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CASE

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SPACE X: DISRUPTING THE SPACE INDUSTRY

This case was prepared by Melissa A. Schilling of the School of Business, New York University.

In April 2018, SpaceX was valued at \$27.5 billion, making it one of the most valuable privately-held companies in the world. In just 16 years since its founding, the company had developed revolutionary space vehicle technology, including the world's first reusable orbital class rocket (the Falcon 9) and the world's most powerful rocket (the Falcon Heavy). Perhaps even more remarkable, the company offered commercial space launches at a price dramatically lower than that offered by its leading competitors. It was estimated that by 2018 SpaceX had already seized over 60% of the global market share for commercial space launches.¹ The meteoric rise of SpaceX, a startup from an industry outsider, was completely re-writing the rules of competition in the space industry.

been perfect; in the mid-1990s the penetration of the internet had growing exponentially, but most businesses did not yet fully understand how to harness it. As Musk noted, "When we tried to get funding in November 1995, more than half the venture capitalists we met with didn't know what the Internet was and had not used it." Soon Musk's company was hosting the websites of nearly 200 media companies, including the *New York Times*' local directory site, "New York Today," and newspapers owned by Hearst, Times Mirror, and Pulitzer Publishing.⁴ In February 1999, Compaq bought Zip2 for \$307 million in hopes that it could use the platform to help one of its other products, AltaVista, become a top portal for search, media, and shopping.⁵

C12-1 MUSK'S MOONSHOT IDEA: COLONIZING MARS

In 2002, Elon Musk was 31 years old, had \$180 million, and was trying to decide what to do with the rest of his life.² He had already created and sold one of the first successful Internet portals, Zip2, a platform that enabled newspapers to create and host their own online "city guides." The timing of the venture had

Musk then founded an online financial services and email payment company, X.com. This company later merged with Confinity, a company that had developed the person-to-person email system PayPal, and the merged companies worked together to make PayPal the most successful online payment system in the world. When eBay bought PayPal for \$1.5 billion in stock in 2002, Musk personally got \$165 million from the sale.

Musk now had a pretty serious nest egg and wondered what he should do next. Money no longer motivated him; instead he wondered what he could do that would be most important to the world. Worried about the human population's overreliance on finite energy sources, he helped to found Tesla Motors and Solar City during this time, but another unusual possibility

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had also begun to take shape in his mind. Musk had been very disturbed to discover that NASA had no intentions of going to Mars, and he began to ponder what it would take. The major problem was not one of technological feasibility, he concluded, but rather expense. Rockets could get into orbit, but they were expensive and typically not reusable. This, he reasoned, was like throwing away your Boeing 747 after every flight across the Atlantic, and it made space travel ludicrously impractical. Musk made the astonishing decision to pick up where NASA had left off.

Musk began to study rocket science texts such as *Rocket Propulsion Elements*, *Fundamentals of Astrodynamics*, and *Aerothermodynamics of Gas Turbine and Rocket Propulsion*. He traveled to Russia with friends Jim Cantrell, Adeo Ressi, and Mike Griffin to see if he could buy an affordable intercontinental ballistic missile to use as a launch vehicle. Though the team met with the Russians three times over a period of 4 months, in the end when Musk suggested he wanted two missiles for \$8 million, the Russians dismissed him, telling him his plan was impossible. As Cantrell recounted, "They looked at us like we were not credible people ... One of their chief designers spit on me and Elon because he thought we were full of shit."⁶ On the flight home, as Griffin, Ressi, and Cantrell somberly toasted the end of the Russian expedition, Musk sat in the row in front of them, frenetically typing on his computer. Suddenly he wheeled around showing them a spreadsheet and saying, "Hey, guys, I think we can build this rocket ourselves."⁷

The other men were skeptical, to say the least. However, Musk passed his computer over to Griffin and Cantrell, showing them a document that detailed the cost of materials needed to build, assemble, and launch a rocket. Musk's calculations suggested that they could build a modest-sized rocket that would specialize in carrying smaller satellites and research payloads to space, and they could do so much cheaper than what the Russians were offering. The spreadsheet also laid out the performance characteristics of the rocket in impressive detail. Cantrell recalls, "I looked at it and said, 'I'll be damned—that's why he's been borrowing all my books. He'd been borrowing all my college textbooks on rocketry and propulsion. You know, whenever anybody asks Elon how he learned to build rockets, he says, 'I read books.' Well, it's true. He *devoured* those books. He knew everything. He's the smartest guy I've ever met, and he'd been planning to build a rocket all along."⁸

Investing \$100 million of his own funds, Musk founded a company in June 2002 in Hawthorne California called Space Exploration—or SpaceX—and began developing a method that would streamline the production of rockets that could be used more than once. If NASA was not going to bring humanity to Mars, Musk would do it himself.

