gz to reduce the chance of GLOC (G-induced Loss of Consciousness). My results found that both groups (strength training group and control group) improved their ability to raise their blood pressure through using and practicing the technique but there was a positive significant difference found with the addition of tailored strength training.

With such high initial costs of around $200,000 and relatively low flight duration (potentially 30 minutes) it makes logical sense to ensure your body and mind are fit for the task. Making the most of this potentially once in a lifetime opportunity is in the best interests of everyone involved. Operators and suborbital astronauts alike will both want to ensure both a) safety and b) enjoyment.

There are many ways these two factors can be increased and physical training and preparation is one of them. The safety factor is obviously important as self preservation is a natural instinct but enjoyment of the occasion and experience may be greatly influenced by prior preparation. The last thing you want as a paying customer of an experience of this price and magnitude is to not enjoy it due to being 'overly' uncomfortable and scared.

If you have confidence in your preparation you will naturally have more confidence in your abilities to withstand the 'unknown' nature of suborbital spaceflight. Sure, you've seen plenty astronauts on television throughout the years but most who will partake will have never experienced anything like it. Technical training, such as the use of a centrifuge to experience G-force coupled with the education and coaching of the use of the Anti-G Straining technique to try and reduce the chance of G-LOC will in itself be something people have never experienced. Ensuring that you have physically prepared

yourself to the best of your ability will give you confidence going into the training let alone the flight itself.

The whole experience of training through to the flight itself should be an immensely rewarding and exciting adventure so maximise it by starting your preparation today!

HOW DO I PREPARE TODAY? DO I NEED A SPECIFIC 'ASTRONAUT TRAINING MACHINE?'

No and Yes.

You cannot recreate G force within the gym environment but your body is the same no-matter what you throw at it and improving base levels of strength and aerobic and anaerobic fitness will help your performance of specific training. To use athletes as an example - a rugby player doesn't just play rugby and do rugby based fitness or skill drills, he builds and improves base levels of strength and fitness within the gym that enhance and help improve the more specific elements of training.

This means you can and should start today with your physical training for your sub-orbital spaceflight (it also makes for interesting social media training posts, watch the questions come flying in!).

HOW DO I DO IT?

The key thing is to remember your body is the same regardless of the training modality you use. The principles and factors you would want to emphasise to specifically help

your spaceflight performance can be adapted and used within any exercise or styles of exercise within reason. Time restraints would be the only caveat however as you need to be more specific if your flight date or training date was fast approaching. If you are starting to prepare well in advance though, you can carry on training the way you enjoy, albeit with some adjustments and tweaks. Bespoke training programs are available for those wishing to maximise their preparation and have professional coaching in the often confusing element of physical training.

WHAT SHOULD I FOCUS ON IMPROVING?

A bespoke program will always be the best way to physically prepare as it takes into account the strengths, weaknesses and ability of the individual but there are areas that anyone can work on and as I mentioned above it doesn't necessarily need to be within a specific exercise or training modality.

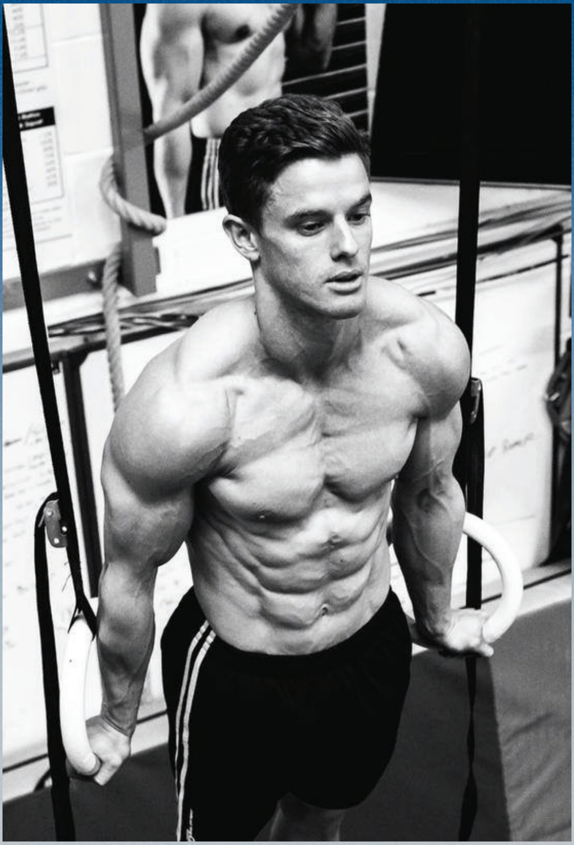
1. BREATHING

The ability to control and utilise different breathing techniques is a massively underused skill within strength training and general fitness as a whole. Most will never practice or experiment with different techniques used for various outcomes and reasons. An example used within Powerlifting which is in some ways similar to the AGSM is the use and control of intra-abdominal pressure or valsalva maneuver. A deep diaphragmatic breath (into the belly, not the chest) which is held against a closed glottis is used to increase Intra-abdominal pressure greatly improving the strength of abdominal bracing needed within a heavy squat or deadlift in particular.

2. MUSCULAR CONTROL

Within the normal personal training/fitness world I'm always coaching the basics. Many people have an understanding of basic exercise technique but few actually understand

and utilise proper muscular contraction on the muscles or group of muscles they should be targeting. To be able to perform specific bracing or techniques that may be complicated the individual must first be able to purposefully contract the desired muscle at a basic level.



3. 'CORE' STRENGTH

A strong body is built on a strong 'core'. Most of the time discussion about the core uses a generalisation of a large group of muscles including the abdominals. To keep it simple, the core plays the primary role of stabilising the entire body. Compound movements or exercises that involve lots of muscles especially from different ends of the body rely on stabilisation through the core to be efficient and effective.

4. CARDIOVASCULAR FITNESS

A high level of cardiovascular fitness will help any prospective sub-orbital astronaut deal with the general rigours of spaceflight. The combination of increased heart rate, blood pressure and muscular contractions can take a large toll on the body. Most would look at the fight duration of around 15 to 30 minutes to be quite short when relating it to the price and perceived enjoyment; from a physiological standpoint, 30 minutes is quite a long time for the body to be under the listed stresses.

In summary, physical preparation will most likely make a huge difference to the overall flight experience and in a lot of cases actually determine whether or not your 'experience of a lifetime' will take place at all.

LOOKING FOR A PLACE TO START?

If you're in the south west of England, check out Starks Fitness in Bristol, where you can benefit from a tailored workout plans specifically developed to help you hit your individual goals. In our case, let's get you ready for space!

info@starksfitness.co.uk / starksfitness.co.uk

Credit: NASTAR

Photo by Jeff Cooper on Unsplash

CHAPTER 4
THE TRAINING; WHAT SHOULD BE PROVIDED

So now that you have been passed medically fit you can start training. Let's take a look at what *should* be part of your spaceflight preparation program and why. There are different types of suborbital spacecraft and this means there are different flight profiles. So each different operator will have their own tailored 'training' program. We will look at all available training to help you prepare for your flight.

The FAA-AST requirement for SFP training is as follows:

> *"The RLV operator should provide safety training to each space flight participant prior to flight on how to respond to any credible emergency situations, which may include but are not limited to cabin depressurization, fire, smoke, and emergency egress"*

First of all 'training' is many things to many people and the FAA-AST is an example of that where they say the requirements is for safety training for credible emergency situations (because they don't want to over-regulate) – so in its simplest form this could mean a classroom briefing. For me, it is about preparing you, not as a passenger (of an aircraft where you do get the emergency briefing) but as a spaceflight participant (aka suborbital astronaut). So you may be the only non-pilot person on board (Lynx, Armadillo) or you may be one of 6 suborbital astronauts (Virgin Galactic et.al) but either way you could negatively affect the other participants or worse, the pilot. Just imagine you are sitting next to the pilot and you throw up over the pilot or the instruments, or you pass out (grey-out through to black out and on to G-Induced Loss of Consciousness [G-LOC]) and then do the 'funky chicken' as you recover and your arms flail[7] and hit the pilot, rendering him/her unconscious! No really – look at the YouTube video.

So it's really important that operators firstly identify these people-based hazards associated with the spaceflight which will vary depending on the design of the spacecraft. Once the accident sequence has been identified then mitigation can be identified to either reduce the probability of the hazard or accident occurring or reducing the severity of the accident. In this instance training forms part of the hazard mitigation i.e. centrifuge training (a hazard control) including the Anti-G Straining Manoeuvre (AGSM) can reduce the likelihood of G-LOC occurring. However, if G-LOC did occur, if you didn't do the drill properly for instance, then to prevent the accident (of your death) the operator profile should limit the time at risk to excessive g-forces (hence this is an accident control).

The purpose of the training is to prepare your mind and your body for an exciting but unnatural experience. So operators need to provide you with both physiological and psychological experiences to enable you to cope with and therefore enjoy the spaceflight. It is no use if you pass out for 10 seconds on the 3g pull-up and then spend another 20 seconds doing the funky chicken or just getting your bearings before being turned upside down and you losing your situational awareness and being sick (in particularly anywhere near the pilots).

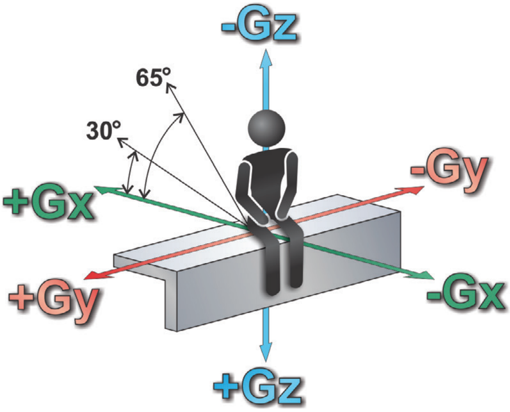
Here is a guide to the different spaceflight training experiences that your operator should and/or could provide you with:

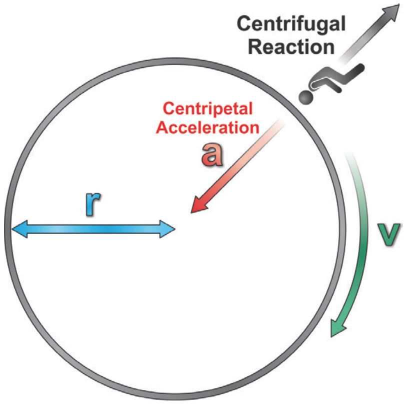
CENTRIFUGE

The centrifuge should be considered as an **essential** part of the preparation program. Indeed, the regulators should mandate this but of course at this stage they (the FAA-AST) do not want to be over prescriptive. In the diagram below we can see that as the Centrifuge spins round at an onset rate of 1G per second the acceleration causing the change in direction of travel is the centripetal acceleration. From Newton's 3rd Law we know there is an equal and opposite reaction and here the perception of the acceleration is that of a centrifugal reaction force in the opposite direction.

The centrifuge is a controlled environment where you will experience +Gz (eyeballs down i.e. head to foot loss of blood) and also +Gx (chest to back). It's called 'eyeballs down' because with centripetal force the blood pools towards your feet when you are sitting up, hence there is a blood pressure reduction to your brain and eyes. The eyes are affected first as a certain amount of blood pressure is needed to maintain the spherical shape; when you look at centrifuge YouTube videos you can see the 'subject' being pressed into the seat followed by 'eyeballs down'. To aid you during your flight,

7 www.youtube.com/watch?v=lGhydNnqJ5E





the spacecraft designer should be thinking about the angle of your seat how it can be adjusted (automatically or manually) to suit the ascent and 're-entry' (descent). I have adjusted the following 'seated-axis' figure above to show possible optimum re-entry angles to lessen the effect of 'G' on the body (80 degrees for suborbital astronauts and 65 degrees for pilots). This is based on various author's papers [8,9] relevant to research in the effects of 'G'. At all other times the seats can be at 30 degrees from the upright so that suborbital astronauts can see the view. Looking at some of the prospective seat designs (Virgin Galactic and Airbus [Astrium]) they certainly look ergonomic and dynamic and so it would appear that some designers are on top of the issue.

Your Aerospace Physician will train you in the AGSM technique prior to and in the centrifuge to prevent you getting 'eyeballs down'. I remember doing this in the centrifuge and it is quite tiring because it involves two aspects; the first is tensing your leg and stomach muscles which squeezes your veins to prevent venous pooling and ensures the blood returns to the heart (rather than your feet). At the same time, you breathe out forcefully whilst constricting your throat and then take rapid intakes of breath every few seconds. Doing the tensing and the 'strained' breathing also increases the pressure on your lungs and this in turn applies pressure to your heart so raising your blood pressure. So done correctly, the combined tensing and straining will ensure you cope with the nominal suborbital g-forces.

Once you've practiced it just sitting down (try it now for say 10-15 seconds or five intakes of breath) you will notice how tiring it can get and that you may feel light-headed. There is a danger whilst in the centrifuge or during the actual flight of getting the technique wrong and this in itself (as a control against G-LOC) could actually result in G-LOC if you strain for too long. Or if you get your straining-breath ratio incorrect i.e. too short, this could result in hyperventilation. - But your operator's physician will ensure you get it right and then you can practice this on low-g runs, say up to +2.5Gz

8 Dietlin LF & Pestov ID, *Space Biology and Medicine –Health, Performance and Safety of Space Crews,* Vol 4, 2004, American Institute of Aeronautics and Astronauts, Inc.

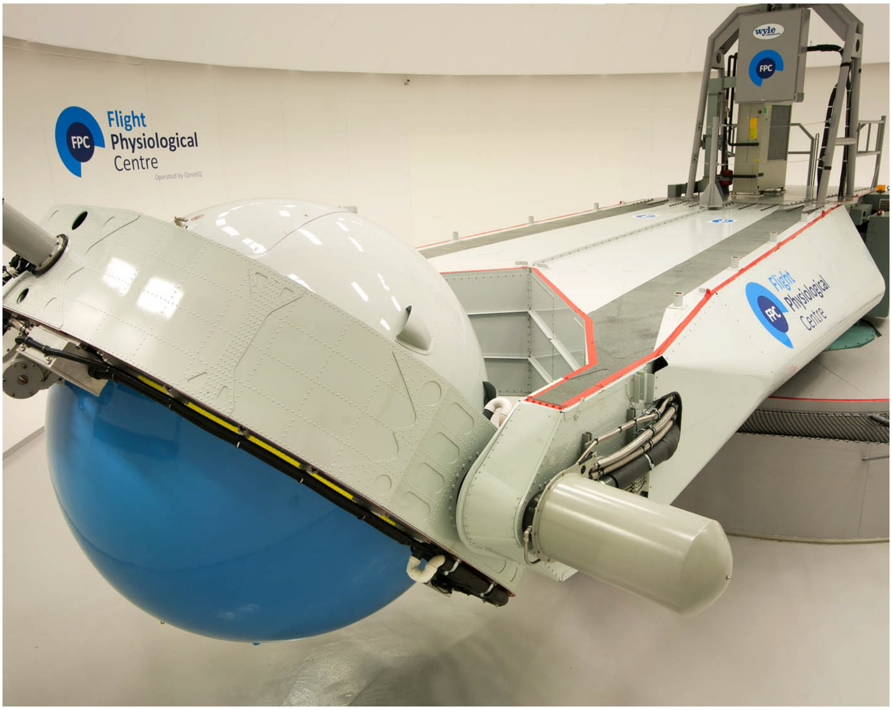
9 Hansford C, *High G and High G Protection; Aeromedical and Operational Aspects*, 1987, submitted to the Royal Aeronautical Society symposium

prior to higher g-force runs. When you're doing your centrifuge run you will feel the onset of G and then being pressed into your seat followed swiftly by the blood flowing towards your feet. At this stage you will get grey-out. For me this was like grey curtains coming in from the side of your vision and if you let them shut in the middle then you will encounter 'black-out'. If the G is sustained (which is shouldn't be on a nominal suborbital flight) then you would succumb to G-LOC where the eyeballs would lose their spherical shape. With further sustained G (extremely unlikely to occur) then this could result in death. So when you start to experience the 'grey curtains' and you do the AGSM you literally push the grey out to the peripherals and away – then if you relax they come back. So I was 'playing' with the 'curtains' on one of my runs just to get the feel of it – check this out on my YouTube channel centrifuge videos (you can find the link over at yourspaceflight.com). On a suborbital flight you should experience no more than +3.5Gz for perhaps five seconds maximum and so by your second rapid intake of breath on your AGSM the spacecraft should have steadied itself into the ascent with the G transferring to Gx.

In the image opposite you can see that the NASTAR centrifuge has a 'cockpit' gondola at the end of the fulcrum. This is a Dynamic Flight Simulator (DFS) because there is a pilot control stick for controlling the amount of g-onset; this is a 'dead-man's stick' as in the event of you blacking out your hand will let go and this brings the centrifuge safely to a halt (it is only one of many emergency stops [E-Stops] because the medical officer has a stop capability, as does the 'pilot instructor' and also the centrifuge operator).

A similar centrifuge to the NASTAR one is the QinetiQ-operated DFS at the Flight Physiological Centre (FPC) at Linköping, Sweden. As detailed in the Spaceport section, Spaceport Sweden has an MoU with QinetiQ to train suborbital astronauts, so go speak to Karin Nilsdotter for your centrifuge experience. You can see a pilot controlling the flight and g-onset in the following figure. The monitors display the selected flight area and simulated profiles are available, including a suborbital profile as shown opposite.

I visited the FPC earlier in 2014 and as well as DFS, QinetiQ operate a hypobaric chamber, hyperbaric chamber and a test pool (for sea survival drills). The FPC is a great facility for spaceflight training and I hope any prospective European-based suborbital astronauts will take the opportunity to start your preparation program early (see Chapter 3 checklist). The FPC is run by an extremely professional and friendly team: James Cooper (Business Development), Thomas Andersson (FPC Manager), Bjorn Klingspetz (DFS), Patrik Oster (Hyperbaric) and Leif Dahlberg (Hypobaric) to name a few.



