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# Blue Origin, NASA, and New Space (A)

Late in the evening on July 20, 1969, a five-year-old boy named Jeffrey Preston Bezos watched along with the world as Neil Armstrong became the first human to walk on the Earth's moon. Forty-five years later, after making his fortune as the founder of online retailing giant Amazon.com, Bezos recalled that moment: "You don't choose your passions; your passions choose you. For me, space is something that I have been in love with since I was 5 years old. I watched Neil Armstrong step onto the surface of the moon, and I guess it imprinted me."[1]

In 2000, just six years after founding Amazon, Bezos would act on that passion by founding a second company, officially named Blue Origin but often called simply Blue in the industry. Blue described itself as "developing vehicles and technologies that, over time, will enable an enduring human presence in space,"[2] a goal Bezos appeared to have had in mind since his high school valedictorian speech, when he spoke of "colonizing space to secure humanity's future."[3] Over the next decade, Bezos and his team pursued this mission quietly—press mentions of Blue were usually preceded by the adjective "secretive"—at a nondescript facility near Seattle and on land in West Texas that Bezos had quietly purchased as a family ranch and launch site.[4] But it was always clear that Bezos hoped to change the space sector as dramatically as Amazon had changed retail.

Blue was part of a surge of entrepreneurial activity in what became known as the New Space sector. A website tracking the industry defined New Space as "a global industry of private companies and entrepreneurs who primarily target commercial customers, are backed by risk capital seeking a return, and seek to profit from innovative products or services developed in or for space."[5] New Space leaders brought with them ideas for reusability, lean manufacturing, and vertically integrated production that they claimed could dramatically reduce costs and improve performance relative to the large aerospace engineering firms such as Boeing, Lockheed Martin, and Northrop Grumman, which had dominated the U.S. commercial and governmental market for spaceflight since the space program's earliest days. Not surprisingly, many of the leading New Space companies were founded by entrepreneurs from the disruptive tech sector of the 2000s and 2010s.

Blue's first major public attention came from its work on the Commercial Crew Development (CCDev) initiative of the National Aeronautics and Space Administration (NASA), the U.S. government's civilian space agency. In 2009, NASA announced that CCDev would be a multi-phase program awarding technology development contracts to a set of private space companies. NASA's stated goal for these commercial partnerships was "to help spur the innovation and development of

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new spacecraft and launch vehicles from the commercial industry, creating a new way of delivering cargo—and eventually crew—to low-Earth orbit [LEO] and the International Space Station [ISS]."[6]

CCDev and its cargo-focused predecessor, the Commercial Orbital Transportation Services (COTS) program, were attempts to use a form of public-private partnership (PPP) to transform activities traditionally funded by the public sector into self-sustaining private sector activities.[7] William H. Gerstenmaier, an Associate Administrator at NASA, testified that "NASA's efforts to assist in the development of U.S. commercial cargo and crew vehicles represent a new way of doing business for the Agency."[8]

Hopes were high that this transformation would yield dramatic gains for NASA, its New Space partners, and the U.S. aerospace industry more broadly. If New Space companies could use NASA's early support to substantially lower the cost of access to space, they could make it possible for NASA to stretch its long-stagnant budget and provide more of the public goods at the core of its mission, while building their own businesses. NASA Administrator Charles Bolden noted in 2010, "These agreements are significant milestones in NASA's plans to take advantage of American ingenuity to get to low Earth orbit, so we can concentrate our resources on deep space exploration."[9] Bretton Alexander, Director of Business Development and Strategy at Blue, emphasized the particular importance of the crewed program, CCDev, to the future of commercial space: "NASA gave up building, owning, and operating the spacecraft and [instead] was going to buy seats. That changes everything."

On the other hand, NASA had achieved its greatest successes through a centralized contracting process that granted it tight control over companies' activities. "Spaceflight is hard, and we have to remember that," said NASA's Deputy Administrator Dava Newman, "but we are confident in the ability of commercial companies to provide the services of commercial cargo and commercial crew."[10] However, skeptics worried that it was unwise to trust the nation's access to LEO to New Space companies whose desire to cut costs could turn into a temptation to cut corners. They warned that enthusiasm for New Space was built more on faith and hope than experience, and they argued that the disruptors' bold claims would falter in the face of the immense difficulty of safely and reliably delivering cargo, and especially crew, to space. To these skeptics of New Space, the success of the current U.S. aerospace sector, resulting from a history of launches tied to national security, was not the inefficient, politicized space-industrial complex some claimed it was. Instead, it was a natural, necessary structure for achieving miraculous—and inherently costly—feats of engineering. One space industry veteran argued:

> Achieving 100 straight launches in a row, without any failures ever, as defense contractors and subcontractors have done . . . was achieved over a multi-decade process of steadily improving designs, and the steadily increasing professionalism and discipline of the workforce required for these important national security launches. The benefit to the nation of the critical military payloads that have *not* been lost is of course something that cannot be quantified. Yet the image of this national treasure has somehow been transformed (erroneously) into complacent, "rent-seeking," price-gouging fat cats performing some routine function that others can do for much less. They are the true professionals that developed their vehicles with minimal federal monetary support. It is inaccurate to call these [New Space] companies "commercial" because their systems were developed with more taxpayer dollars, in absolute terms, than the supposed "old space" launchers. In fact, Boeing and Lockheed Martin lost multiple billions in the development of their defense launch vehicles—of which they funded more than 80%.[11]

The first two phases of CCDev, in 2010 and 2011, attracted interest from a large number of New Space companies and were completed on time and within budget. Among those awarded contracts, Blue received over $25 million to work on an innovative rocket engine design and a system to allow crew members to escape a problematic launch. Blue felt that its participation had been a win-win situation: "[It] was well aligned with our goals," said Erika Wagner of Business Development at Blue Origin.

The third phase of CCDev, launched in September 2011, was designed to be qualitatively different by requiring that participants propose "a complete end-to-end design, including spacecraft, launch vehicles, launch services, [and] ground and mission operations and recovery" for crew transportation that would be ready by 2016, only a little more than four years away.

The greater demands, and rewards, of this third phase posed a difficult decision for Blue's leadership: Should Blue submit a proposal? On the one hand, participants would likely have an advantage in securing awards in the program's future phases, when companies would provide full service to the ISS and LEO. On the other hand, involvement would require Blue to scale up dramatically, potentially distracting Blue's small and world-class team from its objectives and toward NASA's. And as CCDev itself gained scale, it was likely to be increasingly buffeted by political and budgetary pressure, while Bezos's vision for the firm was resolutely long term and his personal fortune (at $50.3 billion in 2015)[12] was likely to be sufficient to match NASA funding for the foreseeable future. In the end, Blue's leadership had to decide whether Blue's future was brighter working for NASA or alongside it. As Blue's president, Rob Meyerson, said, "It was a hard decision."

## The U.S. Space Program: A Brief History

The U.S. space program had roots extending back to 1915, but it surged to prominence as part of the U.S.–Soviet Cold War.[13] On October 4, 1957, the Soviet Union launched Sputnik 1, the world's first artificial Earth satellite. Less than four years later, a Soviet cosmonaut, Yuri Gagarin, became the first human in space and the first to orbit the Earth. Demonstrating technological prowess in space immediately became a matter of national security for the United States. The U.S. Congress passed the National Aeronautics and Space Act of 1958, establishing NASA as the nation's civilian space agency. And in a speech addressing Congress in May 1961, President John F. Kennedy said, "If we are to win the battle that is now going on around the world between freedom and tyranny . . . [it is] time for this nation to take a clearly leading role in space achievement."[14] The president called for the nation's commitment to land a man on the moon by the end of the decade. On July 20, 1969, Neil Armstrong and Buzz Aldrin fulfilled that commitment aboard NASA's Apollo 11 mission.

The dramatic success of NASA in its Apollo lunar missions seemed to signal the dawn of a new era of space exploration, and not just for five-year-old Jeff Bezos. Plans for routine spaceflights, hotels on the moon, and orbiting, spinning colonies that housed tens of thousands or even millions of people were drawn up over the next decade, as the nearly infinite economic, social, and even (perhaps especially) spiritual potential inherent in exploration beyond Earth seemed suddenly within reach.

### *Post-Apollo Retrenchment and the Space Shuttle Era*

Over the next several decades, reality fell far short of that initial promise, and the Apollo era gradually began to be seen as a golden age for NASA and space exploration rather than a new dawn. (Refer to **Appendix A** for a timeline of major events.) Reflecting that disappointment, in 2014, Apollo astronaut Buzz Aldrin told the *Financial Times*, "After the Apollo lunar missions, America lost its love of space—there was no concentrated follow-up and we didn't have any clear objectives."[15]

**The NASA budget returns to Earth** In fact, the trouble for NASA and the U.S. space program began almost immediately after its greatest success, with a dramatic and rapid reduction in NASA's budget after the 1960s. As Bretton Alexander of Blue explained, "Apollo was a proxy for everything that was going on [with the Soviet Union] . . . then other things became proxies." Peaking as a share of the U.S. federal budget at 4.4% in 1966 ($6 billion), the agency's funding tumbled to only 1.2% of the federal budget in 1974 ($3.3 billion), as the costs of the Vietnam War escalated and the U.S. economy entered a recession following a rise in global oil prices. NASA's share of the federal budget continued a steady decline over the next decade, dipping to 0.7% in 1986, then recovered briefly in the late 1980s to just over 1.0%, after which it gradually shrank to less than 0.5% by 2014. (See **Exhibit 1** for NASA budget breakdown by program.)

The drop in NASA funding was consistent with American public opinion at the time. In 1967, 54% of the public felt that the space program was not worth its then-current $5 billion budget.[16] Yet more striking, one year after the moon landing, 56% of Americans felt that it had not been worth the money even though 81% agreed that "nothing can equal seeing the astronauts land and walk on the moon as it happened live on TV."[17] (See **Exhibit 2** for public opinion data.) Much to the detriment of NASA's grand visions for space, it appeared that the surge of support for funding space activities in the 1960s diminished along with the Soviet threat from space. (See **Exhibit 3** for NASA outlays compared to Department of Defense outlays and U.S. GDP.)[18]

**The Space Shuttle era** In the 1970s and 1980s, large shares of NASA's technological prowess and shrinking budget were devoted to a new signature program: the Space Transportation System, or "space shuttle" as it came to be known. As NASA historians wrote, "For an entire generation, the space shuttle was NASA."[19] The shuttle was a vertical takeoff/horizontal landing launch vehicle and reusable spacecraft[a] fueled by liquid hydrogen and liquid oxygen, along with a pair of solid rocket boosters. The fleet of five shuttle orbiters—*Columbia*, *Challenger*, *Discovery*, *Atlantis,* and (later) *Endeavor*—was designed to offer relatively inexpensive access to LEO and the ISS, and together they flew 130 missions over approximately 30 years. The shuttle program's signature accomplishments were in providing semi-routine flight of U.S. and international astronauts into LEO, launching numerous satellites, and facilitating the construction and maintenance of the ISS—that is, providing national and global public goods and services.

Despite its accomplishments, the space shuttle had numerous critics. "[I]t was probably a mistake to develop *this* particular space shuttle design, and then to build the future U.S. space program around it," John Logsdon, a renowned space expert and member of NASA's Advisory Council, wrote in the *MIT Technology Review* in 2011. The shuttle flew much less often than had originally been planned, and at greater cost. The program's total cost rose to over $200 billion (in 2010 dollars), nearly a third of NASA's entire budget from 1974 through 2010 and 68% of its piloted programs budget. As Logsdon wrote, "The shuttle's cost has been an obstacle to NASA starting other major projects."[20] Even the U.S. Department of Defense, whose desire for routine access to space had influenced the selection and design of the shuttle program, lost its enthusiasm for the shuttle over time.[21]

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[a] A spacecraft was the vehicle that entered space carrying a payload (humans, cargo, or satellites, usually measured in weight). A launch vehicle was the rocket assembly that carried the spacecraft to the appropriate altitude before the payload separated and continued to space. Low-Earth Orbit (LEO) was the orbital path around Earth with an altitude between 160 km (~100 miles) and 2,000 km (~1,200 miles). The International Space Station (ISS), a multinational habitation in which astronauts performed scientific experiments and studied the effects of prolonged residence in space, remained in LEO at an altitude of 400 km. All orbital crewed spaceflight, apart from the Apollo lunar mission, was in LEO.

Public opinion on NASA reached a low point in the middle of the shuttle era, but it recovered over the next decade as the agency scored a number of remarkable achievements in non-crewed space exploration.[22] The latter included the Hubble Space Telescope, which provided high-resolution images of deep space and time, and the Mars Exploration Rovers, which broadcast dramatic images and data far beyond even their designers' expectations.

Tragically, two shuttle missions ended in disaster: *Challenger* exploded shortly after launch in 1987, and *Columbia* disintegrated upon reentry in 2003. In the aftermath of the latter, the shuttle program was officially designated for retirement after 2010.