Creating a rocket company is an expensive, risky venture, and most of the space industry found it highly improbable that an outsider with a small team and budget could be successful. As Tom Mueller, one of SpaceX's first engineers notes, "At TRW I had an army of people and government funding. Now we were going to make a low-cost rocket with a small team. People just didn't think it could be done."⁹

Musk, however, felt that the space industry was overdue for modernization. Aerospace companies had little competition and made extremely expensive, high-performance rockets for every launch. Musk, on the other hand, intended to apply Silicon Valley's techniques of running lean and capitalizing on massive advancements in computing and materials technology. Musk's conversations with aerospace contractors convinced him that they all charged too much money and worked too slowly. He decided that SpaceX should try to make as much of the componentry as possible inhouse, including engines, guidance systems, and more. SpaceX would ultimately become an extremely vertically integrated rocket company. These decisions also made it easy to recruit the brightest of engineers—young aeronautics experts were keen to design rockets from the ground up and work for an exciting company without the bureaucracy of a government contractor.

On March 24, 2006, the first Falcon 1, a two-stage rocket,¹⁰ was launched from the Kwajalein islands as a nervous Musk and others watched. Twenty-five seconds into the flight a fire broke out on the rocket, and it began to spin and fall back to the Earth. It took a year to build a new Falcon 1. On March 21, 2007, the second Falcon 1 was launched, and this one made it to the 5-minute mark, successfully separating the first stage of the rocket from the second stage, with the second stage continuing into orbit. The team was

¹⁰Multistage rockets are designed so that different parts of the rocket have their own engine and propellant. This enables stages to be separated from the rocket after they have used up their fuel, thereby reducing the mass of the rest of the craft.

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elated and began to breathe easier. However, just after the 5-minute mark passed, the second stage of the rocket started to wobble and then break apart. It was a devastating blow to SpaceX employees; many had spent almost 2 years shuttling between California and Kwajalein working to prepare for this launch.

Musk assured everyone that he would persist until they were successful, but everyone knew there was a risk that the company would simply run out of money. Unlike traditional aerospace companies which had huge multi-year government contracts, most of SpaceX's funding had come from Musk's personal savings, and SpaceX and Musk's other major venture, Tesla Motors, had already burned through more than half of Musk's cash. Kevin Brogan, one of SpaceX's first employees remembered, "We were burning through a hundred thousand dollars per day . . . Sometimes he wouldn't let you buy a part for two thousand dollars because he expected you to find it cheaper or invent something cheaper. Other times, he wouldn't flinch at renting a plane for ninety thousand dollars to get something to Kwaj because it saved an entire workday, so it was worth it."¹⁰

The third Falcon 1 was launched on August 2, 2008. The launch initially appeared to go perfectly, but at the moment the stages were supposed to separate, unexpected thrust from the first stage caused it to bump the second stage and damage it. Both parts then fell to the Earth. As recounted by Dolly Singh, a recruiter at SpaceX, "It was like the worst [expletive] day ever. You don't usually see grown-ups weeping but there they were. We were tired and broken emotionally."¹¹ An exhausted and discouraged Musk tried to keep a positive front, telling the team "Look. We are going to do this. It's going to be okay. Don't freak out."¹² Musk knew, however, that a fourth flight would be the last – he had spent \$100 million on SpaceX and had no more money to inject into the company because the rest had all gone into Tesla Motors. There simply wouldn't be enough money for a fifth launch.

On September 28, 2008, the team prepared for the fourth Falcon 1 launch. The employees had worked nonstop shifts under intense pressure to reach this point, many of them separated from their families for long periods, living on a tiny island near the launch site under difficult conditions. Now many were queasy with anxiety about what would happen on this launch. This fourth launch, at last, went perfectly. Nine minutes into its journey, the Falcon 1 reached orbit, making it the first privately built space vehicle

ever to do so. The employees of SpaceX roared their cheers, and many (including Musk) fought back tears.

