The Future of American Aerospace

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Introduction

For very nearly the entirety of human space exploration, the United States has led the way.

The general outline of the story is taught to children across the country every year. The Soviet Union's successful launch of the first satellite in 1957, and first man in space in 1961, crystalized an urgency in America to develop a world-class space program. The country initiated the Apollo program in 1961 and succeeded in putting the first humans on the Moon by the end of the decade.

While the legacy of the Apollo program will forever be defined by the triumphant success of its mission, it was also highly inefficient and monumentally expensive. One of the absurdities of the period is that in order to beat the Soviet Union to the Moon, the U.S. was "devoting more than 4 percent of government spending to a 400,000-worker planned economy entirely run by government officials."[1] Between 1960 and 1973, the U.S. spent $28 billion on the Apollo program, which represents $280.6 billion today after adjusting for inflation.[2]

The Apollo program established a procurement model that was used by the National Aeronautics and Space Administration (NASA) for decades thereafter. Agency administrators would determine what was needed for a given mission and specify the parameters to be followed. NASA would then award a contract to a firm to build the component, and in the end, the agency would own and operate the system. Contracts were typically cost-plus, meaning the government was on the hook for any overruns, and only a few companies were involved in the bidding process.

Over time, this system resulted in stagnation. The sector was dominated for decades by a handful of entrenched firms, enabled by institutional biases and preferentially written contracts. The end result was too often delays, inflated prices, and a lack of innovation.

This period is best embodied by the Space Shuttle program. When it began in 1972, the shuttle was envisioned as a cheap platform that would provide regular access to space – perhaps as frequently as once per week – with each flight costing as little as $20 million.[3] The reality turned out to be decidedly less cost-effective. Upon its retirement in July 2011, the Space Shuttle had flown 134 missions, averaging $1.6 billion per launch, with total costs rising to $209 billion.[4]

Clearly a new direction was necessary. The solution to achieve the revitalization of U.S. space exploration had for many years been obvious: increased competition. The idea had been around at least since the President Reagan's Private Sector Survey on Cost Control report, better known as the Grace Commission. The commission's recommendations included an increase in private

[1] "America, China and the race to the Moon," *The Economist*, July 17, 2021, https://www.economist.com/international/2021/07/17/america-china-and-the-race-to-the-moon.
[2] "Project Apollo Cost Data," The Planetary Society, https://docs.google.com/spreadsheets/d/e/2PACX-1vTKMekJW9F8Z3fWnx-IxvHSPD35iZxZxDVoqIp25FaxxXjOqJ2Rk-zS858dND0N_3cwcacbIX8gr9xt/pubhtml.
[3] Mike Wall, "NASA's Shuttle Program Cost $209 Billion – Was it Worth It?" *Space.com*, July 5, 2011, https://www.space.com/12166-space-shuttle-program-cost-promises-209-billion.html.
[4] Ibid.

participation in the commercial uses of space and a shift in responsibility to private industry for launch vehicles.

Fortunately, the last decade has seen such a shift in strategy at NASA. The agency began to team with private sector companies, including entrants with limited experience, to develop exciting new launch technologies. Indeed, private sector investments and intelligent government acquisition strategies have created a new innovative era of American aerospace that not only benefits NASA, but also taxpayers and consumers.

While its policies and procedures were stagnant for several decades, NASA deserves full credit for the remarkable reimagining of its role in developing new technologies. Partnerships between the agency and private aerospace firms have established a successful model for all future space programs, setting the stage for a new era of exploration and commercialization.

A New Model: The Commercial Orbital Transportation (COTS) Program

The strategy of shifting to a partnership with private sector firms cropped up when NASA considered how to replace the Space Shuttle. Its retirement meant a new vehicle was required to deliver cargo to the International Space Station (ISS). Rather than outlaying massive expenditures funding a direct replacement, the agency instead empowered private industry to provide a solution.

The COTS program was a noteworthy departure from preceding NASA procurement programs. Rather than hiring a company to build a spacecraft that would ultimately be owned and operated by the agency, the vessels developed under COTS were owned and largely financed by private sector firms.[5] Instead of operating the rockets directly, NASA would identify necessary missions it wished to fulfill and contract with the companies that developed technology under COTS to complete the task.

In 2006, NASA signed its first agreements with SpaceX and Rocketplane Kistler, the latter being replaced by Orbital Sciences in 2008 due to a lack of private sector investment. Orbital Sciences later merged with another firm to become Orbital ATK and was acquired by Northrop Grumman.

It did not take long for the COTS program to produce results. Less than a year after the retirement of the Space Shuttle, SpaceX's Dragon became the first commercial provider to resupply the ISS.[6] In November 2020, the company became the first private sector operator to carry astronauts to the space station.[7] Orbital ATK would also carry out successful ISS resupply missions. Both companies have since developed innovative technologies that will help to carry

[5] Louis de Gouyon Matignon, "The Commercial Orbital Transportation Services Program," *Space Legal Issues*, June 2, 2019, https://www.spacelegalissues.com/the-commercial-orbital-transportation-services-program/.
[6] Elizabeth Howell, "SpaceX's Dragon: First Private Spacecraft to Reach the Space Station," *Space.com*, August 10, 2020, https://www.space.com/18852-spacex-dragon.html.
[7] Amy Thompson, "SpaceX Dragon launches 4 astronauts to space station in 1st operational flight for NASA," *Space.com*, November 15, 2020, https://www.space.com/spacex-crew-1-astronaut-nasa-launch-success.

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American aerospace into the future, while also serving NASA's mission objectives in the interim, thus validating the COTS strategy.

