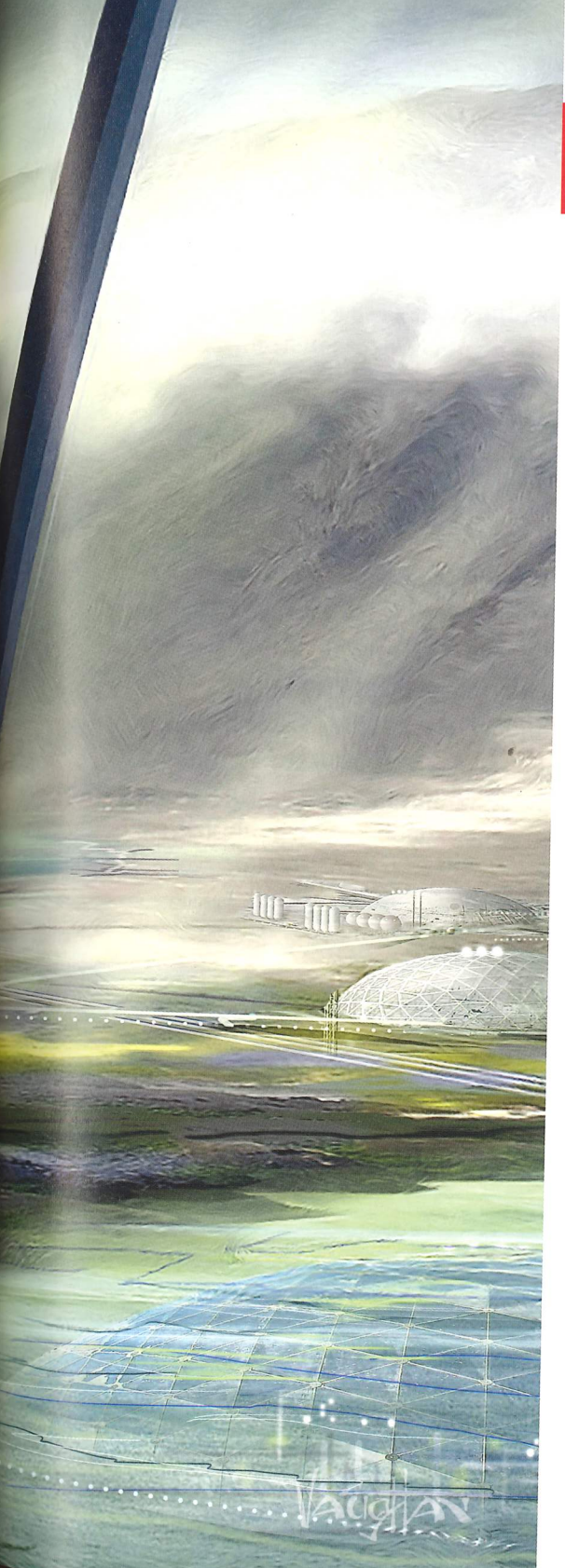
Image credit: James Vaughan



CHAPTER 7

SPACE ENTREPRENEURS

The two-hour drive from Los Angeles to the city of Mojave, population 4,238, is a dreary one. I had set out at 7 AM on a cloudy Friday morning to cross this forlorn desert, an expanse I've seen perhaps forty times but still have not quite gotten used to. Deserts are supposed to be places of desperate and forbidding beauty—huge, sweeping fields of sand dunes, stately saguaro cacti, and the occasional scrawny coyote prowling the hardpan or lone eagle silhouetted against the sky. Not so, this region of Southern California. It is, for the most part, a flat, cocoa-brown wasteland with little vertical relief and only scruffy, wizened shrubs, with the arid Tehachapi Mountains in the distance. The transition from the Los Angeles metropolis to high desert is gradual. Once past the extended suburbs of Palmdale and Lancaster, one passes through sun-bleached housing developments and generic industrial parks until the city runs out, as if it simply lost the will to go on. Only the occasional cluster of gas stations and fast-food outlets break the desolation.

The drive to the city of Mojave, California. Image credit: Wikimedia Commons/ Theschmallfella

Then you cross into the historic city of Mojave, which began life as a railroad town in 1876 and later became a stopover on the main highway between Southern California and the old gold-rush country to the north. In 1964, the construction of Highway 58 largely bypassed the town. The business district is now a combination of gas stations and fast-food franchises interspersed with older, sometimes abandoned buildings, from which paint peels like cornflakes.