### *The Post-Shuttle Gap and New Space*

As the shuttle program wound down, NASA struggled to establish a successor program for human space travel. In January 2004, President George W. Bush announced his Vision for Space Exploration (VSE), calling for the development of a new Crew Exploration Vehicle. To pursue this goal, NASA subsequently proposed the Constellation program for crewed spaceflight back to the moon and eventually to Mars. But President Barack Obama scaled back the Constellation program when he took office in 2009, eventually canceling it in the middle of his first term. The long-term plan for NASA retaining access to space remained unclear as the shuttle flew for the last time in July 2011.

The most glaring problem for NASA—and, conversely, the clearest opportunity for New Space—was that there would be several (if not more) years in the 2010s during which the United States would have no domestically provided way to put astronauts in space, including to the ISS.[23] "The failure of NASA to find a replacement for the shuttle for 30 years shattered the idea of NASA being in charge," said Bretton Alexander of Blue. "When the shuttle was retired, it created this void that allowed NASA to look to the commercial sector."

In fact, NASA had been experimenting with new ways to work with commercial space companies on *cargo* transportation for several years. As early as in the Commercial Space Act of 1998, Congress established that "the Federal Government shall acquire space transportation services from U.S. commercial providers whenever such services are required in the course of its activities. . . . Space transportation services shall be considered to be a commercial item."[24] Soon thereafter, NASA appointed an internal strategic planning team. It recommended that the agency "open the way for U.S. citizens by privatization and commercialization of the space environment."[25] This planning process led to the Alternate Access to Station (AAS) program, which from 2000 through 2002 engaged more than 20 private space companies in studies of various aspects of commercial resupply of the ISS. After the AAS program wound down, it was replaced with the ISS Commercial Cargo Services (ICCS) program, serving similar goals. These early programs laid the foundation for NASA's more dramatic embrace of commercial space—including *crew* transportation—after the *Columbia* disaster. (See **Appendix C** for a summary of NASA's commercial programs.)

A turning point was President Bush's 2004 VSE, which "included a key place for private spaceflight companies" in NASA's exploration program. The VSE directed NASA to "acquire cargo transportation as soon as practical and affordable to support missions to and from the International Space Station," echoing the advice of the President's Commission on Implementation of the U.S. Space Exploration (the Aldridge Commission), which argued that "NASA's role must be limited to only those areas where there is irrefutable demonstration that only government can perform the proposed activity."[26]

Fortuitously for all sides, the emerging New Space sector was eager to fill this gap in space access. And it had public opinion behind it: polls showed that a majority of Americans supported private companies and individuals building their own rockets to take people to space (refer to **Exhibit 2**).[27] But, as Kathryn Lueders, NASA's Commercial Crew Program Manager, recalled a decade later, how exactly New Space, or even Old Space, would accomplish this transition was unclear. "It was a bit of a Hail Mary to rely on commercial to resupply ISS," Lueders said. Indeed, the state of New Space in the mid-2000s gave little sign, except perhaps to its most fervent disciples, of its role in the mid-2010s.

## The Rise of New Space

Early signs that the private sector was exploring a new way of doing business in space—specifically, without NASA—came in the mid-1990s. In 1996, Peter Diamandis, an aerospace engineer and medical doctor who would become a central player in the growth of New Space, created what came to be called the Ansari X Prize: $10 million to the first team that could fly to the edge of space (100 km) and back to Earth twice within two weeks using the same vehicle.[28] It took nearly a decade, but in October 2004 a company named Mojave Aerospace Ventures, financed by Paul Allen and led by aircraft designer Burt Rutan's engineering firm Scaled Composites, achieved the goal.[29] For $121.5 million, Richard Branson licensed the winning designs with plans to offer tickets for a three-day space experience aboard Virgin Galactic for $190,000.[30]

In 2000, a former NASA engineer and investment consultant named Dennis Tito began discussions about buying a seat on board a Russian (government) flight to the ISS with Space Adventures, a space tourism company cofounded by Diamandis and aerospace engineer Eric Anderson. NASA actively opposed the flight, with its then Administrator, Daniel Goldin, saying, "Space is dangerous. It's not about a joyride. Space is not about egos."[31] Despite these protests, in April 2001 Tito rode aboard the Soyuz TM-32 and spent nearly eight days on the ISS. The sticker price: $20 million.

### *Billionaire Believers*

These early steps attracted capital for the new industry, much of it from a small group of wealthy individuals (17 of whom were billionaires) with a combined net worth of $175 billion.[32] These tech-savvy executives and space enthusiasts, many of whom had earned their fortunes through successful start-ups, hoped to apply their experience and expertise to their passion for space. Some of the most prominent participants were Paul Allen (Microsoft and Mojave Aerospace Ventures), Richard Branson (Virgin Group and Virgin Galactic), Jeff Bezos (Amazon and Blue Origin), and Elon Musk (Tesla Motors, PayPal, Solar City, and SpaceX).

These New Space entrepreneurs were inspired by watching NASA's successes as children and were determined to renew that inspiration for a new generation, but they also believed that the constraints on NASA meant a new approach would be required. As journalist and Bezos biographer Brad Stone wrote, "All these dreamers, and others in the movement, doubt if NASA will ever attempt anything truly inspiring in their lifetimes. . . . [T]hey believe they can re-engineer rockets from the ground up, with modern information-technology systems."[33]

The passion and efforts of the New Space entrepreneurs were not, in fact, entirely new to the industry. As Alexander MacDonald, NASA's Emerging Space Program Executive wrote, "Participation by individuals is characteristic of how space exploration in the United States began. . . . [I]nvestments from philanthropists like Daniel Guggenheim, the dedication of inventors like Robert Goddard, and research conducted by amateur rocket societies combined to advance the development of American spaceflight technology. Adjusting for inflation, these early investments . . . were similar in scale to the commitments of the current generation of entrepreneurs in commercial space. Individual Americans investing in and advancing the exploration of space is not a new phenomenon."[34] With this historical context, MacDonald argued that "current commercial space activities are really a return to the way that the space sector worked in America prior to the formation of NASA."[35]

The NASA-centered structure of the U.S. space industry in the 1960s through the 2000s could therefore be interpreted as a historical departure from a more decentralized approach. NASA was created as a command-and-control authority capable of rapidly and forcefully countering the Soviet threat. While many in the incumbent space industry saw that structure as necessary to overcome the complex challenges of space, advocates of New Space argued that it was time for that structure to give way. As Jim Cantrell, a member of the founding team of SpaceX, wrote, "The same aerospace industry that put a man on the moon and defeated the great Soviet threat in the defense of capitalism was, and still is, operating on a Soviet economic model."[36]

## *Technological Advancements*

New Space enthusiasts claimed that a decentralized approach would allow its companies to better take advantage of technologies that would lower the costs of and revolutionize access to space. In recent years, sophisticated manufacturing processes such as computational fluid dynamics, computer-aided design and manufacturing, robotic assembly, and welding techniques had become routine, and advanced composite materials achieved superior performance at lower cost. Independence from NASA would enable New Space companies to use these innovations and shift design away from the intentionally overengineered systems of the past toward simpler, less costly designs without necessarily compromising reliability. Elon Musk articulated this point: "Is a Ferrari more reliable than a Toyota Corolla or a Honda Civic?"[37]

Reusability was the technological advance most emphasized by New Space participants. As the *New York Times* reported, "In rocketry, what goes up usually comes down in pieces. The cost of getting to orbit is exorbitant, because the rocket, with its multimillion-dollar engines, ends up as trash in the ocean after one launching."[38] Elon Musk repeatedly emphasized this point, as in a quote prominently displayed on the SpaceX website: "If one can figure out how to effectively reuse rockets just like airplanes, the cost of access to space will be reduced by as much as a factor of a hundred. A fully reusable vehicle has never been done before. That really is the fundamental breakthrough needed to revolutionize access to space."[39] Reusability would also make it easier for launch vehicles and engines to be used by a wider range of customers, from NASA and the military to commercial customers (including for both cargo and human passengers). By providing scale, this wider applicability could further bring down costs.

Additionally, new and (in particular) reusable launch vehicles would require more advanced, efficient, and powerful engines than those currently available. This need was made particularly salient by the heavy reliance of U.S. military, government, and commercial space actors on the Russian-made RD-180 rocket engine in an era of tense U.S.-Russian relations. New Space companies such as Blue seized the opportunity to alleviate concerns over dependence on foreign supplies and took advantage of clean-sheet engineering to innovate.

### *Motivations*

New Space leaders had a wide range of motives, ranging from the commercial to the sublime.

Commercially, the market for space tourism was a major source of enthusiasm in the industry. A 2012 report by the Tauri Group consultancy surveyed individuals' worth over $5 million and found that 2.5% were likely to spend at least $100,000 on a flight in space.[40] But truly astronomical projections arose if one assumed that innovation and scale would soon make space a feasible destination for merely "affluent" travelers. A 2014 report by Boston Consulting Group put global spending on luxury travel at $460 billion and the overall luxury "experiences" market at $1.8 trillion.[41]

In addition, the launch capabilities being developed by New Space companies were in high demand. Providers of telecommunications, media, Internet, and other services requiring satellites in space had always been the dominant customers of the commercial launch industry. A new source of demand appeared in 2004, when the Federal Aviation Administration (FAA) granted the first commercial licenses to Scaled Composites for Ansari X Prize spaceflights. Over the next decade, the FAA granted 65 licenses and permits to private companies for crew or cargo spaceflight testing and missions. (See **Exhibit 4** for the number of yearly commercial launches.) By 2012, the annual revenue for the commercial launch industry had reached $2.5 to $3 billion, with 50% expected growth over the next decade.[42]

Of course, governments requiring satellite and even crewed space access would continue to be important—even essential—sources of demand. In 2011, NASA Administrator Charles Bolden said: "The potential, I think, is enormous for this sector to expand into other activities with other customers—whether they're industrial, academic, other nations—and become a job-creating engine for decades to come. But we've got to facilitate that success by being the anchor tenant for them initially."[43] Carissa Christensen, space industry analyst and cofounder and Managing Partner of the Tauri Group, pointed to other sovereign actors as a third source of customers: "Small countries could launch to the ISS every year, or more often as needed, without having to develop an entire space launch program large enough to fund operations."

But profit was clearly not the only, and perhaps not even the main, driver of the passionate work and investment of New Space entrepreneurs, many of whom wanted to leave as a part of their personal legacy nothing less than securing the long-term survival of humankind. The primary strategy for pursuing this goal was Mars colonization. At the time of Blue's founding, Bezos told reporters he was currently reading *Entering Space: Creating a Spacefaring Civilization* and *The Case for Mars*, books by Robert Zubrin, a well-known aerospace engineer and author who argued that present-day technology could transport humans to Mars to establish a livable and sustainable environment.[44] In 2014, Elon Musk made even clearer his goals and reasons for settling Mars: "I'm hopeful that the first people could be taken to Mars in 10 to 12 years, I think it's certainly possible for that to occur. But the thing that matters long term is to have a self-sustaining city on Mars, to make life multiplanetary."[45] Musk was echoing a dire warning from the famous physicist Stephen Hawking in 2015, who like others worried that climate change, nuclear war, or even a large asteroid impact threatened humans as long as Earth remained their only habitat: "I don't think we will survive another 1,000 years without escaping beyond our fragile planet."[46]

Some prominent New Space leaders saw their mission in philosophical terms as well. In his book *The Philosophy for the Future*, aerospace engineer George Sowers argued that the overarching goal of humankind was to strengthen the long-term viability of the human species, and he concluded that the "future of humanity lies in space." Sowers was Vice President of Strategic Architecture for United

Launch Alliance (ULA), the joint venture between Boeing and Lockheed Martin that had dominated U.S. government launches for nearly a decade with its Atlas and Delta rockets. Bretton Alexander praised Sowers's book, saying, "It really shows a path toward the future—a path that those of us from a space perspective really can relate to and can understand and can get behind."[47]

Among the dozens of New Space firms, a few stood out for their substantial funding, bold visions, and early successes. (See **Exhibit 5** and **Appendix B** for profiles of these companies.) The space industry as a whole began to organize under organizations such as the Commercial Spaceflight Federation. In 2008, the industry coordinated 13 conferences and symposiums globally. That number tripled by 2015.

## Blue Origin

According to the company's initial bare-bones website, Blue's mission was to develop "vehicles and technologies that, over time, will help enable an enduring human presence in space."[48] This mission was captured in the company's coat of arms, its motto *Gradatim Ferociter* (Latin for "Step by Step, Ferociously"), and its belief that its "incremental development process builds upon each success as we develop ground-breaking spaceflight systems."[49] (See **Exhibit 6** for Blue Origin's coat of arms and logo.)