Credit both above: Qinetiq

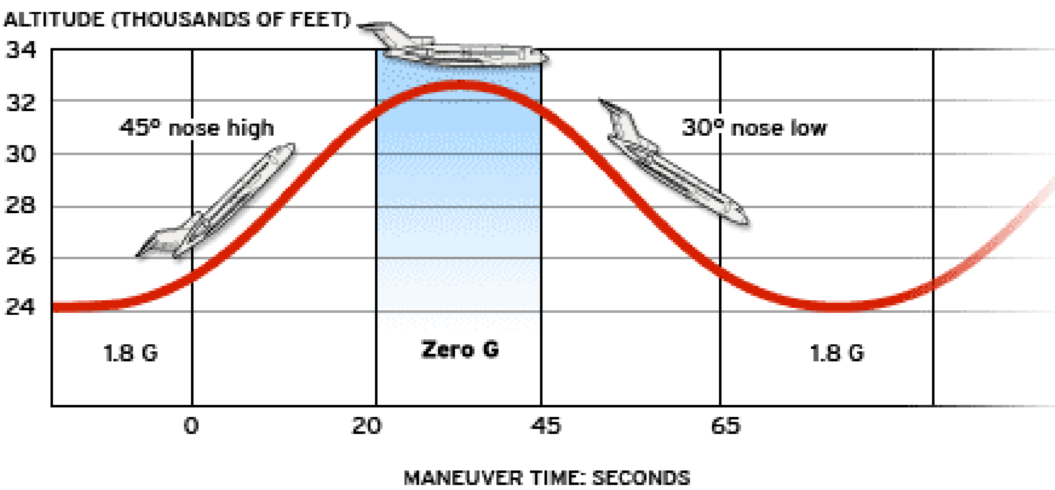
ZERO-G

To experience microgravity conditions should be considered essential for those operators who will let their participants out of their seats to experience 'zero-g'. However, for operators who will not let the participants out of their seat then this is clearly not essential but could be deemed desirable as part of their training. The zero-g experience is on board a modified aircraft certified to undertake parabolas. What this means is that the aircraft fluid systems have been modified so that they do not cavitate during the ballistic part of the profile. The Zero-G Corporation (USA) and AirZeroG (France) provide this service. In the UK Orbital Access are not only developing small satellite launchers but are considering using their mothership, along with other aircraft, to provide zero-g experiences. They also provide a suite of spaceflight experiential packages from zero-g, to high performance (see below) as well as partnering with centrifuge providers and 'edge-of-space' experiences (with the BLOON Pod).

White Knight Two also has the capability to provide zero-g experience to suborbital astronauts who are on board after watching *SpaceShip2* zoom up to the edge of space. Watching this first will also provide valuable psychological training for those about to take the next flight to the edge of space.

The point above is to show that practicaly anyone can participate in zero-g experiences. Indeed Sir Richard Branson has invited Stephen Hawkin to fly to the edge of space in *SS2* and he has already undertaken his zero-g 'training'. This cannot be said necessarily for all training, such as the centrifuge, hypobaric chamber and high-performance jet flights.

Credit: Zero-G Corporation



Credit both above: Zero-G Corporation

HIGH PERFORMANCE AIRCRAFT FLIGHTS

This may be considered by some operators as only desirable and I am sure they will work out the costs of the training into the overall costs and some training may not make the cut. However, I believe these fights to be more essential because they provide 'real' physiological and psychological training. This is because you are fitted out with a flying suit, helmet, oxygen mask and life jacket if required. Then you receive a safety briefing for getting into the ejection seat and what to do in an emergency. Then you are strapped in (more akin to strapping into the spacecraft i.e. this is it!) and the engine started with the noise and vibration – all real. Then it's the taxi to the runway and take-off where you are pressed back into your seat with the acceleration down the runway followed by a pull-up and immediate Gz (eyeballs down) sensation. During the flight you will experience lots of Gz turns and will have a good chance to practice your AGSM – though you may have some Anti-G trousers that will expand to assist you inkeeping the blood up in your brain. Getting used to the oxygen mask and breathing oxygen (partial air/oxygen mix in normal use) is also essential physiological and psychological training to see if you can cope because some people may get claustrophobic for instance. Types of high performance aircraft that could be used include the L-39, MIG-25 (extreme high altitude) and non-jet aircraft such as the Extra 300.

HYPOBARIC TRAINING IN ALTITUDE CHAMBER

The Hypobaric or altitude chamber provides another controlled but real experience in learning about the effects of lack of oxygen (hypoxia) and in using the oxygen mask. This is essential for pilots and arguably essential for participants – though some operators may not think so if their design does not include an oxygen system.

The altitude chamber is able to slowly or instantaneously evacuate the air within the chamber (to a chamber beneath the one you will be sitting in) and hence represent any altitude up to 100,000ft. When the air is evacuated instantaneously it forms a

Credit: Incredible Adventures

Credit: Author in a Hawk prior to flight – photo taken by my most excellent pilot Dave Beresford who provided fantastic experiences of all sorts of g-forces, high-key recovery and fast jet experience. Dave is one of these brilliant fast jet pilots and airline pilot for Virgin Airways – hopefully he will be inducted into the VG team of pilots as they grow commercially.

Credit: RAFCAM - Author on the right in the Hypobaric Chamber

mist (remember this for later). I have participated in training as aircrew up to 25,000ft where you are then required to remove your mask to experience the effects of hypoxia (in case your oxygen system fails during the real flight).

We were allowed to be off oxygen for four minutes maximum as after that the brain suffers from lack of oxygen which would then result in permanent damage and eventually death (if oxygen is not restored). During that time the effects of hypoxia range from a numbness in your lips and fingertips, narrowing of vision and confusion in the brain. This is demonstrated by simple tests on a piece of paper where you start of fine and then eventually can't do simple maths or even respond to instructions (check out Jeremy Clarkson doing this on YouTube - www.youtube.com/watch?v=0UUjI5Bs8mE). I also took part in a training session with fast jet pilots and they have to train to an altitude of 40,000ft in the chamber in case they have a decompression at higher altitudes. At this altitude 100% oxygen is required at a pressure breathing rate because the 'air' is so thin. This is really difficult to get used to and you practice on a rig first – it is so not natural to have oxygen being forced down your mask and you tend to gulp at first and it takes a while to control this. The fast jet pilots take this in their stride but you certainly feel like you are in an emergency situation – even at the rig before you get in the chamber! When in the chamber and under pressure breathing, it is even more imperative you get it right because there is a risk of panic and not taking the oxygen in.

I don't believe you will be required to undergo pressure breathing in a chamber but the point of mentioning it is to make you aware that the higher you go, the more important it is to have your own self-contained oxygen system – so make sure you ask your operator this question (see Part 3 for a list of questions).

SENSORY EXPERIENCES

The spaceflight profile will certainly mess with your sensory system and this can make you feel sick and disoriented. Sensory experiential training will help you get to know how your neurovestibular system copes. The training equipment is very basic and in a controlled environment to help you get used to it. This can involve using a simple spinning machines (with no lights) or 'space-balls' to get that floating upside down feeling (see figure below) and finally vibration machines etc.

Credit: Dr Carol Norberg, UMEA University,` Kiruna Campus, Sweden. Author in the Spaceball, Manned Spaceflight Course, Kiruna

DO YOU HAVE THE 'RIGHT STUFF'?

So can you cope with a suborbital spaceflight? Clearly the point of doing all of the training activities and experiences is twofold: to see if your body can cope and to see if you really do enjoy it. You don't need nerves of steel and you don't need a stomach of iron. You just need to be able to cope and get the most out of the experience – after all it could be a once in a lifetime experience. Most people will be able to cope with the training and indeed the flight. The suborbital operators want to make the experience as inclusive as possible and this should give you confidence that it will be fine and that you do have the right stuff to be a suborbital astronaut.

SUMMARY ON TRAINING

So all of these training experiences really do help in preparing you both physiologically and psychologically to cope with the stressors of the suborbital environment. Each training element in its own right has benefits but cannot replicate the total experience because of the transitions between zero-g and onset of Gx and/or Gz; but having completed the training your operator will have provided a reasonable level of duty of care. More importantly you will expose yourself to the conditions and you will know how well you coped (or not). There is an inextricable link between the medical assessment and the training assessment and any medical conditions not discussed or uncovered may be found during the training within a controlled environment. So having successfully completed both assessments you can be reasonably confident that you will indeed cope with the suborbital flight and hence be able to enjoy the experience all the better!

SPACEFLIGHT TRAINING PERSPECTIVES

In 2017, BBC 2 aired a television show called "Astronauts: Do you have what it takes?", where 12 hopeful candidates took part in a series of tests to find out if they had "the right stuff" to become an astroanut. The winner would recieve former Astronaut Chris Hadfield's backing for their application for the next round of recruitment from space agencies. I caught up with two of the show's participants, Jackie and Vijay, to get their thoughts and persepectives on training for spaceflight.

DR. JACKIE BELL

@sciencesummedup

WHY DO YOU WANT TO GO TO SPACE?

I would love more than anything to go in to space and look back at the beauty of our planet, to see the countries with no borders and to know I was part of something much bigger. The stars and planets have always fascinated me. As a child I always wanted to go off and explore, I had a huge imagination accompanying my quest for knowledge and adventure. The biggest adventure I could think of was going in to space, but my parents and friends never had an interest in space at all, and I never understood why they didn't share my passion to go up there. To be one of a handful of people to have been to space, contributing to humankind's microgravity research and to feel weightlessness would be a dream come true. I know it's not easy up on the ISS, where astronauts work everyday conducting research, maintenance and other tests, but I know I would welcome the challenge and I know I would make a great contribution as an ESA astronaut.

WHICH TRAINING ACTIVITY WAS THE MOST CHALLENGING FOR YOU?

The most challenging test for me was the underwater helicopter survival experience. As a non-swimmer, I had never submerged myself underwater before and I cannot express the fear I felt when I strapped myself in to that 'dunker'. The instructor shouted "BRACE, BRACE" before the capsule hit the water and started filling up. Trying to keep calm, with tears rolling down my face, I braved the capsule rolling over and submerging us upside down. At that moment I breathed in a lot of water from panicking, but I was still able to undo my harness and escape from the capsule, swimming as best I could to the surface. Chris Hadfield commended me on my bravery for facing the dunker not once, but four times, despite my inability to swim. Re-watching the whole thing back on TV was like re-living a nightmare, however I made it my mission to learn to swim this year and face the dunker again before 2018 is over.

DO YOU THINK THAT ANYONE WOULD BE ABLE TO FLY ON A SUBORBITAL FLIGHT, OR DO YOU HAVE TO HAVE THE 'RIGHT STUFF' TO COPE?

I think everyone on the planet should have an equal opportunity to take part in a suborbital flight, however it is unfortunate that it comes down to money, and so not

Credit: BBC

everyone will get a chance in their lifetime. With the correct physical and psychological training I don't see why the average person could not fly on a suborbital flight. They would be able to cope, in my opinion, as long as they were physically fit, healthy and of sound mind.

HOW RISKY DO YOU THINK A SUBORBITAL FLIGHT SHOULD BE, COMPARED TO ORBITAL FLIGHTS FOR INSTANCE?

I would say suborbital flights are probably slightly more risky, however, with current commercial companies like SpaceX, Virgin Galactic and Blue Origin (just to name a few) designing their own spacecraft to take tourists to the edge of space you would hope that they would be extremely safe due to the nature of the companies competing for customers. There is a lot of testing happening at the minute that will hopefully mean suborbital flight will be safer than ever and open to everyone.

DO YOU HAVE WHAT IT TAKES TO BE AN ASTRONAUT (AND WILL YOU APPLY)?

I think I have the mental agility, personality and quick thinking needed to be an astronaut. In terms of the flight experience, swimming, diving and language skills, these are all the things I am focusing on developing this year. I hope that by adding these skills to the list of things I have achieved so far I will be able to stand out when I get the opportunity to apply to ESA. As long as applications open before the time I turn 37 (I'm now 29 years old) I will definitely be applying. Until that day I will keep learning, training and working hard to put myself in the best position possible, so that I'm ready for anything the space agencies throw at me.

I caught up with Vijay over a couple of interviews, during and after the BBC TV series aired. Listen to the full interviews over at yourspaceflight.com, the companion site to this book, where we'll keep you up to date on the latest developments in the second space race.

Do also take a moment to check out Vijay's adventures at his website below, including his epic video showreel from his travels.

VIJAY SHAH

@vijayexplores / www.vijayshah.info

WHAT DID YOU ENJOY MOST DURING THE SERIES?

When we were in Germany, we were taken down this corridor into a room and I saw Chris Hadfield sitting right next to a Soyuz simulator. We had to, without any prioir training, dock that Soyuz onto the International Space Station, just like Chris Hadfield had to!

WHAT WAS THE MOST CHALLENGING TEST?

The hardest challenge for me was driving, controlling the rover from simulated orbit, copying what Tim Peak had done on his mission. The difficulty was that there was a delay in the signal being sent - this was a very painful expereince. We thought we had more than enough time to complete the task but the rover was moving so slowly!

HOW DID YOU GET DOWN TO THE FINAL TWELVE?

The application procedure was very much similar to what they look for in a national or international selection process, that which ESA (European Space Agency) or the Canadian Space agency would use – in fact the Canadian Space Agency had just appointed two new astronauts just prior to filming, so as Chris Hadfield was selecting the 12 contestants for the show, he was using the same procedures that were being used for actual astronaut selection!

DO YOU THINK THAT ANYONE WOULD BE ABLE TO FLY ON A SUBORBITAL FLIGHT, OR DO YOU HAVE TO HAVE THE 'RIGHT STUFF' TO COPE?

Suborbital will of course be different to being part of an orbital mission - you won't be flying the spacecraft, you'll be a passenger, but the dangers are still there. It's still a very dangerous flight profile, and whilst we're still at the beginning of space tourism, people might feel similar to back when transatlantic flights were just beginning: but now we wouldn't think twice about jumping on an airplane.

Do the general public have what it takes? Many will, but for some the risks are always going to be too high.

Credit: BBC

QUOTES FROM THE INTERVIEW

"While the fitness criteria for suborbital flights are lower than orbital, your body still has to cope with a strenous flight profile..."

"... the better you train for dangerous situations, the more you can enjoy the experience, knowing that you'll be able to handle events if they come up... it's not like just jumping on a regular airplane."

"It should be made clear to the public, in a way they can undertsand, what the risks of suborbital flight are..."

CHECK OUT THE FULL INTERVIEW WITH VIJAY OVER AT YOURSPACEFLIGHT.COM

Photo by NASA: Long range view of an unidentified space shuttle lift off taken from an unidentified high flying aircraft.

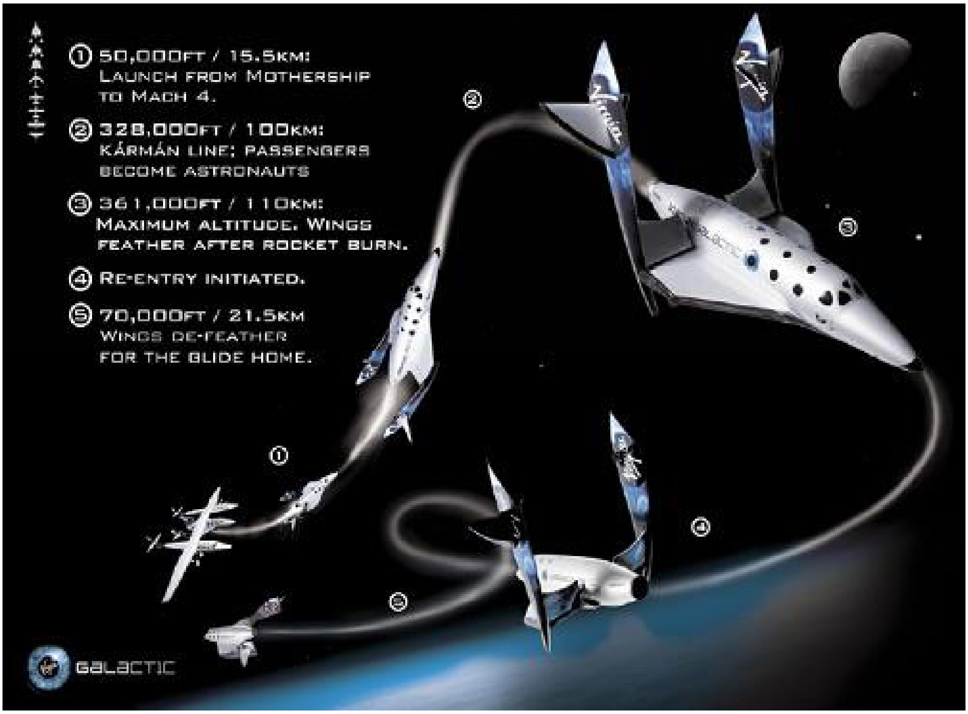
Credit: NASA; ISS012-E-19244 (12 Feb. 2006) — A full moon is visible in this view above Earth's horizon and airglow, photographed by an Expedition 12 crewmember on the International Space Station.

CHAPTER 5
THE SPACEFLIGHT

WE HAVE LIFT OFF

You've passed the medical and passed (and enjoyed) the various physiological and psychological training experiences and here we are – the day of the spaceflight. As you don your spacesuit/pressure suit and check out your personal oxygen equipment you recall the similar experience in the high-performance (fast jet) aircraft flight and so you're feeling confident and excited. You climb into the spaceplane and get strapped in – again like the fast jet flight. You are given the final safety brief of how to exit the seats and the spacecraft in an emergency and the oxygen equipment. All good stuff that you recall from the fast jet flight and pre-briefing from the pilots earlier on. You look at the flight profile posters on the wall and say, let's do this!

All systems check, we are go for launch. 10, 9, 8, 7, 6, 5, 4, 3, 2, 1 ignition! The space-plane is catapulted forward and you are pressed back into your seat (OMG! – or probably stronger profanities). Once again you felt this in the fast jet flight but not quite like this! Then the spacecraft pulls up. You feel the g-force pressing you down (Gz eyeballs down) and the blood rushes from your brain. As well as your ergonomic seat



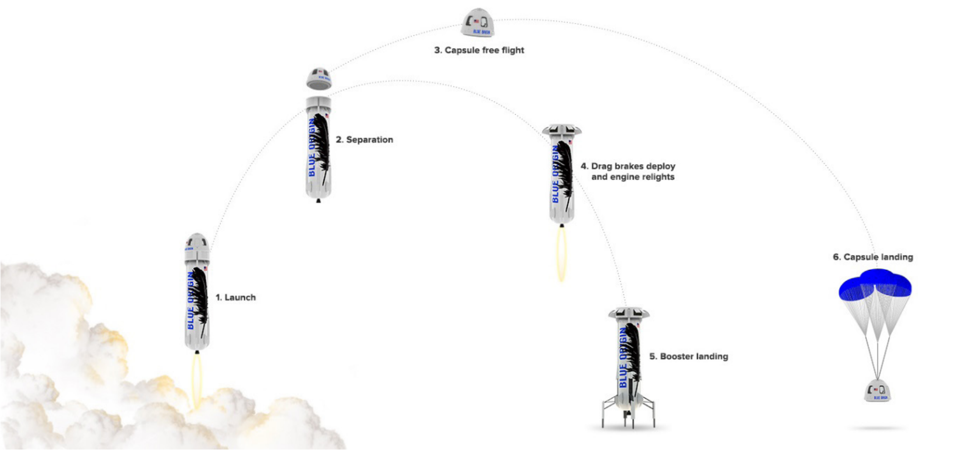
Credit: Virgin Galactic

assisting, you remember the Anti-G straining Manoeuvre from the centrifuge and the fast jet flight and so you cope for the few seconds. Then the 'g' eases off as you climb near vertically and you then feel the 'g' transfer through your chest to your back (Gx). Again you remember this is much easier from the centrifuge and you enjoy the flight and start looking around.