For an investment of $788 million, NASA stood up two viable launch vehicles and two cargo vessels, providing the impetus for the creation of new companies that would go on to serve the agency in the future.[8] Remarkably, the NASA funding was outweighed by the firms. COTS supplied $425 million for Orbital Sciences and the company invested $590 million. Similarly, COTS awarded SpaceX $396 million, compared to $454 million spent by the company.

The beauty of COTS was that it recognized the potential for innovation among private sector firms. Following decades of undertaking contracts that effectively kept spaceflight within the realm of NASA, COTS paved the way for today's boom in commercial aerospace. It did not dictate the specifications of vehicles but instead utilized fixed-priced contracts and goal-based payment schedules. By requiring participating companies to pay a portion of the development costs, it incentivized firms to develop products that would become commercially viable.

In 2011, NASA used a similar structure when it created the Commercial Crew Program (CCP), which produced some of the space capsules now used to transport astronauts to the ISS. NASA has since estimated that private sector investments saved taxpayers between $20 and $30 billion.[9]

NASA's success in this area speaks for itself. Empowering private sector firms to develop innovative solutions not only provides a blueprint for future NASA procurement but also serves as a model for government-wide federal acquisition policies.

Groundbreaking Innovations

New firms producing innovative technologies have been a game-changer for satellite launches, resupply missions to the ISS, and the U.S. space program more broadly. A hallmark of these companies has been a willingness to experiment in an effort to drive down costs. Entrepreneurial initiatives have enabled them to outcompete entrenched firms on both cost and reliability.

Traditional launch technology relied on expendable components, where all stages of launch systems were single-use and destroyed upon reentry. Blue Origin and SpaceX created the technology needed to design reusable components. After launch, the first stages of the rockets transport themselves back to a pre-coordinated landing spot to be used again.

The dramatic reduction in cost made possible by this technology represents an existential threat to the incumbents that long thrived under the status quo. In response to the new competition, the United Launch Alliance (ULA), a conglomerate formed between Boeing and Lockheed Martin, slashed costs. ULA reduced the price of a mission using its Atlas V from $225 million per

[8] National Aeronautics and Space Administration, "Commercial Orbital Transportation Services: A New Era in Spaceflight," February 2014, p. 100, https://www.nasa.gov/sites/default/files/files/SP-2014-617.pdf.
[9] Michael Sheetz, "NASA estimates having SpaceX and Boeing build spacecraft for astronauts saved $20 to $30 billion," CNBC.com, May 13, 2020, https://www.cnbc.com/2020/05/13/nasa-estimates-having-spacex-and-boeing-build-spacecraft-for-astronauts-saved-up-to-30-billion.html.

launch to just over $100 million.[10] SpaceX charges $62 million for a new Falcon 9 launch, and $50 million for a refurbished one.

SpaceX's Starship, a heavy-launch rocket set to be the most powerful in operation since the Apollo program's Saturn V, might one day operate even more economically. Starship could end up costing less than $2 million per launch, and is designed to be fully reusable.[11] Falcon 9's first stage can be relaunched, but the second stage is single-use.

Barriers to Entry

Despite the emphasis on the private sector under COTS, barriers to entry in the competition for the National Security Space Launch (NSSL) program delayed the incorporation of new entrants into the market and a full realization of their benefits.

The NSSL program is charged with contracting out the delivery of satellites into orbit for the country's security agencies. The certification process for participation in the program is notoriously onerous and favors proven technology provided by legacy contractors, regardless of cost. In April 2014, SpaceX brought a lawsuit against the Air Force to open access to the bidding process for NSSL launches. On January 23, 2015, the company dropped its lawsuit when the service allowed SpaceX to bid, and provided an expedited certification process for them to do so.[12] SpaceX was ultimately certified in July 2015.

New firms should not be forced to sue in order to gain access to contracting solicitations. Unfortunately, SpaceX's experience reflects a larger problem in government contracting, which still has far too many barriers to entry blocking nontraditional firms from bidding.

New Firms Dominating Competition

Once allowed access, nontraditional firms have won a high percentage of contracts for national security launches, ISS resupply missions, and funding for future NASA exploration programs. They have also provided improved reliability and an excellent value for taxpayers.

National Security Launches

NSSL launches, as well as its predecessor program, the Evolved Expendable Launch Vehicle initiative, were dominated by Boeing and Lockheed Martin, the only two companies that originally competed.[13] They effectively closed the NSSL market after combining to form the ULA.

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[10] Emre Kelly, "Atlas V rocket set for launch today; ULA CEO says prices lower than expected," *Florida Today*, November 4, 2020, https://www.floridatoday.com/story/tech/science/space/2020/11/04/ula-ceo-our-rocket-launch-prices-even-lower-than-expected-florida/6135231002/.

[11] "SpaceX, a Tesla for the skies," *The Economist*, May 15, 2021, https://www.economist.com/business/2021/05/13/spacex-a-tesla-for-the-skies.

[12] "Elon Musk's SpaceX drops lawsuit against the Air Force," The Associated Press, January 24, 2015, https://apnews.com/article/4617be04c82e47e8a110abe1b37b3e8e.

[13] Congressional Research Service, "Defense Primer: National Security Space Launch," updated December 30, 2020, https://sgp.fas.org/crs/natsec/IF11531.pdf.

However, the ULA's continued viability was cast into doubt following U.S. sanctions placed on Russia in 2014 as a result of the country's military action against Ukraine. The ULA's Atlas V vehicle was reliant on Russian-made RD-180 heavy-lift engines, and the fiscal year (FY) 2017 National Defense Authorization Act limited the ULA to 18 engines through FY 2022.[14] As a result, the ULA needed to develop an alternative launch vehicle. The objective of the legislation was to maintain the ULA's capacity to launch satellites until a domestic replacement could be fielded.