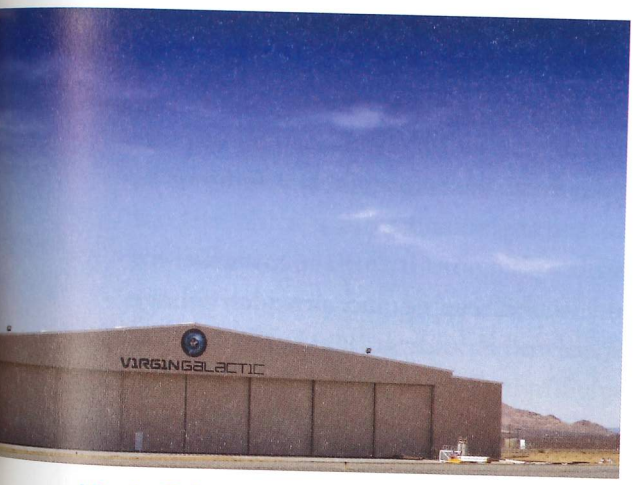
I drove about halfway through the nine-block length of the town to Airport Road and turned right. Here the scenery improves rapidly. A new energy buzzes in old Mojave. Soon the small airport became visible—a cluster of metal buildings surrounding a modern control tower. Mojave Airport serves as a hub for business activity for the region, and within its confines stands Virgin Galactic, where billionaire Richard Branson is slowly realizing his spaceflight dream.

Branson has been working on a plan to democratize space tourism since 2004; he has named his newest spacecraft *Unity*. This modern craft is patterned after a decade of pioneering work by Burt Rutan, the man who built a rocketplane to win the Ansari X Prize. Rutan won the multimillion-dollar cash award in 2004 for flying SpaceShipOne twice in one week to the edge of space. He subsequently merged his efforts with Branson, though Rutan later left the company to pursue other space ventures. But his unique and innovative rocketplane design concepts live on.

Entrance to Mojave Spaceport. Image credit: Wikimedia Commons/Californiacondor

Virgin's assembly facility fills a vast modern building amid smaller, older hangars. The only way you would know that anything special takes place here is the large sign across the single glass protrusion out front bearing the word *FAITH* in tall white letters—an acronym for Final Assembly, Integration, and Test Hangar. From the outside, the facility takes more cues from the rough-and-ready days of test flight than from NASA's massive operations in Florida and Texas. Just a few miles down the road at Edwards Air Force Base, the X-15 tore up the skies in the 1960s. Virgin Galactic seems infused with that pioneering spirit.

I park in a half-empty lot and enter for a tour of the plant. Inside, Virgin Galactic is all business, with little effort wasted on glitz. The double doors swing open and I am greeted with the smells of a classic machine shop—oil and solvents. The workers are young, idealistic, and friendly. After a few brief introductions, they return to building their rocketplane. A few machinists craft parts here and there, and many more folks look intently at the computer monitors haphazardly strewn on banquet tables spread across the workshop floor. Engineers and technicians gather in small clusters, speaking in low tones. If it weren't for the magnificent rocketplane and its carrier craft sitting boldly in the middle of the shop, gleaming white and chrome under the bright lights, it could be any midsized machine



Virgin Galactic's Mojave facility. Image credit: Wikimedia Commons/Ed Parsons

The author inside Virgin Galactic's fabrication and assembly facility, in front of the carrier airplane Eve. This twin-fuselage jet carries Virgin's rocketplane Unity to altitude before it detaches and begins its rocket-powered climb to space. Image credit: Rod Pyle

shop. To someone used to the vast spaces and precise, Germanic layouts of NASA facilities, this looks almost casual—just a couple dozen workers on any given shift, enthusiastically fabricating the future.

A group of engineers—three men and two women—are collected underneath *Unity*'s left wing. The rocketplane is supported on jack stands, and the left landing gear is up, tucked inside the fuselage as it would be during flight. They are about to conduct a gear-down test, simulating the process by which *Unity* will lower its wheels prior to landing. After a bit of fussing, and with nods of agreement, the group moves back to a safe distance. Someone says "clear!" and with an alarmingly loud *bang* the landing gear is forced into a down-and-locked position via high-pressure gas. There are smiles all around, and the crew moves on to their monitors to evaluate the test data. It's a moment of muted excitement and welcome progress. Virgin Galactic is behind schedule—the initial passenger flight was supposed to take place in 2009—so progress is critical.