The rocket motor is loud (even with the helmet) and there is vibration, but you experienced similar in the sensory vibration machines and during the fast jet, though not quite like this! Then silence! The rocket motor is switched off and you continue the ascent towards the edge of space. You look around and see the blue and the black sky and finally feel like you've made it.

You sense the microgravity conditions and the captain clears you to release your straps (depending on the spacecraft). You then float in zero-g and immediately seek out the window. The view of your country is fantastic and you can see further afield towards the sea. You then decide to somersault as you remember doing that on your zero-g flight during the preparation program. You check out the fantastic view and take a moment – your moment. Within minutes the captain orders everyone back to their seats and to strap in as the descent begins.

Depending on the vehicle you will then be pressed to your seat as the g-force build up (possibly up to -6Gx, or you may feel some eyeballs-down 'G' in other vehicles). The glide down is swift and the final approach is steep as you look at the runway (and wonder will we pull up) – but you recall from your fast jet training that this is the



Credit: Blue Origin

correct 'picture' out of the front windows and all is well. The pilot then flares and smoothly touches down on the runway. You did it, your spaceflight, your dream!

If you chose a Blue Origin ticket, then the spaceflight is somewhat more like the old-school orbital rocket launchers – the vertical launch. A suborbital vertical launch and return will take less than 10 minutes in total. What a ride that will be! So let's do this. 10, 9, 8, 7, 6, 5, 4, 3, 2, 1, blast off! The rocket motor roars below you and you feel the power lift the spacecraft from the launch pad. Within a minute you are travelling at Mach 1, then Mach 2 and Mach 3, being pushed into your seat as you lay back like the conventional astronauts on the Soyuz Proton module (though you have more space and comfort). Then silence as you reach main engine cut-off and separation of the Booster. You still feel the Gx in your chest and know that you are heading upwards towards 300,000ft. Your captain informs you that you can release your harness and explore that unique zero-g feeling. You float to the window to check the view and see the Booster falling away further below. Time for those somersaults. After taking that moment, you return to your seat for the descent. Within a minute the g-forces are building up and then a jolt as the drogue chute deploys the main parachutes. Hooray for those large canopies. You then float down and land with a mild bump. You did it – your spaceflight, your dream. And because it will cheaper than the other systems on offer, you say – let's do it again!

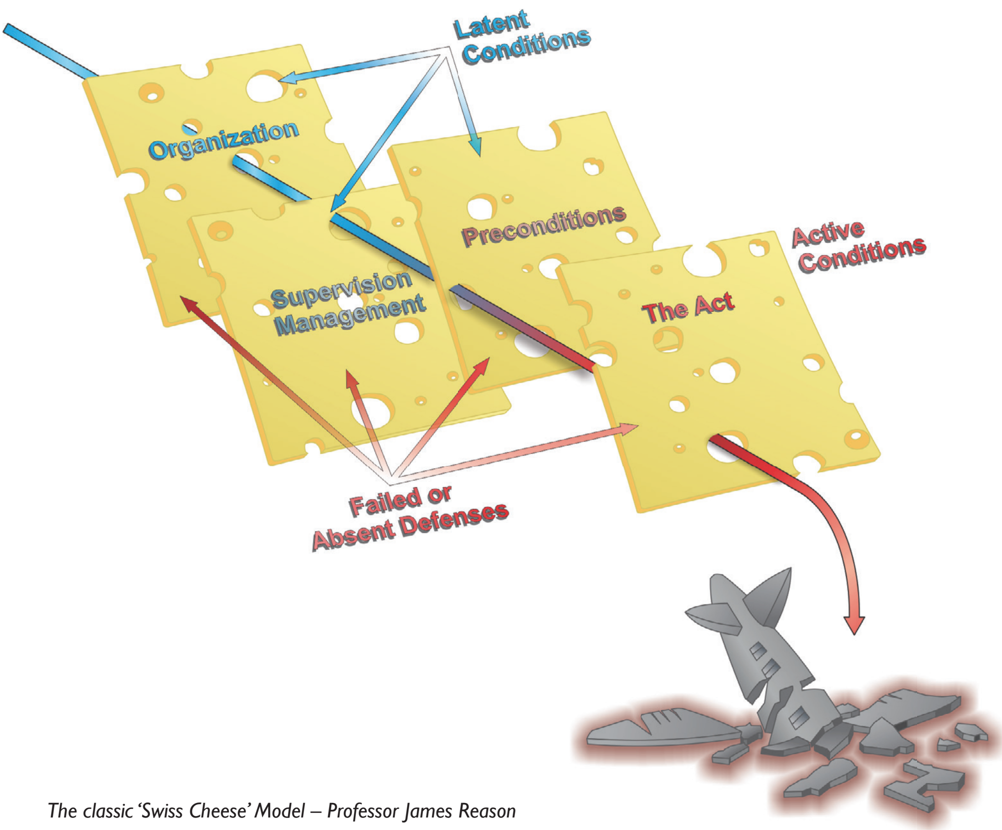
Credit: NASA Archives

Photo by Gian-Reto Tarnutzer on Unsplash

CHAPTER 6
SPACEPORT AMERICA, WE HAVE A PROBLEM

You're at 330,000ft enjoying the view of the Earth whilst floating in zero-g conditions. A window seal fails and the cabin mists up and it gets noisy. You remember from your training that this means a problem with the pressurisation and you are glad the designer decided on a spacesuit/pressure suit combined with a personal oxygen system. The captain orders everyone to get back to their seats and strap in and initiates a slightly early descent (unless you are in a pod from a vertical launcher). "Mayday, Mayday, Mayday – Spaceport America (or wherever) we have a problem". The pilot then expedites the glide back down to a safe altitude in case anyone has a problem with their personal protective equipment (oxygen mask seal for instance after floating around and straining to see the wonderful view) because the pilot knows the cabin altitude is climbing rapidly to meet the actual altitude. Everyone seems fine as the co-pilot checks everyone in on the inter-comm. Then the pilot calmly touches down on the runway and everyone lives to tell the tale.

This story had a happy ending due to the combination of a good spaceplane design, good decision to have everyone in a spacesuit/pressure suit with integral oxygen system and good training coupled with practiced emergency procedures.



The classic 'Swiss Cheese' Model – Professor James Reason

The story of course could have a different and catastrophic outcome. Let's say that the designer had great aspirations of having a 'shirt-sleeve' environment because he was so assured of his double-skinned hull with closed pressure vessel therefore negating the need for a full pressurisation system and oxygen systems (which he would have argued have their own hazards (lower partial pressure of oxygen means a more flammable atmosphere – here is the conundrum for the designer versus the safety engineer versus the financial officer). So the pilots and participants get to wear a flight suit with a headset for communications because during the test flights (where pilots did have an oxygen system just in case) all went well and the final decision was to press on with the 'shirt-sleeve' philosophy.

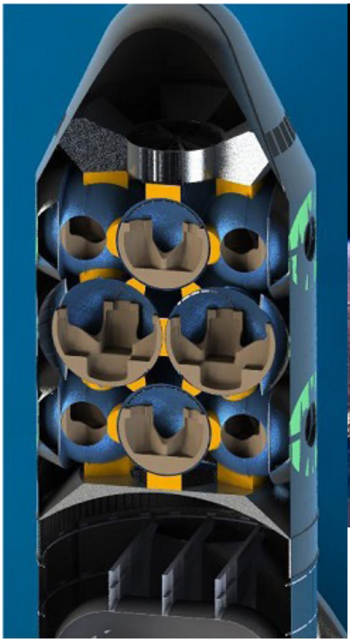
To understand the causes of any accident, we need to look at what may have happened before the flight to cause the situation. In the story given above, the causes may be in the manufacturing phase for the windows and/or the assembly phase, where potential 'mistakes' could have been made. One well known model for how accidents are caused is the 'Swiss Cheese' Model, developed by Professor James Reason. His model describes how latent failures exist and if unchecked and when under certain circumstances (active failures) these latent failures could align with 'active' failures resulting in an accident.

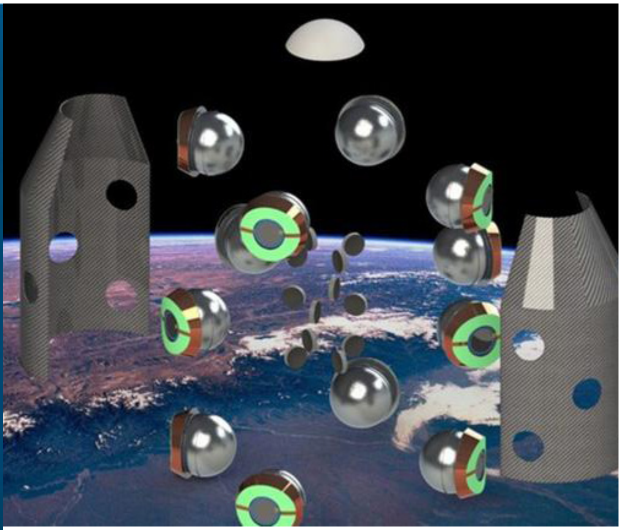
The active events in this case could be a post-flight inspection that did not pick up a minor flaw now growing behind the seal (from the manufacturing latent condition). The next active failure could be after the partial pressurisation of the cabin to 8000ft whereby the pre-launch check didn't pick up that to get to the 8000ft took slightly longer than normal. When 8000ft cabin altitude was reached then 'check', that aspect was confirmed good to go. The final active failure could be the co-pilot not noticing the slight climb in cabin altitude during the rocket launch phase because his focus is on the rocket pressures, temperatures and count-down to engine cut-off. The rocket phase of the flight means vibration and then the window structure fails at the seal. As the occupants do not have oxygen systems then sadly at 330,000ft a catastrophe occurs.

So although the design idea was sound there are other failings (usually human) elsewhere in the development of the vehicle i.e. within manufacture, build, ground checks or flight operations. Hence the safety analyst identifies these hazards and derives mitigation (controls) to prevent the cause escalating to the hazard and if all fails then to prevent the hazard escalating to the accident (usually by procedures, warnings and limitations – and importantly emergency protective equipment). The time of useful consciousness can be as little as 12 seconds at 45,000ft so imagine what little time you have up at 330,000ft in trying to locate your emergency mask! I don't think having 'shirt-sleeve' environments are justification for not having a spacesuit with integral oxygen system – and if your spacecraft operator doesn't have a spacesuit/pressure suit for you then here a question for them is: "Show me the design justification for why there are no spacesuits/pressure suits to save your lives in the event of de-pressurisation at 330,000ft". The example used here is a worst-case scenario and clearly failures can occur at any stage of the flight and the systems' safety engineers analyse the different outcomes ranging from no safety effect, reduced safety margins, mission abort to the catastrophic outcome.

Normally when a safety feature has been identified as a control to a hazard or accident then justification is required to implement it. If this is 'best practice' then the designer will do this in any case (or should do). Don't forget that the designers and operators have a 'duty of care' to you but how far will they go? So if for instance the spacecraft loses control either during the rocket phase or indeed is descending from the zero-g phase and is let's say upside down or spinning out of control, then what can be done? In this case designers/operators should be asking is there a way to save the vehicle and if not is there a way of increasing the chance of survival for the occupants? We're really talking about a Ballistic Recovery System (a parachute for the vehicle) or individual ejection seats or a 'pod' ejection system for more than one participant. Impossible you say? Well to be fair there is a design in the early (concept) development stage that believes in this extra survival/recovery system (post the unthinkable event) and that company is *ShipInSpace*.

In the event of an emergency, the top of the vehicle separates from the main body followed by the cabin walls separating thus leaving the pods to be freed. Then parachutes deploy for each pod carrying 4 participants and of course the pilot's pod. This system will be expensive to produce and test and so how do you justify such a system? We will look at this in Part 2 'Your Safety'.





Credit: ShipInSpace

In the figure to the right you can see how the pods are positioned within the main cabin. If we go back to the slightly exaggerated failure scenario of latent and active failures, then this design provides mitigation for an external window failure because the astronaut and crew pods have their own Environmental Control and Life Support System. Here if this vehicle had a pressurisation problem due to external window failure then there should be no need to initiate emergency separation as shown in the figures; this would be for Loss of Control or Uncontrollable Fire scenarios.

Current designs such as *SpaceShip2* and RocketPlane do not have these systems; though *SpaceShip2* does have the 'feathering system' which ensures the vehicle comes down from the zero-g phase the right way up – so the 'what if' question would be what happens if that system fails and the vehicle is plummeting to Earth? I would imagine that the primary system is hydraulic-based and there should be a mechanical backup (hand-pump/winch?) so the probability of both systems failing should be reasonably low.

Note: clearly there are different failure modes for systems and those that are deemed safety critical need to have redundancy for the 'Loss of Function' scenario – 2 Fault Tolerant for instance, but systems safety engineers should also consider the 'Must Not Work' scenario (i.e. a system functions when not required to do so) and therefore such a system should have 3 Inhibits (per best practice in 'standard' space systems analysis – whether NASA standards or European standards) - see Part 2.

Photo by Greg Rakozy on Unsplash

CHAPTER 8
NEXT STEPS FOR SUBORBITAL

SPACE DIVE

On 15th October 2012, the Red Bull Stratos Team succeeded in getting their capsule to a height of 39km using a high altitude balloon carrying one man on a space jump mission – Felix Baumgartner. After opening the hatch Baumgartner 'bunny-jumped' from the step to reach supersonic speeds (Mach 1.25 843.6 mph) and breaking Joe Kittinger's Space Jump record held since 1960. One headline after the Jump read 'Insane!' And of course, it could have ended in disaster but the engineering and operating team had a learning and safety ethos throughout the development and test phase which provided a good chance of having a successful outcome. Art Thompson, the Chief Engineer, was invited to receive the Jerome Lederer Pioneer Award from the International Association for the Advancement of Space Safety (IAASS). The award is assigned bi-annually to an individual who has made outstanding contributions in the field of

Credit: Red Bull Stratos

space safety (which he cordially accepted on behalf of his team). As the Chair of the IAASS Suborbital Safety Technical Committee I could only admire the gentle giant, Art, as he gave his presentation with his wife and engineering team members looking on proudly. He was certainly frank and open about the problems they encountered; both engineering and operating problems. Art provided excellent videos of the development phases as well as the 'jump' to show the good bits and the learning bits and discussed his safety ethos. He detailed the testing of the capsule sub-systems within an altitude chamber, his insistence for redundancy (for oxygen systems, power systems and parachute systems) and then he discussed how procedural controls and training played a key role. An example being the introduction of a parachute Automatic Activation Device (AAD) for Felix and after a hypoxia parachuting incident during testing. He then strongly advised that all suborbital and space projects should share lessons learned both in development as well as during operations.

So what next, seeing as Baumgartner said he won't be doing that again!

Of course, one of Google's most senior executives, Alan Eustace, broke the record by 8,000ft two weeks later. He did this on the QT, without all of the hype, and not using a pod!

Going forward there are others who have this incredible passion. An article on universetoday.com[10] detailed the Solar Systems Express and JUxtopia LLC space diving suit:

> *Falling through the vacuum of space will be quite different than a dive that begins in the relative thickness of Earth's lower atmosphere. There will be no aerodynamic forces acting upon the diver's body that will allow him to stabilize*

10 www.universetoday.com/102289/revolutionary-new-space-diving-suit-will-rival-anything-youve-ever-seen-in-the-movies

> *his jump. This problem will be solved by a pair of gyroscopic boots and the fingertip controls built into the gloves of the diver's spacesuit. Commands so issued to the control momentum gyroscopes built into his footwear will establish proper attitude and help to steady his fall through the airless void.*
> *As a safety precaution a flat spin compensator will automatically actuate after more than five seconds if the diver is unable to maintain adequate manual control. As the diver descends through the upper atmosphere, eventually the air will thicken to the point where aerodynamic forces will allow him to control the attitude of his body. Olav Zipser, word-renowned skydiver and lead jumper on the Freefly Astronaut Project, praised the new suit. "Your product would be a great way to stabilize my decent during the first 30 seconds of free fall, when there is virtually zero atmosphere," he said.*

Since Armadillo Aerospace have gone into 'hibernation' Zipser is opting for a standard type of vertical launch rocket being developed by Interorbital[11]. So watch this space! Okay and of course we all know that 39km is not the edge of space (considered to be around 100km, known as the Von Karman line and other names). But at that height it's black when you look up, so that's got to feel like space! I'm sure if Zipser et.al manage to develop the technology to allow this to become a regular adventure for adrenaline junkies then who's to argue in calling it a Space Jump?

