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Introduction

The period spanning the late 1980s to the early 1990s was a particularly difficult era for spaceflight in the United States. After the tragic Challenger disaster in 1986 and the Titan rocket launch failures quickly thereafter, all military launches were halted for almost a year.[1] The fall of the Soviet Union in 1991 led to a decline in the U.S. defense budget, which included military program consolidations. There was also a growing concern that the commercial space launch market could shift away from the United States. The United States needed a new launch vehicle that could provide assured access to space for the military and stay cost competitive over time. The National Space Transportation Policy (NSTC-4)[2], signed by President Bill Clinton, designated the Department of Defense as the lead agency for the "improvement and evolution of the current expendable launch vehicle fleet," which led to the creation of the Evolved Expendable Launch Vehicle (EELV) program.

This report explores how the United States came to depend on the Russian RD-180 rocket engine as part of the EELV program, realistic options for the engine's replacement in the coming decade, and potential space launch acquisition strategies for the future. The first section provides an overview of the history of the development and evolution of EELV, including the early origins of both the RD-180 and the EELV program, as well as the EELV acquisition strategy, the creation of the United Launch Alliance, and the entry of other private competitors to the launch market. The second section discusses the more recent controversy over the RD-180 in the United States Congress after Russia's annexation of Crimea in 2014, including recent efforts to cap the number of Russian engines that companies within the U.S. can acquire. The third section describes five options to transition from the RD-180 that could be implemented within several years. These options include the oft-cited "drop-in replacement" option, using new engines on new launch systems, and using currently available alternative launch vehicles. The last section discusses planning for the future of space launch acquisition. This discussion includes: challenges to the current strategy, the major considerations in developing a renewed acquisition strategy, and a few specific examples of what a new national security space launch acquisition strategy could look like.

While the details for how and when the RD-180 will be replaced are not yet settled, the consensus within the U.S. Congress and executive branch remains that the United States must end its reliance on the RD-180. This report explains the impetus for finding an alternative engine, explores the options that are available going forward, and describes the challenges that will placed upon the federal government and the private sector in doing so.

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[1] Lee Hutchinson, "Rocket's red glare: Five spectacular (but harmless) US space launch failures", Ars Technica, July 4, 2013, https://arstechnica.com/science/2013/07/rockets-red-glare-five-spectacular-but-harmless-us-space-launch-failures/.

[2] The White House, "National Space Transportation Policy (NSTC-4)," U.S. Air Force, Washington D.C., August 1994, http://www.au.af.mil/au/awc/awcgate/nstc4.htm.

1. Background

Origins of the RD-180 and the EELV Program

To address changing market conditions and launch needs in the early 1990s, the White House issued several national space policy directives concerning development of new government and commercial launch services. The February 1991 U.S. Commercial Space Policy Guidelines advocated for a competitive international space market that would promote trade, private investment, and market development.[3] Moreover, in July 1991 the National Space Launch Strategy (NSLS) directed DoD and NASA to work jointly on a new launch system to replace the expensive Atlas, Delta, and Titan launch vehicles. The strategy required this new system to reduce operating costs, increase system reliability, improve launch capacity, and be reliable enough for human spaceflight. Since this new launch system could have commercial benefits, the NSLS also directed agencies to explore private sector participation.[4]

In 1993, Congress directed the Department of Defense, through the National Defense Authorization Act for Fiscal Year 1994, to "develop a plan that establishes and clearly defines priorities, goals, and milestones regarding modernization of space launch capabilities for the Department of Defense or, if appropriate, for the government as a whole."[5] A year later, DoD completed the Space Launch Modernization Plan, which became known as the Moorman Study, named after its lead author: then Lt. Gen. Thomas S. Moorman, vice commander of Air Force Space Command. The Moorman Study proposed four potential options for modernizing U.S. space launch capabilities: continue using existing launch systems, upgrade current expendable launch systems, acquire new expendable launch systems, or develop new reusable launch systems. After exploring each of these four options and creating roadmaps to achieve these capabilities, the Moorman study team developed fifteen findings and recommendations. In particular, it recommended that the United States needed to explore innovative and foreign-sourced technologies,[6] and partner with industry where appropriate, to develop a program that achieves maximum payoff with limited dollars.[7] In August of that same year, President Clinton signed the National Space Transportation Policy (NSTC-4), which directed the Department of Defense to lead the development and implementation of a

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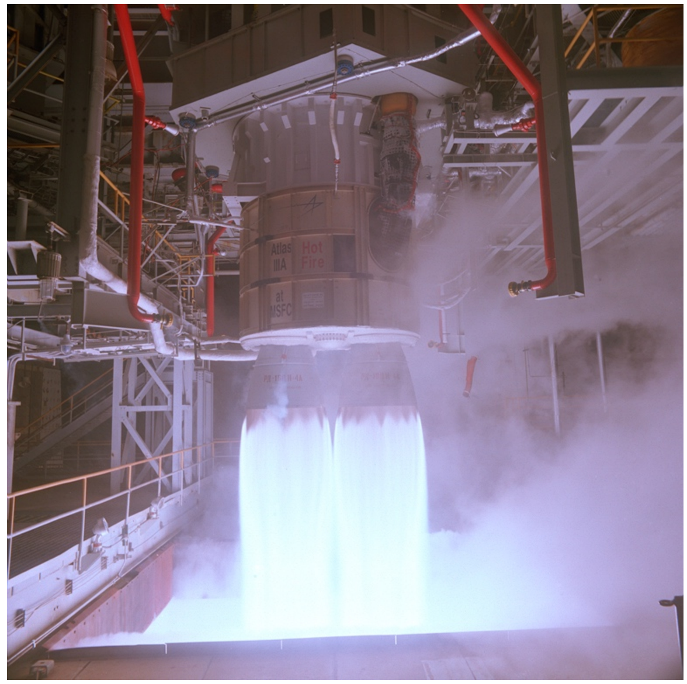
[3] The White House, *U.S. Commercial Space Policy Guidelines*, U.S. Air Force, NSPD-3, February 11, 1991, http://www.au.af.mil/au/awc/awcgate/nspd3.htm.
[4] The White House, *National Space Launch Strategy*, U.S. Air Force, NSPD-4, July 1991, http://www.au.af.mil/au/awc/awcgate/nspd4.htm.
[5] U.S. Congress, "National Defense Authorization Act for Fiscal Year 1994," H.R. 2401 – 103rd Congress, Washington D.C., November 1993, https://www.govtrack.us/congress/bills/103/hr2401/text.
[6] The Moorman Study recommended evaluating Russian engine technologies to find cost savings. The study concluded that the prime candidate was the NPO Energomash's RD-170 engine.
[7] Thomas S. Moorman, Jr., *Space Launch Modernization Plan*, Department of Defense, Washington, D.C., April 1994, http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA332884.

new expendable launch vehicle program, which later became known as the Evolved Expendable Launch Vehicle (EELV) program, and to maintain the Titan IV heavy expendable launch system until a suitable replacement became available, as recommended by the Moorman study.[8]

Figure 1: RD-180 During Test-fire.



Source: NASA

In parallel to these developments, the Space Systems Division of General Dynamics began exploring upgrades to its Atlas II light-to-medium launch vehicle. These upgrades were intended to reduce costs and increase the lift capacity of the Atlas II to make it more competitive in a changing global marketplace. Internal discussion recommended contracting with Russian rocket engine producer NPO Energomash to create a new variant of a liquid fueled engine based on the existing four-chamber RD-170 rocket engine. This new two-chamber engine, essentially half of an RD-170, became known as the RD-180.[9]

Using a Russian rocket engine on a U.S. launch vehicle was feasible, and even desirable, because of the easing of tensions that followed the dissolution of the Soviet Union. U.S. policies and regulations were relaxed in the early 1990s in order to capitalize on foreign technologies that could advance or develop next generation U.S. space systems and help keep Russian rocket scientists gainfully employed so they would not proliferate missile technology to rogue nations.[10]

Cooperation between American and Russian corporations was coordinated through a 1993 trade agreement between the United States and Russia that specifically encouraged cooperation between the two nations in the space launch market.[11] In 1994, General Dynamics signed an agreement with NPO Energomash to develop the RD-180 engine for a

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[8] The White House, "National Space Transportation Policy (NSTC-4)."
[9]Jerry Grey, "We Do Need Russian Rockets, for a While Longer," *SpaceNews*, December 23, 2015, http://spacenews.com/op-ed-we-do-need-russian-rockets-for-a-while-longer/.
[10] The White House, "National Space Transportation Policy (NSTC-4)."
Broad, William. "Russian Rockets Get Lift in U.S. From Cautious and Clever Design." *The New York Times*, October 29, 1996. http://www.nytimes.com/1996/10/29/science/russian-rockets-get-lift-in-us-from-cautious-and-clever-design.html.
[11] Office of the United States Trade Representative, *Guidelines for U.S. Implementation of the Agreement Between the U.S. and Russian Federation Government Regarding International Trade in Commercial Space Launch Services*, Government Publishing Office, September 2, 1993, http://www.gpo.gov/fdsys/pkg/FR-1994-03-10/html/94-5498.htm.

new Atlas launch vehicle.[12] Martin Marietta bought the Space Systems Division of General Dynamics in 1994[13] and merged with Lockheed in 1995 to become the Lockheed Martin Corporation.[14] The new company continued the plan to upgrade the Atlas and reduce launch costs as part of its positioning for the EELV program through private investment.[15] Lockheed Martin put out a request for engines for the new Atlas II variant and received three responses: the NPO Energomash RD-180, the NK-Engines Aerojet-sponsored NK-33, and an updated Rocketdyne MA-5A. Lockheed Martin ultimately selected the RD-180 in January 1996,[16] and in 1997 Pratt & Whitney partnered with NPO Energomash to obtain exclusive rights to sell and produce the RD-180 in the United States under the company RD-Amross.[17] Lockheed Martin reported that its decision to use the RD-180 in the EELV system saved approximately $1 billion and five to six years in development costs.[18]

A 1995 DoD policy memorandum required any former Soviet technology used in launch vehicles for DoD national security missions to be manufactured in the U.S. within four years of the start of the Engineering and Manufacturing Development (EMD) phase of the program.[19] This memo explicitly included propulsion systems, and the Pratt & Whitney agreement with NPO Energomash to form RD-Amross complied with this by planning to create an RD-180 production line in the United States by 1998.[20]

Acquisition Strategy for the EELV Program

DoD released a request for proposal (RFP) in May 1995 for the EELV program, and both Lockheed Martin and Boeing[21] were selected in December 1996 to continue with pre-engineering and development studies. One of the key goals of the EELV program was to