Virgin's approach to launch is unique to commercial passenger-carrying rocketplanes. It will be flown to launch altitude of about 52,000 feet in between the twin hulls of a giant carrier plane, WhiteKnightTwo, or *Eve*, which uses traditional jet engines. *Unity* will then ignite its rocket engine to fly into suborbital space. This launch procedure is based on military rocketplanes from the past such as the X-15. Flying in the 1950s and 1960s, the X-15 was carried to altitude by a B-52 jet bomber before igniting its rocket engine and soaring to the edge of space. Using a carrier plane saves fuel for the rocket engine and provides a huge speed and altitude assist at launch.

An X-15, with extra fuel tanks attached, is carried to altitude by a USAF B-52 bomber before dropping free and igniting its rocket engine. Virgin Galactic's rocketplane operates in a similar fashion. Image credit: US Air Force

Virgin Galactic's plans to carry paying passengers have been consistently delayed. In a ground test in 2007, a rocket engine exploded, killing three engineers. The engine design has since been improved,

Virgin Galactic's newest rocketplane, Unity, mated to its carrier plane Eve, at its first rollout. While it does not return at orbital speeds, Unity still needs extensive thermal protection to survive the high temperatures of reentering the atmosphere. Image credit: Virgin Galactic/Mark Greenberg

but despite numerous test flights, it has still suffered teething problems. One of the biggest complications has been getting the thermal protection on *Unity* right. Despite being a suborbital rocketplane, it still encounters high temperatures during its descent back into the atmosphere.

Virgin Galactic's history is indicative of the perils facing spaceflight entrepreneurs. In 2008, despite the accident, Branson projected that tourist flights would begin by the end of 2009. Then, when that date approached, the company announced that it might take two more years to begin operations. Those years came and went with only intermittent testing occurring. Clearly, creating a space-tourist business was harder than Branson, or any of the others working in the field, had foreseen.

Virgin Galactic hired a new chief executive named George T. Whitesides in 2010. Whitesides is a veteran of other spaceflight activities, including a brief stint as chief of staff at NASA. He was the executive director of the National Space Society from 2004 to 2008. Whitesides and his wife, Loretta, also started a yearly space event called Yuri's Night, a celebration of the dawn of the space age, that has spread globally, resulting in thirty-five events in fifty-seven countries. His father is a prominent chemistry professor at Princeton University who has done

Virgin Galactic's founder, Richard Branson, greets the press at the rollout of Unity. Image credit: Virgin Galactic

George Whitesides, president of Virgin Galactic. Image credit: Virgin Galactic

extensive research in materials science and nanotechnology, so science and tech run in the family.

Once Whitesides settled in at Virgin Galactic, he "adjusted how they did business," as he put it in an interview for the *Guardian* in 2014. "We've changed dramatically as a company . . . When I joined in 2010 we were primarily a marketing organization." Whitesides refocused the emphasis on engineering and testing, and discouraged his boss from setting unattainable operational goals.

By 2013, the workforce had expanded and the company had flown dozens of test flights: fifteen tests with the rocketplane attached to the carrier craft, and sixteen more tests in which the rocketplane separated and glided to a landing. Within the year, two powered tests were flown, with *Unity*'s predecessor performing properly, but not quite attaining the desired targets for speed and duration of flight.[46]

Then, in 2014, with almost fifty tests behind them, an in-flight accident occurred during a powered flight of SpaceShipTwo with two pilots aboard. On October 31, 2014, SpaceShipTwo was dropped from the carrier plane above the Mojave Desert. The engine fired and the rocketplane began to climb. Eleven seconds later the ship malfunctioned and broke up. One pilot survived with injuries, but the other perished in the accident. Despite conjecture about a possible explosion of the sometimes-troublesome rocket engine, the cause of the crash was later determined, after a long and arduous investigation, to be the reentry mechanism. Virgin's rocketplanes have a unique "feathering" system that moves the tail surfaces relative to the main hull during the early stages of descent. This system was apparently—and accidentally—deployed early in the test flight, while the rockets were still firing, rather than after

shutdown, as designed. The craft disintegrated due to violent aerodynamic stresses.

In a press release highlighting its final write-up of the accident, the National Transportation Safety Board (NTSB) noted that there appeared to have been human error involved in the early deployment of the feathering system.