POINT-TO-POINT (P2P)

Once the suborbital companies have proven their systems and the industry starts to flourish then their attention will turn from operating point A to point A towards operating point A to point B (P2P). Some companies have identified this as their prime

11 http://www.synergymoon.com/freeflyastro.html

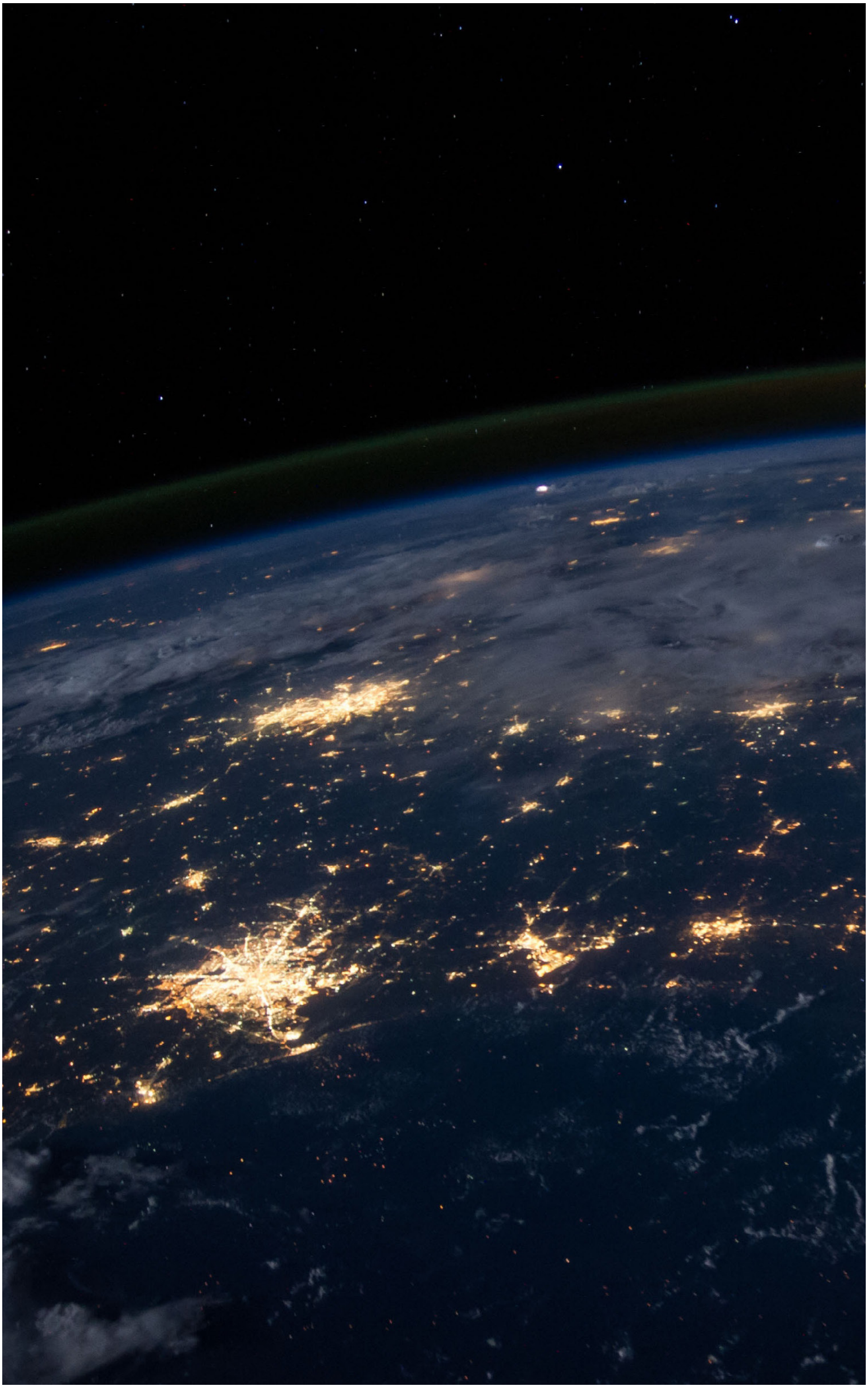
Credit: Kollected Pty

Credit: Aerion

business model and so skipping out the A-to-A development phase. This is a key decision especially if large distances are involved. Rocketplane's proposed model includes point A-to-A but caters for a shorter distance A-to-B.

The large distance A-to-B companies include Hyper-Mach which is a sleek Concorde-style vehicle; though there hasn't been any updates from them in the last 2 years. A similar concept is the Japanese Space Agency (JAXA) high speed transportation (HST) system and US newcomers 'BOOM' and Aerion (above).

Photo opposite by NASA on Unsplash



If you are looking for perfect safety, you will do well to sit on a fence and watch the birds; but if you really wish to learn, you must mount a machine and become acquainted with its tricks by actual trial.

- Wilbur Wright, from an address to the Western Society of Engineers in Chicago, 18 September 1901)

Photo by Lian Jonkman on Unsplash

PART TWO: YOUR SAFETY

Photo opposite by Aaron Barnaby on Unsplash

Photo by Markus Spiske on Unsplash

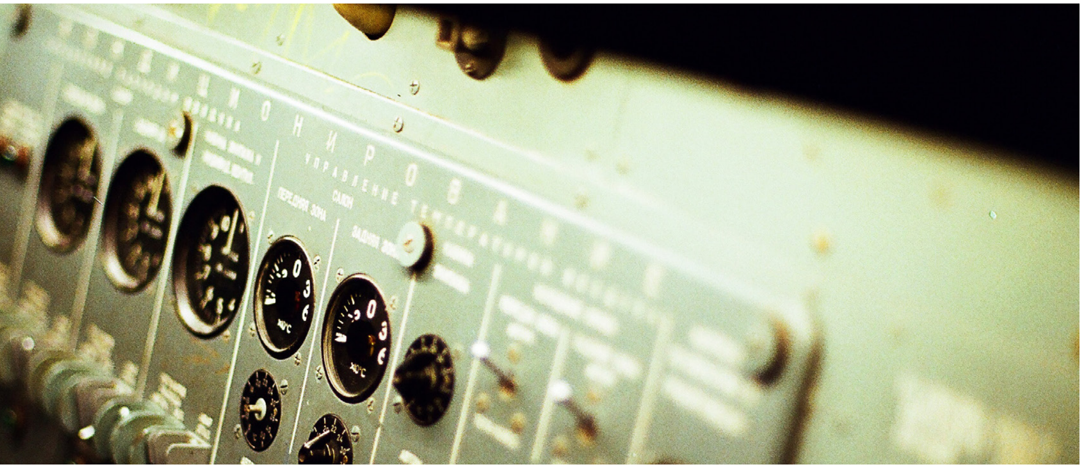


Photo by Sergey Svechnikov on Unsplash

Photo by Pandu Agus Wismoyo on Unsplash

Photo by Mario Azzi on Unsplash

CHAPTER 9
THE BIG QUESTION – HOW SAFE IS IT?

Wilbur Wright was so right – perfect safety does not exist. There will always be residual risk and so the big question is, "*how safe is safe enough*?".

As suborbital astronauts, you will want to know how safe your spacecraft is, as well as how fast it is. In the previous Chapter, we discussed that FAA-AST require operators to disclose the risks involved so that you can make an informed decision (of consent) to fly and to 'waive' your rights to sue the government – essentially because the spaceplanes are not certified. So what about the safety aspects? The FAA-AST requires operators to demonstrate the vehicle has been subject to hazard analysis and that operators have a safety management system.

WHAT IS SAFETY MANAGEMENT & SYSTEM SAFETY ENGINEERING?

The UK Civil Aviation Authority (CAA) state that *"a Safety Management System is as important to business survival as a financial management system"*. It is of no use to have ploughed in $250M (or more) to develop a spacecraft and not to have an embedded safety ethos running throughout the organization. Innovative rocket scientists and engineers generally start off in small teams and believe they are 'inherently' designing safety into their spacecraft; hence this can mean a 'proper' safety engineer comes in much later in the program (because the FAA-AST mandate a 'safety officer' is appointed); hence there is little or no chance to influence the design from systems safety analysis. What I mean by this is that if a safety engineer and safety manager are embedded within the design team from the beginning then not only can they analyse the systems and provide input to the design, but they can also get the safety policy and procedures in place as well as safety communication and safety training and start to grow the safety culture.

Why is this important? Remember the Swiss-Cheese model from Chapter 6? Well, because we have design engineers for the different systems i.e. the rocket, airframes and avionics, they all have their own view of how the spacecraft should look and work. Hence they can add to or influence the 'latent failures'. Then people start to manufacture the systems (possibly with innovative techniques or materials) and then maintainers and pilots contribute to 'active failures' (in the Swiss-Cheese model). So the Safety Management System can be seen as **the 'glue that binds'** all of the disparate activities. However, safety management (the glue) is effective only if integrated from the beginning. If safety management only starts later in a project it will only really be *filling in the cracks* as opposed to building a solid foundation of safety into the spaceship design from the start.

What are our Safety Manager and Safety Engineer trying to achieve? As well as complying with any FAA-AST and derived safety requirements (from the hazard analysis), they should also be demonstrating (or at least trying to predict) the safety levels of the spacecraft, as well as provide judgement on the level of confidence.

ACCEPTABLE LEVELS OF SAFETY & CONFIDENCE LEVELS

Here's your first question for your operator as part of your informed consent process – **what level of safety has been achieved and to what confidence level**? You know that the flight should be 'safer' than orbital spaceflights but perhaps not as 'safe' as the aircraft that you flew on to get to the Spaceport. In terms of accidents per flight or mission this equates to somewhere between 1 in 100 flights (orbital flight achieved rate thus far) and 1 in 10 Million flights for aircraft (it's important to use the same metrics i.e. apples and apples and in this case flights (same as missions) as opposed to flying hours which is the metric used in aviation safety/reliability). You would like to believe an answer from the suborbital operator is somewhere in-between; it is certainly not anywhere near aircraft levels of safety! The ground and flight tests, along with supporting analysis, will provide the design team with a level of confidence in the vehicle. There is no historical flight evidence to call upon so this is not going to be as high a level of confidence to that of the aircraft. Confidence levels are discussed later on.

COMPARING RISKS

Another way of looking at it, is that the individual risk of death per person on the Space Shuttle was about 4% (18 lost souls out of 430). In aviation, the risk is less than 1% (but be mindful of stating that there is not much difference – the aviation statistic is based on millions and millions of flights).

Risk is relative and as discussed in this book is based on your risk perception. Here are some good old statistics that (sometimes) puts things in perspective. The risk of death per hazardous operation is[12]:

CLIMBING EVEREST
1 in 16 climbs

SUBORBITAL FLIGHT
1 in 1000 suborbital flights

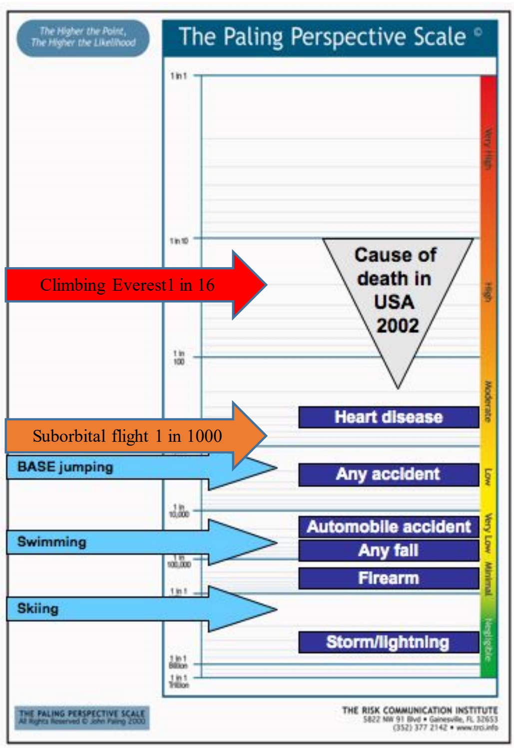
BASE JUMPING
1 in 2300 jumps

SPORTS PARACHUTING
1 in 100,000 jumps

HANG GLIDING
1 in 116,000 glides

Below is the same information in the Paling Perspective Scale [13]:

(Note: suborbital flight statistic inserted for early flights as 1 in 1.000 and Climbing Everest as 1 in 16. Credit: John Paling 2000 (www.riskcomm.com)



12 Some statistics from: www.medicine.ox.ac.uk/bandolier/booth/Risk/sports.html
13 Risk Communication Tool (c) John Paling 2000 (www.riskcomm.com)

Back to spacecraft acceptable levels of risk - you would like to hear what confidence level the risk assessments have been based on. What I mean here is that this is a new industry and the designer/operators will have tested the vehicles on the ground and in the air; so how confident are they with their analysis? The answer will not be 100% 'very high' confidence and you should be ready to face this fact. So the answer we are looking for is at best 'good' confidence (see later in this Chapter) – though during the early commercial suborbital flights this may even be 'medium-to-good' confidence at best. If you are a prospective suborbital astronaut signed up but near the back of the current list then arguably by the time you get to fly, the operator will hopefully have greater confidence in their vehicles – especially as they will iron-out any issues along the way. So you early suborbital astronauts really are pioneers, taking higher risks so that confidence can be gained for later suborbital astronauts.

So now you know that the risk of a catastrophe is say between 1 in 1,000 (early operations) and 1 in 10,000 missions (for mature operations) we can ask whether this risk is the same for all types of suborbital vehicle. But remember, during early operations for you pioneers, this risk level may be even higher than 1 in 1,000 missions.

DIFFERENT SPACECRAFT, DIFFERENT RISKS?

In Chapter One we looked at the different types of spacecraft from vertical launch (Blue Origin, Copenhagen Suborbitals) to Air-Launched (Virgin Galactic) and Aircraft-type vehicles taking off from the runway (XCOR, Airbus, Rocketplane). It's not rocket science (or is it?) to see that some spacecraft will present higher risks than others. Can we categorically say that a suborbital (high altitude) balloon ride without a rocket will be much safer than a spacecraft with a rocket?

Here follows my qualitative judgement whereby different criteria such as phases of flight, types of equipment, safety features all contribute to positive and 'less positive' factors to consider. You can imagine each operator saying 'Our spacecraft is much safer than their spacecraft' but as they are all so different this is hard to justify and of course the point of this exercise is to show that each has positive *and* negative factors. This may help you to make your mind up on which vehicle is okay for you (or not because you've bought tickets on more than one vehicle in any case).

LAUNCH		
Launch/Take-off	**Risk**	**Comments**
Vertical	Moderate-High	History shows control instability as the main issue
Horizontal (from runway) - rocket	Low-Moderate	Can abort on runway before airborne and fire cover etc.
Horizontal (from runway) – engine take off and then rocket launch at altitude	Low	Can abort on runway before airborne and fire cover etc. plus aero-engine take off so safer, with rocket initiation at altitude
Air Launch	Moderate	Can abort prior to release but collision with carrier a risk and if rocket issue can switch off (or if it fails to start) then can glide back to base
Balloon Sail	Low	No rocket so low risk for 'launch' – but sail can fail on ascent
PROPULSION SYSTEM		
Engine	**Risk**	**Comments**
Hybrid	High	Novel design, so riskier. N2O accident already
Liquid innovative system	Moderate	Novel
Liquid 'Off the Shelf'	Low-Moderate	Less risk as history/reliabile but in new context
ROCKET BURN EXPOSURE		
Time	Risk	Comments
> 5 minutes	High	Longer exposure to rocket motor phase increases risk of failure
> 2 but < 5 Minutes	Moderate	Moderate risk
< 2 Minutes	Low-Moderate	Less exposure to rocket motor phase is better in probabilistic sense

RECOVERY		
Control System	**Risk**	**Comments**
Reaction Control System	Low-Moderate	Novel but no back up
Feathering System	Low-Moderate	Novel but with back up and should be fail-safe
Balloons - parafoil	Low-Moderate	Novel but no back up and more exposed to environment
G-PROFILE		
G-forces expected	**Risk**	**Comments**
Greater than +3Gz (eyeballs down)	Moderate risk	You may suffer a 'grey-out' but recover quickly as O2 recovers to the brain after a few seconds
Greater than +5Gx (chest-back)	Moderate-high risk	Fairly difficult to breath. Worse if not back in your seat and someone else lands on top of you
Less than +3Gx or +3Gz	Low	No problem for most but people have suffered grey-out for a few seconds at 2.5Gz – see you tube videos
CONTROLLABILITY (System)		
Level of Control	**Risk**	**Comments**
Software Controlled	Moderate-high risk	History shows developmental assurance issues

Manual Control only	Moderate-high risk	Less aspects to go wrong but human in loop main weakness – as was case in SC-VG accident
Automatic (software) with Manual reversion	Low	Having a human as the monitor and back up optimized solution
CONTROLLABILITY (Pilot)		
Level of Control	**Risk**	**Comments**
Single Pilot Operations	High	If pilot unconscious/incapacitated, then Loss of Vehicle
Single (On board) Pilot with Pilot controllability in Ground Station (like unmanned systems)	Low-Moderate	Provides level of redundancy but less situational awareness (than dual pilot ops) – only business model is WeAreSpaceship in concept phase (not funded yet)
Dual Pilot Operations	Low	Redundancy if one incapacitated, plus situational awareness - though only if have a proper cross-check approach (otherwise what is the point of having 2 pilots)
FLIGHT PROFILE		
Altitude	**Risk**	**Comments**
Greater than 100km	High risk	Higher means more g-forces on re-entry i.e. +6Gx for VG/Blue Origin Risk of de-compression
Greater than 60km, less than 100km	Moderate - high risk	Less G for re-entry i.e. 3Gx (or Gz) Risk of de-compression
Less than 60km	Low-Moderate	Lower suborbital altitudes provide better chance of recovery in emergencies such as de-compression (but trade-off is not so exciting, not such a good view, less or no zero-g time)
SURVIVABILITY		
Safety Measures	**Risk**	**Comments**
Vehicle Survivability Measure	Reduces Risk	Ballistic Recovery Measure/Ejectable Pods. This is the most desirable method – designers would argue it adds weight and costs and may also fail or is not appropriate; my answer is that show me the justification analysis that justifies such a statement – see personal parachute below
No Vehicle Survivability Measure	No Risk Reduction so high risk	No Risk Reduction so high risk
Personal Survivability Measure (intra-vehicular)	Reduces Risk	Still chance of individual errors but good measure
No Personal Survivability Measure (intra-vehicular)	No Risk Reduction so high risk	
Personal Survivability Measure (extra-vehicular i.e. personal parachutes)	Improves chance of survivability	Only applied if vehicle has no system. Still chance of individual errors but good last ditch measure (Indeed the pilot of SS2 PF04 survived after a horrendous break-up – this proves my point)
No Personal Survivability Measure (extra-vehicular)	No Risk Reduction so high risk	Only applied if vehicle has no system. So worst case is no vehicle recovery system AND no personal survivability measure = high risk of death post an accident event such as Loss of Control

You can see there are various positives and negatives (risks) with different designs and it may help or hinder you. The aim in the future is for me to put these into a risk scoring format; but once gain this would be subjective.