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[12] Tim Furniss, "GD signs up for Russian power," *Flight International*, (April 1994), 23, https://www.flightglobal.com/FlightPDFArchive/1994/1994%20-%201037.pdf.
[13] Chris Kraul and James F. Peltz, "General Dynamics Sells Atlas Rocket Unit : Aerospace: Martin Marietta agrees to pay $209 million to broaden its line of commercial and military launch vehicles," The Los Angeles Times, December 23, 1993, http://articles.latimes.com/1993-12-23/business/fi-4948_1_general-dynamics-total.
[14] *A Merger of Equals*, Lockheed Martin Corporation, http://www.lockheedmartin.com/us/100years/stories/merger.html.
[15] Lockheed Martin 1995 Annual Report, (New York City, NY: Taylor & Ives, Inc.), 39, http://www.lockheedmartin.com/content/dam/lockheed/data/corporate/documents/1995-Annual-Report.pdf.
[16] Lockheed Martin. "Lockheed Martin Selects RD-180 to Power Atlas IIAR." News release, January 17, 1996. http://www.ilslaunch.com/node/750.
[17] David M Harland and Ralph Lorenz, *Space Systems Failures: Disasters and Rescues of Satellites, Rocket and Space Probes,* (Chichester, UK: Praxis Publishing, 2005), 155-156.
[18] Ford, Robert, William Pipes, and Jerome Josef. "The next generation in rocket engines - the RD-180," In *AIP Conference Preceedings*, 1-5. Proceedings of Space Technology and Applications International Forum - 1998, New Mexico, Albuquerque. 1051 ed. Vol. 420. 1998. http://aip.scitation.org/doi/abs/10.1063/1.54953.
[19] William Perry, "Department of Defense Policy on the Use of Former Soviet Union Propulsion in Space Launch Vehicles," May 17, 1995; As cited in: Statement of Gwynne Shotwell President & Chief Operating Officer Space Exploration Technologies Corporation (SpaceX) before the Committee on Armed Services Subcommittee on Strategic Forces U.S. House of Representatives March 17, 2015.
[20] Ford, Robert, William Pipes, and Jerome Josef. "The next generation in rocket engines - the RD-180."
[21] The McDonnell Douglass Corporation originally fulfilled the EELV RFP in 1995, but was purchased by the Boeing Company a year later in 1996.
Brian Knowlton and the International Herald Tribune, "Boeing to Buy McDonnell Douglas," *The New York Times*, December 1996, http://www.nytimes.com/1996/12/16/news/boeing-to-buy-mcdonnell-douglas.html.

ensure 98 percent reliability in launch vehicle design, as well as standardize launch pad infrastructure.[22]

Instead of down-selecting to one company to build the EELV, as originally planned, in November of 1997 DoD announced that the EMD award would be split between both Lockheed Martin and Boeing. This change to the acquisition strategy—allowing for two EELV providers instead of one—followed predictions of a growing space launch market that could sustain two providers, which would encourage competition and keep costs low for the government.[23] DoD intended for the ongoing competition between the two companies for launches to reduce launch costs by at least 25 percent while still meeting the RFP requirements.[24] As a result of this award, Lockheed Martin proceeded with the development of the Atlas V launch vehicle using the RD-180 engine, and Boeing developed the Delta IV launch vehicle with the U.S.-produced RS-68 rocket engine powering its first stage.[25]

In October 1998, the Air Force awarded two $500 million EMD contracts (one to each company) for the development of their respective launch vehicles and launch infrastructure. It also awarded firm-fixed-price contracts for a total of 28 launches between the two companies (9 to Lockheed and 19 to Boeing), with a combined value of $2 billion and an average price of $72 million per launch.[26] The launches were procured as a service rather than as a product, which means that the government paid the contractor to place a specified payload into orbit, rather than directly purchasing the launch hardware itself.[27] Moreover, the contracts were awarded as a commercial item, meaning that the government could not require internal cost data from the contractors the way it can under a typical cost-reimbursable contract.[28]

Spiraling Costs and Changes to the EELV Program

The projections for a robust commercial space launch market that DoD relied upon for its dual-source EELV acquisition strategy never materialized, and the difference between DoD's estimated and actual launch prices suffered as a result. The EELV program office reported over $13 billion in cost increases in 2004, which caused a Nunn-McCurdy breach.[29] The

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[22] Steven A. Hildreth, *National Security Space Launch at a Crossroads,* Congressional Research Service, Washington, D.C., May 13, 2016, 2, https://fas.org/sgp/crs/natsec/R44498.pdf.
[23] Ibid., 3.
[24] Maj Gregory E. Wood, "The Evolved Expendable Launch Vehicle: Tough Decisions to Assure Access to Space," Air & Space Power Journal, Summer 2006, http://www.au.af.mil/au/afri/aspj/airchronicles/apj/apj06/sum06/wood.html.
[25] Government Accountability Office, *Evolved Expendable Launch Vehicle: Introducing Competition into National Security Space Launch Acquisitions*, Testimony Before the Committee on Appropriations, U.S. Senate, Subcommittee on Defense, Washington, D.C., March 2014, http://www.gao.gov/products/GAO-14-259T.
[26] U.S. Department of Defense, *Contracts*, Press Operations, No: 536-98, October 16, 1998, http://archive.defense.gov/Contracts/Contract.aspx?ContractID=1383.
[27] Maj Gregory E. Wood, "The Evolved Expendable Launch Vehicle: Tough Decisions to Assure Access to Space."
[28] Government Accountability Office, *Evolved Expendable Launch Vehicle: The Air Force Needs to Adopt an Incremental Approach to Future Acquisition Planning to Enable Incorporation of Lessons Learned*, Report to Congressional Committees, August 2015, 3, http://www.gao.gov/assets/680/671926.pdf.
[29] A Nunn-McCurdy breach refers to a directive in an amendment to the FY 1982 National Defense Authorization Act (NDAA), incorporated into title 10, United States Code (10 USC 2433), which requires either cancellation or a

majority of the cost overrun ($7.8 billion) was due to price increases on the second and subsequent launch services contracts.[30] In 2005, DoD changed the EELV acquisition strategy again, moving to a contract type that allowed the government to obtain internal cost data from the contractors. It created two contracts for each company: a fixed-priced contract for launch services and a cost-reimbursable contract for facilities, launchpads, and other items necessary to maintain the ability to launch.[31] This strategy acknowledged that the U.S. government would be the primary customer of the EELV program and placed mission assurance and assured access to space as the highest priorities of the EELV program, even over cost efficiencies.[32] It also meant that in order to retain assured access to space and support contracts with two independent launch providers, the U.S. government would shoulder more of the two company's fixed costs.

As EELV costs began to rise, one of the casualties was U.S.-based co-production of the RD-180 between NPO Energomash and Pratt & Whitney. At the time, cost estimates for this production facility ranged from $500 million to $800 million,[33] and the timeline for production had slipped to 2008 with the potential for the first U.S.-produced RD-180 on an Atlas V vehicle by 2012.[34] One way to reduce costs was to remove the restriction on purchasing RD-180 used for military launches from NPO Energomash and terminate the plan to develop a domestic production facility. In June 2007, the Air Force gained approval to maintain a sufficient inventory of RD-180 engines instead of paying for the development of a domestic production facility.[35] A year later, the Air Force and ULA formally agree to end co-production.[36]

Creation of the United Launch Alliance

Shortly after this change in acquisition strategy, Boeing and Lockheed Martin announced their intent to merge all their space launch operations for the U.S. government into a joint venture:

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restructure of the program when cost growth on Major Defense Acquisition Programs (MDAPs) exceeds specified thresholds.
Moshe Schwartz and Charles V. O'Connor, "The Nunn-McCurdy Act: Background, Analysis, and Issues for Congress," Congressional Research Service, May 12, 2016, https://fas.org/sgp/crs/natsec/R41293.pdf.

[30] Raymond J. Decker, "Defense Space Activities: Continuation of Evolved Expendable Launch Vehicle Program's Progress to Date Subject to Some Uncertainty," A letter to Wayne Allard and Bill Nelson, Subcommittee on Strategic Forces, Committee on Armed Services, U.S. Senate, June 24, 2004, http://www.gao.gov/new.items/d04778r.pdf.

[31] Government Accountability Office, *Evolved Expendable Launch Vehicle: Introducing Competition into National Security Space Launch Acquisitions*, 3.

[32] Ibid.

[33] McCartney, Forrest, Peter A. Wilson, Lyle Bien, Thor Hogan, Leslie Lewis, Chet Whitehair, Delma Freeman, T. K. Mattingly, Robert Larned, David S. Ortiz, William A. Williams, Charles J. Bushman and Jimmey Morrell, Nati*onal Security Space Launch Report*, (Santa Monica, CA: RAND Corporation, 2006), 33, http://www.rand.org/pubs/monographs/MG503.html.

[34] Raymond J. Decker, "Defense Space Activities: Continuation of Evolved Expendable Launch Vehicle Program's Progress to Date Subject to Some Uncertainty."

[35] Government Accountability Office, *Defense Acquisitions Assessments of Selected Weapon Programs*, GAO-08-467SP, March 2008, 76, http://www.gao.gov/new.items/d08467sp.pdf.

[36] RD-180 Availability Risk Mitigation Study Summary, Space Policy Online, 8, http://www.spacepolicyonline.com/pages/images/stories/RD-180%20Study%20briefing%20charts%20r.pdf.

the United Launch Alliance (ULA).[37] Initially, the Federal Trade Commission (FTC) opposed the joint venture because competition would be lost.[38] Boeing and Lockheed Martin argued that by combining their programs, assured access would continue and lower costs would follow. DoD supported the merger, asserting that the benefits of having two launch capabilities under one entity (ULA) would outweigh the loss of competition.[39] The FTC's concerns about cost were placated, and in 2006, Boeing and Lockheed Martin were allowed to formally create the United Launch Alliance.

