VIRGIN GALACTIC

The First Ten Years

Erik Seedhouse

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Virgin Galactic

The First Ten Years

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To
All those preparing the way for
the suborbital
flight industry

About the Author

Erik Seedhouse is a Norwegian-Canadian suborbital astronaut whose life-long ambition is to work in space. After completing his first degree in Sports Science at Northumbria University, the author joined the 2nd Battalion the Parachute Regiment, the world's most elite airborne regiment. During his time in the "Para's", Erik spent six months in Belize, where he was trained in the art of jungle warfare. Later, he spent several months learning the intricacies of desert warfare in Cyprus. He made more than 30 jumps from a C130, performed more than 200 helicopter abseils, and fired more anti-tank weapons than he cares to remember!

Upon returning to the comparatively mundane world of academia, the author embarked upon a master's degree in Medical Science, supporting his studies by winning prize money in 100-kilometer running races. After placing third in the World 100km Championships in 1992, the author turned to ultra-distance triathlon, winning the World Endurance Triathlon Championships in 1995 and 1996. For good measure, he also won the inaugural World Double Ironman Championships and the Decatriathlon – a diabolical event requiring competitors to swim 38 kilometers, cycle 1,800 kilometers, and run 422 kilometers. Non-stop!

Returning to academia, Erik pursued his PhD at the German Space Agency's Institute for Space Medicine. While studying, he won Ultraman Hawai'i and the European Ultraman Championships, and completed Race Across America. As the world's leading ultra-distance triathlete, Erik was featured in dozens of magazines and television interviews. In 1997, *GQ* magazine nominated him as the "Fittest Man in the World".

In 1999, Erik retired from being a professional triathlete and started post-doctoral studies at Simon Fraser University. In 2005, he worked as an astronaut training consultant for Bigelow Aerospace and wrote *Tourists in Space*, a manual for spaceflight participants. He is a Fellow of the British Interplanetary Society and a member of the Space Medical Association. In 2009, he was one of the final 30 candidates in the Canadian Space Agency's Astronaut Recruitment Campaign. Erik works as a spaceflight instructor for the American Astronautics Institute, professional speaker, triathlon coach, author, and Editor-in-Chief for the *Handbook of Life Support Systems for Spacecraft and Extraterrestrial Habitats*. He is the Training Director for Astronauts for Hire and, between 2008 and 2013, he served as director of Canada's manned centrifuge operations.

In addition to being a suborbital astronaut, triathlete, centrifuge operator, pilot, and author, Erik is an avid mountaineer and is pursuing his goal of climbing the Seven Summits. *Virgin Galactic* is his fifteenth book. When not writing, he spends as much time as possible in Kona on the Big Island of Hawai'i and at his real home in Sandefjord, Norway. Erik and his wife, Doina, are owned by three rambunctious cats – Jasper, Mini-Mach, and Lava.

The author stands in front of the Fram in Oslo, October 2014

Acronyms

A-LOC	Almost Loss of Consciousness
AGSM	Anti-G Straining Maneuver
ADS	Aid Data System
ATV	Atmospheric Test Vehicle
BEAM	Bigelow Expandable Activity Module
CG	Center of Gravity
CSLAA	Commercial Space Launch Amendments Act
DCS	Decompression Sickness
EDS	Emergency Detection System
EPT	Effective Performance Time
ESA	European Space Agency
ETC	Environmental Tectonics Corporation
FAA	Federal Aviation Administration
FAI	Fédération Aéronautique Internationale
FAST	Flights for the Advancement of Science and Technology
FDD	Flight Data Display
FTE	Flight-Test Engineer
G-LOC	Gradual Loss of Consciousness
GOR	Gradual Onset Rate
GPS	Global Positioning System
HTPB	Hydroxyl-terminated polybutadiene
INS	Inertial Navigation System
ISS	International Space Station
ITAR	International Trade on Arms Regulations
KEAS	Knots Equivalent Airspeed
LAPCAT	Long-Term Advanced Propulsion Concepts and Technologies
LEO	Low Earth Orbit
MIT	Massachusetts Institute of Technology
NASTAR	National Aerospace Training and Research

NCRP	National Council for Radiation Protection
NMSA	New Mexico Spaceport Authority
OSC	Orbital Sciences Corporation
PI	Principal Investigator
PLL	Peripheral Light Loss
PUG	Payload User Guide
RAF	Royal Air Force
RCS	Reaction Control System
REM	Research Education Missions
ROR	Rapid Onset Rate
SABRE	Synergistic Air-Breathing Rocket Engine
SARG	Suborbital Applications Research Group
SAS	Space Adaptation Syndrome
SFP	Spaceflight Participant
SMS	Space Motion Sickness
SNU	System Navigation Unit
SwRI	Southwest Research Institute
TONU	Tier One Navigation Unit
TPS	Thermal Protection System
TUC	Time of Useful Consciousness
USAF	United States Air Force
USMC	United States Marine Corps
USML	United States Munitions List
VMC	Visual Meteorological Conditions

Preface

> "Today's flight was another resounding success. We focused on gathering more transonic and supersonic data, and our chief pilot, Dave, handled the vehicle beautifully. With each flight test, we are progressively closer to our target of starting commercial service in 2014."
>
> *Virgin Galactic CEO, George Whitesides*

As the main engine ignites, the crew feels a deep rumble behind them and a sudden sensation of motion as the rocket ignites, trailing a 100-meter-long fountain of exhaust in an inferno of smoke, searing light, and earth-shaking noise. Amid the thunder of launch, the numbing noise, and the incredible acceleration, the crew is pushed forcefully back into their seats. The gut-wrenching journey to suborbital space – an event planned for many weeks and anticipated by the crew for several months – takes less than five minutes. Once in microgravity, the thrill of the ascent is replaced by the immediacy of the moment, as the spaceflight participants – now fully fledged Virgin Galactic astronauts – pull out cameras and float to the nearest window to take snapshots from the vantage point in space.

About

We are Virgin Galactic, the world's first commercial space-line. We are working hard to make access to space orders of magnitude more affordable, frequent, and safe than ever before. We are also having a lot of fun while doing so.

Mission

Make access to space orders of magnitude more affordable, frequent, and safe than ever before.

Description

Virgin Galactic, owned by Sir Richard Branson's Virgin Group and Aabar Investments PJS, is on track to be the world's first commercial spaceline. Our reusable, suborbital spaceship (SpaceshipTwo) and carrier craft (WhiteKnight-Two) have both been developed by the legendary aerospace pioneers Scaled Composites. Founded by Burt Rutan, Scaled developed SpaceShipOne, which in 2004 claimed the \$10m Ansari X-PRIZE as the world's first privately developed manned spacecraft.

Our new vehicles share much of the same basic design, but are being built to carry six customers and two pilots on sub-orbital space flights. Each mission will give our future astronauts an out-of-the-seat, zero-gravity experience offering astounding views of the planet from the black sky of space.

The test flight programs for SpaceShipTwo and WhiteKnightTwo are well under way, leading to Virgin Galactic commercial operations, which will be based at Spaceport America in New Mexico.

In July 2012, we announced a new program called LauncherOne. LauncherOne will be launch small satellites into orbit for a wide variety of commercial and government customers.

www.virgingalactic.com
Welcome to Virgin Galactic's world of suborbital spaceflight

The above snapshot is taken from the Virgin Galactic website. Until recently, spaceflight had been the providence of a select corps of professional astronauts whose missions, in common with all remarkable exploits, were experienced vicariously by the rest of the world via television reports and internet feeds. These spacefarers risked their lives in the name of science, exploration, and adventure, thanks to government-funded manned spaceflight programs. All that is about to change thanks to Virgin Galactic, despite the tragic event on 31 October 2014, when VSS *Enterprise*, a Virgin Galactic test vehicle, suffered a catastrophic breakup and crashed in the Mojave Desert.

As George stated above, each SpaceShipTwo test flight is one step closer to Virgin Galactic's plans to launch daily flights into space. And when those first passenger flights begin, it will be the beginning of a new era in space travel. Passenger space travel has been a staple of sci-fi for almost as long as there have been commercial airlines. As far back as 1968, when Stanley Kubrick's *2001: A Space Odyssey* was released, Pan Am opened a waiting list for trips to the Moon. Part publicity stunt, the airline (it went bankrupt in 1991) estimated the service would begin no later than 2000. They even issued numbered membership cards for the first lunar flights! Inspired by the Moon landing the following year, 98,000 people signed up.

Nearly 50 years later, the bar is set a little lower. When testing is complete, SpaceShipTwo will fly to suborbital altitudes where passengers will enjoy four minutes of weightlessness. Slung beneath the WhiteKnightTwo mothership, SpaceShipTwo's ascent to the 15-kilometer launch altitude takes more than an hour. For passengers, who have paid US\$250,000 for the ride, there is nothing to do but wait for the moment of release. No drinks service on this ride. Once released, the diminutive spaceship drops away, the pilot ignites the rocket motor, and with a roar the spacecraft shudders to full thrust within a tenth of a second, its nose pointed straight up to the edge of space. Even if you've ridden the "fuge", as every passenger has, the acceleration is almost impossible to imagine, as 3 Gs pins them to the back of their seats. Twelve seconds later, the vehicle rockets through Mach 1. Mach 2 follows shortly after. Within 60 seconds, the vehicle is traveling at 4,800 kilometers per hour. Amid the diabolical noise (ear plugs are mandatory), the vibration, and acceleration, the soon-to-be astronauts try to keep their composure as they watch the sky turn from blue to navy, indigo, and then – suddenly – black.

At around 80 seconds, the pilot cuts the engine and, shortly after, the spaceship enters zero gravity. The passengers are now Virgin Galactic astronauts. Releasing their seat belts, they float around the cabin, and gaze at the view: 1,600 kilometers from horizon to horizon, the curvature of Earth subtle but clear, the fine blue line of the atmosphere easily visible against the blackness of space. On-board cameras capture every second of the experience. At the top of its parabolic arc, the rocket plane spends just four minutes in space before it begins its fall back down to Earth. The pilot positions the "feather" for re-entry, and the passenger seats recline to enable the newly minted astronauts to cope with up to 6 Gs of acceleration during their ride back to the desert runway.

If everything goes to plan, Branson hopes not only to give birth to a new industry, but to democratize the government-dominated spaceflight business by opening the space frontier to commercial astronauts, payload specialists, scientists, and, of course, tourists. But, as the tragic event of 31 October 2014 reminded us, the aerospace business is rarely one in which things go to plan. After the accident in which pilot Michael Alsbury was killed, Sir Richard Branson vowed that his Virgin Galactic space programme, saying millions of people "would one day love the chance to go to space". This book tells the story to date.

1

Suborbital Flight: A Primer

1.1 Courtesy: NASA

Those who have followed the media fanfare about the commercial suborbital flight industry over the past several years have cause to be a little disillusioned because it's been quite a waiting game. After the euphoria of the X-Prize in 2004, space fans and media alike discussed the possibility of flying into space the following year or if not the following year then *definitely* the year after that. Virgin Galactic, along with other operators that

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1.2 SpaceShipOne. Mike Melvill waves from the cockpit on 21 June 2004. Courtesy: Wikimedia/The SpaceShip Company

comprised the nascent commercial spaceflight industry, fueled speculation that suborbital passenger flights were just around the corner by making promises they would soon be ready to fly you and your friends into space. Tickets were sold. Hundreds of them. Deadlines came and went. But nothing happened, except for the occasional test flight. One year stretched to two. Two became five. Five became 10. But, in 2014, more than 10 years following SpaceShipOne's iconic flight (Figure 1.2), Virgin Galactic was finally tantalizingly within reach of realizing the promise of the historic 2004 flight. Until the tragic event of 31 October 2014 that is.

EARLY SUBORBITAL FLIGHTS

Those lucky enough to fly on SpaceShipTwo, Mark II, SpaceShipOne's and the original SpaceShipTwo's successor, will experience a spaceflight that few have flown because manned suborbital spaceflights are something of a rarity: two Mercury–Redstone flights, two X-15 flights, one inadvertent Soyuz launch abort, and three SpaceShipOne flights. That's it. Eight flights. But, if you include animals, that list stretches a little, so when you buy your SpaceShipTwo ticket, spare a thought for the animals that made your flight possible. Many years ago, before astronauts risked their lives, it was thought humans might not survive the trip to space and back. So scientists launched animals – monkeys, chimps, and dogs mainly – to make sure they came back alive.

On 14 June 1949, a V-2 rocket flight carrying a monkey, Albert II, reached an altitude of 133 kilometers. Unfortunately, Albert II died on impact. On 31 August 1948, another V-2 carried a mouse that survived impact. Then, on 12 December 1949, the final V-2 monkey flight was launched, carrying Albert IV, a rhesus monkey wired up to biomedical instrumentation. By all accounts it was a very successful flight… until impact. Unfortunately, Albert IV didn't survive.

RUSSIAN SUBORBITAL FLIGHTS

The Soviets, who also had manned spaceflight plans, kept a close eye on the American V-2 project, and decided they should start their own research. Rocket pioneer Sergei Korolev and his team of scientists, that included biomedical expert Vladimir Yazdovsky, used mice, rats, and rabbits as guinea-pigs for their early tests, before using dogs (the Soviets reckoned dogs would be less fidgety than monkeys). Between 1951 and 1952, Soviet R-1 rockets launched nine dogs, three of whom flew twice. Each flight carried a pair of dogs in hermetically sealed containers (Figure 1.3) that were recovered by parachute [1].

On 22 July 1951, Dezik and Tsygan made spaceflight history when they became the first dogs to make a suborbital flight. Both dogs were recovered unharmed after traveling to an altitude of 110 kilometers. Dezik made another suborbital flight in September 1951 with a dog named Lisa but, sadly, neither survived when their parachute failed. After Dezik's death, Tsygan was adopted as a pet by Soviet physicist Anatoli Blagonravov [2]. Tsygan never flew again and lived to old age. The Soviets continued their suborbital animal flights through 1960, but unfortunately not all of them had happy endings.

HAM AND THE ASTROCATS

Before we go any further it's worth defining what a suborbital flight is. In short, a suborbital flight is defined as a flight to an altitude higher than 100 kilometers that does not involve sending a vehicle into orbit. The first unmanned suborbital flight was in early 1944, when a V-2 test rocket launched from Peenemünde, Germany, reached 189 kilometers' altitude. Then, on 24 February 1949, the upper stage of Bumper 5, a two-stage rocket launched from the White Sands Proving Grounds, reached an altitude of 399 kilometers [3]. These flights were followed by the first pioneers of the space age: chimpanzees. As part of the space race with the Soviet Union, Project Mercury (1958–1963) was tasked with putting an American astronaut into orbit and returning him safely. The program was also designed to test how well humans functioned in space. But, before humans could be launched, NASA needed to make sure their astronauts could survive the flight. So, before risking humans, scientists recruited *astro-chimps*. Chimpanzees were an obvious choice because a chimp's physiological make-up is similar to humans. And chimps can be trained. First up was Gordo, a squirrel monkey launched by the US Army on 13 December 1958. Gordo made his suborbital flight with no adverse effects, but paid the ultimate price

1.3 Dezik and Tsygan's ride to space. This is the space dog box used Russian animal test flights. Courtesy: Wikimedia/Airport of Frankfurt, Germany

because the flotation mechanism of the rocket's nose cone failed. Next were Able and Baker. Baker was a male rhesus monkey and Able was a female squirrel monkey. Instrumented with electrodes to monitor their vital signs during the flight, this intrepid pair was launched on 28 May 1959. Both survived the 480-kilometer flight and were recovered. Sadly, Able died on an operating table as doctors performed surgery to remove the sensors from underneath her skin. Six months later, Sam, a rhesus monkey, was launched on board the first US Little Joe. He survived the flight and was recovered.

Then there was Chop Chop Chang who was launched on board a Mercury–Redstone 2 rocket on 31 January 1961. Chop Chop Chang, or Number 65 (Figure 1.4) as he was also

1.4 Suborbital astronaut, Ham, is greeted by the ship's crew after his flight. Courtesy: NASA referred to was, by all accounts, a smart, loveable chimp with a positive temperament – ideal astronaut material. Number 65's mission was to test the environmental control systems inside the capsule to determine whether the Mercury–Redstone rocket was safe for humans, and if primates could function under the stress of space travel. Ensconced in his "cockpit", Number 65 was anything but a passenger because he had a number of tasks to complete. For the correct response, he earned a banana pellet and, for a wrong response, he received an electrical shock. There is no record of whether NASA tried this mode of training with their astronauts!

Number 65's demonstrated chimps could work in flight. During launch, more than six minutes of weightlessness and re-entry, Ham performed all the tasks he had been taught. Unfortunately, the fuel in his rocket burned quicker than anticipated and Ham landed 200 kilometers off course. Making matters worse, Number 65's capsule made a rough landing downstream. Waiting to recover the capsule were six naval destroyers and a landing ship dock, with three helicopters on board. Unfortunately, because of the launch glitch, the task force was waiting in the wrong place but, half an hour after landing, a plane spotted the capsule and helicopters were sent to collect it. Back on the ship, Number 65 shook hands with the captain, ate an apple and half an orange, and was checked by a doctor who pronounced the chimp to be in good condition. Number 65, whose flight earned him a new name – Ham – derived from his home unit, the Holloman Aeromedical Laboratory, wasn't too taken with his spaceflight experience because, when the press wanted photos of him in his couch, he fought to avoid being strapped in. Nevertheless, the flight was pronounced a success and Ham (the main character of the 2008 movie *Space Chimps* was named Ham III, the grandson of Ham) became a cause for celebration. He landed on the cover of *Life Magazine* and was covered by all the newsreels [4]. The Mercury astronauts were especially pleased Ham[1] had suffered no ill effects because they knew it wouldn't be long before one of them would be strapped on top of the Mercury–Redstone rocket.

The American and the Soviets weren't the only countries sending animals into space; in 1963, the French government had a small team of cats undergoing intensive training for possible spaceflight, including compression chamber and centrifuge training. By all accounts, these feline astronauts-in-training don't seem to have suffered too much because 10 were deselected for overeating! Of the lucky few who made the feline astronaut grade, Félix was the one chosen to undertake the first mission. Félix was a Paris street cat, although one report states he was bought by the French government from a dealer. Perhaps Félix didn't fancy being launched into space because he managed to escape, and was replaced at the last minute by a female cat, Félicette [5]. So, on 18 October 1963, it was Félicette who blasted off on top of a French Véronique AG1 rocket from a rocket base in the Sahara Desert. Félicette traveled 160 kilometers into space, where the capsule

[1] Following a thorough medical examination, Ham was placed at the Washington Zoo in 1963, where he lived alone until 1980, before being moved to the North Carolina Zoological Park in Asheboro. Upon his death in January 1983, Ham's skeleton was examined by the Armed Forces Institute of Pathology. His other remains were laid to rest in front of the International Space Hall of Fame in Alamogordo, New Mexico.

separated from the rocket and descended by parachute. During the flight, electrodes implanted in Félicette's brain captured valuable data. The French aviation medical centre, which directed the flights, stated afterwards that Félicette had made a valuable contribution to research. Félicette was recovered, but what happened to her after her adventure is unknown.

MERCURY PROGRAM: MANNED SUBORBITAL FLIGHTS 1 AND 2

Ham and Félicette taught researchers a lot more than could have been learned without them. If there had been no animal testing in the early days of manned spaceflight, the Soviet and American programs might have suffered significant losses. Félicette, Ham and Co gave their lives and their service in the name of medical advancement, paving the way for human space missions, including Virgin Galactic ticketholders. And, thanks to the flights of Ham, NASA decided the Mercury–Redstone rocket was safe to launch an astronaut. So, in May 1961, Alan Shepard (Figure 1.5) clambered on board a capsule on the man-rated version Mercury–Redstone 3 and launched on his suborbital flight (Table 1.1).

Shepard's flight was followed by Mercury–Redstone 4 (MR-4) two months later, piloted by Gus Grissom (Figure 1.6). Engineers had improved Grissom's spacecraft by adding a large viewing window and an explosively actuated side hatch [6]. The hatch utilized an explosive charge to fracture the attaching bolts to separate the hatch from the spacecraft. Securing the hatch to the doorsill were titanium bolts and drilled in each bolt was a tiny hole which provided a weak point. A detonating fuse had been installed between the inner and outer seal around the hatch. When the fuse ignited, gas pressure between the seals would result in the bolts failing. The fuse was ignited by a manually operated igniter after the removal of a safety pin. If necessary, the igniter could be operated externally by an attached lanyard. This last item was to cause problems at the end of Grissom's mission.

On 7 March 1961, the spacecraft was delivered to Hanger S at Cape Canaveral, where instrumentation and items of the communication system were removed for testing. After the items were reinstalled, the systems test proceeded as scheduled. After the tests, which took 33 days, the landing impact bag was installed and a simulated flight was run, after which the parachutes and pyrotechnics were installed and the spacecraft was delivered to the launch pad, where it spent another 21 days. Launch finally took place on 21 July 1961, 7:20 a.m. EST [6]. The flight, which reached an altitude of 190 kilometers, was successful, but the spacecraft was lost during post-landing recovery as a result of premature actuation of the explosively actuated hatch, resulting in the capsule sinking shortly after splashdown. Grissom exited the spacecraft immediately after hatch actuation and was quickly retrieved.

1.5 Alan Shepard. Courtesy: NASA

Table 1.1. Alan Shepard's suborbital flight timeline[1].

Time (min/sec)	*Event*	*Description*
00:00	Lift-off	Mercury–Redstone lifts off
00:16	Pitch program	Redstone pitches over 2°/second from 90° to 45°
00:40	End pitch program	Redstone reaches 45° pitch
01:24	Max Q	Maximum dynamic pressure
02:20	BECO	Engine shutdown – booster engine cut-off. Velocity 2.3 km/sec
02:22	Tower jettison	Escape tower jettison
02:24	Spacecraft Separation	Posigrade rockets fire for 1 second giving 4.6 m/sec separation
02:35	Turnaround maneuver	Automatic Stabilization and Control System (ASCS) rotates spacecraft 180°, to heat shield forward attitude. Nose pitched down 34° to retro fire position
05:00	Apogee	Apogee of 185 km reached 240 km downrange from launch site
05:15	Retrofire	Three retro rockets fire for 10 seconds at 5-second intervals. 170 m/sec is taken off forward velocity
05:45	Retract periscope	Periscope is automatically retracted in preparation for re-entry
06:15	Retro pack jettison	Retro pack is jettisoned, leaving heat shield clear
06:20	Retro attitude maneuver	ASCS orients spacecraft 34° nose-down pitch, 0° roll, 0° yaw
07:15	0.05 g (0.5 m/sec^2) maneuver	ASCS detects beginning of re-entry and rolls spacecraft at 10°/sec to stabilize spacecraft during re-entry
09:38	Drogue parachute deploy	Drogue parachute deployed at 6.7 km slowing descent to 111 m/sec and stabilizing spacecraft
09:45	Snorkel deploy	Fresh air snorkel deploys at 6.1 km. Environmental Control System (ECS) switches to emergency oxygen rate to cool cabin
10:15	Parachute deploy	Main parachute deploys at 3 km. Descent rate slows to 9.1 m/sec
10:20	Landing bag deploy	Landing bag deploys, dropping heat shield down 1.2 m
10:20	Fuel dump	Remaining hydrogen peroxide fuel automatically dumped
15:30	Splashdown	Spacecraft lands in water 480 km downrange from launch site
15:30	Rescue aids deploy	Rescue aid package deployed

[1] Source: http://www.jsc.nasa.gov/history/mission_trans/MR03_TEC.PDF

1.6 Gus Grissom prepares to enter the Liberty Bell 7 prior to his suborbital flight. He reached an altitude of 190 kilometers. Courtesy: NASA

X-15: MANNED SUBORBITAL FLIGHTS 3 AND 4

The Mojave Desert is where Chuck Yeager broke the sound barrier in 1947. It is also the place where test pilots earned their astronaut wings in the X-15. Based at Edwards Air Force Base, home to legendary pilots, the iconic X-15 rocket plane (Figure 1.7) roared to life high above the Mojave landscape for nearly a decade, flying out a program that included 199 flights between 1959 and 1968. Flying close to the edge of space, and sometimes beyond, the X-15 flights mimicked SpaceShipOne's private trek to space more than three decades later.

The X-15 program was a joint effort of NASA, the US Air Force (USAF), and the US Navy (USN). During the program, eight pilots[2] met the USAF criterion for spaceflights by

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[2] Robert White, Joseph Walker, Robert Rushworth, John "Jack" McKay, Joseph Engle, William "Pete" Knight, William Dana, and Michael Adams [7].

1.7 X-15. Courtesy: NASA

passing an altitude of 80 kilometers and were awarded astronaut wings. Two pilots also qualified for recognition by the Fédération Aéronautique Internationale (FAI). After initial test flights in 1959, the X-15 became the first winged aircraft to reach Mach 4, 5, *and* 6, and to operate at altitudes above 30 kilometers. In common with SpaceShipOne and SpaceShipTwo, the X-15 was carried under the wing of another aircraft (Figure 1.8) – a B-52 bomber (Scaled Composites built their own B-52, which they called WhiteKnight; Figure 1.9).

The wedge-shaped tail surfaces of the X-15 provided directional stability at speeds where conventionally shaped airfoils would have had little effect [8]. The large upper and lower fins and the downward slant of the wings allowed the X-15 to remain stable during steep climbs and at high altitudes [9]. Covering the titanium substructure was Inconel X, a nickel alloy capable of withstanding 650°C. Inconel X, like the airframe, thermal protection, flight controls, aerodynamic performance, pilot protection, and just about every other feature on the X-15, was experimental (the aircraft featured the first inertial navigation system). Above the atmosphere, pilots used reaction controls to keep the aircraft stable, while hand controllers in the cockpit were linked to small hydrogen peroxide thrusters at the nose for pitch and yaw control, and on each wing to control roll [10]. During the descent, the pilot switched from thruster control to traditional

1.8 X-15 under its mothership, the B-52. Courtesy: NASA

stick-and-rudder flying, effectively making the X-15 an unpowered glider (Figure 1.10), much like its descendant, SpaceShipOne.

A typical X-15 flight began with the ground crew disconnecting the servicing carts used to prepare the B-52 and X-15 for flight. The B-52 taxied along the dry lake bed with the X-15 strapped beneath the wing. With the two aircraft mated, the X-15 pilot had little to do but check his instruments and wait for the climb to release altitude. After half an hour, the B-52 reached an altitude of 10 kilometers and the pilot released the X-15. Following separation, the X-15 pilot fired the engine and began the powered phase of the mission. This is where the flight path was modified based on the mission's goal. If the aim was to achieve maximum altitude, the pilot burned the engine as long as possible, but if the mission was to break a speed record, the engine was burned on a more gentle incline. Once the burn was finished, the engine was shut down and momentum carried the X-15 through the rest of the flight. On approach to the landing lake at Edwards, the pilot slowed his airspeed to 320 kilometers per hour.

1.9 WhiteKnight and SpaceShipOne during Flight 17P. Courtesy: Wikimedia/D. Ramey Logan

The program's first suborbital flight was Flight 90 in 1963 (see sidebar). It was the first of two X-15 missions that reached space, both flown by Joseph A. Walker (Figure 1.11). The flight made Walker the first US civilian in space and also marked the first time a spaceplane had made a spaceflight (the flight exceeded the Kármán line, denoting the beginning of space).

1.10 X-15 gliding. Courtesy: NASA

X-15 Flight 90[2]

- Mass: 15,195 kilograms fueled; 6,577 kilograms burnout; 6,260 kilograms landed
- Maximum altitude: 106.01 kilometers
- Range: 534 kilometers
- Burn time: 84.6 seconds
- Mach: 5.5
- Launch vehicle: NB-52B Bomber #008
- Mission flown by: X-15 #3, serial 56-6672 on its 21st flight
- Launched by: NB-52B #008, Pilots: Fulton and Bement
- Take-off: 17:19
- UTC landing: 19:04 UTC
- Chase pilots: Crews, Dana, Rogers, Daniel, and Wood
- Acceleration (near end of the burn): 4 *g*
- Weightlessness: 3–5 minutes
- Flight duration: 12 minutes from launch to landing

[2] www.nasa.gov/pdf/470842main_X_15_Frontier_of_Flight.pdf

The X-15 was a pure research vehicle, whose sole function was to explore the effects of hypersonic travel on man and machine. In the end, the X-15 program yielded a treasure trove of hypersonic lessons that proved invaluable to developers of the Shuttle and, more recently, to commercial space vehicle developers such as Scaled Composites. The X-15 also marked the end of suborbital flights for quite some time.

1.11 Joe Walker. Courtesy: NASA

THE *APRIL 5 ANOMALY*: MANNED SUBORBITAL FLIGHT #5

Soyuz 7K-T, also named Soyuz 18a or Soyuz 18-1, and referred to as the *April 5 Anomaly* by some sources, was an unsuccessful launch of a manned Soyuz in 1975. The mission was to dock with the Salyut 4 space station but, due to a failure of the Soyuz launch vehicle, the crew (commander Vasili Lazarev and flight engineer Oleg Makarov) failed to achieve orbit. The launch proceeded as planned until T+288.6 seconds, when the second and third stages began separation (altitude 145 kilometers). Only three of the six retainers locking the stages together separated. The third stage's engine then ignited with the second stage attached. The thrust from the third stage broke the locks, and the second stage was thrown free, putting excessive strain on the booster. Inevitably, the extra strain caused it to deviate from its trajectory. Seconds later, the deviation was detected by the vehicle's guidance system, which activated the abort, which was performed using the Soyuz's engines. The maneuver separated the vehicle from the third-stage booster. It also separated the orbital and service modules from the re-entry capsule [11]. At the moment when the abort system initiated separation, the spacecraft was headed towards Earth, which increased its descent. Instead of the anticipated 15 g acceleration, the crew experienced a crushing 21 g. Despite very high loading, the capsule's parachutes opened and slowed the craft to a survivable landing after a flight of only 21 minutes. But the crew's troubles weren't over because the capsule landed more than 800 kilometers north of the Chinese border.[3] Worse, the capsule had landed on a snow-covered slope and began rolling downhill towards a sheer drop before being snagged on vegetation. Exiting the capsule, the cosmonauts found themselves in chest-deep powder snow and a temperature of −7°C. Since they weren't absolutely sure if they had landed in China, they destroyed classified documents before radioing the rescue team, which confirmed they were in the Soviet Union, near the town of Aleysk. A day later, the crew[4] was airlifted out.

THE LEGACY OF SPACESHIPONE: MANNED SUBORBITAL FLIGHTS 6, 7, AND 8

Fast forward to 4 October 2004,[5] 36 years after the end of the X-15 program. A remarkable event is taking place at Mojave Airport, a sprawling test center in the California desert. Here, at this desolate airport, a small, winged spacecraft built with lightweight composites and powered by a rocket motor using laughing gas and rubber will fly to the edge of space

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3 The exact landing site of the capsule has been a subject of debate amongst space historians. Some say the capsule landed in China and others say it landed in Mongolia.

4 Lazarev never flew to space again and never fully recovered from the accident, while Makarov made two flights to the Salyut 6 space station.

5 The SpaceShipOne team deliberately chose October 4th as the date of their second attempt because of its significance in space history: 47 years earlier, the Soviets had put the world's first satellite, Sputnik 1, into orbit – kicking off the first space race.

1.12 SpaceShipOne. Courtesy: Wikimedia

and into the history books. Registered with the Federal Aviation Administration (FAA) by the alphanumeric designation N328KF, but known to space enthusiasts as SpaceShipOne, this privately developed vehicle (Figure 1.12)[6] will ensure the commercial spaceflight industry will never be the same again [12].

The excitement began building the night before, as cars poured into the parking lot and continued to stream in almost until take-off, by which time crowd-control personnel had almost given up. Rows of trucks with satellite dishes and spotlights greet the spectators as they stream into the airport. It's only five in the morning but a sense of expectancy already wafts through the air together with the smell of coffee and bagels. An Ansari X-Prize banner flutters from the control tower as thousands of space enthusiasts wait for the appearance of the diminutive spaceship. Buzz Aldrin and other space legends rub shoulders with William Shatner and Mojave's maverick engineering genius, Burt Rutan. Just kilometers away at Edwards Air Force Base, test pilot Joe Walker reached the edge of space by flying the X-15 rocket plane to an altitude of 107,333 meters. The X-15 eventually gave birth to the Shuttle, a semi-reusable vehicle embroiled in politics that became a symbol that the

[6] The "N" in the designation is the prefix used by the FAA for US-registered aircraft and 328KF stands for 328 (kilo – "K") feet ("F" in the designation), which is the official demarcation altitude for space.

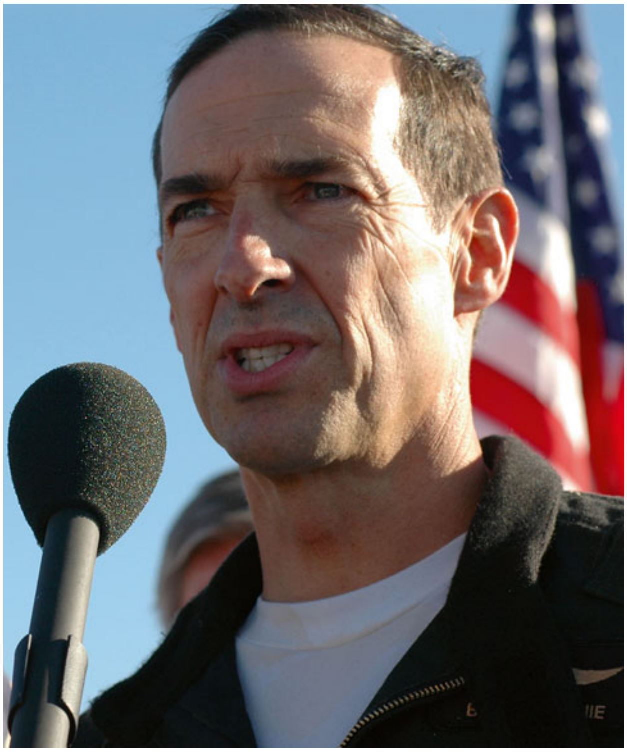
high frontier was the sole dominion of governments and space agencies – a status quo perpetuated for more than three decades. Until now [12].

Like all of Rutan's creations, the world's first private spacecraft is an impressive feat of engineering. Marked by simplicity of design, the vehicle doesn't look like it should fly into space. The interior is spare and devoid of the myriad switches, dials, and toggles that crowd the Shuttle's flight deck. There are a few low-tech levers, pedals, and buttons that suggest the vehicle is designed to fly, but the spartan design doesn't scream "space".

"WhiteKnight is taxiing" crackles over the public address system. The announcement is followed by the sound of high-pitched jet engines that mark the arrival of a gleaming white carrier aircraft. Slung tightly underneath is SpaceShipOne. WhiteKnight and SpaceShipOne take off followed by two chase planes that will follow SpaceShipOne during its ride to separation altitude. "Three minutes to separation" comes the announcement. Spectators scan the sky searching for the thin white line that is SpaceShipOne. At 14,000 meters, SpaceShipOne is dropped like a bomb above the Mojave Desert. Falling wings level, soon-to-be astronaut, Brian Binnie, 51, trims the vehicle's control surfaces for a positive nose-up pitch. Then he fires the rocket motor, boosting the spacecraft almost vertically. "It looks great," says Binnie as he rockets upwards at Mach 3. Within seconds, SpaceShipOne is gone, trailing white smoke. SpaceShipOne accelerates for more than a minute, subjecting Binnie to 3 Gs. At 45,000 meters, the engines shut down and SpaceShipOne continues on its trajectory to an altitude of 114,421 meters. A loud cheer erupts from the spectators, who are following the proceedings on a giant screen, each of them euphoric with the realization that high above them is a spacecraft that may one day carry them into space. With his spacecraft's rear wings feathered to increase drag upon re-entry, Binnie prepares to bring SpaceShipOne back to Earth. On the ground, the spectators wait, straining to hear the double sonic boom announcing SpaceShipOne's return. Seconds later, the unmistakable sound announces that SpaceShipOne is on her way back from her historic mission. Binnie (Figure 1.13) guides SpaceShipOne gently back to Earth, gliding the spacecraft to a perfect touchdown. Welcoming him enthusiastically are nearly 30,000 spectators, including Microsoft's co-founder, Paul Allen, who helped finance the project, Burt Rutan, and Peter Diamandis, chairman of the Ansari X-Prize Foundation [12].

In addition to winning the X-Prize, Binnie's flight smashed the altitude record for an airplane, set by Joseph Walker. Among the VIPs who watched SpaceShipOne were Sir Richard Branson, head of the Virgin Group, and Marion Blakey, head of the FAA. After Binnie landed, Blakey presented him with an astronaut pin and paid tribute to him as well as Melvill, the only astronauts to earn their wings (Table 1.2) from the FAA rather than NASA or the military:

> "The Ansari X Prize is the beginning, it's not the end. Over the course of the last two weeks we have had companies approaching us, we have had wealthy individuals approaching us, about investing in this marketplace. The same thing happened when Lindbergh flew, the same thing happened when Netscape went public, the same thing's going to happen here. Why not have private space travel? Why not be able to climb into a ship and rocket into the sky, and come back and do it again in the afternoon? … Make it accessible to everybody."
>
> *Peter Diamandis*



1.13 Brian Binnie. Courtesy: Wikimedia

Table 1.2. Manned suborbital flights [3].

Date	*Mission*	*Crew*	*Altitude*	*Remarks*
5 May 1961	Mercury–Redstone 3	Alan Shepard	187 km	First manned suborbital flight; first American in space
21 July 1961	Mercury–Redstone 4	Virgil Grissom	190 km	Second manned suborbital flight
19 July 1963	X-15 Flight 90	Joseph A. Walker	106 km	First winged craft in space
22 Aug 1963	X-15 Flight 91	Joseph A. Walker	107 km	First person and spacecraft to make two flights into space
5 Apr 1975	Soyuz 18a	Vasili Lazarev Oleg Makarov	180 km	Failed orbital launch; aborted after malfunction during stage separation
21 Jun 2004	SS1 Flight 15P	Mike Melvill	100 km	First commercial spaceflight
29 Sep 2004	SS1 Flight 16P	Mike Melvill	102 km	First of two flights to win Ansari X-Prize
4 Oct 2004	SS1 Flight 17P	Brian Binnie	112 km	Second X-Prize flight, clinching award

Notes

1. http://history.nasa.gov/printFriendly/animals.html
2. www.manned.net/encyclopedia/Russian_space_dogs/
3. www.danpritchard.com/wiki/Suborbital_spaceflight
4. www.spacechimps.com/theirstory.html
5. www.purr-n-fur.org.uk/famous/felix.html
6. www.virtualsciencecenter.com/airandspacemuseum/libertybell7.net/
7. www.owensarchive.com/aviation-3/test-aircraft-x-planes-349/north-american-x-15-322/
8. www.nasm.si.edu/galleries/GAL100/X-15.html
9. www.fiddlersgreen.net/AC/aircraft/North-American-X15/X-15info/X15-info.htm
10. www.nasa.gov/pdf/470842main_X_15_Frontier_of_Flight.pdf
11. www.encyclopedia4u.com/s/soyuz-18a.html
12. Seedhouse, E. Tourists in Space: A Practical Guide. 2nd ed. Springer-Praxis. 2014.

2

Revolution through Competition

> "Gentlemen: As a stimulus to the courageous aviators, I desire to offer, through the auspices and regulations of the Aero Club of America, a prize of $25,000 to the first aviator of any Allied Country crossing the Atlantic in one flight, from Paris to New York or New York to Paris, all other details in your care.
>
> Yours very sincerely,
>
> Raymond Orteig"

THE ORTEIG PRIZE

The prize offered by Raymond Orteig, was announced in 1919. Eight years later, four pilots had been killed, three others had been seriously injured, and another two had gone missing. Despite these failed attempts, US Mail pilot Charles Lindbergh (Figure 2.1) reckoned he had a chance. He persuaded a group of St. Louis businessmen to support his attempt, using their financing to build an aircraft he called the *Spirit of St. Louis* in honor of his sponsors.

At 7:52 a.m., on 20 May 1927, Lindbergh fired up the *Spirit of St. Louis* and pointed the custom-built, single-seat monoplane (Figure 2.2) down Roosevelt Field. Heavy with fuel, the plane tracked down the muddy runway, before finally becoming airborne, almost touching the telephone wires at the end of the field. There were those who reckoned the plane's single-engine design wouldn't be capable of a trans-Atlantic crossing. They had a point. After all, previous attempts had used multi-engine planes. They had also included co-pilots, whereas Lindbergh had opted to fly solo. Lindbergh also decided against taking a parachute or a radio, choosing to take more fuel – decisions prompting newspapers to call him "the flying fool".

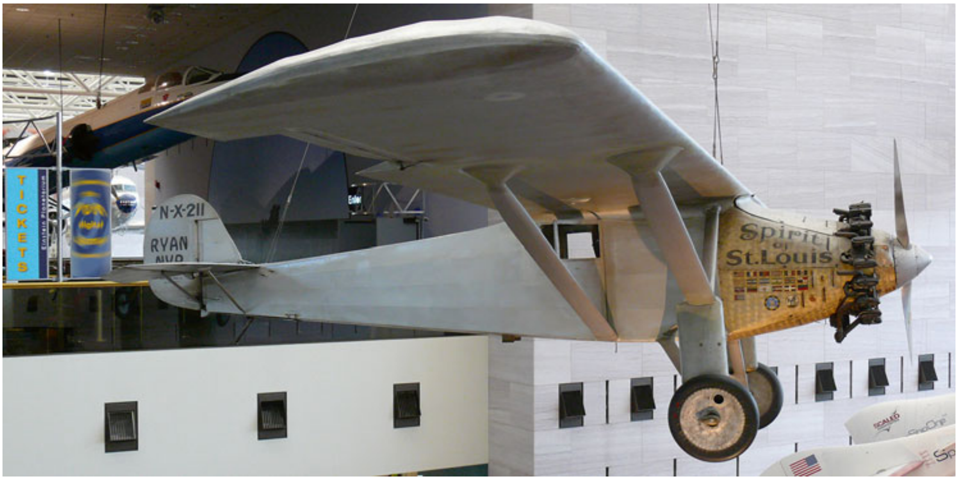
Lindbergh flew over Cape Cod and Nova Scotia, reaching the Atlantic at dusk. Fog made navigation challenging, and sleet formed on the *Spirit of St. Louis* as it flew through the clouds. Fighting drowsiness, Lindbergh struggled to stay awake as he sometimes flew

E. Seedhouse, *Virgin Galactic: The First Ten Years*, Springer Praxis Books,
DOI 10.1007/978-3-319-09262-1_2

2.1 Charles Lindbergh, with the *Spirit of St. Louis* in the background. Courtesy: Wikimedia/ Library of Congress

only three to four meters above the ocean. As he approached Europe, he spotted a fishing boat and, a short while later, he reached land. He flew at an altitude of only 500 meters over Ireland and England, before heading towards France as darkness fell. Shortly before 10 p.m., he saw the lights of Paris, where his landing was witnessed by 100,000 people. The crowd swarmed around the *Spirit of St. Louis* and hoisted Lindbergh on their shoulders. He had covered the 5,810 kilometers in 33.5 hours, and had won the Orteig prize! The papers redubbed him "Lucky Lindy".

On his return home, Lindbergh toured 92 cities in 49 states, and received the Medal of Honor and the Distinguished Flying Cross from President Coolidge. His New York



2.2 *Spirit of St. Louis* photographed in the National Air and Space Museum. Courtesy: Ad Meskens/Wikimedia

reception was the among the most raucous in the city's history, with four million people lining the parade route. In 1941 Lindbergh resigned his commission in the reserves, but served during World War II as an advisor. He also flew a number of combat missions and shot down a Japanese plane. After the war, he worked as an aviation consultant and visited several countries in Latin America at the US government's request of the US government, but he will always be remembered for his epic flight – one that became a singular event that not only captured the world's attention, but changed history and laid the foundation for the development of the aviation industry. Lindbergh later chronicled his daring flight in a book entitled *The Spirit of St. Louis* – a publication that served to inspire a doctor with more than a passing interest in flight. His name was Peter Diamandis.

PETER DIAMANDIS

Born on 20 May 1961, just weeks after Alan Shepard became America's first astronaut, Diamandis was eight years old when he watched Armstrong and Aldrin set foot on the Moon. The Moon landings had a profound effect on the young Diamandis, who decided spaceflight would be his life's mission. He set his sights on becoming an astronaut, deciding that obtaining a medical degree would help his application. To fulfill the undergraduate requirements for medical school, Diamandis studied molecular biology at the Massachusetts Institute of Technology, where he also gained a master's degree in aerospace engineering. While at college, he met NASA astronaut Byron Lichtenberg, who painted a rather bleak picture of astronaut selection, telling Diamandis (Figure 2.3) that the chances of being selected were slim and flights were few and far between. Lichtenberg's account didn't go down well with Diamandis, who decided he would find a different way to get into space. He didn't know how until several years later when a friend gave him a copy of Lindbergh's

2.3 Peter Diamandis enjoying parabolic flight. Courtesy: Peter Diamandis book. Lindbergh's book gave Diamandis the inspiration he needed to create the X-Prize (the "X" stood for the name of the benefactor who remained nonexistent for a long time), figuring that, if it worked for Lindbergh, it could work for spaceflight. And, if it did work, then perhaps Diamandis would get that spaceflight he had been dreaming about for so long. The first step was to find seed money to get the idea off the ground. The active space communities seemed a good fit, but Diamandis's friend, Doug King, the President of the St. Louis Science Center, suggested that St. Louis would be the ideal place to launch the Prize [1]. It was a logical choice of location. After all, St. Louis was where Charles Lindbergh raised the money to build his aircraft, it was home to the McDonnell Douglas Corporation which built the Mercury and Gemini capsules, and St. Louis is historically known as the Gateway for early exploration of the West [1]. Diamandis met with Al Kerth, head of the St. Louis community's Civic Progress Organization, who was quickly convinced of the potential of the X-Prize, suggesting they find 100 St. Louisans to each pledge US$25,000. Donations followed and suddenly the X-Prize was news. Big news.

RICHARD BRANSON

We'll return to the X-Prize shortly, but before we do, we need to introduce another key figure in the genesis of what was to become Virgin Galactic: Richard Branson (Figure 2.4). A renegade billionaire who made his money by making bold plans profitable, Branson was knighted in December 1999 for "services to entrepreneurship". Not bad for a high-school dropout who started his business empire with a mail-order record company called Virgin to help fund his magazine efforts [2]. The mail-order company quickly became a record shop in Oxford Street, London, and, with the success of Virgin, Branson was able to build a recording studio. From there, the Virgin brand was seen everywhere: everything from cars to cosmetics. A believer in living life to the fullest, Branson has experienced some epic adventures. He made several record-breaking attempts to make the fastest Atlantic Ocean crossing, the first of which was in the *Virgin Atlantic Challenger*, which capsized. Branson was rescued by RAF helicopter and received wide media coverage [2]. Then, in 1986, in *Virgin Atlantic Challenger II*, with sailing expert Daniel McCarthy, he beat the record by two hours. The following year, his hot air balloon *Virgin Atlantic Flyer* crossed the Atlantic [2]. In January 1991, the eccentric adventurer crossed the Pacific from Japan to Arctic Canada – a 10,700-kilometer journey, in a balloon, breaking the record for the trip with a speed of 390 kilometers per hour. Branson's next goal was to fly around the world in a balloon. In December 1995, Branson was stuck in the Marriott hotel in Marrakech, Morocco, with Will Whitehorn, waiting for favorable weather to carry the *Global Challenger* balloon on what Branson hoped would be a circumnavigation of Earth. Joining Branson and his co-pilot, Per Lindstrand, was Buzz Aldrin. Since retiring from NASA, Aldrin had played a leading role in promoting a continued role for the US in manned spaceflight. At one point in the evening's proceedings, Branson asked Aldrin why rockets were launched from the ground and not from a balloon. Aldrin replied that the US government had experimented with the concept but, after Sputnik, the tests were put on a backburner as attention was focused on the Gemini program. The following day, Branson made a note to register the Virgin brand for space.

2.4 Richard Branson at the Time 100 Gala, 3 May 2010. Courtesy: David Shankbone/ Wikimedia

The 1995 circumnavigation attempt failed but Branson persisted. In 1998, Branson, Per Lindstrand, and Steve Fossett made a record-breaking flight from Morocco to Hawaii before crashing in the Pacific Ocean. Fortunately, rescue services were nearby. Branson was unable to make another attempt before Bertrand Piccard and Brian Jones circumnavigated the planet in their *Breitling Orbiter 3* in March 1999. Looking for a new challenge, Branson decided to finance Steve Fossett's quest to fly an aircraft nonstop around the world. It was this endeavor that first put Branson in contact with Burt Rutan, when Scaled Composites was commissioned to build Fossett's aircraft, the *GlobalFlyer*. While in Mojave to check on the progress of *GlobalFlyer*, Will Whitehorn, Branson's project manager, noticed a pair of unusual aircraft on Scaled Composites' shop floor: SpaceShipOne and WhiteKnight. Recalling Branson's discussion in Morocco, Whitehorn immediately phoned Branson. Rutan later pitched Branson's enthusiasm for the SpaceShipOne project to Paul Allen, who was writing the checks. Negotiations between Allen and Branson followed, with the outcome that Virgin would purchase an exclusive license to SpaceShipOne's design and technologies. But that couldn't have happened without the X-Prize, so let's return to 1996.