The latest round of NSSL procurement selected winners from a large pool of participants, a good sign for the future of American aerospace. The first phase of the NSSL competition awarded the ULA $967 million, Northrop Grumman $792 million, and Blue Origin $500 million to develop launch systems.[15] SpaceX did not receive initial funding, likely because it's technology was at a more mature state. On August 7, 2020, the Space and Missile Systems Center announced that SpaceX and ULA were selected to launch approximately 34 satellites into orbit for the National Reconnaissance Office and the Space Force between 2022 and 2027.[16]

However, the phase two award split between the ULA and SpaceX is inequitable. ULA will be responsible for 60 percent of the launches, with SpaceX covering the rest. The ULA was awarded $337 million for two FY 2022 launches, while SpaceX received $316 million for its launch.

According to Air Force Assistant Secretary for Acquisition, Technology, and Logistics William Roper, the latest NSSL competition marks "a new epoch of space launch that will finally transition the Department off Russian RD-180 engines."[17] However, if the Department of Defense was concerned with preventing Russia from benefitting from the NSSL program, it might have selected one of the other participants in the bidding process to combine with SpaceX for the launches, or awarded the company the entire contract.

In the meantime, the future participation of the ULA in the NSSL program is uncertain due to delays in its Vulcan Centaur expendable rocket, which uses Blue Origin BE-4 engines, and is the in-house replacement for the Atlas V.[18] Originally projected to fly in 2021, the ULA is now replacing Vulcan-powered NSSL contracted flights with Atlas Vs, thus nullifying the intended effect of ceasing the reliance on Russian-made engines.

New competitors like Blue Origin, Relativity Space, and Rocket Lab may participate in bidding for NSSL's phase 3 launches, which might include contracts for orbital transfer services

[14] Sydney J. Freedberg, Jr., "McCain Compromises on RD-180s: Are Rocket Wars Over?" *BreakingDefense.com,* June 14, 2016, https://breakingdefense.com/2016/06/mccain-compromises-on-rd-180s-in-ndaa-are-russian-rocket-wars-finally-over/.
[15] Amy Thompson, "Pentagon picks SpaceX, ULA to launch national security missions," *Space.com,* August 10, 2020, https://www.space.com/pentagon-picks-spacex-ula-national-security-launches.html.
[16] Valerie Insinna, "After a hard-fought competition, ULA and SpaceX to remain military's rocket launch providers," *DefenseNews.com,* August 7, 2020, https://www.defensenews.com/space/2020/08/07/after-a-hard-fought-competition-ula-and-spacex-to-remain-militarys-rocket-launch-providers/.
[17] Nathan Strout, "SpaceX and ULA win massive national security launch contracts," *C4isrnet.com,* August 7, 2020, https://www.c4isrnet.com/battlefield-tech/space/2020/08/07/spacex-and-ula-win-massive-national-security-launch-contracts/.
[18] Sandra Erwin, "National security launch in transition as Space Force waits for Vulcan," *SpaceNews.com,* August 19, 2021, https://spacenews.com/national-security-launch-in-transition-as-space-force-waits-for-vulcan/.

involving the alteration of existing satellite orbits.[19] In order to drive down costs, Space Force officials should ensure that the host of new companies developing orbital transfer vehicles have full access to NSSL phase 3 bidding.

Missions to the ISS

The commercial space industry reached several critical milestones in the past few years. On May 30, 2020, SpaceX successfully launched American astronauts from U.S. soil for the first time since the retirement of the Space Shuttle in 2011. The mission, named Demo-2, transported two NASA astronauts in SpaceX's Crew Dragon capsule for a tour of duty on the ISS. It was the final test prior to NASA certifying SpaceX for regular service to the ISS. A little less than a year later, on April 23, 2021, NASA for the first time sanctioned SpaceX to operate a previously used rocket to transport astronauts to the station, a crucial milestone along the path of reducing the cost of operations in space.[20]

NASA had previously been relying on the Russian Soyuz program to deliver astronauts to the space station. At $55 million per astronaut, SpaceX costs 36 percent less than the $86 million charged by Russia.[21]

Over the next decade, astronauts will be transported to the ISS under NASA's CCP, which awarded contracts to both Boeing and SpaceX. However, a November 14, 2019, NASA Office of Inspector General (OIG) report found that the latter company provided service at a far cheaper rate. According to the report, NASA will pay Boeing $90 million per astronaut for a ride to the ISS, 64 percent more than SpaceX, and $4 million more than it was paying to Russia.[22]

This reflects a disparity in the total value of the CCP contracts awarded to the companies. The OIG estimated Boeing's contract to be worth $4.3 billion, while SpaceX will be paid $2.5 billion for the same service. Boeing's funding included $2.2 billion for technology development and test flights, $1 billion more than SpaceX.