Despite assurances of lower costs from the merger, EELV program costs continued to grow. In August 2007, DoD reclassified parts of the EELV program into the "sustainment phase," making it exempt from many cost reporting requirements.[40] As a GAO report noted, "the sustainment decision may have been influenced by other factors such as avoiding imminent Nunn-McCurdy unit cost breaches."[41] At the time of this switch, the EELV program had completed 21 launches altogether. However, no single variant of the rockets had completed seven launches—the standard for declaring a launch system operational.[42]

Following the merger, the EELV program's original goals of cost control and low costs of launch were supplanted by the Air Force's focus on mission assurance through the sole-source procurement of launch services through ULA.[43] Putting mission assurance over cost control continued until 2010 when DoD officials predicted that cost-growth would continue at an unsustainable rate, due to instabilities in the launch industrial base and the costly purchasing practice of buying one launch vehicle at a time. DoD conducted several studies to evaluate alternative acquisition approaches and a new EELV acquisition strategy.[44] The U.S. Government Accountability Office (GAO) conducted one such study and produced seven recommendations for the Department of Defense to consider when reworking their EELV acquisition strategy:

- Examine how broader launch issues across multiple government agencies could be coordinated;
- Ensure mission assurance operations are sufficient without being excessive;
- Refrain from waiving Federal Acquisition Regulation (FAR) cost requirements;

[37] "Boeing, Lockheed Martin to Form Launch Services Joint Venture," United Launch Alliance, May 2, 2005, http://www.ulalaunch.com/boeing-lockheed-martin-to-form-launch.aspx?title=Boeing%2c+Lockheed+Martin+to+Form+Launch+Services+Joint+Venture&archived=True&Category=0&Page=54.
[38] "FTC Intervenes in Formation of ULA Joint Venture by Boeing and Lockheed Martin," U.S. Federal Trade Commission, October 3, 2006, https://www.ftc.gov/news-events/press-releases/2006/10/ftc-intervenes-formation-ula-joint-venture-boeing-and-lockheed.
[39] Steven A. Hildreth, *National Security Space Launch at a Crossroads,* Congressional Research Service, May 13, 2016, 4, https://fas.org/sgp/crs/natsec/R44498.pdf.
[40] Defense Technical Information Center, *Evolved Expendable Launch Vehicle: Exhibit R-2, RDT&E Budget Item Justification*, PB 2012 Air Force, February 2011, 1, http://www.dtic.mil/descriptivesum/Y2012/AirForce/stamped/0604853F_5_PB_2012.pdf.
[41] Government Accountability Office, *Space Acquisitions: Uncertainties in the Evolved Expendable Launch Vehicle Program Pose Management and Oversight Challenges*, House of Representatives, Report to the Subcommittee on Defense, Committee on Appropriations, September 2008, 20, http://www.gao.gov/new.items/d081039.pdf.
[42] Ibid.
[43] Steven A. Hildreth, *National Security Space Launch at a Crossroads,* 4.
[44] Government Accountability Office, *Evolved Expendable Launch Vehicle: Introducing Competition into National Security Space Launch Acquisitions*, 4.

- Work more closely with NASA on EELV contract negotiations;
- Reassess the block buy contract length;
- Conduct an independent review of the health of the space launch industrial base, while paying special attention to engine manufacturers; and
- Develop a science and technology plan for improving existing launch technologies.[45]

DoD finalized its new EELV acquisition strategy in November 2011. The strategy recognized the Atlas V and Delta IV vehicles as the only launch services certified for National Security Space (NSS) missions at the time, but it also opened the prospect of competition to take advantage of commercial space launch providers if they could become certified. The primary goal of the 2011 acquisition strategy was to reduce costs while maintaining mission assurance through steady purchases in the form of larger block buys.[46]

In the FY 2012 National Defense Authorization Act (NDAA), Congress re-designated the EELV program as a Major Defense Acquisition Program (MDAP),[47] which forced the program to begin reporting cost data again and to be subject to the Nunn-McCurdy rules for cost overruns. The program immediately incurred a second Nunn-McCurdy breach, and DoD subsequently restructured the EELV program again, this time including a sole-source contract with ULA for a block buy of launchers. Under the block buy, DoD committed to purchasing 36 rocket cores for 28 launches (which included three rocket cores for each Delta IV Heavy launch) from ULA over the next five years.[48]

Entry of the Falcon 9 and Competition

Around the same time, DoD also began to look at other launch vehicle families, such as the SpaceX Falcon 9, in order to increase competition. In a November 2012 Acquisition Defense Memorandum, Under Secretary of Defense for Acquisition, Technology, and Logistics Frank Kendall directed the Air Force to aggressively pursue competition in the EELV program. The Department's plan was to have 14 separate cores, along with the 36 rocket cores that were included in the ULA block buy, remain open for competition through FY 2017.[49] The Air Force saw the block buy as a way to lower costs for the EELV program by improving the Department's ability to negotiate stable unit costs.[50] The Air Force also argued that none of the launches included in the block buy could be performed by a provider other than ULA.

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[45] Government Accountability Office, *Evolved Expendable Launch Vehicle: DOD Needs to Ensure New Acquisition Strategy Is Based on Sufficient Information*, Report to Congressional Requesters, September 2011, 24, http://www.gao.gov/assets/520/511460.pdf.
[46] "Evolved Expendable Launch Vehicle (EELV)," Vandenberg Air Force Base, U.S. Air Force, March 29, 2013, http://www.vandenberg.af.mil/About-Us/Fact-Sheets/Display/Article/338338/evolved-expendable-launch-vehicle-eelv.
[47] U.S. Congress, *National Defense Authorization Act for Fiscal Year 2012*, United States Government Publishing Office, 112th Congress, Public Law 112-81, Sec. 838, December 31, 2011, https://www.gpo.gov/fdsys/pkg/PLAW-112publ81/pdf/PLAW-112publ81.pdf.
[48] Government Accountability Office, *Evolved Expendable Launch Vehicle: Introducing Competition into National Security Space Launch Acquisitions*, 6.
[49] Amit Svitak, "McCain Asks Pentagon IG to Investigate Air Force EELV Decision," *Aviation Week*, April 26, 2014, http://aviationweek.com/blog/mccain-asks-pentagon-ig-investigate-air-force-eelv-decision.
[50] Steven A. Hildreth, *National Security Space Launch at a Crossroads,* Congressional Research Service, 5.

However, the Air Force later conceded that due to changes in launch timing and the success of Falcon 9 development and certification, one launch included in the block buy could have been performed by Space X.[51]

In June 2013, the Air Force and SpaceX signed a Cooperative Research and Development Agreement, which called for SpaceX to demonstrate three successful Falcon 9 launches before the Air Force would begin the independent review process to adopt SpaceX as an EELV contender.[52] In September and December of that same year, SpaceX successfully completed the first two of their certification flights. However, while the Air Force was still in the process of certifying SpaceX, it went ahead and awarded the block buy to ULA for 36 rocket cores without competition. During this time, SpaceX was continually upgrading their Falcon 9 vehicle. However, at the time of the ULA block buy, the Falcon 9 v1.0's payload-to-orbit was about the same as the Atlas 5's smallest variant, making the Falcon 9 less competitive in payload capacity.[53]

SpaceX subsequently sued the government in 2014, arguing that the block buy of 36 rocket cores should also have been competitively bid. The lawsuit was dropped in January 2015,[54] and the Air Force officially certified SpaceX to compete for national security space missions through the EELV program in May 2015.[55] SpaceX won the first EELV launch available for competition in April 2016 at a price of $82.7 million, although ULA declined to compete for this contract.[56] On March 14, 2017 SpaceX won the second EELV launch offered for competition at a price of $96.5 million, this time with ULA offering a competing bid.[57]

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[51] Interview of Lieutenant General Charles R. Davis, Principal Deputy Assistant Secretary of the Air Force for Acquisition, *Aviation Week*, May 7, 2014, http://aviationweek.com/blog/amid-spacex-protest-usaf-defends-sole-source-eelv-strategy.
[52] Secretary of the Air Force Public Affairs, "AF releases results of Space Launch Process review," U.S. Air Force, March 23, 2015, http://www.af.mil/News/ArticleDisplay/tabid/223/Article/581248/af-releases-results-of-space-launch-process-review.aspx.
[53] In 2012, the Falcon 9 v1.0's payload to LEO was 9900kg and to GEO was 4050kg. The Atlas 5 (401) variant's payload capacity was 9050kg to LEO and 4950kg to GEO.
"Falcon-9," Gunter's Space Page, http://space.skyrocket.de/doc_lau/falcon-9.htm.
"Atlas-5," Gunter's Space Page, http://space.skyrocket.de/doc_lau/atlas-5.htm.
[54] Christian Davenport, "Elon Musk's SpaceX settles lawsuit against Air Force", The Washington Post, January 23, 2015, https://www.washingtonpost.com/business/economy/elon-musks-spacex-to-drop-lawsuit-against-air-force/2015/01/23/c5e8ff80-a34c-11e4-9f89-561284a573f8_story.html?utm_term=.7259682669d2.
[55] Secretary of the Air Force Public Affairs, "Air Force's Space and Missile Systems Center Certifies SpaceX for National Security Space Missions," May 26, 2016,
http://www.af.mil/News/ArticleDisplay/tabid/223/Article/589724/air-forces-space-and-missiles-system-center-certifies-spacex-for-national-secur.aspx.
[56] U.S. Department of Defense Press Operations, "Contracts," Release No: CR-079-16, April 27, 2016, https://www.defense.gov/News/Contracts/Contract-View/Article/744434.
[57] U.S. Department of Defense Press Operations, "Contracts," Release No: CR-048-17, March 14, 2017, https://www.defense.gov/News/Contracts/Contract-View/Article/1112618.

2. Russian Sanctions and the RD-180

Since the first flight of the Atlas V in 2002, the RD-180 engine has had a near-perfect record of success.[58] Despite this record, policymakers have initiated an effort to find an alternative engine to the RD-180 in order to lessen the U.S. military's dependence on a Russian-manufactured product for assured access to space. The push to stop using the RD-180 began to accelerate in 2014 after the deployment of Russian military forces in the Crimean region of Ukraine, which prompted a global condemnation of the Russian government.

U.S. Sanction on the Russian Deputy Prime Minister

After the invasion of Crimea, U.S. President Barack Obama publicly declared Russia's actions as "clear violation[s] of Ukrainian constitutions and international law" and authorized "sanctions on Russian officials -- entities operating in the arms sector in Russia and individuals who provide material support to senior officials of the Russian government."[59] The list of sanctioned individuals included Deputy Prime Minister Dmitry Rogozin, the government official responsible for overseeing the Russian defense and space sectors. On March 16, 2014, President Obama signed Executive Order 13,661 — "Blocking Property of Additional Persons Contributing to the Situation in Ukraine" — which blocked all U.S.-held property of Deputy Prime Minister Rogozin from being "transferred, paid, exported, withdrawn, or otherwise dealt in."[60] SpaceX used the new sanctions in its argument to the United States Court of Federal Claims on April 28, 2014. In the formal complaint, SpaceX alleged that the ULA contract, "which was concluded outside of public scrutiny, funnels hundreds of millions of U.S. taxpayer dollars to Russia's military-industrial base, including the monies that may flow to individuals on the U.S. sanctions list."[61] SpaceX alleged that that since NPO Energomash, maker of the RD-180, is majority owned by the Russian government, and Deputy Prime Minister Rogozin oversees the Russian space industry, that money from the sale of RD-180s could potentially benefit Rogozin.