On 18 May 1996, Diamandis, along with NASA Administrators, FAA Associate Administrators, Buzz Aldrin, Owen Garriott, Byron Lichtenberg, and 17 other astronauts and members of the Lindbergh family, stood underneath the St. Louis Gateway Arch, and announced the $10 Million X-Prize for the first team to fly two flights to the edge of space within two weeks (see sidebar). More than 50 media outlets were on hand to report the event. All they needed now was a sponsor to come up with the US$10 million. Diamandis was optimistic, thinking the hardest part was behind him, but finding a title sponsor was to prove a challenge. He presented the concept to several CEOs, but most thought the venture too risky. In 1997, Diamandis traveled to the UK to pitch the idea to Branson, suggesting they call it the Virgin X-Prize. Branson also thought it too dangerous, but Diamandis persisted and, in 1998, he met with Will Whitehorn, who was to become Virgin Galactic's president. Whitehorn liked the idea, but explained that Virgin wanted to build the venture into a business rather just sponsor a prize. He promised Diamandis that Virgin would keep their eye on the project and Diamandis went back to his search. The following year, Whitehorn took a trip to the Mojave with Branson to take a look at the Rotary Rocket (the Roton Atmospheric Test Vehicle, or ATV), a single-stage spacecraft being developed to deliver payloads into space. Whitehorn and Branson witnessed what proved to be a disappointing test flight, but they did get the opportunity to meet Burt Rutan who had helped develop the ATV. Sitting in the Voyager restaurant at Mojave Airport, Whitehorn, Branson, and Rutan discussed possible mission architectures that involved a mothership with a spacecraft slung underneath. The two vehicles were to become the genesis of a secret space project run by Scaled Composites.

X-Prize Rules

1. Build a manned spacecraft. No government funding allowed.
2. Launch three people in the spacecraft to 100 kilometers altitude and return to Earth; this requirement ensured the vehicle would be capable of transporting a pilot and two fare-paying passengers
3. Repeat Step 2 within two weeks; Diamandis wanted a spacecraft capable of repeated flights akin to an airline

Meanwhile, Diamandis continued his search for a sponsor. In 2002, he reckoned he had found one. In 2002, Anousheh Ansari (Figure 2.5), an engineer and the co-founder and

2.5 Spaceflight participant Anousheh Ansari holds a grass plant grown in the Zvezda Service Module of the International Space Station. Courtesy: NASA

chairwoman of Prodea Systems, told a reporter she wanted to fly in space.[1] Diamandis happened to read the article published in *Fortune* magazine and arranged a meeting with Ansari, her husband Hamid, and his brother Amir, who also happened to be space enthusiasts [1]. The timing was fortuitous because the Ansari family had just sold their company for US$750 million, so they weren't short of money. Diamandis traveled to Dallas, where he gave a PowerPoint presentation to Amir and Anousheh, who were sold on the first few slides. As entrepreneurs, the Ansari's knew the huge amount of work it would take to make Diamandis's idea succeed, but they were captivated by his enthusiasm for the project. His vision resonated with the Ansari family, who had been looking for a commercial route to space. They had looked at options, but they hadn't been impressed. The attraction of the X-Prize was that the Ansari's didn't need to decide which company had the greatest chance of building a spaceship and they wouldn't have to pay unless someone won. The investment also acted as an incentive for teams from around the world to compete, and those teams would find sponsors to invest in their technology. The Ansari family signed on to sponsor the prize, which became known as the Ansari X-Prize [1]. Under the terms of the insurance policy, the prize had to be won by the end of 2004. If the prize wasn't claimed,

[1] Ansari got her wish with a flight to the International Space Station in 2006, becoming the first Iranian in space.

the insurance company, XL Capital, would pocket the premiums. For XL Capital, it must have seemed like a good bet!

ANSARI X-PRIZE: BUILDING A SUBORBITAL *SPIRIT OF ST. LOUIS*

26 teams entered the X-Prize. Among the those that took up the challenge were a Californian aviation hero, a Second World War Navy pilot, and aerospace experts from Argentina, England and Russia. Many of the teams included those who had been involved in commercial space travel long before Diamandis's X-Prize was envisaged. While several teams chose to develop high-altitude aircraft or ballistic rockets, with no government involvement it wasn't surprising that these companies used their ingenuity to design all sorts of entries. Some were qualified to do what they were trying to do whereas others were … well, let's just say they were probably going to hurt somebody. In many ways, the competition echoed the earliest days of aviation with a touch of Darwinism thrown in, creating an environment in which only the strongest and smartest survive. The entries included spacecraft shaped like discs and spheres. Some were built out of metal while others used composites. Looking at some of the computer-generated concepts was, in some cases, akin to viewing art in a science-fiction gallery. Here's a snapshot of some of the entries.

Da Vinci

One of the front-runners was Canadian rocketeer, Brian Feeney, who was confident that his sleek *da Vinci* spacecraft would be the first to reach space. The *da Vinci* vehicle was designed to be carried to high altitude beneath a balloon before being dropped and rocketing into space. After re-entry, the vehicle would glide to a landing suspended under a parafoil. Feeney's design was based on solid engineering, good science, and it featured several layers of redundancy [3]. If the primary and secondary sets of explosive bolts (which separated the rocket from its balloon tether) failed, the rocket engines would shut off, and the capsule would separate from the rocket and parachute [3]. There were two backup parachutes in case the main parafoil didn't deploy and, even if all three failed, a ballute would probably save the pilot [3]. And even if the ballute failed to deploy *and* the parafoil failed, the pilot could separate the capsule and float down on its chutes. In an absolute worst-case scenario, the pilot would still have been able to save himself, since his spacesuit featured a military aero-conical chute, as well as a separate ballistic one. The safety was a significant feature because the raison d'être of the X-Prize was kick-starting a commercial future. Feeney had gathered an impressive team of volunteers – engineers, aerospace professionals, and mathematicians. He had also persuaded aerospace organizations to volunteer equipment and expertise. For example, the display technology and much of the avionics equipment on board were made by Omnivex, the pilot's spacesuit was from Nuytco Research, and the spaceflight training was courtesy of the Canadian Defense and Civil Institute of Environmental Medicine [3]. In common with all but one of the competitors, money was Feeney's biggest hurdle, but he had grounds for optimism.

Advent

A different mission architecture was proposed by American Advent Launch Services, which envisioned a methane-fueled vehicle launching from the Gulf of Mexico to sidestep regulatory unease about safety of the launch and landing. NASA engineer and project leader, Jim Akkerman, created the rocket with materials that were either donated or self-financed. He tested the engine in a farmer's field in Texas.

Orizont

In Romania, the Aeronautics & Cosmonautics Romanian Association team, a group of aeronautical engineering students, developed the *Orizont* with an engine fueled by hydrogen peroxide. The monopropellant engine was reusable and made entirely of composite material, which was the first of its kind [4].

Thunderbird

Thunderbird represented a more traditional approach to rocketeering. Designed by Steven Bennett's Starchaser Industries of Cheshire, UK, *Thunderbird* was to be powered by four turbofan jet engines during its climb to high altitude before a liquid-fueled rocket would boost the spacecraft the rest of the way to space [3]. Bennett had already tested a scaled-down version of the *Thunderbird* rocket, when he launched his solid-fuel rocket *Nova*, an 11-meter model, on 23 November 2001. *Nova* did go up and it did return by parachute, but it only achieved 1,500 meters of altitude – less than 2% of the altitude needed to reach suborbital space. Bennett did have a novel means of drumming up funding by trying to sell the seat on board *Thunderbird* for US$650,000.

Cosmopolis

Cosmopolis C-XXI was a rocket-powered spaceship designed to be carried to an altitude of 16,000 meters by an M-55 aircraft. After detaching from the aircraft, the rocket engine would push it past the boundary of space. After re-entry, it would glide to an airplane-style or parachute landing [3].

Condor-X

PanAero's X-Prize entry was the *Condor-X*. Designed by Len Cormier, a former NASA employee who had worked for the space program in the *Sputnik* era, the vehicle featured a large wing allowing it to ascend and descend gradually, reducing re-entry speeds, and G-forces. With its fabric-covered aluminum truss that would have acted as a kite during descent, the *Condor-X* was typical of the novel designs that featured among the X-Prize entrants. Sadly, due to lack of finances, the vehicle was never constructed.

Scaled composites

In the media frenzy about who the likely X-Prize winner might be, the press painted a two-horse race between Scaled Composites, the big-budget competitor in the low-budget space race, and Feeney's *da Vinci* team. But, while Feeney had assembled an impressive array of talent, the guy didn't even have a pilot's license, so building and flying a spacecraft seemed a tall order. In fact, none of the competitors had ever put a spacecraft in space. So picking a favorite was like betting on a greyhound race in which none of the dogs had ever run. And, while Feeney, genius that he is, had a viable spaceship, he couldn't get the backing, which meant that the only greyhound with a chance was Scaled. That was because Scaled had the engineering nous *and* it had the financial support from Allen, co-founder of Microsoft. It was a huge financial advantage, but Scaled kept costs down, spending only what was necessary to compete. We'll talk about the development of SpaceShipOne in the next chapter but, before we do, we need to introduce the final piece of the Virgin Galactic puzzle: a reclusive billionaire and science-fiction fan.

PAUL ALLEN

The first step towards Paul Allen (Figure 2.6) becoming involved in the Virgin Galactic story was when the Microsoft founder met Rutan in 2001 and asked him to develop a spacecraft that could win the Ansari X-Prize. Allen was prepared to put US$30 million on the table to finance the deal. There was only one condition: the project had to be kept secret. Why did one of the world's richest men want to win a US$10 million prize when his personal worth was in the tens of billions of dollars? The name of his company, Vulcan Inc., which manages his various business and philanthropic efforts, gives you a clue. Allen is a science-fiction buff. He's founder of Seattle's Experience Science Fiction Museum, a must-see collection for sci-fi aficionados and those interested in space. He is also, as his company's name suggests, a big *Star Trek* fan. So building a spaceship was an extension of his science-fiction interests and his wish to demonstrate that space exploration could one day be within reach of private citizens. And so, with Allen's pledge of millions of dollars on the table, Scaled went to work developing one of the world's most famous and recognizable spacecraft.

2.6 Paul Allen. Courtesy: Wikimedia/Miles Harris

Notes

1. http://nextprize.xprize.org/2009/09/launching-commercial-space-flight-part.html
2. http://www.redorbit.com/education/reference_library/technology_1/entrepreneurs-ceos/1112920463/sir-richard-branson/
3. http://discovermagazine.com/2002/jul/featprize/
4. http://www.tms.org/pubs/journals/JOM/0411/Byko-0411.html

3

SpaceShipOne

"Genius is one percent inspiration, ninety-nine percent perspiration."

Thomas Edison

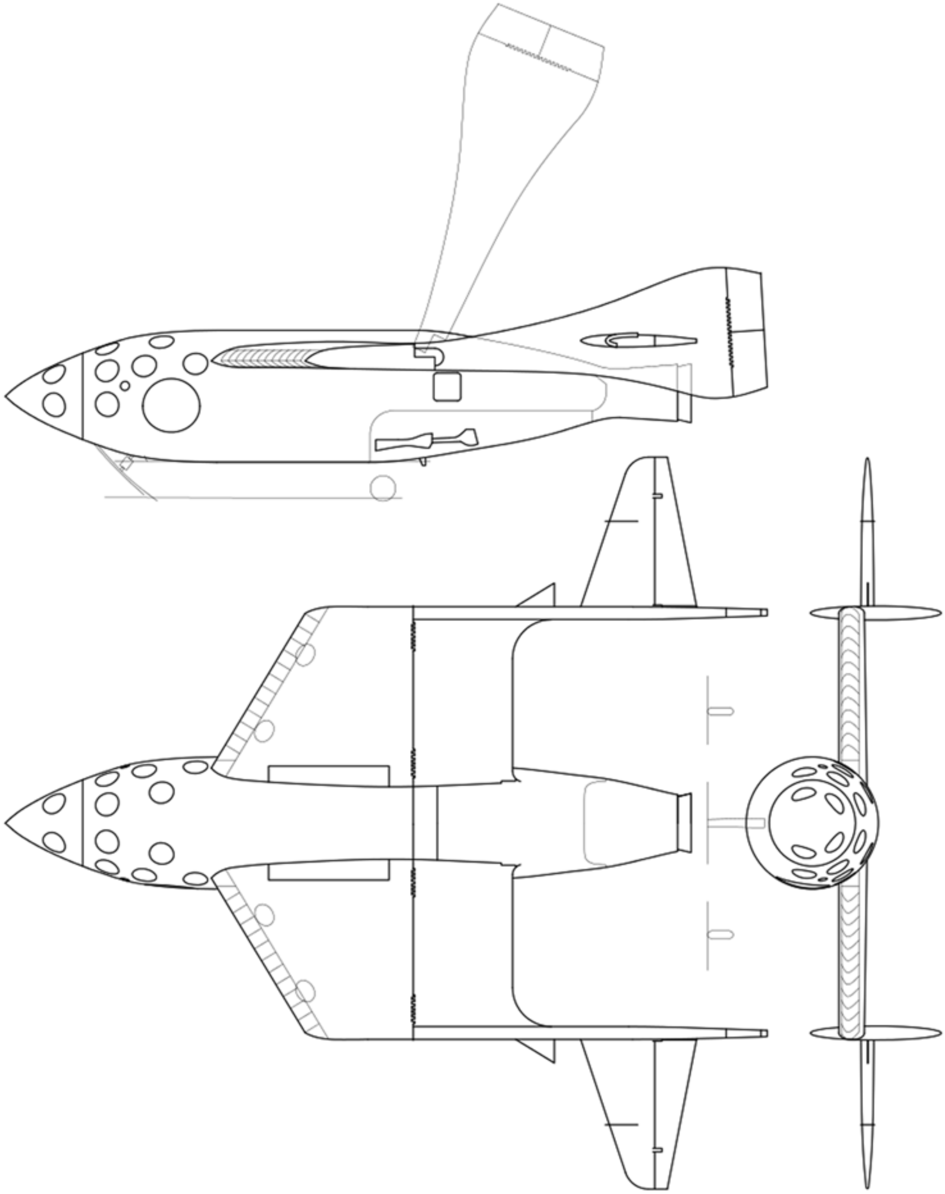
There was Paul Allen's money and Peter Diamandis's vision but, without Burt Rutan, Mojave's resident genius, it is unlikely Virgin Galactic would be where it is today. A legend in the aerospace engineering arena, Rutan has a record of blazing his own trail and pulling off impossible ventures, often by designing very successful small aircraft. In 1986, he stunned the aviation world by launching *Voyager*, a hand-built airplane which was little more than a flying fuel tank with twin booms between the wing and the tail. The ungainly-looking craft sported two engines – one to push and one to pull. It struggled to get off the ground in its first flight laden with 3,100 kilograms of fuel, almost three quarters more than its gross take-off weight. Piloted by Dick Rutan and co-pilot Jeana Yeager, *Voyager* became the first aircraft to fly around the world nonstop without refueling.[1] Twelve years later, Rutan became the first pilot to fly X-Prize hardware: *Proteus*, a twin-jet canard aircraft (Figure 3.2).

BURT RUTAN

When people discuss the topic of famous people in the aerospace arena, the names Charles Lindbergh, Amelia Earhart, Neil Armstrong, and John Young typically crop up because it is usually pilots who garner the attention, while little is said about those who design the technology. An exception to the rule is Burt Rutan (Figure 3.3). Five of his planes now hang in the Smithsonian National Air and Space Museum, including the aforementioned *Voyager*, and

[1] The flight departed Edwards Air Force Base on 14 December 1986. It ended a shade over 9 days later, setting a flight endurance record. The aircraft, which flew westerly 40,212 km at an average altitude of 3,350 meters, broke the previous flight distance record of 20,168 km set by a US Air Force crew piloting a Boeing B-52 in 1962.

E. Seedhouse, *Virgin Galactic: The First Ten Years*, Springer Praxis Books,
DOI 10.1007/978-3-319-09262-1_3



3.1 SpaceShipOne

3.2 Scaled Composites' tandem-wing *Proteus*. Courtesy: NASA

SpaceShipOne. A larger-than-life character who founded Scaled Composites in 1982, Rutan spent more than 45 years working in the high desert designing aircraft unlike any other [1].

As a kid, the young Rutan was a keen model-plane builder, so it wasn't surprising when he translated that interest into a degree in aeronautical engineering. He then became a flight-test engineer at Edwards Air Force Base, before moving to Mojave in 1974, where he founded Rutan Aircraft Factory to design and build aircraft kits for hobbyists.

The following year, he found success with his VariEze aircraft design (it took him less than four months to build), before going on to develop the Long-EZ, an aircraft that had an endurance of more than 3,200 kilometers. Both aircraft, which are made of composite materials, are simple to assemble and have a top speed of about 300 kilometers per hour. In 1982, Rutan formed Scaled Composites to design research aircraft and to specialize in prototype development. His work hit the headlines in 1986 when the *Voyager* flew its epic flight [1].

The space bug

Although he gained recognition as a result of his cutting-edge aircraft designs, space was never far from Rutan's mind. He figured trying to design a spacecraft to fly to orbit would be too difficult, but suborbital was a different animal so, in 1993, he began making notes. Two years later, Scaled was in the process of designing *Proteus. Proteus* was designed to fly at altitudes above 18,000 meters so it could launch a single-person suborbital rocket.

3.3 Burt Rutan. Courtesy: Wikimedia/D. Ramey Logan

When Rutan heard about the X-Prize, he changed the design to a three-person capsule, which was a requirement of the prize. Perhaps the most striking aspects of what was to become SpaceShipOne were the feather-like features that pointed upward and away from the capsule. Acting in a similar way to the feathers on a badminton shuttlecock, the feathers on Rutan's design were designed to decelerate the capsule quickly while simultaneously stabilizing and orienting the capsule. If all went well, the capsule would re-enter in a near vertical attitude. In the original mission design, recovery was by helicopter, but this was later changed. On paper, the design looked a winner, but a problem was encountered when modeling the feather system. While this design worked well at subsonic speeds, it was another story in the supersonic regime, because the feathers refused to trim, which meant the capsule became unstable. The solution, after some lengthy troubleshooting, was to pivot part of the wing and the tail booms to provide a high-drag configuration. The tail-boom assembly of SpaceShipTwo was to come under particular scrutiny following the accident on 31 October 2014.

At the time of the updated spaceship design, the capsule development had been achieved using computer analysis and models. Now, with the major design challenges overcome, Rutan was ready to go to the next stage. So, in 2000, he sat down with Paul Allen, and Vulcan, Inc. and Scaled Composites began a partnership called Mojave Aerospace Ventures. Over the following 12 months the business plan crystallized: Allen would recoup his investment by winning the X-Prize and licensing the product with Virgin Galactic. With that goal set, Rutan and his team went to work in earnest. The secret space program was dubbed Tier One because the spacecraft being developed was intended to fly a suborbital mission: a Tier Two program would design a vehicle that would take people to orbit and a Tier Three program would ferry people to the Moon and Mars.

SPACESHIPONE CONSTRUCTION

SpaceShipOne is a hybrid of several vehicles. Some compare it to the Bell X-1 (Figure 3.4) because of the bullet-shaped fuselage, while others insist that the delta wings and stabilizers at the wingtips make it a dead ringer for NASA's early lifting bodies (Figure 3.5). What is undeniable is that SpaceShipOne (see sidebar) is a unique vehicle.

SpaceShipOne Characteristics [2]

General characteristics

- Crew: one pilot
- Capacity: two passengers
- Length: 8.53 meters (about half the length of the X-15)
- Wingspan: 8.05 meters (slightly wider than the X-15)
- Height: 2.7 meters
- Wing area: 15 meters^2
- Empty weight: 1,200 kilograms
- Loaded weight: 3,600 kilograms
- Powerplant: 1 × N2O/HTPB SpaceDev Hybrid rocket motor, 7,500 kilogram-force (74 kilonewtons)
- I_{sp}: 250 seconds (2,450 newtons per kilogram)
- Burn time: 87 seconds
- Aspect ratio: 1.6

Performance

- Maximum speed: Mach 3.09 (3,518 kilometers per hour)
- Range: 65 kilometers
- Service ceiling: 112,000 meters
- Rate of climb: 416.6 meters per second
- Wing loading: 240 kilograms per meter^2
- Thrust/weight: 2.08

3.4 The Bell X-1 was a supersonic research project built by the Bell Aircraft Company and funded through the National Advisory Committee for Aeronautics, US Army Air Force and US Air Force. Conceived in 1944, the Bell X-1 achieved a speed of 1,600 kilometers per hour. The first of the so-called X-planes, it was the first airplane to exceed the speed of sound in level flight. Courtesy: NASA

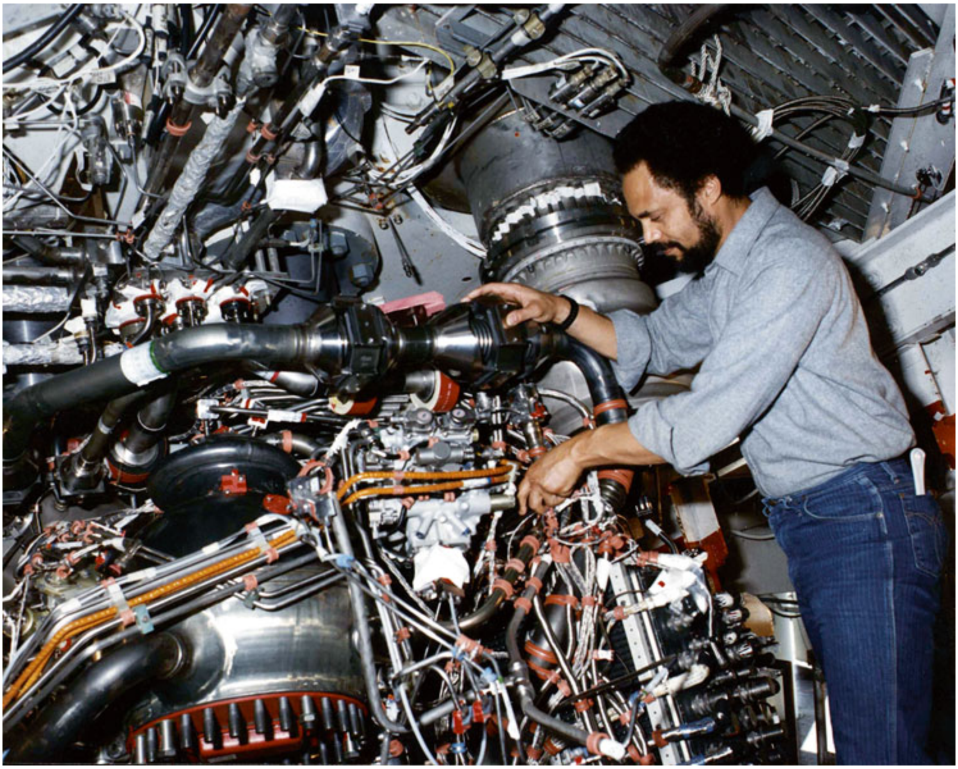
Its construction began with building the carbon fiber/composite subassemblies that comprised the fuselage. These were bonded together in much the same way as a model aircraft is assembled, only with fewer parts. The subassemblies essentially comprised a nose cone and a cabin section. When all the parts were assembled as the fuselage, it comprised a shell within a shell, the inner layer of which was covered by a core of Nomex, a strong, heat-resistant material. The outer layer was covered in panels called skins, which were manufactured using composites and attached to the core. While the fuselage design was fairly straightforward, the wings were anything but. SpaceShipOne's wings had to not only operate in subsonic and supersonic flight, but also withstand heat on re-entry and cope with being moved on hinges. In short, the wings had to be strong. Very strong. This strength was achieved by using very thick ribs and making the wing as thick at the tip as it was at the root. The feather system, the most complex system on SpaceShipOne, was a separate structure from the forward wing sections and had its own spar and ribs. The system moved up or down with the angle that the feather made with the fuselage being preset at 65°. To pivot the feather up or down on its hinge, pneumatic actuators were used, the lower ends of which

3.5 Bill Dana in front of HL-20 after flight H-24-37. Courtesy: NASA

were attached to the fuselage and the upper ends attached to the inner face of the aft wing section. Another pneumatic design feature was the nose skid and rear landing gear which was spring and gravity activated. It was a simple design that reduced weight. SpaceShipOne's doors and windows were one of the vehicle's most distinguishing features. The spacecraft had 16 windows, each 23 centimeters in diameter, providing good visibility for the pilot while maintaining structural integrity and saving weight. Each window had dual panes for redundancy in the event of a decompression. Since the spacecraft had to carry the weight equivalent of three people, weight was at a premium, which is why SpaceShipOne didn't carry ejection seats. Instead, in a worst-case scenario, pilots would simply detach the nose cone and parachute to safety. Another weight-saving measure was in the design of the thermal protection system required for re-entry. Since SpaceShipOne didn't experience high thermal loads for very long, it only required a fairly simple thermal protection system comprising a phenolic resin, of which about six kilograms was applied to the vehicle's skin. And finally: entry. This was via a 66-centimeter diameter dual-sealed plug door on the port side.

Propulsion

SpaceShipOne was a unique spacecraft that required a unique power plant. This was a problem because Scaled had never developed a rocket engine and it wasn't as if it could go online and buy one. Fortunately, Scaled had some help from those in the business (SpaceDev, Thiokol, AAE Aerospace, and Environmental Aeroscience Corporation) of



3.6 A technician performs maintenance on a Space Shuttle main engine. Courtesy: NASA

building rocket engines, but they came up with the configuration themselves. The propulsion system they designed was a hybrid motor, so called because it combines elements from solid and liquid rocket motors. Nothing special you may think, but it's the fuel that really makes this rocket motor interesting.

Rocket fuel is made up of fuel and the oxidizer. Add heat to the fuel, introduce oxidizer, and you get an explosive burst that sends a vehicle into space. In a system using liquid fuel the components are stored separately and combined during ignition whereas in solid rocket fuels the oxidizer is part of the fuel. No matter which fuel is used, this stuff is expensive *and* dangerous to store. So, to reduce cost, complexity, and risk, SpaceShipOne was fuelled by a mix of hydroxy-terminated polybutadiene (tire rubber – the fuel) and nitrous oxide (laughing gas – the oxidizer). Laughing gas is cheap and, since it self-pressurizes at room temperature, SpaceShipOne didn't need to be fitted with a complicated pump and plumbing system to combine the oxidizer with fuel during (Figure 3.6). Of course, there was a downside to this simplicity because the rocket, once started, couldn't be controlled, although the thrust varied. One way it varied was as the pressure in the oxidizer tank decreased, the flow rate reduced, thereby reducing thrust. Another way was in the later stages of a burn when the engine was burning liquid, which resulted in greater burn rate.

As well as being cheap, SpaceShipOne's fuel was very safe, since it could be stored without special precautions, and it was also fairly environmentally friendly because the combustion products were water vapor, nitrogen, carbon dioxide, hydrogen, and carbon monoxide.

Inside SpaceShipOne

Measuring just 152 centimeters in diameter, the interior of SpaceShipOne was not a place for claustrophobe's. The pressurized cockpit, which was entered through the nose, sported a very basic life-support system: air was supplied by oxygen bottles and exhaled carbon dioxide was removed by an absorber system. Humidity was controlled by an another absorber that removed water vapor from the air. It was an effective system that allowed pilots to wear flight suits as opposed to pressure suits.

In common with so many of the vehicle's systems, the mechanical flight control system was very simple, comprising a cable-and-rod linkage that connected the stick and rudder pedals to the control surfaces. In that regard, flying SpaceShipOne was little different from flying a Cessna. The control surfaces were located on the tail booms with an upper and lower rudder mounted on the end of each boom. To control yaw, the pilot simply moved the rudder pedals independently (pushing down on both pedals worked like a speed brake).

To control pitch and roll, the pilot moved the control stick, which moved the elevons (see Appendix I for explanation of aeronautical terms) on the horizontal stabilizer. These controls worked well at subsonic and even supersonic speeds, but a different system had to be used in space. This was achieved using the reaction control system. Way back when the Shuttle was flying, the Orbiter used a cocktail of toxic chemicals to fuel its powerful reaction control system (RCS). But SpaceShipOne didn't need a powerful RCS because it wasn't nearly as big as the Shuttle and it didn't spend more than a few minutes in space, so it made use of a system that consisted of 6,000-psi bottles of air. SpaceShipOne's RCS comprised roll thrusters mounted on each wingtip and pitch and yaw thrusters mounted along the top, bottom, and sides of the fuselage. To operate the system, the pilot fully extended the rudder pedals and the control stick, which activated micro-switches that turned the thrusters on or off.

Because SpaceShipOne was manually controlled, the vehicle's navigation system assumed particular importance. No fly-by-wire in this spacecraft because this would have driven up development costs and ticket prices: those designing SpaceShipOne were aiming for a Toyota Corolla rather than an Audi S4. Flying SpaceShipOne wasn't just a case of lighting the rocket, kicking back, and waiting for weightlessness. The pilot had to fly a very precise trajectory, any deviation from which risked failure to reach target altitude or a landing that was far from the landing site. Neither outcome would prove popular with passengers. Since the vehicle was manually controlled, the only feedback the pilot had about how the spacecraft was flying was via the avionics system. Dubbed the Tier One Navigation Unit (or TONU), SpaceShipOne's avionics system was developed in-house, and comprised two primary components: the system navigation unit (or SNU) and the flight director display (or FDD). The SNU sent guidance and navigation information to the pilot from data generated by the global positioning system (GPS) and inertial navigation system (INS). This information was presented on the FDD, which automatically cycled through the various phases of flight (boost, re-entry, glide). In many ways, the FDD was no different than the glass cockpit of an airliner, showing important readouts and instruments. Of course, one difference between SpaceShipOne and your run-of-the-mill commercial aircraft was that most 777s don't spend much time nose up at supersonic speeds – a maneuver that caused the horizon on SpaceShipOne's FDD to disappear completely.

Once in this attitude, the pilot paid particular attention to the velocity vector, depicted on the display as a green circle with a tail and two wings. The other piece of information the pilot was interested in was the optimum trajectory, represented by a red circle: the pilot's task was to align the green velocity vector with the red circle as quickly as possible, thereby ensuring optimum trajectory. This was far from easy given the speed of the rocket burn and the fact that the TONU didn't automatically control the vehicle. Another key decision the pilot had to make was knowing when to turn the rocket engine off. This decision was aided by a readout from the energy altitude predictor, which gave the pilot an idea of the altitude SpaceShipOne would reach if the rocket engine was shut down at any particular moment in flight. So, say SpaceShipOne's altitude was 30,000 meters and the energy altitude predictor indicated 75,000 meters: this meant that, if the pilot shut down the engine at that moment, the vehicle would coast to a maximum altitude ("apogee" in aerospace parlance) of 75,000 meters – an altitude well short of the 100,000-meter altitude required for spaceflight.

WhiteKnight

One of the greatest expenses of manned spaceflight is launching from the ground. The cost of the fuel required for such an operation is obscene. The reason SpaceShipOne was such a compact spaceship was because it was launched at an altitude that was above 85% of Earth's atmosphere, and the carrier aircraft that made that possible was WhiteKnight (Figure 3.7; see sidebar). WhiteKnight was a high-altitude, twin-turbojet aircraft that took off like a plane from a normal airstrip, with SpaceShipOne slung underneath. The mothership and its spacecraft payload flew together using WhiteKnight's power to the separation altitude of 15,000 meters. At a climb rate of 210 meters per minute, the journey took almost an hour, which gave the pilots plenty of time to contemplate what was to come. As the vehicles approached the drop zone, the pilots ran through a checklist of procedures, one of which was to trim SpaceShipOne 10° nose up so that, when it was released from WhiteKnight, the nose was oriented upwards. In case you're wondering whether this altitude launch method was new, it wasn't. The procedure for airborne launch goes back to the 1920s and, more recently, NASA has used the method for dropping its X-planes (Figure 3.8) and testing the Shuttle (Figure 3.9). It was a tried and tested procedure.

With WhiteKnight flying wings level, the SpaceShipOne pilot armed the release system, which triggered a yellow light in the cockpit of WhiteKnight, prompting the pilot to arm the release system. On completion of this procedure, the release handle inside White Knight was "hot". A crewmember pulled the release handle to retract the hooks, the spring-loaded hooks did their job, and SpaceShipOne dropped away like a bomb as WhiteKnight climbed upward. Once clear of WhiteKnight, the pilot armed the rocket engine, flicked the ignition switch, and grabbed the control stick.

3.7 Scaled Composites' WhiteKnight with a Northrop Grumman radar pod taxis for a test flight at Mojave. Courtesy: Wikimedia/Alan Radecki

3.8 X-15, 56-6671 is dropped from the Boeing NB-52A Stratofortress, 52-003. The XLR99 rocket engine has just started its burn. Courtesy: NASA

3.9 The Shuttle Carrier Aircraft (SCA) was used by NASA to ferry Shuttles from landing sites to the Kennedy Space Center. In test flights conducted in 1977, the Shuttle *Enterprise* was released from an SCA (a modified Boeing 747) and glided to a landing. Courtesy: NASA

WhiteKnight General Characteristics [2]

- Crew: two
- Capacity: 3,600 kilograms payload
- Wingspan: 25 meters
- Fuel capacity: 2,900 kilograms
- Powerplant: 2 × General Electric J85-GE-5 after-burning turbojet
- Service ceiling: 16,000 meters +
- Sea-level cabin qualified for unlimited altitude
- Two crew doors with dual seals and dual-pane windows
- Manual flight controls with three-axis electric trim
- Avionics include INS-GPS navigator, flight director, flight-test data, air-data, vehicle health monitoring, backup flight instruments, and video system
- Hydraulic wheel brakes and nose-gear steering
- Pneumatic main gear retraction
- Dual-bus electrical power system
- Cockpit allows single-pilot operation (VMC-day conditions only)

SPACESHIPONE TEST FLIGHTS

In addition to developing SpaceShipOne and WhiteKnight, Scaled also had to deal with the Federal Aviation Administration (FAA) because SpaceShipOne and its carrier aircraft had to be registered with a tail number. SpaceShipOne was given N328KF (100KM was taken), while WhiteKnight was given N318SL ("SL" for spaceship launcher). WhiteKnight was identified to the FAA as an aircraft so the paperwork was fairly straightforward, but SpaceShipOne proved more of an administrative headache because the FAA required launch licensing which was a lengthy process (Virgin Galactic encountered a similar problem in July 2014 when its application for a launch license for SpaceShipTwo was put on hold while legislators in Washington attempted to fix a quirk in the FAA's regulations governing licenses and experimental permits). But, finally, on 18 April 2003, SpaceShipOne was ready to go public. The curtain was dropped on SpaceShipOne and WhiteKnight performed flybys for those who had gathered in front of the Scaled hangar. Rutan and his team were ready for flight testing.

Launch to landing

For the first five seconds of flight, the pilot controlled SpaceShipOne using the control stick and rudder pedals to keep the wings level. At eight to nine seconds into the flight, control of the vehicle was achieved using electrical trims. At this point, SpaceShipOne was pointing almost vertically and was transitioning from subsonic to supersonic flight. As it continued to arc upwards, the pilot used the control stick to move the nose closer to vertical. At 60 seconds into flight, the rocket engine turned from burning liquid to burning gas – an event indicating the boost phase was almost at the end. At this time in the flight, SpaceShipOne was traveling at Mach 3.09 or 3,518 kilometers per hour. Rocket-engine shutdown occurred at about 64,000 meters following a burn of 84 seconds. The rest of the way to space was achieved from pure momentum, with apogee (≥100,000 meters) being reached approximately 3.5 minutes after the firing of the rocket engine (by comparison, the Shuttle reached orbital altitude of 320 kilometers in 8.5 minutes).

Just before SpaceShipOne reached apogee the pilot flipped a switch that drove pneumatic actuators to jackknife the tail. Once it was over the top, SpaceShipOne picked up speed as it began to trace a ballistic downward arc. Since the vehicle had a lift-to-drag ratio of 0.7 in the feathered configuration the descent was practically vertical. As the deceleration Gs piled on (the pilot didn't wear a G-suit incidentally), the pilot started his anti-G straining maneuver to force blood to his brain. During re-entry, pilots were typically subjected to as much as 6 Gs and SpaceShipOne's skin temperature reached more than 600°C. While SpaceShipOne's re-entry trajectory was very stable thanks to its shuttlecock self-aligning tendency, the pilot still needed to ensure the vehicle came down in the right spot. This spot was designated because SpaceShipOne re-entered into restricted airspace controlled by Edwards Air Force Base, so the Office of Commercial Space Transportation allocated a 6.5-square-kilometer box for SpaceShipOne to come down through. At an altitude of 21,300 meters, SpaceShipOne's feather was retracted and locked, at which point the vehicle was flying subsonically as a glider. Although the most demanding phases of the flight were over, the pilot couldn't relax completely because he still had to glide back to a landing. Fortunately, with a 7:1 glide ratio, SpaceShipOne had a glide range of almost 100 kilometers after it had defeathered, which would have been plenty of distance to deal with a poor trajectory. Pilots used a spiral maneuver to guide SpaceShipOne down to a landing on the runway, which the vehicle approached at an airspeed of 140 knots indicated. It sounds like a straightforward maneuver but SpaceShipOne had very restricted visibility, which meant that when pilots had lined the spacecraft up with the runway they couldn't actually see the landing strip. Fortunately, SpaceShipOne had a chase plane accompanying it on its approaches.

Mission Control

The test flights, which we'll get to shortly, were monitored from an office-based Mission Control and a Tier One mobile Mission Control center, which was responsible for telemetry monitoring and recording, telecommunications, and auxiliary environment control for WhiteKnight and SpaceShipOne. Equipped with computers and radio communication gear, the centers displayed SpaceShipOne's avionics data and telemetry and also allowed staff to communicate with the aircraft and spacecraft during the flights [3].

TEST FLIGHTS

WhiteKnight/SpaceShipOne flight tests [2, 3]

Combined flight-test key:

C = Captive carry
L = Launch
G = Glide
P = Powered

Note: The first letter represents the intended mission for the flight. The second letter represents the actual mission flown. The flight information for this section was sourced from the Scaled website [2] and Dan Linehan's book [3].

Commercial Rocketship Pilots

In the old days, spaceflight was simple. The planet had two corps of astronauts – one Soviet and one American – and to join one you had to be a military test pilot. By the time SpaceShipOne rolled around the rules had changed. You didn't have to be an American or a Russian, and you didn't have to be a government employee, although the test pilot qualification was still required. What sort of pilot becomes a test pilot? I have a couple of friends who are test pilots so I can tell you this elite group is a special breed: they're super-achievers who spend their lives setting their career sights incomprehensibly high. Among the very best, a few stand out. Some of them piloted SpaceShipOne.

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Brian Binnie

Binnie was a program business manager and test pilot at Scaled Composites. At the time of the SpaceShipOne test flights he had more than two decades of flight-test experience and had logged over 4,600 hours of flight time in 59 different aircraft. A licensed airline transport pilot, Binnie's resume includes a BS in aerospace engineering, an MS in fluid mechanics and thermodynamics, and an MS in aeronautical engineering. In addition to being a graduate of the US Navy's Test Pilot School, he is also a member of the Society of Experimental Test Pilots [3].

Flight-test experience (highlights) [1, 3]:

- Scaled's Model 318 WhiteKnight
- Scaled's Model 316 SpaceShipOne
- Roton Flight Test
- F/A-18 Electronic Warfare Suite Testing and Integration
- F/A-18 Tri-service standoff attack missile (TSSAM) Weapon Launch Envelope Expansion. This was intended to be one of the Pentagon's most advanced weapons, to be launched by Air Force and Navy aircraft, and by Army units on the ground
- A-6E TSSAM Weapon Launch Envelope Expansion
- F/A-18 Standoff Land Attack Missile-Expanded Response (SLAM-ER) Weapon Launch Envelope Expansion. This was the most accurate weapon in the US Navy inventory – an air-launched, day/night, adverse weather, over-the-horizon missile, which uses GPS to deliver its warhead
- A-6E SLAM-ER Weapon Launch Envelope Expansion
- F/A-18 Advanced Tactical Airborne Reconnaissance System (ATARS) Transonic Handling Evaluation. ATARS is a system for image acquisition, data storage, and data link used by the US Marine Corps on its F/A-18D Hornet aircraft
- A-7E Structural Flight Test Qualification Program
- F/A-18 KC-10 Wing Tip Refueling Pod Evaluation
- F/A-18 F404 2nd Source (Pratt & Whitney vs GE) Engine Envelope Expansion

Other related experience [1, 3, 4]:

- Conducted flight-test/developed operational flight procedures (tactics)/provided fleet training for F/A-18 and AV-8B EW suites
- Wrote all the operational checklists and provided the Fleet Tactics Manual for the TSSAM Weapon System
- Planned and executed the first (and only) radar chase of the Tomahawk cruise missile to demonstrate more effective surface fleet training

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Peter Siebold

Pete holds a BS in aerospace engineering. An avionics and data acquisition specialist, he was responsible for developing the simulator, avionics/navigation system, and ground control system for SpaceShipOne.

Flight experience [1, 3, 4]:

- 17 years of flight experience at the time of SpaceShipOne testing
- 2,000 hours in 35 different fixed-wing aircraft
- Holds FAA Commercial Airplane, Single Engine, Land (ASEL), Aircraft Maintenance Engineers Licence (AMEL), Commercial Glider, instrument airplane certificates
- Holds FAA Flight Instructor ASEL, AMEL, instrument airplane certificates
- Member of the Aircraft Owners' and Pilots' Association
- Member of Experimental Aircraft Association
- Associate Member of the Society of Experimental Test Pilots

Participated in the flight testing of:

- VisionAire Vantage Model 247 prototype
- Proteus Model 281 prototype
- Scaled Model 318 WhiteKnight
- Scaled Model 316 SpaceShipOne

Mike Melvill

Melvill is a test pilot with more than 20 years of experimental test pilot experience. He holds a commercial pilot's certificate, and has logged 7,050 flight hours in 128 fixed-wing types and 12 rotary wing types. In 1997, he and Dick Rutan flew the Long-EZs around the world.

Doug Shane

Was the Vice President/Business Development, Director of Flight Operations, and Test Pilot for Scaled Composites [3]. At the time of SpaceShipOne testing, he had more than 20 years of experience in aircraft flight test, design, program management, and business development, with particular expertise in research aircraft developmental flight test [1, 3]. He holds a BS in aerospace engineering and, at the time of Tier One, had logged 3,500 hours in more than 130 types of aircraft [1]. In addition to holding an FAA commercial certificate, with ASEL, AMEL, Instrument Airplane ratings, he is a Fellow, Society of the Experimental Test Pilots (SETP), and a winner of prestigious Iven C. Kincheloe Award in 1997 from the Society of Experimental Test Pilots

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Flight experience [2]:

- First flight and large portion of developmental test of the ARES, a single-seat, single-engine jet fighter
- First flight of an experimental jet-engine derivative of the Long-EZ aircraft
- First flight of the VisionAire Vantage business jet
- First flight of the Williams International V-Jet II
- First flight of the Adam Aircraft Model 309 piston twin-engine aircraft
- First flight of the Scaled Model 318 WhiteKnight

Flight 24C/01C: first captive carry

20 May 2003
Flight time: 1.8 hours
WhiteKnight pilot: Pete Siebold; WhiteKnight co-pilot: Brian Binnie

Less than five weeks after revealing its space program, Scaled Composites conducted its first captive carry flight with SpaceShipOne mated with WhiteKnight to assess vibration and aerodynamic interface, and to evaluate the handling qualities of the mated spaceship. The two-ship configuration demonstrated excellent stability and control with no vibration issues. Mach 0.53 was achieved at 14,630 meters following a climb rate of 210 meters per minute [2, 4].

Flight 29C/02C: first manned captive carry flight of SpaceShipOne

29 July 2003
Flight time: 2.1 hours
WhiteKnight pilot: Brian Binnie; WhiteKnight co-pilot: Cory Bird
SpaceShipOne pilot: Mike Melvill

This flight was a man-in-loop launch rehearsal and in-flight checkout of all spacecraft systems including flight controls and the propulsion system. It also tested range control, Mission Control, and the high and low chase platforms. During the flight, all SpaceShipOne's systems were tested, including the environmental control, electrical, pneumatic, and avionics. Since there were no problems, the way was clear for the first glide flight.

Flight 30L/03G: first glide flight of SpaceShipOne

7 August 2003
Flight time: 1.1 hours (SpaceShipOne: 19 minutes)
WhiteKnight pilot: Brian Binnie; WhiteKnight co-pilot: Cory Bird
SpaceShipOne pilot: Mike Melvill

Although pilots trained to fly SpaceShipOne in the simulator, no one really knew how the spacecraft would respond in flight or even if it was flyable. Don't forget this project was a cost-cutting exercise from start to finish, which meant SpaceShipOne had never been tested in a wind tunnel. SpaceShipOne was launched at 14,325 meters and 105 knots, 10 nautical miles east of Mojave. Happily for Melvill, the spacecraft's handling characteristics aligned closely with those of the vehicle simulator, and he reported good trim sensitivity and control harmony during the 19-minute flight before bringing it down onto Runway 30 for a smooth landing.

Flight 31LC/04GC: second glide flight of SpaceShipOne I (aborted)

27 August 2003
Flight time: 1.1 hours
WhiteKnight pilot: Brian Binnie; WhiteKnight co-pilot: Cory Bird
SpaceShipOne pilot: Mike Melvill
High Chase-Starship crew: Pete Siebold
Low Chase-Duchess crew: Jon Karkow

After the successes of the previous three test flights, the test team had reason to be optimistic about extending the flight envelope during the fourth test flight. Unfortunately, 20 minutes prior to separation, the launch had to be aborted due to a GPS malfunction. Fortunately, the balky GPS issue was quickly fixed and SpaceShipOne and WhiteKnight were flying later the same day.

Flight 32L/05G: second glide flight of SpaceShipOne (second attempt)

27 August 2003
Flight time: 1.1 hours (SpaceShipOne: 10 minutes 30 seconds)
WhiteKnight pilot: Brian Binnie; WhiteKnight co-pilot: Cory Bird
SpaceShipOne pilot: Mike Melvill
High Chase-Starship crew: Pete Siebold
Low Chase-Duchess crew: Jon Karkow

The SpaceShipOne's second glide flight assessed flying qualities and performance in feather mode and evaluated pilot workload and situational awareness. The team also investigated the vehicle's performance in a deep stall at high and low altitude, and assessed the envelope expansion out to 200 knots and 4 Gs. The flight also evaluated adverse yaw, roll rate effectiveness, and control including aileron roll and full rudder side slips. The first maneuver was a full stall that resulted in a reduction in speed to 70 knots equivalent airspeed (KEAS),[2] but SpaceShipOne performed well with good lateral control at minimum

[2] The knot is a unit of speed equal to one nautical mile (1.852 km) per hour. Equivalent airspeed (EAS) is defined as the speed at sea level that would produce the same incompressible dynamic pressure as the true airspeed at the altitude at which the vehicle is flying [5].

speed with ailerons. The stall was followed by unlocking the wing to full feathered mode at 65° – a maneuver that occurred at 13,100 meters and 90 knots. This caused SpaceShipOne to pitch up as expected, before returning to a level pitch attitude. Melvill reported he could turn the vehicle right and left with rudder or aileron controls, and full pitch control inputs had minimal effect on the flight path. The airspeed and G-envelope tests were normal, as was the roll performance, which resulted in a low amount of adverse yaw. A smooth touchdown was made on Runway 12, 10.5 minutes after launch.

Flight 37L/06G: third glide flight of SpaceShipOne

23 September 2003
Flight time: 1.5 hours (SpaceShipOne: 12 minutes 15 seconds)
WhiteKnight pilot: Pete Siebold; WhiteKnight co-pilot: Matt Stinemetze
WhiteKnight flight-test engineer: Jeff Johnson
SpaceShipOne pilot: Mike Melvill
High Chase-Starship pilot: Jon Karkow
Low Chase-Duchess pilot: Brian Binnie

This flight evaluated aft center-of-gravity (CG) flying qualities and the performance of the spaceship in the glide and re-entry/feather mode, as well as assessing more aggressive post-stall maneuvering and spin control as a glider and while feathered. The aft CG stall was worse than expected but, apart from that and a slightly more aggressive nose rise during the first stall, the flight proved uneventful.

Flight 38L/07G: fourth glide flight of SpaceShipOne

17 October 2003
Flight time: 1.1 hours (SpaceShipOne: 17 minutes 49 seconds)
WhiteKnight pilot: Pete Siebold; WhiteKnight co-pilot: Cory Bird
WhiteKnight flight-test engineer: Dave Moore
SpaceShipOne pilot: Mike Melvill
High Chase-Starship pilot: Brian Binnie
Low Chase-Extra pilot: Chuck Coleman

The fourth glide flight evaluated the effects of horizontal tail modifications at the forward and mid-range CG locations. The tail modifications included a strake[3] bonded to the tail boom in front of the stabilator and a flow/wing fence[4] mounted on the leading edge of each stabilator. The flight also assessed the rocket motor controller, the “arm”, “fire”, and safing switches as well as the oxidizer dump valve. The modifications improved the aerodynamics as well as solving the nose pitch-up that occurred during the previous test flight.

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[3] A strake is an aerodynamic surface usually mounted on the fuselage to improve flight characteristics either by controlling the airflow (acting as large vortex generators) or by stabilizing effect. In general, a strake is longer than it is wide.

[4] A wing fence is a flat plate attached perpendicular to the wing and in line with the free stream air flow.

Flight 40L/08G: fifth glide flight of SpaceShipOne

14 November 2003
Flight time: 1.4 hours (SpaceShipOne: 19 minutes 55 seconds)
WhiteKnight pilot: Brian Binnie; WhiteKnight co-pilot: Matt Stinemetze
SpaceShipOne pilot: Pete Siebold
High Chase-Starship pilot: Jon Karkow
Low Chase-Duchess crew: Mike Mevvill/Chuck Coleman

This flight was notable for there being a new pilot behind the stick. Pete Siebold, who had been involved in the development of the TONU and the SpaceShipOne flight simulator, became the second pilot to fly SpaceShipOne. Siebold's tasks included assessing the stability and control of SpaceShipOne with new extended horizontal tails in addition to evaluating stall performance at the aft limit CG. Prior to the flight, engineers had added short sections of strings to the horizontal stabilizer to help them determine how air flowed over its surface. During the flight, Siebold reported nominal handling qualities and good nose-pointing ability before overflying the runway to see whether SpaceShipOne could still make the landing coming in too high or low. After just short of 20 minutes of flight time, he guided SpaceShipOne to a touchdown at the targeted runway aim-point.