Clearly if you wish to fly as soon as possible then your options are limited to less than a handful of operators. So let's look ahead 10 years and imagine all players from Chapter One are operating. The risks presented above are subjective and there for guidance; but who do you fly with and on what basis do you make the decision?

- Lowest (perceived) risk?
- Lowest cost?
- Highest (perceived) thrills?
- Type of profile i.e. more zero-g time?
- Type of spacecraft and launch methods (vertical 'v' winged) (air vs ground launched) (type of rocket)?

Or do none of these matter to you and it's a case of which operator can you fly on first? Also, if you can afford it, you may wish to try the different operators because of the different launches and experiences.

WHAT INHERENT SUBORBITAL SPACEFLIGHT HAZARDS MIGHT YOU FACE?

The spacecraft system functional failures (and structural/pressure vessel failures) will be analysed by the design organisations and presented to the FAA-AST to show that these types of hazards have been identified and mitigated as far as is reasonably practicable. However, as with riding a bike, driving a car and flying, there are inherent hazards by the nature of the operation and the environment. During a suborbital flight to the edge of space you will all be exposed to g-forces, microgravity conditions, noise, vibration, sensory disorientation and so on. Your operator (and spacecraft designer) has a duty of care to ensure you are not injured during normal operation. They should also try and protect you in the event of an emergency situation or serious failure condition (now that a parachute has proven to save a life in the event of a structural breakup at Mach 1). So, the safety team will have identified these 'inherent' hazards as well as the system functional failures (for instance rocket propulsion system explosion or flight control system failures) and structural failures as well as pressure vessel failure modes. Your operator is required to let you know of generic suborbital spacecraft hazards which should include these functional and structural/pressure hazards (leading to Loss of Control, Fire, and Structural Failure etc.) and also hazards more directly associated with you.

Hazards exist all of the time and safety is about managing the controls (barriers and recovery measures) because it is the failure of controls that are the 'latent' and 'active' failures in the Swiss-Cheese model mentioned earlier.

In the previous example of Inherent Hazards, the outcome detailed is the worst credible i.e. death for instance. When more knowledge has been gained then analysis can consider the most likely outcome (which may not be the worst credible outcome) but at the beginning of the suborbital industry with no history then the worst credible scenario must be analysed. The safety team will also detail the different phases of flight against each hazard and hence some hazards have different outcomes. What we mean here is that if you have a depressurization during the initial climb phase or during approach then the outcome will not be catastrophic.

HUMAN ERROR AND SYSTEM SAFETY ANALYSIS

During the X-15 program, 199 flight tests were undertaken and 15 of these could be classified as suborbital flights (13 flights to 80km and two flights to 100km). Flight #191 sadly ended in catastrophe due to a 'combination of system anomalies and pilot errors, including display misinterpretation, distraction, vertigo and loss of situational awareness'. Since then, designers and flight test pilots have learned a lot about managing risks and how to push the boundaries of the design safely.

The *SS2* flight test accident testimony by the co-pilot stated that the operating pilot 'armed the feathering device early' (Mach 0.8 instead of the planned Mach 1.4) and that this was a contributory factor in the accident. So just like the X-15 flight test accident, pilot error, plus no cross-check/challenge, *plus* system design (no other safety inhibits and locking mechanism not able to cope with stresses) led to the inadvertent deployment of the feathering device resulting in the vehicle breaking up.

The point is that we are all human and we all make mistakes; some are costlier (catastrophic) than others. So how do we account for this during design development? In the first instance in a normal aerospace design company we have Human-Machine-Integration (HMI)/Human-Machine-Engineering (HME) or Human Factors Integration (HFI). The analysis looks at anthropometric aspects, ergonomics and human failure aspects. Additionally, studies have been carried out within the aviation industry to look at human error rates (seeing as 90% of aircraft accidents are causes by pilot error – sometimes in combination with system anomalies and sometimes not). These studies produced 'generic' human error rates that we in the systems safety world could 'plug-in' to our accident sequence analysis. The thing to understand is that pilots can directly cause a hazardous situation (or in combination with system anomalies) but pilots are also controls to hazardous situations presented by the systems or by the environment (or combination thereof); hence pilots can also get the 'control' wrong.

The point is that under increasing stressful conditions our brain starts to become less effective and therefore the chance of error increases. Of those 90% of human errors causing aircraft accident the top two failings are: a) pilot incorrectly following procedure (34%) and b) ineffective (or no) cross checks (26%); these are statistics from the NTSB.

As mentioned earlier, the designers and flight test pilots have learned a lot since the X-15 days and we should be identifying the human error causes and controls within the systems safety analysis (from the beginning and throughout the development program). Additionally, and most importantly, going through these scenarios with the test pilots to make sure the sequences are correct and credible but also so it reaffirms that the flight test pilots can cause an accident and that they are also controls to an accident. If this interaction of pilots and system safety does not take place, then there is a significant failing in the ‘safety culture’ of the company. Human Factors relates to everyone directly involved with the flight; from the safety ‘officer’, the design engineer, the manufacturing team, the pilots and not forgetting the management (for those Go-No/Go decisions):

Virgin Galactic have since taken the reigns on the *SS2* design modifications based on the NTSB comments and have also reviewed the rest of the vehicle design and operating procedures to account for human (pilot) errors, software errors and general improvements. This is essential for Virgin Galactic and the industry as a whole, to demonstrate that real lessons are identified and real improvements made (and that these are verified by the FAA-AST, as well as the NTSB).

I also hope that the management of the rest of the front-running operators learn that there is a fine balance between pushing on (due commercial pressures) and doing things the ‘right [safe] way’ i.e. not relying purely on the ‘right stuff’ of the pilots.

HAS MY SPACECRAFT BEEN SUFFICIENTLY TESTED?

Part 1, Chapter 1 looked at the different suborbital vehicle designs and most have innovative features and materials and so how to test these and what sort of tests should the suborbital designers be doing right now? The FAA-AST regulations state the following:

> **460.17 Verification program.**
> *An operator must successfully verify the integrated performance of a vehicle’s hardware and any software in an operational flight environment before allowing any space flight participant on board during a flight. Verification must include flight testing*

So put yourself in the designer’s shoes – to meet the above FAA-AST requirement All you have to do is successfully verify your vehicle is to do some integrated testing including flight testing; so shall we say 10 ground tests and 10 flight tests? But let’s watch and see how many flight tests are actually carried out before commercial operations begin…

Since the *SpaceShipTwo* Accident on 31st October 2014, Virgin Galactic now say commercial flights will happen when they are ready i.e. when they have tested the vehicle sufficiently and have confidence in its operation. This is a refreshing and great approach.

There are specific tests that can be carried out on the ground and some that can only be carried out in the flight conditions. Examples of test techniques includes: Load, Vibration (dynamic and modal), Shock, Thermal, Acoustic, Hydro-static, Pressure, Leak, Fatigue, X-ray, Centre of Gravity, Mass Properties, Moment of Inertia, Static Firing, Balance, Test to Failure (simulating non-nominal flight conditions) and other Non-Destructive Tests/Inspections. All of these techniques can be applied to demonstrate to the Authorities that the vehicle is ‘airworthy’ and of course ‘spaceworthy’. However, all of this testing comes at great cost; hence there should be some guidance on what is deemed reasonable i.e. what are the authorities willing to approve prior to commencement of commercial operations.

So how many flight tests are deemed to be sufficient before commercial operations begin carrying suborbital astronauts? There is no specific suborbital regulatory guidance for this so firstly let's look at where Virgin Galactic are in their test program. The thing is that each flight test has different objectives and so out of the 39 with flight tests the breakdown is as follows: Non-powered air-drops (36), powered flights (not full duration, 3 successful - the fourth being catastrophic) and full duration powered flights (0). On top of this the rocket motor has been fired at least 57 times on the ground. All of this gains good developmental experience which demonstrates some reliability and also uncovers faults which can be addressed and re-tested. Note: VG will continue testing and so some of these figures will be out of date and clearly more tests will be done over the coming year.

Let's say a total of 50 flight tests is agreed by Virgin Galactic – would you get on flight number 51? Same question with Blue Origin – will they do 10 flight tests and then put some test astronauts on board for a further 5 flights; so would you go on flight 16? Back to the question posed in the introduction with a Felix Baumgartner space jump scenario – did you answer yes in the introduction (to go on jump number 11)? Some may say this is not the same thing, but at the end of the day the space-jump pod (and spacesuit) could be 'approved' just the same as *SpaceShip2/New Shepard* and you could sign a waiver just the same.

Back to the flight test question. For certification, an aircraft engine is tested thousands of times. It even has a big bird (a chicken carcass from the supermarket, not a live animal!) thrown down the intake as part of the tests as well as being subjected to a 'blade-off' test to see whether the engine can cope with a compressor/turbine blade failure. The airframe is tested to breaking point etc. Suborbital spacecraft are not certified to these airworthiness requirements and nor should they be – the industry cannot afford the flight test criteria required by aerospace design and manufacture

NTSB, Human and Organisational Issues, Human Performance Presentation, Supporting the NTSB SpaceShip2 Accident Report - NTSB/AAR-15/02 PB2015-10545, Aerospace Accident Report, In-Flight Breakup During Test Flight Scaled Composites SpaceShipTwo, N339SS Near Koehn Dry Lake, California October 31, 2014 whereby the development costs would be recuperated by mass sales (to meet the mass market) – hence this is why the levels of safety will never be the same. Additionally, and as an aside, these requirements are to ensure the airworthiness and safety of the aircraft to protect paying passengers and those on the ground, mindful of the 'benign' standard flight profile of an aircraft. In space, we simply ensure the launch is sufficiently remote and carry out the Expected Casualty analysis to meet the safety target for protecting the uninvolved public.

However, where is the suborbital guidance on the required number of ground and flight tests? How many flight tests is 'okay'? 10? 50? 100?

Let's try and see what we are trying to achieve with this verification program. We looked at some of the verification techniques earlier and this can be as part of individual system testing (such as the rocket propulsion system) in the sub-contractor's laboratory/test facilities. The integrated vehicle ground testing will be carried out at the main design facility; these can be as many tests as is required to demonstrate some statistically relevant number that has been worked out in respect to the required confidence level i.e. 'high' confidence (90%). Moving on to flight tests; here (and especially as these suborbital vehicles are unique) there will be 'faults' or 'issues' with the vehicle and these could be as follows:

- **Minor issue** – Slight reduction in functional capabilities or safety margins of aircraft; the flight test can continue and the fault/issue will be logged and resolved prior to the next flight
- **Major issue** – Significant reduction in functional capabilities or safety margins of aircraft; the flight test may still continue but perhaps be limited and not meet all of the objectives of that flight test
- **Hazardous issues** – Large reduction in functional capabilities or safety margins of aircraft; this results in an Abort of the flight test and return to base.

The next level severity is of course catastrophic loss of the vehicle. In relation to meeting the verification objectives for the flight test program designers should (but don't) have a 'target' from which to measure success (and agreed with the Authorities). This needs to take into account predicted vehicle Loss Rate per mission (and/or Abort rate), number in prospective fleet, prospective confidence level and expected vehicle design life (i.e. 1000 missions).

The flight test phase should not be based on a 'wild-assed-guess' (WAG), or '10 flights should do it', nor should it be predicated by commercial pressure to be ready by a certain date; it should not be taken lightly! For suborbital designs, I believe it should be down to the level of confidence (proven and quantifiable) backed up by systems safety predictions. This seems to be where Virgin Galactic are headed, stating they will be ready when they are ready (confidence in the system).

SAFE ENOUGH?

So with the (proposed) chance of a catastrophic event about 1 in 1,000 missions in the early days, are you still good to go? I hope so. Yes, it's risky but we're talking about a

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spacecraft! But what if it is a lot worse (higher) during early operations? Do you have the right stuff or optimisation bias to risk your life?

What about a more sedentary flight in the high-altitude balloon to 36km – surely that's much safer? These vehicles may be an order of magnitude or two 'safer' at a catastrophic event rate of between 1 in 10,000 and 1 in 100,000 missions for example, but there will be more of these, flying more often so over a 10-year period they may still have 1 accident (the same as rocket-propelled vehicles possibly). Statistics, eh! Of course, it's not all about predictive statistics for emerging industries like ours and hence good engineering judgment is essential in terms of qualitative assessment (which can then be backed up by predictive quantitative analysis and moderated with uncertainty); only then can you have the full picture. Designers should have carried out Justification Analysis as part of design trade-off analysis – which you can't do (effectively) without numbers…

Is this good enough for me and would I fly? Simple answer – yes. But (I hear a few groans) I have my own criteria because of what has been mentioned in this book and my own knowledge of the aviation and space design and operator processes – also because my own pioneering risk-taking characteristic may be slightly lower than you or those other pioneers. Here's my own criteria:

1. Vehicle achieved predicted safety rate of better than 1 in 1,000 per mission (preferably nearer 1 in 10,000) with the predictions (safety analysis) verified independently.
2. Vehicle survival system such as Ballistic Recovery System/ Ejectable Cabin (verified by test)
3. Personal survival system such as ejectable pods/seats or parachutes (verified by test)*
4. Evidence of systems safety engineering involved from the beginning

Credit: Blue Origin

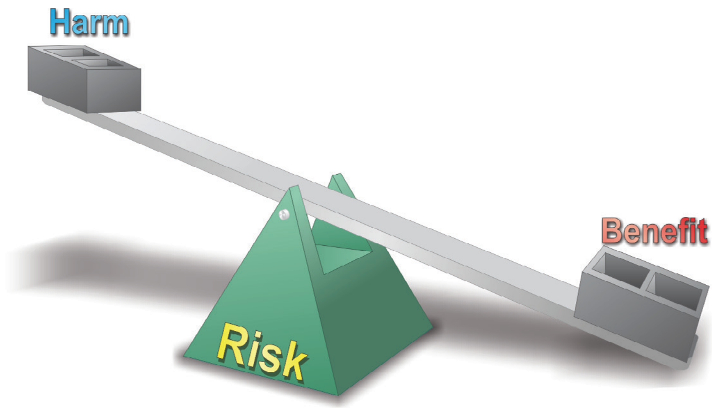
5. Engine ground-tested successfully over 100 times for full rocket phase time (ergo the engine will have had a few hundred shorter duration power runs under its belt)
6. Powered Flight tested successfully over 100 times for full rocket phase time (ergo the vehicle will have been flight tested 100 times or more in addition during aerodynamic drop tests and partial powered flight tests etc.) – so I definitely don't have the right stuff to be a pioneer…… (so I wouldn't climb Everest, but would climb a smaller mountain)

**Note: I appreciate that you don't get to escape a vehicle at high altitude and high speed and you need to be in a 'survivable envelope' (think of a military fast jet pilot ejecting at 200mph at 20,000ft, as opposed to 400mph at 40,000ft and you get the idea). Also we now have a pilot surviving the SC-VG accident with a parachute.*

Ideally I would have been involved in the vehicle's design from the beginning and in this case I would of course be the first volunteer for flight tests with 'test participants' in the cabin (after the 100 engine ground tests and 100 flight tests with the test pilots). Hence meeting all of the above criteria I would have 'medium-to-high' confidence that the vehicle is 'safe enough' for me to risk my life and have a great experience. The only aspects I would relax would be if the vehicle did not have a survival system (item 2 above) but did have personal survival systems (per item 3) – which was verified in the development and additional training was given.

Would I personally fly on either of the front-runner operator's vehicles as suborbital astronaut #1? The answer is No. As stated, I wouldn't climb Everest either, though I am willing to do a parachute jump.

Would I fly on *SpaceShip2* as suborbital astronaut no. 700 & 701 (like the Winklevoss



twins[14]) – with the previous 116 flights occurrence reports showing no serious issues – possibly yes because of the 100 test flights plus 116 (successful) commercial flights and if I had a parachute (I would have to make a big decision because ideally I would want a pressure suit). Would I launch with Blue Origin - with say 100 successful flights – yes as it would meet my criteria point #2 above (rocket-assisted escape mode for the cabin).

I've flown in fast jets (Jaguar and Hawk aircraft) and happy to do so because of the ejection seat in case of loss of control or loss of thrust, so why would I want to fly in a vehicle in a more dangerous environment with less safety measures? Why is this – am I that risk averse?

Back to the point made in the introduction **-** Why do some people want to fly in a suborbital vehicle and why do others not want to fly? The answers are not that simple but here's one theory (or a mix); **optimism** bias:

> *The optimism bias[15] (also known as unrealistic or comparative optimism) is a cognitive bias that causes a person to believe that they are less at risk of experiencing a negative event compared to others. There are four factors that cause a person to be optimistically biased: their desired end state, their cognitive mechanisms, the information they have about themselves versus others, and overall mood. For example first-time bungee jumpers believing that they are less at risk of an injury than other jumpers.*
>
> *Although the optimism bias occurs for both positive events, such as believing oneself to be more financially successful than others, and negative events, such as being less likely to have a drinking problem, there is more research and evidence suggesting that the bias is stronger for negative events. Different consequences result from these two types of events: positive events often lead to feelings of well-being and self-esteem, while negative events lead to consequences involving more risk,* **such as engaging in risky behaviors and not taking precautionary measures for safety.**

14 Founded the Social Network 'HarvardConnect', a pre-Facebook social network.
15 https://en.wikipedia.org/wiki/Optimism_bias

I actually want to do a parachute jump (despite having analyzed parachutes for the MoD and understanding the risk of death is 1 in 100,000 jumps) and want to fly in a suborbital vehicle; both of which are risky activities. But I specifically want to do so with certain measures in place (the parachute risk is mitigated by having a spare parachute and undertaking appropriate training). Other people are willing to take more risk and that too is a calculated risk, but their/your risk thresholds are set differently to mine. As eluded to throughout this book, the aim is not to change your risk thresholds to meet mine, but to be able to arm you with facts, and in particular questions, to ask of your chosen operator(s) such that you get a more accurate picture of the risks involved i.e. a balanced perspective.

The benefits are obvious (for those of us that want to fly) and your bias is already set; so just for confirmation, do ask some or all of the questions in Part 3... after all, it IS rocket science!