Two days later, Federal Claims Court Judge Susan Braden ordered a preliminary injunction that prohibited the Air Force and ULA "from making any purchases from or payment of money to NPO Energomash" until the Treasury, Commerce, and State Departments submitted unanimous opinions "that any such purchases or payments will not directly or indirectly contravene Executive Order 13,661."[62] The appropriate officers from the three

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[58] Jeff Foust, "ULA confirms engine issue on latest Atlas launch," SpaceNews, March 24, 2016, http://spacenews.com/ula-confirms-engine-issue-on-latest-atlas-launch/.
[59] Barack H Obama, "Statement by the President on Ukraine," Address, March 17, 2014, https://obamawhitehouse.archives.gov/the-press-office/2014/03/17/statement-president-ukraine.
[60] Exec. Order No. 13661, 3 C.F.R. 6 (2014).
[61] Space Exploration Technologies Corp. v. The United States, 1, The United States Court of Federal Claims April 28, 2014, Complaint.
[62] Space Exploration Technologies Corp. v. The United States and United Launch Services, 3, LLC, The United States Court of Federal Claims, April 30, 2014, Order Issuing Preliminary Injunction.

departments quickly submitted unanimous opinions confirming that "purchases from or payments to NPO Energomash would not directly or indirectly contravene Executive Order 13,661."[63] The government argued that, although the Treasury and State departments have the power to block an entity under a designated individual's control, the two departments did not agree to prevent the acquisition of RD-180s.[64] On May 8, 2014, the Court of Federal Claims dissolved the preliminary injunction, despite SpaceX's continued objections, on the grounds that it received letters from the appropriate departments confirming that the sale of RD-180 engines does not violate the sanctions.[65]

Figure 2: Tweet from Deputy Prime Minister Rogozin.

Note: In this tweet, the Deputy Prime Minister writes "The one who can't jump is a Moskal." In another tweet, he wrote "After analyzing the sanctions against our space industry, I suggest to the USA to bring their astronauts to the International Space Station using a trampoline."
Source: Twitter, NBC News

In a press conference days later, Deputy Prime Minister Rogozin retaliated against Executive Order 13,661 by stating that "we will proceed from the fact that we can no longer deliver these engines to the United States, and that we can no longer maintain and repair previously shipped engines, unless we receive guarantees that our engines are used only for launching civilian payloads."[66] This statement was made *after* the judge lifted the preliminary injunction and cleared the way for ULA and the Air Force to continue purchasing the RD-180, and it appeared to threaten that Russia would disrupt sales of the engine to the United States in retaliation for the sanctions.

In response to rising tensions with Russia, the Air Force commissioned a study in early 2014 to explore alternatives to the RD-180. The "RD-180 Availability Risk Mitigation Study," also known as the "Mitchell Study," was briefed in a March 13, 2014 hearing in front of the Committee on Armed Services.[67] The Mitchell Study examined the viability of a domestically produced RD-

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[63] Space Exploration Technologies Corp. v. The United States and United Launch Services, LLC, 2, The United States Court of Federal Claims, May 6, 2014, Defendant's Motion to Dissolve Preliminary Injunction, and Request for Expedited Consideration.
[64] Ibid., A1.
[65] Space Exploration Technologies Corp. v. The United States and United Launch Services, LLC, The United States Court of Federal Claims, April 30, 2014, Order Issuing Preliminary Injunction.
[66] Dinitry Rogozin, "Briefing by Deputy Prime Minister Dmitry Rogozin and Head of the Federal Space Agency Oleg Ostapenko on international space cooperation," May 13, 2014, http://government.ru/en/news/12363/#.
[67] U.S. Congress, "Hearing on National Defense Authorization Act for Fiscal Year 2015 and oversight of previously authorized programs before the Committee on Armed Services," House of Representatives Committee on Armed Services, 113th Congress, second session: full committee hearing on fiscal year 2015 national defense authorization budget request from the Department of the Air Force, hearing held March 14, 2014, Cong.

180, an entirely new engine, and alternative launch vehicles as potential mitigation options. The study determined that while "impacts of the RD-180 loss are significant, near term (FY14-FY17) options to mitigate them are limited." It recommended that the United States "not initiate U.S. production of [the] RD-180" because it "does not improve the current situation," and instead recommended the development of a new engine.[68]

U.S. Congressional Action

The Russian threat of retaliation by withholding sales of the RD-180 from the U.S. military worried some in Congress and led to legislative changes. On December 19, 2014, President Obama signed the National Defense Authorization Act for Fiscal Year 2015 (FY15 NDAA) into law. Section 1604 of this legislation required the Secretary of Defense to deliver a report within 180 days on possible alternatives to the RD-180 engine. The replacement engine is required to: "be made in the United States; meet the requirements of the national security space community; be developed by not later than 2019; be developed using full and open competition; and be available for purchase by all space launch providers of the United States."[69] Congress also added $220 million in FY 2015 funding for the "Next Generation Launch System Investment" program, which would be used to begin development of an RD-180 replacement, and followed up with additional funding in FY 2016.[70]

On June 26, 2015, the House Armed Services Committee Subcommittee on Strategic Forces held a hearing on the RD-180 issue.[71] The hearing featured one panel of industry leaders from commercial space companies and one panel of government experts primarily from the Department of Defense. The first panel included representatives from United Launch Alliance (ULA), Blue Origin, Aerojet Rocketdyne, Orbital ATK, and SpaceX. Currently, both ULA and Orbital ATK rely on Russian rocket engines (the RD-180 and the RD-181, respectively), but only ULA uses the Russian engines for national security payloads.[72] Alternatively, Blue Origin and SpaceX designed and manufactured their own engines within the United States (the BE-4 and the Merlin 1D, respectively). Aerojet Rocketdyne, an American rocket propulsion manufacturer with a proposal to replace the RD-180 with a newly designed American-made engine known as the AR1, was an outlier as the only company represented at the hearing that did not offer launch services.

With the exception of Aerojet Rocketdyne, each company's representative articulated that the RD-180 replacement process would not be as straightforward as engineering a drop-in replacement engine. The President of Blue Origin, Robert Meyerson, presented this

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[68] H. J. Michell and Michael Griffin, "RD-180 Availability Risk Mitigation Study Summary," http://www.spacepolicyonline.com/pages/images/stories/RD-180%20Study%20briefing%20charts%20r.pdf.
[69] U.S. Congress. Carl Levin and Howard P. "Buck" McKeon National Defense Authorization Act for Fiscal Year 2015, Sec. 1604. Cong.
[70] U.S. Air Force, "FY17 Research, Development, Test, and Evaluation Budget Justification Book," Vol. 2, 575.
[71] U.S. Congress, "Assuring national security space: investing in American industry to end reliance on Russian rocket engines: hearing before the Subcommittee on Strategic Forces of the Committee on Armed Services," Committee on Armed Services, House of Representatives, 114th Congress, first session, hearing held June 26, 2015, Cong.
[72] The RD-181 is a single-chamber derivative of the RD-170, and thus is similar in design to the RD-180. The RD-181 is used on the Antares launch vehicle, which is primarily used for commercial resupply missions to the International Space Station.

consensus succinctly when he testified that “no new engine can simply be dropped into an existing launch vehicle. Launch vehicles have to be designed around their engines. And launch providers are the ones who are best able to decide what type of engine they need.”[73] Conversely, Aerojet Rocketdyne’s representative, Julie Van Kleeck, Vice President of Advanced Space and Launch Systems, drew attention to the design similarities between the AR1 and the RD-180. In a detailed answer to a congressman’s question, Ms. Van Kleeck stressed that “the AR1 uses the same propellent. It has the same engine cycle, so it has a very similar environment. It would use the same tankage, would have the same attach points. It is 11 inches longer. But we have been told by ULA engineers that the length is not an issue; there is length to work with. That will affect minor ground support equipment but it is very minor.”[74]

The FY15 NDAA placed some restrictions on the use of the RD-180 for national security launches, but it was not an absolute prohibition. The bill allowed use of engines that were part of the block buy contract awarded to ULA on December 18, 2013 and allowed the use of engines ULA had contracted to procure prior to the Russian annexation of Crimea. It also provided the Secretary of Defense with the authority to sign a waiver if deemed “necessary for the national security interests of the United States” or if the capabilities required could not otherwise “be obtained at a fair and reasonable price.”[75]

The FY16 NDAA amended the law to place a stricter limit on the number of RD-180s that could be used under the exceptions for pre-existing contracts. It provided that only five Russian engines could be used “that prior to February 1, 2014, were either fully paid for by the contractor or covered by a legally binding commitment of the contractor.” It also provided that up to four additional Russian engines could be used for contracts not covered by the other exceptions. While some members of Congress were opposed to allowing a total number of nine engines, that language was agreed upon in the armed services committees and became law on November 25, 2015.[76]

A few weeks later, as Congress was considering the FY 2016 appropriations bill, two Senators from the appropriations committee, Senator Richard Durbin (D-IL) and Senator Richard Shelby (R-AL), added a policy provision that effectively removed all restrictions on the use of RD-180s for national security launches. It stated that “notwithstanding any other provision of law, award may be made to a launch service provider competing with any certified launch vehicle in its inventory regardless of the country of origin of the rocket engine.” The appropriations bill was signed into law on December 18, 2015.[77]

In a hearing on President Obama’s FY17 budget request, Senator Shelby asked Secretary of Defense Ashton Carter how many more RD-180s would be required to maintain assured access to space until the development of additional launch systems. Secretary Carter responded that unless the Department of the Defense chose to fly national security payloads

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[73] U.S. Congress, “Assuring national security space: investing in American industry to end reliance on Russian rocket engines: hearing before the Subcommittee on Strategic Forces of the Committee on Armed Services,” Committee on Armed Services, House of Representatives, 114th Congress, first session, hearing held June 26, 2015, Cong.
[74] Ibid., 14.
[75] U.S. Congress, National Defense Authorization Act for Fiscal Year 2015, Sec. 1608, Cong.
[76] U.S. Congress, National Defense Authorization Act for Fiscal Year 2016, Sec. 1607, Cong.
[77] U.S. Congress, Consolidated Appropriations Act, 2016, Sec. 8048, Cong.

on the Delta Heavy system, "which is technically feasible, but much more expensive,"[78] continued use of the Atlas V would require "purchases of up to 18 more RD-180 engines." Secretary Carter's suggestion perfectly mirrors that of William LaPlante, Assistant Secretary of the Air Force for Acquisition, which he made in a letter to Senator Shelby in June 2015.[79]

In accordance with the "Next Generation Launch System Investment," the Air Force began investing in a new rocket engine in FY 2015. In February 2016, the Air Force awarded a contract to Aerojet Rocketdyne for AR1 development and testing. Under the agreement, the Air Force will contribute up to $536 million and Aerojet will contribute up to $268 million, a 67/33 split between the government and private sector.[80] The agreement extends through December 2019, when Aerojet plans to have a fully functioning engine certified, although it may require up to two additional years for the engine to be integrated with the launch vehicle.