Blue leveraged Jeff Bezos's financial support to pursue excellence from the start. Beginning with a staff of 10 in 2000, the company hired a mix of established aerospace industry members, start-up veterans, and recent graduates on its way to 300 employees by 2013. The career section of Blue's website was clear: "Our hiring bar is exceptionally high, and we want to keep our team small and collaborative. You have to want to work in an environment where the people occupying each and every role are among the most technically gifted in their area of expertise. You should be at the top of your field, remarkably dedicated, and excited about shaping our future in space."[50] Ariane Cornell (MBA 2014), of Blue's Business Development and Strategy group, said: "Everyone that works here has a real passion for space." The company's facilities grew as well, eventually filling a former Boeing factory with cutting-edge machinery from friction stir welders to 3D metallic printers.

Bezos's personal wealth and enthusiasm gave Blue another unique advantage in the industry: time. Experienced space industry members, from both NASA and the private sector, claimed that a major obstacle to progress in space was the unpredictability of NASA budgets and therefore uncertainty over which private and public sector programs would be seen through to fruition. Blue's president, Rob Meyerson, noted, "The political process means very short-term thinking. If NASA could have a three-year budget, you could plant seeds and give them time to grow before you burn the field down."

Bezos himself stressed this point: "The willingness to be patient and to know we're going to have to iterate, that we're going to have to keep going. That kind of steadiness, I think, is unbelievably valuable, and that's something that I can bring that's actually difficult for even NASA to sometimes bring or any kind of government-funded program [that] is sometimes subject to starts and stops."[51] Blue's ability to chart a course and stick to it, largely independent of NASA, set it apart from nearly all other New Space ventures. It also prompted gratitude among its employees: "We're very lucky to work in the space industry at a time when there are people like Jeff [Bezos] willing to invest in it for the long run," said Cornell.

While guaranteed funding could run the risk of reducing incentives inside the firm, Meyerson noted that by establishing "incremental milestones," planning demonstrations around which the firm could rally, and—most important—"hiring people who are passionate about space," the benefits of Bezos's deep pockets could be made to far outweigh the costs.

Blue took its motto, *Gradatim Ferociter*, seriously. "We have been focused on the suborbital mission as the starting point to serve as practice for later development of our orbital launch system.[b] That way, we intend to prove out underlying technologies while building out a very small and innovative company capable of repeated success," Meyerson commented.[52] Between 2006 and 2011, Blue launched five test vehicle flights from its West Texas site,[53] one of which was lost due to "flight instability." Bezos seemed to take the loss in stride: "Not the outcome any of us wanted, but we're signed up for this to be hard, and the Blue Origin team is doing an outstanding job. We're already working on our next development vehicle."[54]

Blue's biggest project was its suborbital vehicle, the New Shepard (whose name referenced astronaut Alan Shepard, who in 1961 became the first American to travel into space). New Shepard was designed to launch a six-person pressurized capsule atop a suborbital, reusable vertical takeoff/vertical landing rocket using advanced propulsion and safety systems and a new Blue Engine 3 (BE-3) liquid-fueled engine. "The BE-3 is a versatile, low-cost hydrogen engine applicable to NASA and commercial missions," said Meyerson.[55] The crew capsule would separate from the launch vehicle and continue on its suborbital trajectory. The launch vehicle would then return to Earth, landing on four legs using highly controlled throttling techniques, and the capsule would eventually land using a series of parachutes and retro-thrusters to cushion the landing.

Echoing Amazon's famous focus on the customer experience, Blue designed the New Shepard crew capsule with the space tourist in mind. The interior offered the largest windows of any spacecraft, one for each astronaut, which transmitted 92% of visible light just as ordinary glass would. (See **Exhibit 7** for photos of the crew capsule.) The capsule's interior was 530 cubic feet, large enough for all crew members to float around freely in the absence of gravity.[56] Safety for crew members was also a priority. The design implemented a "full envelope" escape system that allowed the crew to escape at any point during the flight.

Blue credited its participation in CCDev with helping facilitate its progress on New Shepard. "Working with NASA accelerated our BE-3 development by over a year in preparation for flight testing on our New Shepard suborbital system and ultimately on vehicles carrying humans to low-Earth orbit," said Meyerson.[57]

By the end of 2012, Blue had successfully tested the full-scale suborbital New Shepard capsule system from its launch site in West Texas as part of its CCDev partnership with NASA. On the day of the successful capsule launch, Bezos's excitement was evident: "The first test of our suborbital Crew Capsule is a big step on the way to safe, affordable space travel. This wouldn't have been possible without NASA's help, and the Blue Origin team worked hard and smart to design this system, build it, and pull off this test. . . . Gradatim Ferociter!"[58]

[b] Suborbital spaceflight was achieved when a spacecraft reached space (higher than 100 km above sea level); however, the perigee (the point on the spacecraft's parabolic trajectory back down where it was closest to the point of takeoff) either intersected the Earth's surface and landed, or was below the 100 km altitude boundary of space and thus did not have enough speed to exit the atmosphere and enter a full orbital revolution around the Earth. Orbital spaceflight was achieved when the vehicle reached speeds high enough to propel it out of the atmosphere. In the vacuum of space, the curvature of the vehicle's trajectory became that of the Earth, and the vehicle entered an orbital path.

## NASA's Strategy for New Space

While hopes were high that New Space would resurrect the American human spaceflight program after the shuttle's retirement, making commercial service to LEO and the ISS a reality required NASA to undertake several major reforms in its rules and its thinking. First was reform to the regulatory structure under which NASA and commercial space companies collaborated. The Commercial Space Launch Amendments Act, passed in 2004 by the U.S. Congress and widely referred to as the CSLA, would provide the framework for these reforms.

### *Regulatory Changes under the 2004 Space Act*

Throughout its history, NASA had contracted with private firms for the manufacture and service of most of its equipment. For nearly the entire post-Apollo era, the vast majority of those contractual relationships were governed by a set of rules called Federal Acquisition Regulation (FAR). As Eligar Sadeh, president of Astroconsulting International, wrote in the journal *Astropolitics,* "[under FAR,] the government pays for technology development on a cost-plus basis that covers total cost for industry, as well as an additional amount for profit. . . . [A]pproximately 90% of the work effort on space programs and projects [is] contracted out to industry under this contracting model."[59]

FAR contracting was designed to insulate private companies from the inherent risk of ambitious space projects, and it was thus the main way in which incumbent companies—including Boeing, Lockheed Martin, and Northrop Grumman—worked with NASA to achieve its objectives. Spacecraft and rocket production required extraordinary up-front investments with substantial cost risk, due both to the cutting-edge nature of the business and to policy uncertainty. By guaranteeing that private companies' costs would be covered, plus a margin, FAR made it possible for NASA to outsource much of its equipment needs, while the elaborate oversight provisions within FAR were designed to guard against abuses of this cost-plus structure. Skeptics of New Space pointed out that it was the projects funded by these contracts that laid the groundwork upon which the newcomers built their "lean" models.

But FAR contracting was a source of fierce criticism from outsiders, especially from New Space companies who found it challenging to manage. "[FAR] is a lot of bureaucracy for a small firm looking to be quick and nimble," said Erika Wagner. "It inhibits a company from moving quickly." Wagner was referring to the fact that, in FAR cost-plus contract partnerships, NASA had complete oversight over the design, development, manufacture, and test specifications for each system, and contracted companies were subject to hefty government requirements, documentation, and bureaucratic inefficiencies. These costs weighed particularly heavily on small New Space companies that lacked the administrative infrastructure or resources to manage them. Also, under FAR contracts firms did not bear the risk of cost overruns, while many New Space firms viewed their cost efficiency as an advantage over larger players. Critics of NASA alleged that FAR enabled a space-industrial complex that was bloated, inefficient, and driven by political rather than technical considerations—in short, "a jobs program." Finally, under FAR contracts with NASA, the government took ownership of technologies developed. Commercial partners were required to petition the NASA Administrator to waive the government's rights and allow the firms to retain title to their technologies, a priority for many New Space entrepreneurs.

In an effort to stimulate commercial development, NASA moved to replace FAR with a system that emphasized the power of the agency's *insight* rather than *oversight*. In particular, it employed fixed-price "funded Space Act Agreements" (SAAs) rather than conventional FAR contracts. In SAAs, NASA would share technical expertise and experience with commercial space companies while leaving those companies with the freedom to design, build, manufacture, test, and operate their own approaches. Companies were also granted greater responsibility over safety systems, though they were still to be held to the same high government standards. Critically, unlike the FAR method, SAAs allowed the private firms to retain ownership of intellectual property (IP) they developed. Blue's president, Rob Meyerson, emphasized this point: "A key component of SAA is IP protection."

New Space firms welcomed the increased freedom the shift from FAR to SAAs provided. The first funded SAAs were implemented with SpaceX and Rocketplane-Kistler as part of the COTS program in 2006.[60]

This regulatory shift also had benefits for NASA, particularly in cost control. SAAs required the private venture to complete performance-based milestones in order to collect fixed, predetermined payments.[61] "Firm fixed price agreements allow the objective of the contractor and the agency to be aligned in an affordable fashion, shifting the burden of cost overruns onto the private sector," Eric Stallmer, president of the Commercial Spaceflight Federation, told Congress.[62] Stallmer continued by highlighting that one of the key advantages of the SAA model was that it offered NASA diversification across individual commercial partners, any one of which might fail, as well as across types of commercial partners, such as nimble but risky start-ups and stable incumbents.[63]

### *NASA as One of Many Customers: The COTS Program*

With the VSE and regulatory reform in place, NASA could undertake a second reform crucial to the commercialization of its LEO and ISS activities: thinking of itself as "just another customer." In 2005, Mike Griffin became NASA's Administrator and brought to the agency his background as a physicist, aerospace engineer, and former president of In-Q-Tel, the CIA's in-house venture capital firm for national defense technologies. Consistent with fulfilling the goals of the 2004 VSE, Griffin said, "I can provide mechanisms where if the commercial provider shows up, the government will stand down and will buy its services and its capability from the industrial provider and let them have the competition among themselves."[64]

To facilitate this reform, Griffin created the Commercial Crew and Cargo Program Office (C3PO) in 2005 and requested that $500 million of NASA's FY2006 budget be allocated to the COTS program. The stated goal: "challenging private industry to establish capabilities and services that can open new space markets while meeting the logistics transportation needs of the International Space Station."[65]

In an interview, Griffin described one vital feature he envisioned for COTS: "The total amount of money available would be a small percentage of what was likely to be required to complete the system. So most of the money would have to come from private capital sources . . . by going to combinations of private equity firms, investment banks, angel investors, venture capital firms, whatever they wanted to do. . . . That I thought was crucial."[66]

According to Griffin, government funding of more than 5%–10% would be excessive and would turn COTS into a mechanism to use public funds without the appropriate level of oversight customarily expected when spending government resources:

> In my view, a good way to get started would be to make available to successful commercial developers the government market, and even to provide them a little bit of seed money. . . . [O]ne could achieve valid public purposes with a little bit of money, while not corrupting the market. . . . It's extremely important that if you're going to utilize the virtues of the marketplace you can't corrupt it with government funding. . . . [I]t's best to understand where a government enterprise is most useful and

> where a private enterprise is most useful, and then let them interact through what in the marketplace are called arm's length transactions.[67]

In 2006, NASA awarded SpaceX and Rocketplane-Kistler (Kistler) SAAs under COTS. SpaceX completed all milestones on time toward the development of the Falcon 9 rocket launch system and Dragon spacecraft and received $396 million from NASA. This public funding made up slightly less than half of SpaceX's costs, as the company raised a total of $454 million from private sources, including $100 million of founder and CEO Elon Musk's personal capital. Kistler did not complete the milestones it set out. NASA granted $32.1 million of the $207 million it originally allotted before terminating the contract due to numerous missed milestones.[68]

In 2008, Orbital Sciences was awarded the remaining $170 million originally intended for Kistler; the company ultimately received a total of $288 million, including follow-on funding for additional milestones to develop Orbital's Antares rocket and Cygnus spacecraft.[69] Orbital, already an established aerospace firm at the time of COTS, had been founded as an industry disruptor in 1982 by three Harvard Business School classmates: David Thompson, Scott Webster, and Bruce Ferguson. Over the intervening decades, it had grown to be one of the dominant players in the industry, with 2014 revenues of $4.4 billion and 12,000 employees in 20 countries.[70] Orbital had extensive experience under FAR contracts as a private aerospace contractor for NASA, the military, and commercial partners.[c]

While implementation of fully designed cargo transportation systems was not within the scope of the initial COTS program, additional "augmentation" funding was granted to SpaceX and Orbital in 2008 due to the companies' performance. The successful SpaceX and Orbital COTS demonstrations also culminated in fixed-price, milestone-based ISS Commercial Resupply Services (CRS) contracts. NASA awarded 12 flights (valued at $1.6 billion) for SpaceX and 8 flights (valued at $1.9 billion) for Orbital to resupply the ISS.[71,72] SpaceX began its resupply missions to the ISS in 2012, and Orbital launched to the ISS the following year.