"The National Transportation Safety Board determined the cause of the Oct. 31, 2014 in-flight breakup of SpaceShipTwo was Scaled Composite's [Rutan's original company] failure to consider and protect against human error and the co-pilot's premature unlocking of the spaceship's feather system as a result of time pressure and vibration and loads that he had not recently experienced."[47]

The report continued to detail that the pilots had not been properly trained, and that the feathering system should have had a safety-interlock system, which has since been added. Some blame was apportioned to the FAA as well—it was suggested that the agency had been too generous in granting operational waivers and exceptions for experimental flights. The report then provided a summarizing statement that might best describe why entrepreneurial efforts, such as Virgin Galactic's, take longer than anticipated: "Manned commercial spaceflight is a new frontier, with many unknown risks and hazards. In such an environment, safety margins around known hazards must be rigorously established and, where possible, expanded." The report concluded, "For commercial spaceflight to successfully mature, we must meticulously seek out and mitigate known hazards, as a prerequisite to identifying and mitigating new hazards."

This second accident, after the 2007 engine explosion, shook Virgin Galactic to its core and resulted in further strong and proactive steps to ensure future safety. More test flights were scheduled to ascertain that each system and subsystem was safe and reliable.

The entire private spaceflight industry also took notice; accidents can happen, but when human life is at risk, you must act promptly, and even more urgently when those lives are civilian passengers. Just because you can get something approved by a government entity like the FAA does not mean you can stop obsessing about safety. You must go above and beyond to ensure that your system is as trustworthy as you can make it.

Many existing regulations have been built around decades of activities by NASA and the military, and they have yet to fully catch up with the private sector's new spaceflight efforts. And while new regulations are needed, spaceflight will never be 100 percent safe. As American author John A. Shedd famously said in 1928, "A ship in harbor is safe, but that is not what ships are made for." To

move outward, we must leave the harbor, an inherently risky business. As space entrepreneurial efforts proceed, especially those carrying humans, more risk will be assumed, and we must collectively learn to accept it, within the regulations, rules, and processes that will be established to mitigate and minimize that risk.

For any commercial spaceflight company to succeed, it must be able to provide frequent, reliable, and affordable access to space while generating a profit. But the challenges of conducting safe spaceflight in an airline-like business model are substantial. You can see why this is a realm best suited to billionaire investors—it takes a lot of time and money to accomplish, and no revenue is generated during the development and testing period. Profits are still in the future for Virgin. The word *FAITH* on the hangar's exterior would appear to be a key attribute of people like Branson. He and his partners have been investing for almost two decades and have shown incredible tenacity in their continuing pursuit and development of tourist spaceflight.

Virgin Galactic has moved on since the accident in 2014, and *Unity* is now engaged in an aggressive test-flight program. The company has also expanded its efforts to include launching unmanned cargoes—satellites and other small payloads—with new systems that build on their unique technologies.

The first 2018 test of Unity, Virgin's new rocketplane. Image credit: Virgin Galactic

This satellite-launching spin-off company, called Virgin Orbit, was initiated in 2015 with the opening of a separate facility in Long Beach, California. The goal is to fly midsized satellites on a rocket called LauncherOne, which will be carried to launch altitude by a converted Boeing 747, much as *Unity* is carried to altitude by *Eve*.

I spoke to George Whitesides at length about Virgin Galactic's plans and the trials before them. "Space is a challenging technical endeavor and it is very unforgiving given the current technology," he said. "We're trying to do hard things in a world that has more risk aversion than fifty years ago."

When asked about the overarching plan for the company, Whitesides said, "I'm really hopeful that over the course

Artist's concept of Virgin Orbit's carrier plane, a modified 747, lifting the uncrewed satellite launcher to altitude. Image credit: Virgin Orbit

of the next decade we can send hundreds, probably thousands, of people into space." He noted that for the last sixty years, since the beginnings of the first space age, on average, about ten people have been sent into space during a year. "That's gotten lower since the end of the shuttle program," he added. "So that would be a huge shift—we can go to a world where the average person knows someone who has gone into space."

Until then, Virgin will continue test flights to be certain that it has the safest possible rocketplane in which to carry paying passengers. On April 5, 2018, the company completed its first self-powered test of *Unity* after two years of ground and unpowered drop tests. *Unity* was carried to altitude by *Eve*, then dropped free of the carrier plane at 46,500 feet. *Unity*'s rocket motor ignited, and it climbed at an 80-degree angle, flying at almost twice the speed of sound. It reached an altitude of about 85,000 feet before descending to a successful landing on Virgin's Mojave runway. It was an important milestone for the company, bringing it a step closer to passenger flights.