Antonio Gracias, chief executive officer of Valor Equity Partners, investor in both Tesla and SpaceX and Musk's friend, noted how deeply impressed he was by Musk's strength and resolve during this time: "He has this ability to work harder and endure more stress than anyone I've ever met. What he went through in 2008 would have broken anyone else. He didn't just survive. He kept working and stayed focused." He adds, "Most people who are under that sort of pressure fray. Their decisions go bad. Elon gets hyperrational. He's still able to make very clear, long-term decisions. The harder it gets, the better he gets. Anyone who saw what he went through firsthand came away with more respect for the guy. I've just never seen anything like his ability to take pain."¹³

The successful launch was a watershed moment that reinvigorated everyone's faith in the company, but SpaceX was still in a financially precarious position. It already had two other projects underway, the Falcon 9 (a much bigger rocket), and the Dragon capsule (a reusable cargo spacecraft that would be launched by the Falcon 9 and used to deliver supplies to the International Space Station), and Musk had to borrow money from his friends just to make the company's payroll. To make matters worse, Tesla Motors was also in dire financial straits – both companies were on the verge of bankruptcy. However, on December 23, SpaceX was notified that NASA would be awarding the company a \$1.6 billion contract to service the Space Station, effectively saving the company. Then on December 24th, just hours before Tesla would have entered bankruptcy, Musk negotiated an investment from Draper Fisher Jurvetson that saved the auto company. As the deals went through, Musk broke down in tears.

C12-1a Next Steps

Having demonstrated the company's ability to successfully launch the Falcon 1, SpaceX turned its attention to its other, even bigger projects. First, it developed the Falcon 9, a rocket with nine Merlin engines and the ability to carry just over 50,000 pounds into orbit. The Falcon 9 was designed to be human-rated, requiring extreme reliability. Its avionics and controls were made triple-redundant, and according to Musk its flight computers will "issue the right commands even if there is severe damage to the system."

The Falcon 9 can also keep flying if it suffers an engine shutdown; after about 90 seconds, it can even survive a second engine shutdown.¹⁴

By 2010, SpaceX proved that the Falcon 9 could carry the Dragon capsule into space and then recover the capsule safely after an ocean landing. In 2012, the SpaceX Dragon capsule became the first private company to dock with the International Space Station. In 2015, SpaceX demonstrated that its Falcon 9 could land vertically—the first time this had been achieved for an orbital class rocket, and then in 2017 it successfully reused a Falcon 9 in a second flight, achieving what most stalwarts of the space industry had said was impossible.

The Falcon 9 competed directly against the Delta IV and Atlas V launch systems made by United Launch Alliance (ULA), a joint venture of Boeing and Lockheed Martin. The Delta and Atlas launch families had been the standard space launch systems used by the U.S. government for more than 50 years, carrying payloads including weather, telecommunications, and national security satellites, as well as deep space and interplanetary exploration missions in support of scientific research. ULA had a virtual monopoly before SpaceX's jarring arrival,¹⁵ but after the introduction of the Falcon 9 it was clear that the space industry had changed. Traditionally in

the United States, rockets were designed by government agencies (e.g., NASA), and then companies like Lockheed Martin were commissioned to build them as external contractors. Now for the first time, the government could choose from rockets designed and built by a private U.S. company that were not only as powerful as those designed by NASA, but were also remarkably less expensive. Launch contracts awarded to SpaceX and ULA by the Air Force in 2018, for example, indicated that ULA's launch prices for the Atlas V were almost double those for the Falcon 9. The government decided to give both companies contracts because having two launch companies better assured the U.S. government's access to space, however it was clear that pressure would now be on ULA to bring their costs down as well. This was implicitly stated by Air Force Secretary Heather Wilson in her testimony to the U.S. House defense appropriations subcommittee, "The cost of launch is plummeting" and commercial space ventures now "have multiple choices." "We're coming to a point," she said, that low-cost launchers are "enabling business plans to close in space that never were possible before."¹⁶

In 2011, SpaceX had also begun developing the Falcon Heavy, by far the world's most powerful rocket (see Table 1) with 27 Merlin engines and the ability

Table 1 Comparison of Heavy Payload Launch Vehicles

Launch Vehicle	Manufacturer	Payload to Low Earth Orbit (lbs)
Falcon Heavy	SpaceX	140,660
Space Shuttle	United Space Alliance Thiokol/Alliant Techsystems (SRBs) Lockheed Martin/Martin Marietta (ET) Boeing/Rockwell (orbiter)	53,790
Proton M	Khrunichev	50,710
Delta IV Heavy	United Launch Alliance	49,740
Titan IV-B	Lockheed Martin	47,800
Ariane 5 ES	Arianespace	44,090
Atlas V551	United Launch Alliance	40,810
Japan H2B	JAXA and Mitsubishi Heavy Industries	36,380
China LM38	China Aerospace Science and Technology	24,690