### *The Paradigm Shift: The Commercial Crew Development (CCDev) Program*

Members of the transition team for President-elect Barack Obama, who would take office in January 2009, were encouraged by the success of COTS and eager to extend the role of commercial space to crew through the CCDev program. A particularly strong voice for expanding commercial activities was Lori Garver, a longtime space policy expert as well as Obama's choice for both the job of reviewing NASA during the transition and, in 2009, Deputy Administrator of NASA. As Garver said in an interview in 2014, "We are now on a very positive track to have our astronauts flying in space through these commercial vehicles. We should have been funding that much earlier and we wouldn't have had this [shuttle] gap."[73]

Garver and Charles Bolden, Obama's appointee as NASA Administrator, would oversee CCDev. As Blue's Bretton Alexander said, "COTS was a good start, but the real paradigm shift is crew."

**CCDev1** On August 10, 2009, NASA announced CCDev1, which was funded through the American Recovery and Reinvestment Act. In addition to its $19 billion total budget, NASA received $1 billion through the Recovery Act, of which $50 million was dedicated to CCDev1.[74] (Refer to **Exhibit 1** for NASA's budget breakdown.)

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[c] For a discussion of this company, see Das Narayandas and John A. Quelch, "Orbital Sciences Corporation: ORBCOMM," HBS No. 598-027 (Boston: Harvard Business School Publishing, 1997).

NASA received 35 proposals for CCDev1 and selected 5, including $3.7 million for Blue to develop its "pusher" Launch Escape System (LES) and composite pressure vessel.[75] Blue's proposal was selected in part due to its plan to apply its New Shepard suborbital development efforts to orbital transportation (e.g., to the ISS). Other strengths in Blue's proposal were its existing level of development capabilities and its capsule pusher escape concept, which differed from the traditional pull systems used for crew transportation systems. Testing and development in these areas created additional technical options and knowledge that NASA thought would be valuable.[76]

CCDev1 was a success, with each chosen firm completing all milestones on time and within budget.

**CCDev2**[77] Following the success of CCDev1, NASA put out a call for proposals for CCDev2. Announced on October 25, 2010, the mission of CCDev2 was to support commercial partners to further mature previous system designs. In its budget request for 2010, NASA requested $200 million from Congress for CCDev2 and ultimately was able to award a total of $270 million to four companies to further demonstrate safe, reliable, and efficient transport systems.[78]

Of the 22 proposals received for CCDev2, NASA selected to enter SAAs with 4 companies, including one worth $22 million with Blue.[79] (See **Appendix D** for details on the CCDev1 and CCDev2 activities of the companies other than Blue.) In its selection announcement statement for CCDev2, NASA underscored the importance of diverse technologies in its selection process.

Blue was selected to advance the development of its reusable biconic-shaped[d] orbital crew vehicle (see **Exhibit 7**), which was designed initially to be launched from a ULA Atlas V but was also capable of being launched on multiple platforms, including Blue's own reusable system once available. Further development and testing of Blue's BE-3 rocket engine was also emphasized in the company's plan.

NASA noted that Blue's capsule proposal was selected for funding because the biconic design reduced overall risk to its human passengers due to the shape's lower peak deceleration and thus reduced forces exerted on the crew. The NASA selection committee appreciated the company's overarching approach to develop "step by step, ferociously." "The strategy of 'walk before you run' with suborbital demonstrations first then orbital demonstrations was realistic and achievable," commented Philip McAlister, NASA Selection Authority. McAlister also praised Blue's proposal for having "realism in future markets through diminished dependency on early revenues for sustainability, demonstrating commitment to a long-term strategy that was unique among all proposers."[80]

In 2012, NASA continued partnerships with several companies, including Blue, in unfunded SAAs to leverage technical capabilities in exchange for assistance with system development and integration. In Blue's unfunded SAA, NASA provided insight, resources, and access to its facilities and its review scientists, while NASA benefited from learning about the company's work. Erika Wagner described the benefit of the unfunded extension: "It's seen as a two-way street. It keeps the communication flowing and fosters the cultural bridge between Blue and NASA."

**CCiCap: CCDev's third phase** NASA specifically did not request fully integrated crew transport system designs in CCDev2. These full demonstrations were to be part of CCDev3, renamed

[d] The term "biconic shape" refers to a vehicle configured of two cones. A smaller cone sits atop the frustum (the portion of a cone or pyramid between the two parallel base planes) of a larger base cone, where the radius of the top cone is equal to the radius of the bottom cone's frustum at the point where the two meet.

the Commercial Crew integrated Capability initiative (CCiCap). CCiCap called for private companies to develop, test, and validate mature end-to-end crew transportation capabilities by the end of 2016. In its draft request for proposals, NASA returned to a FAR-based funding structure, noting that fully integrated designs would require a high degree of government oversight. NASA's Deputy Administrator, Dava Newman, noted, "One size does not fit all. We have many funding instruments and we have to determine what's the right instrument for the partnerships we're looking for."[81]

Complicating CCiCap, the commercial crew development program received deep budget cuts for the 2011 and 2012 fiscal years. For FY2011, Congress approved only $500 million of the $836 million requested for commercial crew development by NASA.[82] In response, NASA opted to return to the SAA funding mechanism. "With a [FAR] contract, if we don't get the funds that we anticipated, it makes it tough to renegotiate the contracts," said William Gerstenmaier, Associate Administrator for human exploration and operations. "There's an inefficiency with renegotiating that contract. We don't actually get the product we want out of this activity."[83] The official request for proposals was released February 7, 2012, and proposals were due March 23, 2012.

**Rising risks** Despite its record of success through two rounds, the CCDev program faced several hurdles as it expanded its scope and complexity with CCiCap.

First, while New Space companies favored the SAAs that CCiCap ended up employing, NASA had concerns over funding integrated systems for human transport while granting the same high degree of freedom to the private sector as in the previous rounds of COTS and CCDev. This tension was discussed in a testimony to Congress in October 2011 by Paul Martin, NASA's Inspector General:

> Every requirement NASA imposes on commercial vehicles has a cost associated with it in time, money, or decreased innovation. . . . Conversely, incurring these costs is often necessary to appropriately manage risk, particularly when the issue is human crew as opposed to cargo. . . . [NASA must] ensure they meet agency requirements and maximize safety and reliability without burdening commercial partners with unnecessary demands that lead to higher development and operations costs.[84]

Second, the task of managing risks without obstructing innovation was made more difficult by the start-stop-start nature of Congress's financial support for commercial development.[85] The resulting uncertainty left the private sector hesitant to rely on the government's continued support. Newman, NASA's Deputy Administrator, noted, "A top priority is our commercial crew program. . . . No one is comfortable with the gap in American capabilities."[86] However, Hoyt Davidson, an aerospace investment banker, explained, "too many have been burned by governments changing their minds about priorities."[87] The budget requests leading up to the CCiCap decision rounds illustrated these concerns. Although Congress approved only half ($406 million) of the commercial crew and cargo budget NASA requested for FY2012, the $805 million the agency sought in that year[88] was 60% greater than the 2006 COTS program funding request, sending mixed signals to the private firms intending to participate over the government's true level of support.

Third, as a result of fiscal tightening, and despite the original intent of CCDev to foster competition, in its 2011 budget recommendation, the U.S. House of Representatives directed NASA to focus its funding on a single main contender or one vehicle rather than on a portfolio of options. "In a climate of decreasing non-defense discretionary spending, the committee does not believe that the administration's proposed budget runout for commercial crew is sustainable," the House Appropriation Committee reported.[89] The Senate Appropriations Committee echoed this warning in its statement to NASA to "ensure that multiple competitors remain, but also . . . be mindful that, faced with a stagnant future budget, NASA should not take on obligations to more companies than can be practically supported." It seemed as though the robust competition envisioned by former NASA Administrator Mike Griffin was being eroded due to budget constraints.

## Blue's Decision

By entering SAAs with NASA under CCDev, Blue was consciously diverging from the guarded approach it had established early on, and bidding on CCiCap would dramatically expand that divergence. Rob Meyerson (Blue's president) noted that the new workers Blue would need to fulfill a bid for CCiCap would be, by themselves, "a company that is bigger than we are today [in 2011]."

Aside from the dislocation such dramatic growth could bring, Blue's leadership had concerns about more closely intertwining their strategy with NASA's. Working with the government risked distracting Blue's relatively small and select group of engineers and designers from their priorities, especially as more complex projects brought with them more intensive oversight. As Meyerson said, "The real challenge with working with NASA is requirements." And although Blue recognized the small but useful role NASA had played in the development of New Shepard, the influence of politics and political gamesmanship on NASA meant that close cooperation with the agency could put Blue's workflow at risk of substantial disruption. "There's a calculated risk to innovation and we can take that risk. NASA can't," said Bretton Alexander. Finally, unlike most space companies that depended on NASA for the bulk of their funding, Blue could pursue its goals based entirely (at least for the foreseeable future) on Bezos's wealth.

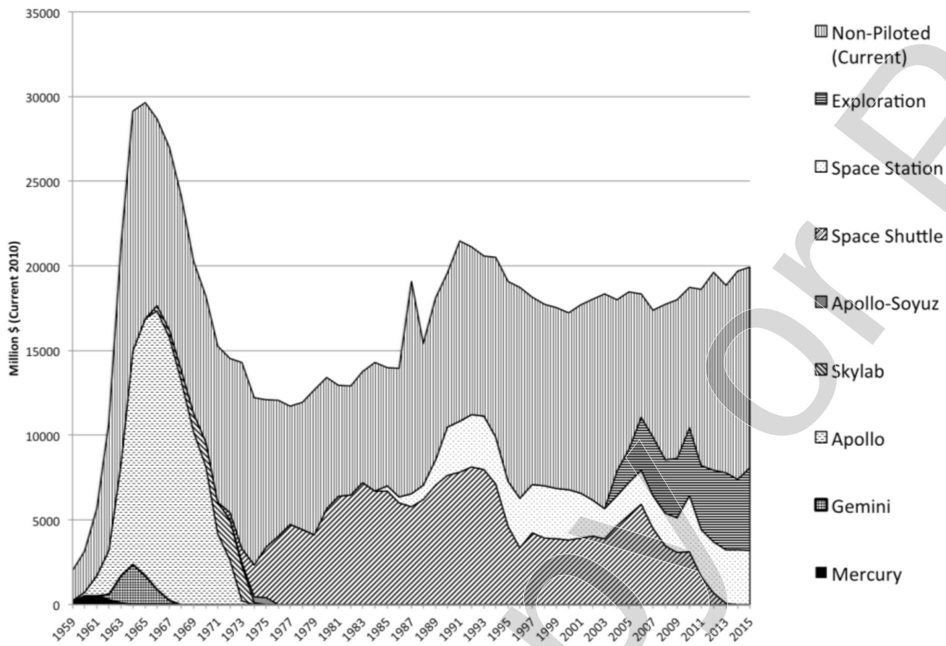
At the same time, Blue was a company filled with scientists, engineers, and businesspeople who had identified space with NASA for their entire lives and who retained deep respect for the agency and admiration for its cutting-edge work. Bezos himself embodied this view, writing:

> NASA is a national treasure, and it's total bull that anyone should be frustrated by NASA. The only reason I'm interested in space is because they inspired me when I was five years old. How many government agencies can you think of that inspire five year olds? The work NASA does is technically super-demanding and inherently risky, and they continue to do an outstanding job. The ONLY reason any of these small space companies have a chance of doing ANYTHING is because they get to stand on the shoulders of NASA's accomplishments and ingenuity.[90]

Cooperation with NASA would keep Blue at the center of the rapidly changing space sector and provide access to the unparalleled resources and talent that NASA could offer. "If crew continued to become a major focus of NASA, *not* participating would be a huge subsidization for our competitors," Alexander pointed out. Participation might also lead Blue into partnership opportunities it would otherwise miss and lines of business it would otherwise ignore. And perhaps the optimistic faith and grand designs of New Space visionaries would prove to be naive, such that the more conventional role of NASA as space companies' dominant customer would always be the case. Was it simply too risky to rely on Bezos's personal fortune as the dominant source of capital?