Virgin Orbit is moving ahead quickly, as well. With far smaller, nonhuman payloads, there is much less at stake. It's an easier path to tread than space tourism. If a satellite is lost, it will have an impact on the companies that create and insure it, but nobody will perish.

But launching satellites is also a business with more current and potential competition than space tourism. Today, Virgin Galactic's only real rival to carry civilians into space is Jeff Bezos's Blue Origin, which is also building and

Unity's rocket engine firing during its first powered test flight. Image credit: Virgin Galactic

testing spacecraft that will shuttle tourists. With satellites, though, there are many up-and-coming launch businesses. Virgin Orbit will need to move aggressively to stake its claim in this marketplace.

Virgin Orbit's biggest current rival is Orbital ATK, a company that has been operating in the air-launched "smallsat" business for almost thirty years and was acquired in 2018 by Northrop Grumman. Rebranded Northrop Grumman Innovation Systems, its small satellite launcher, called Pegasus, is dropped from a carrier plane just as Virgin Orbit's will be. The Pegasus can haul just under 1,000 pounds to low Earth orbit. But it is expensive, as much as $50 million per launch, and Whitesides thinks that Virgin will be able to compete aggressively and lower that price dramatically.

Innovation Systems will not be Virgin's only competition for long, however. Virgin Orbit is just one of many new companies entering the smallsat launch arena. Nipping at its heels are dozens of other contenders intending to launch small payloads at reduced prices. It's a much simpler point-of-entry into the private spaceflight business than flying people. It's also much easier from a regulatory and insurance point of view, with far lower barriers to entry for new entrepreneurs. There's a big market for these commercial ventures as well. A 2016 analysis reports that about 3,000 small satellites may be queueing up for launch between now and 2022, and this does not include the large constellations of broadband-supplying satellites that will be launched by SpaceX and others. Estimated counts of these small broadband providers range from as few as 2,000 to over 10,000 satellites.[48]

There are too many small companies to detail all of them here, and many of them in existence today will not establish themselves as going concerns. But there are a number of serious contenders already conducting test launches of well-financed hardware that deserve mention.

Stratolaunch is the heavyweight in this category. Its planned rocket will be able to launch larger satellites, as hefty as 10,000 pounds, or clusters of hundreds of smallsats. The company is owned by Microsoft billionaire Paul Allen, who hired Burt Rutan after he left Virgin Galactic, and also operates out of Mojave. Stratolaunch will use a huge carrier plane, like the Virgin LauncherOne concept, but built with advanced lightweight composites, to lift a three-stage rocket to high altitudes. The carrier plane is a behemoth, with a 385-foot wingspan and six jet engines salvaged from 747 aircraft. Commercial operations are expected to begin in 2019 or 2020.

Other companies are aiming at smaller single payloads, about 1,300 pounds or less. With rapid advances in

An Orbital ATK Pegasus satellite launcher drops free of its carrier plane. In moments, its rocket engine will fire, propelling it into orbit to deliver a satellite. Image credit: Northrop Grumman Innovation Systems