In the meantime, in addition to providing a cheaper service, SpaceX has proven more reliable than Boeing. During its December 20, 2019 maiden launch to the ISS, Boeing's Starliner crew capsule was unable to dock.[23] On February 6, 2020, a NASA safety review panel found that Boeing averted a "catastrophic failure" that was unrelated to its failure to dock.[24] A second

[19] Ibid.
[20] Christian Davenport, "SpaceX launches NASA's Crew-2 to orbit, its third human space flight in less than a year," *The Washington Post*, April 23, 2021, https://www.washingtonpost.com/technology/2021/04/23/spacex-launches-nasas-crew-2-orbit-its-third-human-spaceflight-less-than-year/.
[21] Michael Sheetz, "Everything you need to know about SpaceX's historic Demo-2 launch, its first with NASA astronauts," CNBC.com, May 26, 2020, https://www.cnbc.com/2020/05/26/spacex-demo-2-nasa-astronaut-launch-everything-you-need-to-know.html.
[22] National Aeronautics and Space Administration Office of Inspector General, "NASA's Management of Crew Transportation to the International Space Station," November 14, 2019, p. 11, https://oig.nasa.gov/docs/IG-20-005.pdf.
[23] Brendan Byrne, "In Uncrewed Test, Boeing's Starliner Capsule Fails to Reach Space Station," National Public Radio, December 20, 2019, https://www.npr.org/2019/12/20/790098677/in-uncrewed-test-boeings-starliner-capsule-fails-to-reach-space-station.
[24] "Boeing's botched Starliner test flirted with 'catastrophic' failure, NASA finds," Reuters, February 7, 2020, https://www.cbc.ca/news/science/boeing-starliner-nasa-review-1.5406311.

attempt on August 4, 2021 was scrubbed after 13 propulsion valves failed to open during preflight testing.[25] All further launches of Starliner have been delayed until at least early 2022.[26]

Before transporting astronauts to the ISS under the CCP, Boeing must first demonstrate the technology using an un-crewed Starliner vessel. Until this occurs, NASA will be limited to one participant in the CCP.

SpaceX is also involved in the second form of ISS resupply missions, the Commercial Resupply Services program (CRS), which is the unmanned version of the CCP. Along with Orbital ATK, the company has been servicing the ISS through CRS missions since 2012.

Artemis

On December 11, 2017, then-President Trump signed Space Policy Directive 1, a plan to return U.S. astronauts to the Moon for the first time since Apollo 17 in 1972. The initiative was later rebranded Artemis, and the crewed lunar mission was moved up from 2028 to 2024. Artemis was also meant to one day facilitate sending astronauts to Mars.

Artemis is built upon several NASA components that had been in development for years. These include the Space Launch System (SLS), the primary launch vehicle, the Orion capsule, designed to house astronauts during the trip from Earth to lunar orbit, the Commercial Lunar Payload Services program, which will send various scientific payloads like robotic landers to the targeted landing site, and the Lunar Gateway, a space station in lunar orbit designed to support the landing by providing communications or potentially serving as a stopover for astronauts en route to the Moon.

The Human Landing System (HLS) program was also created as a part of Artemis. This element is designed to transport astronauts from the Orion capsule or Lunar Gateway to the surface of the Moon and back again. In April 2020, NASA provided funding to three companies to develop HLS modules over the course of approximately 10 months, after which it would make a final decision.[27] Blue Origin, partnering with Lockheed Martin and Northrup Grumman, thought at the time to be the furthest along, received $579 million. Dynetics, a subsidiary of Leidos, received $253 million to work on an HLS system in conjunction with Sierra Nevada Corp. SpaceX, which put forward its Starship vessel, received $135 million.

Boeing submitted a bid but was not selected by NASA. It later surfaced that NASA Associate Administrator Doug Loverro tipped off a senior Boeing employee that the company was not

[25] Christian Davenport, "13 valves failed to open on Boeing's Starliner spacecraft, a more widespread problem than previously reported," *The Washington Post*, August 9, 2021, https://www.washingtonpost.com/technology/2021/08/09/boeing-starliner-launch-delay-valves/.
[26] Edward Moyer, "Boeing Starliner test flight to ISS pushed back to 2022," CNET.com, October 9, 2021, https://www.cnet.com/news/boeing-starliner-test-flight-to-iss-pushed-back-to-2022/.
[27] Christian Davenport, "Jeff Bezos and Elon Musk win contracts for spacecraft to land NASA astronauts on the moon," *The Washington Post*, April 30, 2020, https://www.washingtonpost.com/technology/2020/04/30/jeff-bezos-elon-musk-win-contracts-spacecraft-land-nasa-astronauts-moon/.

going to be picked, which caused Boeing to resubmit its bid.[28] The scandal was investigated by the NASA OIG and the Justice Department, resulting in Loverro's resignation and Boeing agreeing to an independent review of the company's ethical practices.

On April 16, 2021, NASA picked SpaceX to develop the HLS, awarding the company $2.9 billion.[29] The selection of just one company was unexpected as it went against the original plan of funding two companies in order to foster competition and ensure a viable backup. While budget limitations contributed to the decision (SpaceX submitted the lowest bid, halving what Blue Origin would have charged), it also represented an indication of trust in SpaceX to develop a viable HLS. Blue Origin would later challenge the decision in both the courtroom and through the Government Accountability Office, but both complaints were dismissed.[30]

Unfortunately, the viability of the Artemis timeline has been called into question because of delays and cost overruns in several areas, including new spacesuits. Existing spacesuits "…have exceeded their design life by more than 25 years, necessitating costly maintenance to ensure astronaut safety."[31] They also do not accommodate different body shapes; the first all-female spacewalk outside the ISS was cancelled because the existing suit was too large.

An August 10, 2021 NASA OIG report updated its review of NASA's work on next-generation spacesuit technology, which began in 2007. After spending nearly $200 million over nine years, NASA created a new program for Exploration Extravehicular Mobility Units in 2017, after which it spent another $220 million, for a total of $420 million. The OIG reported that these spacesuits, which are designed for the ISS and the Artemis mission, will not be ready until 2025.[32] The combination of interruptions stemming from the COVID-19 pandemic, funding gaps, and technical challenges have been part of the delay, but in the end, the program will produce just two spacesuits and cost more than $1 billion. A November 15, 2021 NASA OIG report found that delays associated with developing new spacesuits and the legal challenges to the HLS contract means NASA "will exceed its current timetable for landing humans on the Moon in late 2024 by several years."[33]

The OIG report also noted that "NASA lacks a comprehensive and accurate cost estimate that accounts for all Artemis program costs."[34] Spending on Artemis over 13 years extending to FY 2025 will reach $93 billion, with each launch of the SLS and Orion capsule costing $4.1 billion.