Credit: Blue Origin

Photo by Samuel Zeller on Unsplash

Photo by Davide Cantelli on Unsplash

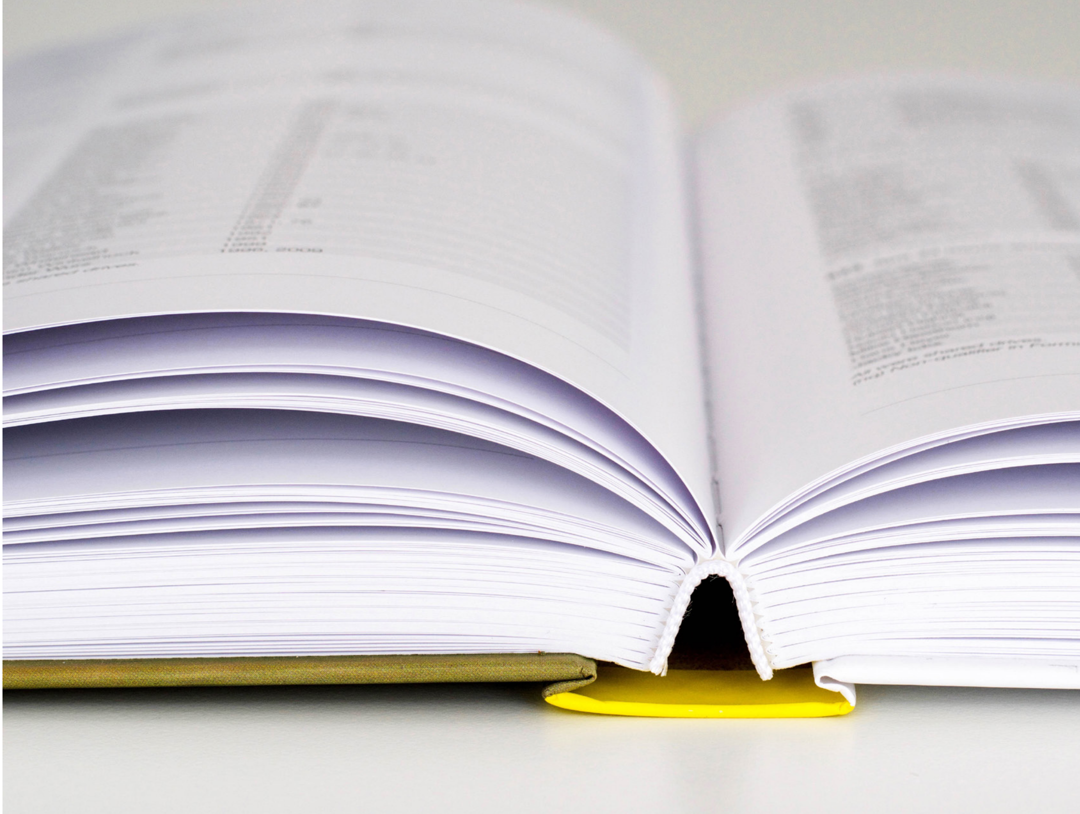


Photo by Alex Read on Unsplash

CHAPTER 10
REGULATORS; WHAT DO THEY SAY ABOUT SAFETY?

Currently the only framework allowing suborbital flight is in the USA. The FAA-AST launch licensing regulations covers both orbital and suborbital vehicles through the Commercial Space Launch Amendments Act of 2004 (CSLAA). The regulations are contained within the Code of Federal Regulations (CFR) Title 14 Chapter III[16] and detail the procedures and requirements for commercial space transportation activities.

To allow the industry to grow Congress implemented a moratorium on the FAA-AST regulating the design or operation of the vehicles until October 2015. After which the FAA-AST intention was to 'certify' the spaceflight participants (SFPs)/crew and then by 2018 certify the vehicles. This has clearly slipped with H.R. 2262 (114th Congress, 2015), extending the learning period through to 2025.

To do this though, Congress stipulated that 'waivers' must be in place because of the lack of certified airworthy (spaceworthy) vehicles. To do this, operators must provide certain information to inform the SFPs (suborbital astronauts) about the risks involved such that the SFPs are sufficiently knowledgeable to be able to sign the waiver i.e. SFPs are providing their informed consent to flying in a non-certified vehicle. So what does

16 Under the United States Code (USC) Title 49, Subtitle IX, Chapter 701

the FAA-AST say that your operators should be informing you of? CFR 460.45 states you must be told the following:

INFORMING SPACE FLIGHT PARTICIPANTS OF RISK

- Before receiving compensation or making an agreement to fly a SFP an operator must:Inform each SFP in writing about the risks of the launch and re-entry including the safety record of the launch or re-entry vehicle type
- Information must be presented in a manner that can be readily understood by a SFP with no specialized education or training

Author's Notes: *we will have a look at these in the next Chapter to help you understand a bit more about safety risk.*

RISK DISCLOSURE IN WRITING

The written disclosure must contain:

- For each mission, each known hazard and risk that could result in a serious injury, death, disability or total or partial loss of physical and mental function
- That there are hazards not known and
- That participation in space flight may result in death, serious injury, or total or partial loss of physical or mental function

Author's Notes: *in the next Chapter there are examples of inherent hazards that you may face, some of which could lead to death, and so we will also look at some of the controls that your operator should be implementing to reduce the severity of an accident or the likelihood of an accident.*

U.S. GOVERNMENT HAS NOT CERTIFIED VEHICLE AS SAFE

- Operator must inform the SFP that the U.S. Government has not certified the launch vehicle and any re-entry vehicle as safe for carrying crew or SFPs

Author's Notes: *this means the vehicle has not been designed, built or tested to an agreed set of certification requirements (per aviation vehicles and NASA vehicles). The vehicle you will fly in has followed the Launch License regime which is primarily to protect the uninvolved public. Should an accident occur then the FAA-AST can step in and demand certification standards are implemented*

SAFETY RECORD OF ALL VEHICLES THAT HAVE CARRIED HUMANS

Operator must inform SFPs of the safety record of all launch or re-entry vehicles that have carried one or more persons on board, including both U.S. government and private sector vehicles. This information must include:

- Total number of people who have been on a suborbital or orbital space flight and total number of people who have died or been seriously injured on these flights, and
- Total number of launches and re-entries conducted with people on board and number of catastrophic failures of those launches and re-entries

Author's Notes: *in the future this should be about suborbital vehicles 'in general' and if you're flying with Virgin Galactic or launching with Blue Origin then there isn't a great deal of history to derive some figures for you. If you're flying in a few years' time, then this will be meaningful. In the meantime, they will tell you of all suborbital operator's test flights and actual flights – hopefully without incident. The orbital flights with humans is interesting because of the number of fatalities versus orbital flights.*

SAFETY RECORD OF OPERATOR'S VEHICLE

Operator must describe the safety record of its vehicle to each SFP. Operator's safety record must cover launch and re-entry accidents and human spaceflight incidents that occurred **during** and after vehicle verification performed in accordance with section 460.17 and include;

- Number of vehicle flights
- Number of accidents and human spaceflight incidents as defined by section 460.15, and
- Whether any corrective actions were taken to resolve these accidents and human spaceflight incidents

Author's Notes: *actually section 460.17 is the only specific requirement concerning you (all others relate to protecting the uninvolved public on the ground [or air, in other aircraft] – more about protection of the public angle below). The requirement is about ensuring the verification program has been complete before letting on any SFPs. Section 460.15 concerns human factors meaning design and operating aspects concerning the crew and their ability to perform safety-critical tasks (like control the vehicle). So here operators should detail contributory causes to any incidents or accidents (such as human factors like cockpit layout issues, g-force protection, noise stressors etc.).*

The SpaceShipTwo flight test accident will need to be discussed and VG will need to report on the NTSB findings and hence detail what design and/or procedural mitigation has been implemented to ensure that the event will not happen again (or that the likelihood of the event will be extremely improbable). Here, VG will detail the locking pin, with software control, to prevent the Feathering Device arming issue and also that the pilots no longer touch the device during the rocket phase.

SFP REQUESTING ADDITIONAL INFORMATION

Operator must inform a SFP that he or she may request additional information regarding any accidents and human spaceflight incidents reported.

Author's Notes: *Focus on any accidents that your operator has had during development program (or reported incidents [meaning reported to you and the FAA-AST – as this may not be common knowledge]). So ask whether the issue has been designed out or is there just a procedural or limitation control in place (clearly the answer should be the former but sometime this may not be possible without total redesign – if this is the case then ask whether they did a Justification Analysis to prove this – covered in the next Chapter). There may have been previous flights with 'minor or major' incidents with suborbital astronauts i.e. people suffering from grey-out or sickness or other inherent issue.*

OPPORTUNITY FOR THE SFP TO ASK QUESTIONS

- Before flight an operator must provide each SFP an opportunity to ask questions orally to acquire a better understanding of the hazards and risk of the mission.

Author's Notes: *Rightly so and the next chapter will provide you with some questions*

FEDERAL AVIATION AUTHORITY GUIDELINES

So now we have discussed waivers and your informed consent and what the operators are required to discuss with you, let's have a look at what the FAA-AST say in terms of safety.

The FAA-AST does have a safety target but this is a safety target to protect the non-involved public (3rd parties) on the ground and so the operators must demonstrate that their flight (or overflight thereof with vehicle failure) would not result in death or injury to the public at a rate of 100x10-6 per mission (1x10-4); meaning a risk of death for the public of 1 in 10,000. This is termed Expected Casualty analysis and will be discussed briefly in the spaceports section.

This Expected Casualty target is the only safety target. The FAA-AST does not mandate any level of acceptable risk for you or your crew. Though there is a qualitative requirement concerning the crew. As part of the requirement to protect public safety, they mandate that the crew must be able to control a Reusable Launch Vehicle (RLV) and be capable of acting in emergency scenarios. Crew actions and RLV operability are covered in the hazard analyses that a 'permitee' and licensee must supply and show compliance with the FAA acceptability matrix in order to be approved for operation.

Here are some other FAA-AST safety requirements; (www.faa.gov/about/office_org/headquarters_offices/ast/regulations/), though you'll notice they are about protecting the public (nothing about requirements for protecting you):

417.107 FLIGHT SAFETY

(b) Public risk criteria. A launch operator may initiate the flight of a launch vehicle only if flight safety analysis performed under paragraph (f) of this section demonstrates that any risk to the public satisfies the following public risk criteria…… (this relates to the Ec safety target of 100x10-6 per mission mentioned above – was 30x10-6 per mission).

417.121 SAFETY CRITICAL PRE-FLIGHT OPERATIONS

General. A launch operator must perform safety critical pre-flight operations that protect the public from the adverse effects of hazards associated with launch processing and flight of a launch vehicle. The launch operator must identify all safety critical pre-flight operations in the launch schedule required by §417.17(b)(1). Safety critical pre-flight operations must include those defined in this section.

417.127 UNIQUE SAFETY POLICIES, REQUIREMENTS AND PRACTICES

For each launch, a launch operator must review operations, system designs, analysis, and testing, and identify any unique hazards not otherwise addressed by this part. A launch operator must implement any unique safety policy, requirement, or practice needed to protect the public from the unique hazard. A launch operator must demonstrate through the licensing process that any unique safety policy, requirement, or practice ensures the safety of the public.

460.5(A)(2) CREW TRAINING FOR PUBLIC SAFETY

Each crew member must – complete training on their role on board or on the ground so the vehicle will not harm the public

460.5(B) CREW ABILITY TO WITHSTAND STRESSES OF SPACEFLIGHT

Each member of the flight crew must show their ability to withstand stresses of spaceflight (e.g. accelerating or deceleration, microgravity, and vibration) and still be able to carry out their duties so the vehicle will not harm the public.

Nope – there's nothing there specifically about protecting you. In nominal flights with no safety issues then fine and dandy. I like to have some protection in case of emergencies, but more of that in the next Chapter. To be fair there are some requirements about providing crew with redundant oxygen supplies, fire and smoke detection etc. so as not to incapacitate the flight crew (which would then lose control and possible harm the public). There is one requirement (CFR 460.11(a)) concerning the Life Support System whereby the operator must provide atmospheric conditions adequate to sustain life and consciousness for all inhabited areas within a vehicle; this is once again so the flight crew are not incapacitated and harm the public, but is also implicitly directed at you as an occupant.

There is one requirement specifically for you: **CFR 460.17 – Verification Program**

> *Operator must successfully verify the integrated performance of a vehicle's hardware and any software in an operational flight environment before allowing any space flight participant on board during a flight. Verification must include flight testing.*

Thank goodness for that; but having discussed this is the previous chapter do they mean after 10 or 100 flight tests? No – as it is not specific, operators can therefore get you on-board after a handful of flight tests! See my points in the next Chapter and questions to ask operators. I would hope that the front-runners and all who follow will have learned from the SS2 accident such that the test pilot did not die in vain.

The FAA-AST's hands are actually tied by Congress and the moratorium i.e. not to over-regulate and 'stifle' the industry. But that shouldn't stop industry setting good design practices, but we *are* setting 'best practices' they say. Okay I can see that in some aspects but *not* in other aspects (see next and concluding Chapters) and remember – one practice is certainly not best practice, so come on guys/gals, get with the

Photo by Sebastian Pichler on Unsplash

International collaboration on suborbital guidelines – not just your own! Indeed, the ICAO and UNOOSA have now formed a Space Learning Group, which I am a member along with National Authorities, and the focus is on commercial suborbital spaceflight. Here's hoping for some Standards And Recognised Practices (SARPs) in the future.

OTHER STANDARDS & GUIDELINES:

There is a dearth of spaceflight standards that designers/operators could review and adopt as appropriate. There are various guidelines that regulators could call upon or even reference but right now there are no specific suborbital standards (as recognized by the International community).

The FAA-AST has produced a 'Human Rated Practices' document – but this is mainly for the orbital industry and has had the suborbital aspects added.

WHAT ARE INDUSTRY MEMBERS SAYING?

At the 16th FAA-AST Conference in 2013 (Commercial Spaceport Panel slide 10), Mojave Air & Spaceport (MASP) CEO, Stuart O. Witt, asked

> *'Why is Western Society's Obsession with "Absolute Safety" driving Space Policy?'*[17]

I agree that there is no such thing as Absolute Safety (even in certification) – we are

17 https://www.faa.gov/about/office_org/headquarters_offices/ast/16th_cst_Presentations/media/Commercial_Spaceports_LopezAlegria_et_al.pdf

not asking for absolute safety! Just designers and operators who understand why there are certain safety requirements that should simply be followed – irrespective of launch licensing or certification; here I'm talking about the basics of understanding that an inadvertent functional failure mode leading to a catastrophic outcome should have 3 INHIBITS….. think about it!

At the ICAO-UNOOSA AeroSPACE symposium in Montreal (March 2015) I noted a brilliant and poignant statement from Canadian Astronaut Juliette Payette:

> *"It is imperative for our planet to advance – commercial space is a reality that will become a norm in the next decade – always push the frontier. We need to do this in a safe and intelligent manner – and as properly as you can with effective regulation, standards & best practice".*

Juliette was talking about spaceflight from experience and tailoring this for the ICAO-UNOOSA event understanding that suborbital and orbital flight carries higher risk levels than aviation yet the two domains must mix within the atmosphere.

Another inspiring presentation was from Pascal Jaussi, CEO of S3. His view is that to become a viable business his vehicle will have to reach an acceptable level of safety in the order of 1 in 10,000 per mission for the unmanned satellite launcher system and 1 in 100,000 per mission for a manned version. Sadly Pascal and S3 are no longer progressing their project.

Airbus Defence & Space (previously EADS-Astrium) Chief Engineer, Christophe Chavagnac had similar views in the design approach i.e. a certification requirements based development.

Photo by Ryan Hutton on Unsplash

PARTS 1 & 2 SUMMARY
THE GOOD, THE BAD AND THE UGLY

We have looked at the good, the bad and the ugly in order to inform you of some of the risks associated with your suborbital flight. We've looked at who you can fly with to the edge of space, where the Spaceports are and a typical flight and not so typical flight with emergencies. We've also looked at whether you can actually participate; a vital factor – your health and fitness. In doing so it is plain to see that operators want you to fly and are trying to be as inclusive as possible; so don't worry if you have a minor medical issue, because there may be a way, in time, when more bio-data becomes available.

There is essential training that you need to do as part of a spaceflight preparation program and this starts with the centrifuge. It's all about 'g' and you need to experience it and to train to use the Anti-G Straining Manoeuvre. There is also other desirable training available that you should do to experience all aspects of the flight that you will be exposed to; starting with the spacesuit and oxygen system through to noise, vibration and zero-g. None of this is currently mandated but should be considered 'best practice' nonetheless.

In answering the question 'how safe is it?' we looked at the operating and design aspects for different types of suborbital spacecraft and concluded that the different vehicles have positive aspects and negative aspects that would result in them having different risk levels for different phases of flight. Also, we looked at what would be considered an acceptable level of safety, concluding that suborbital flights should be safer than orbital flights and not as safe as aircraft flights; hence you could be exposed to 1 catastrophic event in 1000 flights during the early operations (or higher likelihood). We also looked at the inherent hazards you will be exposed to during the flight and identified the safety measures to protect you such as design controls, operating procedures and protective equipment (spacesuits/pressure suits incorporating oxygen system and ergonomic seats to assist with the g-forces and not forgetting the last-ditch parachute).

Due to the number of flight test accidents (Armadillo Aerospace, Blue Origin, Copenhagen Suborbitals and Virgin Galactic [Scaled Composites]) it is clear that these innovative systems will take longer to reach commercial status than planned. It is essential that these forerunners now take their time with the flight test program and not be set on a specific number i.e. 10 or 20 flights and 'we're good to go for commercial ops'.

No – as VG are now saying – we will be ready when we're ready! Now that's more like it!

So still want to fly? Excellent – me too. I had hoped not to change anyone's mind in deciding to fly on a suborbital flight and I don't think I have with the points raised in this book; that was certainly not the intent. What I hope to have achieved is to put the safety risks in perspective and informed you (as part of the informed consent) of what to expect during the flight and what the operator should be doing to minimise the likelihood of an accident occurring (or reducing the severity should an accident or incident occur).

Pioneering ventures will be inherently riskier for the frontrunners compared to those 2nd or 3rd tier players in any nascent industry. Flying to the edge of space during these pioneering flights will take suborbital astronauts with that 'extra-factor', that risk-taking mentality, that bias towards believing your flight will be fine.

Photo by Tim Mossholder on Unsplash

PART THREE: CHECKLIST

Indeed ‘let’s go’!

And so here is a checklist and some thoughts on the preparation for your spaceflight. A lot of this is common sense but also based on my research into suborbital flight and from my knowledge of safety. The safety angle is about understanding that medical standards, training, procedures and safety equipment all relate to operational mitigation measures (controls) to prevent an accident happening to you on your spaceflight. Also included are some all important questions for you to ask your operator (as allowed by the FAA-AST requirements).