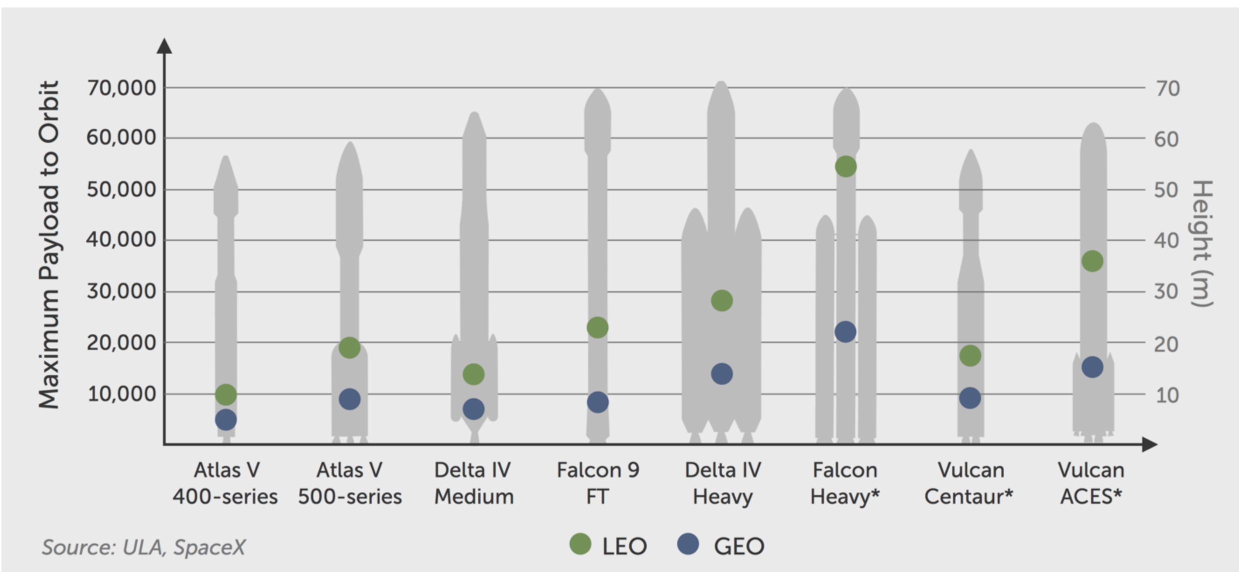
In June 2016, Senator Bill Nelson (D-FL) forged a deal between the authorizers, who wished for a fast replacement of the RD-180 and strict limits on the number of RD-180s that could be used during the transition period, and the appropriators, who feared that banning the engine would leave the U.S. without assured access to space. This compromise was written into Section 1602 of the FY17 NDAA and was signed into law on December 13, 2016. It allows for a total of 18 Russian engines that could be used through the end of 2022.[81]

[78] United States Senate, "Shelby Questions Defense Secretary Carter on Use of the RD-180 Engine for National Security Launches," News release, April 28, 2016, http://www.shelby.senate.gov/public/index.cfm/newsreleases?ID=85F31CBC-5848-4151-9F95-599192560728.
[79] William A. LaPlante to The Honorable Richard C. Shelby, Letter, United States Senate, July 16, 2015.
[80] Department of Defense, Press Operations, *Contracts*, CR-037-16, February 29, 2016 , https://www.defense.gov/News/Contracts/Contract-View/Article/682238.
[81] U.S. Congress, National Defense Authorization Act for Fiscal Year 2017, Sec. 1602, Cong.

3. Options to Replace the RD-180

A key decision facing U.S. policymakers today is how best to manage the transition from the RD-180 to alternative launch options for the U.S. military. In making this transition, the government must consider the full range of options available, the time period over which this transition will occur, and the costs and risks of transition. This chapter explores the options available and the factors that should be weighed when assessing these options. For the purposes of this analysis, the range of options considered is limited to those that can replace (or nearly replace) the capabilities of the current Atlas V family of launch vehicles. As shown below in Figure X, the smallest configuration of the Atlas V (the Atlas V 401 configuration) can carry up to 9,072 kg to low-Earth orbit (LEO) and 4,750 kg to geostationary transfer orbit (GTO). In comparison, the Atlas V 551 configuration (the most powerful version that has been used) can carry 18,814 kg to LEO and 8,900 kg to GTO.[82]

Figure 3: Maximum Payload Capability to Two Reference Orbits for Select Launch Vehicles.



Policy Assumptions

Underlying this analysis are three main policy assumptions. The first assumption is that the requirement to end the U.S. military's use of the RD-180 engine by 2022 or sooner, as specified in the FY17 NDAA, will remain in effect.[83] Some disagreement remains in Congress as

[82] United Launch Alliance, *Atlas V Launch Services User's Guide*, (Centennial, CO: March 2010), 1-8 http://www.ulalaunch.com/uploads/docs/AtlasVUsersGuide2010.pdf.
[83] U.S. Congress, "National Defense Authorization Act for Fiscal Year 2017," S.2943 – 114th Congress, Sec. 1602 (Washington D.C., December 2016).

to the exact timing, the number of RD-180 engines than should be used during the transition, and which alternatives should be pursued. Nevertheless, as the previous chapter illustrated, the underlying consensus of Congress has been that the military should end its dependence on the RD-180. While the impetus for this policy began due to the deterioration in the relationship with Russia, the current consensus is now unlikely to be altered, even if the relationship with Russia were to improve. The Air Force, Congress, and space launch industry have all moved too far along the path toward ending the use of the RD-180 to be redirected at this point.

The second assumption is that the United States will continue its policy of maintaining two independent vehicles for national security space launch. This policy is codified in law and states that the United States will provide resources and policy guidance to sustain "the availability of at least two space launch vehicles (or families of space launch vehicles) capable of delivering into space any payload designated by the Secretary of Defense or the Director of National Intelligence as a national security payload."[84] As is evident in the acquisition strategy used for the EELV program, maintaining two independent launch vehicles was a priority for DoD even before it was codified into law. Having a second, independent family of launch vehicles gives the military an alternative to continue launching national security payloads should one family of vehicles become grounded due to technical problems or a launch failure. It also provides the ability to surge launch capacity if necessary. Moreover, two launch vehicles provide the opportunity for some level of competition for national security launches, which can incentivize contractors to lower prices, improve reliability, and invest in vehicle improvements.

The third assumption is that SpaceX's family of Falcon launch vehicles (including the Falcon 9 and Falcon Heavy) will be one of the launch vehicles used by the U.S. military. While SpaceX has not yet launched a satellite for the military as of this writing, the Air Force has certified its Falcon 9 vehicle, and its first EELV launch is scheduled for 2018.[85] The Falcon Heavy—a larger vehicle that uses three of the first stage rocket cores from the Falcon 9—has not yet flown, but its maiden flight is

Figure 4: Falcon 9 at Lift-off.

Source: SpaceX

[84] 10 U.S. Code § 2273 (2016).
[85] Department of Defense, Press Operations, *Contracts*, CR-079-16, April 27, 2016, https://www.defense.gov/News/Contracts/Contract-View/Article/744434.

scheduled for later in 2017.[86] Once the Falcon Heavy is certified, this family of vehicles will be able to cover the full range of launch capabilities currently provided by the Atlas V and Delta IV. This analysis is therefore focused on which options are available for a second independent launch vehicle in addition to the Falcon family of vehicles.

Assessment of Options

A variety of factors should be considered when evaluating launch options for the U.S. military, including schedule, cost, technical risks, and the long-term competitiveness of the U.S. space launch industrial base. This section uses these criteria to evaluate five options that would end the U.S. military's use of the RD-180 by 2022 while maintaining a second independent family of launch vehicles.

Option 1: AR1 on a Modified Atlas V

One option is to build a replacement rocket engine for the RD-180 that would continue to use the Atlas V booster—what is often referred to as a "drop-in replacement." The RD-180 uses an oxygen-rich, closed-cycle, staged-combustion system that allows it to deliver significantly higher performance than other engines. The specific impulse (I_{sp}) of an engine is a measure of efficiency that is calculated by dividing the thrust of an engine by the weight of propellant consumed per second. A higher I_{sp} indicates a greater efficiency in turning propellant into thrust. The RD-180 has an I_{sp} at sea level of 313 seconds,[87] which compares to an I_{sp} of 282 seconds for SpaceX's Merlin 1D engine used on the Falcon 9[88] and 265 seconds for the F-1 engine used on the Saturn V[89] (both of which use the same LOX/RP-1 propellants as the RD-180). The RD-180 achieves this high level of performance by operating at a high combustion chamber pressure using technology and materials developed by Soviet rocket scientists dating back to the 1970s.[90]

[86] Samantha Masunaga, "From its Falcon Heavy to reusing its rocket boosters, SpaceX faces 4 crucial missions in 2017," Los Angeles Times, February 9, 2017, http://www.latimes.com/business/la-fi-spacex-goals-20170207-htmlstory.html.
[87] Mark Wade, "RD-180," http://www.astronautix.com/r/rd-180.html.
[88] Mark Wade, "Merlin 1D," http://www.astronautix.com/m/merlin1d.html.
[89] Mark Wade, "F-1," http://www.astronautix.com/f/f-1.html.
[90] Brooke Mosley, *RD-180 Engine: An Established Record of Performance and Reliability on Atlas Launch Vehicles*, United Launch Alliance, (Littleton, CO), http://www.ulalaunch.com/uploads/docs/Published_Papers/Evolution/RD180EstablishedRecord201108_0201.pdf.

Figure 5: Pair of Aerojet Rocketdyne's AR1 engines.

Source: Aerojet Rocketdyne

Aerojet Rocketdyne has begun work on a replacement for the RD-180 known as the AR1. Like the RD-180, the AR1 uses LOX / RP-1 as propellants, but the AR1 does not operate at the high combustion chamber pressures of the RD-180. Additionally, the RD-180 has one set of turbo pumps that feeds two combustion chambers and two nozzles, while the AR1 requires two completely separate engines with two sets of turbo pumps to power the Atlas V. This makes the AR1 engines heavier and lowers the thrust to weight ratio. To compensate for its lower I_{sp} at sea level and lower thrust to weight ratio, the AR1 is designed to reach a higher maximum thrust.

Because the performance characteristics of the AR1 are different than the RD-180, it is not a simple "drop-in replacement" and would require some modifications to the Atlas V. Namely, the structure would need to be strengthened to withstand the higher thrust levels of the AR1, and a modified interface would need to be developed and tested for the engines. These modifications, along with the lower I_{sp} of the AR1, would reduce the overall lift capability of the Atlas V.