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[28] Joey Roulette, "Exclusive: Boeing to face independent ethics probe over lunar lander bid – document," Reuters, September 9, 2020, https://www.reuters.com/article/us-space-exploration-boeing-exclusive/exclusive-boeing-to-face-independent-ethics-probe-over-lunar-lander-bid-document-idUSKBN2603F2.
[29] Christian Davenport, "Elon Musk's SpaceX wins contract to develop spacecraft to land NASA astronauts on the moon," *The Washington Post,* April 16, 2021, https://www.washingtonpost.com/technology/2021/04/16/nasa-lunar-lander-contract-spacex/.
[30] Christian Davenport, "Federal judge rules against Jeff Bezos's Blue Origin in lunar lander suit, allowing NASA to proceed with Elon Musk's SpaceX," *The Washington Post,* November 4, 2021, https://www.washingtonpost.com/technology/2021/11/04/blue-origin-nasa-spacex-lawsuit/?utm_source=alert&utm_medium=email&utm_campaign=wp_news_alert_revere&location=alert&wpmk=1&wpisrc=al_technology__alert-economy--alert-tech&pwapi_token=eyJ0eXAiOiJ.
[31] Ibid.
[32] National Aeronautics and Space Administration Office of Inspector General, "NASA's Development of Next-Generation Spacesuits," August 10, 2021, p. 3, https://oig.nasa.gov/docs/IG-21-025.pdf.
[33] National Aeronautics and Space Administration Office of Inspector General, "NASA's Management of the Artemis Mission," November 15, 2021, p. 12, https://oig.nasa.gov/docs/IG-22-003.pdf.
[34] Ibid., p. 19.

The report identified the key drivers for the high cost, including the issuance of "sole-source, cost-plus contracts; the inability to definitize key contract terms in a timely manner; and the fact that except for the Orion capsule, its subsystems, and the supporting launch facilities, all components are expendable and 'single use' unlike emerging commercial space flight systems."[35] Perhaps most damningly, the OIG reported that, "[B]y failing to develop an official cost estimate that includes all relevant costs, NASA is underreporting the true funding requirements for a long-term Artemis program."[36] The agency will therefore "face significant challenges to sustaining its Artemis program in its current configuration."[37]

Struggles of the SLS

The SLS has routinely been a cause for concern regarding the ultimate viability of Artemis. A March 10, 2020 NASA OIG report blamed both Boeing, the prime contractor, and NASA for lax oversight that led to poor performance and spiraling costs in the program. Every main component of the rocket designed for the first Artemis test "experienced technical challenges, performance issues, and requirement changes that collectively have resulted in $2 billion of cost overruns and increases and at least 2 years of schedule delays."[38]

Unfortunately, this is only the beginning of the ever-inflating price of the SLS. In 2014, NASA estimated that Artemis 1 – the maiden launch of the SLS and Orion capsule – would cost $10.2 billion. As of December 2019, the price had reached $14.8 billion. The OIG report projected a number of cost increases that would be incurred should the SLS fail to meet a series of launch deadlines, all of which were subsequently missed. The delay of the November 2020 launch to Spring 2021, more than two years after the first proposed launch date, further increased costs to $18.3 billion.

Artemis 1 has since been delayed yet again, this time until February 12, 2022. All of this will have knock-on effects for subsequent stages of the program. According to the OIG report, if the Artemis 2 launch date is postponed until 2023 (now a near certainty; the new projected launch date is May 2024), program costs would balloon to $22.8 billion. The total costs for the SLS and Orion programs will reach $50 billion by 2024, and this figure will rise steadily as subsequent tests of the SLS are shunted further along in the decade.

In March 2021, NASA initiated a cost study analyzing the affordability of the SLS.[39] This reaction was possibly a bit tardy as the agency has spent $20 billion to develop the vehicle and ground systems.

The current poor performance of the SLS might have been foreseen given its inauspicious beginning. The George W. Bush administration's Constellation program directed NASA to build a new heavy-lift rocket, the Ares V, to facilitate a return to the Moon and eventual Martian

[35] Ibid., "Results in Brief," p. 2.
[36] Ibid. p. 20.
[37] Ibid., "Results in Brief," p. 2.
[38] National Aeronautics and Space Administration Office of Inspector General, "NASA's Management of Space Launch System Program Costs and Contracts," March 10, 2020, p. 4, https://oig.nasa.gov/docs/IG-20-012.pdf.
[39] Eric Berger, "NASA has begun a study of the SLS rocket's affordability," ARSTechnica.com, March 15, 2021, https://arstechnica.com/science/2021/03/nasa-has-begun-a-study-of-the-sls-rockets-affordability/.

exploration. The Orion capsule was also created and funded by this proposal. After five years of extraordinary cost growth and deficient performance, Constellation was cancelled by then-President Obama effective in FY 2011.

However, four senators, each with a significant NASA presence in their states, managed to save the Ares V (renamed the SLS), and Orion. Sen. Richard Shelby (R-Ala.), former senators Kay Bailey Hutchison (R-Texas) and Barbara Mikulski (D-Md.), and former senator and now NASA Administrator Bill Nelson (D-Fla.) succeeded in securing funding for the rocket and capsule, and even directed the SLS design to be based upon legacy hardware used in the Space Shuttle program.[40] The strong backing over the years by legislators in the upper chamber of Congress earned the SLS a new moniker, the "Senate Launch System."