Source: Payload data from SpaceX

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to carry 140,660 pounds into orbit. It was also developing Dragon capsules rated for human transport. Both programs would be crucial for achieving Musk's ultimate goal: colonizing Mars. The Falcon Heavy can carry equipment and supplies to Mars, and both its stages can be recovered and used repeatedly. Crew would be transported to Mars in a Dragon capsule. As of 2018, SpaceX was also developing a rocket dubbed BFR ("Big Falcon Rocket") that would take an even heavier payload than the Falcon Heavy, and do so with a single core rather than the triple core used in the Heavy (in essence, the Falcon Heavy used three Falcon 9s as its core), thereby making it simpler and more reliable to launch.¹⁷

C12-1b Doing Things Differently at SpaceX

There were numerous ways in which SpaceX's strategies diverged from space industry norms, and almost all of them had direct implications for the cost of its launch systems. First, whereas most aerospace companies give their designs to myriad third-party contractors who create the hardware for them, SpaceX produced roughly 80% of its launch hardware in-house.¹⁸ SpaceX builds its own motherboards and circuits, vibration sensors, radios, and more. In most industries, vertical integration *increases* the costs of firms by not enabling them to benefit from competitive bidding between efficient suppliers. In the aerospace industry, however, the entrenchment of norms around using parts specialized for the space industry ("space grade"), and the bureaucratic rules defined by government contractors, had kept supply costs very high. SpaceX decided instead to build many of its own parts, or to buy parts not considered "space grade" and modify them to achieve "space grade." For example, rather than paying \$50,000 to \$100,000 for an industrial-grade radio, SpaceX was able to build its own for \$5,000, and shaved 20% of the weight off at the same time.

SpaceX's willingness to produce their own parts came as a shock to suppliers. For example, Tom Mueller recounts a time when he asked a vendor for an estimate on a particular engine valve: "They came back [requesting] like a year and a half in development and hundreds of thousands of dollars. Just way out of whack. And we're like, 'No, we need it by

this summer, for much, much less money.' They go, 'Good luck with that,' and kind of smirked and left." Mueller's team created the valve themselves, and by summer they had qualified it for use with cryogenic propellants. "That vendor, they iced us for a couple of months," Mueller said, "and then they called us back: 'Hey, we're willing to do that valve. You guys want to talk about it?' And we're like, 'No, we're done.' He goes, 'What do you mean you're done?' 'We qualified it. We're done.' And there was just silence at the end of the line. They were in shock."¹⁹

As noted, a big factor driving savings at SpaceX is that it often builds its components out of readily available consumer electronics rather than equipment already deemed "space grade" by the rest of the industry. Twenty years ago "space grade" equipment would have had far superior performance characteristics compared to consumer electronics, but today that is no longer the case – standard electronics can now compete with more expensive, specialized gear. For example, at one point SpaceX needed an actuator that would steer the second stage of the Falcon 1. The job fell to engineer Steve Davis to find the important part, and because he had never built a part like that before he sought out suppliers who could make it for them. Their quoted price for the device was \$120,000. As Davis recalls, "Elon laughed. He said, 'That part is no more complicated than a garage door opener. Your budget is five thousand dollars. Go make it work.'"²⁰ Davis ended up designing an actuator that cost \$3,900. Another example is provided by the computers that provide avionics for a rocket. Traditionally NASA's Jet Propulsion Laboratory bought expensive, specially toughened computers that cost over \$10 million each to operate its rockets. Musk told engineer Kevin Watson that he wanted the bulk of the computer systems for Falcon 1 and Dragon to cost no more than \$10,000. Watson was floored, noting, "In traditional aerospace, it would cost you more than ten thousand dollars just for the food at a meeting to discuss the cost of the avionics."²¹ Watson was inspired by the challenge, however, and ended up creating a fully redundant avionics platform that used a mix of off-the-shelf computer parts and in-house components for just over \$10,000. That same system was then also adapted for use in the Falcon 9.

SpaceX's willingness to experiment with new designs and technologies was a huge competitive advantage. For example, by using "friction stir welding,"

SpaceX was able to fuse large, thin sheets of metal together without rivets or other fasteners, reducing the weight of the rocket body by hundreds of pounds. This technology had previously not been considered feasible for such a large structure, but SpaceX proved it could work. The technology was then also transferred to Tesla, where it could help make lighter, stronger cars.