In February 2016, the Air Force awarded a contract to Aerojet Rocketdyne for AR1 development and testing. Under the agreement, the Air Force will contribute up to $536 million, and Aerojet will contribute up to $268 million, a 67/33 split between the government and private sector.[91] The agreement extends through December 2019, when Aerojet plans to have a fully functioning engine certified, although it may require up to two additional years for the engine to be integrated with the launch vehicle.

While the recurring unit cost of the AR1 is not yet known, it is likely to be higher than the RD-180. The RD-180 has been in production for decades and has progressed further down the learning curve. The labor costs of NPO Energomash in Russia are also presumably lower than those of Aerojet Rocketdyne in the United States. Because the cost of the Atlas V is already substantially higher than the Falcon 9, any additional increases in cost due to a new engine would make the Atlas V even less competitive for government and commercial launches. Under this option, the Delta IV Heavy vehicle would need to be kept in operation as a second independent vehicle capable of launching heavier payloads. The government is already

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[91] Department of Defense. Press Operations. *Contracts*. CR-037-16. February 29, 2016 https://www.defense.gov/News/Contracts/Contract-View/Article/682238.

preparing for a continued reliance on the Delta IV by procuring some Delta IV launches merely to keep the production line warm. The Delta IV Medium variant of the rocket is being used to launch satellites that could also be launched on a less expensive Atlas V, like Wideband Global SATCOM (WGS). ULA currently plans to retire the Delta IV Medium variant in 2018.[92]

For both the Atlas V and Delta IV product lines to be sustainable under this option, the government would need to continue buying launches at a minimum sustaining rate for each vehicle. This would effectively mean that the government would be paying higher than market rates for launches in order to sustain two non-competitive launch vehicles (Atlas V and Delta IV), which would not provide meaningful competition for the Falcon 9 and Falcon Heavy. While having these secondary vehicles available would meet assured access to space requirements for the military, it is not likely to be politically or economically sustainable over the long-term.

Option 2: AR1 on Vulcan

Launch vehicles are highly optimized for the engines they use, which is why changing the engine on the Atlas V will inevitably reduce its overall performance. To avoid this, the same AR1 engine could instead be used on a new vehicle designed specifically for its performance characteristics. ULA has begun work on a new vehicle, the Vulcan, that would cover the full range of missions currently performed by the Atlas V and would be optimized for a new engine. ULA is currently exploring two new engines for the Vulcan, the AR1 and Blue Origin's BE-4 (discussed in Option 3 below).

Using the AR1 on the Vulcan would achieve a higher performance than on the Atlas V because the launch vehicle can be optimized to the engine. Despite having a higher payload capacity, the Vulcan / AR1 with the existing Centaur upper stage would not be able to cover all of the missions performed by the Delta IV, so the Delta IV product line would need to be sustained in parallel in order to provide a second vehicle capable of lifting the heaviest payloads. However, ULA has also announced plans for a new upper stage for the Vulcan that would replace the Centaur. This new upper stage, known as the Advanced Cryogenic Evolved Stage (ACES), would significantly improve the overall performance of the rocket, allowing it to lift all payloads currently served by the Delta IV Heavy and eliminating the need to maintain a separate product line. The development timeline for the Vulcan / AR1 option is similar to Option 1, with the AR1 engine certified by the end of 2019 and integrated for use on the new Vulcan launch vehicle by 2021. The ACES upper stage is not planned to be available until 2023.[93]

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[92] Mike Gruss, "ULA Targets 2018 for Delta 4 Phase-out, Seeks Relaxation of RD-180 Ban," *Space News*, March 3, 2015, http://spacenews.com/ula-targets-2018-for-delta-4-phase-out-seeks-relaxation-of-rd-180-ban/#sthash.RdS2sQX0.dpuf
[93] United Launch Alliance, "Vulcan Centaur and Vulcan ACES," http://www.ulalaunch.com/Products_Vulcan.aspx.

Option 3: BE-4 on Vulcan

A third option being pursued is to use the Blue Origin BE-4 engine on the new Vulcan launch vehicle. The development of this engine began in 2011 for use on the first and second stages of Blue Origin's heavy lift vehicle, the New Glenn. Because the BE-4 was already in development, it will likely be certified for use nearly two years before the AR1, with a first flight on Vulcan in 2019.[94] The BE-4 is powered by LOX and liquefied methane and has a maximum thrust with two engines of 1,100,000 pounds of force at sea level. The higher thrust level means that the Vulcan vehicle with the BE-4 engine would not need strap-on solid rocket motors, which cost $10 million each, for as many missions, which would help reduce the recurring unit cost.[95] The maximum payload to GTO of the Vulcan with the BE-4 engine using the Centaur upper stage would be similar to the Vulcan / AR1 described in Option 2. With ACES, the Vulcan / BE-4 would exceed the capacity of the Delta IV Heavy and eliminate the need to maintain the Delta IV product line.

Figure 6: Blue Origin's BE-4 engine.

Source: Blue Origin

Blue Origin advertises that the BE-4 is completely financed with private-sector funds.[96] However, as part of the Air Force's Next Generation Launch System Investment project, ULA was awarded a contract in February 2016 for the Vulcan / BE-4 and ACES development. Under the agreement, the Air Force will contribute up to $202 million, and ULA will contribute up to $134 million, a 60/40 split between the government and private sector.[97] As is the case with the AR1, the recurring unit cost of the BE-4 is not yet publicly known. Because the BE-4 will also be used in the New Glenn rocket, with seven engines powering the first stage and one on the second stage, the Vulcan could benefit from economies of scale in the future if production of the BE-4 ramps up as planned.

There are technical risks associated with the development of any new rocket engine, which is a factor for both the AR1 and the BE-4. However, these risks are arguably higher on

[94] Jessica Orwig, "Jeff Bezos' private spaceflight company is building a monster engine that'll launch the business to new heights," Business Insider, December 07, 2015, http://www.businessinsider.com/about-blue-origins-be-4-engine-2015-12.
[95] Blue Origin, "BE-4: America's Next Rocket Engine," https://www.blueorigin.com/be4.
[96] Ibid.
[97] Department of Defense, *Contracts*, Press Operations, CR-037-16.

the BE-4 because it will be the first engine to use liquefied methane at thrust levels this high. Blue Origin also does not have a deep corporate history of developing and testing rocket engines like Aerojet Rocketdyne. However, both of these factors could be put to rest soon, because the first hot firing of a full scale BE-4 engine is scheduled for early 2017. If successful, this test will demonstrate the maturity of critical technologies in the new engine. Once the hot firing tests are completed, ULA plans to make a final selection between the AR1 and the BE-4 for the Vulcan.

Option 4: Continued Use of Delta IV

Another option that has been explored is using the Delta IV family of launch vehicles to substitute for the Atlas V. The smallest variant of this family, the Delta IV Medium, has a lift capability similar to that of the Atlas V 401 configuration, and the largest variant, the Delta IV Heavy, is currently the only vehicle that can launch the heaviest national security payloads. The Delta IV uses the Aerojet Rocketdyne RS-68 engine for its first stage and LOX / Hydrogen propellants. In the Heavy configuration, three of the booster cores are used in parallel.

Figure 7: Delta IV Heavy at Lift-off.

Source: ULA

The Delta IV family of vehicles is significantly more expensive than the Atlas V. For this reason, ULA has chosen not to offer the Delta IV for contracts that are competitively awarded because it is not price competitive.[98] In 2015, ULA announced that it plans to end production of all Delta IV variants except the Heavy by 2018 and to retire the Heavy variant once the Vulcan rocket with the ACES upper stage is ready.[99]

The cost of this option depends on how many Atlas V launches are transferred to the more expensive Delta IV, rather than SpaceX's less expensive Falcon 9. At a minimum, the government would likely need to guarantee a production rate of 3 to 4 Delta IV launch vehicles per year to keep the production line running, even if all other launches are awarded to the Falcon 9. The technical risks in this option are lower than in the three options

[98] Government Accountability Office. *Evolved Expendable Launch Vehicle The Air Force Needs to Adopt an Incremental Approach to Future Acquisition Planning to Enable Incorporation of Lessons Learned*, 19.
[99] Mike Gruss, "ULA Targets 2018 for Delta 4 Phase-out, Seeks Relaxation of RD-180 Ban," SpaceNews, March 05, 2015, http://spacenews.com/ula-targets-2018-for-delta-4-phase-out-seeks-relaxation-of-rd-180-ban/.

previously discussed, because the Delta IV is a flight-proven vehicle with a near-perfect record.

However, the most significant issue with this option is the long-term viability of the Delta IV as a second independent launch vehicle for national security space missions. The Delta IV is not currently a commercially viable vehicle, and if maintained at the minimum production rate, it would become progressively less competitive over time. Other than its maiden flight in 2002, when a Delta IV Medium launched a Eutelsat communications satellite, the Delta IV family of vehicles has not had any commercial customers as primary payloads. Even if the government agreed to underwrite the full costs of maintaining the Delta IV production line indefinitely, there is no long-term business case for this platform because there is no path to revenue growth without being commercially viable.

Option 5: Allied Launch Provider

Foreign launch vehicles could also provide a second independent source of launch if policymakers were to replace restrictions on the use of foreign launch vehicles for national security payloads. Currently, national security satellites are only launched on U.S. launch vehicles from U.S. launch sites. Section 1604 of the FY 2017 NDAA requires DoD (in coordination with the Director of National Intelligence) to develop a plan for using launch vehicles from allied nations for national security satellites in the event it becomes necessary.[100] Perhaps the most promising vehicle that meets the requirements of the NDAA-mandated plan is the Ariane 5 family of launch vehicles made by Arianespace, a subsidiary of Airbus Safran Launchers, which is headquartered in France with shareholders from 17 other European companies.

Figure 8: Ariane 5 at Lift-off.

Source: Arianespace

The Ariane 5 currently launches from Kourou, French Guiana, which is ideally located at 5° North latitude with open ocean to the East. This near-equatorial launch site improves performance for launches to GTO and geosynchronous orbit (GEO). The Ariane 5 can lift payloads up to 10,000 kg to GTO, which covers the full range of the Atlas V capabilities

[100] U.S. Congress, "National Defense Authorization Act for Fiscal Year 2017," S.2943 – 114th Congress, Sec. 1604, (Washington D.C., December 2016).

but does not match the capabilities of the Delta IV Heavy.[101] This means that even if the Ariane 5 is used as a second independent launch vehicle, the U.S. government would still need to fund the Delta IV production line as a second vehicle for heavier payloads.