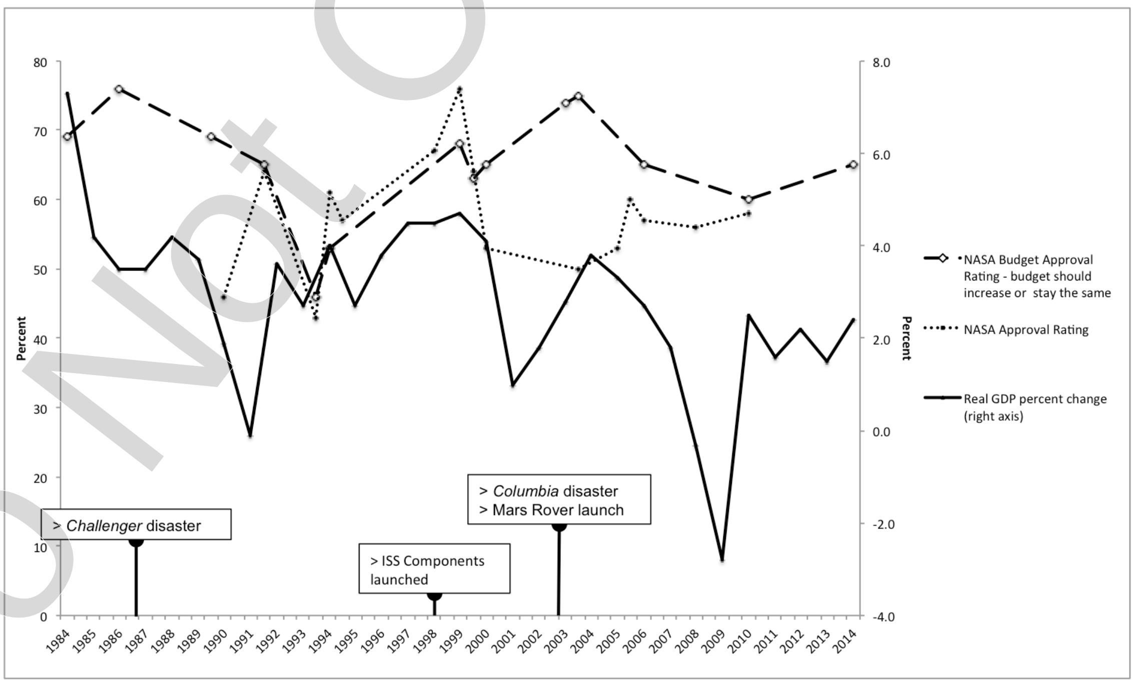
Jeff Bezos, Rob Meyerson, Bretton Alexander, and the rest of the Blue team had to decide whether to submit a proposal for CCiCap. Were the goals of CCiCap well enough aligned with Blue's objectives? Could Blue realistically step away from NASA and go it alone?

**Exhibit 1** NASA's Budget over Time, by Program



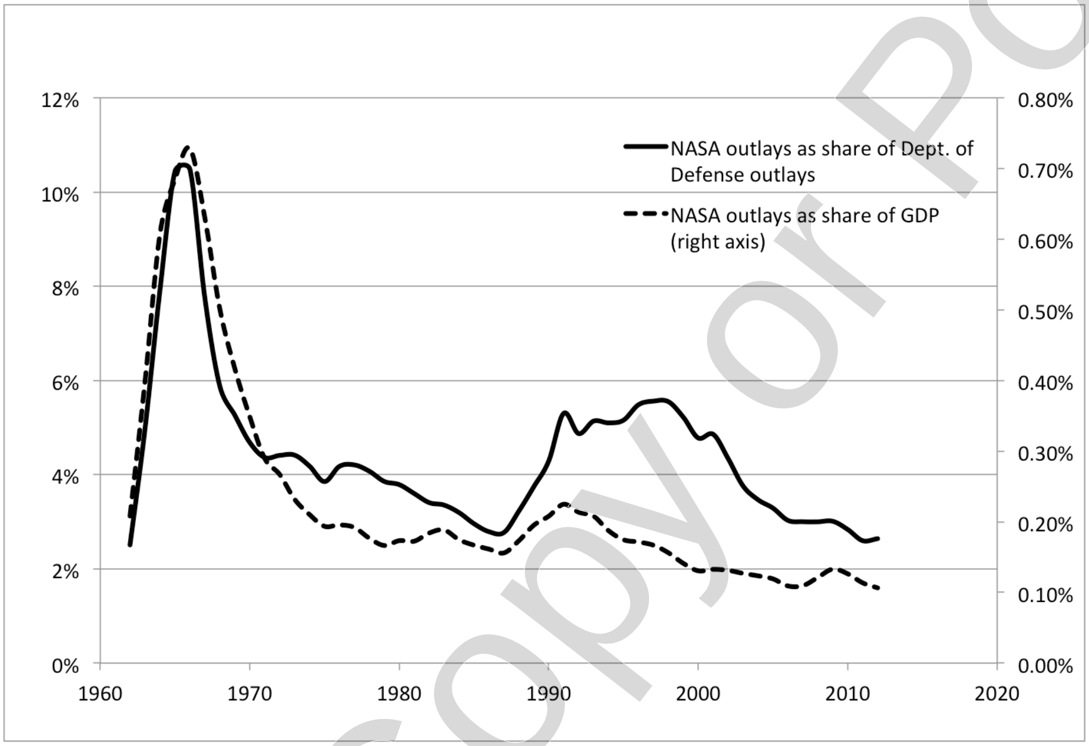

Source: Compiled from The Space Review, www.thespacereview.com, and NASA documents.

**Exhibit 2** Public Opinion on NASA over Time



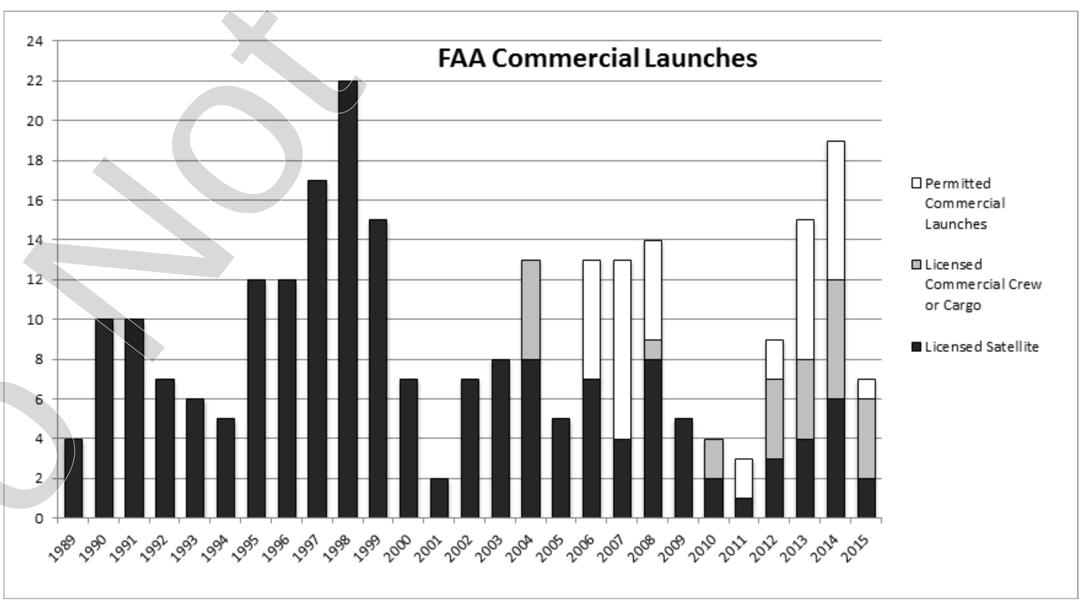

Source: Compiled from Gallup, http://www.gallup.com/poll/121736/majority-americans-say-space-program-costs-justified.aspx, and the Bureau of Economic Analysis, http://www.bea.gov/national/index.htm#gdp.

**Exhibit 3** NASA Outlays as a Share of Outlays for the Department of Defense—Military Programs and GDP




Source: Compiled from Office of Management and Budget, U.S. government, historical data and World Bank Global Development Indicators data.

**Exhibit 4a** FAA Commercial Launches




Source: FAA.

**Exhibit 4b** FAA Commercial Crew or Cargo Launches (permitted and licensed)

| Year | Payload | Vehicle | Company |
|---|---|---|---|
| **2015** | SpaceX Dragon 7 CRS-5, CRS-6, CRS-7 Spacecraft | Falcon 9 Version 1.1 (3 launches) | SpaceX |
| | No payload; Pad Abort Test | Dragon crew | SpaceX |
| | No payload | New Shepard System | Blue Origin |
| **2014** | Orion Exploration Flight Test 1 (EFT-1) reentry vehicle | Delta IV Heavy | ULA |
| | Cygnus Capsule, Orb-2 Cygnus Spacecraft | Antares Configuration 120 & 130 (3 launches) | Orbital Sciences |
| | CRS-4 Dragon 6 Capsule | Falcon 9 Version 1.1 | SpaceX |
| | Dragon | Falcon 9 | SpaceX |
| | N/A | Falcon 9-R (5 launches) | SpaceX |
| | Flight PF03 | SpaceShipTwo (2 launches) | Scaled Composites |
| **2013** | Cygnus | Antares (2 launches) | Orbital Sciences |
| | Dragon Reentry Capsule | Falcon 9 | SpaceX |
| | Scientific | STIG-B III | Armadillo Aerospace |
| | Flights PF01-PF02 | Grasshopper (5 launches) | SpaceX |
| | Flight PF02 | SpaceShipTwo (2 launches) | Scaled Composites |
| **2012** | Dragon Reentry Capsule | Falcon 9 (2 launches) | SpaceX |
| | Scientific | STIG-B (2 launches) | Armadillo Aerospace |
| | No Payload | Grasshopper (2 launches) | SpaceX |
| **2011** | N/A | PM 2 (2 launches) | Blue Origin |
| **2010** | Dragon Reentry Capsule | Falcon 9 (2 launches) | SpaceX |
| **2008** | Payload Mass Simulator | Falcon 1 | SpaceX |
| | N/A | QUAD (Pixel) | Armadillo Aerospace |
| | N/A | MOD-1 (3 launches) | Armadillo Aerospace |
| | N/A | Ignignokt | TrueZer0 |
| **2007** | N/A | MOD-1 (5 launches) | Armadillo Aerospace |
| | N/A | QUAD (Pixel) (2 launches) | Armadillo Aerospace |
| | N/A | PM 1 (2 launches) | Blue Origin |
| **2006** | N/A | PM 1 | Blue Origin |
| | N/A | QUAD (Pixel) (5 launches) | Armadillo Aerospace |
| **2004** | Flights 13P-17P | SpaceShipOne (5 launches) | Scaled Composites |

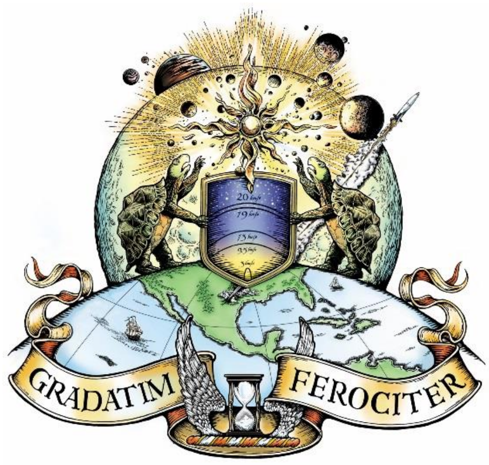
Source: Compiled from Federal Aviation Administration, "Launches," https://www.faa.gov/data_research/commercial_space_data/launches/?type=license; http://www.faa.gov/data_research/commercial_space_data/launches/?type=permitted.

**Exhibit 5** New Space Company Comparison

| Company | Year Established | Founder | Employees (2015) | Key Products |
|---|---|---|---|---|
| Bigelow Aerospace | 1999 | Robert Bigelow | 100 | Genesis II & TransHab space habitats |
| Blue Origin | 2000 | Jeff Bezos | 100 | New Shepard Launch System & Crew Capsule; BE-3 & BE-4 rocket engine |
| Scaled Composites | 1982 | Burt Rutan | 500 | SpaceShipOne spacecraft; White Knight aircraft |
| Sierra Nevada/acq. SpaceDev | 1963/2008 | John Chisholm | 3,063 | Dream Chaser spaceplane |
| SpaceX | 2002 | Elon Musk | 3,000 | Falcon 9 spacecraft; Dragon space capsule; Merlin rocket engine |
| Stratolaunch/ Vulcan Aerospace | 2011/2015 | Paul Allen, Burt Rutan | N/A | Unnamed carrier aircraft and orbital spacecraft |
| Virgin Galactic | 2004 | Richard Branson | 233 | SpaceShipTwo spacecraft; WhiteKnightTwo aircraft |

Source: Compiled from Hoover's Inc., www.hoovers.com, and Company Database and Business Alabama http://www.businessalabama.com/Business-Alabama/October-2013/Stratolaunch-Wants-to-Leapfrog-the-Launch-Pad/, accessed September 14, 2015.