BEFORE THE FLIGHT

HEALTH & FITNESS

Your pulmonary function, neurovesibular function and cardiovascular system need to be able to cope with the flight and so it’s important that your body is in reasonable shape. Whilst counting down the months and then weeks to your flight you should have sufficient motivation to start think about improving your health. Even if you’re overweight you should still be able to cope with a bit of exercise without hyperventilating or feeling faint. Your tolerance to +Gz is also dependent on your physical condition; ergo the fitter you are the more likely you can cope with the g-forces and other vehicle and environmental aspects (heat and vibration for instance). So if you’re not particularly fit and your spaceflight is not scheduled for some time then now is a good time to improve your general fitness i.e. to *condition your body* ready for the training and the flight!

As you near the training and flight date then increase your hydration (and reduce your alcohol intake) in line with physical training as this will help in coping with ‘g’ – I said reduce, not stop! A tailored training program would be more effective than a generic or regular style program. A base level of fitness will help but you will see more of a carryover with a specific program that emphasises the techniques needed to take on the physical challenge of suborbital spaceflight. It will also take into account your current strengths and weaknesses so you can spend time working on the elements that benefit the most.

My son Alex is a Personal Trainer with a degree in Exercise and Sports Science from the University of Exeter having researched training to improve your tolerance to g-forces. He offers tailored programming and coaching either in person at the specialist gym, Body Development, in Bath or remotely through online training. You can also experience an ‘intensive’ day where Alex will travel to you to coach you through every aspect of your tailored programming. For more information contact alex@movementmethod.co.uk.

SPACEFLIGHT TRAINING

In Chapter 4 we discussed the different training experiences that should form part of your spaceflight preparation program. We discussed that some activities are physiological and some psychological and some are both. The key point is that you must have experienced pretty much most aspects of your flight in a simulated and controlled environment, as well as near 'real-deal's such as a high performance MIG-25 near space experience or even experiencing high G in an L-39. The checklist table at the end of this section states whether they are essential, desirable or just fun activities.

BEFORE YOU SIGN THAT WAIVER

THE ALL IMPORTANT QUESTIONS TO ASK

Throughout the book we identified some questions to ask your operator per one of the six points required by the FAA-AST CFR 460.45:

QUESTION 1

WHAT LEVEL OF SAFETY HAVE YOU ACHIEVED AND TO WHAT CONFIDENCE LEVEL?

The operator (designer) may be able to say that a [predicted] catastrophic loss rate has been demonstrated to be better than (for example) 1x10-3 per mission i.e. 1 in 1000 flights. This is done by Fault Tree Analysis for the functional failures based on predictive quantitative analysis from Failure Modes Effects and Criticality Analysis. They don't have to show you the whole analysis but the top 'number' is easily obtained and is the value the operator will provide the FAA-AST with (this has to be moderated with a 'confidence' statement because of the lack of historical data for suborbital flights).

As we discussed earlier the answer should be more safe than orbital spacecraft and less safe than airliners – the question is how much safer than orbital spacecraft. Instead of stating that this is impossible and meaningless because there have been no suborbital flights beforehand, an operator should be able to say comforting things like 'an order of magnitude better/safer than the Space Shuttle' i.e. have a reasonable judgement on a comparative safety figure that would make sense to you.Earlier we gave a comparison to climbing Mount Everest and Base-Jumping, so what's wrong with comparing against Space Shuttle, Aircraft or even dangerous adventure activities?

QUESTION 2

HOW MANY FLIGHT TESTS HAVE YOU DONE AND HOW MANY OF THOSE HAVE BEEN FULL POWER, FULL PROFILE? HOW MANY ENGINE GROUND TESTS HAVE BEEN CARRIED OUT? WHAT LEVEL OF CONFIDENCE DOES THAT PROVIDE?

Here, you are realistically looking for well over a hundred flight tests and a 'fair' *percentage of these in full power, full profile.* The operator should also be able to detail how many ground tests of the engine has been carried out and other relevant information such as drop tests for SS2 etc. If the answer is a handful or low 10s of tests then ask what confidence they have (and ask them to show you how they arrive at that from their analysis).

QUESTION 3
WHAT HAVE YOU DONE TO ENSURE THE ACCIDENTS/INCIDENTS THAT OCCURRED ON YOUR TEST PROGRAM WILL NOT OCCUR ON OUR FLIGHTS?

There will have been some aborted flights with serious incidents and minor issues during testing and after a ‘fly-fix-fly’ regime the designer/operator will submit their analysis to the Authorities to gain their ‘launch’ approval. You want confidence that they have actually changed the design to address issues and not just applied a ‘procedural’ control measure or limitation (these are latter controls are ‘weaker’ mitigation against the issue). They can’t necessarily apply a design change for every issue, but you want to know they are strong enough as an organisation to admit they have got something wrong and have advanced the design to be safer.

The *SpaceShipTwo* flight test accident will be discussed with you as the suborbital astronaut and VG will report on the NTSB findings in detail and hence state what design and proceduralmitigation has been implemented to ensure that the event will not happen again (or that the likelihood of the event will be extremely improbable). They will detail the design changes as a locking pin on the arming system controlled by the computer (to prevent inadvertent deployment). Additionally, they will say that the procedure has now changed such that the pilots *do not* touch the feathering system at all until the rocket motor phase has concluded (whether from full burn to 90 seconds or during abort situations).

QUESTION 4
IN THE EVENT OF AN EMERGENCY SUCH AS LOSS OF CONTROL OF THE VEHICLE, HAVE YOU DONE ALL THAT IS REASONABLY PRACTICABLE TO SAVE MY LIFE? (PICK ONE OR MORE OF THE FOLLOWING);

For those without pressure suits:

> *Show me the justification analysis for why there are no spacesuits to save our lives in the event of de-pressurisation at 330,000ft (or relevant apogee).*

Rationale: *although the operator may have a reason for not providing some form of safety feature such as spacesuits they should back this up by Justification-Analysis such that they can demonstrate they have reduced the risks* ***so far as is reasonably practicable***.

For those without a vehicle Ballistic Recovery System:

> *Show me the justification analysis for why there is no vehicle Ballistic Recovery System.*

Rationale: *although the operator may have a reason for not providing some form of safety feature such as vehicle parachutes they should back this up by Justification-Analysis such that they can demonstrate they have reduced the risks so far as is reasonably practicable*

For those without a personal escape means such as pods or ejector seats with parachutes, or just individual parachutes:

> *Show me the justification analysis for why there are no personal survival safety measures*

Rationale: *In the event of loss of control or structural failure there are either vehicle survival measures or personal survival measures that could be implemented – to have neither would require a conclusive counter-argument from the designer/operator which would need to be backed up by justification analysis (the pilot survived the SS2 flight test accident BECAUSE of the parachute).*

QUESTION 5

CAN YOU RUN THROUGH THE INHERENT HAZARDS THAT I WILL BE EXPOSED TO DURING THE FLIGHT AND LET ME KNOW HOW YOU WILL REDUCE THE LIKELIHOOD OF THE HAZARD BECOMING AN ACCIDENT OR INCIDENT?

The hazard list that we are talking about is the physical hazards that you will be exposed to during the flight (see page 61) such as lack of oxygen from system faults, exposure to g-force (this is why we are going for a start – the thrill of the ride; but you should not be exposed to an extent where you will either pass-out temporarily or be harmed with excess g-forces and have other suborbital astronauts land on you and crush you during the re-entry phase for instance). Per the FAA-AST 6 points they should detail these and so listen and ask questions about mitigations (efficacy thereof or why there are none!)

QUESTION 6

RISK FROM OTHER SUBORBITAL ASTRONAUTS: HOW WILL YOU KEEP ME SAFE FROM BEING PINNED TO THE FLOOR BY ANOTHER SUBORBITAL ASTRONAUT?

After floating in zero-g, if you don't get back into your seat and strap in, you will be forced to the floor as the Gx forces build up (up to 6Gx). It's difficult to move your arms/body and if someone else lands on top of you….

QUESTION 7

RISK FROM PILOTS – HOW MANY FULL POWERED FLIGHTS HAVE THE PILOT(S) UNDERTAKEN? WHAT CLASS OF MEDICAL DO THEY HOLD?

If your vehicle is flown manually by pilots then you would like to know you are in safe hands – pilots with the 'right stuff'. These high-calibre individuals should have flown fast jets for a living (ex-military/NASA), and inherently would have held a Class 1 Aerospace Medical (unlike the FAA-AST requirement for a Class 2). You don't want your pilots making basic procedural mistakes under pressure, let alone in a non-nominal or emergency situation. Let's say your operator has only flown 14 test flights and they have seven pilots – doesn't make for great experience across the board. Over time (and a very good flight test programme), these pilots will amass a great deal of experience, which is exactly what you want.

QUESTION 8
WHAT ARE THE GO/NO-GO RISK CRITERION?

Management are sometimes under pressure to 'launch' – let's say that your flight has had technical delays and then a weather front comes along that pushes the cross-wind limits to the edge (roughly 15-knot cross-wind for instance) and your 'launch window' is only valid for the next 90 minutes because the airways that were closed will re-open; does your operator GO or delay for another day? Clearly this is a judgment call but the point is what level is their risk appetite? In an ideal world it would be good of the operators to brief you the day before (hopefully after some fun and informative training) of the process that they must go through prior to launch – here they can provide some 'heads-up' on what is known, such as weather predictions, vehicle technical status, time of launch and how much scope there is the launch window, etc.

QUESTION 9
DO WE ALL HAVE OUR OWN PRESSURE SUITS & WILL WE SURVIVE IN CASE OF WINDOW FAILURE AT EXTREME ALTITUDES? (IN RELATION TO Q5) – IF NOT, WHY NOT?

It's all very well having a 'shirt-sleeve' environment but at exo-atmospheric altitudes the chances of survival are minimal in the event of depressurisation due technical or environmental/operational failures. You may be told that partial pressures suits with oxygen are not needed and that these can have their own problems hence it is a balance between keeping things simple versus safety. Designers/operators should have provided some justification (analysis) for their decisions.

QUESTION 10
IF WE DETECT A PROBLEM WITH THE VEHICLE (WINDOW CRACKING, ICING, SMOKE, FIRE, ETC.) HOW DO WE COMMUNICATE THAT TO THE PILOTS?

You may see a problem that no one else has. The pilots may be too busy with the rocket phase and other suborbital astronauts may be feeling the effects of g etc. So you need to be able to communicate with the pilots (or perhaps they may have a comms link to ground control) – they will be monitoring your 'vitals' via telemetry anyway.

QUESTION 11
HOW WOULD WE KNOW IF THERE IS A PROBLEM WITH THE CABIN LIFE SUPPORT SYSTEM OR OUR OWN PERSONAL OXYGEN SYSTEMS? WILL THERE BE (VISUAL OR AUDIBLE) WARNING SYSTEMS?

You may have had training in the hypobaric (altitude) chamber. If not ask why not because the point of this is so you can experience wearing oxygen masks (if supplied) and when you remove this during the training it is to experience lack of oxygen (extremities tingle, blueness in lips, light headed and happy, unable to do simple tasks). So during your training/briefing the operator should go all of the visual and audible warnings that you may see or hear during the flight.

QUESTION 12
IS THE WEATHER GOOD FOR THE UPCOMING FLIGHT AND WITHIN LIMITATIONS?

This relates to Q8, and is specifically concerned with operating limitations. Is there a Jetstream above us that we need to know about? What's the visibility like for the approach (the vehicles are not fitted with instruments for flying in cloud and hence there needs to be sufficient visibility)?

You should be armed with as much information about your flight as possible. If there is a Jetstream above, you then you will fly through it at Mach 1 or 2 and there could be a small chance of momentary buffet/shear. Arguably your operator will want to avoid this, but they may take a risk (as part of their Go-No/Go decision making) and hence you should be aware of this. Likewise, with the visibility. You have signed your Waiver based on the risks from the vehicle – you also need to know about environmental risks.

THE FLIGHT

PERSONAL PROTECTIVE EQUIPMENT

Irrespective of the suborbital flight profile and suborbital flight vehicle you should be provided with personal protective equipment on top of the vehicle's design safety features. Whether you embark on a sedentary high altitude balloon ride to 36km or an ear-splitting g-inducing rocket ride to 80-130km there is still a chance of loss of habitable environment.

In the most basic cases you should be provided with life support system (depending on vehicle design/operation), hearing protection, g-force protection (depending on vehicle profile), eye protection (for glare and loose articles in the zero-g phase), fire protection (gloves, whole body and head protection, with some breathing apparatus if no spacesuit/pressure suit with oxygen system). A parachute is not really protective equipment, rather it is survival equipment – and you should definitely have one of those.

NORMAL PROCEDURES

Procedures that you need to practice will be demonstrated in the simulator and/or in the vehicle. You will need to know a fair bit more than your average passenger flight – **this is why you are a suborbital astronaut and indirectly but actively involved i.e. a 'spaceflight participant'.** Procedures such as:

- Normal operation of the door for ingress and egress

- Normal operation of your seat and harness
- Normal operation of your life support system (if worn or fitted)
- Operation of the communications panel for your station
- Returning to your seat after the zero-g phase

EMERGENCY PROCEDURES

Hopefully there won't be any emergencies but in case there are you need to practice a few certain drills such as:

- Emergency egress
- Emergency operation of your seat and harness
- Emergency operation of your life support system (if worn or fitted)
- Possible fire-fighting
- Emergency return to your seat during the zero-g phase
- Emergency crash positions

POST FLIGHT

After the flight and particularly during the early phases of operations it will be important to de-brief all suborbital astronauts in order to identify issues such that lessons can be learned. Additionally, biometrics will be extremely useful in assisting others who may have medical conditions preventing them from flying but over time may be allowed due to the data gathered on how we cope.

The Checklist in the following appendicies is meant to keep you focussed on preparing you for your spaceflight. Fill out your details including your current health & fitness and then ask yourself a hard question that needs an honest answer – 'do I feel fit and healthy to fly to space right now?' Hopefully the book has given you some pointers to answer this question. If the answer is immediately yes, then great. If you need to think about anything then there may be reasons why you cannot go just now, or indeed perhaps you cannot fly at all. By this I mean if you're wondering whether that operation you had last year will affect you during the flight or you are really overweight and wondering whether you can cope with g-forces.

When you fill the in the checklist remember that the 'medical' and training' activities are all safety barriers to mitigate the inherent hazards discussed in Part 2. Also remember that if you do have a medical condition that means you cannot fly just now that this may be due to a lack of medical data and the operators just don't want to take the chance – they really do want to be 100% inclusive but they do have a duty of care and will let you know if you should wait until more data has been collated and analysed. This data is not just from the flights but from the centrifuge and other training activities. So if you are not flying for a while then get in shape so you can enjoy the flight a bit better.


Photo by Zoltan Tasi on Unsplash

YOUR SPACEFLIGHT, YOUR SAFETY: A SUMMARY

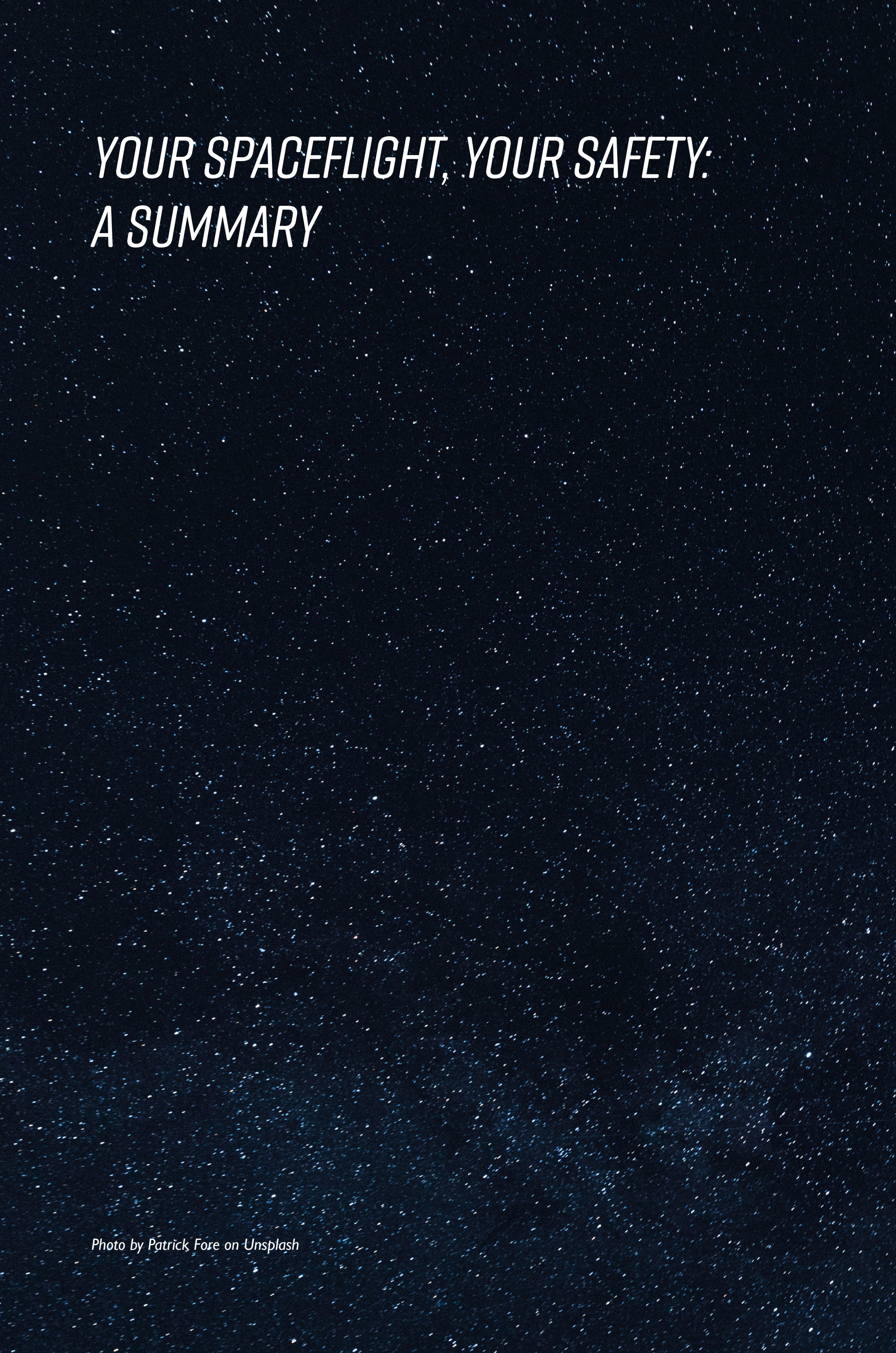


Photo by Patrick Fore on Unsplash

WHAT DID WE COVER?