Flight 41L/09G: abort contingency assessment

19 November 2003
Flight time: 2.1 hours (SpaceShipOne: 12 minutes 25 seconds)
WhiteKnight pilot: Brian Binnie; WhiteKnight co-pilot: Cory Bird
SpaceShipOne pilot: Mike Melvill
High Chase-Starship pilot: Pete Siebold
Low Chase-Duchess crew: Chuck Coleman/Matt Stinemetze

While Scaled Composites was very confident in the performance of the rocket engine and the handling characteristics of SpaceShipOne, there was always the possibility of an abort event, which had various consequences depending on the state of the vehicle. For example, if SpaceShipOne aborted while full of fuel and oxidizer, the vehicle wouldn't be able to land without first dumping 1,360 kilograms of mass. So, to assess such a contingency, Melvill evaluated an emergency landing after first dumping ballast. The test went well, after which the landing pattern was flown at a higher airspeed than previous flights which allowed for a more controlled flare and landing at the touchdown point.

Flight 42L/10G: seventh glide flight and propulsion system check

4 December 2003
Flight time: 1.3 hours (SpaceShipOne: 13 minutes 14 seconds)
WhiteKnight pilot: Pete Siebold; WhiteKnight co-pilot: Matt Stinemetze
SpaceShipOne pilot: Brian Binnie
High Chase-Starship pilot: Jon Karkow
Low Chase-Extra crew: Mike Melvill/Chuck Coleman

The seventh glide flight of SpaceShipOne was flown by Brian Binnie, the third pilot to fly the spacecraft. This flight was intended to be the final glide flight before testing the rocket engine with the vehicle. SpaceShipOne was released at an altitude of 14,750 meters, the highest release altitude to date. Binnie performed a cold run of the rocket, using the controls and instruments normally used for operating the engine, including flowing the oxidizer through the case/throat/nozzle, thereby simulating an actual rocket burn. After practicing the rocket burn, Binnie completed airspeed and G-force envelope expansion tasks that included a 4-G pull-up and inducing sideslip and yaw rates. The vehicle recovered to a stable attitude and descent after only a single oscillation while recovering stable attitude. Once again, SpaceShipOne had performed as expected and the stage was set for rocket test flights.

Flight 43L/11P: supersonic flight/first powered flight

17 December 2003
Flight time: 1.2 hours (SpaceShipOne: 18 minutes 10 seconds)
WhiteKnight pilot: Pete Siebold; WhiteKnight co-pilot: Cory Bird
SpaceShipOne pilot: Brian Binnie
High Chase-Starship pilot: Jon Karkow
Low Chase-Starship pilot: Mike Melvill/Chuck Coleman

The first rocket test flight was a monumental step into the unknown. Scaled Composites was attempting to become the first private company to launch a vehicle into space, but the company had never built an aircraft that had broken the sound barrier. Actually, no company had built an aircraft that had broken the sound barrier without government support. That's because breaking the sound barrier is tough. One of the challenges is understanding the phenomenon of shockwaves that occur during supersonic flight. When air flow moves from supersonic to subsonic, a shockwave is formed. This shockwave (Figure 3.10) is an area across which are all sorts of violent changes in pressure and temperature, and these shockwaves change with the speed of the aircraft. As all aerodynamicists know, air flows faster over the top of a wing than over the bottom. This means that when an aircraft is traveling slower than the speed of sound, air may be moving over the wing faster than the speed of sound. This causes a shockwave. There is also the problem encountered when the aircraft approaches supersonic speed when drag increases exponentially and the lift generated by the wings falls sharply. While aircraft have been flying supersonic since 1947, there are still problems associated with faster-than-sound flight that can cause headaches for the aerodynamicist – problems such as pitch-up and inertial coupling for instance, either of which can prove fatal. Given the challenges of such a test flight, it would seem the obvious pilot choice would be the one with the most stick time, but Binnie was the one selected, probably because of his experience flying supersonic jets for the US Navy.

SpaceShipOne was released from an altitude of 14,600 meters. At 13,530 meters, flying at Mach 0.55, Binnie lit the engine. Nine seconds later, SpaceShipOne broke the sound barrier. After 15 seconds' burn duration, Binnie shut down the rocket engine as SpaceShipOne reached Mach 1.2 (1,290 kilometers per hour), after having pulled 3 Gs. SpaceShipOne was pointing upwards at 60° and continued to climb, eventually reaching

3.10 US Navy F/A-18 approaching the sound barrier. The white halo is formed by condensed water droplets which result from the shockwave shedding from the aircraft. Courtesy: USAF

an apogee of 20,670 meters. The only event that was less than nominal was the landing: a damper in the flight controls had frozen, causing the controls to be less responsive, the result of which was SpaceShipOne hitting the runway hard, the main landing gear collapsing, and SpaceShipOne veering off to the left.

Flight 49L/12G: twelfth flight of SpaceShipOne/unpowered glide test

11 March 2004
Flight time: 1.3 hours (SpaceShipOne: 18 minutes 30 seconds)
WhiteKnight pilot: Brian Binnie; WhiteKnight co-pilot: Matt Stinemetze
SpaceShipOne pilot: Pete Siebold
High Chase-Starship pilot: Jon Karkow
Low Chase-Extra crew: Mike Melvill/Chuck Coleman

After the stress of the rocket flight, the 49L/12G flight was a rather more mundane affair, the main objectives being pilot proficiency, RCS functionality checks, and stability and control and performance of the vehicle with the thermal protection system installed. It was Siebold's second time flying SpaceShipOne, which was released from 14,780 meters, the highest altitude to date. Apart from some of the thermal protection system cracking, the flight was uneventful and the team looked forward to the second powered flight. But first there was the business of *Gopherus agassizii* to attend to.

Show-stopping tortoises

The second powered flight required a longer burn, which meant Scaled Composites needed a commercial launch license, which in turn required the company to complete an environmental impact report as part of the application process. Part of the environmental impact assessment included a head count of desert tortoises, or *Gopherus agassizzii.* While conducting the sweep of the runways for stray tortoises (Figure 3.11), Scaled personnel fervently hoped they wouldn't find any, because that would have required them to contact a desert tortoise control specialist who was a three-hour drive away. Fortunately, no tortoises were found, Scaled got their FAA paperwork, and Flight 13P was given the green light.

Flight 53L/13P: second powered flight/transonic–supersonic handling

8 April 2004
Flight time: 1.3 hours (SpaceShipOne: 16 minutes and 27 seconds)
WhiteKnight pilot: Brian Binnie; WhiteKnight co-pilot: Matt Stinemetze
SpaceShipOne pilot: Pete Siebold
High Chase-Alpha Jet crew: Marc de van der Schueren/Jeff Johnson
High Chase-Starship crew: Jon Karkow/Robert Scherer
Low Chase-Extra crew: Mike Melvill/Chuck Coleman

3.11 *Gopherus agassizzii*, the (potentially) troublesome desert tortoise. Courtesy: Wikimedia/ Tigerhawkvok

The second powered flight of SpaceShipOne was essentially a trial run for the actual ride to space since SpaceShipOne was fully ballasted. SpaceShipOne was released at an altitude of 13,900 meters and immediately experienced problems caused by the extra weight. Siebold pulled the nose up and realized the wings couldn't lift the vehicle, resulting in the spacecraft stalling a lot earlier than expected. The flight crews faced a dilemma because they didn't want to abort the flight with so much weight on board and dumping the nitrous oxide would push the CG too far aft. After some discussion, Mission Control decided to press on and Siebold lit the rocket engine at an altitude of 11,760 meters. Following a 40-second rocket burn, SpaceShipOne was moving at Mach 1.6. Following the coast phase, SpaceShipOne reached its apogee of 32,000 meters – about a third of the altitude it needed to reach to win the X-Prize. All in all it was a successful flight that augured well for the flights to come.

Flight 56L/14P: third powered flight/supersonic feather stability and control

13 May 2004
Flight time: 1.5 hours (SpaceShipOne: 20 minutes 44 seconds)
WhiteKnight pilot: Brian Binnie; WhiteKnight co-pilot: Matt Stinemetze
SpaceShipOne pilot: Mike Melvill
High Chase-Alpha Jet crew: Marc de van der Schueren/Jeff Johnson
Low Chase-Duchess crew: Pete Siebold/Dave Moore

By this stage in flight testing Scaled Composites had checked off most of the test objectives, but one key performance characteristic was missing, and that was how the vehicle performed during a supersonic feathered re-entry. SpaceShipOne released from WhiteKnight at an altitude of 14,202 meters and, 10 seconds later, Melvill lit the rocket engine, which boosted SpaceShipOne to an altitude of 45,720 meters and a speed of Mach 2.5. Following the coast phase, SpaceShipOne topped out at an altitude of 64,430 meters, but avionics had been lost during the boost phase which meant the vehicle was oscillating. Melvill used the RCS to resolve the oscillation issue and SpaceShipOne made its feathered re-entry descent at Mach 1.9 as predicted. The stage was set for the first commercial astronaut flight.

Flight 60L/15P: first Fédération Aéronautique Internationale (FAI) commercial astronaut flight

21 June 2004
Flight time: 1.6 hours (SpaceShipOne: 24 minutes 5 seconds)
WhiteKnight pilot: Brian Binnie; WhiteKnight co-pilot: Matt Stinemetze
SpaceShipOne pilot: Mike Melvill
High Chase-Alpha Jet crew: Marc de van der Schueren/Jeff Johnson
High Chase-Starship crew: Jon Karkow/Robert Scherer
Low Chase-Extra crew: Chuck Coleman/Cory Bird

A few days before Flight 15P, Mojave Airport received its launch site operator license and officially became Mojave Air and Space Port. Given the significance of the occasion, it wasn't surprising that thousands of spectators turned up to witness the occasion. Some wore space costumes, some were engineers, and others were just space enthusiasts keen to witness a moment in history. SpaceShipOne was dropped at an altitude of 14,330 meters. Melvill unguarded the "Arm" and "Fire" switches and lit the rocket motor. In less than 10 seconds, SpaceShipOne was supersonic and Melvill felt the "eyeballs in" tug of 3 Gs as the cigar-shaped spacecraft arrowed upward. Shortly before completing the pull-up, wind shear caused the vehicle to roll to the left, prompting Melvill to push down hard on the rudder pedal to regain control. The control inputs worked, but SpaceShipOne was off course; 60 seconds into the burn, the rocket transitioned from gas to liquid, which was followed by a series of loud bangs as chunks of unburned fuel flew out of the nozzle (the bangs were so loud Melvill thought part of the vehicle had fallen off). The rocket engine cut off at 54,860 meters at Mach 2.9 (3,460 kilometers per hour) after firing for 76 seconds, before continuing to coast upwards to an apogee of 100,124 meters, clearing the magic line in the sky by less than 130 meters. Melvill didn't have much time to admire the view but, while he was weightless, he reached into his flight suit and grabbed a handful of M&Ms, which he released into the cockpit. Video of the event played repeatedly later that day. SpaceShipOne reached Mach 2.9 and 5 Gs on re-entry, defeathering at 17,370 meters, before coming in to a perfect landing (Figure 3.12). It was only the vehicle's

3.12 SpaceShipOne on touchdown. Courtesy: D Ramey Logan/Wikimedia

3.13 Patricia G. Smith, Associate Administrator for Commercial Space Transportation at the FAA, presents Michael Melvill with the department's first commercial astronaut wings. Source: http://ast.faa.gov/education/history/. Courtesy: Wikimedia/US Government

fourth powered flight. Waiting to congratulate Earth's 433rd astronaut (Figure 3.13) were Buzz Aldrin, Burt Rutan, Paul Allen, and Patti Grace Smith, the FAA's Associate Administrator for Commercial Space Transportation, who presented Melvill with the first-ever commercial astronaut wings. The flight had been an outstanding success but, with the Ansari X-Prize set to expire in six months, the race was on to perform the qualifying flights.

Flight 65L/16P: first X-Prize flight (X1)

29 September 2004
Flight time: 1.6 hours (SpaceShipOne: 24 minutes)
WhiteKnight pilot: Brian Binnie; WhiteKnight co-pilot: Matt Stinemetze
SpaceShipOne pilot: Mike Melvill
High Chase-Alpha Jet crew: Marc de van der Schueren/Jeff Johnson
High Chase-Starship crew: Jon Karkow/Robert Scherer
Low Chase-Extra crew: Chuck Coleman/Cory Bird

The X-Prize wasn't just one flight. To win the US$10 million, SpaceShipOne had to fly two flights within two weeks. Any setback might delay a launch with the result that 2004 would become 2005 and the X-Prize would be no more. And, with no X-Prize-winning spacecraft, there would be no commercial space business and the new space age would stall. But there was more riding on SpaceShipOne than money and prestige. Richard Branson was waiting with his check book to give Rutan the money needed to build a fleet of spaceships for his Virgin Galactic enterprise, and wealthy space tourists weren't going to hand over US$190,000 for a ride in a vehicle that spun out of control or cracked its landing gear. In short, the X-Prize flights had to be perfect. Flawless. And, with the whole world watching, Tier One had to deliver.

Like its predecessor, the *Spirit of St. Louis*, SpaceShipOne was stripped of everything but the bare essentials. Unlike its first excursion into space, when it carried just the weight of the pilot, the X1 flight would be ballasted with 180 kilograms to simulate the weight of two passengers, so every gram counted: it was calculated that the removal of every kilogram enabled SpaceShipOne to fly another 100 meters. It didn't help that Melvill weighed only 73 kilograms – under X-Prize rules, he had to be ballasted up to 90 kilograms.

The scene that greeted WhiteKnight and SpaceShipOne on flight day was little different than it had been three months earlier as thousands of eager X-Prize spectators (Figure 3.14) watched the take-off at 7:12 a.m. PST. Less than an hour later, SpaceShipOne was released from an altitude of 14,170 meters, after which Melvill fired the rocket motor before lining up the donuts on the TONU display. The rocket burn lasted for 77 seconds, boosting the vehicle to Mach 2.92, or 3,400 kilometers per hour. At motor burnout, SpaceShipOne was at 48,770 meters and from there it coasted into space reaching an apogee of 102,900 meters. At 60 seconds into the burn, large roll rates of 190° per second

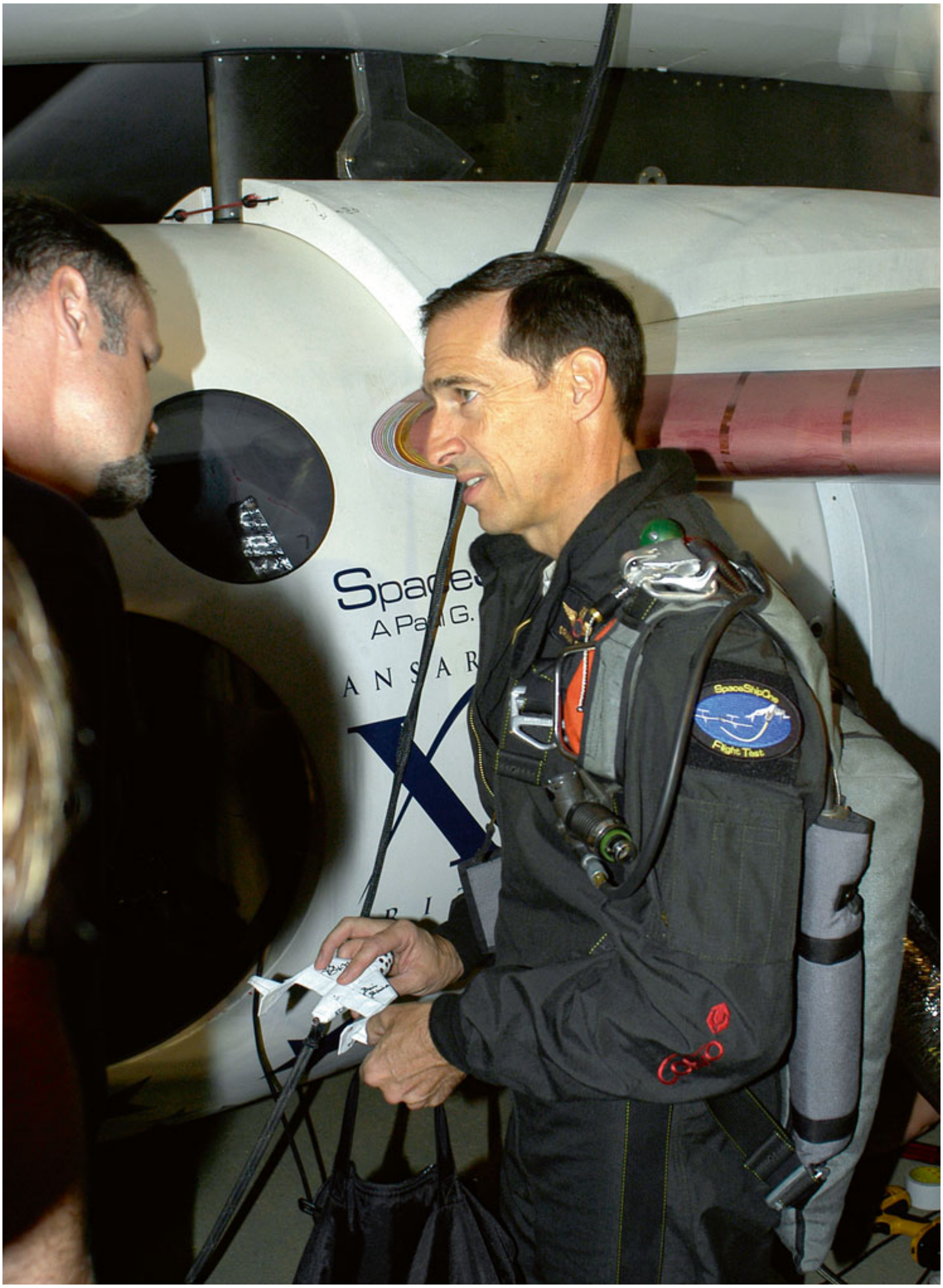
3.14 X-Prize spectators. Courtesy: Wikimedia/D Ramey Logan were experienced and it wasn't possible to stop the rolls using only aerodynamic flight controls, forcing Melvill to use the RCS to damp the roll rate. During his 3.5 minutes of weightlessness, Melvill used a digital camera to shoot some pictures before preparing for the supersonic feathered atmospheric entry. During its descent, SpaceShipOne reached a peak G-force of 5.1 Gs at 32,000 meters and hit a top speed of Mach 3.0. The descent was smooth, with only small oscillations, and Melvill was able to guide SpaceShipOne to a smooth landing on the runway lined with crowds of cheering spectators.

Flight 66L/17P: second X-Prize flight (X2)

4 October 2004
Flight time: 1.6 hours (SpaceShipOne: 24 minutes)
WhiteKnight pilot: Mike Melvill; WhiteKnight co-pilot: Matt Stinemetze
SpaceShipOne pilot: Brian Binnie
High Chase-Alpha Jet crew: Marc de van der Schueren/Jeff Johnson
High Chase-Starship crew: Jon Karkow/Robert Scherer
Low Chase-Extra crew: Chuck Coleman/Cory Bird

The Tier One team had set themselves two objectives for Flight 17P – one was winning the X-Prize and the other was breaking the X-15 record of 107,900 meters. The stakes for the flight X2 were the highest of any SpaceShipOne flight and, for Brian Binnie (Figure 3.15), his 4:30 a.m. pre-flight briefing couldn't have come soon enough. A veteran of more than 30 combat missions flown as a naval aviator in the Gulf War, Binnie had always had his sights set on becoming an astronaut. Now he had his chance.

A large crowd of space enthusiasts, dignitaries, and X-Prize guests (Figure 3.16) cheered as WhiteKnight, with SpaceShipOne slung underneath (Figure 3.17), took off at 6:49 a.m. PST. At the launch altitude of 14,360 meters, Melvill flipped the switch that unlocked the hooks securing SpaceShipOne. Melvill asked flight engineer Stinemetze if he was ready and Stinemetze pulled the release lever. SpaceShipOne fell free and Binnie fired the rocket motor. The rocket burn lasted for 83 seconds, boosting the vehicle to more than 3.09 Mach, or 3,518 kilometers per hour. At motor burn out, SpaceShipOne was at 64,920 meters and from there it coasted the rest of the way into space, reaching an apogee of 112,000 meters, exceeding the X-Prize altitude by 12 kilometers. Binnie feathered the vehicle as dynamic pressure approached zero during ascent and used a digital camera to shoot pictures before busying himself with a series of zero-G flight tests of a small paper SpaceShipOne model. Binnie experienced approximately 3.5 minutes of weightlessness as the vehicle slowly decelerated to apogee before beginning its descent. Maximum Mach during entry was 3.25, which was the highest recorded during any of the test flights. During the descent, Binnie, who had just become the 434th human to have flown in space, experienced 5.4 Gs deceleration at 32,000 meters. Retracting the feather at 15,540 meters, Binnie enjoyed the remainder of the descent before guiding SpaceShipOne to a perfect landing at Mojave just 24 minutes after being dropped by WhiteKnight. The flight not only broke the X-15 record and won the X-Prize, but was a perfect flight to end the program, with no anomalies noted. The public's perception of spaceflight had changed forever.



3.15 Brian Binnie pre-flight before SpaceShipOne Flight 17P. In 2014, XCOR Aerospace announced that Binnie had joined the company as Senior Test Pilot. Courtesy: D Ramey Logan/Wikimedia

3.16 Brian Binnie's family react as he launches into space on the final SpaceShipOne flight. Courtesy: D Ramey Logan/Wikimedia

3.17 SpaceShipOne slung underneath WhiteKnight. Courtesy: Wikimedia/D Ramey Logan

SPACEFLIGHT FOR THE MASSES: THE SPACESHIPONE LEGACY

4 October 2014. That was the 10-year anniversary of the winning of the Ansari X-Prize. Those who witnessed SpaceShipOne's landing felt sure they were witnessing the launch of commercial space travel and they were right. They just didn't know they would have to wait a while. A long while as it turned out, and that waiting period became a lot longer in the aftermath of the SpaceShipTwo accident. But the new industry that SpaceShipOne and the X-Prize gave birth to is real in the same way that Lindbergh's flight was seen as the catalyst for today's US$300 billion aviation industry. And, in the minds of many, the legacy goes beyond an influx of cash: for the spaceflight enthusiasts, the X-Prize gave teams the opportunity to think about building spaceships. The competition also created public excitement, expectations, and, ultimately, future customers who queued up to buy a seat. The eight-year race to winning the X-Prize [6] also helped define the policy allowing commercial spaceships to carry paying passengers. And the industry? Well, it's been a long wait for revenue flights, but more than US$1 billion has been invested in commercial spaceflight since SpaceShipOne's epic flight, and much of that has to do with Richard Branson's marketing genius and the creation of Virgin Galactic.

Notes

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2. http://www.scaled.com
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4

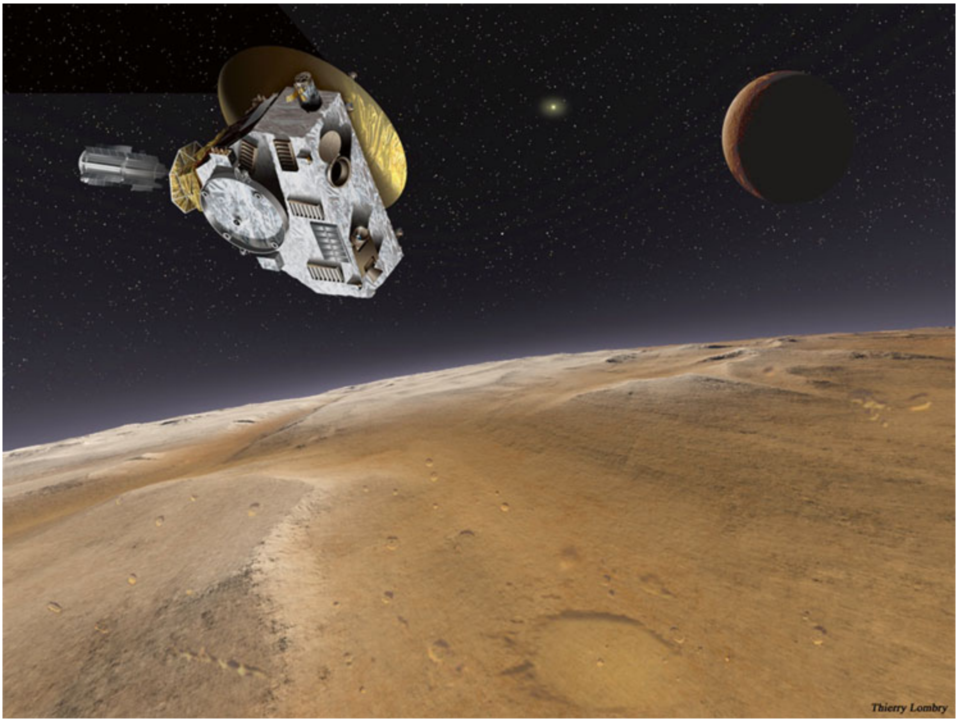
SpaceShipTwo: VSS *Enterprise*

> "As a child, I read about some of the things that happened … the early X-1 flights, the whole X-series … I guess I thought that was over and done with, and probably wouldn't be seen again. And yet, here we are with a very similar system, an air-launched spaceship."
>
> *David Mackay, veteran aviator and chief pilot for Virgin Galactic*

THE FINAL FLIGHT OF SPACESHIPONE

The image in Figure 4.1 is of the space probe *New Horizons* which was launched in 2006. Its destination is the dwarf planet Pluto where it will arrive in June 2015. You may be wondering why the image is included in a chapter about commercial spaceflight but this section explains all. After the whirlwind surrounding the X-Prize had died down, there was a plan to continue flying SpaceShipOne on a regular basis. In fact Rutan planned to fly it once a week for five months, figuring that with that sort of flight experience it would be possible to present a business plan with a high degree of confidence. If Rutan's plans had been realized, another 44 passengers could now count themselves as Virgin Galactic astronauts, but it wasn't to be. Not long after the winning X-Prize flight, Rutan received a letter from Valerie Neal, a curator for the Smithsonian Institution's National Air and Space Museum. In the letter, Neal expressed the National Air and Space Museum's interest in acquiring SpaceShipOne to present it in the Milestones of Flight gallery (Figure 4.2), where it would join the *Spirit of St Louis* and the *Bell X-1* that broke the sound barrier. Rutan consulted Allen and, after some discussion, it was agreed SpaceShipOne would be transferred to the museum. So, after presenting the historic vehicle at the Oshkosh air show, Melvill took off for Dulles Airport, where an air traffic controller noticed an object

E. Seedhouse, *Virgin Galactic: The First Ten Years*, Springer Praxis Books,
DOI 10.1007/978-3-319-09262-1_4



4.1 NASA's New Horizons is a space probe launched to study Pluto and its moons. Proposed by principal investigator Alan Stern, who has tickets to fly science missions on SpaceShipTwo, New Horizons will perform a flyby of Pluto on 14 July 2015. Courtesy: NASA

4.2 SpaceShipOne in the Milestones of Flight section at the Smithsonian. Courtesy: Wikimedia that looked suspiciously like a missile slung underneath WhiteKnight and ordered Melvill to turn around. Melvill explained the flight had been pre-authorized but the air traffic controller was having none of it until some airline pilots on the same frequency advised the controller that Melvill was the guy delivering SpaceShipOne to the museum. And the Pluto link? New Horizons carries a small piece cut from SpaceShipOne: installed on the lower inside deck of the interplanetary probe, the two-sided inscription reads, on the front [1]:

> "To commemorate its historic role in the advancement of spaceflight, this piece of SpaceShipOne is being flown on another historic spacecraft: New Horizons. New Horizons is Earth's first mission to Pluto, the farthest known planet in our solar system."

And on the back:

> "SpaceShipOne was Earth's first privately funded manned spacecraft. SpaceShipOne flew from the United States of America in 2004."

VIRGIN GALACTIC

Those watching SpaceShipOne's historic flight can't have failed to have noticed the bright red Virgin logo on the vehicle's tail booms and rocket fairing. It was a signal to everyone that Virgin Galactic intended to be the first to capitalize on this new industry. Branson, whose business ventures include Virgin Atlantic, Virgin Records, and the Virgin Health Bank, has always had a penchant for extreme travel, but he faced a problem when Virgin Galactic was trademarked in 1996: there was no spaceship to carry his passengers. But, seven years later, Virgin executive Will Whitehorn visited Scaled Composites to visit Rutan, who was building Global Flyer for Branson. Whitehorn was shown SpaceShipOne, and immediately phoned Branson, who then phoned Rutan and asked him if he could build a commercial version of SpaceShipOne. Rutan declined citing a heavy workload and the fact that Scaled wasn't that type of company. But Branson, being Branson, persisted and Rutan put him in contact with Paul Allen, who brokered the deal that brought Virgin Galactic one step closer to reality. The plan was simple: Virgin Galactic would comprise a fleet of five spaceships, each carrying six passengers and two pilots. These vehicles would rocket into space from the Mojave several times a week before moving their home base to a new purpose-built spaceport near Truth or Consequences, New Mexico. Prospective Virgin Galactic astronauts would spend three days training, which would include G-training, high-altitude indoctrination, and zero-G flights. Once in the weightlessness phase of the flight, passengers would unclip their restraints and fly around the spacious cabin. On their return, a shiny set of Virgin Galactic astronaut wings would be pinned to each passenger's flight suit in a champagne celebration attended by family and friends – all for the price of US$190,000. The question was when this would happen. Virgin Galactic, which collected US$13 million in deposits for tickets by early 2006, predicted revenue flights would start in 2007, but that didn't happen. Continued delays have created a number of skeptics who doubt Virgin's pronouncements and point to ongoing problems with the development of the vehicle's rocket motor. They also highlight the drawn-out development and flight-test program. So what is the real story?

DEVELOPING SECOND-GENERATION SPACECRAFT

Manufactured by The Spaceship Company, SpaceShipTwo is a spacecraft designed to ferry passengers to the edge of space. Before the SpaceShipTwo tragedy, commercial flights were expected to begin sometime in 2015. After SpaceShipOne won the X-Prize, Scaled Composites and Virgin Galactic formed The Spaceship Company to commercialize to develop and build SpaceShipOne's successor – SpaceShipTwo and its carrier vehicle, WhiteKnightTwo. The Spaceship Company announced a series of development and construction milestones, but progress came to a standstill in 2007 when a fatal fire during a ground test underscored the reality that developing rockets is anything but routine. Despite Rutan's flawless record in designing radical aircraft, things go awry and, on 26 July 2007, a cold-flow test of nitrous oxide went wrong. Very wrong.

There were 17 people observing the test, six of whom had taken cover at a mobile command post 130 meters away, where they planned to watch the test on a monitor. The rest watched from behind a fence a dozen meters away as the cold-flow test began. Seconds later, a sudden reaction caused a tank to rupture with such explosive force that the decompressing gas blew 15 centimeters of concrete off the pad beneath the test stand [2]. The explosion killed three and injured three others [2]. The California Occupational Safety and Health Administration investigated the accident and reported that Scaled Composites had not provided sufficient training about the hazards of using nitrous oxide rocket fuel. The investigation also noted that Scaled Composites did not implement a procedure to correct unsafe conditions while conducting tests of the propulsion equipment, and that the company did not monitor the test site during ensure employees were not exposed to excess levels of nitrous oxide [2]. The investigation found Scaled guilty of not following proper workplace practices, but it couldn't explain what had happened (Scaled conducted its own investigation, calling in experts from Lockheed, Northrop, and Boeing, but the cause of the accident remained unresolved.

Rutan stopped work on SpaceShipTwo and shortly thereafter stepped down from running Scaled after being hospitalized with heart problems. He later relocated to his ranch in Idaho after 36 years in Mojave. Work stopped on SpaceShipTwo for a year and the company struggled to get back on track. Once again, Virgin Galactic revised its forecast for revenue flights from 2009 to 2011, and the estimated costs of the program, first calculated at US$20 million, rose to US$400 million – more than 15 times the original estimate [3]. The setback didn't seem to deter potential passengers because the tickets kept selling: in 2012, Ashton Kutcher became the 500th person to buy a ticket.

A change in fortune appeared to be on the cards in July 2008 when Virgin Galactic held a major launch event at the Mojave Air and Spaceport to showcase the first plane in the WhiteKnightTwo class. It was named *Eve*, in honor of Branson's mother. The event was not only a highlight in Virgin's stated goal of launching the world's first private spaceflight company, but also provided the public and ticket holders with tangible evidence that the ambitious project was for real. Designed by aerospace firm Scaled Composites (who else?), WhiteKnightTwo (Figure 4.3), with its twin-boom, catamaran-like design features, four turbofan jets engines and a 42.6-meter wingspan, is the largest carbon-composite aircraft ever constructed.

4.3 The Scaled Composites Model 348 WhiteKnightTwo is a jet-powered carrier aircraft that will be used to launch SpaceShipTwo. Courtesy: D. Miller/Wikimedia

WhiteKnightTwo Technical Specification

- First flight: 21 December 2008
- Largest 100% carbon-composite plane in service
- Twin-boom/fuselage construction
- Propulsion and power: four Pratt & Whitney PW308 engines
- Wing span: 42.6 meters
- Length: 23.7 meters
- Tail height: 7.6 meters
- Crew: two (flight crew)
- Capacity: payload 17,000 kilograms to 15,000 meters
- Service ceiling: 21,000 meters
- Differences between WhiteKnight and WhiteKnightTwo:
  - WhiteKnightTwo is roughly three times larger than WhiteKnight
  - WhiteKnightTwo is a twin-fuselage design with four jet engines mounted two on each wing
  - WhiteKnight used two T-tails; WhiteKnightTwo uses two cruciform tails
  - Engine configuration: WhiteKnightTwo has four engines hung underneath the wings on pylons, while WhiteKnight's pair of engines were on either side of its single fuselage

4.4 SpaceShipTwo. Courtesy: Bill Deaver

Eighteen months and 22 WhiteKnightTwo test flights later, Virgin Galactic unveiled SpaceShipTwo (Figure 4.4) to a crowd of 800 press, future astronauts, and VIP guests, including Governors Bill Richardson and Arnold Schwarzenegger [4]. After being carried down the runway by her mother ship, VMS *Eve*, to a spectacular display of floodlights and music, SpaceShipOne's successor was christened VSS *Enterprise*, after its Star Trek namesake. Construction of the scaled-up version of SpaceShipOne, which had been carried out in near-total secrecy, had begun in 2007. Although the enthusiastic crowd was told revenue flights would start as soon as 2011, meeting that deadline was always going to be an uphill battle for the simple reason that SpaceShipTwo was built with a design philosophy requiring a much greater factor of safety than government standards for manned space flight. Historically, the safety of government manned spaceflight is less than optimal for a space-tourism industry, since 4% of all the astronauts who have left the atmosphere have died. Since Virgin Galactic is in the business of attracting customers, demonstrating that their vehicle could fly safely was much more important than meeting an arbitrary deadline.

When the successor to VSS *Enterprise* is ready for revenue flights, it will carry six passengers up past an altitude of 100,000 meters. In theory.[1] Flights will begin with SpaceShipTwo slung underneath WhiteKnightTwo, which will carry the executive jet-sized spaceship to 15,000 meters (see sidebar). Once released from its mother ship, SpaceShipTwo will fire its rocket engine for 70 seconds before shutting down for the coast phase to space. Passengers will feel weightless for up to four minutes – plenty of time to experience an out-of-seat zero-gravity experience. On re-entry, SpaceShipTwo will feather its rudders to increase the drag and control the yaw of the spacecraft, allowing the pilot to better control the spacecraft during its descent through the atmosphere. At 22,900 meters, SpaceShipTwo will have enough air around it to move the rudders back to a gliding configuration. It will then land on a normal runway [5].

SpaceShipTwo Flights

Crew: two
Passengers: six
Length: 18.3 meters
Wingspan: 8.3 meters
Height (rudders down): 5.5 meters
Cabin diameter: 2.3 meters

Flight profile

1. SpaceShipTwo carried to 15,500 meters by WhiteKnightTwo
2. After release from WhiteKnightTwo, SpaceShipTwo fires its rocket engine for 70 seconds and accelerates to 4,000 kilometers per hour
3. After the rocket engine is shut down, SpaceShipTwo enters the coast phase which carries it to an altitude higher than 100,000 meters
4. Passengers experience up to four minutes of weightlessness
5. Re-entry with rudders in feathered configuration
6. At 22,900 meters, rudders are defeathered and SpaceShipTwo becomes a glider
7. Landing gear is deployed and SpaceShipTwo lands on runway

The world's first commercial suborbital spaceship factory is located across the flight line from Scaled Composites. Dubbed the Final Assembly, Integration and Test Hangar (Faith), this is where WhiteKnightTwo and SpaceShipTwo took shape. The bulk of the fabrication took place in Building 79 – a site used to produce composite panels, subassemblies like SpaceShipTwo's cabin section, WhiteKnightTwo fuselages, and wing

[1] Although Virgin Galactic has repeatedly said its customers would reach at least 100-km altitude aboard SpaceShipTwo, the company's service agreements stipulate a minimum height of *at least 80 km*. This is not space, unless you happened to have been an American pilot in the 1960s. So, those flying with Virgin Galactic won't be recognized as having traveled in space by the World Air Sports Federation, the world governing body for astronautical records, unless they pass the Karman Line.

skins. Once manufactured, the parts were shipped to Faith for final assembly. The largest parts made in Building 79 were the composite wing spars for the WhiteKnightTwo, which measured 41 meters in length. The spars were laid by hand before being cured in sections by a vacuum oven. Inside Faith, WhiteKnightTwo and SpaceShipTwo took shape beginning with wing assembly and followed by cabin, fuselage, and empennage. Once these stages had been completed, system integration and testing took place before rollout for flight testing. Each SpaceShipTwo cabin was assembled into a complete pressure vessel from sections and reinforced with longerons and offset vertical frames. The cabin has three large windows on either side measuring 43 centimeters across in addition to six 33-centimeter-diameter windows in the crown, while the cockpit has four 53-centimeter-diameter windows. Behind the cabin is a pressure bulkhead separating the compartment from the oxidizer tank, while the rocket engine is located at the rear within the composite skin section (the single-use rocket engine will be replaced after every flight). The cabin has been thoroughly tested by being dynamically twisted, bent with hydraulic rams, and subjected to static testing in a water tank. It's tough. SpaceShipTwo's wing has a 55° leading-edge sweep angle built around two main spars, forward and aft, in addition to a series of deep ribs that act to stabilize the wing skins. The wing's leading edge is attached to shear webs that support various control systems, while the trailing edge and booms support the flight control surfaces, including two rudders, two horizontals, two elevons, and two speed brakes. For maneuvering in space, SpaceShipTwo will use a cold-gas reaction control system (RCS), with nozzles in the nose for pitch and yaw, and nozzles in the wing tips to control roll. The feathering mechanism, comprising the tail booms and feather flaps, rotate around four hinges that are wound onto the rear spar. The feather position is changed using two pneumatic actuators. SpaceShipTwo's manual flight control systems make use of hybrid composite-steel cables designed to match the coefficient of expansion experienced during the cold soak phase at high cruise altitude. Composite steel was chosen because the material doesn't contract or expand as much as conventional steel: one of the problems encountered during the flight testing of SpaceShipOne was the effect of the cold soak period at high altitude, which caused the steel cables to contract so much that significant control input was required by the pilot to perform even minor control-surface deflections.

Dyna-Soar

Those who know their space history will see the similarities between SpaceShipTwo's design and the NASA/USAF Boeing X-20 Dyna-Soar glider (Figure 4.5). Dreamt up in 1957 as the next step to follow the X-15 rocket plane, Dyna-Soar was America's first manned spacecraft that was actually built. Based on Eugen Sänger's Silbervogel (Silver Bird) bomber concept, the Dyna-Soar was to have been an 11-flight program, but the project was cancelled because the spacecraft didn't have a viable military mission. So, in 1963, with just one non-flying mock-up built, the USAF's astronaut corps began training for the Manned Orbiting Laboratory instead.

(continued)

(continued)

4.5 The Boeing X-20 Dyna-Soar (sidebar) was a USAF program to build a spaceplane for reconnaissance, bombing, space rescue, and satellite sabotage. Costing US$660 million in 1960s dollars – about $5 billion today - , the program was cancelled shortly after construction had begun. Courtesy: NASA

Those who have examined photos of WhiteKnightTwo and its cargo may have noticed the similarity between the fuselages. That's because the cabin and forward fuselage of SpaceShipTwo is structurally identical to WhiteKnightTwo's fuselages. And, while on the subject of the twin-fuselage design, it's worth noting that the concept developed following studies of a scaled-up WhiteKnightOne suggested potential problems for emergency egress. While WhiteKnightTwo is designed for the same launch condition as its predecessor, the aircraft is three times larger. The need for more room in the cabin also compounded the egress issue, so the solution was to go with a twin-fuselage design. Linking the two fuselages is that long wing, which resembles a flattened "W" in profile, thanks to a kink with dihedral outboard of the booms and anhedral inboard to provide sufficient ground clearance for its cargo. Those who have followed the evolution of Rutan's designs will notice that the wing looks similar to the wing used in the GlobalFlyer design, but with a slightly thicker cross-section. WhiteKnightTwo has a maximum take-off weight of 29,500 kilograms, of which 3,630 kilograms will be fuel. This gives the aircraft a range of 4,100 kilometers, which will be useful when spaceports are established outside of the US.

SUBSONIC GLIDE TEST FLIGHTS: 14 JUNE 2010–SEPTEMBER 2012

Flight-test key – GF, glide flight; P, powered flight; GC, aborted glide flight

Note: Test flight details sourced from Scaled website [6].

The test-flight phase got underway on 14 June 2010, with three hours of taxi tests of SpaceShipTwo to condition the brakes and evaluate the landing gear/brake steering/skid shoe performance and general ground handling. The vehicle performed as expected and the team prepared to move on to the manned phase of the test program which began four months later on 10 October with Flight 41/GF01. This glide flight, piloted by Pete Siebold with co-pilot Alsbury, evaluated clean release, stability and control, flutter envelope, and landing performance. After being released at an altitude of 14,000 meters, Siebold and Alsbury expanded the envelope to 180 KEAS and 2 Gs, and assessed the speed brake before executing a clean landing. Two weeks later, it was the turn of Stucky to fly SpaceShipTwo on Flight 44/GF02. Accompanied by co-pilot Alsbury, the pilots spent 10 minutes evaluating stability and control and roll evaluation and expanded the envelope to 230 KEAS and 3 Gs. Three weeks later, Siebold and Nichols flew Flight 45/GF03 to evaluate stability and control and expand the flutter envelope. The flight, which expanded the envelope to 246 KEAS and 3.5 Gs, achieved all its objectives. Next on the slate was Flight 47/GF04, an 11-minute flight that took place on 13 January 2011. Piloted by Stucky and Nichols, the flight assessed the center of gravity (CG) with water in a ballast tank and also expanded the flutter envelope. The tests, which evaluated flutter modifications to 250 KEAS, also expanded the envelope to 3.8 Gs. Flight 56/GF05 took place on 22 April 2011. Piloted by Siebold and Shane, the 14-minute flight extended the flutter envelope expansion and met all the glide test objectives. Five days later, Flight 57/GF06 repeated many of the assessments of the previous flight, the 16-minute flying time marking the longest flying time of the program to date. Stability and control continued to be assessed as the flight program continued into its 11th month, but Flight 58/GF07, which took place on 4 May 2011, also evaluated feathering and flutter susceptibility. This flight was followed up by Flight 59/GF08, just six days later, which repeated the objectives on the previous test-flight card. Nine days later and another test flight – the fifth in less than a month – and another flutter assessment and envelope expansion. The flight-test program was moving ahead at a steady rate of knots. SpaceShipTwo's tenth glide flight, which took place on 25 May 2011, was piloted by Stucky and Brian Binnie, who performed the second feather flight and also evaluated a shortened runway approach. This flight was followed by back-to-back flights on 14 and 15 June. Glide Flights #11 and #12 marked the quickest turnaround time yet between solo flights, and reinforced the unique and transformational ability of Virgin Galactic's spaceflight system to undertake daily flights to space. Both flights (Flight 64/GF11 and Flight 65/GF12) saw early morning take-offs, followed by high-altitude releases at around 15,800 meters. The quick turnaround, which demonstrated an important factor in Virgin Galactic's planned commercial operations, was followed by Glide Flights #13, 14, and 15, each of which met test-flight objectives. Following Flight 68/GF15 on 27 June 2011, SpaceShipTwo headed for a quiet period to allow the Scaled team time to analyze the data from the test-flight program before the next phase of test flights.

Following the summer break, flight testing got underway on 29 September 2011, with Flight 73/GF16. Pilot Stucky and co-pilot Nichols evaluated flutter expansion, stability, and control, and assessed the effect of extra weight in the form of water ballast on landing. Another item on the test card was rapid descent, which SpaceShipTwo entered immediately following release from WhiteKnightTwo. The descent caused a downward pitch rate that caused a stall of the tails, but the crew followed procedure, selecting the feather mode to revert to the nominal flying condition. Following the 16th glide flight, there was an eight-month break from flight testing, which resumed on 1 June 2012, with a series of taxi tests with three different pilots evaluating the decelerating performance with new higher-capacity brakes. The tests were performed at speeds between 50 and 100 kilometers per hour and all objectives were achieved. Three weeks later, on 26 June, Pete Siebold and Alsbury flew Flight 87/GF17, piloting SpaceShipTwo for more than 11 minutes while collecting flutter data, checking the speed brakes, and performing an airborne functional test of the RCS. Once again, all items on the flight-test card were met. Three days later, Stucky and Mackay piloted SpaceShipTwo on Flight 88/GF18 for 13 minutes, to assess strake and to familiarize Mackay with the operation of SpaceShipTwo. Flight 90/GF19 took place on 18 July with Siebold and Nichols at the controls of SpaceShipTwo. In addition to evaluating aft CG and expanding the airspeed envelope, Siebold and Nichols also assessed the effect of extra weight during landing without any problems. The flight testing was progressing smoothly, laying a solid foundation of experience that would prove invaluable when the time came for powered flights. In fact, powered flights were not far over the horizon, with only three more glide flights in the glide flight-test program. Flight 91/GF20 was flown on 2 August to evaluate elevon dampers and rudder locks and to assess forward CG landing, Flight 92/GF21 was flown five days later to expand the aft CG angle-of-attack and the effect of extra weight on an aft CG landing, and Flight 93/GF22 was flown on 11 August to test maximum glide flight Mach and airspeed envelope expansion. With this round of six flights, the Scaled team cleared the full glide flight envelope for airspeed, angle-of-attack, CG, and structural loads. Virgin Galactic had largely finished its subsonic and unpowered flight tests of SpaceShipTwo, prompting George Whitesides, President of Virgin Galactic, to state: "We've explored the envelope in a way that we now feel fairly comfortable that we're ready for the next stage, from an aerodynamics perspective." [7] The next stage had to wait while SpaceShipTwo's hybrid liquid/solid rocket engine was installed but, by December, the team were ready to resume testing. Before commencing powered flights, the engineers wanted to be sure the vehicle glided as it should with the rocket engine installed and also wanted to perform some non-ignition tests of the rocket motor. Once Virgin Galactic was satisfied the vehicle and rocket motor functioned as expected, the way would be clear for powered flights. So, on 19 December 2012, Stucky and Alsbury flew Flight 109/GF23 to check the installed rocket motor systems and nozzle, assess the vehicle's thermal protection system (TPS), and evaluate different flight control modes. During the 13-minute flight, the pilots noted better aerodynamic performance than expected and no negative issues. There were now just two flights to perform before the way was clear for powered flights. The first of these, Glide Flight #24, took place on 3 April 2013, with Stucky and Nichols at the controls. The short nine-minute flight evaluated an in-flight nitrous vent test and feathered flight with no anomalies noted. Nine days later, Stucky and Alsbury flew the mission rehearsal flight (Flight 114/CF01) for the first powered flight, once again assessing the nitrous vent test.

POWERED FLIGHTS PHASE: 29 APRIL 2012–31 OCTOBER 2014

By the time 29 April 2012 rolled around, Virgin Galactic had been waiting a long time to fly SpaceShipTwo's powered qualification flight. The flight test began at 7:02 a.m. local time when SpaceShipTwo took off from Mojave Air and Space Port mated to

WhiteKnightTwo, which was piloted by Chief Pilot Dave Mackay, and assisted by Clint Nichols and Brian Maisler [8]. Piloting SpaceShipTwo were Mark Stucky and Mike Alsbury. After reaching an altitude of 14,300 meters and 45 minutes into the flight, SpaceShipTwo was released from WhiteKnightTwo [8]. Moments later the pilots triggered ignition of the rocket motor, the main oxidizer valve opened and the igniters fired. SpaceShipTwo rocketed upward, reaching a maximum altitude of 17,130 meters and Mach 1.2 following a 16-second burn [8]. It was without doubt the most important flight test to date. As with almost all the test flights, Flight 115/PF01 proceeded by the checklist and brought Branson's space company another step closer to achieving cost-effective access to space. Joyrides to the edge of space had just gotten closer to reality:

> "Like our hundreds of customers from around the world, my children and I cannot wait to get on board this fantastic vehicle for our own trip to space and am delighted that today's milestone brings that day much closer [9]."
>
> *Richard Branson, following SpaceShipTwo's first powered flight*

After the euphoria of Flight 115/PF01, it was back to basics and time to allow other pilots to gain experience flying SpaceShipTwo, which was the objective of Flights 130/GF25 (25 July 2013) and 131/GF26 (8 August 2013), piloted by Mark Stucky and Mackay. After another brief hiatus over the summer Virgin Galactic was once again primed for the next powered flight – Flight 132/PF02.