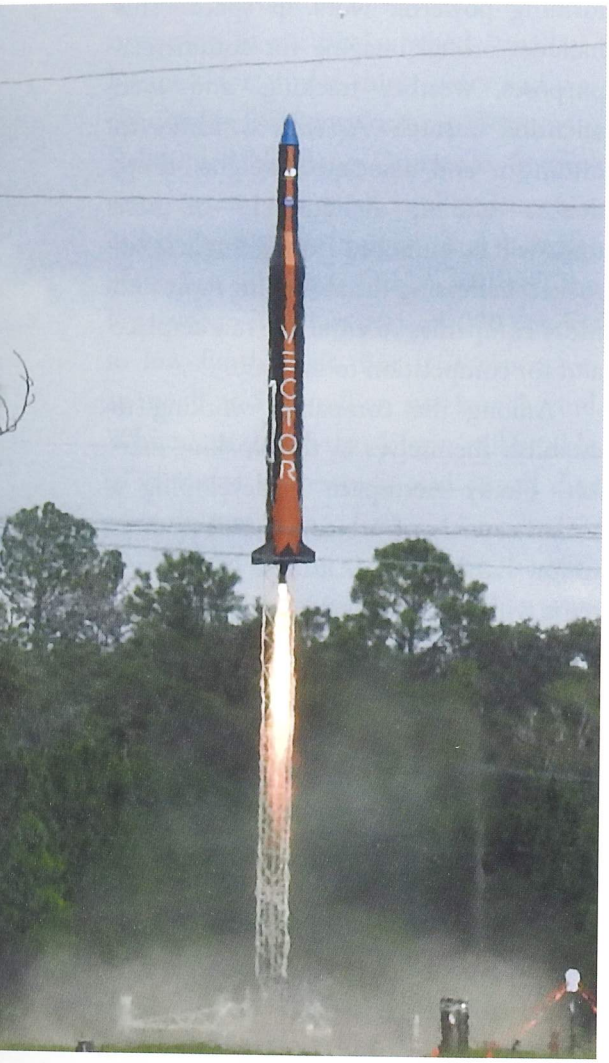
technology, the lower limit of this weight category is falling quickly—smallsats are getting even smaller. A few years ago, people in the business just called a satellite a satellite. Then, as satellites shrank due to more advanced, miniaturized technology, the term "smallsat" was coined. Soon there were "cubesats,"even smaller designs shaped like a box, about four inches per side, with standardized payloads weighing about three pounds. Then the term "nanosat" entered the vernacular, covering anything from two to twenty-two pounds (and confusing the terminology somewhat). There are even "femtosats," which weigh just a few ounces. It's a quickly evolving field.

These small satellites increasingly use off-the-shelf technology, with some experimental units being designed around cell phone computer processors. With their sides covered in little solar panels, even the tiniest cubesats are capable of performing powerful work in space. This includes orbital imaging for commercial purposes, weather tracking, and even scientific research. As sizes continue to diminish, and associated weights drop, dozens—and up to hundreds—of these units will be launched from a single small rocket, increasing the ability for more and more companies to enter the marketplace and for competition to increase.

Among the companies working to establish themselves in the smallsat market, Firefly Aerospace is developing a rocket capable of orbiting 2,000 pounds to low Earth orbit. (All these launch systems will be quoted to low Earth orbit.) Firefly's two founders previously held positions at other space companies—in this case, Virgin Galactic, Blue Origin, and SpaceX. Firefly began operations in Hawthorne, California, in 2014, and has since moved to Texas.

Rocket Lab was founded in 2006 and is located in both Southern California and New Zealand. Its Electron rocket is expected to be capable of launching 330-pound payloads to a polar orbit, at about 300 miles altitude, going over Earth's poles, at a cost of about $5 million.

Polar orbits offer twenty-four-hour coverage as the Earth rotates below the satellite's orbit. The company has flight-tested its rocket, and completed a launch facility in New Zealand in 2016.



A Vector test launch in 2017. Image credit: Vector Space Systems

Vector Space Systems, a relative newcomer, was founded in 2016 by Jim Cantrell and other aerospace and software industry veterans. Cantrell was associated with SpaceX early on. Located in Tucson, Arizona, the company made quick progress, launching its first test vehicle in 2017. It plans to launch out of traditional sites such as Cape Canaveral, as well as various other locations, using smaller mobile facilities. Vector's rocket is designed to carry 145 pounds to orbit, and to do so more than a hundred times per year.