**Exhibit 6** Blue Origin Coat of Arms and Feather Logo



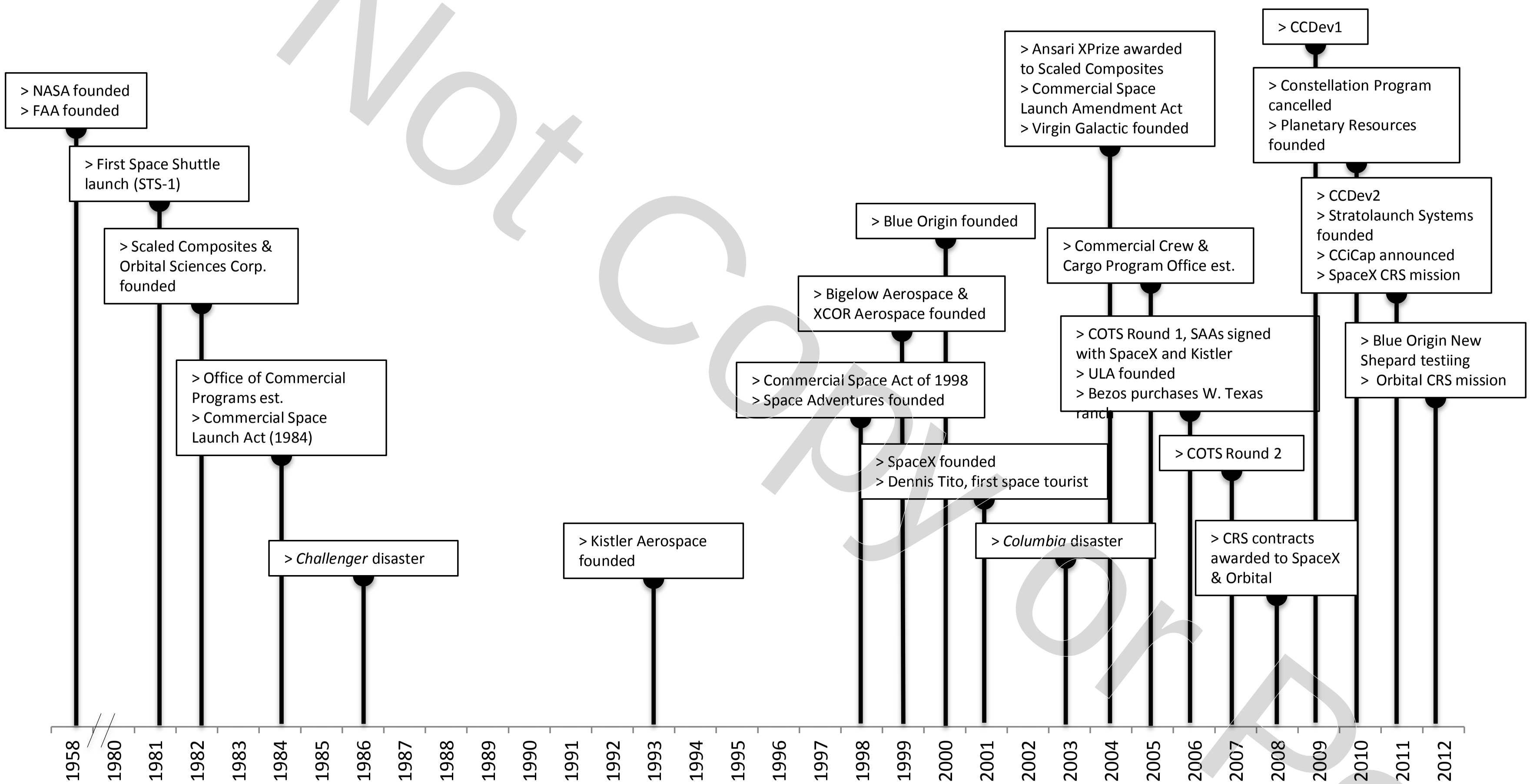

Source: Authors' interview with Ariane Cornell, Kent, WA, July 17, 2015.

Notes:
Coat of arms: The winged hourglass in the center of the banner symbolized human mortality. The two tortoises reaching for the stars alluded to the fable "The Tortoise and the Hare," wherein slow and steady wins the race. Ships sailing in the oceans paid homage to feats of exploration of the past. The Latin motto, *Gradatim Ferociter*, translated to "Step by Step, Ferociously." Feather logo: The feather symbolized the manifestation of flight on Earth, the home planet for which Blue Origin was named.

**Exhibit 7** The New Shepard Crew Capsule


Source: Blue Origin website, https://www.blueorigin.com/technology, accessed September 2015.

## Appendix A: History of Key Space Events




Source: Compiled from Chris Dubbs and Emeline Paat-Dahlstrom, *Realizing Tomorrow: The Path to Private Spaceflight* (Lincoln: Board of Regents University of Nebraska, 2011); Commercial Crew & Cargo Program Office (C3PO), "Commercial Orbital Transportation Services: A New Era in Spaceflight," NASA, 2014; and NASA Office of the Chief Technologist, "Emerging Space: The Evolving Landscape of 21st Century American Spaceflight," NASA, 2014.

## Appendix B: New Space and Legacy Space Companies

**Bigelow Aerospace** Founded in 1999 by Robert Bigelow, the billionaire founder of Budget Suites America, Bigelow Aerospace targeted the space habitats niche with flexible, inflatable modules. Bigelow initially focused on near-range goals. In 2000, Congress banned NASA from continuing R&D on its inflatable technology, Transit Habitat (TransHab). Bigelow purchased the intellectual property and incorporated it into its Genesis I and II systems, experimental space habitats. By 2006, Bigelow had invested $75 million of his personal capital to extend the company's rights to exclusive commercialization of NASA's existing expandable systems, and by 2010, he had invested a total of $180 million into technology development.[91]

In June 2007, Bigelow's own experimental space habitat, Genesis II, was launched into orbit aboard a Russian rocket for initial testing.[92] However, Bigelow had larger ultimate goals. The company proposed its own orbital spacecraft capable of supporting crew. Commercial Space Station Skywalker and the Next-Generation Commercial Space Station would consist of a number of expandable modules linked together by docking nodes and propulsion buses, to be used as private and public research labs and space tourists' "space hotels." Challenges to bringing these ambitious goals to reality stemmed from the industry's void of acceptable launch and transport systems. Bigelow was very supportive of private vehicle developers and NASA's role in the efforts. Bigelow's space stations would require 6–24 flights per year. "We will be a substantial customer of rockets and capsules and all kinds of hardware for these things," said the company's founder.[93]

**Planetary Resources** Founded in 2010 by Space Adventures cofounders Eric Anderson and Peter Diamandis, Planetary Resources had a mission different from that of many of the tourist-focused New Space companies. The company aimed to be "the asteroid mining company." Diamandis argued that "everything we hold of value on this planet—metals, minerals, energy, real estate, fuel—the things we fight wars over, are literally in near-infinite quantities in our solar system. The Earth is a crumb in a supermarket filled with resources."[94,e]

**Scaled Composites** Established in 1982 by Burt Rutan, an accomplished aerospace engineer, Scaled Composites had a history of impressive aircraft achievements. When the Ansari X Prize was announced in 2003, Rutan and the Scaled Composites team set out to develop the first privately funded spacecraft, SpaceShipOne, to win the $10 million prize. On December 17, 2003, SpaceShipOne became the first fully privately funded aircraft to achieve supersonic flight, launched on the horizontal takeoff carrier aircraft White Knight. After the launch, Paul Allen, Microsoft cofounder, announced he had been the venture's angel investor. SpaceShipOne had also been financed by Sir Richard Branson of the Virgin Group. On June 21, 2004, Scaled Composites made history when it successfully completed its second SpaceShipOne suborbital flight from the Mojave Spaceport and won the X Prize.

**Sierra Nevada** Founded in 1963, Sierra Nevada became a leader of the commercial orbital transport systems in 2008, when the company acquired the aerospace company SpaceDev and took over development of an orbital spacecraft named Dream Chaser. The Dream Chaser, a reusable spaceplane, was designed to launch vertically with an attached rocket, perform as a spacecraft once separated from its launch rocket in space, and act as an aircraft while in Earth's atmosphere, landing horizontally on conventional runways. The Dream Chaser was part of SpaceDev's unsuccessful proposal for NASA's COTS program and Sierra Nevada's successful proposal for both phases of

[e] For an in-depth study of the company, see Anette Mikes and Amram Migdal, "Planetary Resources, Inc. (A)," HBS No. 114-087 (Boston: Harvard Business School Press, 2014).

CCDev. In 2010, Sierra Nevada was awarded $20 million in Phase 1 of CCDev, and in 2011 it won an additional $80 million for Phase 2. Sierra Nevada accomplished all four milestones (program implementation plans, manufacturing readiness capability, hybrid rocket test fires, and preliminary structure design) on time during CCDev Phase 1.[95] CCDev Phase 2 milestones, which included airfoil fin testing, flight software integration, and full-scale captive carry flight tests, were also completed successfully and on time.[96]

**Space Exploration Technologies (SpaceX)** SpaceX was founded in 2002 by serial entrepreneur Elon Musk. Musk, who had also founded PayPal, Tesla Motors, and Solar City, said that his inspiration for creating SpaceX stemmed from his curiosity about why NASA had not taken the next "obvious goal after the moon" and sent a person to Mars: "I went on the NASA website and I couldn't find a date for a manned Mars mission," Musk recalled.[97] SpaceX's first strategy was to bring down launch costs by more than a factor of 10 with fully reusable rockets through novel approaches such as efficient use of materials and a cutting-edge stir friction welding process. "It's the fundamental thing that's necessary for humanity to become a spacefaring civilization. America would never have been colonized if ships weren't reusable," said Musk.[98]

SpaceX had an impressive early record. It was awarded $396 million for successful completion of all milestones in NASA's COTS program for its work on the Falcon 9 rocket launch vehicle. And while the company's proposal was not selected to receive support for Round 1 of CCDev, it was awarded $75 million in CCDev Phase 2 to develop a launch abort system for the Dragon spacecraft system. In May 2012 SpaceX launched its Falcon 9 vehicle and Dragon spacecraft, which successfully docked to the ISS and returned to Earth, becoming the first private company to undertake a NASA resupply mission.

**Stratolaunch Systems** The collaboration between Paul Allen and Burt Rutan continued with the founding of Stratolaunch Systems in 2011. The company designed a launch system to use Scaled Composite's carrier aircraft and a corresponding launch vehicle, both designed by Vulcan Aerospace, Allen's spaceflight company. Dynetics Engineering performed the mating and integration of the two components. Through its development process, Stratolaunch also partnered with other New Space companies, including SpaceX, Orbital ATK, and Sierra Nevada. The Stratolaunch carrier aircraft boasted being the largest aircraft ever to be developed, with a wingspan measuring 117 meters across, double that of a commercial Airbus A380 plane.[99]

**Virgin Galactic** In 2004 Sir Richard Branson, founder of the Virgin Group, created Virgin Galactic. Branson brought his flair for marketing to Virgin Galactic to target the blossoming space tourism industry. The company reported it could bring the cost of a tourist's flight to space down to $200,000 per seat, two orders of magnitude less than Denis Tito's flight. In 2005, Virgin Galactic and Scaled Composites announced a joint venture to manufacture SpaceShipTwo and WhiteKnightTwo, the next iterations of the Ansari X Prize–winning spacecraft designs. SpaceShipTwo could carry six paying passengers and two pilots to space, where they would experience weightlessness and view the curvature of the Earth through large windows. In 2005, the state of New Mexico offered Virgin Galactic a $225 million tax-funded launch facility, SpacePort America, which the company built over the next few years.[100]

### *Traditional Aerospace Players*

Incumbent aerospace companies that had experience as NASA contractors were intent to hold on to their lucrative positions at the center of the space sector.

In 2006, Boeing and Lockheed Martin merged their defense and space systems teams to form the joint venture United Launch Alliance (ULA). ULA took on the expendable launch systems Delta II and Delta IV from Boeing, and Atlas V from Lockheed. ULA had a virtual monopoly on government heavy launch services including weather, national security satellites, and deep space missions for scientific research. The Delta system family was also provided for nongovernment satellite launches, although Lockheed Martin retained commercial rights for the Atlas systems.

Separate from the traditional contract work Boeing developed for NASA, the company participated in the New Space sector with its CST-100 (Crew Space Transportation) crew capsule, the basis of the company's CCDev proposal. The CST-100 was designed to be compatible with the ISS and with Bigelow Aerospace's Orbital Space Complex design.

Orbital Sciences, founded in 1982 by three Harvard Business School graduates, developed and launched rocket systems for NASA, the military, and commercial partners. In February 2008, Orbital Sciences won NASA's COTS contract with its Taurus II launch vehicle and advanced maneuvering Cygnus spacecraft, beating a host of other competitors, including Boeing.

Aerojet Rocketdyne, formed by GenCorp in 2012, had roots in the U.S. space shuttle contracts. The company was the result of a merger between GenCorp's Aerojet and Rocketdyne from Pratt & Whitney, which was a descendent of Rockwell International, the main contractor for NASA's space shuttle. Aerojet Rocketdyne continued to develop high-performance rocket engines for private and government launch vehicles.