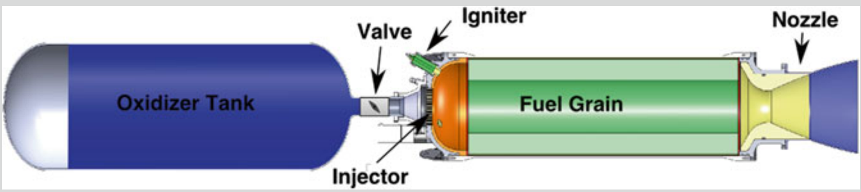
On 5 September, pilots Mark Stucky and Clint Nichols were at the controls during SpaceShipTwo's second powered flight, which started at about 8:00 a.m. local time. After being dropped from 14,000 meters, SpaceShipTwo's engine lit up, coasted to the top of its arc, angled its wings into a feathered shuttlecock configuration to slow its descent, then righted the wings again to glide to a Mojave runway landing at 9:25 a.m. local time [10]. It was very much a business-as-usual flight that hit all the parameters on the test card. The rocket was rocket engine was fired for 20 seconds, sending SpaceShipTwo to Mach 1.43 and an altitude of 21,000 meters. The second powered flight brought the total of test flights to 29 as the Scaled Composites' test program called for a series of increasingly ambitious powered flights. With such a record of success, it wasn't surprising that the prospect of revenue flights sometime in 2014 was a real and tantalizing possibility. One of the many sending congratulatory words was Sierra Nevada Corporation, manufacturer of SpaceShipTwo's hybrid rocket engines (see sidebar):

> "With three successful crewed test flights completed as planned for Virgin Galactic, our rocket engine technology continues to demonstrate its excellence in terms of safety, performance and reliability. Today's test provides another confirmation that our propulsion motor technology is reliable and repeatable. To date, SNC has performed more than 70 hot fire tests of this rocket motor technology [11]."
>
> *Mark Sirangelo, corporate vice president and head of SNC's Space Systems*

Testing resumed on 11 December 2013, with a pilot training flight (Flight 145/GF27), piloted by Mark Stucky and Masucci, as Scaled prepared for the third powered flight

Hybrid Rockets: A Primer

Why use a hybrid rocket? Well, hybrid rockets are safer than liquid and solid rockets because it is nigh impossible for oxidizer and fuel to be mixed. Unlike solid rocket engines which can't be shut down, hybrids can be shut down and the thrust can varied much like a throttle on a car. Hybrids also have more bang for the buck, or a high specific impulse in rocket engineer language. They may be more complicated than solid rocket engines, but hybrids are safer simply because it's dangerous manufacturing and handling solids. Very simply, a hybrid rocket (Figure 4.6) comprises a combustion chamber that contains the solid propellant, a pressure tank that holds the liquid propellant, and an isolating valve.



4.6 Conceptual schematic of a hybrid rocket propulsion system. Courtesy: Jonny Dyer

scheduled to take place early in the new year. On 10 January 2014, Flight 147/PF03 departed Mojave Air and Space Port at 7:22 local time. After climbing to 14,000 meters, SpaceShipTwo, with Virgin Galactic's Chief Pilot Dave Mackay and Scaled Composites' Test Pilot Mark Stucky at the controls, was released and the rocket motor ignited, powering the vehicle to 21,640 meters (its highest altitude to date) and Mach 1.4 [12]. During the flight, Mackay and Stucky tested SpaceShipTwo's RCS, the newly installed thermal protection coating on the vehicle's tail booms, and the feather re-entry system. It was another flawless flight and Branson couldn't have been happier, confidently announcing that 2014 would be the year that SpaceShipTwo finally made it into space. It was yet another bold statement and one that was questioned at the time by investigative reporter Tom Bower, author of *Branson: Behind the Mask*, which was published less than a month after SpaceShipTwo's third powered flight. In his book, Bower cast doubt that Virgin Galactic's long-touted rocket ride would *ever* happen, pointing to slipped dates and the technical challenges involved:

> "It's clear that he launched Virgin Galactic without remotely understanding the complexity of the technical challenges involved and, probably, still doesn't."
>
> *Quote from* Branson: Behind the Mask*, by Tom Bower*
> *(Faber & Faber, ISBN-13: 978-0571297108)*

One of Bower's more serious claims, supported by little evidence at the time, was that SpaceShipTwo's rocket motor wasn't powerful enough to achieve the velocity necessary to reach suborbital altitude with two pilots and six passengers on board. What Bower didn't seem to appreciate in his book were the difficulties encountered in any flight testing program and that flight testing is a caution-driven and incremental process. This is especially true when testing a new spacecraft that has to carry paying passengers to space and back safely. To bolster his case that Virgin Galactic used dangerous fuel in RocketMotorTwo, Bower cited the rocket motor explosion in 2007 that killed three engineers, sidestepping the fact that blame for the deaths fell on lax safety measures and the problem was not in the fuel itself, but in the construction of the test tank. Branson responded to the charges in Bower's book by saying "Rome wasn't built in a day" but, as Scaled prepared for more powered flights, it still faced some daunting problems, many of which concerned safety.

One of the safety issues was how the Federal Aviation Administration (FAA) could certify SpaceShipTwo as safe for passenger flight. In the commercial airline world, it may take as long as two years for the FAA to clear a new airliner for service, and this process involves extremely well-understood technical issues and mature technology. In short, when it comes to your 787s and 777s, there is little that has never been done before, and most that hasn't been done before involves software, not structure. The challenge faced by Virgin Galactic was that nothing had been done before. In the wake of SpaceShipOne's success, Congress debated how to regulate commercial human spaceflight, arguing about how to deal with crew and passenger safety and the extent of authority that should be vested with the government. There were some legislators who supported a "fly at your own risk" approach, which echoed the policy that had made commercial spaceflight relatively free from regulation, much like the days of Lindbergh. Draft bills submitted before Congress suggested regulating passenger training and setting crew medical standards. Other proposals included defining the extent to which passengers would have to be informed of the risks, and whether passengers would need to supply written, informed consent to the risks associated with flights. The end result of all the debating was the Commercial Space Launch Amendments Act (CSLAA), which was signed into law by President George W. Bush on 23 December 2004. That Bill included a provision that restricted the FAA's Office of Commercial Space Transportation (AST) from enacting safety regulations except for cases linked to the "serious or fatal injury" of crew or participants, or events that "posed a high risk" of such injuries, during licensed or permitted flights [13]. According to the law, the restriction expired eight years after enactment, to allow the industry to build experience upon which future safety regulations could be based. But the industry developed far more slowly than anticipated in late 2004, with no crewed commercial suborbital flights since the final SpaceShipOne flight [13]. This led to calls for an extension to the SLAA, which is what happened in late 2013 when the US House of Representatives approved the Space Launch Liability Indemnification Extension Act (H.R. 3547) that extended for one year the commercial space transportation risk-sharing and liability regime established with passage of the CSLAA [14]. But the CSLAA paperwork doesn't allow Virgin Galactic to launch passengers into space because, by September 2014, the FAA had yet to grant Virgin Galactic a commercial operator's license. What's more, the FAA hadn't laid out safety rules like those for airlines and their aircraft, and there were no plans to do so until at least October 2015. The operator's license, which is known as a Reusable Launch Vehicle Mission Licence (see sidebar), was the final piece of paperwork Virgin Galactic needed before Paris Hilton, Leonardo di Caprio, and Russell Brand could take their seats on board SpaceShipTwo. Without the licence, only test pilots, former astronauts and military pilots could fly on SpaceShipTwo. Realizing the license was one of the company's final major milestones, Virgin Galactic submitted the paperwork in late August 2013. The office had six months to review the application, meaning Virgin Galactic could have reasonably expected approval by as early as February 2014 (see sidebar).

Committee Passes Bill Allowing FAA to Issue Permits and Licenses for Same Vehicle

In April 2014, The Senate Committee on Commerce, Science, and Transportation approved S. 2140, legislation that would fix burdensome federal laws to allow for more advancement in the commercial spaceflight industry. The legislation changed current laws that are slowing progress for the reusable launch vehicle (RLV) industry to ensure space companies can continue to test their vehicles. The Bill would allow a commercial space company to take a licensed vehicle out of commercial service and use it as an experimental platform for safety and performance improvements when needed, and allow one or more vehicles of the same design to be used for test flights under a permit, while other vehicles of the same design are used in commercial operations under a license. For Virgin Galactic, the Bill was a step in the right direction, by not only addressing key technical issues, but also updating and streamlining federal laws so they are more in line with today's commercial spaceflight operations.

§431.3 Types of Reusable Launch Vehicle Mission Licenses [15]

(a) Mission-specific license. A mission-specific license authorizing an RLV mission authorizes a licensee to launch and reenter, or otherwise land, one model or type of RLV from a launch site approved for the mission to a re-entry site or other location approved for the mission. A mission-specific license authorizing an RLV mission may authorize more than one RLV mission and identifies each flight of an RLV authorized under the license. A licensee's authorization to conduct RLV missions terminates upon completion of all activities authorized by the license or the expiration date stated in the re-entry license, whichever occurs first.

(b) Operator license. An operator license for RLV missions authorizes a licensee to launch and reenter, or otherwise land, any of a designated family of RLVs within authorized parameters, including launch sites and trajectories, transporting specified classes of payloads to any re-entry site or other location designated in the license. An operator license for RLV missions is valid for a two-year renewable term.

But February 2014 came and went and Virgin Galactic still didn't have their license. Given that regulators had been preparing for commercial human space flight since 2004, you may be forgiven for thinking that 10 years is plenty of time to process some paperwork, but these regulators were caught between a rock and hard place. On the one hand, they needed to protect the public's safety (and the safety of assorted celebrities) and, on the other, they didn't want to be perceived as being the barrier that stood in the way of the emerging commercial spaceflight industry (see sidebar). Let's face it, the last thing anyone wants is for spaceflight to be inadequately regulated and for there to be an incident that causes loss of life and the collapse of the industry due to loss of confidence – the *Titanic* scenario. In 2014, one of the challenges facing regulators drafting safety rules was the lack of test flights that had been conducted. When the FAA began creating its process for regulating the industry, it was anticipated that dozens, if not hundreds, of test flights would have occurred by 2014, providing them with plenty of data that could be used to inform the drafting of rules, but that didn't happen. And, until SpaceShipTwo actually reached its target performance with six passengers aboard, nobody knew how it would perform.

Of course, in early 2014, it wouldn't have mattered if Virgin Galactic had received the operator's license because they were still in the midst of their flight-test program. And,

How We Perceive Risk

Next time you buy a cup of coffee, take a moment to read the disclaimer printed on the side stating "the beverage you holding is very hot". Then consider the surge in the popularity in extreme sports over the last decade – a surge that includes guided expeditions up K2, the world's most dangerous mountain. It seems a contradictory approach to risk, which is compounded by the misperceptions people hold about the dangers of certain activities. For example, in the US, there are some who consider flying much riskier than driving, completely ignoring the black and white fact that, over the course of a lifetime, the average person has a much, *much* higher risk of being killed in a car wreck than in a plane crash (according to the National Safety Council, an American has about a 1-in-80 chance of dying in a car accident in their lifetime versus 1-in-4,608 for a flying accident) [16]. But how many people do you know who have a fear of driving? It's all about how we perceive risk. Now think back to the Columbia accident for a moment – be careful with that coffee! NASA officials and some members of Congress argued that NASA needed to get back to flying the Shuttle as soon as the recommendations identified by the Columbia Accident Investigation Board were implemented. The public agreed: 68% of those polled by Zogby thought the benefits of manned spaceflight outweighed the benefits [16]. But, with an accident rate of one every 62.5 missions, in which 14 American astronauts lost their lives, translating that risk to commercial aviation would have meant thousands of people would be killed each day [16]. I wonder what proportion of that 68% would be willing to fly commercial if the risk of death was 4%? So what level of risk is acceptable for those flying Virgin Galactic? 1%? 0.1%? 0.01%? And who should make that call?

while they were behind their original schedule, their enthusiasm hadn't been dampened, and with good reason given that with each test flight they were progressing closer to their target of commercial service. One piece of good news was announced at the end of May 2014 when Virgin Galactic secured the rights to plan the world's first space-tourism flights. What that meant was that Branson had secured permission from the FAA to begin setting guidelines and plans in motion before the actual launches begin. Whilst the agreement with the FAA didn't give them permission to begin launches, it was another step towards revenue flights because it meant Virgin Galactic was now authorized to operate just like a regular commercial airline, and would be included in the United States National Airspace system, meaning that all that was left to do for Virgin Galactic was to make sure SpaceShipTwo passed the testing and safety procedures required by law to enter space commercially. Of course, they also needed to find someone willing to insure the craft and those aboard it too, in case anything went wrong. After the tragedy (see Epilogue) that killed Michael Alsbury, this will take some time. This in turn may mean that the media focus on Virgin Galactic, which was way ahead of their rivals at the time of the accident, will be more focused on the other suborbital spaceship company: XCOR.

XCOR

In the years since the Virgin Galactic brand first entered the fledgling business of blasting tourists to the edge of space, commercial spaceflight – New Space – has become more and more crowded. And competitive. Virgin Galactic's closest competitor is XCOR Aerospace, which will use its Lynx (Figure 4.7) to ferry its passengers on their suborbital ride.

Since its founding in 1999, the small, Mojave, California-based company has built a solid reputation for steady and incremental progress. The company has successfully built rockets and rocket engines before, and in many ways the Lynx is seen as another step on a technology path towards competing in the space-tourism marketplace [17]. Andrew Nelson is XCOR's Chief Operating Officer and Vice President of Business Development [17]. He's responsible for leading XCOR's business team that deals with establishing commercial operations of the Lynx at operating locations around the US and abroad, regulatory compliance and export licensing, sales and marketing functions of the company, and intellectual property strategy. As well as being a recognized leader in New Space, Nelson is the originator of the Space Vehicle Wet Lease concept [17] that is at the core of XCOR's marketing strategy. The concept allows sovereign countries, corporate entities, and individuals the opportunity to experience the benefit of their own manned spaceflight program without the headaches associated with operating and maintaining a spaceship. In addition to brokering wet lease agreements, Nelson has been responsible for the successful fundraising and business development program at XCOR that has resulted in significant investment and revenue for the company [17]. He has also led the company's efforts in building the engine development and sales business at XCOR that has produced aerospace supplier clients such as United Launch Alliance:

> "We're trying to position the Lynx adventure as kind of The Right Stuff experience."
>
> *XCOR chief test pilot and former NASA astronaut Richard Searfoss*

4.7 The author seated in the right seat of the Lynx. Courtesy: Author's collection

The Lynx

The Lynx will take off from a runway, just like an aircraft, and will climb just as high as SpaceShipTwo, where the sole passenger will be able to view Earth's curvature and experience four minutes of weightlessness, although he/she won't have as much room as their Virgin Galactic counterparts because they will sit in the co-pilot's seat, which means flying around the cabin is a non-starter. The entire flight will take about 25 minutes and passengers can expect to pay US$95,000 for their flight.

With so much attention directed on the media extravaganza that is Virgin Galactic, it's sometimes been difficult to keep track of the Lynx. But, just down the road from where Scaled is building the replacement to SpaceShipTwo, XCOR's Lynx is closing in on the beginning of test flights, due to commence in July 2015. Although the sporty spaceship only has two seats, its compact size and high octane fuel mean it can launch off runways directly, without all the hassles of a mother ship. It can also fly several times per day, which should equate to cheaper flights. Like SpaceShipTwo, the Lynx is rocket-powered, but that's about all the vehicles have in common. To begin with, the diminutive Lynx, with its 190-knots take-off speed, gets off the line (it can get airborne with only 400 meters of runway) a whole lot quicker than SpaceShipTwo.

Powered by four kerosene and liquid-oxygen engines, the Lynx's propulsion system is way more efficient than SpaceShipTwo's because the Lynx's engines provide more thrust per kilogram of fuel. XCOR's liquid fuel approach should also allow fast turnaround times between flights because all crews will need to do will be to fill the tanks and fire up the engine again (SpaceShipTwo's engine must be replaced after every flight). Thanks to this quick turnaround, which is expected to take no longer than two hours, XCOR reckons they can fly four missions a day.

The first Lynx is the Mark I, a sub-suborbital prototype, designed to reach Mach 2 and a maximum altitude of 61,000 meters. That's 39,000 meters shy of space, but the altitude still allows a couple of minutes of weightlessness: the successor to the Mark I, the Mark II, will reach 100,700 meters. On the technical side, the Mark I will feature a carbon-composite skin that will be changed as the test flight program evolves. In contrast, the Mark II will feature a more rugged composite that will better withstand the heating caused by re-entry. Looking towards the horizon, there is the Mark III, which will feature a dorsal pod, from which a rocket booster will launch a satellite.

The experience of flying on board the Lynx will be a little different than flying on SpaceShipTwo. For one thing, there are the cozier confines and, for another, passengers won't be allowed to unstrap after engine cut-off. Both pilot and passenger will wear pressure suits as a safety measure in case cabin pressure is lost during the flight.

Lynx step by step

Lynx has an all-composite airframe and a TPS on the nose and leading edges to deal with the heat of re-entry. The double-delta wing area is sized for landing at moderate touch-down speeds near 90 knots. Measuring 9 meters in length with wings that span 7.5 meters, the Lynx is in the sports-car category of spacecraft [17].

The Lynx Mark I

The Lynx Mark I is a prototype vehicle that will be used to characterize and flight test the vehicle's sub-systems including life-support, propulsion, tanks, structure, aeroshell, aerodynamics, and re-entry heating. Designed to reach an altitude of 61 kilometers, the vehicle will be used to train pilots and crew for the Lynx Mark II [17].

The Lynx Mark II

The Mark II is the production version, designed to service the suborbital tourism market and other markets that make use of the vehicle's payload volume. The Mark II, which is designed to reach an altitude of 100 kilometers, uses the same propulsion and avionics systems as the Lynx Mark I, but has a lower dry weight and hence higher performance [17].

The Lynx Mark III

The Lynx Mark III is a modified version of the Lynx Mark II that features an external dorsal pod capable of carrying a payload experiment or an upper stage capable of launching a small satellite into low Earth orbit (LEO). The Mark III features upgraded landing gear, aerodynamics, core structural enhancements, and a more powerful propulsion package than the Mark II [17].

Propulsion

Four XR-5K18 rocket engines, each producing 12.9 kN (2900 lbf) vacuum thrust with kerosene and liquid-oxygen propellants, provide the power to launch the Lynx into space. The engine, which features XCOR's proprietary spark torch ignition system, has the ability to stop and then restart [17].

Payload mission capabilities

The Lynx will offer a variety of multi-mission primary and secondary payload capabilities ranging from in-cockpit experiments and externally mounted experiments to astronaut training and personal spaceflight [17]. Lynx vehicles will carry their payloads in the area to the right of the pilot or, in the case of the Mark III, in an experiment pod [17]. For the Mark II version, the primary internal payload will accommodate a maximum mass of 120 kilograms to 100 kilometers, while the Mark III vehicle will be capable of carrying up to 650 kilograms in its external dorsal mounted pod – large enough to hold a space telescope or a carrier to launch multiple nanosatellites into LEO [17].

SPACESHIPTWO VERSUS LYNX

So, which is the best way of reaching space? SpaceShipTwo or Lynx? Well, getting into space with Virgin Galactic is complicated because SpaceShipTwo has to be carried part of the way by the WhiteKnightTwo. This extra vehicle means added expense and a longer turnaround, and the design of SpaceShipTwo's engine means much of it will have to be replaced after each flight. Lynx, on the other hand, is an altogether simpler concept comparable to a fighter jet because it can reach space without a support craft. XCOR claims that its propulsion engine can be reused 5,000 times whereas Virgin Galactic has to replace two-thirds of its engine. For the Lynx, you just put gas in, run through the checklist, and off you go. While XCOR may never compete with the glitz that is Virgin Galactic, their mode of operations may prove more successful. After all, it stands to reason that, as with the airline industry, the most successful spacecraft operators will be the ones with the fastest turnarounds for the simple reason that you don't make money when the wheels are on the ground. Take Ryanair for example. They are Europe's lowest-cost airline because they worked out how to fly a fleet of aircraft for low-maintenance man hours per flight. Then again, while a fast turnaround could be crucial to profitability, the advantage of SpaceShipTwo is that its cabin is large enough to allow passengers to float around while in space – assuming their flights reach space of course and not just 80 kilometers! And those passengers won't be alone, because the cabin fits half a dozen passengers, whereas XCOR's single passenger sits in the cockpit beside the pilot. Neither will be doing much floating around, although since the passenger will be sitting next to XCOR's flight captain, they may feel a bit like a co-pilot (see Rick Searfoss's quote).

In 2014, Virgin Galactic had the edge in ticket sales, having sold more than 700, compared with less than 200 (nearly 100 are full partners who have paid the full US$95,000, while others are "futures", who have made a 50% deposit) for XCOR, which needs 75 customers a year to make US$7 million and break even. XCOR hopes to start revenue flights of its Mark I sometime in 2015, while the first suborbital flight of the Mark II could happen in 2017, by which time Virgin Galactic may have completed test flights of its replacement SpaceShipTwo. But ultimate success in a new market doesn't necessarily go to the first company to deliver the product because many lessons become obvious only as the market develops and competitors can sometimes avoid some of the potholes. Until the 2014 SpaceShipTwo disaster, Virgin Galactic had long been the odds-on favorite to begin commercial flights first, which wasn't surprising since it started before XCOR and is backed by the Virgin Group. But for XCOR, their motivation was never about beating Virgin Galactic, but in succeeding.

Notes

1. http://www.universetoday.com/20155/stowaways-revealed-on-new-horizons-spacecraft/
2. http://www.americaspace.com/?p=31681
3. http://www.wired.com/2009/11/ff_whiteknight/all/
4. http://www.newspacejournal.com/page/6/
5. http://www.space.com/19021-spaceshiptwo.html
6. http://www.scaled.com
7. http://www.flightglobal.com/news/articles/virgin-galactic-finishes-unpowered-flight-test-376475/
8. http://www.space.com/27623-virgin-galactic-spaceshiptwo-test-flight-milestones.html
9. http://www.hcigulf.com/momentous-day-for-space-travel/
10. http://www.nbcnews.com/science/science-news/spaceshiptwo-goes-supersonic-flips-its-wings-second-powered-flight-f8C11080331
11. http://www.sncorp.com
12. http://sen.com/news/spaceshiptwo-and-cygnus-make-fresh-strides-for-commercial-space
13. http://www.spacepolitics.com/2011/12/30/the-other-december-2012-countdown/
14. http://www.faa.gov/about/office_org/headquarters_offices/ast/media/FAALiabilityRiskSharing4-02.pdf
15. http://www.faa.gov/documentlibrary/media/advisory_circular/ac431.35-3.pdf
16. http://www.thespacereview.com/article/41/1
17. www.xcor.com

5

Spaceport America

Spaceport America Preview Bus Tours by Follow the Sun, Inc. features guided, exclusive access to the Spaceport site and provides you an up close and personal encounter only available during the current pre-operational phase. You'll take a journey through time, learning the history and evolution of transportation and trade in the American continent from the Spanish and Native American pioneers of the past to the space pioneers of the future. The approximately 3-hour experience gives you an in-depth look at the scenic beauty and rugged ranges of New Mexico's Old West, as well as man's efforts to survive in the high desert. No doubt your visit to the world's first purpose-built commercial spaceport will be a memorable experience!

Tours are only available on Friday, Saturday and Sunday. Tour length is approximately 3.5 hours. Reservations are required, with minimum of three guests (or equivalent) per tour. Step-on guide service is also available. Please call for details [1].

Pick up location(s):
2201 F.G. Amin St, Truth or Consequences, NM
710 Hwy 195, Elephant Butte, NM
Contact Follow the Sun Inc. at +1-575-740-6894
Toll Free: +1-866-428-4SUN(786)

The above invitation is posted on Spaceport America's website [1]. Also posted is the following note: "*We strongly recommend that you do not drive out to Spaceport America on your own! Due to its remote location there are no service stations, restrooms or other amenities along the way, and cell-phone service is limited at best*" [2]. That's because Spaceport America is in the middle of nowhere. But, if you do want to drive there, be prepared to bounce over kilometers of rough road that threads its way through scrubland lined with purple sage and ramshackle ranch houses. Stop along the route, switch off the ignition, and all you'll hear is silence. Gaze into the sky and you may see the occasional wisp of cirrus set against the crystal blue sky. In the distance you may catch sight of the

E. Seedhouse, *Virgin Galactic: The First Ten Years*, Springer Praxis Books,
DOI 10.1007/978-3-319-09262-1_5

5.1 Las Cruces, New Mexico. Credit: David Herrera

odd buffalo. This is New Mexico (Figure 5.1), home of Spaceport America. It may be remote, but it's an apt location for the business of suborbital spaceflight. After all, it was in this state that America launched its first suborbital rockets at the White Sands Proving Grounds. The rockets in question were Wernher von Braun's captured V-2's (Figure 5.2) which, between 1946 and 1950, flew to altitudes as high as 160 kilometers. And the V-2 isn't the only space legacy New Mexico has to offer. Not if you believe the Roswell event.

WHAT IS A SPACEPORT?

A spaceport caters to the various types of space adventurer. These include the wealthy who can afford to buy a ticket, the commercial astronauts employed to conduct research, and the not-so-rich who hope to be able to afford the experience when prices are reduced. When these space adventurers and adventurers-in-waiting arrive, they will want to feel relaxed and welcome, so an environment similar to a cruise ship terminal will be needed. This is what Spaceport America (Table 5.1) offers [3].

Spaceports also offer training facilities, which include centrifuges, hypobaric chambers, spatial disorientation trainers, classrooms, and dunker training equipment. This training is stressful, so medical facilities should be co-located to ensure the health of these future spacefarers. This will be particularly necessary in the early stages of flight operations because the wealthy individuals who can afford these flights tend to be older and less healthy than most. There will also need to be emergency facilities in case of an accident.

5.2 V-2 rocket. Courtesy: German Federal Archives

To cater for Virgin Galactic's astronauts' friends and family, hotels will need to be built near the spaceports. Ideally, entertainment facilities (an IMAX theater perhaps?) should be co-located, so family and friends can occupy themselves during the training. If these facilities are well designed they could be a destination in themselves: a Space Camp/Academy for kids perhaps?

And finally, the public will need access to witness the launches. This should be an area where the public can wander around while launch preparation is taking place, and where they can watch events unfold. And, in case there are delays, there should be an abundance of restaurant facilities. Oh, and souvenir shops!

In addition to hosting Earth's most popular alien landing, New Mexico, a state about half the size of France but with a population of less than two million, is now at the cutting edge of the space tourism business thanks to a building that has the plush look of a Mercedes showroom combined with the elegance of a Four Seasons lobby. Designed by Foster and Partners, Spaceport America (Figure 5.3) is a sinuously-shaped building that was designed to make a minimal impact on the environment [4]. It was built using local materials and regional construction techniques and is sustainable and sensitive to its surroundings. Inside the low-lying form, there is a balance between privacy and accessibility. For example, the control room is visible, but has limited access, while the astronauts' areas and visitor spaces are integrated with the rest of the building.

Table 5.1 Spaceport Features.[1]

Class	*Feature Description*
Local Infrastructure	Runway
	Railhead
	Road Access
	Hotels, restaurants and shops
	Qualified local workforce
	Proximity to University
Site Facilities	Pads for sounding rockets
	Pads for small, medium and large sRLVs
	Horizontal takeoff/landing capability
	Fuel Handling/Solid
	Fuel Handling/Liquid
	Fuel Handling/Hybrid
	Chemical analysis facilities
	Ordnance facilities
	Vehicle Integration/Checkout
	Payload processing-hazmats
	Processing - dynamic balance.
	Spacecraft storage facilities
	Engineering/Mission Management Offices
	Range Radars, cameras
	Telemetry data retrieval
	Payload processing-vibration
	Engine test stands
	Materials testing facilities
	Hazmat training
	On-site research labs
	Broadband access
	Emergency Response teams
	Downrange payload retrieval.
Space training	Medical facilities
	Training facilities
	Simulators
	Space Academy
	Family facilities/residential
	Family facilities/entertainment
Financial/Admin	Financial Incentives/trade zones
	International facilities/customs
	Security for military users
	High Tech company incubators
	Simplified Admin (safety, environment)

[1]Adapted from www.spaceportassociates.com [3].

5.3 Spaceport America under construction. Credit: Jeff Foust

Skylights allow for plenty of natural light to enter the building while the terminal's glazed façade provides a great view of the runway. Other features of the spaceport include an exhibition space that documents the history of Sierra County alongside a history of space exploration, a gallery level that houses the spacecraft and the simulation room.

Spaceport America at a glance [1]

Location: Sierra County, New Mexico, USA
Client: New Mexico Spaceport Authority (NMSA)
Tenant: Virgin Galactic
Architectural Lead Design: Foster + Partners
Architecture: SMPC Architects
Environmental Design: PHA Consult
Site Area: 27,880m^2 including apron
Gross Area: 10,219m^2
No. of floors: 3
Elevation: 1,401 meters
Coordinates: 32°59′25″N 106°58′11″W
Runways: 16/34. 3,048 meters (concrete)
Website: www.spaceportamerica.com

Built at a cost of more than $200 million, Spaceport America was designed for one purpose only: to process space travellers. And, in anticipation of revenue flights, there are signs of growing confidence in the project as evidenced by the announcement in late 2013 that leading US broadcaster NBC was launching a TV series called *Space Race* that will show contestants competing for a prized flight on board SpaceShipTwo. Produced by Mark Burnett, the mastermind of *Survivor* and other reality-TV shows, *Space Race* will air during prime time on NBC and NBC's Peacock Productions will chronicle the project across a spectrum of NBC/Universal brands, including NBCNews.com, NBC, CNBC, MSNBC, Syfy, and the even the Weather Channel [5]. NBC is also set to air a prime-time special on the night before Branson's launch followed by a three-hour live event on TODAY, hosted by Matt Lauer and Savannah Guthrie. In addition to reality TV shows, tourist buses have been bringing day-trippers to Spaceport America since 2011. For $59, visitors, who come from as far afield as Russia, Norway, and Japan, get to see for themselves how close to operational the site is. With so much activity there is a feeling that flights aren't far away, which is why Virgin Galactic has reached out to local entrepreneurs to provide a range of services, including accommodation, catering and laundry, couriers, interpreters, translators and even suppliers of gourmet coffee. That's probably a good thing given the sort of passenger Virgin Galactic will be flying. Let's face it, Ashton Kutcher and Paris Hilton probably won't be satisfied with a Holiday Inn: while there are plenty of hotels in the area there is little in the luxury market, except for CNN founder Ted Turner's Sierra Grande Lodge and Spa. But with Truth or Consequences primed to become the epicenter for space tourism, developers are scoping out the area, with plans for a visitor center and new hotels. Already $14.5 million has been earmarked to build a new southern access road to take traffic directly to the spaceport from locations like Las Cruces and El Paso, Texas. And Spaceport America, which already employs 1300 people across New Mexico, plans to add another 1,800 jobs by 2018. Why so many? Well, Virgin has a shopping list of products and service requirements: everything from facility maintenance services to food service equipment and from shuttle bus services to staff uniforms. And to meet those requirements the company is encouraging local entrepreneurs interested in starting a new business or expanding into a new business line to engage Virgin Galactic on these opportunities, which is good news for Truth or Consequences, which has had a hard time economically of late.

If you're interested in visiting, Spaceport America is located west of the U.S. Army White Sands Missile Range in Sierra County, in New Mexico, or about 50 kilometers southeast of Truth or Consequences [1]. The spaceport is easily accessible by county roads from Interstate-2 and it has been operational for a while; several flight tests have taken place since 2006. Overseeing the spaceport's development is the NMSA, the state agency that built the structure using funding provided by the State of New Mexico [1]. While the spaceport may look like a futuristic airport, it's not the sort of place you can land your Citation jet because it is designated to operate as a prior permission required airport, which means there are no services for general or commercial aviation [1]. Another downside is that there are no commercial airline flights to Spaceport America, so when you're planning your rocket ride you will have to fly to El Paso International Airport (ELP) or Albuquerque International Sunport (ABQ).

OTHER SPACEPORTS

While the first batch of Virgin's passengers will take off from New Mexico, future space tourists will have the option of jetting off from other spaceports. We'll discuss two of the most likely candidates here.

Abu Dhabi

Abu Dhabi isn't exactly a beacon for transport innovation, which makes it an unusual choice for locating a spaceport. It is one of the few countries in the world that doesn't operate a passenger rail service and the emirate boasts no metro routes, although it does have a bus service, which was launched five years ago. But if Virgin Galactic has its way, the capital of the United Arab Emirates will soon be at the forefront of travel when it opens a spaceport. The rumors of a spaceport in Abu Dhabi have been gathering momentum since 2009 when Aabar Investments, a government-owned investment vehicle, shelled out $280 million for a 31.8% stake in Virgin Galactic. Although the vision of a space hub in Abu Dhabi is part of Virgin's vision, the project will need export approvals (sidebar) from the American government to set up a new site outside the United States. Assuming those are granted, it is possible that Virgin Galactic passengers could be launching from Abu Dhabi sometime in 2017.

Your spacecraft is a weapon![1]

An example of this regulatory approval is placing spacecraft on the United States Munitions List (USML). For years the US commercial space industry fought to remove export restrictions placed on it during the 1990s. In 2013 change was on the horizon but it was a case of one step forward and two steps back because man-rated suborbital spacecraft were added to the list! This is a problem because any item on the USML requires an export license from the US State Department. Even worse, putting suborbital spacecraft on the USML places them under the restrictive umbrella of the International Traffic in Arms Regulations (ITAR). Why is this being done? Well, the 1990s restrictions were intended to block the flow of space technologies to nations such as China and to maintain US space competitiveness. The upshot of this was that the restrictions harmed rather than strengthened the US commercial satellite industry; US satellite makers were denied access to foreign markets and lower-cost launchers for their products. The result? A significant US share of the global commercial satellite market was lost to China! And you wonder why politicians are unpopular! But, in December 2012, after years of lobbying by the US satellite industry, a provision in the 2013 defense authorization bill passed by the US Congress struck out the 90s language that placed satellites and related items on the USML.

[1] Adapted from 'Suborbital' by Erik Seedhouse. Published by Springer-Praxis, 2013.

(continued)

(continued)

On May 24th 2013, the Obama administration published its proposed new USML Category XV, which added man-rated suborbital spacecraft, an addition that would make it difficult for New Space firms to sell and operate their vehicles outside the US. Not surprisingly, New Space companies, aerospace industry groups and advocates viewed this as a backwards step because the draft USML Category XV could harm the US suborbital space industry the same way the US commercial satellite industry was harmed in the 2000's.

Spaceport Sweden

www.spaceportsweden.com, Email: info@spaceportsweden.com
Twitter: @SpaceportSweden, Phone: +46 (0) 980 80 880.
Mon-Fri 09:00-17:00 hrs CET.

Hot weather not your style? No problem. Very soon, Virgin Galactic passengers may be able to take a flight to Stockholm and head north to Kiruna, home of the *Spaceport at the Top of the World*. Given its location Kiruna may seem an unlikely place to build Europe's first commercial spaceport. But it's not just the town's location that seem to make it an improbable place to attract the wealthy jet-set because the town boasts an awful lot of disadvantages: an iron mine that is expanding, vast swaths of forests, no sunlight for days and weeks on end, and temperatures that for several months of the year barely reach -5°C - great for polar bears, but not so good for tourists (the average high in July is just 7°C incidentally). Yet, despite this, in 2007, the Swedish government announced an "agreement of understanding" with Richard Branson's Virgin Galactic to make Kiruna the company's first launch site outside the United States [6]. If all goes to plan, suborbital space tourists may one day be able to fly through the Aurora Borealis (Figure 5.4).

While Kiruna may be new to many tourists, it isn't completely undiscovered. The town has been home to aerospace activities since a space research center - Esrange - was built there in 1964. Esrange, which includes a 5,600 km^2 range for launching sounding rockets (Figure 5.5), may attract space enthusiasts, but most visitors will be more interested in the Arctic adventure activities and staying in a hotel made of ice (Figure 5.6).

Before the Virgin Galactic's interest, Kiruna wasn't the place you came for anything except reindeer watching. Except for iron ore, the town had few natural resources. But Kiruna has a talent for marketing, as evidenced by their IceHotel, a hotel with rooms built out of snow and ice (*snice*). Building an ice hotel and charging upwards of $500 a

5.4 Aurora borealis. Courtesy: NASA

night sounds seem like an outrageous business plan, but the plan succeeded, so it's not surprising that Kiruna is supporting Virgin Galactic's equally bold plans, because the arrival of suborbital astronauts with money to spend could mean another tourist boom. After all, a space tourist who can afford a $250,000 a ticket can probably afford to bring their nearest and dearest along to share the experience. That adds up to lots of hotel rooms. Which is why the IceHotel's marketing department is already working with Spaceport Sweden to come up with a plan to take care of Virgin Galactic's customers.

So that's tourism taken care of. But what about sending rockets into space? Well, thanks to Esrange, which stages up to ten launches per year, most of the necessary infrastructure already exists. If Virgin Galactic begins operating above the Arctic Circle, the SpaceShipTwo's will take off from Kiruna airport. Anticipating this reality, Spaceport Sweden is creating the Kiruna Science Center at the airport and also plans to develop spaceflight training infrastructure for Virgin Galactic's astronauts. Part of that training will include parabolic flights that simulate weightlessness and another part will be G-training, which will take place in Linköping, where British firm QinetiQ have built a purpose-built centrifuge.

5.5 Final launch of Skylark sounding rocket from Esrange, Sweden, on 2 May 2005. Credit: Gealen Marsden

5.6 The Ice Hotel in Sweden. Credit: Stephan Herz

Notes

1. www.spaceportamerica.com
2. http://www.sierracountynewmexico.info/attractions/visit-spaceport-america/
3. http://spaceportamerica.com/wp-content/uploads/2012/07/SPACEPORT-AMERICA-SUSTAINABLE-DESIGN-AND-CONSTRUCTION-IN-THE-DESERT_Rev-3.pdf
4. http://www.fosterandpartners.com/projects/spaceport-america/
5. http://www.nbcnews.com/news/other/nbc-air-virgin-galactic-founder-richard-bransons-trek-space-f8C11554124
6. http://www.airspacemag.com/space/spaceport-at-the-top-of-the-world-27475249/?no-ist

6

Medical Screening and Training for Package-Tour Astronauts

"A human being should be able to change a diaper, plan an invasion, butcher a hog, con a ship, design a building, write a sonnet, balance accounts, build a wall, set a bone, comfort the dying, take orders, give orders, cooperate, act alone, solve equations, analyze a new problem, pitch manure, program a computer, cook a tasty meal, fight efficiently, die gallantly. Specialization is for insects."

Robert A. Heinlein, Time Enough for Love, 1973

6.1 Courtesy: NASA

E. Seedhouse, *Virgin Galactic: The First Ten Years*, Springer Praxis Books,
DOI 10.1007/978-3-319-09262-1_6

An astronaut needs to be a Jack of all trades. They need to be able to operate a robotic arm from inside the International Space Station (ISS), conduct all sorts of experiments, fix balky toilets, and promote the space program to kids at schools and colleges. Astronauts are scientists, explorers, teachers, preachers, and plumbers all rolled into one. They are explorers with a mission, even though nowadays these missions seem to be rather few and very far between. Astronauts also have to be in great shape and have strong bones and muscles, reinforced by plenty of cardiovascular and weight-training exercise. In short, these orbital workers have to love multitasking, which is why it routinely takes those hell-bent on being an astronaut decades to accumulate all the qualifications necessary just to be able to submit an application. And, even if you check all the boxes, there is no guarantee you'll fly. That's because for as long as there have been astronauts, the supply of candidates has far exceeded demand, which means government agencies pick only the very cream of the crop. In short, only those in the very best of health and with the very best skill-sets even have a prayer of being selected. With such strict requirements, the system ensures that astronauts (Figure 6.2) are in the highest percentiles of every performance metric among the general population.

But, with the emergence of the commercial human spaceflight industry, the process of medically screening and training astronauts is a very different business. That's because Virgin Galactic isn't interested in choosing just the elite – except when it comes to its pilots obviously! For Branson's business plan to succeed, he needs to fly as many people who can afford to buy a ticket as possible. This means accepting passengers whose health and fitness levels may be far below the upper percentiles typical of a government selected astronaut and who may also have a variety of ailments. To 'select-in' as many passengers as possible, Virgin Galactic need to develop a selection procedure that screens out only

6.2 Government-employed astronauts train for years before a mission. Courtesy: ESA those who would be at risk during a suborbital flight. It also needs to develop a training regimen for passengers that ensures they are prepared for the flight without bogging them down with months of preparation.

MEDICAL SCREENING

One of the problems faced by Virgin Galactic when deciding which medical requirements should be implemented was the lack of a large body of medical data they could refer to that explained how people reacted to acceleration, weightlessness, and the other myriad challenges of spaceflight [2]. That's because fewer than 600 people have flown in space. Ever. And those fortunate few were in peak health [2]. Space medical doctors simply don't know all the risks of flying in space – especially when it comes to those with medical problems. In the history of manned spaceflight, no space agency has ever faced the question of what to do with an astronaut applicant who has three stents, a history of bypass surgery, and Type II diabetes, for the simple reason that those medical conditions are immediate disqualifiers [2]. But, thanks to Virgin Galactic, data are slowly emerging about how a broader slice of the public can tolerate spaceflight stresses. In 2009, Virgin Galactic took a number of its early customers, or Founders, to the National Aerospace Training and Research (NASTAR) Center outside Philadelphia for centrifuge training (Figure 6.3) [2]. There, the Founders were put through centrifuge tests that simulated the accelerations they will feel during launch and re-entry of a SpaceShipTwo flight. Before the beginning of the program,

6.3 André Kuipers inside a centrifuge. Courtesy: ESA

Virgin Galactic had no idea what to expect, but crossed their fingers that 80% of those they had sold tickets to would be successful [2]. Fortunately, the results exceeded Virgin's expectations. Of the 70 people tested at NASTAR, 93% passed [2]. Of the five who didn't, two had their training delayed and one their training curtailed, and only two were unable to continue. The group ranged in age from 22 to 88, and had various medical issues, including one passenger who had had heart bypass surgery in the last five years [2].

Virgin Galactic's openness about sharing the health issues of their spaceflight passengers is invaluable because it helps the industry gain experience and evaluate screening criteria, but what does the Federal Aviation Administration (FAA) have to say about it? Surprisingly little actually. In the regulations, the FAA notes that spaceflight participants: (1) be informed of risk; (2) execute a waiver of claims against the US government; (3) receive training on how to respond to emergency situations; and (4) not carry any weapons on board! [3] In short, the FAA has opted to leave the medical screening procedures in the hands of commercial spaceflight operators, although there are a number of peer-reviewed articles that offer more precise guidelines to those entrusted with assessing the medical fitness of aspiring space tourists. We'll get to the finer points shortly but, before we do, it's worthwhile taking a look at the risks Virgin Galactic passengers will face when they fly. We'll start with the mission profile.

MISSION PROFILE

SpaceShipTwo will have two pilots and up to six spaceflight participants. The cabin atmosphere will be pressurized to 2,440 meters' altitude, or lower, with re-circulated atmospheric air comprising 21% oxygen [4]. The flight begins with a horizontal take-off underneath the carrier aircraft WhiteKnightTwo with a 45–60-minute flight to 15,000 meters where SpaceShipTwo will be launched. The boost phase will be 70 seconds long, during which passengers will be subjected to a maximum of 3.8 Gs. Mach 1 will be reached at eight seconds, Mach 3 at 30 seconds, and maximum speed will be 4,180 kilometers per hour [4]. The 0 *g* coast phase will last about four to five minutes and the vehicle will reach a maximum altitude of 110 kilometers [4]. During the coast phase, spaceflight participants (but not the flight crew) will be able to float around in the 3.7 × 2.3 meter cabin. During the deceleration phase, passengers (now newly minted Virgin Galactic astronauts) will be subjected to a peak of 6 *g*, but their seats will recline (automatically) to convert most of the forces to +Gx (the flight crew will experience most of the deceleration forces in the +Gz-axis). At 24,400 meters, the glide phase will begin with a return to an unpowered horizontal runway landing that will occur after a glide of 25 minutes for a total flight time of about 150 minutes [4].

MEDICAL RISKS

If you're a Virgin Galactic ticket-holder or a prospective customer, you're probably aware that space is an environment far more hazardous than what you experience when flying on a commercial airline (see Appendix II). But, while most of the medical requirements for suborbital spaceflight are not as demanding as those for orbital spaceflight, pre-existing medical conditions may be a problem during a suborbital ride.

Decompression

Let's start by assessing a couple of the risks common to the airline passenger and spaceflight participant: cabin pressure and decompression. We know that air pressure decreases with increasing altitude and is close to zero in space. You may also know that when it comes to designing spacecraft (and aircraft) cabins, the lower the cabin pressure the better, because this reduces cabin weight. Of course, passengers need some air pressure so they can breathe, so a compromise is necessary. Until 1957, commercial airline cabins were required to be pressurized to a maximum equivalent altitude of 3,050 meters (523 mmHg), after which they were required to maintain a maximum altitude of 2,440 meters (564 mmHg) [2]. The latest aircraft have cabins pressurized to about 1,525 meters because research showed that the 2,440-meter limit might have an adverse effect on some passengers. For example, one study found that a substantial proportion of healthy passengers aged 65 years or more would have inadequate arterial oxygen levels while breathing air at that altitude [2]. So, if you're a Virgin Galactic passenger aged 65 or older with breathing problems, SpaceShipTwo's 2,440-meter pressure altitude may be a challenge.

Another problem facing Virgin Galactic is protecting their precious cargo in the event of a rapid decompression. If such an event was to occur in space, cabin pressure would be lost quickly. Very quickly. Decompression to about 7,500 meters leaves a healthy young person conscious for five to six minutes, but time of useful consciousness (TUC; see sidebar) decreases to just 15 seconds at 13,700 meters [2]. Death follows shortly thereafter. To deal with a rapid decompression event, passengers can either breathe supplemental oxygen or the cabin can be pressurized. Or both. The problem with either of these solutions is *weight* because an oxygen subsystem must be integrated into the spacecraft cabin. Also, breathing pure oxygen is limited to certain altitudes. At 10,000 meters, breathing pure oxygen is about the same as breathing air at sea level. Above 12,000 meters, 100% oxygen must be under positive pressure to maintain the equivalent altitude of 3,050 meters and, at altitudes above 15,000 meters, a passenger requires a pressurized suit to be safe [5]. At 16,700 meters, atmospheric pressure is so low that water vapor in the body appears to boil, causing the skin to inflate like a balloon, and at 19,200 meters (the Armstrong Line[1]), blood at normal body temperature (37°C) appears to boil [5]. Any vehicle that ventures beyond the Armstrong Line will operate at such high altitudes that there is also a risk of a rapid or explosive decompression, either of which could result in hypoxia and/or death due to *hypoxia* or *ebullism* [4]. In case you're wondering just how bad such an event might be, here's what the *USAF*

[1] The Armstrong Line (19,200 m) has nothing to do with Neil Armstrong. The "line" is named after Harry George Armstrong, who founded the US Air Force's Department of Space Medicine, and it represents the altitude that produces an atmospheric pressure so low that water boils at normal body temperature. In fact, if you were exposed to an altitude above the line, your exposed bodily liquids would boil away and you'd be dead within a minute or two.

Flight Surgeon's Guide has to say about some of the effects due to mechanical expansion of gases during rapid decompression [6].

> "Gastrointestinal tract during rapid decompression
>
> One of the potential dangers during a rapid decompression is the expansion of gases within body cavities. The abdominal distress during rapid decompression is usually no more severe than that which might occur during slower decompression. Nevertheless, abdominal distension, when it does occur, may have several important effects. The diaphragm is displaced upward by the expansion of trapped gas in the stomach, which can retard respiratory movements. Distension of these abdominal organs may also stimulate the abdominal branches of the vagus nerve, resulting in cardiovascular depression, and if severe enough, cause a reduction in blood pressure, unconsciousness, and shock."

Sounds painful doesn't it? Well, rapid decompression is probably more survivable than explosive decompression: here's what Dr. Tamarack R. Czarnik, a specialist in aerospace medicine, has to say about the medical effects of an explosive decompression:

> "Damage to the lungs in rapid or explosive decompression occurs primarily due to pulmonary overpressure, the tremendous pressure differential inside versus outside the lungs. 80 mm Hg is enough to cause pulmonary tears and alveolar rupture; pulmonary hemorrhaging, ranging from petechiae to free blood is also seen. Emphysematous changes are seen especially in the upper lungs, while atelectasis and edema predominate in the lower lungs. When we get to the patient, the lungs will be a bloody, ruptured mess.
>
> Though these are the most life-threatening changes seen in ebullism, subcutaneous swelling is also seen, due to creation of water vapor under the skin. This can rapidly distend the body to twice its normal volume. Our patient will look no better than he feels, though this means little in terms of survival" [7].