The SLS's state of limbo has been characterized by former NASA Deputy Administrator Lori Garver as "a rocket that has been looking for a mission."[41]

As is often the case with expensive procurement programs that lack a defined purpose, the wide disbursement of jobs across the country helps ensure continued congressional support. According to NASA, the SLS supports around 25,000 jobs across 43 states, generating an impact of $4.7 billion.[42]

There is a stark contrast between the SLS, based on Space Shuttle hardware designed in the 1970s, and the technology developed over the past decade by new rocket firms. As noted by the NASA OIG, only one component of the SLS, the Orion capsule, is reusable.

The remarkable rise of new aerospace companies has led some to suggest that the SLS and Orion capsule might be replaced by a private sector alternative. During a November 9, 2021 press event, NASA Administrator Nelson was asked about the potential for Starship to substitute for the SLS. He responded, "Let me just point out right now there's only one rocket that's capable of doing this, and this is SLS and Orion on top. And that's stacked as we speak, and it's going to launch next February. So, we're going with what we got. And if anybody comes up with another alternative, we're glad to look at any other alternative."[43]

Viable alternatives may soon exist. SpaceX is designing Starship to launch, refuel in Earth orbit, and then fly to the Moon or Mars before returning to Earth. Starship has already undergone a series of tests, with the next, an orbital launch, awaiting approval by the Federal Aviation Administration.[44] It will likely fly in early 2022, with perhaps as many as 11 more tests to follow in the same year.

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[40] Christian Davenport and Joel Achenbach, "NASA rocket becomes Boeing's latest headache as Trump demands moon mission," *The Washington Post*, March 22, 2019, https://www.washingtonpost.com/technology/2019/03/22/nasa-rocket-becomes-boeings-latest-headache-trump-demands-moon-mission/.
[41] Ibid.
[42] National Aeronautics and Space Administration, "Marshall Economic Impact," https://www.nasa.gov/sites/default/files/atoms/files/g-150680_fy15_msfc_econ_impact_flyer.pdf.
[43] Eric Berger, "NASA delays Moon landings, says Blue Origin legal tactics partly to blame," ARSTechnica.com, November 9, 2021, https://arstechnica.com/science/2021/11/nasa-delays-moon-landings-says-blue-origin-legal-tactics-partly-to-blame/.
[44] Michael Sheetz, "Elon Musk says SpaceX will 'hopefully' launch first orbital Starship flight in January," CNBC.com, November 17, 2021, https://www.cnbc.com/2021/11/17/elon-musk-spacex-will-hopefully-launch-starship-flight-in-january.html.

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The incorporation of Starship would significantly reduce the cost of the Artemis mission. According to a March 15, 2021 *Ars Technica* article, Starship "could potentially out-lift the SLS rocket, be reusable, and cost a fraction of the price. If SpaceX succeeds in getting Starship into orbit, there would be little technical justification for continuing government subsidization of the less capable SLS booster, which is expendable and costs much, much more."[45] In addition, the New Glenn, Blue Origin's heavy-launch vehicle under development, is currently scheduled for its maiden launch in the final quarter of 2022.[46]

That might also be a suitable time to fundamentally rethink the Artemis program. Given the poor state of affairs in the SLS program, NASA must consider a substitution should superior alternatives arise.

Development of New Business Models

Private firms have developed a host of new business ventures made possible by impressive technological innovations that have drastically reduced the cost of launches. In short order, such costs have been reduced from hundreds of millions per launch to $50 million charged by SpaceX. The company anticipates that the cost of launching Starship may end up below $2 million.

While the size of payloads differ, Relativity Space is set to launch the first 3D-printed rocket in 2022, which will cost $12 million to launch.[47] Rocket Lab's model will be even cheaper at $5.7 million per launch.[48] Low-cost launches have sparked a virtuous cycle, leading to an increase in satellites in orbit and thus cheaper satellites as economies of scale take root.

Satellite Internet

The rise of cheaper access to space has several companies planning to improve on an old idea: providing internet service via satellite. Many companies have tried and failed to provide satellite internet to regions of the globe that are underserved or unserved by current internet service providers. Billions were spent by Globalstar, Iridium, and Teledesic, among others before they all went belly up. These efforts were hampered by the significant cost of launches.

Now that launch costs have significantly declined, several companies believe they can succeed where their predecessors failed. Legacy providers rely on fewer satellites in geostationary orbit, far from Earth.[49] However, the great distances between the satellites and users mean high latency. New business models involve peppering the sky with thousands of low Earth orbit

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[45] Ibid., Berger, "NASA has begun a study of the SLS rocket's affordability."
[46] Blue Origin, "New Glenn's Progress Towards Maiden Flight," https://www.blueorigin.com/news/new-glenns-progress-towards-maiden-flight.
[47] Michael Sheetz, "Relativity Space unveils a reusable, 3D-printed rocket to compete with SpaceX's Falcon 9," CNBC.com, February 25, 2021, https://www.cnbc.com/2021/02/25/relativitys-reusable-terran-rocket-competitor-to-spacexs-falcon-9.html.
[48] Guy Gugliotta, "Small Rockets Aim for a Big Market," *Air and Space Magazine*, April 2018, https://www.airspacemag.com/as-next/milestone-180968351/#:~:text=Rocket%20Lab%20will%20charge%20a,hundreds%20of%20thousands%20of%20dollars.
[49] Chris Velazco, "The latest space race is all about improving Internet access. Here's what you should know," *The Washington Post*, November 2, 2021, https://www.washingtonpost.com/technology/2021/11/02/satellite-internet-starlink-kuiper-faq/.