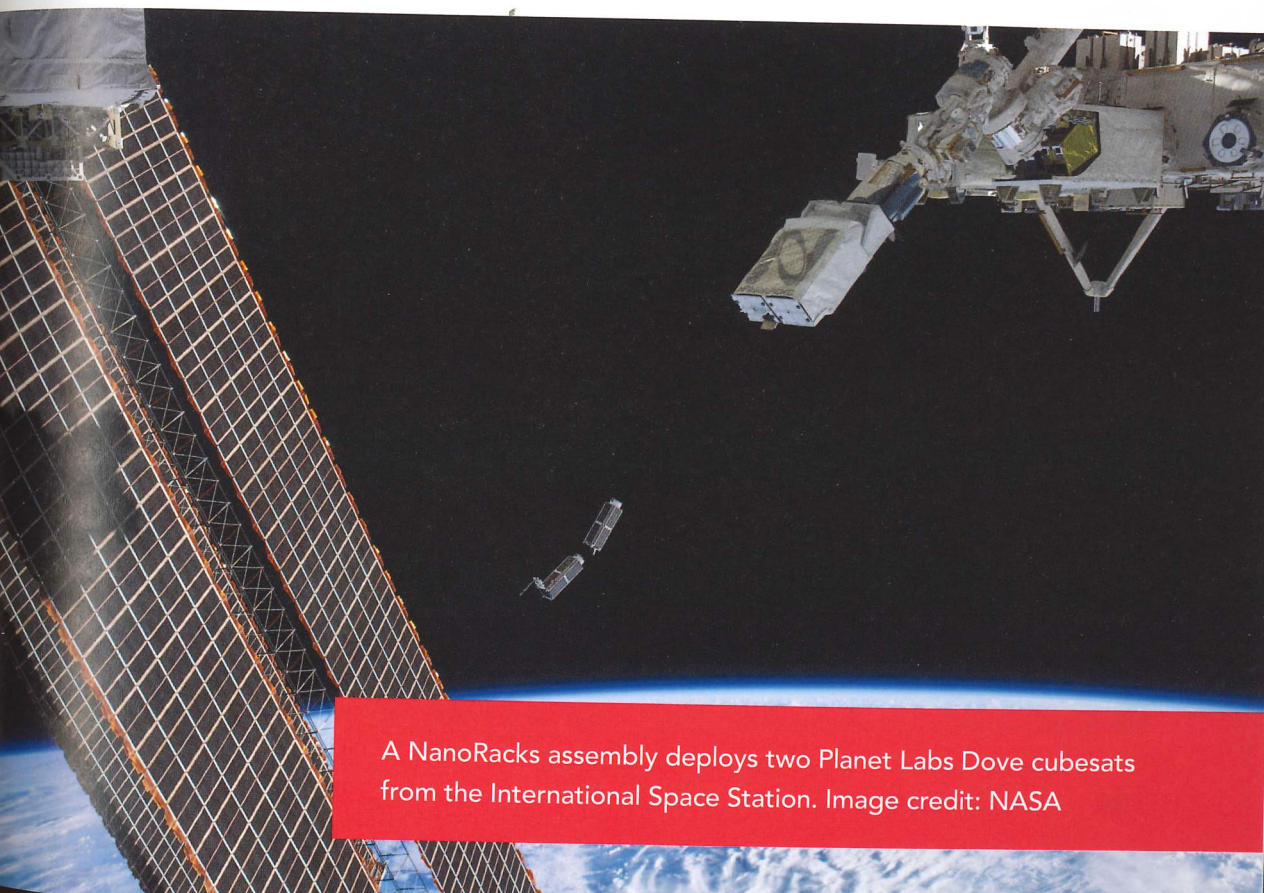
This is just a sampling of the major providers in the private smallsat launch business. These fledgling companies have in common relatively low costs and the ability to launch quickly once an order is

Artist's concept of a Vector launch, with cubesats being deployed in orbit. Image credit: James Vaughan

placed. Still, they face some similar challenges to the big payload companies: funding, launch-facility regulation by the government, the rigors of designing small, reliable rocket motors, and guiding those rockets—and the payloads they carry—into the proper orientation in space.

So far I've talked about launch providers. These rocket builders are the George Clooneys and Taylor Swifts of the space business, with lots of flash and dazzle. But there are countless other enterprises working in less obvious categories in which space entrepreneurs are making a difference—and, in some cases, hefty profits.

Perhaps the most notable of these is a company called NanoRacks, founded in 2009 to fill a niche in which few had seen profit potential—an area called standardized flight interfaces. Until a few years ago, satellite hardware was custom designed, unique to its builder, and had to be created to fit a given rocket. This is an expensive and complex way to do business. NanoRacks was founded to provide a standard interface between satellites and the rockets they fly on. A very simple metaphor is the charging jack on newer smartphones—most now use a USB-C connector. But just a few years back, smartphones used many different types



A NanoRacks assembly deploys two Planet Labs Dove cubesats from the International Space Station. Image credit: NASA

of power connectors, and it was a nightmare for consumers. Like the USB-C connector on a cellphone or computer, the NanoRacks launch interface simplifies and regiments the link between satellites and rockets. NanoRacks has taken this a step further by providing standardized cubesat deployment mechanisms that work with the International Space Station's robotic arm.