Average Effective Performance Time for Aircrew without Supplemental Oxygen [8]*

4,570–5,490 meters	30 minutes or more
6,700 meters	5–10 minutes
7,620 meters	3–5 minutes
8,530 meters	2.5–2 minutes
9,140 meters	1–2 minutes
10,670 meters	30–60 seconds
12,190 meters	15–20 seconds
13,700 meters	9–15 seconds

* Factors that determine EPT:

- Altitude – EPT decreases at high altitudes
- Rate of ascent – the faster the rate, the shorter the EPT
- Physical activity – exercise decreases EPT considerably
- Day-to-day factors – physical fitness and other factors (smoking, health, stress) may affect ability to tolerate hypoxia

So how will Virgin Galactic passengers protect themselves from a decompression event? Well, one way will be to wear a pressure suit. But one of the drawbacks of wearing a pressure suit is that it requires extra training and extra time because of the need to complete an oxygen pre-breathe to reduce the risk of decompression sickness (DCS). DCS is caused by dissolved gases coming out of solution in the body. These gases form bubbles inside the body during depressurization. And because these bubbles can form anywhere in the body, DCS can cause joint pain, paralysis, and death. But, while a pre-breathe reduces the incidence of DCS, it is logistically complicated and expensive, and there is still that risk of DCS. Another problem while wearing a pressure suit is restricted mobility, which puts a dampener on how much fun Virgin Galactic passengers can have during their very precious three to four minutes of weightlessness. It's the reason why Virgin Galactic's passengers won't be wearing a pressure suit. Instead, they will be wearing personalized flight suits, soft-soled shoes, and a soft flight helmet that contains headphones and a microphone. The helmet will be able to have an oxygen mask attached. Just in case. But what happens if one of those windows fails? Well, first of all, SpaceShipTwo is built of composites, which have the advantage of being able to be made stronger by adding a few layers around high-stress areas like windows (this is difficult with metals because fasteners or adhesives are needed to strengthen the window). Another factor in SpaceShipTwo's favor is usage. Commercial aircraft are high-cycle vehicles that undergo tens of thousands of pressurization and depressurization cycles during their many, many years of operation, whereas SpaceShipTwo is a very low-cycle vehicle that will see a fraction of that flying: because the number of pressurization cycles is a lot lower, there will be much less stress on those windows. And, while we're on the subject of usage, SpaceShipTwo's style of flying is completely different from that of an airliner because it will fly only under very predictable conditions. Temperature differentials won't be a problem either because, as any aerospace engineer will tell you, periods of elevated temperatures gradually degrade many materials, but composites have a lot lower thermal expansion than aluminum, which reduces issues with expansion in the fuselage.

But what if? Let's face it, even at 12,000 meters in a 787, a loss of cabin pressure has a safe alternative – the drop-down silly-cups and pure oxygen. What can you do at zero PSI? If you've flown commercial, you're no doubt familiar with the safety briefing that explains how the oxygen mask will drop in front of you in the event of pressure loss. The supply of oxygen is good for about 8–10 minutes because commercial aircraft are only a short time away from survivable atmospheric air pressure. It's a different story if you happen to be flying on SpaceShipTwo though, because a suborbital spacecraft is committed to the ballistic part of its trajectory from the final phase of the rocket motor burn until it gets back down to breathable (survivable) air. This could take several minutes in the event of a depressurization event during the burn and, depending on when the depressurization occurred, this period of time would be way beyond the ability of a passenger to survive without a pressure suit. But the shirt-sleeve environment[2] has always been part of Virgin Galactic's

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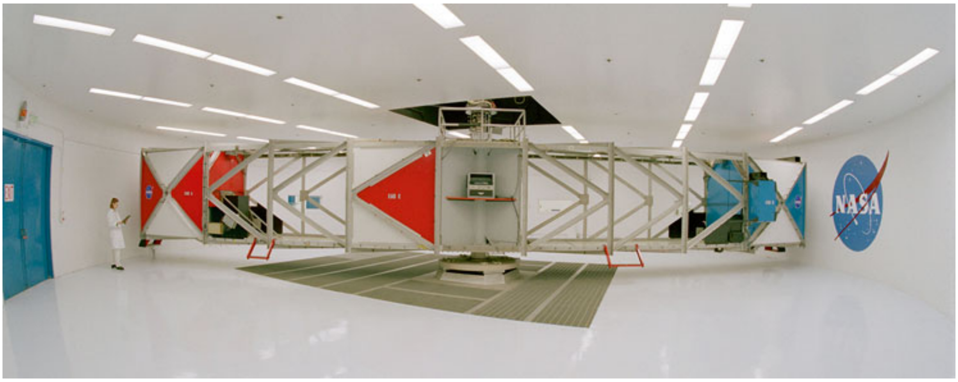
2 Incidentally, the Feds decided *not* to endorse the use of pressure suits on suborbital vehicles because they consider pressure suits are too complex to integrate into a vehicle, and the risks associated with pressure loss can be engineered out of a design. Some have argued that the test pilots who flew SpaceShipOne took a calculated risk flying without a suit, but that doesn't make the same risk acceptable to paying passengers. It's a strange ruling because the FAA acknowledges that the most dangerous phases of spaceflight are during ascent, entry, and landing, and a suborbital flight profile is exposed to these phases for almost the entire duration of the trip!



6.4 The Wyle centrifuge. Courtesy: NASA

baseline design, so what will the crew do if SpaceShipTwo has a serious structural issue in space? Well, residual compressed air will flood the cabin with oxygen until the vehicle descends to a denser atmosphere. And you, the passenger, will dig out your personal little scuba bottle – they're good for a few minutes. Hopefully that's all you'll need [9].

Acceleration

If you watched the SpaceShipOne flights, you don't need to be a flight surgeon to know these flights will expose you to an environment much riskier than what you experience when flying on Delta or United. So, if you happen to have any pre-existing medical conditions, it's probably worth seeing a physician just to make sure a suborbital flight won't make things worse. For the general population, most of the medical issues related to suborbital spaceflight are fairly straightforward because suborbital flyers don't have to worry about the more serious medical problems associated with orbital flight such as bone loss and radiation exposure. But there is still that G problem,[3] especially the rapid change from acceleration launch forces to weightlessness followed quickly by re-entry deceleration [4]. Even a relatively benign flight profile like SpaceShipTwo's is provocative enough to make even the most ardent rollercoaster fan a little queasy. And, medically, these transitions could lead to cardiovascular and neurovestibular effects that are currently undefined because there haven't been many people who have flown suborbital flights. Although you can test your G-tolerance in a centrifuge (Figure 6.4) and your zero-G-tolerance in parabolic flight, it's impossible to simulate the forces of the suborbital flight environment except for the actual experience of suborbital spaceflight.

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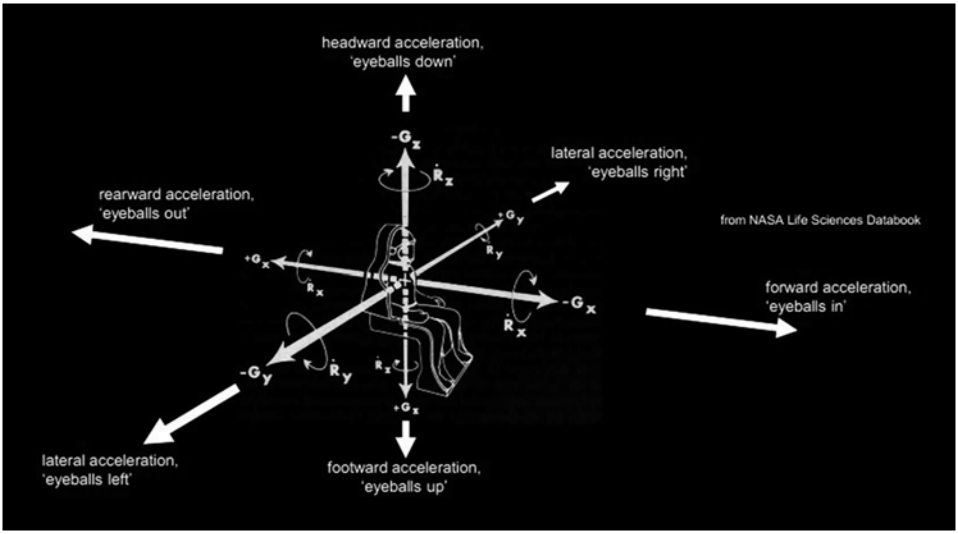
[3] A *G* is the acceleration of an object normalized by the acceleration caused by gravity. Without considering air resistance, gravitational pull causes free-falling objects to change their speeds by a constant of 9.81 m/sec^2 [10]. Dividing acceleration (change of velocity divided by time) by this constant and you get the acceleration in Gs.



6.5 The different ways you feel gravity. Courtesy: NASA

From the flight surgeon's perspective, some of the most troubling issues of a suborbital flight profile are encountered during launch *acceleration* and re-entry *deceleration*, especially when acceleration exposure is in the head-to-foot ("eyeballs down" or +Gz) direction (Figure 6.5). That's because Gz acceleration can cause a number of neurovestibular, cardiovascular, *and* musculoskeletal problems. Exposure to Gz can also affect pulmonary function proportionally to its applied force magnitude – for example, at the lower end of the G-scale, say 2–3 Gs, most people will experience difficulty breathing, while at the other end of the G-load spectrum, say 5–6 Gs, there is a risk of airway closure.

Obviously, Virgin Galactic wants to ensure their passengers' experience is as safe as it can be, so they tried to limit the launch and re-entry acceleration forces by ensuring most of the acceleration is in the +Gx ("eyeballs in") direction (see sidebar). That's because people are more tolerant to +Gx acceleration and, with the heart and brain located at approximately the same level within the acceleration field, there is less risk for *gravity-induced loss of consciousness* (G-LOC) or *almost loss of consciousness* (A-LOC) [4]. Imagine spending $250,000 on a flight of a lifetime only to be rendered unconscious because you G-LOC'ed and are not able to remember the best part of your flight! Acceleration stress is the issue that most worries flight surgeons because it is *dysrhythmogenic*, which means the heart's rate, rhythm, *and* conduction can be upset. In fact, high G-forces, and/or particularly long exposures to acceleration, could potentially increase the frequency of a heart problem known as *dysrhythmia*, which is why spaceflight acceleration has, for the most part, been in the +Gx-axis.

"G": A Primer

When exposed to an increase in +Gz (head-to-toe acceleration), the pressure required to perfuse the eyes and brain increases and blood begins to pool in the large blood vessels of the legs [10]. As the G-levels ramp up, greater perfusion pressure is needed and the volume of blood returning to the heart decreases. Making matters worse, the eyes and brain receive less and less oxygenated blood. And, if the duration of +Gz is long enough, the eyes, which require a certain amount of perfusion pressure to function, can't perform normally. This is why a pilot under G may suffer loss of peripheral vision, which can proceed to total loss of vision if the acceleration is high enough and long enough [10]. Then, if the acceleration level and duration continue to increase, pilots will lose consciousness – G-LOC – and only regain consciousness once the acceleration level is below the pilot's perfusion pressure threshold. Don't worry though – I've seen dozens of pilots G-LOC without any lasting effects, except for some slight neck pain.

To better understand why G-LOC poses such a threat to SpaceShipTwo passenger safety, it's helpful to understand what happens to the body when subjected to positive G. The most significant effect of +Gz on the brain and the eyes is a reduction in blood pressure and blood flow. The eyes react first. As G increases and blood pressure drops, passengers may experience grayout (loss of color and clarity), tunneling of vision, and blackout – some of Virgin Galactic's passengers will have experienced this during their G-runs in the centrifuge. If Gs continue to increase beyond blackout, the passenger will G-LOC because, when the brain loses its blood supply and exceeds its oxygen reserve, it abruptly fails [11]. Once it fails, it stays "turned off" for a variable length of time, even after blood flow is restored. Consciousness can be maintained when the G-onset rate is low enough that visual symptoms are recognized (say 1 G per second) but, when G-onset rates are high (5 or 6 Gs per second) and the peak G-level sustained is high, G-LOC can occur without any visual warning signs [11]. G-LOC is a serious problem because no one is immune.

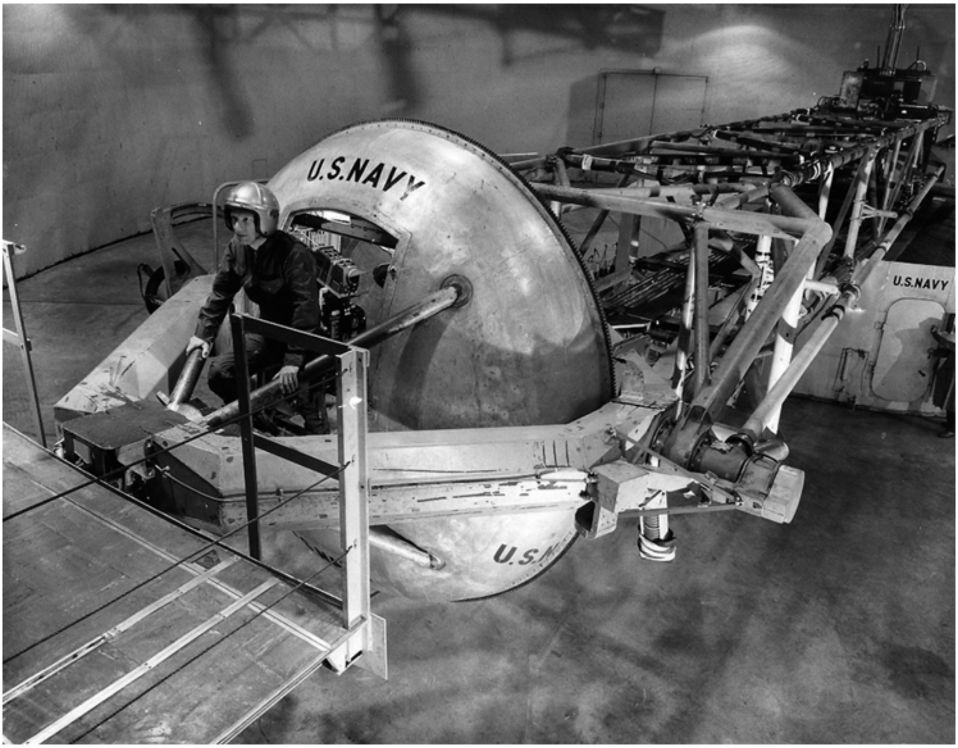
Once a passenger G-LOCs, their brain enters a state called *absolute incapacitation*. This can last for up to 15 seconds, although the range is between 5 and 30 seconds). Absolute incapacitation occurs even if the G is unloaded, which means the passenger will be unaware of their environment and unable to respond to any outside stimuli during this period. Eventually the brain's blood supply returns and the brain begins to "wake up" before entering a state of *relative incapacitation* which lasts another 12–15 seconds. The absolute *and* relative incapacitation states combined are known as the *total incapacitation time* [11]. At the end of this, the passenger will recognize where they are and be able to respond to the environment. The next phase of G-LOC recovery is the return of cognitive processing skills, but this may require several minutes before a return to full function is realized [11]. During this period, functional motor skills and situational awareness may be compromised. This is not a good scenario for someone riding in a spaceship rocketing along at Mach speeds.

How will the passenger feel when they recover from G-LOC? First of all, they may not even recognize the G-LOC incident because one of the symptoms of G-LOC is partial amnesia caused by impaired oxygen flow to the brain. As they gradually recover from the discombobulating feeling of regaining full consciousness, they may also experience tingling around the mouth or in the extremities and perhaps a sense of dreaming – part of the constellation of symptoms that are collectively defined as the G-LOC syndrome [3]:

- loss of peripheral vision;
- tunnel vision;
- blackout (complete loss of vision);
- loss of consciousness;
- loss of motor control (purposeful movement);
- loss of sensory input to the brain;
- lack of memory formation;
- myoclonic convulsions;
- dreamlets;
- recovery of consciousness;
- neurological reintegration;
- neurological external environment reorientation;
- return of purposeful movement;
- transient tingling or slight numbness of the extremities;
- alteration of psychological state (anxiety, confusion, embarrassment).

While a G-LOC event may cause our Virgin Galactic astronaut to feel a little queasy, the syndrome is a protective mechanism that has evolved to protect us in a gravitational field and to ensure the optimum protection of the organ system that is the key to its evolutionary success on Earth: the brain. And it's not as if the brain gives up at the slightest hint of G-stress. Far from it. As soon as G-stress is detected, the cardiovascular and neurological systems initiate protective reflex mechanisms, so functional compromise does not occur easily. With the passenger unconscious, the brain is in a minimal energy expenditure state, with loss of sensory, motor, and consciousness function [3]. If a G-LOC'ed passenger were to be hooked up to an electroencephalogram (EEG), a flight surgeon would observe a synchronized slow wave pattern that would persist until the recovery process started – the relative incapacitation period. At this stage, blood flow would begin to return to normal levels and *myclonic* twitching (involuntary muscle jerk) might occur. You may wonder why the passenger would start convulsing, but the mechanism, like all the G-LOC recovery processes, has a purpose. The twitching serves to contract the muscles in the extremities and abdomen thereby enhancing return of blood to the central circulation and ultimately the brain [3]. Having said that, having a twitching, convulsing passenger seated next to you may prove disconcerting for some!

+Gz also exerts mechanical effects on soft tissues and compresses the spine, and it affects the cardiovascular and pulmonary systems, creating visual symptoms and the risk of G-LOC [12]. Gz is just as bad because it causes visual and cardiovascular disturbances and is just as capable of causing G-LOC. Then there are the mechanical effects of acceleration which causes soft tissues to sag with the result that a person subject to G appears to have aged prematurely! Fortunately, it's a reversible change. The bottom line is that the sheer magnitude of G in any axis causes problems. Above 2.5 Gs, most people find it



6.6 The Johnsville "fuge", where astronauts spent hours being subjected to the dreaded "G". Courtesy: USAF

difficult to rise from a seat and, when that acceleration increases to 3 Gs or more, raising an arm is a workout. Crank up the Gs to more than 8 Gs and any gross movement is next to impossible. Even if your name is Arnold Schwarzenegger!

In the early days of manned spaceflight, the direction of acceleration was even more important than it is today because of the sheer magnitude of acceleration. For example, the Mercury, Gemini, and Apollo flights had launch accelerations of 4.5–6.5 +Gx for six minutes and anywhere from 6 to 11 +Gx during re-entry [4]. NASA was so concerned about the possible effects acceleration might have on the astronauts that they forced them to spend countless hours in the centrifuge (up to 45 hours in some cases) (Figure 6.6). Then the Shuttle came along and astronauts were given a break from the punishing Gs: the now-retired Shuttle had a maximum of *only* 3.2 +Gx during launch and 1.2 +Gz (briefly 2.0 +Gz during turns) during re-entry. Fortunately for the new breed of Virgin Galactic astronauts, the acceleration forces imposed by SpaceShipTwo should be reasonably comfortable for most, although there will be some who will do better than others.

How Virgin Galactic passengers perform in the centrifuge is partly down to the physiological luck of the draw. That's because tolerance depends on factors such as individual susceptibility to +Gz acceleration, which is, in turn, dependent on height and weight, smoking history, fitness level, hydration, the type of acceleration profile, previous and recent exposure to +Gz forces, and recent centrifuge training. For example, tall thin people typically don't fare well in a centrifuge because the blood has to travel a longer distance to the brain and the eyes (Paris Hilton beware!). Smokers tend to do well because their arterial beds are less flexible which means it's easier for blood to travel through them. So, if you're a short, squat, chain-smoker, chances are you're ideal centrifuge (and astronaut) material! The type of G exposure is important too because the maximum +Gz level, exposure duration, and the rate of +Gz onset determine the risk of injury to your heart and musculoskeletal system. The most problematic acceleration is rapid-onset rate (ROR), defined as increases greater than 0.33 Gs per second. ROR tolerance limits are approximately 1 +Gz lower than gradual-onset rate (GOR) tolerances because they exceed the ability of the cardiovascular system to get enough blood to your brain. RORs can also result in the dreaded G-LOC without any visual warning symptoms such as tunnel vision, grayout, or blackout [4]. To prevent this happening when they're performing aerobatic maneuvers, fighter pilots wear anti-G-suits (Figure 6.7) which increase their +Gz tolerance by up to 1.5 +Gz. Another way fighter pilots increase their G-tolerance is to practice the anti-G straining maneuver (AGSM) which can increase tolerance by as much as 3 +Gz.

Tolerance limits for +Gz acceleration are usually signaled by visual symptoms such as peripheral light loss (PLL), tunneling, grayout, and blackout. During gradual onset of acceleration, a relaxed subject not wearing an anti-G-suit typically experiences initial visual symptoms at about +4 Gz [4], although susceptible individuals may experience PLL as low as +2 Gz. "G monsters", on the other hand, may not notice anything until +7 Gz. In my job as director of Canada's manned centrifuge operations, I witnessed about half a dozen such individuals, one of whom casually chatted away as the G-level crept close to the 7 G mark! For most people, once they have experienced initial visual symptoms, the next symptom will likely be blackout at about +5 Gz and unconsciousness if the Gz continues to increase. Once the individual has lost consciousness, they are deemed to have G-LOC'ed. Witnessing an episode of G-LOC can be a little disconcerting. First, the head drops to the chest and seizure-like flailing motions may occur – some people have broken limbs as a result of this. While their limbs are flailing, the now-unconscious individual may exhibit myoclonic, spastic-like twitching. Fortunately, consciousness returns quickly (a typical G-LOC period is 15 seconds) and the individual will slowly raise their head, looking very, VERY confused. This confusion is quickly exacerbated when they realize they don't remember the incident and, when asked if they know what happened, some even deny losing consciousness. If the G-LOC incident occurred in a centrifuge, there is a video that the individual can watch to prove otherwise! But imagine if such an event occurs in the confines of SpaceShipTwo! Like I said, I've witnessed plenty of pilots recovering from G-LOC and it's not a pretty sight: the word "discombobulated" goes some way to explaining the confused state of those recovering from G-LOC. And, since Virgin Galactic won't be flying any flight attendants, it will be up to the other passengers to deal with any G-LOC incidents. We'll talk about that some more in the training section.

Over the years, scientists have developed a model of +Gz tolerance limits that consider +Gz magnitude, duration, and rate of onset (generally, with no protection, most healthy people can tolerate up to 4 +Gz acceleration for ROR profiles and up to +4.5 Gz with GOR profiles). Okay, so that's +Gz tolerance, but what about −Gz and the transition from one type of G to another? This transition is where most problems occur because transition to

6.7 The author gets fitted for his G-suit. Courtesy: Author's collection

+Gz can cause a big drop in your brain's blood pressure and that's bad news for the cardiovascular system because it can take quite a while before your body compensates. In fact, if you're exposed to –Gz before transitioning to +Gz, you can become a victim to the "push–pull effect". The "push–pull effect", which has been the cause of several fatalities, is most commonly experienced by fighter pilots during combat engagements. Even now, with a whole library of G-data, scientists don't fully understand the issue, which means there are no robust countermeasures. We don't know if passengers will be affected by the "push–pull effect" in the transition from microgravity to re-entry, but the problem has been experienced in parabolic flight and there are some who are concerned it could occur in suborbital flights. That's because, in suborbital flight, the "push–pull effect" is prolonged by increasing the duration of the prior –Gz exposure [13]. Normally, the –Gz exposure is only a few seconds in combat flight, whereas in parabolic flight the exposure is 20–25 seconds. But what about after four minutes of suborbital flight? Truth is, we just don't know whether four minutes of microgravity will provoke the same response or cause a further deterioration in +Gz tolerance [13].

In tandem with the mechanical effects are the hydrostatic effects. This occurs because acceleration increases the "weight" of the blood, and this in turn increases the pressure gradient in the hydrostatic column, which creates havoc in the cardiovascular system. +Gz makes for some labored breathing because the diaphragm is pulled down and the acceleration collapses the air sacs in the lungs (the greater the G, the more air sacs collapse – like a balloon collapsing), causing a G-induced symptom known as *acceleration atelectasis*.

An abnormality of the neurological or neurovascular system will most likely preclude an individual from engaging in high-G activity, since any such abnormality might compromise blood supply to the brain. And, since the cardiovascular system is the system primarily affected by $+G_z$, any abnormality in cardiovascular anatomy or physiology is reason for concern in aerospace safety. Equally, medications that alter cardiovascular physiology are viewed with caution, especially pharmacological agents that alter blood pressure and/or the function of the heart [3]. The heart is particularly susceptible because acceleration is a *dysrhythmogenic* stress which means that anything that affects cardiac rate or rhythm is a threat to safety. Flight surgeons have a name for the group of symptoms that may affect the heart during +Gz: *tachydysrhythmias*. Like most medical terms, *tachydysrhythmia* appears to have been borrowed from an alien language but, in layman terms, it simply means a quickening of heart rate (ventricular tachycardia) and premature beats (supraventricular and atrial) which are common during $+G_z$. For the symptoms that occur following $+G_z$, flight surgeons have another tongue twister: *bradydysrhythmias*. Like its counterpart, this term has a simple explanation, describing the out-of-sequence beats (sinus arrhythmia), bradycardia, and spontaneous heart beats (ectopic atrial rhythm) that occur following $+G_z$.

Musculoskeletal problems, particularly those affecting the neck and back, are of particular concern during $+G_z$ stress. For example, any anatomical abnormality that decreases neck or spinal strength or stability has to be carefully considered [3]. It's the reason pilots are prescribed neck and back muscle strengthening exercises to prepare themselves for the G environment. The pulmonary system is also significantly affected by $+G_z$ stress because blood can be drawn away from the lungs, resulting in less oxygen being delivered to the muscles and to the nervous system.

So how do you reduce the effects of G? There are two approaches. The first is to decrease the vertical distance between the heart and brain by tilting the seat back, and the second is to apply counter pressure against the legs and abdomen to reduce blood pooling there [2]. The counter pressure can be generated by performing the AGSM and/or by wearing a G-suit. One of the biggest medical disqualifiers in suborbital flight will probably be related to cardiovascular problems that are exacerbated under G and here's why. Heart rate increases and the vascular return pressure is *reduced* (decreasing preload) under acceleration, which means the heart is starved by decreased filling of the atria during diastole [2]. This isn't a problem in passengers with a healthy cardiovascular system because the muscle straining associated with the AGSM will increase resistance to circulation which increases the systolic pressure. But, if a passenger has some kind of cardiovascular abnormality (an arrhythmia for example), this sequence of events may not happen in exact synchrony with G-loading, with the result that the heart after-load (peripheral flow resistance) will fluctuate – possibly out of control. Now you may be thinking that passengers with suspect hearts won't be allowed to fly because these arrhythmias will be detected in the medical exam. Not so. That's because the effects on the heart that were just described are not always detected on an electrocardiogram (ECG), whether the ECG is conducted under resting or exercise conditions. A treadmill exercise protocol is a great way of assessing whether someone can run a marathon but, because such a test doesn't drop preload or cardiac output and because peripheral resistance to blood flow is decreased and output from the heart increases with exercise on a treadmill, this test can't assure that a passenger will survive prolonged G-stress [2].

On the subject of heartbeat abnormalities (arrhythmias) that occur during acceleration, it's worth pointing out that in a series of 1,180 centrifuge training sessions involving professional aeromedical attendees at the USAF School of Aerospace Medicine, 47% resulted in arrhythmias. Of these, 4.5% should have resulted in termination of the session [2]. The point is that these *arrhythmias can occur in pre-screened individuals*; the arrhythmias might be harmless for the person in the street but, when subjected to G-load, the abnormality could be lethal. At least in a centrifuge, if a passenger were to develop an electrocardiographic abnormality, the centrifuge can be stopped but, if the problem manifests itself during a suborbital flight, the result may be a dead passenger – don't forget, if this happens during the boost phase, the vehicle is committed to the ballistic phase of the flight.

Microgravity effects

Like acceleration, there will be significant inter-individual physiological changes resulting from exposure to microgravity. While suborbital microgravity exposure will only last three to four minutes, if you happen to be inexperienced, non-adapted, or highly sensitive, chances are you will experience neurovestibular and/or cardiovascular symptoms. While we can't be sure until revenue flights begin, it would seem logical that recent parabolic flight experience might be a way to alleviate suborbital flight symptoms.

Cardiovascular effects

A common cardiovascular effect observed in Shuttle astronauts while they were lying down awaiting launch was a shift in fluids from their legs to their head. Part of the reason for this was due to the slightly head-down pre-launch position. In orbit, due to the absence of gravity, fluids shifted again, with body fluids rushing to the head, giving astronauts a sensation of head fullness. Fortunately, most of these effects won't be a problem during a SpaceShipTwo flight simply because these physiological changes take time to develop in microgravity.

Neurovestibular effects

In common with fluid shifts, the neurovestibular effects won't be much of a problem for most Virgin Galactic passengers because these effects also take time to manifest themselves. After orbital flight, astronauts suffer an altered ability to sense tilt and roll, defects in postural stability, impaired gaze control, and changes in sensory integration [4]. Basically, they're discombobulated! While suborbital passengers probably won't be affected to the degree that astronauts returning from orbit are, there have been neurovestibular alterations observed in even short exposures to zero-G in susceptible individuals. For example, somatogravic illusions with spatial disorientation were reported on several X-15 flights [13]. Now you may think why not test this in a simulator, but the problem is that rapid launch acceleration followed by zero-G followed by re-entry deceleration can't be tested in continuity.

X-15 neurovestibular experience

Although we don't have much suborbital flight experience, it's worth taking a look at the experience of those pilots who flew similar flights back in the 1950s and 1960s. The most notable suborbital flights were flown by the X-15, three of which were built for a program that comprised 199 test flights.

Among the 12 pilots of the X-15 program were future astronauts Neil Armstrong and Joe Engle [4]. During the program, eight pilots met the USAF spaceflight criteria by exceeding an altitude of 80 kilometers, thus qualifying them for astronaut status. Of all the X-15 missions, only two flights[4] (piloted by Joe Walker) qualified as spaceflights according to the FAI definition [13, 14]. Although biomedical data weren't measured on the X-15 flights, pre-flight and post-flight flight surgeon examinations were performed and nothing unusual was reported. Also, pilot performance wasn't impaired by launch acceleration followed by zero-G followed by re-entry (don't forget, these were phenomenally experienced pilots – probably the very best on the planet), although the G-forces imposed on the pilot during the boost phase of the flight often resulted in severe vertigo [4]. In fact, vertigo was a serious problem throughout the program and was blamed for the death of Major Mike Adams. Major Adams's seventh flight took place on 15 November 1967. At 10:30 in the morning, his X-15 dropped away from the NB-52B at 13,700 meters and, at 10:33, he reached a peak altitude of 81,000 meters. On reaching its maximum altitude, the X-15's heading was off by 15° and, as Adams descended, the aircraft began drifting to the right [15]. Then, at 70,000 meters, encountering rapidly increasing dynamic pressures, the X-15 entered a Mach 5 spin [15].

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[4] Flight 90 on 19 July 1963 reached 105.9 km. Flight 91 on 22 August 1963 reached 107.8 km.

NASA controllers advised Adams he was "a little bit high" but in "real good shape". Adams replied that the aircraft "seems squirrelly" (see sidebar). At 10:34, a troubling call came: "I'm in a spin." With no heading information, controllers saw only large and very slow pitching and rolling motions and thought Adams was overstating the case. But Adams radioed again: "I'm in a spin." Unfortunately, there was no spin recovery technique for the X-15 and engineers knew next to nothing about the aircraft's supersonic spin behavior. The chase pilots, realizing Adams would never make Rogers Dry Lake, raced for the emergency lakes. Somehow the aircraft recovered from the spin at 36,000 meters and went into an inverted Mach 4.7 dive [15]. Adams now had a good chance of rolling upright, pulling out, and landing. But then the aircraft began a rapid pitching motion, diving at 49,000 meters per minute [15]. Dynamic pressure increased intolerably and, as the aircraft neared 19,000 meters, it was diving at Mach 3.93 and experiencing over 15 *g* vertically, both positive and negative, and 8 *g* laterally [15]. The aircraft broke up 10 minutes and 35 seconds after launch.

NASA and the Air Force convened an accident board, which concluded Adams had suffered severe vertigo during climb-out which caused spatial disorientation [4].[5] Small heading deviations caused by a degraded flight control system were made worse by incorrect pilot inputs at an altitude of over 20,000 meters. The board concluded Adams had misinterpreted a roll indication for a slide slip indication and had made control inputs in the wrong direction [4].[6] As a result of the accident investigation, it was recommended all future X-15 pilots be medically screened for labyrinth (vertigo) sensitivity.

Burt Rutan and Major Mike Adams's Accident

Adams was a friend of Burt Rutan, who was stationed at Edwards Air Force Base at the time of the accident (which, according to Rutan, was caused because the requirement to do a precision re-entry had not been met). Adams's accident was one of the reasons Rutan got into the business of designing aircraft.

Space motion sickness

Do you get motion sick? Well, not to worry, because there is little or no correlation between being sick on Earth and being sick in space. In fact, some people who are chronically motion sick on Earth are just fine during a parabolic flight. Equally, those who have never experienced terrestrial motion sickness are sometimes sick as the proverbial dog when

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[5] Some experts reckoned the cause was X-15's re-entry into the atmosphere with too much sideslip caused by a stability issue. It was one of the reasons that Burt Rutan, a friend of Adams, designed the stability feature on SpaceShipOne.

[6] Mike Adams was posthumously awarded Astronaut Wings for his last flight in the X-15-3, which attained an altitude of 266,000 ft. In 1991, his name was added to the Astronaut Memorial at the Kennedy Space Center in Florida.

they reach orbit. No doubt about it, space motion sickness (SMS) is a problem. In fact, more than 70% of first-time astronauts flying orbital spaceflights suffer from it: the syndrome, thought to be due to a sensory conflict between visual, vestibular, and proprioceptive stimuli, has been a problem as long as there have been astronauts [4]. Symptoms typically occur within the first 24 hours, but some astronauts have reported symptoms – dizziness, pallor, sweating, severe nausea, and vomiting are the most common – immediately after main engine cut-off. Vomiting, which can be especially messy in zero-G, can crescendo suddenly without any warning (prodromal) symptoms [13]. And, in a multi-passenger vehicle, one passenger becoming nauseated can potentially trigger nausea in the other vehicle occupants – just imagine trying to take pictures while barfing into a vomit bag or trying to dodge balls of stomach contents as they are ejected from your fellow passengers! It's an image Virgin Galactic has played down, and for good reason, because, after spending $250,000 on a ticket, nobody wants to have their once-in-a-lifetime experience spoilt by projectile vomiting. Of course, anti-motion sickness medications can be used, but these tend to have side effects which aren't always conducive to enjoying spaceflight.

Bail-out

SpaceShipTwo has no emergency egress capability, but for a moment let's consider it does and lets imagine something goes wrong shortly before re-entry and the lone passenger (this very rich passenger wanted the flight to himself) is instructed to bail out. From 100,000 meters! Would he survive? Perhaps. Perhaps not. What *is* certain is that he would be in for a memorable ride. Here's what might happen. For the first 73 seconds, he would descend to about 81,400 meters and accelerate to about 700 meters per second. As the descent continued, acceleration would continue up to about 1,020 meters per second (Mach 3.1) at 114 seconds into the fall. At this point, our astronaut is at about 45,400 meters' altitude and finally begins to decelerate until crossing 9,100 meters 243 seconds into the fall at a speed of about 90 meters per second; 325 seconds into the bail-out, the astronaut would cross 3,000 meters at 60 meters per second. During the bail-out, 22 seconds would be spent above 2 Gs, 18 seconds above 3 Gs, 13 seconds above 4 Gs, and 6 seconds above 5 Gs. Maximum acceleration would be about 5.8 Gs at 137 seconds into the fall and an altitude of about 26,500 meters. In addition to the acceleration forces, our bail-out victim would also have to contend with extreme cold and the problem of maintaining stability. This latter factor is probably the most dangerous of all, especially during the high-acceleration phases of entry into denser atmosphere because if the astronaut enters a flat spin, blood is centrifuged into the extremities and blackout is the result. This is what happened to sky-diver "Fearless" Felix Baumgartner when he made his record-breaking jump from the stratosphere. Baumgartner entered a flat spin while supersonic, spinning for 13 seconds at 60 revolutions per minute, making more than a dozen spins before regaining control. As sky-diving legend Joe Kittinger noted after the jump, if an experienced sky-diver like Baumgartner with close to 3,000 jumps couldn't stop a flat spin, "an astronaut, pilot or space tourist could not overcome this spinning probability" [16].

Radiation

Next is radiation. When we talk about harmful radiation in space, we're usually referring to *ionizing radiation*, which comprises subatomic particles. These particles can interact with body tissues and damage strands of DNA, causing genetic damage that can in turn lead to mutations. Sources of ionizing radiation are galactic cosmic radiation (GCR), solar radiation, solar flares, and trapped radiation from the Van Allen belts [4]. GCR consists of 87% hydrogen nuclei protons, 12% helium nuclei alpha particles, and 1% high-energy heavy nuclei such as iron, while solar cosmic radiation comprises plasma ejected from the Sun's surface. How much radiation is too much? Well, the dose standard for radiation exposed workers is 20 mSieverts (Sv) per year (averaged over five years): exposure to this level over four decades causes an excess lifetime fatal cancer risk of 3.2% [4]. By comparison, orbital spaceflight results in a radiation dose exposure that depends on altitude and solar activity and ranges from 0.01 to 0.1 Sv per month [4]. Radiation levels at a suborbital flight altitude would be similar to high-altitude Concorde flights, which means Virgin Galactic's customers should receive less than 15 μSv per hour during their flight. To put this in perspective, you would need to fly more than 10 suborbital flights to experience the same radiation dose as you get from an X-ray. So don't worry too much about radiation.

Noise

Launching a rocket – any rocket – is a noisy business and SpaceShipTwo requires powerful thrust that happens to be noisy. Very noisy. And this noise is transmitted through the whole vehicle and, because the vehicle is an enclosed space, this noise is reflected multiple times off the walls, bulkheads, floors, and ceilings. Although the duration of the noise is relatively short, the magnitude can be quite intense – so intense that passengers may suffer reduced visual acuity, vertigo, nausea, disorientation, and ear pain [4]. Because of this assault on your hearing, auditory protection will definitely be required by all Virgin Galactic passengers.

Vibration

As well as all that noise, the power being unleashed to launch SpaceShipTwo will generate an awful lot of vibration (watch the in-cabin videos of the SpaceShipOne flights during ascent and you'll see what I mean). How much? Think about the vibration you feel when an aircraft takes off and multiply that by several orders of magnitude and you'll have some idea. While vibration won't be more than a mild and temporary inconvenience for fare-paying passengers, for commercial astronauts tasked with flying payloads it could be a problem. That's because vibration can cause manual tracking errors and can interfere with ability to visually track displays, which could be a problem for an astronaut tasked with keeping an eye on an experiment.

MEDICAL QUALIFICATION

So what do these risks mean in terms of how healthy Virgin Galactic passengers need to be? Well, the FAA thought about this and appointed a team to evaluate the medical standards that would be appropriate for suborbital passengers. The report, led by principal investigator Dr. Richard Jennings and co-investigators Drs. James Vanderploeg, Melchor Antunano, and Jeffrey Davis, is entitled "Flight Crew Medical Standards and Spaceflight Participant Medical Acceptance Guidelines for Commercial Space Flight". What follows is a synopsis of the report.

The FAA-sponsored medical guidelines project was conducted in three phases, the first of which collected and reviewed documents addressing suborbital crew member and spaceflight participant medical certification. In the second phase, a preliminary document incorporating the guidelines and recommendations outlined in Phase I was prepared and a working group of experts was convened to consider the comments from Phase II. Then, in Phase III, a consolidated set of recommendations for the medical certification of crew members, medical acceptance guidelines for spaceflight participants, and recommended training procedures was prepared and the document was provided to the FAA [17].

The first part of this document outlined a reference mission, which set out a number of assumptions. The first was that a suborbital spacecraft will provide a shirt-sleeve cabin environment with an appropriate temperature, a cabin pressure no higher than 2,440 meters, and appropriate oxygen and humidity levels. The second assumption was that the acceleration in a suborbital spacecraft should not exceed +6 Gx, +1 Gy, and +4 Gz. If the acceleration profile exposed passengers to greater than +4 Gz, then the spaceflight participants should be medically screened according to the guidelines outlined for orbital passengers. The third assumption dealt with flight rates, and assumed that passengers will only participate in one suborbital flight per day, whereas commercial astronauts or flight crew could make multiple flights per day. The document also noted that repeated flights to the acceleration limits listed, with four minutes of zero-G exposure between launch and entry, haven't been performed before, so caution should be exercised until an experience base is acquired. Finally, the document assumed that radiation dose will not exceed the yearly commercial airline passenger dose, defined as no more than 1 mSv per year.

The next part of the document dealt with the guidelines for screening. The guidelines suggested that the content and extent of a medical questionnaire and physical exam should be related to each operator's flight profile and that passengers should complete a medical questionnaire and a physical exam by a qualified physician with knowledge of the spaceflight environment. If you're planning buying a ticket on SpaceShipTwo, chances are you will need to indicate a history of the following conditions [18]:

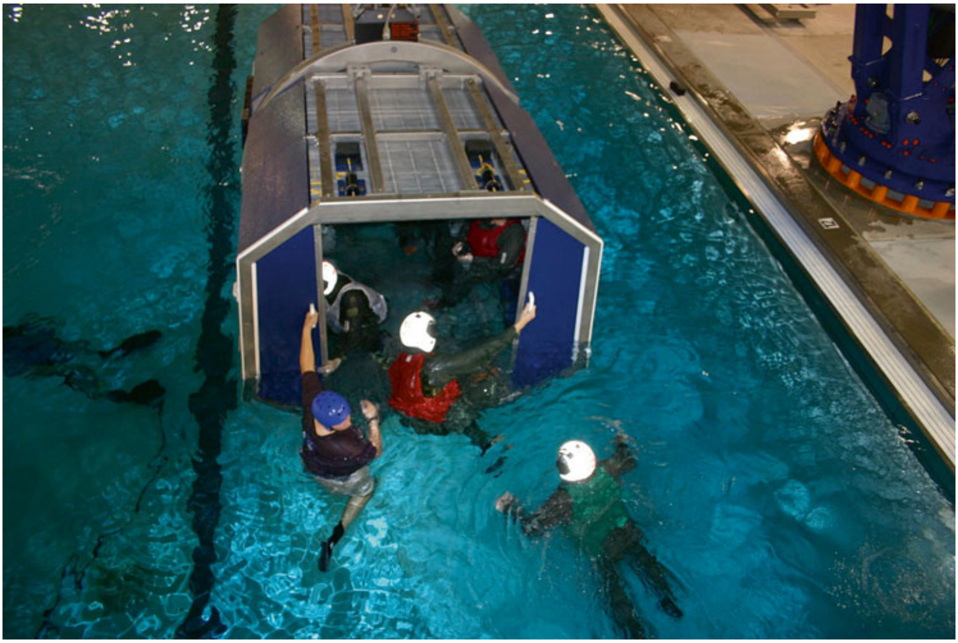
- otitis, sinusitis, bronchitis, asthma, or other respiratory disorders;
- mental disorders, anxiety, or history of hyperventilation;
- dizziness or vertigo;
- claustrophobia;
- fainting spells or other loss of consciousness;
- attempted suicide;
- seizures;

- use of medications;
- tuberculosis;
- alcohol or drug dependence or abuse;
- surgery and/or other hospital admissions;
- current pregnancy or recent spontaneous or voluntary termination of pregnancy;
- visits to health care provider in last three years;
- recent significant trauma;
- history of DCS;
- diabetes;
- anemia or other blood disorders;
- cancer;
- heart or circulatory disorders, including implanted pacemaker or defibrillator;
- rejection for life or health insurance;
- disability or deformity requiring accommodation.

In addition to completing the questionnaire, you will be required to inform the doctor if you have a medical condition that would impair your ability to safely perform a suborbital flight without compromising the safety of other occupants and/or safely perform an emergency egress without assistance. While there are no hard and fast suborbital medical standards, there are some conditions that could be cause for concern. For example, any condition that may result in an in-flight death or injury is obviously a red flag. Also, a person that has a condition with functional defects that could interfere with the use of personal protective equipment or interfere with an emergency egress probably won't be sold a ticket. Another medical issue is any problem that may be exacerbated by the operational environment or flight-related stress. So what do you do if you don't meet the recommended guidance criteria? One option is a mitigation strategy, although the aerospace medicine physician must ensure that the condition and the mitigation process won't impair your ability to safely perform activities required for the flight, including an emergency egress. Part of this mitigation strategy may involve training, which forms the subject of the second part of this chapter.

TRAINING

The extensive training professional astronauts (Figure 6.8) receive after selection to the astronaut corps is clearly not appropriate for Virgin Galactic's passengers. So what kind of training is suitable? Well, that's something the industry hasn't standardized (don't mention that word if you're talking to someone in the commercial spaceflight industry by the way!) and, for the time being, doesn't want to. Even the FAA has provided only vague guidelines as to what suborbital flight training should include. Which, for Virgin Galactic, is a good thing. After all, it's not as if Virgin Galactic hasn't thought about this stuff already. Ultimately, the goal for Virgin Galactic is for a successful long-term business in the commercial human spaceflight industry, and that gives the company just two key requirements: safety and a booming market [2]. And, since a booming market requires safety, as long as Virgin Galactic's training and operational procedures are safe, a successful business outcome should follow. Of course this may all change following the outcome of the NTSB investigation into the SpaceShipTwo accident.



6.8 Virgin Galactic passengers won't be trained in sea survival, but dunker training is a useful skill to have … just in case. Courtesy: A4H

Given that astronauts have been launched into space for more than five decades, you'd think we'd have figured out the training by now, but don't forget we're talking about *suborbital flight*. And the operational experience for manned suborbital spaceflight is very limited, consisting of just two Mercury-Redstone rocket flights in 1961, two X-15 flights in 1963, a Soyuz launch abort in 1975, and three SpaceShipOne flights in 2004 [4]. And the stresses of suborbital flight are by several orders of magnitude smaller than those imposed by orbital flight, so it stands to reason that training should reflect this. But how much training should Virgin Galactic passengers have and where should they be trained?

NASTAR

In 2004, when SpaceShipOne flew its epic flight, there were no commercial astronaut training centers, although there were a few places that specialized in aerospace training, mostly for the military. One of these was the NASTAR Center, located in Southampton, Pennsylvania. The center is a world leader in aviation and spaceflight training, so it wasn't surprising that Virgin Galactic signed them up to provide training for their suborbital space travelers.

According to the contract, NASTAR (see sidebar) was initially responsible for training Virgin Galactic's Founders (the first 100 ticket-holders scheduled to fly with Virgin Galactic). The contract also covered ongoing training of Virgin Galactic's space travelers after the Founders and for those seeking a Virgin Galactic-branded spaceflight experience.

The two-day Sub-Orbital Space Flight Training program, which Virgin Galactic passengers complete, is a realistic training program that provides full spectrum preparation for each phase of launch and re-entry thanks to NASTAR's centrifuge that can uniquely replicate the dynamic envelope of SpaceShipTwo. Those who have completed the course – including the Virgin Galactic Founders – have found it invaluable. There is also a "try before you buy" appeal to those who perhaps aren't quite sure whether they will enjoy the suborbital flight experience. For $3,000, these maybe wannabes can sign onto the course and, after two days of coursework, being spun around in a centrifuge and deprived of oxygen, they can make an informed decision about whether they want to fork out $250,000 for a flight. For nearly all participants, the experience is a successful one, since the course graduation rate is 94%.

NASTAR

NASTAR houses state-of-the-art equipment and professional staff to support the training and research needs of the aerospace community, including military aviation (fixed and rotary wing), civil aviation (fixed and rotary wing), space travel (government and private), and research support and data collection [19]. Established in 2006, the center began as a product showcase, engineering development, and test center for its owners, the Environmental Tectonics Corporation (ETC), but soon became recognized for its unique approach and sophisticated interactive flight training technology. The center contains all sorts of space training equipment, ranging from high-fidelity simulators to a multi-axis centrifuge – the ATFS-400 Phoenix.

At the beginning of the course, students are given a tour of the facility, during which they are shown the ejection seat simulators, the yaw, pitch, and roll confusion generators, hypobaric chamber, and of course, the centrifuge, complete with spaceflight simulator pod. Then, the budding astronauts are fitted for flight suits and instructed on the basics of aerospace physiology. In the afternoon, they complete their high-altitude indoctrination inside the hypobaric chamber while attempting to solve problems on a worksheet to test their reaction to hypoxia.

The second day begins with prepping for the G-tolerance test, which includes teaching students the AGSM. After practicing their AGSM, students perform four centrifuge runs ("Flights" in NASTAR parlance). After enjoying/surviving the centrifuge, students participate in a distraction exercise which takes place in a room with a black interior and set-up with a Virgin Galactic SpaceShipTwo-sized cabin area.

A few of my space industry colleagues have had the NASTAR experience and they say it's a blast. But does two days of training really prepare you for flying into space, even as a tourist? After all, there is no emergency egress training in NASTAR's program, so what happens if SpaceShipTwo suffers a major malfunction and you have to bail out? And, after bailing out, what do you do if you find yourself in the ocean? Might not survival training be useful? And what happens if a fellow passenger has an attack of nerves and freaks out? Who's going to deal with that?