Source: Compiled from Bigelow Aerospace website, http://bigelowaerospace.com/; Anette Mikes and Amram Migdal, "Planetary Resources, Inc. (A)," HBS No 114-087 (Boston: Harvard Business School Publishing, 2014), p. 2; Chris Dubbs and Emeline Paat-Dahlstrom, *Realizing Tomorrow: The Path to Private Spaceflight* (Lincoln: Board of Regents University of Nebraska, 2011); Damon Poeter, "Check Out Paul Allen's Giant Rocket-ting Monster Plane," *PC Magazine*, February 26, 2015, http://www.pcmag.com/article2/0,2817,2477458,00.asp; Commercial Crew & Cargo Program Office (C3PO), "Commercial Orbital Transportation Services: A New Era in Spaceflight," NASA, 2014; and NASA Office of the Chief Technologist.

## Appendix C: NASA Commercial Crew and Cargo Programs

| Agreement or Contract | Year | Investment by 2014 (Million) | Commercial Partners | Scope |
|---|---|---|---|---|
| Alternate Access to Station (AAS) | 2000 | $0.902 | Andrews Space, Microcosm Inc., HMX, Inc., and Kistler Aerospace Corp. | Feasibility study of developing commercial vehicles to resupply ISS |
| ISS Commercial Cargo Services (ICCS) | 2005 | $140 | N/A | General technical requirements for purchase of launch, delivery, and earth return services for ISS cargo |
| Commercial Orbital Transportation Services (COTS) | 2006–2008 | $891 | Orbital and SpaceX | Cargo transportation system technologies and concepts |
| Commercial Resupply Services (CRS) | 2008 | $3,400 | Orbital and SpaceX | Cargo resupply services to the ISS |
| Commercial Crew Development Round 1 (CCDev1) | 2009 | $50 | Blue Origin, Boeing, Paragon, Sierra Nevada, and ULA | Crew transportation system technologies and concepts |
| Commercial Crew Development Round 2 (CCDev2) | 2010 | $315 | Blue Origin, Boeing, Sierra Nevada, and SpaceX | Elements of a crew transportation system |

Sources: Commercial Crew and Cargo Program Office (C3PO), "Commercial Orbital Transportation Services: A New Era in Spaceflight," NASA, 2014; and NASA Office of the Chief Technologist, "Emerging Space: The Evolving Landscape of 21st Century American Spaceflight," NASA, 2014.

# Appendix D: CCDev Details

## *CCDev1 Projects*

NASA noted that one of its criteria for awarding contracts was whether the company proposed realistic and tangible test and demonstration milestones within the SAA time frame. Blue, Boeing, and Sierra Nevada provided these milestones for engine test firing, hardware or system demonstrations, or material testing. Paragon, ULA, and Boeing reached out to other providers in the industry to learn where their systems would fit in to existing technology of potential service providers to demonstrate that their proposed technologies and systems would integrate well.

Boeing was chosen to continue the development of its CST-100 crew capsule that the company had unsuccessfully proposed to NASA as part of the COTS program. The selection committee noted that Boeing's experience working with NASA in previous contracts, including the space shuttle and the ISS, increased its confidence that Boeing would uphold the government's high safety standards.

Paragon proposed an environmental control and life support system (ECLSS) and was selected because its development would be critical to any crewed transportation system. Paragon included letters from four other companies that were developing commercial crew transportation systems that expressed their support of Paragon's system and their commitment to work with Paragon to develop requirements for the ECLSS.

Sierra Nevada was selected to build all systems and test a prototype of the Dream Chaser lifting body[f] crew spacecraft, which would be launched on a ULA Atlas V launch vehicle. The Dream Chaser design was unlike most other functioning lifting body concepts. Referred to as a spaceplane, the design resembled a cross between an airplane and a traditional spaceship. It would launch vertically on the Atlas V and land horizontally on traditional runways.

ULA was granted its CCDev1 funding to continue the development of the modular Emergency Detection System for its Atlas V and Delta IV launch vehicles. Multiple companies indicated their reliance on ULA's Atlas V or Delta IV vehicles as the launch vehicle for their own commercial crew transport systems. This reinforced ULA's overall development strengths and, NASA noted, highlighted the importance of continued support for further development of these vehicles.

Bigelow's proposal was rejected in part due to NASA's concern that projected development continued to rely on a single actor's financial contribution and that the management team lacked strong space systems expertise. Funding source was a factor of concern for NASA with regard to SpaceX's proposal as well. SpaceX requested significant government contribution, which NASA felt was excessive compared to the level of technology and risk mitigation activities the company would exchange, especially compared to the levels of support requested and technological development promised by other companies such as Boeing and Sierra Nevada. Although XCOR's technology looked promising, NASA's selection committee noted that it did not seem likely that its development would further accelerate commercial crew transportation within the SAA agreement based on the state of the technology at the time of selection.

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[f] A lifting body spacecraft configuration had small fixed wings, and the lifting force required for flight was produced from the fuselage, or craft's body, rather than from the wings, as was the case in traditional "flying wing" commercial aircrafts, for example. Lifting body crafts used small wings to minimize drag to achieve the high velocities required in spaceflight. The alternative spacecraft design was the non-winged capsule spacecraft.

*CCDev2*

Boeing was awarded an SAA to further develop its reusable CST-100 capsule-shaped spacecraft designs and integration systems. The capsule would have configurations for seven astronauts or equivalent cargo and crew mass, and was designed to be reusable up to 10 times and to be compatible with multiple available launch vehicles, initially to be tested with ULA's Atlas V. Noted capabilities under development included the spacecraft's Launch Abort Engine and attitude control propulsion system thruster engines. This was follow-up work from Boeing's prior developments under COTS and CCDev1 and fostered confidence from NASA in the company's ability to leverage prior experience to significantly accelerate crew transport capabilities.

Sierra Nevada proposed an extension of the Dream Chaser spaceplane development, and NASA awarded the company an SAA in part to support and learn from the development of a diverse portfolio of crew spacecraft, as the Dream Chaser used a lifting body transport system rather than a capsule design. NASA was particularly interested in the specific technical challenges and range of capabilities that were associated with lifting body configurations. In the business plan portion of its proposal, Sierra Nevada planned to partner with Virgin Galactic and use its WhiteKnightTwo carrier to launch tests of its crew transport system and to handle marketing of its commercial services, further convincing NASA that selecting to fund Sierra Nevada would have long-term benefits to the industry.

Although SpaceX was not selected in CCDev1, the company had continued work on its Falcon launch vehicle and Dragon spacecraft development nonetheless, which had begun under COTS. By 2010, SpaceX had become the first commercial actor to design and launch a spacecraft and have it return to Earth. SpaceX addressed NASA's concerns that led to its unsuccessful Phase 1 by bolstering the business plan section of its CCDev2 proposal. Combined with its risk mitigation strategy and state of development of the Falcon 9 vehicle, SpaceX was selected to enter a funded SAA with NASA to further develop the Dragon capsule's launch abort system and life support systems.

Additional optional pre-negotiated milestones were added to Boeing's and Sierra Nevada's Agreements, which increased NASA's support by $20.6 million and $25.6 million to each, respectively.

ATK was selected for an unfunded SAA to work on its Liberty Launch Vehicle, which used the company's solid rocket boosters derived from the space shuttle program. Similarly, Excalibur Almaz was selected to refurbish and upgrade its existing human spacecraft capsules with modern capabilities, including the integration of Paragon Space Development's CCDev1-funded Environmental Control and Life Support Systems. ULA was also selected for an unfunded SAA to further develop safety systems and further launch analysis for its Atlas V rocket, which NASA as well as commercial players already relied on for launch services or as part of its CCDev proposed technological systems.

Source: Compiled from Geoffrey Yoder, Selection Statement for Commercial Crew Development, NASA Selection Authority, December 8, 2009; and Philip R. McAlister, Selection Statement for Commercial Crew Development Round 2 NASA Selection Authority, April 4, 2011.

## Endnotes

[1] Joel Achenbach, "Big boost for low-profile Bezos space venture," *Washington Post*, September 18, 2014, p. A14.

[2] Jim Hu, "Geeks in Space," CNet News.com, October 6, 2004.

[3] Brad Stone, "Bezos in Space," *Newsweek,* May 5, 2003.

[4] Further details are provided by Brad Stone in *The Everything Store: Jeff Bezos and the Age of Amazon* (New York: Back Bay Books, 2013). For example, Jeff Bezos's dream to open access to space became clear at an early age. Bezos's high school valedictorian speech not only began with the *Star Trek* opening "Space, the final frontier," but described Bezos's vision of permanent colonies orbiting Earth to save humanity. Part of Bezos's tireless drive for success with Amazon, according to his biographer Brad Stone, came about because he saw such success as a way to facilitate the pursuit of his dreams for space. After Amazon's initial success, Bezos's high school girlfriend, Ursula Werner, commented that "the reason he's making so much money is to get to outer space." Amid concerns by some investors over Amazon's business model, Bezos quietly founded Blue Origin in March 2000 with the mission to establish an enduring human space presence. Blue's existence remained largely a rumor until 2003, when *Newsweek* reporter Brad Stone, working to gather information for Bezos's biography, visited the company's nondescript warehouse headquarters in Kent, Washington, an industrial suburb of Seattle, and elicited the following statement from Bezos: "It's way premature for Blue to say or comment on anything because we haven't done anything worthy of comment."

[5] NewSpace Global, "Glossary," NewSpace Global website, https://www.newspaceglobal.com/home, accessed May 28, 2015.

[6] Commercial Crew and Cargo Program Office, "Commercial Partners," NASA website http://www.nasa.gov/offices/c3po/partners/ccdev_info.html, accessed May 2015.

[7] Analysts noted similarities between this effort and the U.S. government's involvement in the expansion of the railroad industry in the nineteenth century. Dr. Roger Launius, associate director at the Smithsonian National Air and Space Museum, described the analogy in the journal *Astropolitics*: "The direct comparison of the public-private partnership that created the transcontinental railroads is the potential for government stimulation of the space launch industry. The challenge is technological in the sense that new launchers are necessary for efficient operations, just as the laying of track and the acquisition and operation of rolling stock were critical to the transcontinental carriers of the nineteenth century. The similarities include the high start-up costs associated with new, more efficient launchers, the highly regulated operational environment, and the high-risk/high-return potential of the endeavor. The question before policymakers, like Congress of 1862, is how best to 'do enough, and only enough, to induce capitalists to build' new space transportation systems." Source: Roger D. Launius, "The Railroads and the Space Program Revisited: Historical Analogues and the Stimulation of Commercial Space Operations," *Astropolitics*, 2014, p. 174.

[8] U.S. House of Representatives Committee on Science, Space and Technology, Subcommittee on Space and Aeronautics, testimony of William H. Gerstenmaier, Associate Administrator for Human Exploration and Operations, NASA, October 12, 2011.

[9] Frank Morring Jr., "The New Space Race," *Aviation Week*, April 25, 2011.

[10] Dava Newman, phone interview by authors, October 19, 2015.

[11] Space industry business manager, interview by authors, October 21, 2015.

[12] Kate Vinton, "Jeff Bezos Just Gained $7 Billion in an Hour to Become World's Fifth Richest," *Forbes*, http://www.forbes.com/sites/katevinton/2015/07/23/jeff-bezos-just-gained-7-billion-in-an-hour-to-become-worlds-fifth-richest/, accessed May 2015.

[13] NASA's predecessor, the National Advisory Committee for Aeronautics (NACA), was founded in 1915 to advise the U.S. president and coordinate research in aeronautics. During its nearly 50 years of operation, NACA helped pave the way for advanced research and development in aviation, aeronautics, and astronautics. After World War II, the Cold War between the United States and the Soviet Union stimulated NACA's development of missile warhead technology, and the so-called space race between the two superpowers began.

[14] "May 25, 1961: JFK's Moon Shot Speech to Congress," Space.com, http://www.space.com/11772-president-kennedy-historic-speech-moon-space.html, accessed September 4, 2015.

[15] John Sunyer, "The new market space," *Financial Times,* March 1, 2014.

[16] Monmouth University, "Poll: Space Travel in the 21st Century: American Public Sees Benefits But Balks at Cost," SpaceRef, February 22, 2015, http://spaceref.com/news/viewpr.html?pid=45123, accessed September 17, 2015.

[17] Benjamin Wormald, "Americans keen on space exploration, less so on paying for it," Pew Research Center, April 23, 2014, http://www.pewresearch.org/fact-tank/2014/04/23/americans-keen-on-space-exploration-less-so-on-paying-for-it/, accessed September 17, 2015.