NanoRacks' CEO Jeffrey Manber previously worked on various space enterprises, including a stint as a business ambassador between NASA and the Soviet Union's space program. The company's short history is impressive, with about six hundred payloads handled to date. Their client list includes companies small and large, with payloads ranging from national security satellites to tiny cubesats engineered by university students. They also provided some of the first commercial hardware to fly on the ISS.

Planet Labs is another Space 2.0 success story. The company was founded in 2010 by a pair of NASA engineers to design, manufacture, and fly small satellites that would be capable of imaging Earth at a fraction of the cost of existing satellites. The company's designs are based on the cubesat form factor. Planet Labs' satellites are called 3U (3-unit) cubesats, and they are about four by four by twelve inches in size. They don't require dedicated launches as traditional Earth-imaging

Planet Labs cubesats ready to go. Image credit: NASA/Planet Labs

satellites do, and can be included as secondary payloads—sometimes on NanoRacks hardware. Today, a swarm of these cubesats creates a complete image of the Earth's surface each day, available by subscription via a web-based interface. With almost two hundred satellites currently in orbit, their "fleet" is currently the largest ever flown by one company.

Made In Space, Inc. is another interesting example of space entrepreneurism operating in a newly discovered market niche. The company was started in 2010 by four students who met at a Silicon Valley training program. The quartet created the first space-rated 3-D printers in a small lab set up in the NASA Ames Research Park in Mountain View, California. By 2011, they were flying their experimental printers in NASA-provided zero-g simulations, and in 2014, after

years of exacting design and testing, they flew a 3-D printer to the ISS—the first such machine to enter space.

The technical constraints of working on a highly regulated government project were demanding for a small start-up; to fulfill NASA safety requirements, everything from the heaters that soften the plastic for printing, to the wiring that powered them, to the fumes from the melted plastic, had to be tested and approved by the space agency. Of course, the printer also had to function reliably in zero-g—no small feat in itself. Tests on the ISS were successful, with a number of useful plastic parts manufactured. The company's founders have far larger visions for the future, including printing with metal and even dirt from asteroids, the lunar surface, and Mars. Made In Space is currently designing 3-D printers that can work with metal to process materials found on asteroids into useful products for spaceflight, larger 3-D printers for use in the ISS, and even the manufacturing of specialized fiber optics in space.

Not all space companies will make products that operate *in* space. Kymeta was founded by former Microsoft executive Nathan Myhrvold with funding from Microsoft and other investors; it's designing a laptop-sized unit that will be able to track and communicate with satellites in low Earth orbit. Maintaining a signal with these constantly moving targets can be difficult, but Kymeta's new system promises to increase reliability at greatly reduced cost. The unique technology can direct a radio beam toward a mobile object in space without the use of moving parts. Metamaterials—special chips that can "tune" the direction of incoming signals—allow Kymeta to use lightweight, flat receivers to accomplish the same tasks that previously required steered parabolic dishes.

There are hundreds of other small enterprises jumping into the commercial space sector with unique high-tech products. Some are well-funded start-ups, while others are being created in university labs and garage workshops. Some have small NASA contracts, but most are operating on their own dime. NASA has long worked with small vendors, but it's diversifying how it does so. The agency supports small start-ups and university students with "hackathons" to promote new software and technology designs. Much of this support takes the form of competitions. One example is the "Space Poop Challenge," which, despite its whimsical name, sought to address a very real problem in spaceflight: the elimination of waste from the human body. Traditionally, special diapers have been used in space suits to contain waste from astronauts during EVAs and long periods strapped in their seats, but extended exposure of skin to urine and feces can create

irritation and even infections. The competition was launched to find better solutions and attracted 20,000 competitors from 130 countries, who submitted 5,000 completed designs. The $15,000 grand prize was awarded to Thatcher Cardon, an Air Force flight surgeon from Florida, who prototyped his winning entry with parts bought from thrift and budget stores.[49] Runners-up included students and consumer product designers. Such outreach to small inventors and start-ups is part of the "new NASA," striving to find improved and more cost-effective solutions to the daunting problems of spaceflight.

This is but a small sampling of the ways in which bright individuals and entrepreneurs are embracing the space trade. These are people who, just a decade or two ago, would likely not have entered the business. It's a big move away from the old-school methodologies established during the space race, when money flowed to mostly large, established suppliers. But not all the participants in Space 2.0 are small operations. A few large companies, started by well-heeled internet billionaires, are taking the lead in building the new space economy. One of these luminaries is the Tony Stark of Space 2.0: Elon Musk.