Seating and reseating

> "My big concern is getting people back to their seats. This is one of the central design considerations. My guess is it will be as simple as saying 'OK everybody; get back in your seats'. Then gravity will kick in.
>
> George Whitesides"
>
> *Quote from "Richard Branson: Galactic Spaceship to Blast Off in 2013", Barry Neild, CNN, 12 June 2013*

You've seen the computer-generated images of Virgin Galactic passengers floating around the SpaceShipTwo cabin in their cool flight suits. Virgin Galactic aims to provide its spacefarers with a view of Earth and the opportunity to float free of seat restraints. When the engine shuts down, there will be absolute silence and passengers will have the opportunity to get out of their seat to experience a few minutes of weightlessness. And there will be plenty of room because the spaceship has been designed so the seats recline to allow maximum space for astronauts to move around and allow them to get as close to the windows as possible to view Earth from orbit. Once gravity takes hold again, passengers will be strapped in their reclined seats and, by the time SpaceShipTwo has dropped down to 21,000 meters, the seats will be raised to the upright position again before a high-altitude glide down to the Spaceport America runway. It sounds simple and safe. And it will be. Provided everybody follows the rules. But un-strapping and re-strapping in such a short time frame may be a risky endeavor because some passengers will be so engrossed by the spectacular view that they may simply not hear the order to take their seats or may even ignore the request. I've seen it happen in parabolic flight (Figure 6.9): one of the

6.9 Seating and reseating may be a challenge in such a dynamic environment. Courtesy: ESA researchers on my flight was enjoying his 22 seconds of weightlessness when the order came to sit back down. This researcher didn't, with the result that when the aircraft entered the 2-G dive, he crashed to the floor and was knocked unconscious. Imagine if this were to happen to Justin Bieber. Or Paris Hilton perhaps?

Now throw motion sickness into the mix and imagine trying to wrestle a projectile-vomiting passenger into their seat. You can throw in all the audible and visual cues you want but a chronically barfing passenger probably isn't going to take much notice. And who is going to be man-handling the wayward astronaut anyway? No flight attendants remember. Perhaps Virgin Galactic will require passengers to buddy up the same way scuba-divers do – after all, it's a proven and reliable system. Perhaps Katy Perry could pair up with Paris Hilton or perhaps Leonardo di Caprio could buddy up with Brad Pitt? Who knows!

Notes

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7

Pilot-Astronauts, Passengers, and Personnel

PILOT-ASTRONAUTS

Since SpaceShipOne's flight, there have been many signs that commercial passenger spaceflight was becoming a reality, one of which was the April 2011 job announcement from Virgin Galactic seeking pilot-astronauts. The rare opportunity (see sidebar) was a chance for the new breed of commercial astronaut to work as part of Virgin Galactic's WhiteKnightTwo and SpaceShipTwo system test and development team in Mojave, before taking the experience gained from that program to the company's operations at Spaceport America, in New Mexico.

Virgin Galactic Essentials for Successful Pilot-Astronaut Candidates [1]

- Must be a US citizen – compliant with ITAR (22 CFR §120.15)
- A current Federal Aviation Authority (FAA) commercial (or equivalent) pilot certificate and FAA medical
- Degree-level qualification in a relevant technical field
- Graduate of a recognized test pilot school, with at least 2.5 years' post-graduate flight-test experience
- A diverse flying background with a minimum of 3,000 flying hours to include considerable experience in large multiengine aircraft and high-performance fast-jet aircraft, and low lift-to-drag ratio glide experience (e.g. simulated flameout landings) in complex aircraft
- Operational experience of an aerospace aviation project or business
- Excellent, current knowledge on a diverse range of aerospace matters
- Ability to communicate aviation knowledge and safety-related information simply, succinctly, and clearly

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E. Seedhouse, *Virgin Galactic: The First Ten Years*, Springer Praxis Books,
DOI 10.1007/978-3-319-09262-1_7

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- Previous responsibility for authorizing and implementing policies and procedures to ensure a safe and efficient operation
- Be a proven team player

Very limited exceptions to the above may be considered for those with truly outstanding test-flying or spaceflight experience.

Preference will be given to those with experience of:

- Spaceflight
- Commercial flight operations
- Flight instruction

David Mackay

The first commercial space pilot to be employed by Virgin Galactic was British flying ace David Mackay, who will most likely be at the controls for SpaceShipTwo's first revenue flight. Mackay admits to having a fear of heights, although that isn't a problem when he's flying a plane. Or a spaceship. A former Royal Air Force (RAF) pilot, Mackay's job as chief test pilot is a dream come true for the one-time Scottish resident. He watched the black-and-white images of the Apollo landings and discovered that NASA's astronauts were ex-military test pilots, so he decided to join the RAF and become a test pilot, hoping the path would eventually lead to him becoming an astronaut. But by his early thirties, he realized becoming an astronaut in the UK was a long shot, especially since the country didn't have a manned space program. So, in 1995, after 16 years in the RAF, Mackay joined Virgin Atlantic as a long-haul pilot, until 2011, when he was asked to quit his job to be chief pilot for Virgin Galactic. Assuming Virgin Galactic can recover from the SpaceShipTwo accident, there is chance that Mackay may become one of the few pilots to deliver the in-flight announcement informing passengers they have reached zero gravity.

Keith Colmer

Helping Mackay test fly the new SpaceShipTwo will be Keith Colmer, another former (USAF) test pilot with more than 5,000 hours of flight time. Colmer, who has logged hours on 90 types of aircraft, also worked for the USAF spacecraft program, and served as Operations Officer for the 416th Flight Test Squadron at Edwards Air Force Base, where he led flight-test operations, specializing in high angle-of-attack flight tests and F-16 training. Colmer then went on to complete two classified assignments, before completing his active duty tour as a Combined Test Force Director and Squadron Commander for a classified program [2].

Frederick Sturckow

The most recent additions to Virgin Galactic's roster of commercial pilot-astronauts are Frederick "CJ" Sturckow and Michael "Sooch" Masucci, who joined the very select team in 2013. Sturckow (Figure 7.1), a four-time Shuttle flyer and a retired colonel in the US Marine Corps, was the first agency astronaut to be hired by Virgin Galactic. Thanks to those four Shuttle missions he has logged more than 1,200 hours on orbit. Added to those space-based flying hours are 6,500 regular flight hours, flown in more than 60 types of aircraft. A Navy Fighter Weapons School (TOPGUN) graduate, Sturckow was selected by NASA in December 1994, flying as pilot on STS-88 in 1998 (the first International Space Station (ISS) assembly mission) and on STS-105 in 2001. Following STS-88, Sturckow served as Crew Commander on STS-117 in 2007 and STS-128 in 2009. After retiring from the Marines while on board the ISS, Sturckow served as Deputy Chief of the Astronaut Office for the final Shuttle missions.

Mike Masucci

Before joining Virgin Galactic, Masucci, a retired USAF Lieutenant Colonel, was a Citation X Captain with XOJET Inc., a private airline company. Like Sturckow, Masucci has accumulated a considerable amount of military operational and test-flying experience

7.1 Former NASA Space Shuttle commander Frederick "CJ" Sturckow is the first astronaut to be selected from NASA's ranks by Virgin Galactic. Courtesy: NASA with more than 9,000 hours logged in over 70 types of aircraft. After completing the USAF Test Pilot School in 1993 he served as a U-2 pilot and helped develop and test the aircraft's glass cockpit and power-upgrade programs. He also instructed in the F-16 and T-38 aircraft at the USAF Test Pilot School.

Pilot-astronaut duties

Virgin Galactic's pilot-astronauts' primary duties are to operate SpaceShipTwo in accordance with government regulations and company policies and procedures, and deliver a safe suborbital spaceflight service [1]. It sounds like a simple job description, but it involves myriad tasks. The pilots are responsible for flight-planning, coordinating Mission Control activities, ground-to-air support, and the full spectrum of training obligations. For example, flight-planning requires coordinating route planning and airspace with Spaceport America and the local Federal Aviation Authority (FAA) Air Traffic Control, while Mission Control tasks include ensuring the continuity of the operation by ensuring personnel are informed of what is going on [1]. Then there is the training of new company pilot-astronauts to consider. This includes the supervision of ground and flight training and implementation of improvement programs for Virgin Galactic's pilot-astronaut's. The pilot-astronauts are also involved in training customer-astronauts in the days leading up to a flight to ensure familiarity with the communications systems, seat and harness mechanisms, and flight procedures. During these pilot-interaction sessions, chances are the pilots will emphasize the reseating procedure discussed earlier [1]. Mackay and his team are also involved in the development and flight testing of SpaceShipTwo. In this role, they assist with the spacecraft design, flight testing, and introduction to service of the new SpaceShipTwo. On top of all those tasks, the pilots are responsible for evaluating SpaceShipTwo's systems, handling qualities, performance, and pilot workload. And, in preparation for the start of revenue flights, Masucci and Co. will be establishing recruitment standards for the next generation of pilot-astronauts and assist in the selection and training of this group of pilots. This will require developing company manuals, defining new operating procedures, mission rules, and – especially important in the wake of the SpaceShipTwo accident – refining new in-flight emergency response procedures.

PASSENGERS: THE RICH AND FAMOUS

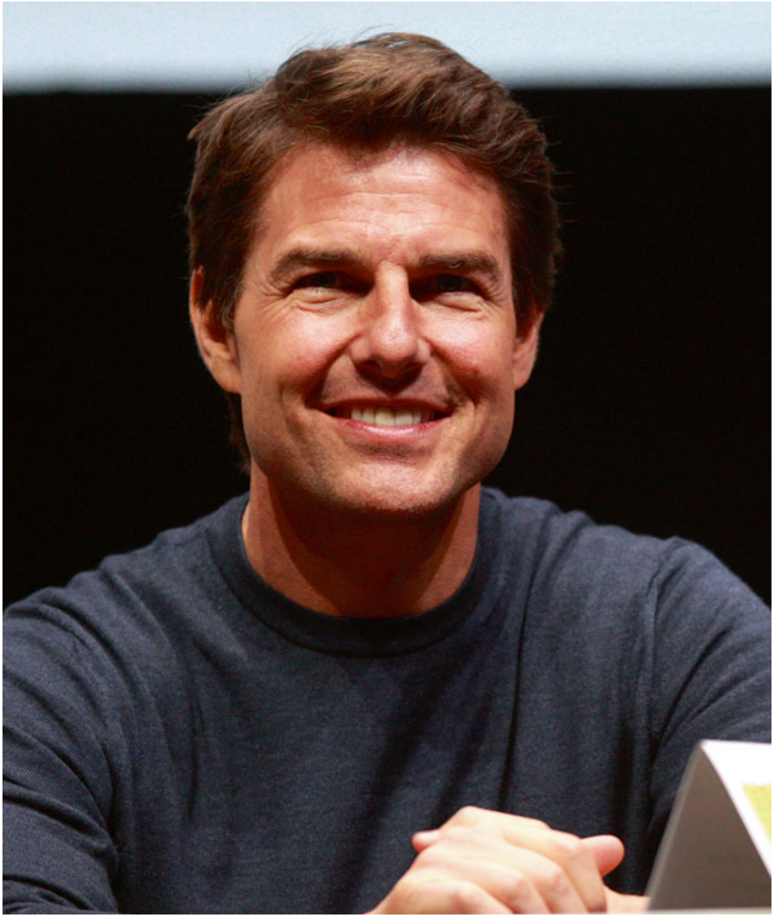
Movie director Bryan Singer is going. So is socialite Paris Hilton and actress Kate Winslet. Princess Beatrice is signed up to become the first royal in space, while science-fiction fan Tom Cruise will also *probably* be among the first few to join one of the most exclusive clubs in the world. *Probably* – because Virgin Galactic's passenger list is confidential. Having said that, among the rumors there are plenty of celebrities who have confirmed their flights. For example, Ashton Kutcher was announced as the 500th passenger. It's also rumored that Leonardo DiCaprio (see sidebar), Brad Pitt, and Angelina Jolie have paid for tickets. Yes, that's right: they paid, because it doesn't matter how famous you are, Branson is in the business of making money, so no free trips on this spaceship. Unless your name is Kate Winslet. Her ticket is said to be a thank-you gift for rescuing Branson's 90-year-old mother Eve from a fire at his Necker Island hideaway in August 2011 after lightning struck the house. But it's not just budding celebrities who have signed up. The list, which numbers more than 600 (another 100,000 customers have registered their interest on Virgin Galactic's website), also includes politicians, business executives, famous sportsmen, and scientists. Here's a snapshot of a few of them.

> With so many celebrities scheduled to fly on SpaceShipTwo, it wasn't surprising when a trip to space to fly with one of them was auctioned off. That's what happened in May 2014, when, as part of an effort to raise money for research for AIDS treatment, Leonardo Di Caprio auctioned off a voyage up to space with him to the highest bidder at an AIDS fundraiser event in Cannes. One wealthy bidder paid nearly 700,000 Euros (~US$1million) for the seat next to the famous *Wolf of Wall Street* actor. Interestingly, the auction came after the news SpaceShipTwo might not make it to the 100-kilometer space threshold.

Who might be flying into space?

Virgin Galactic's passenger list includes the rich and famous but, the media being the media, much of the attention has focused on actors, so let's start with them. Some of the actors rumored to have bought a ticket, such as Tom Hanks, have made it to space on screen (*Apollo 13*), so it will be interesting to see what they make of the real thing. But, contrary to the chitchat, Hollywood star Tom Hanks, a well-known space enthusiast and a member of the board of directors of World Space Week, dismissed Virgin Galactic flights. Asked in 2013 if he fancied a trip on SpaceShipTwo in an interview to promote his latest film *Captain Phillips* with London magazine *Shortlist*, he said: "No, I don't fancy that because it's not a long enough flight for me. I'd do it if they were going to go up for 10 orbits or something but to go up and then come down, that would be far too tantalizing, with not enough pay-off." Another major movie star rumored to have bought a ticket is Tom Cruise (Figure 7.2). Cruise, a big spaceflight fan, has starred in several science-fiction films including *Minority Report*, *War of the Worlds*, *Oblivion*, and *Edge of Tomorrow*. Unlike fellow A-lister Hanks, Cruise is planning on buying a ticket on SpaceShipTwo but wants to see a few passengers test it out first.

While Hanks is waiting for Virgin to offer orbital rides, a number of his fellow A-listers are rumored to have signed up, including Angelina Jolie (Figure 7.3) and Brad Pitt, and Victoria Principal, star of the phenomenally successful show *Dallas*. She became a pin-up after landing the role of Pamela Ewing in the drama *Dallas* in 1978, and nowadays divides her time between racing cars and working as a skin-care magnate. Space travel has always been her dream though: 30 years ago she wrote a movie script about the first female



7.2 Tom Cruise at the 2013 San Diego Comic Con International in San Diego, California. Credit: Gage Skidmore

astronaut, and one of her favorite movies is *The Right Stuff*. All these movie stars adding their names to the manifest is great news for Branson, not only because it endorses the product, but it also gives Virgin Galactic another opportunity to plug the business venture.

The Rich and Not-So-Rich Who May or May Not Be Ticket-Holders

Niki Lauda (Austria), three-time World Formula 1 Champion

Niki Lauda (Figure 7.4) has done it all. Well, nearly. After retiring from Formula One racing a double world champion in 1979, he came back in 1982 and won the championship again two years later. Then he retired from racing again, ran his own airline

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7.3 Angelina Jolie. Credit: Cancillería Ecuador/Ecuador Foreign Ministry

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(Lauda Air), acted as a consultant to Ferrari, managed the Jaguar Formula 1 team, worked as a commentator for German-language station RTL, and wrote four books. Now in his sixties, Lauda is waiting his turn to become an astronaut.

Bryan Singer (US), Hollywood movie director

Bryan Singer (Figure 7.5) got the idea of buying a ticket on SpaceShipTwo while planning a Shuttle disaster scene for his movie *Superman Returns* [3]. He could have called NASA for advice but instead dialed Branson, later admitting it was an excuse

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7.4 Daniel Brühl, Niki Lauda, and Peter Morgan at the premiere of Rush in Vienna, Austria, 30 September 2013. Credit: Elena Ringo

7.5 Bryan Singer at the 2013 San Diego Comic Con International in San Diego, California. Credit: Gage Skidmore

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to talk to the entrepreneur. Singer, whose other films include *X-Men* and *The Usual Suspects*, met Branson at a hotel in Australia where Branson described his plans to offer commercial spaceflights [3]. Singer, a long-time science-fiction fan whose favorite TV series is *From the Earth to the Moon*, didn't hesitate.

Stephen Hawking (UK), former Lucasian Professor of Mathematics at the University of Cambridge and author of A Brief History of Time

Even if you don't keep a close eye on developments in the world of physics, chances are you've heard of Stephen Hawking, who has a knack of making diabolically complex concepts accessible to the layman – see *A Brief History of Time*. In his long and distinguished career, Hawking, who has been living with neurogenerative disease for decades, has racked up all sorts of awards: induction into the Royal Society, the Pius XI Gold Medal for Science, and the Hughes Medal from the Royal Society. He was also awarded the US Presidential Medal of Freedom. In 2007, at the age of 65, he got to take the ride of a lifetime, thanks to the Zero-G Corporation. Hawking enjoyed the experience so much he signed up Virgin Galactic. Hawking's health will be an issue, just as it was for the zero-G flight, and medical staff will most likely have to ride along.

Alan Watts (UK), Managing Director GE and first air miles astronaut

Two million. That's the number of air miles clocked up by British businessman Alan Watts to become the first air miles astronaut. Over a period of six years, Watts made 50 Upper Class flights to his holiday home in Florida to rack up those miles [4]. He also spent thousands of pounds on a Virgin credit card. When Virgin contacted Watts to let him know he had qualified for a free spaceflight, he thought it was a crank call.

Edward Roski Jr (US), real estate developer and sports team co-owner

The billionaire and part owner of the Los Angeles Lakers has climbed to Base Camp on Mount Everest, biked across Mongolia, and toured the wreck of the *Titanic*, where the real estate magnate spent six hours three kilometers below the surface, exploring the famous ocean liner. After visiting one of the deepest spots on Earth, Roski thought it would be nice to go up in the other direction and snagged ticket #128.

James Lovelock (UK), atmospheric scientist

Lovelock (Figure 7.6) is best known for proposing Gaia theory, which proposes Earth is a living, self-regulating organism. Having worked at the Jet Propulsion Laboratory, he had the opportunity to marvel at images of the Earth transmitted by orbiting spacecraft, so now he's looking forward to the chance to view Earth from a different angle. When he received a letter from Branson inviting him to go, Lovelock didn't blink, despite his age – he'll be 90+ when he flies.

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7.6 James Lovelock is an environmentalist and futurist best known for proposing the Gaia hypothesis. Credit: Bruno Comby

Lina Borozdina-Birch (US), chemist

For Borozdina-Birch, a chemist for a pharmaceutical company, visiting space is one of two dreams she's had since she was a girl in the former Soviet Union (the other dream was to visit Disneyland) [3]. In 1991, she came to the US and sought asylum and wasted no time visiting Disneyland. The spaceflight had to be put on hold though. Until 2004. That was when her husband, Jo, contacted Virgin on her behalf, to discuss buying a ticket. After some deliberation, the couple decided to finance her ticket by taking out a second mortgage on their home in San Diego [3].

While the celebrity corps wait for revenue flights to ramp up, for some the wait has been too long. In 2011, venture capitalist Alan Walton asked for a refund on his Virgin Galactic ticket. For someone who has climbed Mount Kilimanjaro, and sky-dived over Mount Everest, a suborbital rocket ride to enjoy a few minutes of zero-G would have been the adventure to end all adventures. But, having waited seven years to fly, Walton, who was one of the Founders, decided enough was enough and asked for a refund. And Walton isn't the only ticket-holder to voice frustration at Virgin Galactic's reluctance to give a date for their flight. Lebanese technology tycoon Bassim Haidar (*http://lebanonsfirstastronaut.com*) wanted to be the first Arab in space, so he signed up right away but, like everyone else, he hasn't been able to get a flight date from Branson. Fortunately for Virgin Galactic, the issue of the odd multi-millionaire being disgruntled because their space flight has been delayed is a relatively minor issue because Branson and his PR team know how to soothe upset ticket-holders. Until the SpaceShipTwo accident, Virgin Galactic was probably even less concerned about the delays because there were no competitors out there that were likely to fly for a number of years. By mid-2014, XCOR still hadn't mated the cockpit of its Lynx spaceplane to the fuselage and test flights weren't due to start until July 2015. Following the SpaceShipTwo accident, the delay to suborbital flights will inevitably stretch to a few more years, by which time XCOR will likely have flown its first passengers. For Virgin Galactic passengers, all this waiting must seem a far cry from the heady days of 2004 when the promises of space travel for the masses reached a euphoric pitch.

VIRGIN GALACTIC'S PROMISES AND BROKEN DREAMS

Back in 2004, those who witnessed the epic flights of SpaceShipOne might have felt as if they were living in the future. But 10 years later, in the second decade of the 21st century, commercial space travel has yet to happen. While Virgin Galactic had a few technical and regulatory hurdles to jump over, after 10 years of waiting, there was the perception that the company was just one of those companies promising one of those perennial dreams of the future and not delivering. After all, Richard Branson had spent over a decade insisting he was just a few years away from providing commercial spaceflights. And many wanted so badly to believe him. But those who had been following the Virgin Galactic story knew they had to keep their expectations in check.

1999

"Virgin employees have been researching the feasibility of offering space flights for about $100,000 each, as soon as 2009." That was Virgin Atlantic spokesman, Paul Moore, talking to the *Bloomberg News* on 19 May 1999. Less than a week later, on 24 May, the *Cedar Rapids Gazette* carried the following Branson story: "Richard Branson, ruler of the Virgin empire, is planning a hotel in space and has registered a company, Virgin Galactic Airways, to fly guests into orbit." Branson was quoted as saying: "I hope in five years a reusable rocket will have been developed which can take up to 10 people at a time to stay at the Virgin Hotel for two weeks [5]."

2004

Five years later, after the flights of SpaceShipOne, the story was a little more believable. On 28 September 2004, the *Associated Press* featured the following sound-bite: "Airline mogul and adventurer Richard Branson announced plans Monday to boldly go where no private transport company has gone before – into space. Branson's Virgin Group said it would offer commercial space flights by 2007, with Branson himself joining the inaugural journey [6]."

2005

A year later, on 15 December, it was the *Associated Press* again, reporting: "Virgin Galactic officials said 100 people already have paid $200,000 apiece to fly into space. They include actress Victoria Principal, who told the news conference she looked forward to being on the first civilian flight of Virgin Galactic, perhaps as soon as 2008 [7]."

2006

On 8 August, the *Associated Press* ran a piece about Trevor Beattie, Britain's most recognizable face in advertising and the man in charge of the advertising for Virgin Galactic. "The buzz is about Virgin Galactic, the fledgling spaceline founded by British airline mogul Sir Richard Branson. It strategically chooses its clients to be the public face of the company in an effort to draw attention to and, it hopes, corner the infant space-tourism market. Take Trevor Beattie, a London-based advertising guru with a trademark mop of curly black hair. Beattie was in Los Angeles at a space conference this spring hyping a flight he expects to take in 2008 – the program still awaits federal approval and the completion of its rocket-ship [8]." Fast forward eight years and Virgin Galactic was still waiting federal approval because it still hadn't received its re-entry license.

2007

On 14 February, five months before the deadly Scaled Composites accident, the *Doylestown Intelligencer* reported: "Branson and some family members will make the first passenger flight, in mid-2009. Regular flights will follow. The plan is to fly once a week for the first year, then twice a week, and eventually twice a day [9]." That date changed following the tragic events on 26 July, when an explosion killed three Scaled Composites employees, as reported by the *Associated Press* on 27 August: "Stephen Attenborough, Virgin Galactic's astronaut liaison, reassured the founders in an e-mail that the accident's impact on the first commercial spaceflights – expected in late 2009 or 2010 – will be 'minimal' and that it was 'business as usual' [10]." In reality, it was anything but – 2010 stretched to 2011 and 2012 and … well, you get the picture.

2008

For a while, it seemed as though Attenborough might be right following the 2008 unveiling of the WhiteKnightTwo mothership. On 27 July, the *Associated Press* reported: "The rollout – a year after a deadly accident at Rutan's test site – marks the start of a rigorous flight-test program that space-tourism advocates hope will climax with the first suborbital joy rides by the end of the decade. More than 250 wannabe astronauts have paid $200,000 or put down deposits for a chance to float weightless for a mere five minutes."

2009

The following year, the buzz was all about the construction of Spaceport America. Once again, the event featured a prediction of when revenue flights would start: "Gov. Bill Richardson and others are preparing to break ground Friday on construction of a terminal and hangar facility at the world's first commercial spaceport built with the idea of launching private citizens into space for profit. Some 250 people are lining up to pay $200,000 each to take the trip as early as next year" (17 June 2009, *Associated Press*).

2010

Next year rolled around but there were *still* no flights on the horizon, although plenty of people were making predictions: "'If the plans of people like Sir Richard Branson of Virgin Galactic are accurate, in the next three to five years there will be very frequent space tourism launches,' said Scott Hubbard, a professor of astronautics and aeronautics at Stanford University" (22 August 2010, *Associated Press*).

2011

Seven years after the flights of SpaceShipOne, Spaceport America was open for business and almost 400 customers had forked out deposits totaling US$50 million. Once again, Branson was confident: "We're very, very close now – with the spaceport finished, with the mother ship finished, with the spaceship finished, with the final tests going on - to starting commercial spaceship travel" (18 October 2011, *The Telegraph*).

2012

A year later, the story was much the same, only by now more than 500 passengers had paid a US$20,000 deposit on the US$200,000 suborbital flight. George Whitesides was quoted as saying that Galactic was "'roughly on track' for a late 2013 commercial launch" (16 June 2012, *Techcrunch*).

2013

On 12 June, CNN reported: "Virgin chief Richard Branson has put a time frame on his plan to launch tourists into space, claiming he and his family will blaze a trail for hundreds of fare-paying passengers by blasting off in December 2013."

2014

That time frame, like so many others, came and went, and we found ourselves in 2014, more than 10 years after SpaceShipOne's record-setting flight. The year started promisingly, with the resounding success of SpaceShipTwo's third rocket-powered supersonic flight, Virgin Galactic reporting they had accomplished all of the test-flight objectives: "With each flight test, we are progressively closer to our target of starting commercial service in 2014," George Whitesides reported. SpaceShipTwo ticket-holders waited expectantly for more test flights, but February slipped by, then March. Then April and still no test flights. What was the hold-up this time? Well, according to the *Sunday Times*, cracks had been discovered in WhiteKnightTwo's wings. The article explained that the cracks were discovered during an inspection conducted after Virgin Galactic took possession of WhiteKnightTwo from Scaled Composites. The cracks were along the spars (Appendix I) where the spars connect with the fuselage. Because the cause of the cracks was uncertain, the engineers were in uncharted territory, although Virgin Galactic denied there were cracks in the wings, claiming they were adhesive imperfections that had been repaired.

Worse was to come.

On 12 May 2014, the *International Business Times* ran a story suggesting the wing defects would delay the commercial spaceflight operation until at least 2015, but that even when flights did take off, passengers might technically not be flying into space. That bombshell came from a report in the *Sunday Times* that claimed to have seen the customer contract Virgin Galactic had drawn up: in the small print, it guaranteed to fly passengers to an altitude of "at least 50 miles". While this altitude is high enough to experience weightlessness, the universally accepted boundary between Earth's atmosphere and space (the Kármán Line) lies at an altitude of 100 kilometers above sea level [6]. So, anyone flying with Virgin Galactic to an altitude of "only" 50 miles[1] won't be eligible for astronaut wings. George Whitesides explained the situation to the *International Business Times* thus:

> "NASA and the US Air Force have a long tradition of celebrating everything above 50 miles (~80km) as spaceflight, and we look forward to joining those ranks soon as we push onward and upward. We are still targeting 100km. As we have always noted, we will have to prove our numerical predictions via test flights as we continue through the latter phase of the test program. Like cars, planes, and every other type of vehicle designed by humans, we expect our vehicle design and performance to evolve and improve over time. When SpaceShipTwo reaches space for the first time – which we expect will happen just a few short months from now – it will become one a very small number of vehicles to have ever done so, enabling us to commence services as the world's first commercial spaceline; our current timetable

[1] The reason is SpaceShipTwo's hybrid rubber–nitrous oxide engine performs poorly. Very poorly. So bad that the vibration in the version they used for the first three test flights could have torn SpaceShipTwo apart if it had been fired for full duration. Initially, Virgin Galactic planned to fix it by modifying SpaceShipTwo with additional helium tanks that would dampen the vibration. But the additional weight would have affected engine performance, which would have led to lower altitudes, so it wasn't surprising in May 2014, after months of speculation, that Virgin Galactic announced it would be switching to a new plastic fuel. Instead of the hydroxyl-terminated polybutadiene (HTPB), SpaceShipTwo will burn a polyamide-based fuel, which the company describes as a "benign thermoplastic". There was no single issue that caused the switch: Virgin Galactic simply saw better performance on a few different criteria, which translated into an increased apogee.

has Richard's flight taking place around the end of the year." And then 2014 turned from bad to worse when, on 31 October, SpaceShipTwo disintegrated in the sky. Branson was quoted in the media as saying 'the dream lives on'. Perhaps it will. But it will likely be many years before that first historic Virgin Galactic flight—with passengers aboard—takes place.

Spaceflight is a tough business. Building a commercial spaceship *is* rocket science so it's not really surprising that something like this could happen. The important point is that Branson is trying, forging the road ahead of anyone else. Mock him all you want but don't forget that SpaceX was written off dozens of times by ill-informed media before finally prevailing. Of course, SpaceX didn't kill four people along the way, but technological development can be hard, expensive, dangerous, and much slower to realize than the media would like it to be, but how many other companies do you see blazing a trail to suborbital space? Exactly. Spaceflight is a tough business.

7.7 George Whitesides. Courtesy: NASA

PERSONNEL

We've talked about the pilots and the celebrity passengers and we'll get to the other passenger categories shortly but, before we do, it's worth highlighting a couple of the key personalities in the Virgin Galactic enterprise. You'll have noticed the name George Whitesides (Figure 7.7) a few times already. George, who previously served as Chief of Staff for NASA, is the CEO of Virgin Galactic and is responsible for guiding all aspects of the company to commercial operation. In addition to this role, George is usually the one the media come running to for a sound-bite whenever there is a delay or a problem, so he had his hands full in 2014.

Another former NASA executive (and Flight Director) is Mike Moses, who is the Vice President of Operations. Moses, a two-time recipient of the NASA Outstanding Leadership Medal and a highly regarded leader in the human spaceflight arena, oversees the execution of operations of Virgin Galactic's suborbital spaceflight venture. Before joining Virgin Galactic, Moses served as the Launch Integration Manager from 2008 until the final Shuttle mission in July 2011. This job meant he was responsible for overseeing all Shuttle processing activities from the time of landing of one Shuttle to the launch of the next. He was also chair of the Mission Management Team and it was Moses who was responsible for launch decision authority for the final Shuttle 12 missions, overseeing the flights of 75 astronauts. In his Virgin Galactic role, Moses will develop and lead the team responsible for spaceship operations and logistics, flight crew operations, customer training, and spaceport ground operations [10].

PASSENGERS: THE SCIENTISTS

With so much media interest focused on Virgin Galactic's list of celebritynauts, SpaceShipTwo's capabilities for microgravity research have largely been overlooked. That's a shame, because with 14 cubic meters (the most of any crewed suborbital vehicle under development) of cabin volume available for experiments, SpaceShipTwo's cabin can fit the equivalent of 20 Space Shuttle middeck lockers and still have room for a flight-test engineer [11]. SpaceShipTwo can also carry 600 kilograms to an altitude of up to 110 kilometers, so it's no surprise that scientists have taken an interest in flying their experiments on the spacecraft. The first to do was the Southwest Research Institute (SwRI)[2] which, in February 2011, announced an agreement to send three scientists as payload specialists on board SpaceShipTwo. The program, supported by SwRI funding, is led by SwRI Space Science and Engineering Division Associate Vice President Dr. Alan Stern (Figure 7.8).

The SwRI agreement was an innovative and groundbreaking event in the world of suborbital spaceflight because it represented another step closer to an era of routine field work in space research. With its contract, SwRI and its small corps of suborbital astronauts will

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[2] SwRI made full deposits for two researchers to fly on SpaceShipTwo, with the intent to make similar arrangements for an additional six seats for a total value of US$1.6 million.

7.8 Alan Stern following his Starfighter training. Courtesy: SwRI

perform pathfinder experiments that will lay the groundwork for those who follow [12]. Along the way, Stern and his colleagues will define best practices, safe processes, optimum flight profiles, and open interface standards that will be a key trigger that opens up this research marketplace [12]. And SwRI isn't the only organization that has recognized the importance of SpaceShipTwo as a research platform: NASA has its Commercial Reusable Suborbital Research Flight Opportunities program, which will provide all sorts of opportunities for scientists to fly suborbital. The SwRI agreement not only signaled the scientific potential of SpaceShipTwo, but also highlighted the role of science flights as an important growth area for Virgin Galactic. Which is a good thing because there is a limited supply of Justin Biebers and Paris Hiltons! We'll get to the nuts and bolts of how science flights will operate in Chapter 8, but first let's meet Stern and his colleagues, who in all likelihood will become history's first commercial suborbital scientists (Alan hedged his bets and also bought tickets for the Lynx, which will probably fly ahead of SpaceShipTwo Mk II).

Dr. Alan Stern

Dr Stern is one of the most recognized personalities in the suborbital spaceflight arena and spaceflight in general, so it shouldn't surprise you to know he was named in the Time 100's list of most influential people. A planetary scientist, space program executive, and author, Dr Stern is also the Associate Vice President at SwRI. Among his other interests is an aerospace consulting firm that counts Blue Origin, the Odyssey Moon Google Lunar X-Prize team, and Virgin Galactic as former and current clients. As NASA's chief of space and Earth science programs between 2007 and 2008, Dr. Stern directed a US$4.4 billion organization that included 93 missions and a program of more than 3,000 research grants. He has published more than 200 technical papers and 40 popular articles, and given over 300 technical talks and over 100 lectures and speeches about astronomy and the space program. He has worked on spacecraft rendezvous theory, terrestrial polar mesospheric clouds, and studies of tenuous satellite atmosphere, and he is also the Principal Investigator (PI) of NASA's Pluto-Kuiper Belt mission [12, 13]. To commercial spaceflight devotees he is perhaps best known for conceiving the Next Generation Suborbital Researcher's Conference (NSRC), which brings the research and education communities together with suborbital vehicle operators and funding agencies. Thanks Alan.

Dan Durda

Dan (Figure 7.9) is one of SwRI's planetary scientists and an Adjunct Professor in the Department of Sciences at Front Range Community College [14]. Among his many research interests are the collisional and dynamical evolution of main-belt asteroids and Kuiper belt comets. Before taking up his position at SwRI, Durda was Director of the Student Teaching Observatory at the University of Florida and Director of Public Relations for the Department of Astronomy and an Adjunct Professor in the Department of Natural Sciences at Santa Fe Community College in Gainesville [14]. An avid pilot and scuba diver, Durda is an instrument-rated pilot and holds multiple certifications in scuba- and cave-diving from various certifying agencies, including NAUI and PADI [14]. He has authored several scientific publications and has served as a manuscript referee for articles published in *Icarus, Science, Planetary and Space Science,* and *Earth, Planets and Space*.

Cathy Olkin

SwRI's third suborbital scientist astronaut is also a planetary scientist with interests in icy outer solar system worlds. As part of her work, Dr. Olkin uses near-infrared and infrared spectroscopy to study icy surfaces and stellar occultations to investigate tenuous atmospheres. A member of Dr. Stern's New Horizons team, Dr. Olkin (Figure 7.10) has worked at SwRI since 2004 [14]. Before arriving at SwRI, she worked at the Lowell Observatory, where she studied the rings of Uranus and Saturn using stellar occultation observations and STIS spectra, and measured the mass ratio of Charon to Pluto using HST Fine Guidance Sensors. She completed her NASTAR training in May 2011.

SwRI suborbital payload specialist team

Together, Drs. Stern, Durda, and Olkin comprise SwRI's suborbital payload team, and their training and experiment preparations are going well. All have passed their FAA flight physicals and checked off centrifuge and zero-G training at NASTAR in addition to flights (lucky them!) on board the Starfighter F-104 jet. In addition to the training, SwRI's

7.9 Dan Durda. Courtesy: SwRI

payloads, which are designed to assess the ability of suborbital vehicles for science applications are ready to go. And, as with any space mission, the SwRI flight team has its own mission patch (Figure 7.11).

SPACE RACE

Not a celebrity? Don't have US$250,000 lying around? No problem. A reality TV show may be able to help because NBC has picked up *Space Race*, which will follow space fans as they compete to win a free ride on SpaceShipTwo [15]. Veteran reality TV show producer Mark Burnett, the mind behind *Survivor* and *The Apprentice*, will serve as executive producer. Some of you may remember a similar show being pitched back in the Mir era. The space-themed reality TV series was entitled *Destination Mir*, with the winner flying to Russia's Mir space station. That deal literally went up in flames in 2001 when Mir re-entered Earth's atmosphere [15]. Word is that *Space Race* will be reminiscent of *Survivor*, so it could get ugly. Having said that, the show should boost public interest in the

7.10 Cathy Olkin (on the right). Courtesy: SwRI

commercial space program in a manner echoed by no less a celebrity than Homer Simpson. *The Simpsons* fans (myself included) will no doubt recall the classic episode *Deep Space Homer*, which featured an under-funded NASA increasing public awareness of the space program by launching average American Homer Simpson into orbit. It could be that *The Simpsons* cartoon was prophetic about space travel! And, on the subject of television shows, Virgin Galactic has inked an exclusive deal with NBC Universal that will see their first commercial flight aired on TV. The flight will be part of a special three-hour edition of the *Today Show*, probably taking us through how the company was created, what Virgin Galactic astronauts can expect, and so on – just like this book but in not as much detail! Viewers will probably get a walk-through of the new SpaceShipTwo, and the first tourists will probably be interviewed [16]. You should be able to watch the flight on NBC, as well as other NBC Universal platforms like MSNBC, CNBC, SyFy, and NBCNews.com [16].

THE FLIGHT

Not a Virgin Galactic ticket-holder and wondering what the flight will be like? Passengers will begin their trip to space at Spaceport America, where they will spend three days training, acclimatizing themselves to the experience of space travel. This will involve spending

7.11 SwRI's patch symbolizes suborbital flight with its arch trajectory, and the manned nature of the flights with the constellation Orion. SwRI's logo is featured below the suborbital trajectory together with the stars and stripes, which symbolizes the American nature of the impending suborbital industry. Courtesy: SwRI a fair amount of time in a simulator, which will reproduce the myriad thumps and bangs these soon-to-be Virgin Galactic astronauts will hear during their flight. For example, most passengers won't know what the sound of a spaceship's landing gear being retracted sounds like. Not to worry – that's what the simulator is for. And that simulator time will be invaluable because the spaceflight will bombard these astronauts-in-waiting with so much that's new there is a chance of sensory overload. But, thanks to time spent in the simulator, their memory should be able to make sense of the new sensations and sounds and fix them in place. Passengers will also be given a series of training activities that will include scripting the spaceflight minute by minute and vital communication drills. Chances are passengers will have the opportunity to familiarize themselves with the vehicle that will be taking them into space. What will they see when the crawl around the cabin? Well, perhaps one of the most striking features of the SpaceShipTwo cabin is the large windows. In the early days of Virgin Galactic, designers polled the first ticket-holders, asking them what they wanted from the experience. One of the most resounding responses was that passengers wanted to see Earth from space and they wanted a good view. A really good view. So Virgin Galactic put in big windows. Lots of them. The next request was for comfort and a suitably cool interior design. So Virgin Galactic appointed Adam Wells, the man who designed the Virgin Atlantic flat bed and the purple mood-lit Virgin America cabin. Wells opted for a muted white and silver combination – colors that wouldn't draw attention from what was happening outside the window. The rest of the cabin is fairly spartan – no plush leather seats here (too much weight). And, on the subject of those seats, Virgin Galactic passengers will be drilled on how to use their seat properly – as in being able to get in and out of it without assistance – because there are no flight attendants on these flights. Why is there so much emphasis on the operation of a seat? Well, these seats have quite a lot of technology (most of it adapted from automotive designs) built into them, which allows the seats to tilt backwards and forwards in conjunction with the phase of flight. It's a system that removes a lot of the Gs during the boost and re-entry phases because, if the passenger is lying flat, the Gs are predominantly in the feet-to-head direction, which is a lot easier to deal with [17]. Passengers will also learn how to unfasten their belt and safely return to their seat when it's time to go home [17]. While this will seem easy on the ground, in space the task may prove a little more challenging and time-consuming. But, with SpaceShipTwo's smoother G-transitions relative to parabolic flights, maneuvering into and out of seats shouldn't take more than 15–20 seconds – provided the passenger isn't stricken with space motion sickness.

Let's take a moment and discuss this problem. In 1985, during his flight on the Shuttle *Discovery*, Senator Jake Garn became very ill for reasons often attributed to motion sickness, or space adaptation syndrome. After his return, some NASA personnel began measuring the intensity of space sickness in *Garns*. By that scale, one *Garn* represents the maximum level of space sickness anyone can attain. Most astronauts may suffer one-fifth or one-tenth of a *Garn*. If that. And Virgin Galactic passengers? Well, Virgin Galactic is crossing its fingers that no passenger suffers one *Garn*. Or any fraction of a *Garn* for that matter. But, just in case, anti-motion sickness medication will be available, although the decision to use preventative medication, and which form of medication to use, will be made on a case-by-case basis by each passenger.

Launch day

Launch day will begin with breakfast served in the spaceport restaurant. While you may have an image of spacefarers enjoying a breakfast of steak, eggs, and coffee, the reality will be somewhat different because most passengers will probably be too damn nervous to eat anything more than half a slice of toast! But breakfast will be a mandatory photo opportunity for the media people – this is a Virgin flight after all! So most passengers will probably fake a carefree smile and pretend to eat. After the meal, the crew will perform one final pre-flight briefing before reviewing the weather forecast.

Unlike NASA astronauts, whose first challenge wasn't dealing with the acceleration stress following launch or adjusting to weightlessness, but donning the rather cumbersome launch and entry suit, Virgin Galactic's suborbital astronauts only have to contend with slipping on a regular flight suit topped off with a helmet. But there will be suit techs available to check the integrity of the suit and the communication system. While the passengers suit up, the vehicle will be inspected in the same way a regular aircraft is inspected. Using cameras and sensing devices, the pilots will methodically check every surface of the vehicle, looking for abnormal temperature readings or anything else that might indicate a problem. Once they finish their inspection, they will report to the Launch Director.

Once suited up, the passengers will wander over to the vehicle and find their seats. No closeout crew for this group of spacefarers – just a simple tug of the straps and snap into the communication system. The hatch will be closed and a moment later the crew's ears will pop as the cabin is pressurized. Meanwhile, back in Mission Control, the flight director will thumb through the flight procedures manual, which documents the take-off procedures (Table 7.1) and the instructions to be followed in the event of a scrubbed take-off, preplanned contingency procedures and emergency instructions.

Boarding

No announcements about the captain having turned on the "Fasten Seat-Belt" sign and no reminders to stow your carry-on luggage in an overhead bin on this flight. Instead, passengers will simply be told to clip into their seat. Before the hatch is closed in a regular commercial flight, the captain usually introduces himself and explains the flight. What the pilot will say on this flight is anyone's guess but it may sound something like this:

> "Good morning ladies and gentlemen and welcome on board SpaceShipTwo. This is your pilot speaking and I thought you might be interested in some of the flight details. Our flight time this morning will be two hours and we expect to arrive in space on schedule at 0815 local time. Weather en route couldn't be better. The temperature at our destination, about 100 kilometers above us, is minus 73 degrees Celsius, with clear black sky. On behalf of all our crew, thank you for choosing Virgin Galactic today. We hope you have a wonderful flight."

Safety demonstration

There will be no flight attendants to demonstrate safety features or to point out the emergency exits, so the pilot will probably remind passengers about contingency

Table 7.1. Launch countdown milestones.

Time		*Event*
T–HH	*T–MM*	
02	00	Crew eats breakfast and conducts media interviews
01	30	Crew suit-up begins assisted by suit technicians. Crew takes anti-motion sickness medication
01	00	Mission management team meeting
00	50	Avionics checkout and pilot walk-around of SpaceShipTwo and WhiteKnightTwo
00	45	Crew weather briefing
00	40	Crew ingress/board vehicles and commence pre-flight checks
00	35	Flight crew equipment stow
00	35	Communication activation
00	30	Crew and crew/cabin communication checks
00	25	Debris inspection
00	20	Take-off list
00	15	Apron clear of non-essential personnel
00	10	Final crew weather briefing
00	05	Hatch closure. Vehicle pressurized
00	05	WhiteKnightTwo taxis to runway
00	04	Mission Control take-off status verification
00	00	**Take-off**

procedures and the sequence of events in the unseating and reseating process. Perhaps the announcement will go something like this:

> "For your information, oxygen and cabin pressure are always being monitored. But, in the unlikely event of a decompression, follow the procedures practiced in your training and, in the equally unlikely event of an emergency, assume the brace position. Lean forward with your hands on top of your head and your elbows against your thighs. Ensure your feet are flat on the floor."

Take-off/ascent

Flying up to 15,000 meters attached to WhiteKnightTwo will be similar to any other plane ride, except for a heightened sense of anticipation. And it's a long spiral climb to 15,000 meters, made longer by the absence of an in-flight entertainment system and no flight attendants to hand out hot or cold drinks. The pilot may keep you informed (Table 7.2) of what is happening, but for the most part passengers will probably be left alone with their thoughts, contemplating what is to come. Once WhiteKnightTwo reaches target altitude, passengers will be able to see Earth's curvature, and they can begin to prepare themselves for uncoupling from the carrier aircraft, knowing that in a few moments they will be going from zero to 60 in half a second. A moment of silence will precede rocket ignition. It's about a three-second fall, but it will feel longer. Once the pilot fires the rocket, the acceleration will push passengers back into their seats: seconds after the rocket ignition,

Table 7.2. SpaceShipTwo transcript.

Time	*Speaker*	*Dialog*	*Notes*
08:00:00	Mission Control	Go for release and ignition	SpaceShipTwo pilot pushes control stick forward to prepare for release
08:00:03	WhiteKnightTwo pilot	Three. Two. One	
08:00:06	WhiteKnightTwo pilot	Release	
08:00:09	SpaceShipTwo pilot	Release	
08:00:10	SpaceShipTwo pilot	Armed	
08:00:11	SpaceShipTwo pilot	Fire	This will feel like the acceleration of a dragster on a race track. The difference will be that this "kick" will go on and on and on
08:00:20	Mission Control	Coming up on 10 seconds	Rocket engine burn time
08:00:21	SpaceShipTwo pilot	Copy	
08:00:29	Mission Control	Start nose-down trim	
08:00:41	Mission Control	Forty seconds	Rocket engine burn time
08:00:42	Mission Control	Trajectory looks good	Actual trajectory is tracked with predicted trajectory
08:00:45	SpaceShipTwo pilot	Copy	
08:01:01	Mission Control	Fifty seconds	Rocket engine burn time
08:01:03	Mission Control	Two hundred energy	Projected altitude (200,000 ft/60,960 m) SpaceShipTwo would reach if the rocket engine shut down
08:01:18	Mission Control	Three hundred thousand	Predicted altitude is 300,000 ft/91,440 m
08:01:23	Mission Control	Three twenty-eight	Predicted altitude is 328,000 ft/100,000 m
08:01:25	SpaceShipTwo pilot	Copy	
08:10:30	Mission Control	Three fifty. Shutdown	Rocket is still firing but pilot shuts it down. SpaceShipTwo will coast to 350,000 ft (106,700 m)
08:01:31	SpaceShipTwo pilot	Roger. Shutdown	By the time SpaceShipTwo passes 200,000 ft (60,960 m), there are virtually no measurable aerodynamic loads on the vehicle. At this point, the pilot will allow passengers to unstrap
08:01:40	Mission Control	Eighty seconds	Rocket engine has burned for 80 s
08:01:56	Mission Control	Feather is green	
08:01:57	SpaceShipTwo pilot	Feather unlock	
08:02:05	SpaceShipTwo pilot	RCS on	Reaction control system

(continued)

Table 7.2 (continued)

Time	*Speaker*	*Dialog*	*Notes*
08:02:15	SpaceShipTwo pilot	I show feather up	
08:02:17	Mission Control	We show feather up	
08:02:26	SpaceShipTwo pilot	Trim is set	
08:03:27	SpaceShipTwo pilot	One minute	This is the first audible update to passengers of how long they have been weightless
08:03:30	Mission Control	Current position is …	Mission Control will provide regular updates to the pilot about their location relative to the spaceport
08:03:35	Mission Control	Entry point is …	This gives the chase planes information about where SpaceShipTwo will re-enter
08:04:10	Mission Control	All systems in the green	
08:04:11	SpaceShipTwo pilot	Copy	
08:04:27	SpaceShipTwo pilot	Two minutes	This is the second audible update to passengers of how long they have been weightless
08:05:27	SpaceShipTwo pilot	Three minutes. Stow cameras and prepare for reseating	This is the third audible update to passengers of how long they have been weightless
08:05:57	SpaceShipTwo pilot	Passengers take your seats	
08:06:27	SpaceShipTwo pilot	All passengers seated. Seats reclined	
08:06:28	Mission Control	Copy	

08:06:54	Mission Control	Passing two sixty	SpaceShipTwo's altitude is 260,000 ft/79,250 m
08:07:26	Chase plane	Chase plane has a visual	
08:07:27	SpaceShipTwo pilot	Copy	
08:08:31	Mission Control	One fifty	SpaceShipTwo's altitude is 150,000 ft/45,720 m
08:08:37	SpaceShipTwo pilot	Three G	Re-entry G
08:08:41	Mission Control	Mach three	Mach speed
08:08:46	SpaceShipTwo pilot	Five G	
08:09:04	Mission Control	Seventy-five thousand	
08:09:27	Mission Control	Seventy thousand	
08:09:30	Mission Control	Feather when you're ready	
08:09:47	Mission Control	Sixty-three thousand	
08:09:57	Mission Control	RCS off	
08:10:00	SpaceShipTwo pilot	RCS is off	
08:10:01	Mission Control	Copy	
08:10:11	Mission Control	Fifty-four thousand	
08:10:21	SpaceShipTwo pilot	Feather is locked	
08:10:22	Mission Control	Copy	

passengers will be traveling at the speed of sound. As SpaceShipTwo rockets into the sky, WhiteKnightTwo, its job done, will head home. Meanwhile, SpaceShipTwo will accelerate from zero to 4,000 kilometers per hour in eight seconds. Passengers will experience a cacophony of noise (ear plugs will be mandatory) and bone-rattling acceleration that they will feel through their body until engine cut-off. At the instant the rocket motor shuts off, everything inside the cabin will become weightless. This is when the pilot will initiate the space phase of the mission, informing passengers they can get out of their seats and float around. When the spacecraft nears apogee, the sky will fade from blue to black and, with a touch of the reaction control system (RCS), the pilot will orient the spaceship so passengers get the best view of Earth. The passengers meanwhile will probably be making a beeline for one of the windows. They may notice the intense silence, because there is no noise in space, and SpaceShipTwo won't be operating any equipment. After spending up to four minutes (which works out to US$1,041 a second incidentally) looking at Earth, passengers will return to their seats for re-entry.