Because the Ariane 5 is an existing launch vehicle already in operation, the technical and schedule risks associated with this option would be minimal. The Ariane 5 family of vehicles has had 77 consecutive successful launches since 2003, although the vehicle did experience two complete failures and two partial failures prior to 2003.[102] The most notable failure occurred on the first launch of the Ariane 5 in 1996, which was later determined to be caused by an error in the flight control system software.[103]

The most challenging issues with using an allied launch vehicle are political and security-related. There is likely to be substantial political resistance to using a foreign company for space launch because it would effectively use U.S. taxpayer funds both to assist a competitor to the U.S. space launch industry and to support high-tech manufacturing jobs in other countries. Launching from a location outside the United States, such as French Guiana, would also present numerous logistical and security issues. These could be mitigated in part by creating launch facilities for the Ariane 5 at Cape Canaveral so that sensitive national security satellites would not need to be transported out of the country, although launching from a higher latitude would somewhat reduce the payload capacity of the vehicle.

Summary

Each of the five options presented has both challenges and opportunities that must be weighed relative to one another. For example, using the Delta IV or Ariane 5 launch vehicles (Options 4 and 5) would support the fastest transition away from the RD-180 with limited technical risks, because both vehicles are currently in production and have an extensive record of successful launches. However, the Delta IV option would cost substantially more per launch, and the Ariane 5 option would be fraught with political and security risks. Moreover, neither of these options would support a viable second U.S. launch provider in the long-run.

The remaining three options each involve the development of a new engine and either modifications to the existing Atlas V or a new launch vehicle. This increases technical risks and requires more time before a second family of vehicles is available. Among these, Options 2 and 3 are the best positioned to support a commercially viable second launch provider in the United States. The current Atlas V vehicle design is already more than two decades old and is not price competitive with the Falcon 9. Changing the engine on the Atlas V, as proposed in

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[101] Arianespace, *Ariane 5 User's Manual*, Issue 5, Revision 2, October 2016, http://www.arianespace.com/wp-content/uploads/2011/07/Ariane5_Users-Manual_October2016.pdf.
[102] Arianespace, "Arianespace orbits two digital HDTV satellites, SKY Brasil-1 and Telkom 3S, on Ariane 5's 77th successful launch in a row," February 14, 2017, http://www.arianespace.com/press-release/arianespace-orbits-two-digital-hdtv-satellites-sky-brasil-1-and-telkom-3s-on-ariane-5s-77th-successful-launch-in-a-row/.
[103] Jacques-Louis Lions et al, *Ariane 5 Flight 501 Failure Report by the Inquiry Board*, Ariane 501 Inquiry Board, European Space Agency, (Paris, France: July 19, 1996(, http://esamultimedia.esa.int/docs/esa-x-1819eng.pdf.

Option 1, is likely to make it more expensive rather than less and will reduce its performance. Moving to a new launch vehicle and a new engine, as proposed in Options 2 and 3, creates at least the possibility of a viable competitor to SpaceX's Falcon family of launch vehicles. The key differentiators between Options 2 and 3 are development costs and schedule. Because Blue Origin is self-funding the development of the BE-4, the government investment required for Option 3 is less than Option 2. The development of the BE-4 is also farther along than the AR1, which means Option 3 is likely a more expeditious path to a new engine at this point. But judgement should be reserved until initial hot fire testing of the BE-4 commences later in 2017, at which point the remaining development challenges for the BE-4 will become clearer.

Ultimately, the best overall option depends on how each of the factors considered are weighted relative to one another. If the highest priority factors are minimizing costs and supporting the long-term competitiveness of the U.S. space launch industrial base, Option 3 (Vulcan / BE-4) appears more attractive. Alternatively, if the highest priorities are minimizing technical risks and transitioning away from the RD-180 as quickly as possible, Option 4 (Delta IV) appears more attractive.

4. Alternative Acquisition Strategies

Just as critical as the technical options for eliminating the United States' dependence on the RD-180 are the alternative business approaches to developing and purchasing space launch. Examining these alternatives makes it clear that the Department of Defense needs a new acquisition strategy for national security space launch. The EELV acquisition strategy, which led to the dependence of the U.S. on the RD-180 engine and resulted in two Nunn-McCurdy breaches, is no longer viable. Further, it is not clear that there is a viable strategy currently in place to guide the acquisition of national security space launch going forward. This chapter will explore current challenges to the national security space launch acquisition strategy, ingredients that should be considered in assembling a future strategy, and options for that future strategy.

Current Challenges to the Space Launch Acquisition Strategy

As previously described, the final iteration of the EELV acquisition strategy, which was developed between 2011 and 2013, had two prongs: a block buy from ULA consisting of launches, which only ULA could perform, and 14 other projected launches where competition was expected. This strategy has been massively disrupted. The imposition of the Budget Control Act caps in 2013 delayed many planned launches, and the first launch that was notionally going to be competed was contracted to SpaceX after ULA did not submit a bid. The proximate cause for ULA's decision not to bid in that source selection was ULA's understanding that, with the law in force that limited use of the RD-180 at the time of contract award, they could not use an RD-180 engine without undermining other contracted launches. The FY17 NDAA has resolved the immediate legal barrier to using the RD-180 until a U.S. replacement is developed. Even so, general consensus is that the Atlas V cannot win a primarily price-based competition with the Falcon 9, given the difference between ULA's launch costs and the launch prices that SpaceX has provided to the U.S. government and other customers to date.[104] Furthermore, the Air Force is working to end[105] another aspect of the EELV acquisition strategy—the EELV Launch Capability (ELC) contract—which is likely to result in the shift of even more costs onto future bids by ULA.[106] Additionally, ULA's contracts

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[104] The Air Force statement at the time of contract award indicates that the $82.7 million cost of the GPS III launch awarded to Space X was 40% cheaper than the initially projected cost of that launch.
Dana Hull, "SpaceX Launch Contract With U.S. Air Force Reduced Costs By 40%," Bloomberg, April 27, 2016, https://www.bloomberg.com/news/articles/2016-04-27/spacex-wins-defense-contract-launching-satellite-for-air-force.

[105] Mike Gruss, "U.S. Air Force evaluating early end For ULA's $800 million in yearly support," SpaceNews, January 27, 2016, http://spacenews.com/u-s-air-force-looks-at-ending-ulas-launch-capability-payment/.

[106] The ELC contract dates from the period where ULA was the sole launch provider to the U.S. government, and it provides funding to support launch infrastructure and production capabilities that are not directly tied to individual launches. At the time of the ELC contract, the government's primary objective was to maintain the existence of two launch vehicle families, as required by law, and to improve mission assurance. The ELC contract was designed to facilitate those goals by supporting the production lines and maintaining the launch infrastructure for Atlas V and Delta IV. SpaceX has no similar contract with the Air Force.

with the Department of Defense require the use of government cost accounting and other oversight mechanisms required in traditional government contracts. These administrative burdens are not included in commercial-style contracts such as those used with SpaceX. The use of different contracting approaches between ULA and SpaceX sharply limits the extent to which these contractors are competing on a level playing field. As a result, it is not clear that the "competitive" launch market envisioned for the launches outside the ULA block buy will occur at all under the existing acquisition strategy.

Figure 9: Delta IV During Booster Integration.

Source: NASA

Use of Public-Private Partnerships for Developing Space Launch Capability

Then Secretary of the Air Force Deborah Lee James and then Under Secretary of Defense for Acquisition Technology and Logistics Frank Kendall described DoD's concept for space launch going forward before the Senate Armed Services Committee on January 27, 2016. They outlined a plan to enter into public-private partnerships designed to lead to a situation in 2022 where there would be two U.S. providers of space launch using U.S. rockets with no dependence on Russian engines. They conceded, however, that this approach had a major flaw. While Congress has added over $350 million[107] to DoD to fund the development of alternatives to the RD-180, it had limited those funds to the development of a replacement rocket engine. However, as discussed in the previous chapter, DoD and others argued that developing only a new rocket engine runs the risk of producing a suboptimal technical outcome, and it likely does not deliver a market environment with two competitive launch systems. DoD requested, and Congress granted in the FY17 NDAA, the ability to use the funds provided by Congress to support the development of alternative launch approaches through public-private partnerships with companies interested in providing the government with launch as a service. It is not entirely clear, however, how DoD will achieve effective competition over the next five years, what market DoD envisions accessing when the planned

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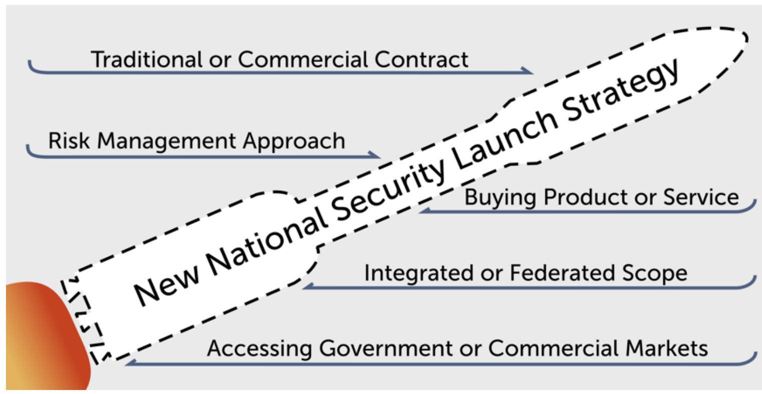
[107] This funding was added in increments of $220 million in FY15 and $134 million in FY16. The Air Force separately budgeted $84 million in FY16 and requested $297 million in the FY17 budget for "Next Generation Launch System Investment" and projects spending a total of $1.684 billion through FY2021.
Department of the Air Force, *Fiscal Year 2017 President's Budget Submission Research*, Development, Test, and Engineering, Volume II, 575-589.

public-private partnership(s) deliver results, and how the Department would respond if current plans are disrupted by the failure of a critical development program or market participant. These considerations should all be addressed in a future national security space launch acquisition strategy.

The Ingredients of a National Security Space Launch Acquisition Strategy

There are several key considerations that must be addressed to develop an acquisition strategy for national security space launch. One way to think of these considerations is as ingredients that combine as part of the overall acquisition strategy "recipe" to deliver the desired outcome. The following discussion looks at these ingredients—as well as some of the factors that may be in play in the space launch market in the next five to ten years that could influence the selection of these ingredients—as a prelude to discussing options for the space launch strategy.

Figure 10: Factors to Consider While Developing the Next National Security Launch Acquisition Strategy.