Vertical integration also gave SpaceX more control over when and how things are done, making it significantly more nimble than traditional aerospace companies, and having almost all of SpaceX's engineers under one roof greatly streamlines the process of designing, testing, and improving the launch systems. For example, if a fault was found in a launch sensor, NASA would have traditionally responded with paperwork, meetings with suppliers, and a 3-month delay to wait for a new launch window. SpaceX, on the other hand, is known for fixing faults fast and on the fly—often enabling the launch to continue as planned. As Tom Mueller describes, “We make our main combustion chambers, turbo pump, gas generators, injectors, and main valves ... We have complete control. We have our own test site, while most of the other guys use government test sites. The labor hours are cut in half and so is the work around the materials. Four years ago, we could make two rockets a year and now we can make twenty a year.”²²

SpaceX's rockets are also designed with commonality of parts and modularity in mind, which also reduces costs and development time. Consider, for example, the contrast between the Falcon 9 and ULA's Atlas V. Atlas V was the workhorse of the space industry, used for everything from probing distant planets to launching spy satellites. The Atlas V uses up to three kinds of rockets, each tailored for a specific phase of flight. In the first stage, RD-180 engines (built in Russia) burn a highly refined form of kerosene called RP1. Optional solid-fuel strap-on boosters provided additional thrust at liftoff, and a liquid hydrogen engine in the upper stage takes over in the final phase of flight. Using three kinds of rockets helped to optimize the performance of the Atlas V, but at a steep price. As Musk noted, “To a first-order approximation, you've just tripled your factory costs and all your operational costs.” All of the engines on SpaceX's Falcon 9 and Falcon Heavy rockets, by contrast, are its own SpaceX-designed Merlin engines powered by RP1 and liquid oxygen. Making all of the

engines the same reduced the amount of tooling and the number of processes required, resulting in what Musk calls “huge cost savings.”²³

SpaceX's vertical integration has also led to it creating advances in state-of-the-art of space technology. For the Dragon's heat shield, for example, the company intended to use a material called PICA (phenolic impregnated carbon ablator), first developed for NASA's Stardust comet-sample-return spacecraft. The prices they were offered by the manufacturer, however, were too high, so they decided instead to work with NASA's Ames Research Center to make the material themselves. What they came up with, PICA-X, turned out to be better than the original material and 10 times less expensive. In fact, Musk states that a single PICA-X heat shield can withstand hundreds of returns from low Earth orbit, and can even handle the much higher energy reentries from the moon or Mars.²⁴

The largest cost advantage SpaceX has, by far and away, is the fact that its rockets use reverse thrusters to lower themselves safely back to the ground so that they can be reused. Reusing the rockets means that much of the cost of producing the rocket will be amortized over multiple flights, dramatically lowering the cost of space travel relative to systems in which the rockets are considered expendable. In fact, SpaceX estimates indicated that with a larger volume of launches and improvements in launch technology, it could get the cost of a Falcon 9 launch down to about \$20 million. This cost difference between SpaceX and traditional space vehicle manufacturing was a gamechanger. SpaceX was not just undercutting U.S. manufacturers in price; it was also well under the price of its rivals in Europe, Japan, Russia, and China. As gleefully noted by venture capitalist and SpaceX board member Steve Jurvetson, “SpaceX lowered the cost of going into space by 10x. The ministers of China say, ‘We can't compete on price with that. In how many industries have you heard ministries of China say ever say that?’”²⁵

C12-1c Staying Private and Focused on Mars

Despite pressure from employees and would-be investors, Musk has resisted the urge to take SpaceX public. Shareholders tend to put intense focus on

quarterly earnings, which can create pressures that are at odds with a firm's long-term goals and investments. The board of directors of a publicly held firm would thus undoubtedly force SpaceX to make changes that would improve its profitability at the expense of its chances for reaching Mars. As Musk

wrote in a letter to his SpaceX employees, "Creating the technology needed to establish life on Mars is and always has been the fundamental goal of SpaceX. If being a public company diminishes that likelihood, then we should not do so until Mars is secure."²⁶

NOTES

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¹¹*Ibid.*, p. 199.

¹²*Ibid.*

¹³*Ibid.*, p. 211.

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²⁰Vance, *Elon Musk: Tesla, SpaceX, and the Quest for a Fantastic Future*, p. 236.

²¹Vance, *Elon Musk: Tesla, SpaceX, and the Quest for a Fantastic Future*, p. 237.

²²Vance, *Elon Musk: Tesla, SpaceX, and the Quest for a Fantastic Future*, p. 258.

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