Descent/final

This is the G-force part of the trip. It's much less unpleasant if the Gs are concentrated in the feet-to-head direction so this is where Virgin Galactic's personalized seat configuration will help. The seating system reconfigures itself so there is no need for passengers to do much except align their bodies with the contours of the seat and sink into it. It will be completely intuitive.

Astronaut wings

Until very recently, the only people walking around with astronaut wings were those trained either by the military or civilian space agencies such as NASA. That changed on 21 June 2004, when the FAA issued the first pair of commercial astronaut wings[3] (Figure 7.12) to Mike Melvill following the final test flight of SpaceShipOne. Incidentally, Melvill was 63 years old that day so don't worry about being too old to be an astronaut! Three and a half months later, Brian Binnie became the second commercial astronaut when he also piloted SpaceShipOne. The identities of the next batch of commercial astronauts? Most likely they will be flying with Virgin Galactic, which raises the question: Will passengers also qualify for astronaut wings? Afraid not, says the FAA. The wings are only for the pilot and crew. Does that sound fair? Well … yes, it does. After all, passengers on airliners, which is where this commercial space business is leading to, don't receive pilot wings, do they? Perhaps it's a case of semantics. Prior to the rise of commercial airlines, anyone who flew in an airplane was an aviator and, if the trend seen in aviation holds true, then the term "astronaut" may be reinterpreted to be an occupational title and everyone else will be simply passengers. But that won't work for Virgin Galactic, who are looking to capitalize on the burgeoning

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[3] The FAA wings were suggested by Michelle S. Murray, an aerospace engineer in the aviation agency's Office of Commercial Space Transportation, which regulates businesses that are off the planet [18].

7.12 The FAA's commercial astronaut wings. A commercial astronaut is a person trained to command, pilot, or serve as a crewmember of a privately funded spacecraft [19]. The Fédération Aéronautique Internationale (FAI) defines spaceflight as any flight over 100 kilometers' altitude. Courtesy: US Government/FAA [19]

space-tourism market, because their marketing uses the astronaut designation as a selling point: the chance to become a fully fledged astronaut is a strong motivation for purchasing a ticket. So will the number of "astronaut" passengers dilute the value of the title? Perhaps not. Standard FAA wings have private pilot wings (slick), instrument-rated pilot (add a star on top), and commercial-rated pilot (add a star and wreath on top). They also have variations of the same FAA wing for Air Transport pilots and Observers (non-pilot!), so why not do the same for Virgin Galactic passengers? After all, if you've just forked out US$250,000 for a ticket to space, you want to make sure that flight comes with the bragging rights of being an astronaut. And don't worry if you happen to be a Virgin Galactic passenger – you will receive astronaut wings: Virgin Galactic branded! Now, in case you're wondering why everyone who flew on the Shuttle received astronaut wings, even though only two people piloted the mission, the reason is that, under the agency's rules, the criteria are more for participation than sitting in the right seat.

Notes

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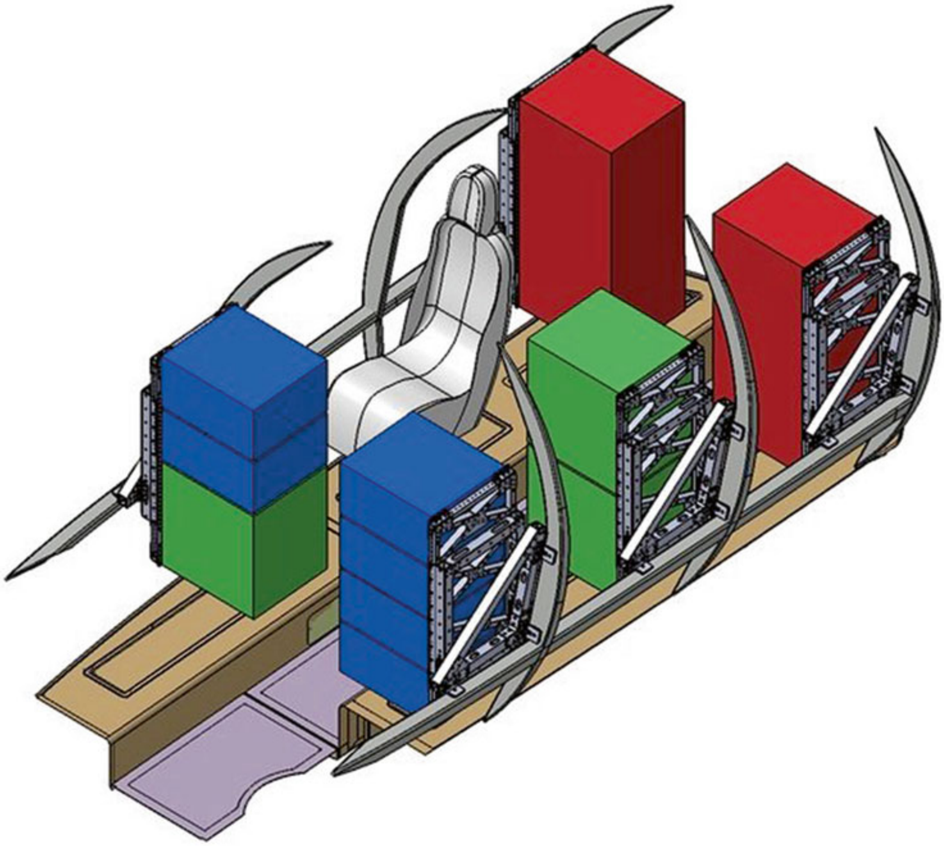
8

Science and Payload Missions

> "You spark this industry with tourists, but I predict in the next decade the research market is going to be bigger than the tourist market." [1]
>
> *Dr. Alan Stern, Southwest Research Institution*

Alan is almost certainly right. Once revenue flights start, there will be a lot of fuss about celebrities rocketing into space. But, as discussed in the previous chapter, there is a limited supply of Lady Gagas, so what happens when Virgin Galactic has flown its manifest of the rich and famous? Well, space-tourism jaunts will still be flown, but the major source of revenue for Branson's suborbital operation will likely come from science and payload flights. After all, the same unique and cutting-edge design that makes SpaceShipTwo the perfect spaceship to carry the Ashton Kutchers of this world to the edge of space also make it an appealing research platform perfectly suited for scientists and engineers. The large volume and payload capacity, altitude, and flight rate of SpaceShipTwo allow Virgin Galactic to offer a unique platform for technology development in space. To that end, Virgin Galactic plan to offer two categories of research flights. The first of these will offer researchers the opportunity to fly to space with their experiments while the other will carry payloads only. Payload flights will carry up to 600 kilograms that will be fixed to Virgin Galactic's rack system. The rack system (Figure 8.1) accommodates mounting systems for CubeSats (Figure 8.2), Middeck Lockers, and 48-centimeter equipment racks. If your payload doesn't fit these systems, Virgin Galactic can accommodate payloads on a case-by-case basis. Need an experiment activated during the flight? No problem: a Virgin Galactic Flight Test Engineer (FTE) will be on hand.

E. Seedhouse, *Virgin Galactic: The First Ten Years*, Springer Praxis Books,
DOI 10.1007/978-3-319-09262-1_8



8.1 SpaceShipTwo payload racks. Courtesy: Virgin Galactic

NASA'S ROLE

One major player in the business of flying commercial science and payloads is NASA. The agency has stated it will work with the private space industry to help budding scientist astronauts write the next instalment in space science and technology. And NASA is making good on its promise, signing contracts with companies such as Virgin Galactic to fly technology payloads on board suborbital spacecraft. So, once Ashton Kutcher and his friends have had their fun in space, SpaceShipTwo will be flying technology payloads to the edge of space. That's a huge step towards fulfilling NASA's idea of commercializing space for scientists. Just think of the benefits.

8.2 The Norwegian satellite NCUBE2 waits to be shipped to the Netherlands to be integrated with the European Space Agency (ESA) SSETI-Express satellite Courtesy: Bjørn Pedersen, NTNU

Firstly, this agreement opens up an affordable route to suborbital space, and secondly, it supports the commercial space sector by opening up a welcome revenue stream for Virgin Galactic and its competitors such as XCOR.

Potential payload providers interested in flying with Virgin Galactic can visit NASA's Flight Opportunities Program, through which NASA has already chartered several flights of SpaceShipTwo (see sidebar). Through this program, NASA will select proposals submitted via the Announcement of Flight Opportunities and cover all flight costs for winning proposals.

Virgin Galactic's Services

It's not only research organizations like Southwest Research Institute (SwRI) that are getting in on the suborbital science market. In 2009, Aabar Investments, the Middle East investment fund that bet big on Mercedes-Benz (it bought 9.1% of the German auto maker) paid about US$280 million to buy nearly a third of Virgin Galactic [2]. Aabar Investments' venture gave Branson's suborbital project a financial boost at a time when many sources of revenue had dried up due to the recession. It also gave Abu Dhabi a chance to develop a spaceflight industry of its own and to extend its economy beyond the oil sector. In exchange for its stake in Virgin Galactic's holding company, Aabar Investments will acquire "exclusive regional rights" to eventually launch Virgin Galactic research spaceflights from the United Arab Emirates (UAE) capital [3].

More recently, Virgin Galactic and Aabar Investments were selected by NASA to provide opportunities for those wishing to fly science payloads into space. This agreement marked the first time NASA had contracted with a commercial partner to provide flights on a suborbital vehicle. It also represented a vote of confidence in the value of commercial space access for science. Although generally regarded as a space-tourism company, Virgin Galactic has recognized that providing access to suborbital space to scientists is a key mission segment and an important business opportunity, which is why SpaceShipTwo can be configured for tourists or scientists. Virgin Galactic has also assembled a team of partners to provide flight services for the impending science missions, including Southwest Research Institute of Texas, NanoRacks, and Spaceflight Services of Washington.

SCIENCE FLIGHTS

Using suborbital spacecraft for science, research, and education missions will be nothing short of revolutionary, which is why scientists have reacted so positively to the promise of flying on board SpaceShipTwo. Not only will this spaceship allow unparalleled access to suborbital space, it will offer a novel means to engage scientists and students. But the benefits extend further. Much further. Apart from the affordable flight costs, quick turnarounds and a choice of trajectories to choose from, SpaceShipTwo can support unmanned science and human-tended payloads, and features rapid-turnaround and human-in-the-loop capabilities. Think of the possibilities for students studying space-related disciplines: not only will SpaceShipTwo science flights help them acquire new scientific and technical knowledge; these missions will also help them prepare to participate in future space missions that extend beyond the suborbital realm. What sort of science (Figure 8.3) are we talking about? Here's a snapshot:

8.3 Project PoSSUM (Polar Suborbital Science in the Upper Mesosphere) is a suborbital science flight scheduled on board the Lynx. The project will investigate noctilucent clouds which are sensitive indicators for what goes on in the upper-mid atmosphere. Courtesy: Jason Reimuller

- satellite and spacecraft systems, components, environments, and operations;
- systems engineering techniques and communication system engineering;
- space exploration science and technology;
- life sciences, astronomy, and astrophysics;
- Earth systems science, including remote sensing of atmospheric composition, and atmospheric dynamics;
- satellite image analysis for landscape changes that have an impact on natural emissions and on deposition processes;
- airborne and ground-based remote sensing measurements in support of science and validation contributions to satellite missions;
- airborne remote sensing campaigns to further scientific understanding of changing sea ice and/or landscape conditions;
- testing satellite instrument prototypes for remote sensing or measuring greenhouse gases, air quality species, or meteorological variables;
- solar-terrestrial science including *in situ* measurements or remote sensing of energetic particles, magnetic fields, electrical fields, and atmospheric geospace–atmosphere interaction [4].

Think about the number of PhD and postdoctoral-level research publications that can be generated, to say nothing of the experience gained through collaborative research activities involving industry, and foreign researchers [4]. And then there are the space-related skill sets that will be acquired by students flying their science on SpaceShipTwo: project management skills such as resourcing, scheduling, and compliance with budgets, the skills involved in payload assembly, integration, testing and operation, software development, data analysis, and, of course, interpersonal communication and leadership [4].

SUBORBITAL APPLICATIONS RESEARCHERS GROUP

With science and payload flights on SpaceShipTwo on the horizon, organizations are being created to advocate, educate, and promote awareness of these flights. One of these organizations is the Suborbital Applications Researchers Group (SARG), created by the Commercial Spaceflight Federation (CSF) in conjunction with Southwest Research Institute (SwRI). SARG's Ambassador Program, chaired by Alan Stern, seeks those with an interest in supporting suborbital technology. As a member of SARG's Research Education Missions (REM), SARG Ambassadors are provided with promotional materials and knowledge to help promote the utility of suborbital vehicles. As a coordination and advisory committee of the CSF, SARG comprises scientists and researchers whose goal is to promote the research and education potential of suborbital vehicles such as SpaceShipTwo. Thanks to SARG's help, and the easy accessibility to SpaceShipTwo, it's possible that science missions may become more popular than tourist flights.

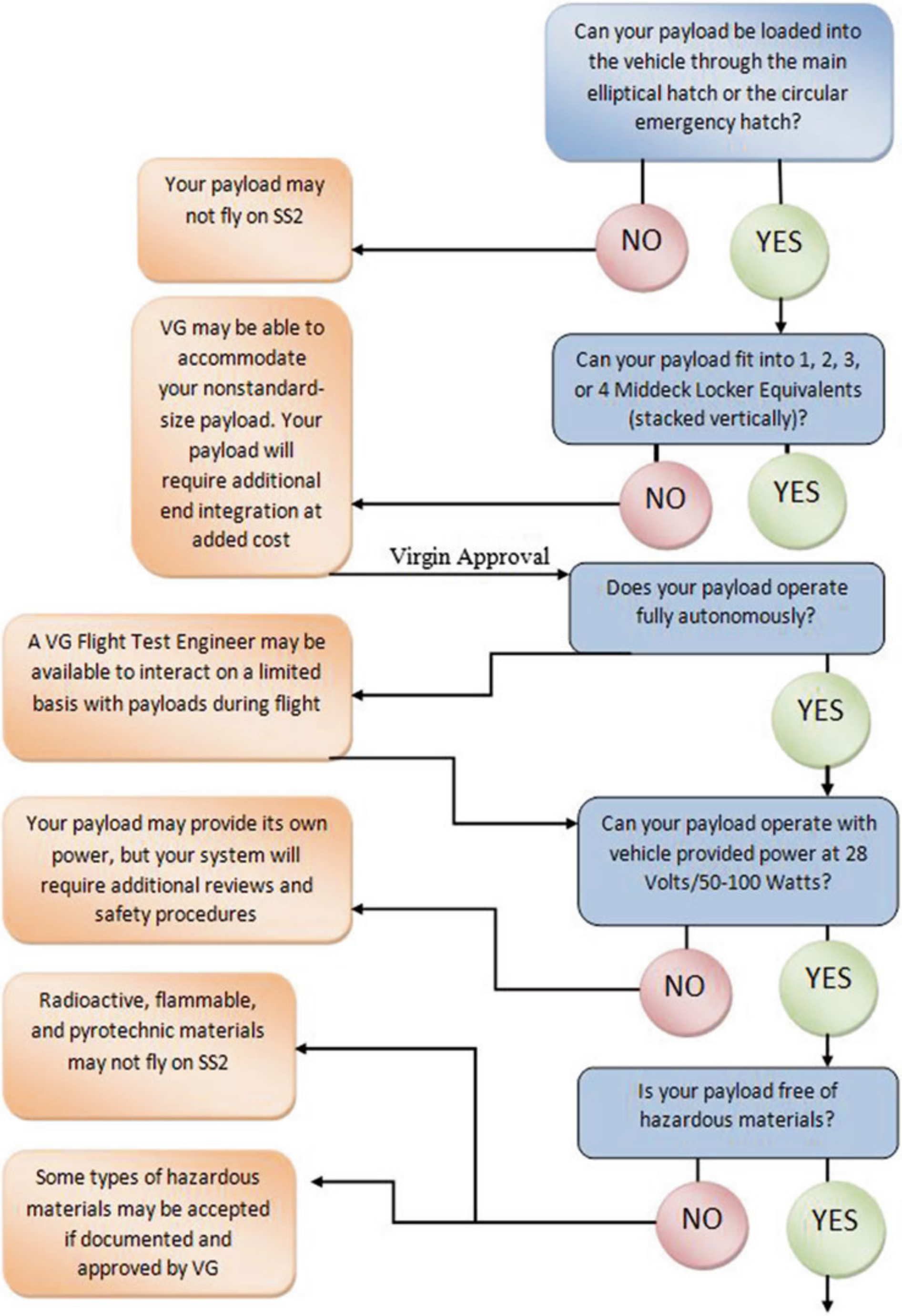
FLIGHTS FOR THE ADVANCEMENT OF SCIENCE AND TECHNOLOGY

Suborbital science groups aren't limited to the US. Over the border in Canada, the Flights for the Advancement of Science and Technology (FAST) provides grants to Canadian universities in support of research projects that offer hands-on opportunities to graduate students flying their experiments on suborbital platforms [4]. FAST is a great way to not only contribute to the advancement of knowledge and technology development, but also to enhance Canada's future competitiveness and productivity in the space sector [4]. At the same time, the program will create a few astronauts along the way. Not only will SpaceShipTwo provide Canadian university students with unique educational opportunities, the mission life cycle of research projects [4] using this suborbital platform corresponds closely to the length of time required to complete a master's or PhD program. What better way to acquire practical experience before applying for a job?

PAYLOAD FLIGHTS

Chances are, if you're a scientist, you will be taking some equipment along with you on your flight. One headache suborbital scientist astronauts may face is how to install their payload into SpaceShipTwo simply because there are all shapes and sizes of payloads. Virgin Galactic has spent some time thinking about this and has come up with a versatile scientific payload and rack configuration, which will include window access for the collection of atmospheric and spectrographic data. To give you an idea of what is involved, Virgin Galactic explains the payload checklist in their online Payload User Guide (PUG), which is abbreviated in Figure 8.4.

So that's the procedure, but what about the flight environment for you and your payload? Let's begin with G-loading. If you're flying a payload on SpaceShipTwo, you won't have to worry too much about G-loading because this spacecraft was designed to carry humans. So, as long as your payload is designed to operate under the nominal flight loads



8.4 SpaceShipTwo payload checklist [5]. Courtesy: Virgin Galactic

Table 8.1. Expected G-loads for flight and crash conditions [5].

	Maximum boost loads	*Maximum re-entry loads*	*Crash loads*
Front/back (Gx)[1]	+0.1/–3.4	+1.4/–1.5	+15.8/–0.0
Left/right (Gy)[2]	+0.0/–0.0	+1.8/–1.8	+2.8/–2.8
Down/up (Gz)[3]	+3.7/–1.0	+8.4/–0.1	+4.5/–4.5

[1]Forward direction (eyeballs out). [2]Sideways direction (eyeballs left/right). [3]Up and down direction (eyeballs up/down).

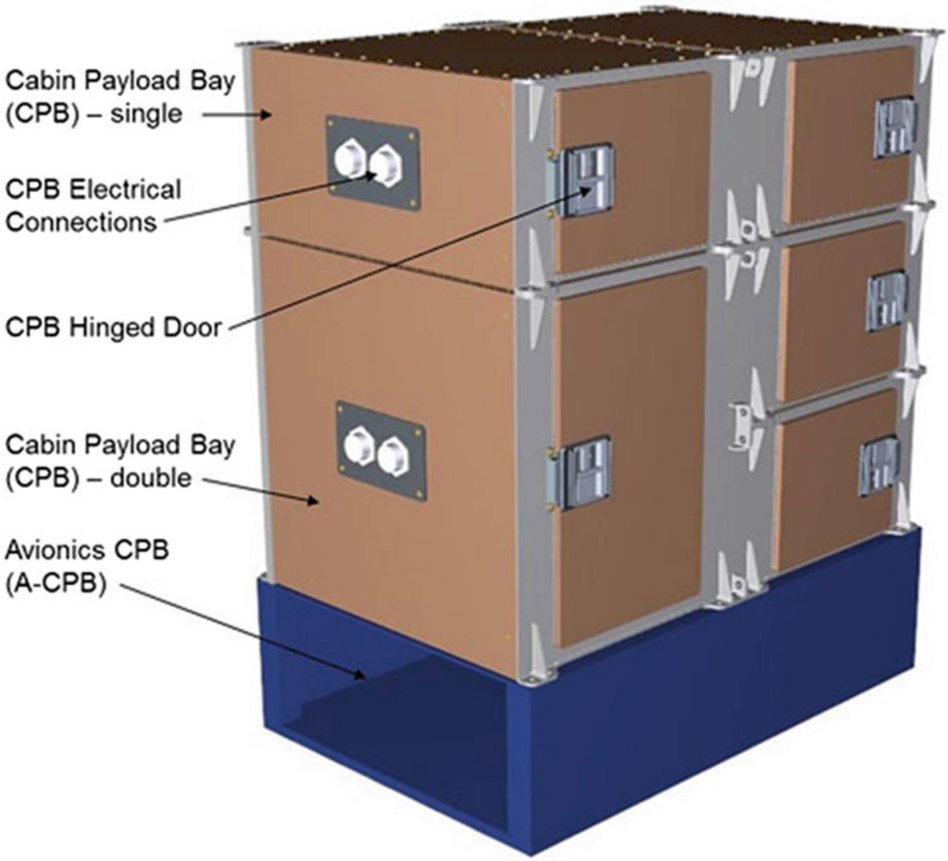
(Table 8.1), you shouldn't encounter any problems. But, to ensure safety, your payload and its mounting hardware must be designed to withstand the nominal and off-nominal loads indicated, which means the payload structure can't detach when subjected to crash loads.

Other factors to consider are cabin humidity, temperature, and pressure environment. During flight, SpaceShipTwo will be pressurized to 2,440 meters' equivalent altitude (a little higher than the current breed of commercial airliners) and, while the vehicle is mated to WhiteKnightTwo, the cabin will be monitored for pressure (12.2 psia), temperature (between 5°C and 32°C), and humidity (less than 75%) to ensure a shirt-sleeve environment. Prior to release, SpaceShipTwo will isolate itself from WhiteKnightTwo and switch to its dry air pressurization system.

If you're a suborbital scientist, you will probably arrive at Spaceport America a few days before launch to integrate your payload. Ideally, you should probably budget at least three days for training and another two for payload integration. In its payload configuration, SpaceShipTwo features a set of mounting plates, which provide support and structure for all sorts of payloads [5]. Each mounting plate was designed to accommodate a variety of payload containers, including NASA Shuttle Middeck Lockers (Figure 8.5), Cargo Transfer Bags, server racks, and CubeSats [5]. If you happen to have your own container system, Virgin Galactic can provide you with a mounting system … at an additional cost. One mounting plate can accommodate as many as four Middeck Lockers or containers, and each mounting plate can accommodate up to 90 kilograms, including containers [5].

On a regular science flight, SpaceShipTwo will be fitted with up to eight plates, with five on the port side and three on the starboard side, which contains the crew emergency egress hatch; this is where the FTE will sit to deal with any unexpected situations [5]. Another feature you should be familiar with is the bolt pattern on each payload rack. The bolt pattern is designed to accommodate the Middeck Locker but it can also be used with custom structures [5]. Each of the 16 mounting holes is a sleeve bolt receptacle that will require the proper threaded insert on your payload attachment. Obviously, to expedite payload integration, it makes sense to design your payload to fit within Virgin Galactic's payload specifications. Not only will this speed up your integration process it will also keep your costs low. A standard SpaceShipTwo science flight configuration will utilize payload containers or mounting stations of three different sizes (Table 8.2) and will offer six spots for Standard Payloads, two spots for Small Payloads, and three for Mini Payloads [5]. If you want to avoid extra paperwork required for structural analysis, Virgin Galactic encourages users to use the NASA Shuttle Middeck Lockers or Cargo Transfer Bags.

Chances are, your science experiment and/or payload will need electrical power. No problem, because SpaceShipTwo provides a 28-volt power supply per payload location, with other



8.5 Shuttle Middeck Lockers. Courtesy: NASA

Table 8.2. Payload sizing specifications.

	Dimensions	*Volume: Middeck Locker equivalent*	*Weight (kg)*
Quad	Width: 47 cm Height: 118 cm Depth: 54.5 cm	4	120
Double	Width: 47 cm Height: 58.4 cm Depth: 54.5 cm	2	60
Single	Width: 47 cm Height: 58.4 cm Depth: 54.5 cm	1	30

Source: *SpaceShipTwo: An Introductory Guide for Payload Users*, Virgin Galactic, Revision Number: WEB004, Release Date: 12 June 2013.

power levels offered on a case-by-case basis [5]. In addition to power, payload users may require vehicle data and flight instrumentation through an Ethernet interface, a service that comes as standard since data from SpaceShipTwo's inertial navigation system (INS), global positioning system (GPS), and air data system (ADS) can be provided to the payload.

When it is time to fit your payloads, be sure to note the size of the points of entry: an elliptical main hatch with a major diameter of ~84 centimeters and a minor diameter of ~66 centimeters, or the circular emergency exit hatch with a diameter of ~66 centimeters [5]. If your payload doesn't fit through these openings, you have the option of disassembling your payload and piecing it together inside the cabin, but Virgin Galactic prefers to avoid the ship-in-a-bottle approach! As far as positioning your payload is concerned, you can install it in the left or right side of the cabin just as long as the payload doesn't impede egress.

During a science flight, the SpaceShipTwo crew will consist of a pilot, co-pilot, and the FTE appointed by Virgin Galactic. It's the FTE's job to monitor payloads for anything unusual that could jeopardize the vehicle and/or crew. If a switch needs to be flicked or a button pressed, chances are the FTE can do that, but that's not in their job description so, if your payload requires more human interaction, it's probably best to either have a second Virgin Galactic FTE or fly yourself. Of course, this becomes expensive!

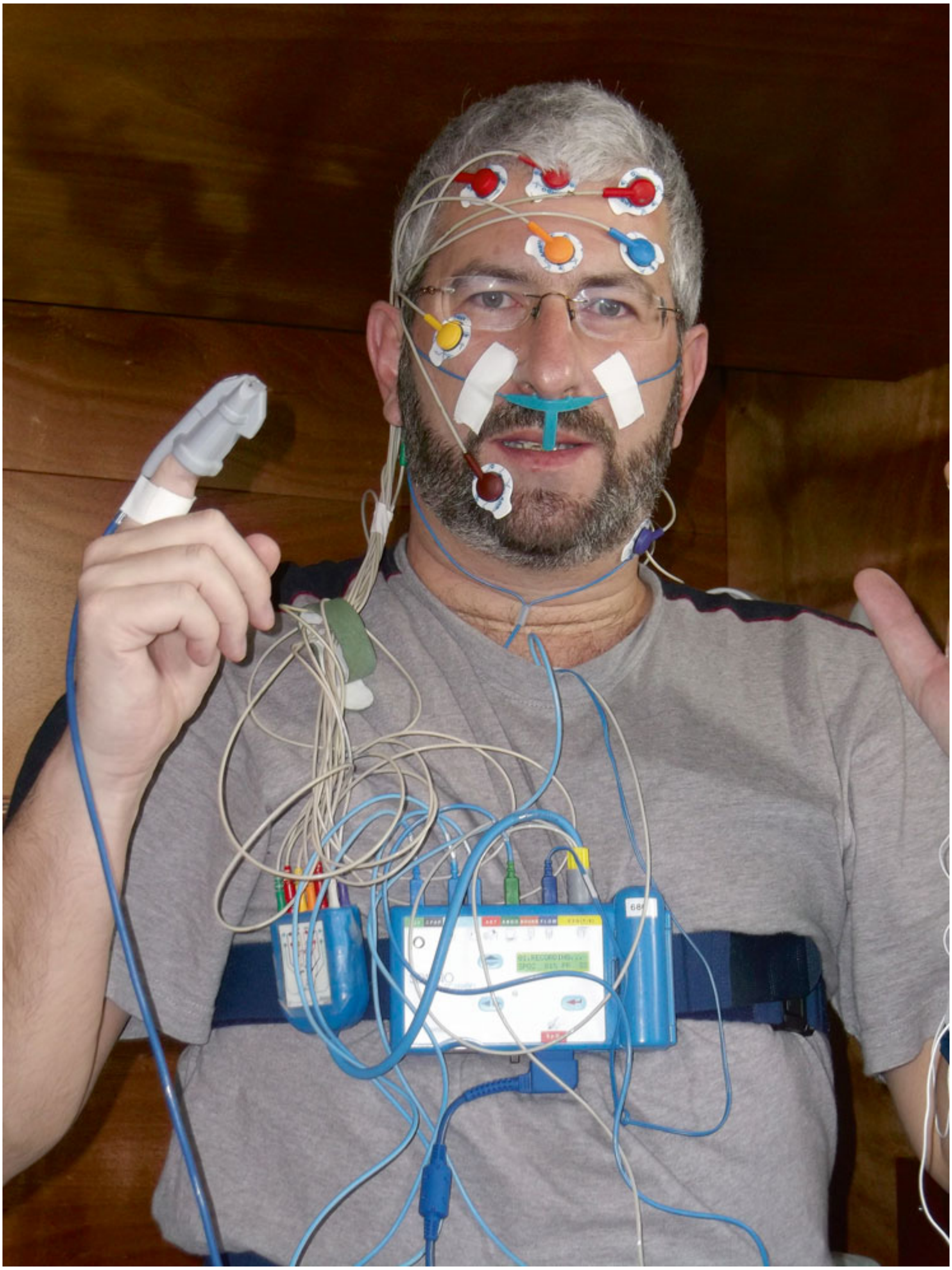
Looking over the horizon, Virgin Galactic plan to offer payload mounting options outside the pressurized cabin. These payloads will be exposed to an environment similar to space. Virgin Galactic may also offer payload customers the ability to deploy payloads from the vehicle during flight [5].

How much will all this cost? It depends on the requirements of your payload but, generally speaking, pricing will be commensurate with pricing for astronaut flights, which means that full flights will cost US$1.5 million before payload analysis and integration costs are factored in. Payloads occupying about the same mass and volume as an astronaut will cost approximately the same as a single seat ticket price – US$250,000 [5]. If that's too much money, you can always go the XCOR route, although the Lynx doesn't have a roomy cabin to float around in.

GAME-CHANGING MISSIONS

With its spacious interior and payload versatility, SpaceShipTwo will offer all sorts of science opportunities, but perhaps the field with the most potential, given the number of tourists that will be flown over the next few years, is human physiology. Don't forget that our experience in manned suborbital flight extends to half a dozen manned flights and the odd animal flight. With so many tourists and scientists flying, it will be important to characterize neurovestibular responses (see sidebar), orientation upsets, space motion sickness, and fluid shifts. To characterize these responses, passengers will be instrumented (Figure 8.6) for heart rate, electrocardiogram, blood pressure, blood volume, and electroencephalogram activity.

In addition to characterizing all these responses, scientists will want to start building a database that compares passenger profiles with respect to fitness levels, smoking, stress, body mass index, high blood cholesterol, and inactivity. They will also want to compare responses based on age, gender, race, flight experience, and various medical conditions, and then compare these factors against the cumulative effects of repeated exposures to



8.6 Building a biomedical suborbital database will require scientists to be instrumented before, during, and after their flights. Courtesy: NASA

Neurovestibular Responses to Flying in Space

Even during a short suborbital flight, the body will undergo some changes that may make the transition back to Earth gravity a little challenging for some. For example, some crewmembers may find it difficult standing upright after the flight due to orthostatic intolerance. Such a simple task may prove problematic because when you are upright, gravity is placing a lot of stress on the cardiovascular system. A human standing up can be thought of as a column of water. As gravity pulls down on that column, each level of water is affected. In any body of water, the pressure at the surface of the water is equal to atmospheric pressure, but the pressure rises by 1 mmHg for each 13.6-millimeter distance below the surface [6]. This pressure is caused by the weight of the water above it and is known as *hydrostatic pressure* [6]. Hydrostatic pressure also occurs in our cardiovascular system because of the weight - thanks to gravity - of the blood in the vessels. But when a passenger spends time in suborbital space, their cardiovascular system will try adjusting to functioning without gravity. And, for those with a inefficient cardiovascular system, the return to Earth gravity may prove challenging. To test a passenger's orthostatic intolerance, life scientists have suggested administering the "Stand Test" pre and post flight (the pre-flight measurements will serve as baseline control measurements against which to compare the post-flight data). The measurements can give scientists an indication of what may be happening in the body to cause orthostatic intolerance and help them develop countermeasures [6]. The Stand Test consists of a 29-minute supine period during which the passengers will be instrumented to measure heart rate and blood pressure. Next, the passengers will be asked to stand for 10 minutes, during which measurements will be taken again.

suborbital flight. Another interesting study will be assessing the transitions between various G-loading "push–pull" effects from single and repeated exposures. In short, there will be plenty of projects to keep scientists busy, but how does one go about actually flying one of these projects?

ANATOMY OF A SPACESHIPTWO SCIENCE MISSION

Imagine your university has given you US$250,000 to fly your research project on board SpaceShipTwo. Lucky you! What sort of timeline will you follow before actually strapping in? A generic timeline is outlined in Table 8.3. The process begins with you as the appointed Principal Investigator (PI). First, you'll need to plan the research you hope to perform on the flight, which could take up to six months or longer. Sometime during the research design period, you will receive an experiment form from Virgin Galactic, requesting you provide them with the particulars of the scientists involved in the experiment, experiment objectives, experiment description, and a technical description of the experiment set-up [7]. You will then need to provide a description of each system, an explanation of each experiment rack, diagrams of the experiment, electrical power details, a manifest of all items,

Table 8.3. Timeline for a suborbital science flight [7].

	L – 36	*L – 30*	*L – 24*	*L – 18*	*L – 12*	*L – 6*	*L – 3*	*Launch*
Submit proposal	▲							
Proposal review	⟷	⟷	⟷					
Proposal acceptance			▲					
Research design			⟷	⟷	⟷	⟷	⟷	⟷
PI receives experiment form				▲				
PI confirms participation					▲			
Medical exam				⟷	⟷			
Operator receives experiment form						▲		
PI and scientists visit operator							▲	
Execute changes to research							⟷	⟷
Design frozen								▲
Medical docs submitted to operator								▲
Test of payload								▲
Safety review meeting								
Changes if necessary								
Liability form submitted to operator								
Pre-flight training								⟷

images of the experiment configuration, and your team's approach for configuring the experiment [7]. Other items on the form may include power consumption, in-flight procedures, approval for the use of human subjects, a liability waiver, and a hazard list [7]. It's a lot of paperwork but it doesn't stop with the experiment form because, two months before the flight, the equipment data package form arrives. On this you will need to provide information such as a structural load analysis, proof of mechanical resistance of each structure, details of the data acquisition system, and test operation limits and restriction [7].

Once that round of paperwork is out of the way, you and your team can look forward to the safety visit. This is the final review before the flight and allows Virgin Galactic to inspect your equipment, check any modifications, and approve or disapprove your flight. Around this time, your team will submit their medical certificates and insurance details to Virgin Galactic. After the safety visit, you and your team head home and work on any changes to the payload. Then, a week before flight, you pack your bags and go to the spaceport to begin your pre-flight. One of the first things you will need to do is more paperwork; Virgin Galactic will verify everyone has their medical certificates in order, that liability and waiver forms, if required, are signed, and all modifications have been made [7]. Virgin Galactic will then give you an overview of the week's activities and training. Once all the paperwork completed, the scientists will begin positioning their payload in the spacecraft, assisted by Virgin Galactic's checkout team who will help the scientists with attachment interfaces and electrical input and output requirements. This will take about two days, after which you will commence your pre-flight training.

FOUR RIDICULOUSLY EXPENSIVE MINUTES

All set to go? Great! Now, how do you make the most of those very precious and exorbitantly expensive four minutes of weightlessness? Well, first of all, you would do well to apply the principles of the three "Ps" – prior preparation and planning – but we'll get to that shortly, because all the preparation in the world will be worthless if you can't avoid the dreaded space motion sickness/space adaptation syndrome (SAS). The last thing you want to be is sick as the proverbial dog during your flight, so take some anti-motion sickness medication (be cognizant of any side effects), just to be on the safe side.

Now let's imagine you're one of the lucky ones not affected by SAS and you're about to enter the microgravity phase and you're feeling great. How are you going to make the most of those four minutes? Remember, you'll have one shot and one shot only to gather data and perform whatever science experiment you've been tasked with. No doubt you'll have practiced your routine dozens, if not hundreds, of times so you don't have to worry about the sequence of events. The big killer here is the unknown, especially the sudden transition from boost phase to microgravity coast, which will be distracting no matter how much you anticipate it. This transition will be compounded by all the activity going on in the cabin as other scientists start to prep for their experiments. And then there's that view (Figure 8.7) through the windows. Very distracting! No matter how well trained and focused you are.

Experienced astronauts often speak of rookie flyers having all the grace of the proverbial bull in a china shop, which inevitably leads to a disruptive workflow. So rookie astronauts are taught "slow equals fast" – a mantra that will definitely apply within the confines of SpaceShipTwo. Another important mantra to remember is that the only certainty about an extravehicular activity is uncertainty (a quote attributed to legendary six-time Shuttle flyer, Story Musgrave – it will apply equally to intravehicular activity). In other words, despite all

8.7 The view that a US$250,000 ticket on SpaceShipTwo will buy you. Courtesy: NASA

those tasks on your checklist, you have to plan for things to go wrong. You can minimize off-nominal events by extensive pre-visualization and thinking through every – EVERY – detail, which includes nominal and off-nominal events. You can also help yourself by knowing your environment and keeping track of everything, either using Velcro, lanyards, duct tape, or all three! Another critical skill will be the ability to maintain your situational awareness because your fellow space scientists won't appreciate getting kicked in the head as they try to prepare their payload racks. You'll also need to keep a firm grip on your "space brain" as your mind becomes saturated with visual and task overload: don't forget, you'll most likely be required to perform several tasks within what seems to be an impossibly small amount of time, so it will be critical you use tethers (Velcro works as well) to keep track of your gear. You will also want to use a detailed plan of action, placards, and cuff checklists to make sure you do everything you need to do in the sequence that it needs to be done. And don't forget to plan for contingency because even the simplest devices fail and you have to know how to repair them quickly. It's all part of your operational planning (Table 8.4). In short, don't leave anything to chance. Anything. The next step in your training is flight preparation, which should include training in as high a fidelity environment as possible – ideally a spacecraft mock-up. Failing that, you can utilize 1-G bench-top payload training and pre-visualization of the full sequence of mission operations.

FUTURE OF SCIENCE FLIGHTS

Flights on board SpaceShipTwo will not be exclusively for well-heeled tourists, although that's the perception many will have when revenue flights start. But, as Virgin Galactic flies out its manifest of the rich and famous, scientists will take over, and we will be one step closer

Table 8.4. Suggested events leading up to suborbital science launch.

Time	*Event*
L – 7 days	Scientists and team members arrive at spaceport. Review by Principal Investigator
L – 6 days	Commence experiment preparation at Spaceport science staging facility
L – 5 days	Configure experiment into spacecraft
L – 4 days	Commence pre-flight training day #1 of 4 – a.m.: academic instruction on high-altitude indoctrination and high acceleration. p.m.: slow and rapid decompression in high-altitude chamber followed by emergency egress procedure training
L – 3 days	Pre-flight training day #2 of 4 – a.m.: flight G profile in centrifuge followed by task acquisition exercise review. p.m.: zero-G pre-flight familiarization followed by pressure suit acquaintance and testing (donning and doffing)
L – 2 days	Pre-flight training day #3 of 4 – a.m.: survival brief. p.m.: payload training
L – 1 day	Pre-flight training day #4 of 4. a.m.: more payload training. p.m.: flight safety briefing followed by presentation of each experiment by respective PIs
L – 1 hour	Scientists meet at Spaceport for final pre-flight debrief. Optional anti-emetic medication given. Scientists conduct final check of payload
L – 30 minutes	Scientists and crew board spacecraft. Experiments switched off
L – 20 minutes	Hatches closed. Passengers requested to be seated and spacecraft begins taxiing. Spacecraft electrical panel switched off
L – 10 minutes	Spacecraft electrical panel switched on
Launch	Spacecraft takes off
L + 15 minutes	Passengers leave their seats and switch on experiments
L + 20 minutes	Passengers switch off experiments and adopt landing configuration. Electrical panel switched off
L + 35 minutes	Landing and debrief
L + 4 hours	Modifications and preparation of experiments for following day

Adapted from 'Suborbital' by Erik Seedhouse. Published by Springer-Praxis, 2013.

to an era of routine "field work" in space research. And, as more and more researchers fly their experiments in space, the transformational power of SpaceShipTwo to advance all sorts of research will truly become evident. Eventually, as the scientific community realizes they can put payloads and scientists into space affordably, the floodgates will open even wider.

Notes

1. http://cosmiclog.nbcnews.com/_news/2009/08/21/4350546-scientists-go-suborbital?lite
2. http://www.ngnews.ca/News/2009-07-28/article-332541/Mideast-fund-Aabar-buys-almost-a-third-of-Richard-Bransons-Virgin-Galactic/1
3. http://abcnews.go.com/Business/story?id=8191703
4. http://rd-review.ca/eic/site/033.nsf/vwapj/sub128.pdf/$file/sub128.pdf
5. http://www.parabolicarc.com/2013/02/05/a-closer-look-at-spaceshiptwos-microgravity-research-capabilities/
6. http://spiral.imperial.ac.uk/bitstream/10044/1/1456/1/EUCASS07_scimitar_5_08_03.pdf
7. Ferrone. K. The development of a commercial crew service. 2012 IEEE Aerospace Conference, 03, 2012.

9

Beyond Suborbital

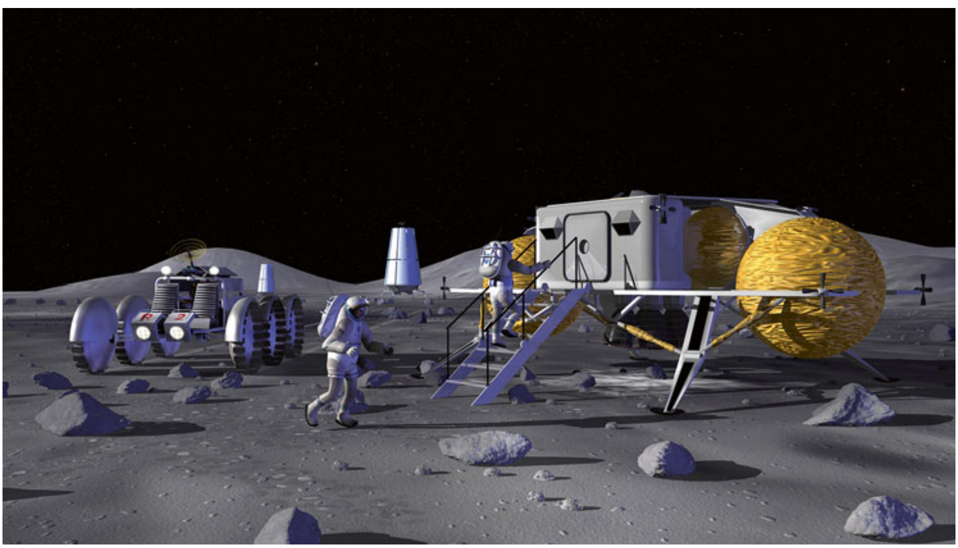
> "Using small, purpose-built, two-man spaceships based at space hotels our guests will be able to take breathtaking day trips programmed to fly a couple of hundred feet above of the Moon's surface. They will be able to take in with their own eyes awe-inspiring views of mountains, craters and vast dry seas below. A little closer to home, as we build out our orbital business, we will leverage our experience and resources to deliver a transcontinental capability for our vehicles leapfrogging the long awaited supersonic aviation successors to Concorde. It is no accident that we shunned the inherent limitations of ground based rockets in favour of winged spacecraft when we chose the design of our first Virgin SpaceShip."
>
> *Excerpt from speech given to Virgin Galactic customers by Richard Branson in September 2013 [1]*

Having cornered the market for suborbital joyrides, Richard Branson is already planning space hotels and lunar jaunts. In his September 2013 speech to Virgin Galactic customers, he set out an expansive vision (Figure 9.1 and 9.2) of the future of his company's space program which looked far beyond suborbital flights [1]. But, to realize these goals, he will need to hitch or develop a ride to low Earth orbit (LEO) and that, as any aerospace engineer will tell you, is a whole different kettle of fish. Reaching orbit requires speeds[1] significantly higher than SpaceShipTwo can accomplish, and then there's the increase in risk and technical complexity, all of which adds up to horrendous cost. But don't bet against Branson. Virgin Galactic is already underway developing an orbital vehicle – albeit unmanned – called

[1] To get to LEO, you have to accelerate to 28,100 km/h. Earth's escape velocity is 40,000 km/h so, once you get into orbit, you have to add another 11,900 km/h. If you can do that, you can, as Heinlein's quote (see page 176) says, go anywhere. In practice, it's a little more complex, but the point is that the major effort is expended getting to LEO. Remember the Saturn V? The entire first and second stages, as well as some fuel from the third stage, were needed just to get into orbit. But, once in orbit, all that was required to send astronauts on their way to the Moon was a burn of a few minutes from the small third stage.

E. Seedhouse, *Virgin Galactic: The First Ten Years*, Springer Praxis Books,
DOI 10.1007/978-3-319-09262-1_9

9.1 Courtesy: Boeing Company



9.2 NASA concept of a lunar outpost. Courtesy: NASA

LauncherOne, which builds on the technology of SpaceShipTwo [2]. And, if Branson can find an affordable way to ferry his passengers to orbit, the rest of Virgin Galactic's plans are feasible – perhaps even getting to the Moon [2].

LAUNCHERONE

LauncherOne is being designed to deliver a 225-kilogram payload to low inclination equatorial LEO and 100 kilograms to polar Sun-synchronous orbit at higher altitudes. The two-stage rocket will be air-launched from WhiteKnightTwo in the same way as SpaceShipTwo. Falling from an altitude of 15,000 meters, its main-stage (first-stage) engine will ignite four seconds after release. Virgin Galactic plans to launch its satellite-launching venture from Spaceport America and other US facilities. Later flights (which will require various regulatory licenses) could launch from a spaceport in Abu Dhabi, home of Virgin partner Aabar Investments. In this case, LauncherOne's first and second stages will be mated, checked out, and shipped to the spaceport for storage (LauncherOne can be stored unfueled), until WhiteKnightTwo and the client's payload arrive.

The purpose of LauncherOne is to provide an affordable, dedicated ride to orbit for smaller payloads (see sidebar). The maximum payload volume is quite large for a launch vehicle of this class, since the fairing is just one meter in diameter. In addition to providing an affordable service to small satellite users, LauncherOne revenue will supplement Virgin Galactic's suborbital human spaceflight business (four companies have signed up for satellite launches: Skybox Imaging, GeoOptics, Spaceflight Inc., and Planetary Resources) [3]. Key to its success are the engines, developed and built by Virgin Galactic. The 3,500-pound-thrust NewtonOne and 47,500-pound-thrust NewtonTwo are the first- and second-stage engines. NewtonOne, the upper-stage engine, has completed a full-mission duty cycle on the company's test stand and has had multiple firings for short durations, including one that came within a 12-hour turnaround for engine swap-out to demonstrate responsiveness. Components for an upgraded NewtonThree engine are undergoing testing [3].