(LEO) satellites, which operate between 500 to 2,000 kilometers from Earth, thus improving transmission speeds.

Among providers following this model, SpaceX's Starlink service leads the way with 90,000 customers. It has thus far launched close to 2,000 LEO satellites, and plans to reach 10,000.[50] To place this number in context, the number of Starlink satellites currently in operation account for 25 percent of all satellites in orbit.[51] Blue Origin intends to launch 3,236 LEO satellites supporting its foray into the market, named Kuiper.[52] Other companies, like Omnispace, OneWeb, and Telesat, are planning similar systems.

With approximately four billion people worldwide lacking internet service, the potential market is vast. Satellites "offer to connect unserved populations in rural and remote areas with high-speed connectivity and provide competition for broadband services in places that have never experienced any."[53] They are among several technologies, including cable, fiber, mobile broadband, TV white space, wireless, and wireline communications, that can also "bring improved access to broadband to rural areas of the country that would otherwise be left behind due to distance or topography."[54]

Space Tourism

While seven "space tourists" paid for rides to the ISS on the Russian Soyuz vessel between 2001 and 2009, in 2021, three companies took the first step to exponentially broaden the access and ability of paying customers to experience space travel. In 2022, more individuals may pay to go to space than those launched on government-funded space vehicles.[55]

Virgin Galactic kicked things off on July 11, 2021, when its founder Richard Branson along with three employees reached a suborbital altitude of 53.5 miles above the surface of the Earth.[56] On July 20, 2021, Blue Origin founder Jeff Bezos and three other passengers traveled to 66.5 miles above the Earth on board the New Shepard.[57] The rocket took off again on October 13, 2021, with a crew of four, including actor William Shatner, who became the oldest person to go to space.[58] In between the two Blue Origin flights, on September 18, 2021, four individuals

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[50] Christian Davenport, "Elon Musk is dominating the space race. Jeff Bezos is trying to fight back," *The Washington Post*, September 10, 2021, https://www.washingtonpost.com/technology/2021/09/10/musk-bezos-space-rivalry/.
[51] Ibid, "SpaceX, a Tesla for the skies."
[52] Michael Sheetz, "Amazon plans to launch its first internet satellites in late 2022," CNBC.com, November 1, 2021, https://www.cnbc.com/2021/11/01/amazons-project-kuiper-launching-first-internet-satellites-in-q4-2022.html.
[53] Citizens Against Government Waste, "CAGW Joins Coalition Letter to FCC on 12 GHz Spectrum," November 17, 2020, https://www.cagw.org/legislative-affairs/letters-officials/cagw-joins-coalition-letter-fcc-12-ghz-spectrum.
[54] Citizens Against Government Waste, "CAGW Files Additional Comments on Use of 12 GHZ Spectrum Band," June 11, 2021, https://www.cagw.org/legislative-affairs/agency-comments/cagw-files-additional-comments-use-12-ghz-spectrum-band.
[55] "What next? 22 emerging technologies to watch in 2022," *The Economist,* November 8, 2021, https://www.economist.com/the-world-ahead/2021/11/08/what-next-22-emerging-technologies-to-watch-in-2022.
[56] Kenneth Chang, "Branson Completes Virgin Galactic Flight, Aiming to Open Up Space Tourism," *The New York Times,* July 11, 2021, https://www.nytimes.com/2021/07/11/science/richard-branson-virgin-galactic-space.html.
[57] Christian Davenport and Dalvin Brown, "Jeff Bezos, Mark Bezos, Wally Funk and Oliver Daemen reach space, return safely on Blue Origin's New Shepard rocket," *The Washington Post*, July 20, 2021, https://www.washingtonpost.com/technology/2021/07/20/bezos-space-flight-live-updates-video/.
[58] Michael Sheetz, "Jeff Bezos' Blue Origin successfully launches crew with William Shatner to space and back," CNBC.com, October 13, 2021, https://www.cnbc.com/2021/10/13/watch-william-shatner-go-to-space-with-jeff-bezos-blue-origin.html.

returned from a 72-hour orbital trip via SpaceX's Falcon 9 rocket and Crew Dragon capsule.[59] And on December 12, 2021, the New Shepard took off again with six passengers, including National Football League Hall of Famer and ABC's "Good Morning America" host Michael Strahan.[60] SpaceX has five more launches planned, and one individual has booked a trip around the Moon on the Starship vehicle. Blue Origin has booked approximately $100 million in sales on future commercial flights.

Regular spaceflight for tourists underscores the dramatic development in technology achieved by the new guard of rocketry firms, and others are piling in. While space tourism is limited to those with the ability to pay the sizeable ticket price, a competitive and growing market exists. Estimates vary widely, but a March 17, 2019 UBS study estimated that space tourism will be worth $3 billion by 2030.[61]

Point-to-point service might prove even more profitable. Should rocketry firms begin to compete with long-distance airlines (SpaceX claims that Starship could one day carry 100 passengers between New York and Shanghai in 39 minutes, as opposed to the current 15 hours by plane), existing long haul passenger flights "would be cannibalized." Under this scenario, the value of that industry might reach $20 billion annually.[62]

Private Sector Space Stations

The first ISS modules were launched in 1998 and were intended to last for 15 years. With replacement parts and upgrades, the station could continue to operate until 2028, but the time has arrived for NASA to consider the best manner in which to replace the activities carried out on the ISS.