The purpose of this book is to provide you, the suborbital astronaut, with some facts and figures and opinion to assist in your decision to sign a waiver – as part of the informed consent required by legislation.

The book provides information about your spaceflight and includes details about the suborbital operators, the training you should undertake and discusses medical criteria and issues that may prevent some from flying (though the majority of people should cope).

The book finishes with a number of questions for you to ask your suborbital operator (other than 'when can I go and where is my spacesuit/pressure suit') – and by the way, don't expect to be hopping in one of the front-runner vehicles!

We also provide some useful ancillary material in the following Appendices, such as a checklist, specifics on the informed consent and a table of hazards you may face.

SO: HOW SAFE IS IT?

Spaceflight is inherently risky; we could argue that 50 years of space and 70+ years of aviation should provide some clue as to designing safety into the vehicles and undertaking effective systems safety engineering throughout the design lifecycle.

All we can say is that the current designs (of *SpaceShip2* and *New Shepard*) should be more safe than the Space Shuttle (rate of one accident every 100 flights) but less safe than the aircraft you will fly in to the spaceport (one accident every 10 million flights).

I like to believe that suborbital vehicles should be at least an order of magnitude safer than orbital vehicles: I would predict an accident rate of circa 1 in 1000 flights to give you an idea. This will improve over time, but even this threshold may not be achieved in these early years of the industry: the spacecraft are ***not*** yet designed to certification standards, which is why the operator will ask you to sign a waiver.

The intent of the book is not to change your mind or to alter your risk appetite to match mine, and I don't believe I will have. I hope to have given you information that adds to your knowledge of the exciting flight that awaits you, that stokes your appetite, and allows you to engage with your operator during the training and briefing, to feel more involved – to give your informed consent.

APPENDIX: YOUR RESOURCES

Photo by Helena Lopes on Unsplash

SPACEFLIGHT CHECKLIST

SUBORBITAL ASTRONAUT DETAILS			
Name		Weight	
Date of Birth		Hat Size	
Sex		Shoe Size	
Height		Glove Size	

YOUR SPACEFLIGHT MEDICAL ASSESSMENT			
Describe your current health:		How many units of alcohol per week:	
Describe your current fitness level:		Do you smoke & how many per week:	
Detail Fitness Conditioning Program:		Summary Advice & Recommendations based on assessment	**[a] Continue Health & Fitness Regime** **[b] Alter Health & Fitness Regime** **[c] Start/Improve Health & Fitness Now**
Your Medical Consent	I do/do not [delete one] give consent for first aid on board/ post-flight (during emergencies)	**Signed:**	

	Requirement for Training & Flight	**Rationale**	**Pass** (Go)	**Fail** (No-Go)	**Retake**	**Date Completed**
Your General Practitioner (GP) Assessment	Essential	Your first medical 'filter'; general health, history, current issues,				
Operator's Aero-Medical Assessment	Essential	Specific aero-medical to participate in training and spaceflight				

YOUR SPACEFLIGHT TRAINING EXPERIENCES

Training/ Experience	Requirement for Training	Rationale	Comments	Date Completed
Centrifuge	Essential	Gz (eyeballs down) and Gx (chest to back) experience and training in the Anti-G Straining Manoeuvre (AGSM)		
Zero-G	Essential-Desirable	Provides experience of microgravity conditions and train how to move to get the most of the limited zero-g time	Depends on spacecraft	
High Performance Aircraft	Desirable	Provides experience of safety & flight briefs, kitting up, strapping in, real flight environment (noise, vibration) and Gz		
Hypobaric Chamber	Desirable	Provides understanding of oxygen requirements and wearing of mask and doing emergency drills		
Sensory Equipment	Less than Desirable but fun	Provides experience of sensory functions		
Spacecraft Simulator	Essential (Desirable if drills carried out in actual spacecraft)	Provides experience of getting in and out of the vehicle, use of seats, communications, and fire-fighting equipment. Can practice all of this is a controlled environment		
'Ground School' Briefings	Essential	Provides briefing on: Acceleration Altitude	Looks at g-force and how you will be effected. Looks at altitude and the characteristics of oxygen and how you could be effected. Both of these aspects will prepare you for the physiological training i.e. this is part of your psychological preparation	
'Ground School' Practical	Essential	Provides demonstration and practice on: Spacesuit Personal Oxygen AGSM	It is vital you know how the features of your equipment work i.e. normal use and selection of emergency oxygen (if applicable) and training in the AGSM before you get anywhere near the centrifuge, ac or spacecraft	

WEBSITES

Here is a list of websites from this book plus other space-related websites:

- bigelowaerospace.com
- www.blueorigin.com
- bristolspaceplanes.com
- copenhagensuborbitals.com
- www.redbullstratos.com
- www.rocketplane.com/technology.html
- shipinspace.com
- www.S-3.ch/en/home
- spacefleet.co.uk
- www.virgingalactic.com
- www.xcor.com
- www.wearespaceship.com
- worldviewexperience.com
- www.0II00.com
- www.spaceportsweden.com
- spaceportamerica.com
- caribbeanspaceport.com
- spaceportmalaysia.com/V3
- iaass.space-safety.org
- www.faa.gov/about/office_org/headquarters_offices/ast
- www.gov.uk/government/publications/commercial-spaceplane-certification-and-operations-uk-government-review
- www.nastarcenter.com/aerospace-training/space
- www.rocketeers.co.uk
- spacenews.com
- www.parabolicarc.com
- spaceflightnow.com

INFORMED CONSENT SUMMARY

Regulation	Requirement for Informed Consent	What You Need to Know
§ 460.45(a)	Risks of the launch and re-entry	An operator must present technical information in a manner that ensures the space flight participants are informed of the risks of the launch or reentry and that those risks can be readily understood with no specialized education or training. Will the operators provide a level of safety? - This book mentions the chance of survival as being estimated at 1 in 1000 per mission for the early suborbital flights (it could be worse, but arguably should be more safe than Space Shuttle for instance, and less safe than General Aviation flights.
§ 460.45(a)	Safety record of the launch or reentry vehicle type	A table detailing the safety record of the suborbital vehicle type should be provided – see below. It must cover launch and reentry accidents and human space flight incidents that occurred during and after vehicle verification performed in accordance with §460.17
§ 460.45(a)(1)	Each known hazard and risk that could result in a serious injury, death, disability, or total or partial loss of physical and mental function	There are physical inherent hazards due to the G-Forces, Microgravity, Noise, Vibration, etc.) and psychological aspects (claustrophobia, anxiety/ excitement, vertigo, etc.). The main risks will be from loss of control, propulsion fire/explosions, structural failure (includes total failure and minor breaches occurring at extreme altitudes when no pressure suits are provided), etc. The FAA-AST guidance is based on the assumption of an inflight cabin environment with a barometric pressure not exceeding 8,000 ft (10.91 psi), where passengers are not required to wear a pressurized suit.
§ 460.45(a)(2)	That there are hazards that are not known	Here the operator will state that they have told you of the known hazards and that there is a potential for unknown hazards to arise. This is because they do not have the experience and full understanding of the vehicle's operating issues and flight crew factors.
§ 460.45(a)(3)	That participation in space flight may result in death, serious injury, or total or partial loss of physical or mental function	During the pioneering flights, this is a stark reality – you may die or have severe injuries. This could be due to vehicle failure, flight crew error or your medical health/ psychological issues. There is no defined safety 'target' and no history of achievements for suborbital flight. This book mentions the chance of survival as 1 in 1000 per mission for the early flights – over time, with fix-fly-fix, learn, then more reliability should be gained and more confidence of successful flights. Pursuant to 49 CFR 830.2: "serious injury means any injury which: (1) Requires hospitalization for more than 48 hours, commencing within 7 days from the date of the injury was received; (2) results in a fracture of any bone (except simple fractures of fingers, toes, or nose); (3) causes severe hemorrhages, nerve, muscle, or tendon damage; (4) involves any internal organ; or (5) involves second- or third-degree burns, or any burns affecting more than 5 percent of the body surface."
§ 460.45(b)	Non-certification statement	Government has not certified the launch vehicle and any re-entry vehicle as safe for carrying crew or space flight participants. Vehicles will not have undergone nearly the amount of testing that normal commercial travel style vehicles undergo before they are licensed for commercial use. That there are no 'accepted' standards for the vehicle or flight crew

§ 460.45(c)	Description of human space flight safety record	Includes any flight with a human on board regardless if it occurred before, during, or after vehicle verification. Note: "safety performance related to an earlier, experimental model is not directly relevant to a final, passenger-carrying model."
§ 460.45(c)(1)	Total number of people who have died or been seriously injured	A table with for orbital and suborbital flights should be provided – see below
§ 460.45(c)(2)	Total number of launches/ reentries and catastrophic failures	A table with for orbital and suborbital flights should be provided – see below
§ 460.45(d)	Description of vehicle safety record	A table with for orbital and suborbital flights should be provided – see below
§ 460.45(d)(1)	The number of vehicle flights	A table with for orbital and suborbital flights should be provided – see below
§ 460.45(d)(2)	The number of accidents and human space flight incidents	A table with for orbital and suborbital flights should be provided – see below
§ 460.45(d)(3)	Whether any corrective actions were taken	For example, the SS2 modifications per the NTSB recommendations will be detailed along with other aspects that were modified based on the VG revised safety/design approach.
§ 460.45(f)	Consent (by the space flight participant) (1) Identifies the specific launch vehicle that the consent covers; (2) States that the space flight participant understands the risk, and his or her presence on board the launch vehicle is voluntary; and (3) Is signed and dated by the space flight participant.	In order to sign a waiver (your consent) then this must be done by someone with cognisance of the risks and of a suitable age (general guide would be 18 years) and mental disposition. It must also be recognized that no conclusive data exist concerning the potential adverse physiologic and pathologic effects of space flight on infants or young children. For this reason, operators may wish to establish a minimum age for passengers participating in aerospace flights.

SOURCES OF PHYSICAL HAZARDS

From APT Research Inc.

Source of Physical Hazard	Mission Phase and/ or Failure Mechanism Causing Hazard	Potential Physical Effects
High Decibel Noise	– Excessive engine noise – Inadequate acoustical shielding – Explosion on ground	– Ear drum damage – Temporary or permanent hearing loss – Vestibular effects on balance
High Pressure	– Breached high-pressure vessel – Explosion – In-flight aerodynamic pressure	– Loss of consciousness – Severe ear drum or tissue trauma due to overpressure – Concussion – Brain damage – Death
Low Pressure	– Explosive decompression – Loss of cabin pressure due to leak – Loss of atmospheric control systems	Trauma due to exposure to vacuum: – Brain or spinal cord injury (temporary or permanent) – Lung injury – Other tissue damage – Death Trauma due to pressure change and trapped gas: – Gastrointestinal pain – Tooth, ear and sinus pain – Potential tissue damage in affected areas
High G-forces (Sustained Acceleration)	Acceleration during launch phase, de-acceleration during descent phase (due to grab of aerodynamic control surfaces)	G-Profile over flight may have adverse physiological and/or pathological effects particularly on the cardiovascular response of compromised participants. – Cardiovascular – Neurovestibular – Musculoskeletal
Microgravity	At high altitudes during sub-orbital flight.	Short exposures to microgravity may cause acute physiological responses in several bodily systems – Cardiovascular – Respiratory – Neurological: • Vestibular • Motion Sickness • Vision – Musculoskeletal – Hematological – Psychological – Gastrointestinal SFPs may expect these symptoms: – Unfamiliar effects on physical movement – Internal displacement/ entrapment of body fluids – Decreased gravity-dependent circulation in lower extremities – Changes in the chemical makeup of blood

High Temperature	– On-ground fire or explosion – In-flight fire or explosion – Heat of re-entry and loss of heat dissipation systems	– Tissue damage – Serious burns – including third degree – Death
Low Temperature	Cabin breach, loss of heating systems	– Frost-bite – Death
High Radiation levels	– Shielding not adequate – High radiation levels in space	– Radiation sickness – Loss of bodily fluids – Increased long-term cancer risk – Death
Sunlight	Prolonged looking at unfiltered sunlight	Eye damage
Physical Impact Trauma Abbreviated Injury Scale (AIS) 5,6	Crash or structural failure of spacecraft (due to system failure, pilot error, weapons fire, impact with space debris, etc.)	Serious injury or death
- AIS 3,4	Ground or In-flight – numerous mechanisms	Moderate injury
- AIS 1,2	Entry/exit from spacecraft	Minor injury
Exposure to Toxic Chemicals	Release of toxic substance on-board or from ground storage tanks	– Respiratory or skin damage – Death
Electrical shock	Contact with exposed high voltage source of electrical potential (on-board or on ground)	– Severe burns – Electrocution / Fatality
Loss of breathable atmosphere/change in composition of atmosphere/ contaminants and particulates	– Loss of atmospheric control systems and backup systems – Cabin flooded with non-breathable gases	– Asphyxiation / Fatality – Brain and other organ damage – Death
Loss/damage of personal effects on board or at launch site	On-pad explosion and/ or nominal launch effects to participant property on ground (cars, jets, vehicles)	Loss of assets

GLOSSARY

Term	Meaning
1st Party Personnel	Individuals directly involved in operating the re-usable launch and re-entry vehicle/suborbital aircraft i.e. the flight crew/pilots
2nd Party Personnel	Individuals directly involved in supporting the spacecraft/suborbital aircraft (i.e. maintainers) and individuals participating in the flight who are not members of the flight crew i.e. passengers (spaceflight participants)
3rd Party Personnel	The uninvolved public and other uninvolved personnel within the vicinity of the spacecraft/suborbital aircraft i.e. near the vehicle on the ground such as within the boundaries of the Spaceport
Acceptably Safe	The Risk to a suborbital aircraft has been demonstrated to have been reduced so far as is reasonably practicable and that relevant prescriptive safety targets and safety requirements have been met for all phases of the suborbital flight
Accident	An unplanned event or series of events that results in death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment.
Crew	Any employee of a licensee or transferee, or of a contractor or subcontractor of a licensee or transferee, who performs activities in the course of that employment directly relating to the launch, re-entry, or other operation of or in a launch vehicle or re-entry vehicle that carries human beings.
Failure Condition	A condition having an effect on either the airplane or its occupants, or both, either direct or consequential which is caused or contributed to by one or more failures or errors considering flight phase and relevant adverse operational or environmental conditions or external events
Flight crew	Any employee of a licensee or transferee, or of a contractor or subcontractor of a licensee or transferee, who is on board a launch or re-entry vehicle and performs activities in the course of that employment directly relating to the launch, re-entry, or other operation of the launch vehicle or re-entry vehicle
Flight Safety System	Destructive or non-destructive system designed to limit or restrict the hazards to public health and safety and the safety of property presented by a launch vehicle or re-entry vehicle while in flight by initiating and accomplishing a controlled ending to vehicle flight
Flight Termination System	Explosive or other disabling or thrust-terminating equipment installed in a launch vehicle, plus any associated ground equipment, for terminating the flight of a malfunctioning vehicle or stage
'g' (in relation to G-Force)	The ratio of actual acceleration to that of the earth's gravity 'g' of 9.8m/s^2
Hazard	A physical situation, *condition*, or state of a system, often following from some initiating event, that *unless mitigated* may lead to an accident
Human Factors	The systematic application of relevant information about human capabilities, limitations, characteristics, behaviours and motivation to the design of systems.
Human Rating	A human-rated system is one that accommodates human needs, effectively utilizes human capabilities, controls hazards and manages safety risk associated with human spaceflight, and provides to the maximum extent practical, the capability to safely recover the crew from hazardous situations

Mishap	Unsuccessful mission due to an accident or incident
RLV	A Reusable Launch Vehicle (RLV) is a spacecraft designed to enter space (or fly to the edge of space), then re-enter (or return from the edge of space) and land such that the vehicle can be launched again
RLV Pilot	A designated member of the RLV flight crew who has the ability to exercise flight control authority over a launch or re-entry vehicle
Safe	Risk has been demonstrated to have been reduced to a level that is ALARP and broadly acceptable, or tolerable, and relevant prescriptive safety requirements have been met, for a system in a given application in a given operating environment
Safety Case	A structured argument supported by a body of evidence that provides a compelling, comprehensive and valid case that a system is safe for a given application in a given environment
Safety Management	The systematic management of the risks associated with operations, related ground operations and aircraft engineering or maintenance activities to achieve high levels of safety performance
Safety Management System Safety Engineering	A safety organizational function concerned with implementing and managing safety policies and procedures necessary to undertake formal safety risk management Systems Safety Engineering involves
'Safing'	An action or sequence of actions necessary to place systems, Sub-systems or component parts into predetermined safe conditions
Space Suborbital Astronaut	The environment above the Earth, beginning at 62 miles (100km) THE Von Karman Line My term for you. I think that we should have some sort of classification of astronauts; we sort of already have this by using current orbital astronaut's full title i.e. NASA Astronaut, ESA Astronaut, Cosmonaut, Taikonauts, etc. for government employed personnel. So fee paying astronauts should be afforded a mantle based on what activity they are undertaking. So maybe Commercial Orbital Astronaut, Commercial Suborbital Astronaut and eventually Commercial Lunar Astronaut
Space flight participant (SFP) SQEP	An individual, who is not crew, carried within a launch vehicle or re-entry vehicle Suitably Qualified Experienced Personnel; involves every employee but in this book relates in particular to safety personnel and pilots
Suborbital rocket	A vehicle, rocket-propelled in whole or in part, intended for flight on a suborbital trajectory, and the thrust of which is greater than its lift for the majority of the rocket-powered portion of its ascent
Suborbital trajectory	The intentional flight path of a launch vehicle, re-entry vehicle, or any portion thereof, whose vacuum instantaneous impact point does not leave the surface of the Earth
Tolerable	A level of risk between broadly acceptable and unacceptable that may be tolerated *by society* when it has been demonstrated to be As Low As Reasonably Practicable

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To keep up to date on the latest happenings in the second space race, check out the website accompanying this book over at

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