[18] In this context, reduced funding for NASA after the *Sputnik* crisis passed was consistent with standard economic principles as well, and in particular with analysis of public goods provision. NASA provided what economists call public goods—products (goods, services, ideas, etc.) that are available to everyone without restriction and regardless of how many people consume them. Private actors have little incentive to provide public goods, as individuals have little incentive to pay for them, so governments often subsidize (or even control) their provision. But governments must fund public goods through taxes, and voters (like consumers) have the incentive to try to pass the costs of public goods provision on to others. The 1960s were the exception that proved the rule regarding public support for funding NASA. National security had long been a high priority for the United States, with its military budget hovering around 5% of GDP for the four decades following the Apollo programs. When the Soviet Union appeared to be threatening national security with its space activities in the 1960s, the free-rider problem that would plague future NASA budgets was easily overcome. But once the U.S. landed on the moon and the Soviet threat in space diminished, so too did the willingness to fund activities in space. Nearly 50 years later, the American satirical magazine *The Onion* parodied the gap between the budgets of NASA and the Department of Defense with an article saying that NASA was planning to equip an orbital telescope with torpedoes so that it could get some government funding. (See "NASA Hoping to Get In on Some Defense Funding with Plan for Torpedo-Equipped Orbital Telescope," *The Onion*, October 8, 2015, http://www.theonion.com/article/nasa-hoping-get-some-defense-funding-plan-torpedo--51499, accessed October 9, 2015).

[19] NASA, "The Shuttle," NASA website, http://www.nasa.gov/externalflash/the_shuttle/, accessed May 2015.

[20] John M. Logsdon, "Was the Space Shuttle a Mistake?," *MIT Technology Review*, July 6, 2011, http://www.technologyreview.es/printer_friendly_article.aspx?id=37981, accessed May 8, 2015.

[21] Roger Launius, "NASA's Space Shuttle and the Department of Defense," Roger Lanius's Blog, https://launiusr.wordpress.com/2012/11/12/nasas-space-shuttle-and-the-department-of-defense/, accessed October 20, 2015.

[22] In 1993 a number of setbacks for NASA—including the loss of contact with the Mars Observer and canceled shuttle missions—contributed to only 46% of poll respondents being in favor of maintaining or increasing spending on the U.S. space program. Approval of NASA as a whole reached a similarly low level. But approval for the agency recovered, hovering under 60% during the 2000s. See Jeffery M. Jones, "Majority of Americans Say Space Program Costs Justified," Gallup Poll, July 17, 2009, http://www.gallup.com/poll/121736/majority-americans-say-space-program-costs-justified.aspx, accessed September 17, 2015.

[23] With the shuttle's retirement, NASA was forced to rely on Russian Soyuz vehicles for $70 million per seat.

[24] Commercial Space Act of 1998, HR 1702, 105th Cong., *Congressional Record* 105, no. 303, daily ed. (October 28, 1998).

[25] Commercial Crew and Cargo Program Office, "Commercial Orbital Transportation Services: A New Era in Spaceflight," NASA, 2014.

[26] *Report of the President's Commission on Implementation of United States Space Exploration Policy* (Washington, DC: Government Printing Office, 2004), http://www.nasa.gov/pdf/60736main_M2M_report_small.pdf, accessed July 10, 2015.

[27] Monmouth University, "Poll: Space Travel in the 21st Century: American Public Sees Benefits But Balks at Cost," SpaceRef, February 22, 2015, http://spaceref.com/news/viewpr.html?pid=45123, accessed September 17, 2015.

[28] The name of the prize is due to the support of the Ansari family, and in particular of Anousheh Ansari, an engineer and entrepreneur who would become the first female "private astronaut."

[29] Chris Dubbs and Emeline Paat-Dahlstrom, *Realizing Tomorrow: The Path to Private Spaceflight* (Lincoln: Board of Regents University of Nebraska, 2011), p. 218.

[30] Dubbs and Paat-Dahlstrom, *Realizing Tomorrow*, p. 218.

[31] When Tito and his fellow Russian crewmates arrived at Johnson Space Center in March 2001 for cross-training requirements, they were sent home by Bob Cabana, manager of NASA's International Space office. "We will not be able to begin training

because we are not willing to train with Dennis Tito," Cabana stated. Source: Dubbs and Paat-Dahlstrom, *Realizing Tomorrow*, p. 120.

32 John Sunyer, "The new market space," *Financial Times,* March 1, 2014.

33 Stone, "Bezos in Space."

34 Alexander MacDonald, "Emerging Space: The Evolving Landscape of 21st Century American Spaceflight," NASA, 2014, p. 17.

35 Alexander MacDonald, interview by authors, October 7, 2015.

36 Jim Cantrell, "Old Space Meets New Space," *Spacenews,* October 19, 2015. http://spacenews.com/op-ed-old-space-meets-new-space/, accessed October 21, 2015.

37 Andrew Chaikin, "Is SpaceX Changing the Rocket Equation?," *Air&Space Magazine*, January 2012, http://www.airspacemag.com/space/is-spacex-changing-the-rocket-equation-132285884/?no-ist, accessed October 15, 2015.

38 Kenneth Chang, "SpaceX's Next Frontier: Landing a Rocket on Earth," *New York Times,* January 4, 2015, http://www.nytimes.com/2015/01/05/science/space/next-frontier-for-spacex-and-elon-musk-landing-a-rocket-on-earth.html?_r=0, accessed October 21, 2015.

39 Though the space shuttle was reusable, the rockets that launched it were in practice not recoverable. Moreover, the shuttle itself required costly refurbishing after each flight. "Reusability: The key to making human life multi-planetary," SpaceX, June 10, 2015, http://www.spacex.com/news/2013/03/31/reusability-key-making-human-life-multi-planetary, accessed October 21, 2015.

40 The Tauri Group, "Commercial Human Spaceflight," *Suborbital Reusable Vehicles: A 10-Year Forecast of Market Demand Report*, 2012, pp. 28–29, http://www.faa.gov/about/office_org/headquarters_offices/ast/media/Suborbital_Reusable_Vehicles_Report_Full.pdf, accessed August 3, 2015. Note that spaceflights were used for marketing purposes as well: between 2008 and 2012, 26 suborbital flights had been given away in contests or promotions, with millions of entries worldwide, revealing widespread public enthusiasm for space tourism.

41 Olivier Abtan et al., "Shock of the New Chic: Dealing with New Complexity in the Business of Luxury," Boston Consulting Group Report, January 2014.

42 NASA, "Public-Private Partnerships for Space Capability Development: Driving Economic Growth and NASA's Mission," NASA Report, April 2014.

43 Reid Wilson, "NASA Looks to Uncertain Future," *National Journal,* July 7, 2011.

44 Stone, *The Everything Store,* p. 154.

45 Karma Allen, "Elon Musk Promises SpaceX Will Stay the Course for Mars," NBC News, June 17, 2014, http://www.nbcnews.com/science/space/elon-musk-promises-spacex-will-stay-course-mars-n133971, accessed November 5, 2015.

46 Joanna Rothkopf, "Stephen Hawking's dire warning: humanity won't last another 1000 years on earth," *Salon*, April 27, 2015, http://www.salon.com/2015/04/27/stephen_hawkings_dire_warning_humanity_wont_last_another_1000_years_on_earth/, accessed October 18, 2015.

47 Bretton Alexander, as quoted in *ISPCS 2014 – Spotlight on Bretton Alexander*, International Symposium for Personal and Commercial Spaceflight, 2014.

48 After his purchase of land in West Texas, Bezos interviewed with Larry Simpson, a reporter for a local Texas newspaper. Simpson commented: "[Bezos is] so closemouthed that it's almost frustrating . . . but ultimately, his thing is space colonization." Source: Michael Graczyk, "Amazon.com founder's space venture has West Texas county abuzz," Associated Press, March 12, 2005.

49 Blue Origin, "Our Approach to Technology," Blue Origin website, https://www.blueorigin.com/technology, accessed September 10, 2015.

50 "Working at Blue Origin," Blue Origin website, https://www.blueorigin.com/careers, accessed September 28, 2015.

[51] Calla Cofield, "Secrets, Sci-Fi & Uncertainty: Jeff Bezos and the Future of Private Spaceflight," Space.com, October 7, 2015, http://www.space.com/30767-jeff-bezos-blue-origin-spaceflight-goals.html, accessed October 9, 2015.

[52] Frank Morring, "True Blue," *Aviation Week*, December 9, 2013.

[53] Federal Aviation Administration, "Commercial Space Data: Launches," FAA website, https://www.faa.gov/data_research/commercial_space_data/launches/?type=Permitted, accessed September 11, 2015.

[54] Jeff Foust, "Blue Origin has a bad day (and so do some of the media)," *NewSpace Journal,* September 2, 2011.

[55] NASA, "NASA Commercial Crew Partner Blue Origin Test-Fires New Rocket Engine," NASA website, December 3, 2013, https://www.nasa.gov/press/2013/december/nasa-commercial-crew-partner-blue-origin-test-fires-new-rocket-engine/#.VfLScnv893M, accessed September 11, 2015.

[56] Blue Origin, "Our Approach to Technology."

[57] NASA, "Blue Origin Test-Fires New Rocket Engine," NASA website, December 3, 2013, https://www.nasa.gov/content/blue-origin-test-fires-new-rocket-engine/#.Vg6Ufnv893M, accessed September 7, 2015.

[58] Blue Origin, "Blue Origin Conducts Successful Pad Escape Test," Blue Origin website, October 22, 2012, https://www.blueorigin.com/news/news/blue-origin-conducts-successful-pad-escape-test, accessed September 10, 2015.

[59] Eligar Sadeh, "Public Private Partnerships and the Development of Space Launch Systems in the Unites States," *Astropolitics*, 2015, p. 101.

[60] A second set of regulatory reforms in the 2004 Space Act was also valuable to New Space companies. The Commercial Space Launch Act (CSLA) of 1984 was the first dedicated set of regulations governing commercial space activity. However, the CSLA had set prohibitive licensing and specification barriers to entities interested in launching space vehicles or operating a launch site in the U.S. With increased commercial success, highly publicized by the Ansari X Prize, Congress recognized the need to revise the CSLA, and used the 2004 Space Act to minimize previous restrictions. The 2004 Space Act allowed experimental permits granted by the Federal Aviation Administration (FAA) for reusable launch vehicle R&D from commercial ventures. The law positioned the government to focus on protecting the uninvolved public and required licensed commercial operators to assume financial liability for associated risks and either purchase high-cost insurance for space activities or otherwise demonstrate enough financial capital to cover third-party damages up to the Maximum Probable Loss (MPL) determined by the FAA. The government would cover any accident damage above the MPL. Source: Tim Fernholz, "What It Took for SpaceX to Become a Serious Space Company," *Atlantic,* October 21, 2014.

[61] Administrator Griffin elaborated on his intentions for the program: "[The companies] would only capture our money if they achieved milestones of interest to us. We would not be involved in reviewing the designs or the development practices of the companies involved. They would have to bring the product to market in their own way, in their own time, by their own means, according to their own standards. . . . We NASA, we the government, would only buy those things if we found them suitable. Our money would never be in ahead of the product development. They would first have to develop whatever they were developing, then they would have to demonstrate it, and then they would get the payment." Source: Michael D. Griffin, NASA Johnson Space Center Oral History Project, interview by Rebecca Wright, January 12, 2013, http://www.jsc.nasa.gov/history/oral_histories/C3PO/GriffinMD/GriffinMD_1-12-13.htm, accessed September 15, 2015.

[62] U.S. Senate Committee on Commerce, Science and Transportation, Subcommittee on Science, Space, and Competitiveness, testimony of Eric Stallmer, president, Commercial Spaceflight Federation, February 24, 2015.

[63] As is typical in the space sector, proposed schedules were aggressive and NASA anticipated delays, explained NASA manager Alan Lindenmoyer, so that missed deadlines did not automatically terminate an SAA as long as acceptable advances had been made. If a milestone were missed, NASA would evaluate the cause and determine if continued efforts were aligned with the government's objectives. Source: Alan Lindenmoyer, "Commercial Orbital Transportation Services, Appendix: COTS Model for NASA Public-Private Partnerships," NASA Commercial Crew & Cargo Program Office, April 18, 2010.

[64] Jeff Foust, "A vision for commercialization," *Space Review*, July 25, 2005.

[65] Commercial Crew and Cargo Program Office, NASA website, http://www.nasa.gov/offices/c3po/about/c3po.html, accessed May 2015.

[66] Griffin, NASA Johnson Space Center Oral History Project, interview by Wright.

[67] Griffin, NASA Johnson Space Center Oral History Project, interview by Wright.

[68] Commercial Crew and Cargo Program Office, "Commercial Orbital Transportation Services," p. 58. The figures are taken from an interview with C3PO director Alan Lindenmoyer, as cited in that document's note 266.

[69] Commercial Crew and Cargo Program Office, "Commercial Orbital Transportation Services," p. 76.

[70] "Orbital ATK Company Overview," Orbital ATK website, https://www.orbitalatk.com/about/company-overview/, accessed October 2, 2015.

[71] Fernholz, "What It Took for SpaceX to Become a Serious Space Company."

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