Similar to other areas of aerospace, a private sector model offers the best path forward. Given the considerable amount of funding required to build and maintain the ISS over the past 23 years (NASA footed the majority of the $150 billion needed to construct the ISS and pays an additional $4 billion per year in maintenance costs), shifting NASA's role from owner to paid user will result in substantial savings.

Happily, NASA appears to have learned a valuable lesson from COTS. In March 2021, the agency established the Commercial Low Earth Orbit Destinations (CLD) project, which aims to provide $400 million to as many as four companies to develop private space stations.[63] NASA intends to award a second CLD contract to one or two of the most promising platforms in 2025. Beyond the immediate savings achieved by forgoing the construction of an ISS replacement,

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[59] Jackie Wattles, "SpaceX just brought the first all-tourist crew back from space. Here's what's next." CNNBusiness.com, September 20, 2021, https://www.cnn.com/2021/09/20/tech/spacex-inspiration4-space-tourism-whats-next-scn/index.html.
[60] Isabel Vincent, "Former NFL star Michael Strahan says outer space trip 'unreal,'" *New York Post*, December 11, 2021, https://nypost.com/2021/12/11/former-nfl-star-michael-strahan-heads-to-outer-space/.
[61] Michael Sheetz, "Super fast travel using outer space could be $20 billion market, disrupting airlines, UBS predicts," CNBC.com, March 18, 2019, https://www.cnbc.com/2019/03/18/ubs-space-travel-and-space-tourism-a-23-billion-business-in-a-decade.html.
[62] Ibid.
[63] Michael Sheetz, "NASA wants companies to develop and build new space stations, with up to $400 million up for grabs," CNBC.com, March 27, 2021, https://www.cnbc.com/2021/03/27/nasa-commercial-leo-destinations-project-for-private-space-stations.html.

paying private companies to host astronauts or conduct experiments might save NASA up to $1.5 billion annually.[64]

According to Phil McAlister, who oversees the CLD for NASA, "I think now is the right time to start moving away from the International Space Station, which is really just a government monopoly on space destinations, and moving them over to the private sector."[65] Since the ISS takes up nearly 20 percent of its annual budget, NASA views the privatization of space stations as crucial to freeing up the agency to focus on deep space exploration.

About a dozen companies submitted proposals for CLD funding, which indicates significant private sector interest.[66] NASA has stated that commercialization of access to space stations should allow private companies to operate sustainably without relying on government contracts.[67] Potentially lucrative markets exist, including hosting astronauts and space tourists and conducting pharmaceutical and biotechnological research under microgravity conditions.

A variety of plans for private sector stations are in the works. Blue Origin and Sierra Space are developing a station that would be constructed out of inflatable bladders. Lockheed Martin and Nanoracks have envisioned one that would be manufactured by stitching together discarded upper stage rockets in orbit.

NASA already awarded a $140 million contract in 2020 to Axiom Space to build four modules connected to the ISS that will detach once the station is decommissioned.[68] On December 2, 2021, NASA announced a CLD contract award of $415.6 million: $160 million to Nanoracks, $130 million to Blue Origin, and $125.6 million to Northrop Grumman.[69] Streamlined efficiency more readily achievable in the private sector and cheaper components mean that the new space station could cost approximately one-hundredth of the amount paid by taxpayers to build the ISS.

Conclusion

The reliance on legacy contractors to design and manufacturer systems that NASA would own and operate is a notion that should be retired. The chief argument for the old model, and the old guard of aerospace, had long been reliability. However, the success of the next generation of aerospace firms means this justification no longer holds water. Innovative technologies have paired dramatic cost reductions with increased launch capacity, safety, and reliability. This combination has vastly improved commercial prospects in space and promises to deliver more cost-effective and efficient results for taxpayers and NASA's missions of exploration.

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[64] "Private space stations will soon be in orbit," *The Economist*, October 30, 2021, https://www.economist.com/science-and-technology/private-space-stations-will-soon-be-in-orbit/21805944.
[65] Daniel Oberhaus, "What Comes After the International Space Station?" *Wired*, October 27, 2020, https://www.wired.com/story/what-comes-after-the-international-space-station/.
[66] Michael Sheetz, "NASA reviews private space station proposals, expects to save over $1 billion annually after ISS retires," CNBC.com, September 20, 2021, https://www.cnbc.com/2021/09/20/nasa-evaluating-private-space-station-proposals-for-iss-replacement.html.
[67] Ibid., "Private space stations will soon be in orbit."
[68] Ibid., Sheetz, "NASA reviews private space station proposals, expects to save over $1 billion annually after ISS retires."
[69] Michael Sheetz, "NASA Awards Blue Origin, Northrop Grumman, and Nanoracks with contracts to build private space stations," CNBC.com, December 2, 2021, https://www.cnbc.com/2021/12/02/nasa-private-space-station-contracts-blue-origin-nanoracks-northrop.html.

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The innovations that resulted in substantial cost reductions and increased potential would not have been possible under the closed market that was previously dominated by incumbent firms. For future missions, NASA can now simply contract with commercial aerospace firms to utilize existing technology rather than undertaking lengthy and expensive development and acquisition programs. It follows suit that unlike previous agreements where the government paid most of the development costs, these companies should be allowed to maintain control over their intellectual property and equipment.

Private firms operating under contract with the federal government have formed the new backbone of space commercialization and exploration. The technologies developed in the past decade mean that the next decade will provide more cost-effective access to space and far greater potential for exploration.

The smashing success and inclusion of new firms in all areas of aerospace contracting represents a rare procurement triumph for the federal government. Through COTS and similar programs, NASA seeded the development of the current breakaway success in American aerospace. The private-sector model has proven its worth, and should be relied upon not just at NASA, but across all federal agencies, when pursuing future ventures.