Surrey Satellite Technology Ltd (SSTL)

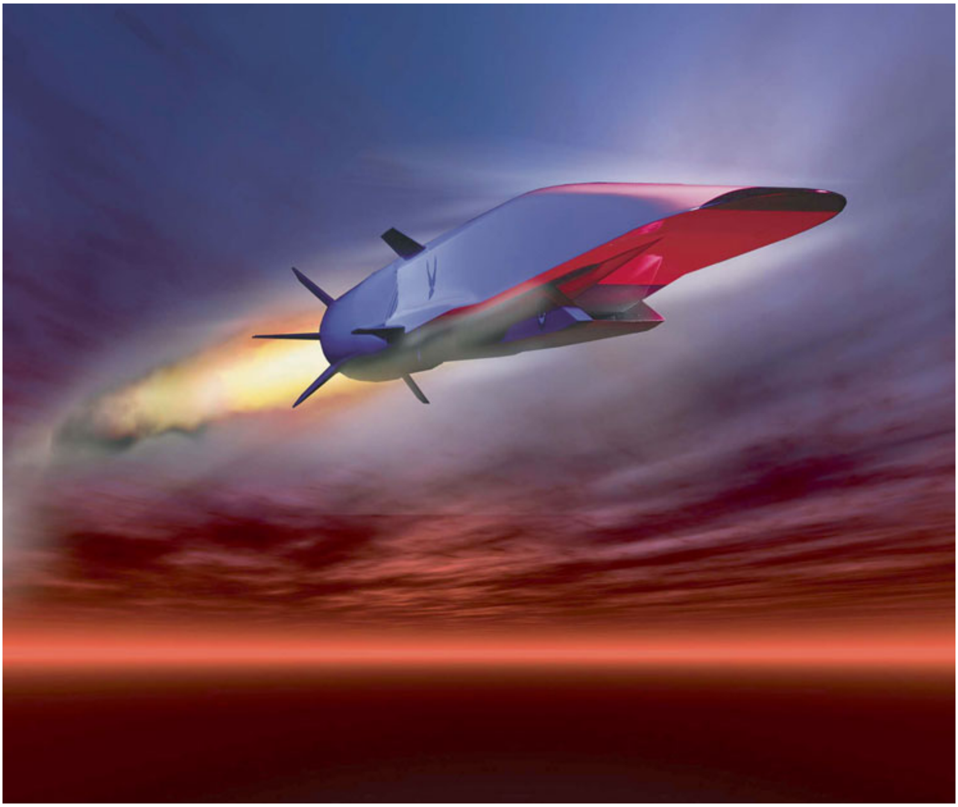
In July 2012, Surrey Satellite Technology (SST)-US signed an agreement with Virgin Galactic in which the two companies agreed to collaborate in the design and development of LauncherOne. SST-US, the US operation of Surrey Satellite Technology Ltd (SSTL), has a reputation for leading the way in developing affordable space missions. Established in 2008 to address the American market and to provide small satellite solutions and services, the activities of SST-US utilize many of the capabilities of the Surrey group, which has launched dozens of satellites as well as providing training, consultancy services, and mission studies for NASA and the US Air Force. Now that they're involved with Virgin Galactic, they are optimizing their satellites for LauncherOne and, in doing so, offering engineers and researchers who build satellites to send them into space at a fraction of the price they could in the past [4].

What's the difference between LauncherOne and SpaceShipTwo's rocket motor? Well, SpaceShipTwo's power-plant (see Chapter 4), which is built by Sierra Nevada Corporation, is a modified version of the motor that SpaceDev (a subsidiary of Sierra Nevada) provided for SpaceShipOne [3]. Both rocket motors are powered by a non-toxic solid fuel and nitrous oxide, whereas LauncherOne's Newton engines use RP-1 kerosene and super-cooled liquid oxygen [3]. Will we see LauncherOne's liquid propulsion system developed into one that can be used on SpaceShipTwo? Probably not. But if Virgin Galactic are serious about pursuing point-to-point suborbital travel on SpaceShipThree, a more powerful version of the Newton system could help realize that goal [3]. So the liquid rocket engines Virgin Galactic is testing for LauncherOne may help Branson develop his satellite launch service quickly, while also helping the company develop more capability so they are ready to power those future vehicles when the time comes. Basically, Branson's dreams about flying from London to Los Angeles in 45 minutes will be achieved off the Launcher One propulsion architecture, not the SpaceShipTwo propulsion architecture.

POINT-TO-POINT

The emerging suborbital tourism market has been seen by many as an intermediate step towards point-to-point travel, which is hardly surprising as there is no guarantee that the single-point suborbital tourism market will be able to sustain a viable revenue stream in the long term. Until the advent of SpaceShipTwo, we didn't know how to go to space cheaply, although some may argue whether a US$250,000 ticket qualifies as "cheap". But, thanks to SpaceShipTwo's regular suborbital trips, Virgin Galactic may be able to develop a vehicle that goes not just up and down to the same place, but from here to the other side of Earth. And the fastest way to do that will be to go outside the atmosphere. What sort of trip times are we talking about? Well, a trip from London to Sydney – the "Kangaroo Route" – will take about two hours. Sounds appealing, but the technical challenges are formidable. For example, the European Union's Long-Term Advanced Propulsion Concepts and Technologies (LAPCAT), which has produced one potentially viable design by Reaction Engines, reckons it will take 25 years before a vehicle goes into production [5]. Twenty-five years! For those familiar with the slow progress of hypersonic transportation (Figure 9.3), this timeline won't be surprising, but that length of time could conceivably be shortened in the presence of a sustained development effort such as the one Virgin Galactic is planning. That and a more favorable regulatory regime.

When engineers dream of revolutionary new technology, the typical response is: "Can it work?" In the case of point-to-point travel, one technology in question is the Synergetic Air-Breathing Rocket Engine (SABRE). Designed by Alan Bond, one of the engineers behind a 1980s reusable spaceplane concept championed by Rolls-Royce and what was then British Aerospace, the multi-Mach SABRE rocket engine promises single-stage-to-orbit suborbital point-to-point travel by burning atmospheric oxygen at low altitudes. How? It's all down to the engine's unique cooling system that enables it to operate in two modes, allowing the vehicle to take off like an airliner but provide the power of a rocket. During its flight in the lower atmosphere, the oxygen part of the vehicle's fuel will be drawn from the air in the same way as a jet engine but,



9.3 The Boeing X-51 is an unmanned hypersonic scramjet test and demonstration aircraft. Also known as X-51 WaveRider, it flew its first hypersonic flight on 26 May 2010. On 1 May 2013 the X-51 flew for over six minutes, exceeding Mach 5 for 210 seconds. Courtesy: NASA

at around Mach 5, the engine converts to rocket mode using stored supplies. The elegance of this design is that the vehicle will take oxygen from the atmosphere during the first part of the flight, which would reduce the amount (about 250 tonnes) of oxygen that needs to be stored, thereby boosting the vehicle's thrust-to-weight ratio. The catch? How to cool the air entering the engine during flight. In air-breathing mode, that air must be compressed to around 140 atmospheres before being injected into the combustion chambers which raises its temperature (1,000°C) to such a level that it would melt any known material [6]. To avoid this, SABRE engineers decided to use a precooler heat exchanger to cool the air (to −150°C) until it is almost a liquid, after which a conventional turbo compressor using jet engine technology can be used to compress the air to the required pressure [6]. To achieve such a rapid rate of cooling, the system uses an arrangement of one-millimeter thin pipes filled with condensed helium to draw the heat from incoming air and reduce its temperature before entering the engine [6]. In November 2012, Reaction Engines convinced the European Space Agency (ESA) that it had solved the pre-cooler problem and asked for financial help to build a demonstrator SABRE engine. Up to that point, the company had spent US$390 million, so the technology of point-to-point travel isn't cheap, although the primary purpose of Skylon would be orbital access. If all goes well, Reaction Engines' plan to spend around US$12 billion to get SABRE and Skylon flying should see results in the early 2020s, after which the company's business plan is to sell the vehicles for US$1 billion each. If you're in the market for a Mach 5 point-to-point vehicle, Skylon promises recurring costs of US$10 million per flight. With room for a 30-passenger cabin, that equates to US$333,333 per passenger, which is about 66 times the cost of a first-class ticket on British Airways between London and Sydney. No doubt it would be a game-changer, but a very expensive one. But what if you could build a vehicle that could go almost as fast but carry 300 passengers? Well, that's the idea behind the A2 Mach 5 vehicle. The A2's airframe shares a lot of its technology with the Skylon launch vehicle, except that the A2 isn't designed for re-entry, although it still has to withstand speeds of up to Mach 5. The A2's characteristics are:

- Capacity: 300 passengers
- Length: 143 meters
- Wingspan: 41 meters
- Wing area: 900 meters^2
- Maximum take-off weight: 400,000 kilograms
- Fuel capacity: 198 tonnes liquid hydrogen
- Cruise speed: Mach 5.2 (6,400 kilometers per hour)
- Range: 20,000 kilometers

If the A2 becomes operational, passengers would be able to fly the Sydney - London route in less than five hours [7]. Not as quick as the Skylon, but for a tenth of the price. After leaving London, the A2 would fly sub-sonically above the North Atlantic, gradually accelerating until it reached Mach 5 across the North Pole. It would then head over the Pacific at a cruise altitude of over 30 kilometers to Australia. Total flight time? A snappy 4 hours and 40 minutes. Compare that to the current flight time of 22 hours and 50 minutes for airliners flying between England and Australia. Oh, and the name "A2" – it's a designation[2] similar to those used by Nazi rocket scientist and NASA rocket pioneer Wernher von Braun, but this is purely coincidental.

"Once you're in low Earth orbit you're halfway to anywhere."

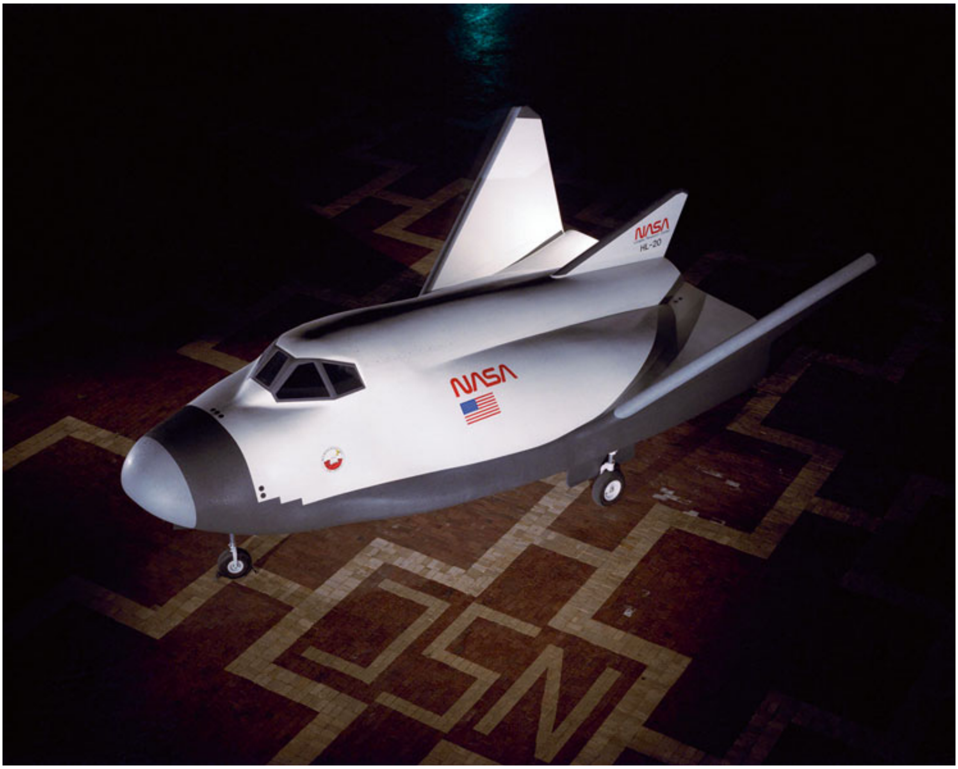
Robert Heinlein

[2] The German A2 rocket was a precursor to the A4, which was subsequently renamed by Hitler as the V-2 for Vengeance (Vergeltung) weapon.

ORBITAL

Virgin Galactic started planning ahead in 2010 when it announced it would be working with Orbital Sciences Corporation and Sierra Nevada Space Systems on developing commercial space vehicles. As part of the agreement with Sierra Nevada, Virgin Galactic would explore ways to use its sales and marketing experience to provide services for Sierra Nevada's Dream Chaser – an effort that could include selling seats on the vehicle as well as investigating the possibility of using WhiteKnightTwo as a carrier aircraft for the Dream Chaser during its atmospheric flight-test program [8]. Sierra Nevada has been developing the Dream Chaser to ferry crew and cargo to the International Space Station (ISS), but the multi-purpose vehicle is also designed to service many types of commercial LEO missions. The vehicle (Figure 9.4), which looks like a scaled-down Shuttle, is a reusable, piloted lifting-body spacecraft capable of carrying seven crewmembers and cargo to and from LEO. The vehicle's design is based on the NASA HL-20 (Figure 9.5) and is a robust spacecraft that features a very passenger friendly low G-force ride during re-entry. To date, Sierra Nevada has conducted several flight tests of the vehicle and completed several critical milestones designed to advance the design of the Dream Chaser for orbital flight.

9.4 The Dream Chaser will launch on an Atlas V rocket and land horizontally on conventional runways. The vehicle is a reusable crewed lifting-body spaceplane designed to carry up to seven people to and from low Earth orbit. Courtesy: Ken Ulbrich/NASA



9.5 NASA's HL-20 Personnel Launch System was conceived as a lifting-body re-entry vehicle similar to the Soviet BOR-4 spaceplane design. It was never built. Courtesy: NASA/James Schultz

Orbital Sciences, one of the world's leading space technology companies, has been developing its Cygnus cargo logistics spacecraft, the first of which launched on an Antares launch vehicle to the ISS in January 2014. Under a US$1.9 billion contract with NASA, Orbital will use Antares and Cygnus to deliver cargo to the ISS over eight missions through late 2016. The Cygnus consists of a common service module and a pressurized cargo module, but there are no plans to develop a man-rated version, so Virgin Galactic passengers with orbital aspirations may only have two options available: buying a seat on the utilitarian Dream Chaser or wait for a SpaceShipThree to be developed. Of those two options, Dream Chaser will be the first to be operational, with a first manned flight scheduled for late 2016. The Dream Chaser/Atlas configuration should be a very safe route to orbit given the Atlas vehicle's 100% success rate. Another layer of safety will be added when the stack is fitted with an emergency detection system (EDS), which will be critical to the Dream

9.6 NASA Deputy Administrator Lori Garver is given a tour of the Bigelow Aerospace's Space Station Alpha mock-up. Courtesy: Bill Ingalls/NASA

Chaser crew during the Atlas V countdown, and during the separation from the Centaur upper stage. Obviously, it is hoped the system won't be needed, but if an EDS-triggered launch abort were to occur, Dream Chaser's engines would separate and clear the spaceplane from the destructing Atlas V before returning to a nearby airport. Another attraction for Virgin Galactic is the spaceplane's 1,500-kilometer cross-range capability and its ability to land safely at any commercial airport [8]. While orbital flights won't be as frequent as suborbital jaunts, Sierra Nevada is anticipating a two-month turnaround (mainly to replace parts of the thermal protection system) of the vehicle between flights to LEO. But where will these passengers go once they get to LEO? Well, Virgin Galactic isn't the only company thinking orbital. Bigelow Aerospace[3] is developing expandable space habitats (Figure 9.6) that could be configured as space hotels. To ferry customers to their destination Bigelow has teamed with rocket-makers Boeing and SpaceX.

Bigelow Aerospace has always been on the destination side of the spaceflight coin. In 1999, Robert T. Bigelow's inflatable habitat venture began when he read that NASA had cut funding for a program to develop inflatable habitats, which were designed to be folded

3 You can read all about this pioneering company in *Bigelow Aerospace*, published by Springer-Praxis and written by yours truly.

up and tucked into a rocket before being expanded in orbit to house astronauts. Bigelow persuaded NASA to grant him an exclusive license to the technology and he launched Bigelow Aerospace. The technology has been going from strength to strength ever since. In 2006 and 2007, the company launched test inflatables, Genesis I and II (they're still up there), and in 2015 it will fly a Bigelow Expandable Activity Module (BEAM) on board the ISS as part of a US$17 million deal with NASA to test the inflatable technology on orbit. Why? Well, the ISS is rigid and made of aluminum, which may not provide the best protection against radiation. Bigelow's habitats also expand to three times the size of the housing units on the ISS. While the company is in discussions with foreign governments about helping them move forward with their own plans for space, there is nothing preventing Virgin Galactic buying a Bigelow inflatable and fitting it out as a hotel.

Notes

1. http://www.educatinghumanity.com/2013/10/virgin-galactic-space-plans.html
2. http://www.scientificamerican.com/article/virgin-galactic-space-hotels/
3. http://www.nbcnews.com/storyline/virgin-voyage/hello-newton-virgin-galactic-unveils-its-other-rocket-engine-n15051
4. http://www.sstl.co.uk/Press/Government-investment-brings-low-cost-radar-satell?story=2044
5. http://www.virgingalactic.com/human-spaceflight/research-flights/
6. http://www.reactionengines.co.uk/tech_docs/JBIS_v60_188-196.pdf
7. http://articles.economictimes.indiatimes.com/2013-07-17/news/40635475_1_virgin-galactic-spaceplane-sabre
8. http://www.sncspace.com/mediakit/?category=FAQ

10

Epilogue

STATEMENT FROM VIRGIN GALACTIC FOLLOWING THE CRASH OF SPACESHIPTWO

4th November 2014

Over the past several days, we have received new information about the tragic incident that resulted in the death of Scaled Composites' co-pilot Michael Alsbury and injuries to pilot Peter Siebold. Our thoughts and prayers remain with the families and friends of these brave men. The following summarizes what has been learned from the formal investigation.

On October 31, 2014, SpaceShipTwo conducted a powered test flight and experienced a serious anomaly that resulted in vehicle failure. The National Transportation Safety Board (NTSB) is in charge of the investigation and we are cooperating fully with their work. While we cannot speculate on the causes of the incident, the NTSB has provided important information about the facts surrounding this case and in their final onsite press conference they described a timeline of events based on the telemetry data in their possession. The investigation will now continue offsite.

Based on information they have released about their investigation to date, the NTSB has recovered the intact engine and rocket propulsion fuel tanks with no signs of burn through or mid-air explosion. This definitively dismisses the premature and inaccurate speculation that the problem was related to the engine or the fuel.

The NTSB also evaluated the vehicle's feathering mechanism, which is the unique technology that turns the wing booms into position for re-entry. The NTSB indicated that the lock/unlock lever was pulled prematurely based on recorded speed at the time, and they have suggested that subsequent aerodynamic forces then deployed the feathering mechanism, which resulted in the in-flight separation of the wings and vehicle. At this time, the NTSB investigation is still ongoing and no cause has yet been determined – these are purely facts based on initial findings. We are all determined to understand the cause of the accident and to learn all we can.

At Virgin Galactic, safety is our guiding principle and the North Star for all programmatic decisions. Our culture is one of prioritizing safety as the most important factor in every element of our work, and any suggestions to the contrary are untrue. We are

E. Seedhouse, *Virgin Galactic: The First Ten Years*, Springer Praxis Books,
DOI 10.1007/978-3-319-09262-1_10

committed to learning from this incident and ensuring something like this can never happen again. To that end, we will work closely with the NTSB and will focus intense effort on its findings and guidance.

For Virgin Galactic, everything rests on our vision of creating accessible and democratized space that will benefit humanity in countless ways for generations to come. Like early air or sea technologies, the development is not easy and comes with great risks, but our team of more than 400 dedicated engineers and technicians are committed to realizing the potential of this endeavour. From research, to travel, to innovation, we believe that the technology our industry is pioneering is crucial to the advancement of humanity.

Over the last few days, we have been so grateful for the outpouring of support and inspiration shared by countless Future Astronauts (customers), members of the space community and the public at large. Testing programs, reaching back to early aviation, have distinct risks, and our customers know that we will not move ahead with commercialized space travel until our expert engineers and pilots deem the program to be safe. These are among the brightest and most experienced professionals in the industry and our success has and will continue to be ensured by their expertise.

While this has been a tragic setback, we are moving forward and will do so deliberately and with determination. We are continuing to build the second SpaceShipTwo (serial number two), which is currently about 65% complete and we will continue to advance our mission over the coming weeks and months. With the guidance of the NTSB and the assurance of a safe path forward, we intend to move ahead with our testing program and have not lost sight of our mission to make space accessible for all. We owe it to all of those who have risked and given so much to stay the course and deliver on the promise of creating the first commercial spaceline.

http://www.virgingalactic.com/press/statement-virgin-galactic-november-4-2014/.

This space travel stuff is a serious and risky business. It also happens to be dangerous, unpredictable, and there are a *lot* of unknowns. Those facts were hammered home on 31 October 2014 following the crash of SpaceShipTwo, a tragedy in which co-pilot, Michael Alsbury, died, and the pilot, Peter Siebold, was seriously injured. The SpaceShipTwo accident was also a major blow to the fledgling private space industry, not only because the images of crumpled fuselage lowered public confidence in commercial spaceflight but also because it highlighted the difficulties of achieving even a four-minute sub-orbital flight.

Eventually they'll crash one. Because it's hard – they're discovering how hard.

Canadian Space Agency astronaut Chris Hadfield (retired), speaking in 2013 about the Virgin Galactic commercial spaceflight project.

Sadly, Chris Hadfield was right. When tragedy struck, SpaceShipTwo was on its most ambitious test flight yet as Siebold and Alsbury planned to push the craft higher than ever. To reach space, SpaceShipTwo had to fly under its own power for about 60 seconds. In its first three powered tests, its engine had burned for no more than 20 seconds. On its final flight, Virgin Galactic's swallow-shaped spaceship fired its engines 21 seconds past 10.07 am local time. Nine seconds after ignition, a cockpit camera showed Alsbury pushing the lever to unhook the wings. At this point, according to a source who saw the footage, Alsbury appeared to have realised his mistake. As panic set in, he apparently tried to shut off the engine. But to no avail. 25 seconds later, the wings began to deploy. From that point, all data was lost. While the pistons would have held the wings flat at Mach 1.4, or even Mach 1.2 as on previous test flights, SpaceShipTwo was at that moment breaking the sound barrier and aerodynamic turbulence forced the pistons and pushed the wings upwards. The effect was like slamming on the brakes at the moment of peak acceleration.

In the aftermath, Virgin Galactic admitted some (about three percent) of its 800 spaceflight customers had asked for refunds, but for the vast majority their resolve remained unshaken. How soon Virgin Galactic will be flying again will be up to the regulators. In the decade following the flight of SpaceShipOne in 2004, private spaceflight companies enjoyed very few limitations on the testing and operation of their spacecraft. That was thanks to the Commercial Space Launch Amendments Act (CSLAA), which was passed by Congress in 2004 to restrict the Federal Aviation Administration (FAA) from introducing any design or operational regulations on commercially built spacecraft. This meant that until the SpaceShipTwo disaster, private companies really only needed to obtain a testing permit, provide certain safety-related information, and adhere to a few other standards to get their vehicles off the ground.

That may all change. As of December 2014, the FAA was waiting on the results of the SpaceShipTwo accident investigation before it made any official regulatory changes. But the agency hinted at modifications to come in a November 2014 statement to Bloomberg News:

> However, we will look to utilize any and all available platforms to leverage lessons learned that will result in increased safety. We know that spaceflight is inherently risky and we expect that valuable lessons will be learned from these unfortunate events that will lead to increased safety and help this industry continue to evolve.
>
> Quote from *Space Tourists Treated Like Thrill Seekers in Regulation*. By Alan Levin, Bloomberg News, 8 November, 2014.

The idea behind the CSLAA was to help spur the growth of the young commercial spaceflight industry. Free of government hindrances, private companies had the room they needed to be innovative with their designs, helping the industry to grow at a faster pace. There was also an unspoken assumption that test pilots, much like other risk takers, knew what they're getting themselves into, negating the need for too much red tape. But the regulation-free environment wasn't meant to last forever. In 2012, Congress extended the CSLAA to last until 1 October 2015, with no plans to keep it going after that. Overall, the measure was intended as a freeze on regulations, contingent on the fact that no pilots died or suffered serious injury during spaceflight testing. That line was crossed with the death of Michael Alsbury. Now the debate will be where to draw the line. To that end the FAA will leverage lessons learned that will hopefully result in increased safety while at the same time allow the industry to continue to evolve.

Some argue the goal of commercial manned space flight should be a safety record similar to that of commercial aviation, but the statistics aren't encouraging. Back in the Shuttle era, NASA estimated the risk of losing a Space Shuttle was 1 in 90, or 1.1 percent. Other unregulated human activities are much riskier. A 2007 study found that the chances of dying while climbing Mount Everest (Figure 10.1) were about one in 62, or 1.6 percent. The FAA provided an outline of what commercial spaceflight regulations may look like in

10.1 Mt Everest from Goyko Ri. Courtesy Wikimedia

a report published 27 August 2014 laying out recommended practices for such ventures. The 56-page report by the FAA's Office of Commercial Space Transportation, titled "Recommended Practices for Human Space Flight Occupant Safety," provided safety guidelines for suborbital and orbital crewed vehicles and covered aspects of the design, manufacturing, and operations of such vehicles. It included dozens of safety recommendations, from having fire suppression systems to preventing electrical shocks, but the report stopped short of defining specific levels of acceptable risk because that "may inadvertently limit innovation." By comparison, in the world of commercial aviation, the FAA requires manufacturers such as Boeing to prove that failures of systems that could take down a plane - such as a fractured wing - must be "extremely remote." That term is defined as one that occurs no more than once in 1 billion flights, which makes such an event unlikely during the history of an aircraft's lifetime. Even with the brightest engineers streaming to commercial space ventures, it will be many, *many* years before rockets and spacecraft become as reliable as aircraft. That's because space travel uses extremely complex technology and it's impossible to test that technology in flight very frequently because of the cost. This also means making the '1 in a billion' kinds of odds standard for spacecraft is nigh on impossible, although increased regulation will hopefully make commercial spaceflight safer than it is today. And while more regulations may sound potentially debilitating, such a move will indicate a positive transition for commercial space companies. Private spaceflight is no longer in its infancy, and a more regulated industry will indicate that these technologies are moving into the mainstream.

DOES VIRGIN GALACTIC STILL MATTER?

> It will be the start of a whole new space era.
> Richard Branson, 2014 United Arab Emirates Government Summit

Virgin Galactic hopes to complete construction of a second SpaceShipTwo in mid-2015 and begin test flights before the end of the year. For now, its official name is 202VG – the second series of the SpaceShipTwo family. But is there still a chance that Virgin Galactic can make good on Richard Branson's words?

In the decade leading up to SpaceShipTwo's accident, Virgin Galactic delayed their revenue flights many, *many* times. And, after a steady flow of hype filled with promises and reassurances too often at odds with the realities in Mojave, the media took aim, accusing Virgin Galactic of public obfuscation and deception. Was it justified? Perhaps the best person to answer that question was one of Virgin Galactic's ticket-holders, who had this to say after the SpaceShipTwo crash:

> I was shocked but also I know this kind of thing can happen. It's rocket science, it's not easy, it's complicated. Thank God it wasn't on a commercial flight with six passengers and two pilots. I have been a ticket holder now for almost five years and I have watched the progress. I know it's possible because of what happened with SpaceShipOne. It's just scaling up the rocket motor to a bigger craft. It's not easy. They had an accident back in '07 which killed three people on the ground, and now we have lost a life in the air. But it's technology, it's dangerous and those of us who signed up understand there's risks. I am part of that generation that watched Neil Armstrong and Buzz Aldrin walk on the Moon, and we thought we'd get to go to space a lot earlier than we are going to go. I take it seriously. I am a space enthusiast I understand how it works, I have trained for this. If they can figure out what went wrong and they can fix it then I think the industry down the road is fine. But if they can't then that's the problem and that's when people will start to reconsider I think.
>
> Passenger number 610, Jim Clash, 01 November 2014, Sky News.

Remember, Virgin Galactic is trying to provide their passengers with an enjoyable and *safe* experience and the company is privately funded, which makes the whole enterprise much, *much* more challenging, as evidenced by the tragic crash of SpaceShipTwo. Also, remember that this suborbital passenger business has never been done before, so there are bound to be engineering problems and several other challenges to overcome. That's why Virgin Galactic has such a great team of engineers working the issues. But still, it will be a tough climb ahead. But don't discourage that audacity, because Virgin Galactic still matters.

It matters because Virgin Galactic is a company synonymous with a pioneering spirit, technological innovation, and sense of adventure, but it's much more than brash advertising and audacious promotions. Remember the Moon landings? The Apollo Program was championed by politicians and financed with billions of taxpayer dollars. But, by the time astronauts actually stepped onto the lunar surface, NASA's budget was already being cut. And since Apollo, just about every space program from the Shuttle to the International

Space Station (ISS) has suffered from political compromise and lack of ambition. Private spaceflight, on the other hand, is unburdened by the favor of taxpayers or whims of politicians. If the company can raise the cash, it can build a spacecraft. And Virgin Galactic is still leading the way, despite the unfortunate event of 31 October 2014.

It matters because Virgin Galactic is already inspiring a new generation of engineers. That's because working on SpaceShipTwo means working in small teams with limited resources, which is completely different to the way space agencies work, where most engineers sit behind a desk most of the day. Those working on SpaceShipTwo don't. They walk onto the shop floor and turn wrenches and fire rocket engines. Inspiring.

It matters because, until very recently, if you wanted to fly into space, you needed to have US$35 million in your pocket and be prepared to spend six months away from home training for your flight. And you had to learn Russian. Not anymore. The cost of reaching space is going down thanks to Virgin Galactic. Not just for tourists, but for scientists and researchers who can now fly their missions for a fraction of the cost. The final frontier just became a whole lot more economically viable and accessible for a lot more people. Thanks to Virgin Galactic.

Appendix I

A Very Short Primer on Aeronautics[1]

Anhedral is the downward angle from horizontal of the wings or tailplane of a fixed-wing aircraft.
Center of Gravity is the longitudinal and lateral point in an aircraft where it is stable – the static balance point.
Dihedral is the upward angle of a fixed-wing aircraft's wings where they meet at the fuselage.
Elevons are aircraft control surfaces that combine the functions of the elevator (used for pitch control) and the aileron (used for roll control). An elevon that is not part of the main wing, but instead is a separate tail surface, is a stabilator.
Empennage, which is also known as the tail, gives stability to the aircraft, in a similar way to the feathers on an arrow. The aircraft's cockpit voice recorder and flight data recorder are often located in the empennage.
Flaps are movable, usually hinged airfoils set in the trailing edge of an aircraft wing, designed to increase lift or drag by changing the camber of the wing or used to slow an aircraft during landing by increasing lift.
Flight Envelope describes an aircraft's performance limits, specifically the curves of speed plotted against other variables to indicate the limits of speed, altitude, and acceleration that a particular aircraft can not safely exceed.
Fuselage is an aircraft's main body section that holds crew and passengers or cargo.
Longerons are thin strips of material to which the skin of the aircraft is fastened.
Pitch specifies the vertical action, the up-and-down movement.
Roll specifies the action around a central point.
Rudder is the movable part of a vertical airfoil which controls the *Yaw* of an aircraft.
Spars are beams that extend from wing root to tip.
Speed Brakes are a type of flight control surface used on an aircraft to increase drag or increase the angle of approach during landing.
Trailing Edges are the rear edges of wings where the airflow separated by the leading edge rejoins.
Yaw specifies the side-to-side movement of an aircraft on its vertical axis.

[1] Adapted from http://www.aerofiles.com/glossary.html

E. Seedhouse, *Virgin Galactic: The First Ten Years*, Springer Praxis Books,
DOI 10.1007/978-3-319-09262-1

Appendix II

Just How Risky Is Flying on SpaceShipTwo?

> "Eventually they'll crash one. Because it's hard. They're discovering how hard. They wanted to fly years ago and faced a lot of obstacles, but he's a brave entrepreneur and I hope he succeeds. The more people who can see the world this way, the better off we are."
>
> *Chris Hadfield, being interviewed by* The Guardian *in October 2013 about the risks of the suborbital spaceflight business. The Canadian astronaut, whose tweeted photos, videos, and rendition of David Bowie's "*Space Oddity*" brought him global fame while commanding the International Space Station, said the nature of space travel meant that at some point a Virgin Galactic craft would crash*

Sometime in the near future, assuming Virgin Galactic can recover from the SpaceShipTwo tragedy, WhiteKnightTwo will carry SpaceShipTwo to an altitude of 15 kilometers and release it. SpaceShipTwo will fire its rocket and blaze upwards, carrying its precious cargo to an altitude of >100 kilometers before gliding home to a safe landing next to Spaceport America. The passengers – now fully-fledged Virgin Galactic astronauts – will have the time of their lives, enjoying a few minutes of microgravity and stunning views of Earth. Champagne and the presentation of Virgin Galactic astronaut wings will follow (the pilots may receive their Federal Aviation Administration (FAA) wings if the flight reached an altitude exceeding 100 kilometers). After far too long, the era of routine space access will finally have arrived. But how safe will it be? Well, Burt Rutan, founder of Scaled Composites, has said that SpaceShipTwo "is designed to be at least as safe as the early airliners in the 1920s". To anyone aware of the history of aviation, that quote may not be particularly reassuring, especially in light of the SpaceShipTwo crash.

Rocket-powered vehicles have always been popular, and for good reason: their speed, rate of climb, and ability to reach high altitude were superior to jet aircraft. Which is why so many aircraft-building nations in the 1940s, 50s, 60s, and 70s spent a fortune developing rocket planes. Some countries, like Nazi Germany, even put one – the *Me 163 Komet* – into mass production. So why did we have to wait so long for SpaceShipTwo? Well, part of the reason is that jet-engine development overtook the rocket as a viable aviation power-plant. The other reason is rocket planes crashed. A lot. Make no mistake, SpaceShipTwo is a marvel of aeronautical engineering, but rocket engines are complex

E. Seedhouse, *Virgin Galactic: The First Ten Years*, Springer Praxis Books,
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pieces of engineering. To give you an idea of the risks involved, consider the following numbers, which cover rocket planes belonging to the UK and US (those of other nations are not well documented). In a 30-year period starting in 1947, 16 rocket planes of seven types (Bell X-1 and X-2, Douglas Skyrocket, NAA X-15, Northrop HL-10, SARO SR53, and Martin X-24) made 846 flights (compared to thousands of jet aircraft making hundreds of thousands of flights in the same period) with an accident rate of about 1 in 105! This risk may be acceptable for volunteer test pilots, but are fare-paying passengers prepared to face it? In comparison, the Shuttle suffered two fatal crashes in 135 flights for an accident rate of about 1 in 65. The point is, it is generally agreed that spaceflight is inherently risky and that adverse physical and psychological effects can be experienced even during successful spaceflights. There are also numerous vehicle and/or system failures that could result in severe injury, dismemberment, or death. So, for those who are SpaceShipTwo ticket-holders, I've summarized the physical and potential psychological hazards together with a summary of the probability of occurrence and severity.

SECTION 1: PHYSICAL HAZARDS

Table 1. Summary of physical hazards[1].

Hazard	*Mission phase/failure mechanism*	*Potential physical effects*	*Risk*
High-decibel noise	Excessive engine noise Inadequate acoustic shielding Explosion on ground	Ear damage Temporary/permanent hearing loss Vestibular effects on balance	Low if ear plugs are used
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
Low pressure	Explosive decompression Rapid decompression Loss of atmospheric control systems	Trauma due to exposure to vacuum: • Brain injury • Lung injury • Other tissue damage • Death Trauma due to pressure change and trapped gas: • Gastrointestinal pain • Tooth, ear, sinus pain	Low
High G-forces (sustained acceleration)	Acceleration during launch phase, de-acceleration during descent phase	G profile may have adverse physiological effects on the cardiovascular response of susceptible passengers • Cardiovascular • Neurovestibular • Musculoskeletal	Low if passenger coped well with centrifuge training

(continued)

Table 1. (continued)

Hazard	*Mission phase/failure mechanism*	*Potential physical effects*	*Risk*
Microgravity	At high altitudes during suborbital flight	Short exposures to microgravity may cause acute physiological responses in: • Cardiovascular system • Respiratory system • Neurological system – Vestibular – Motion Sickness – Vision • Musculoskeletal system • Gastrointestinal system	
High temperature	In-flight fire/explosion Heat of re-entry/loss of heat dissipation systems	Tissue damage and/or serious burns Death	Low
Low temperature	Cabin breach	Frostbite/death	Low
Physical impact trauma	Crash/structural failure of spacecraft	Serious injury or death	Low
	Egress from spacecraft	Minor injury	Low
Exposure to toxic chemicals	Release of toxic substance on board	Respiratory/skin damage Death	Low
Electrical shock	Contact with exposed high-voltage source	Severe burns Electrocution/death	Low
Loss of breathable atmosphere/ contaminants, and particulates	Cabin flooded with non-breathable gases	Asphyxiation/death Brain/organ damage Death	Low

[1] Adapted from ‘Suborbital’ by Erik Seedhouse. Published by Springer-Praxis, 2013.

SECTION 2: PSYCHOLOGICAL RESPONSE HAZARDS

SpaceShipTwo passengers are not subject to the same level of medical screening as professional astronauts, so some may experience excessive physiological and/or psychological response(s) during their flight as described in Table 2.

Table 2. Summary of psychological response hazards[2].

Source of physiological/psychological response/hazard	*Potential cause of response*	*Potential effects of physiological/ psychological response*
Claustrophobia	Enclosure in confined space	Excessive agitation Inability to perform required duties
Excitement/agitation/fear	Response to unexpected occurrences Response to known risks Mental instability	Commit irrational and possibly violent, acts Produce anxiety in other passengers Incapacitation
Motion sickness	Dynamic motion	Nausea, vomiting Inability to perform required duties/ incapacitation
Vertigo – loss of bearing or balance	Dynamic motion	Nausea, vomiting Inability to perform required duties/ incapacitation
Rapid pulse/increased blood pressure	Excitement	Cardiac arrhythmia Inability to perform required duties/ incapacitation

[2] Adapted from 'Suborbital' by Erik Seedhouse. Published by Springer-Praxis, 2013.

SECTION 3: SUMMARY OF POTENTIAL EFFECTS ON PASSENGERS

Any vehicle being launched into space risks a system or vehicle failure that might result in serious injury or death. Such failures have a variety of potential causes – propulsion system failures, explosion of propellants on the ground or in the vehicle, loss of vehicle control, explosive decompression, and ground impact. The potential hazards of strapping into a spacecraft have been listed in Sections 1 and 2. Tables 3 and 4 rank these effects based on their probability of occurrence and the severity of the resulting consequence.

Table 3. Potential hazards – probability of occurrence[3].

Probable/certain
Gastrointestinal issues caused by microgravity
Dysrhythmia (changes in cardiac rate, rhythm) due to acceleration stress
Exposure to actions of other passengers
Somewhat likely
Motion sickness caused by unusual attitude and/or microgravity
Faint feeling caused by acceleration and deceleration
Fatigue caused by low-pressure cabin environment
Panic/fear/fright
Possible
Gravity-induced loss of consciousness caused by acceleration
Moderate injury caused by impacts inside cabin
Vertigo caused by loss of bearing
Significant pulmonary/respiratory effects caused by acceleration in susceptible individuals
Cardiovascular effects caused by acceleration/microgravity
Claustrophobia – hopefully this will have been screened for
Rare – vehicle or safety system failure
Death/severe injury/dismemberment
Asphyxiation caused by loss of cabin atmosphere
Temporary or permanent hearing loss
Burns due to ground accident
Ear drum damage

[3] Adapted from 'Suborbital' by Erik Seedhouse. Published by Springer-Praxis, 2013.

Table 4. Potential hazards – severity of consequence[4].

Critical
Death/critical injury/dismemberment caused by vehicle accident
Asphyxiation caused by decompression
Permanent hearing loss
Bone fractures
Loss of consciousness caused by acceleration
Significant
Moderate injury caused by ground failure or impacts within craft
Connective tissue damage caused by acceleration
Ear drum damage
Temporary hearing loss
Vestibular effects – vertigo/balance

(continued)

Table 4. (continued)

Nuisance
Exposure to actions of other passengers
Dysrhythmia in susceptible individuals
Motion sickness
Faint feeling
Headaches
Fatigue
Panic/fear/fright
Claustrophobia
Inability to think rationally
High-altitude sickness

[4] Adapted from 'Suborbital' by Erik Seedhouse. Published by Springer-Praxis, 2013.

Appendix III

The SpaceShipTwo Accident

A.IVa NTSB Go-Team inspects a tail section of the crashed SpaceShipTwo. This image is a frame of the B-roll video recorded by NTSB. Courtesy NTSB

This appendix was written in December 2014 and was based on the National Transportation Safety Board (NTSB) findings released up to that date. According to the NTSB, SpaceShipTwo's two moveable tail booms unexpectedly began to deploy into a "feathering" position two seconds prior to point at which the spacecraft began to break up. Camera footage and telemetry show that approximately nine seconds after ignition of the hybrid rocket, the mechanism that controls the stowage of the moving tails moved from "lock" to "unlock." As SpaceShipTwo accelerated through about Mach 1, the co-pilot was seen to move the locking handle. Normal procedure is to unlock the feathers after Mach 1.4 so that aerodynamic forces do not prematurely extend the mechanism.

E. Seedhouse, *Virgin Galactic: The First Ten Years*, Springer Praxis Books,
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In normal operations the feathering device is designed to be activated at very high altitude before the vehicle begins its descent. In addition to the locking mechanism, the feathering device requires the activation of a second handle. The feather system acts like a shuttlecock and was designed by Burt Rutan as a carefree re-entry for recovery of SpaceShipOne. The feathering system was deliberately deployed at beyond Mach speed as a part of earlier powered flight tests of SpaceShipTwo (the second powered flight on 5 September 2013, when SpaceShipTwo reached Mach 1.43 and a maximum altitude of 69,000 ft). However, in each previous deployment, activation either occurred at higher altitudes (where the air is very thin), or during unpowered flights at much slower speeds than the tragic flight of 31 October.

The NTSB also reported that the fuel and oxidizer tanks as well as the hybrid rocket motor were all intact and showed no signs of being breached. These findings supported the photographic evidence of the mishap which showed a successful ignition and continuing rocket burn before the structural breakup.

The flight was the fourth powered test of SpaceShipTwo and the first to use a new plastic-based fuel designed to provide a more powerful and smoother acceleration. Initially, the switch to the new fuel led to speculation that this would form the focus of the investigation, but the NTSB inquiry shifted to the inadvertent deployment of the feathering mechanism and the impact of excessive aerodynamic loads on the structure.

As this appendix was being written, acting NTSB chairman Christopher Hart had confirmed that the safety lock on Virgin Galactic's SpaceShipTwo feathering mechanism had been prematurely unlocked shortly before breakup. The NTSB had completed its data gathering and the team had returned to Washington DC with the data to undertake the facts compilation followed by the analysis. The NTSB reported that the test flight was rich in telemetry, a fact that would expedite the analysis but the board still cautioned that they expected the investigation to take 12 months to conclude and release a final report.

From the data released to date, the NTSB stated that the feathering was not to be deployed until SpaceShipTwo had achieved Mach 1.4. That statement referenced the Flight Card, which is the plan of actions and constraints for the flight. If this was the wording on the Flight Card, then it would have permitted a pilot to interpret it in various ways. As a private pilot who also has experience flying in fighter jets I am somewhat familiar with the impact that flight conditions have on operations of an aircraft. To provide a greater insight into what may have happened to SpaceShipTwo I decided to canvas some of my professional pilot colleagues, many of whom have flown supersonic jets. The following is a composite analysis of some of their observations.

The SpaceShipTwo constraint of Mach 1.4 for executing feathering was intended to be viewed by the pilots as the descent speed after SpaceShipTwo had achieved suborbital altitude, which is 100,000 meters or higher. During a descent from suborbital altitude, Mach 1.4 would obviously be achieved at a much higher altitude where the air density is much lower and stresses from the feathering would also be much lower than at an altitude of 15,000 meters, which is the altitude at which SpaceShipTwo disintegrated. During previous tests of SpaceShipTwo when feathering was tested at low altitude, the vehicle was flying far below Mach 1 (subsonic). In that flight regime the spacecraft had no difficulty withstanding stresses during the feathering test.

For the NTSB, which investigated its first space-related accident, the task of data gathering was made easier due to the masses of flight-test telemetry and multiple sources of air- and ground-based imagery. The agency was also able to gather evidence from the debris, which was scattered across eight kilometers of the Mojave Desert. The NTSB (sidebar) determined that shortly after rocket ignition, SpaceShipTwo's movable twin tail-booms unexpectedly deployed into an upward-canted "feathering" position, over-stressing the airframe and causing it disintegrate.

Timeline of events leading up to breakup of SpaceShipTwo as stated by the NTSB

10:07:19: SpaceShipTwo released from the carrier craft, WhiteKnightTwo. Until this point, SpaceShipTwo had performed as expected. It took off from the Mojave Air and Space Port in California, hanging beneath its carrier aeroplane. It then detached in preparation for firing its rocket motor.

10:07:21: SpaceShipTwo's engine starts. As the craft made its ascent, the pilots would have been pinned against their seats, as G-forces increased rapidly.

10:07:29: SpaceShipTwo reaches Mach 0.94. In the three seconds it took for the craft to climb from Mach 0.94 to Mach 1.02, co-pilot Mike Alsbury made what the NTSB believe was the fatal mistake that led to the disintegration of SpaceShipTwo.

10:07:31: SpaceShipTwo exceeds the speed of sound – Mach 1.02. Between **10:07:29** and **10:07:31**: Feathering safety unlocked. Two steps are normally required for feathering: video footage retrieved from the cockpit shows that one of the pilots completed the first step when the vehicle was moving at only the speed of sound. The second action was not performed, but seconds later, the tail booms began moving to their feathered position anyway.

10:07:34: All telemetry lost. At this point, the forward section of the vehicle pitched up violently as the feathers activated. Breakup was virtually instantaneous. The booms and feather flaps detached first, followed by separation of the cabin and cockpit section forward of the pressure bulkhead that divided the compartment from the oxidizer tank. The rocket motor, still producing thrust, continued a short way before crashing.

Having established that the tails moved, the big question was why? To activate the feathering device, the crew first had to unlock the system using a prominent handle located centrally, similar to the throttle on a conventional aircraft. The handle is large to be used wearing gloved hands. A separate activation handle is then engaged to command movement of the feathering system by two actuators. It is the actuators that move the booms and the "feather flaps," which run along the trailing edge of SpaceShipTwo's delta wing. The assembly rotates to approximately 65° around hinges wound into the composite rear spar, with the pistons extending the forward section of each boom downward below the pivot axis.

As for Peter Siebold, who survived a 16-kilometer fall back to Earth, his experience may be regarded as one of the most amazing test flight survival stories of all time. Talking to investigators, Siebold says he fell from the vehicle as a result of the break-up sequence and unbuckled from his seat before the parachute deployed automatically. SpaceShipTwo has no ejection system and, as the entire cabin vessel is pressurized using bleed air from an air-cycle machine while attached to WhiteKnightTwo, the crew does not wear pressure suits. Although the crew does breathe oxygen at positive pressure, it is not known for how long Siebold was free-falling through low oxygen levels at high altitude before his parachute deployed. Unfortunately,

Siebold's testimony to the NTSB (on 7 November 2014) threw little light on the reasons for the apparent actions of Alsbury. The NTSB stated that Siebold "was unaware the feather system had been unlocked early by the copilot. His description of the vehicle motion was consistent with other data sources in the investigation."

As this book is going to press the NTSB is continuing their investigation. This will include a vetting of such issues as pilot training, pressure to continue testing, safety culture, design and procedures, and a further review of the accident itself.

Appendix IV

SpaceShipTwo Aftermath

Following the SpaceShipTwo tragedy, Virgin Galactic took down its website and posted a statement about the accident[1]. Three weeks later, the website was relaunched and updated with a different design and some changes about safety, passenger capacity and altitude. Let's start with payload capacity. Virgin Galactic's claim prior to the SpaceShipTwo tragedy was as follows:

> *SpaceShipTwo* uses all the same basic technology, carbon composite construction and design as SpaceShipOne. However it is around twice as large as that vehicle and will carry six passengers and two pilots.[2]

The revised claim now reads:

> SpaceShipTwo is a reusable, winged spacecraft designed to repeatedly carry as many as eight people (including two pilots) into space — a larger total flight crew than any previous space mission except for NASA's 8-member STS-61-A mission in 1985.[2]

The interesting part of the above statement is the promise to carry passengers into space, which leads us to the altitude claim. Previously, Virgin Galactic's website posted a diagram of SpaceShipTwo's mission architecture, which clearly showed the vehicle reaching a maximum altitude of 110 kilometers. Since this altitude is above the Kármán line of 100 km, this would clearly meet the internationally recognized definition of space.

Following the SpaceShipTwo crash it seems Virgin Galactic passengers will no longer be guaranteed a trip to space unless space happens to be higher than 80 kilometers. The website goes on to explain that the U.S. Air Force used to award astronaut wings to X-15 pilots who exceeded 80 km. The website states: "Everyone on board SpaceShipTwo will earn official astronaut status, just like the pilots who flew the X-15 spaceplane." This is misleading because no Virgin Galactic passenger will earn 'official' astronaut status,

[1] For those interested in reading more about the changes to Virgin Galactic's website, visit Parabolic Arc and read Doug Messier's post on 22 December 2014: http://www.parabolicarc.com/2014/12/22/virgin-galactic-significantly-altered-claims-spaceshiptwo-crash/

[2] www.virgingalactic.com

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whether they fly to 100 kilometers or 10,000 kilometers. The only ones earning official astronaut status will be the pilots who will be awarded FAI commercial astronaut wings and the pilots will only earn these if they exceed 100 kilometers. If the new SpaceShipTwo only reaches 99 kilometers, too bad! No wings. But Virgin Galactic passengers will receive Virgin Galactic astronaut wings regardless of the altitude flown. That's because these wings will not be official because they will not have the status of the FAI wings. I don't know about you but I would be more than a little upset if I had paid $250,000 for a sub suborbital joyride to 80 kilometers.

The website addresses the issue of a space boundary stating that various organizations have identified specific altitudes in an attempt to codify what is space and what is not. The USAF used the 80 kilometer threshold while the Kármán line of 100 kilometers is the internationally accepted and FAI approved altitude. If you are a passenger reading this and you really want to reach space you may want to consider trading in your Virgin Galactic ticket and buy one for the Lynx Mark II. Chances are you will get an earlier flight and you will reach suborbital altitude. Your choice.

And so to the safety issue. Those familiar with the Virgin Galactic website prior to the accident will remember phrases about safety being the company's North Star. These claims have now been removed, which isn't surprising given that four people have been killed in pursuit of realizing Virgin Galactic's suborbital dream. Other changes on the website include the removal of the section explaining how safe and simple hybrid motors are. This has been replaced by a section explaining how well suited this type of motor is for SpaceShipTwo.

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