What DoD is Buying

It is tempting to think of buying space launch as buying rockets, and the nature of the current space launch debate, which revolves around launchers, rocket engines, and upper stages, reinforces this temptation. Indeed, the re-designation of EELV as an MDAP in 2012 essentially declared national security space launch to be a rocket acquisition program by legislative fiat. However, the commercial space sector treats space launch as a transportation service, and in fact, the official U.S. government policy is to treat space launch as a service as well. The reality is that national security space launch is something of a hybrid between a product and a service, exhibiting characteristics of both. In an environment where space launch is fully a transportation service, the government customer would generally not specify the transportation mechanism, i.e. the launcher. The government would simply specify its payloads, orbits, and timelines and leave the decision making about how to deliver them into the proper orbit up to the service provider. Instead, DoD specifies how its payloads are to be launched in some detail, requiring detailed knowledge about the launcher and its manufacturer and directing its launch service providers to use launchers from a family of launch vehicles that are capable of serving all of the government's needs. The government has maintained a deep level of involvement in the decision making of its launch service providers, especially during the period after the ULA joint venture was formed but before

Figure 11: Falcon 9's First Stage Landing on a Barge.

Source: Ars Technica

SpaceX was certified. During this time, there was no competition in national security space launch, and the government had an especially strong hand in every decision made relating to the launch of its payloads.

With a functioning, competitive, commercially-viable U.S. space launch market, launch acquisition can become more service-like. The potential emergence of an effective, reusable launch vehicle could play a decisive role in selecting between a product or service approach. If the space launch market reaches a point where acquiring a launch is no longer tied directly to acquiring a rocket, it will become much more imperative that launch be treated as a service. The challenge of specifying what DoD is acquiring is the most basic one involved in crafting an acquisition strategy. While appearing simple, it is not without risk. The 1997 EELV strategy assumed that DoD would be able to buy launch as a commercial service. When the U.S. commercial space launch market failed to materialize as expected, and changing business conditions led Boeing and Lockheed to combine their space launch businesses, the government was left with a sole-source launch provider with little commercial business. Moreover, the government was left with a set of commercial business arrangements that weren't designed for a sole-source, mostly government launch market. The government responded by imposing a variety of government-unique contract requirements on ULA in later years. The next space launch acquisition strategy will need to carefully assess how fully to treat launch as a commercial service.

The Market DoD is Accessing

Holding an Industry day, an event used to present current or future programs to industry for feedback, is typically one of the first steps that a new program manager takes when formulating a new acquisition strategy. This is because the next most critical aspect of formulating an acquisition strategy is knowing the market for the product or service you are buying. The market players, their strengths and weaknesses, and the incentives they respond to are all valuable inputs into the formulation of the acquisition strategy. As Chapter 3 shows, the options currently available in the national security launch market that meet DoD's legislatively mandated criteria are fairly clear. What is much less clear, however, is how the commercial launch market will evolve independent of DoD's plans. If the commercial space launch market grows rapidly, it could drive down costs in national security space launch, but it could also unbalance the relationship between, or undermine the market position of, DoD's launch providers. It may also generate new entrants, such as Blue Origin, who may desire to seek certification and join the competition, as happened with SpaceX. Because having the stability required for assured access to space is likely to remain the government's main priority, the government is unlikely to adopt a strategy that relies on emerging or unproven market actors. However, ignoring the evolution of the commercial launch market is likely to engender an equally dangerous failure of imagination with regards to the formulation of the national security space launch strategy.

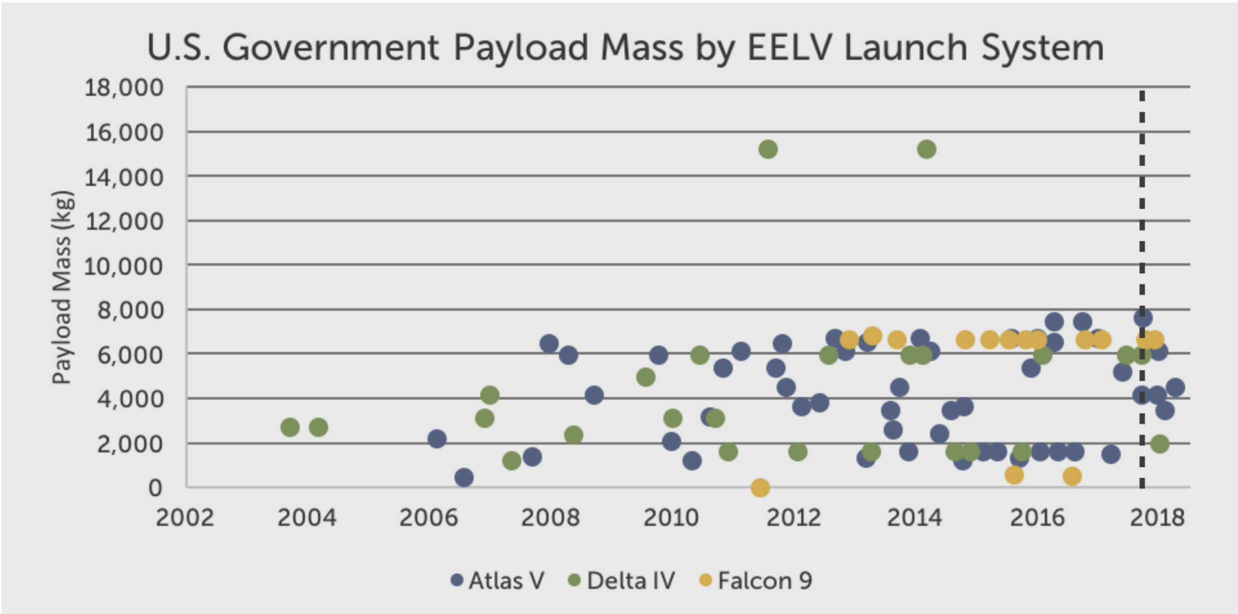
The Scope of What DoD is Buying

Another major ingredient for the acquisition strategy is scope: what range of launch services is DoD buying, and how integrated or federated does the service need to be? These questions are best explained through examples. The initial EELV acquisition strategy was designed to be highly integrated. Each EELV contractor was to develop and provide a single family of launch vehicles capable of launching the full range of government payloads. Today, however, the launch market is federated. SpaceX currently cannot launch the largest national security payloads (although the certification of the Falcon Heavy would alter this situation), and ULA launches the largest payloads with the Delta IV only, while using Atlas V for almost all other launches, except those allocated to Delta IV for reasons of supporting the production line. Use of the Delta IV for small and medium payloads, except when absolutely necessary, is cost prohibitive. There are three launch vehicle families in use today, none of which currently satisfies the full range of national security missions. As discussed in Chapter 3, U.S. law[108] requires DoD to have two space launch vehicles (or families of vehicles) capable of carrying any designated national security payload into space. The fact that the requirement is for a capability, rather than a demonstrated reality, is significant. The Atlas V has the capability to launch very large payloads if combined with several strap-on boosters and multiple upper stages, but this capability has not been used. If, on the other hand, the Falcon Heavy and the Vulcan deliver successfully on their plans, DoD would finally have access to two fully integrated families of vehicles.

The optimal scope of the launch services DoD needs to acquire is logically tied to the expectation of future national security launch manifests. For example, as a result of engineering trade-offs, a highly integrated launch family approach may involve paying slightly higher costs on smaller launches in order to pay lower costs on heavier launches. Such an approach may make great sense if the mix of launches is relatively even between heavy payloads and lighter ones (as has sometimes been the case for national security space launch). However, if the payload mix changes, a more federated approach could produce a better outcome. If, for example, the future manifest of launches consisted more predominantly of small payloads, and the cost of launching small satellites were to fall dramatically as a result of market disruptions (such as reusability), it might not make economic sense to use a single family of launchers to do both small and heavy payloads. In choosing the scope of the acquisition strategy, DoD must make predictions about the composition of future national security launch manifests and the future of the space launch market in general.

[108] 10 U.S. Code § 2273 (2016).

Figure 12: U.S. Government Payloads from 2002 to 2018



As Figure 12 shows, national security payloads during the period from 2006 to 2014 were distributed fairly broadly and evenly across the payload mass spectrum. In more recent years, however, payloads have tended to cluster around masses of 1600 and 6700 kilograms. This clustering is due in part to the development of smaller satellites that can either be packaged together in large numbers or launched as secondary payloads with larger satellites, which ensures that the launcher's full launch capacity is being utilized on each launch. The development of smaller satellites and the utilization of diverse approaches to payload packaging suggests that the market assumptions that supported older families of launch vehicles may already be shifting.

The Mechanism for Buying

A key decision in the acquisition strategy is the mechanism for buying launch. As already mentioned, the government is currently using widely different mechanisms to buy from ULA and SpaceX. ULA has traditional government contracts that ensure its costs are reimbursed and profit is paid. That said, those contracts come with significant overhead, requiring the use of government-unique accounting standards and including numerous contract clauses protecting the government's interests. The Department of Defense contract awarded to SpaceX was a firm fixed-price contract for a commercial item, which excludes most government-unique clauses.[109] SpaceX's commercial contract covered launch vehicle production, mission integration, and launch operations. If ULA had bid for this contract, it theoretically would have enjoyed the same commercial contract terms as SpaceX. However, given that previous government contracts required ULA to implement the full suite of

[109] Federal Business Opportunities, *EELV Phase 1A GPS III Launch Services*, No: 15-102, https://www.fbo.gov/index?s=opportunity&mode=form&id=0b1283691d975376e5d0a0a0118a84428&tab=core&_cview=1.

government-unique standards and practices, it is unlikely that ULA would have had the opportunity to engage in a commercial business approach for this contract. A related factor that is hard to quantify is the differential cost implications between SpaceX's certification process and the mission assurance requirements imposed on ULA in the aftermath of the late 1990s launch failures. The fact that the government is attempting to run a competition with these two launch providers while using fundamentally dissimilar contracting mechanisms and different mission assurance processes is problematic because it does not create a level playing field. These differences are illustrated in the table below.

Table 1: DoD Space Launch Contract Comparison

Firm	ULA		Space X
Contract	Block Buy Launch	Launch Capability	GPS III Launch
Contract Description	Launch Services, Rocket Hardware	Production Facilities, Launch Infrastructure	Launch Service
Contract Type	Firm Fixed Price	Cost Reimburseable	Firm Fixed Price
Commercial Item	No	No	Yes
Price Basis	Negotiation	Negotiation	Bid Price
Accounting Method	Govt. Cost Accounting	Govt. Cost Accounting	Commercial
Mission Assurance	Specified by Govt.	Specified by Govt.	USAF Certification

DoD has the opportunity going forward, however, to establish a new path and a more level playing field to facilitate real competition. DoD testified to the Senate Armed Services Committee that the public-private partnerships it would like to pursue for launcher development would be structured as Other Transaction Authority (OTA) agreements.[110] OTAs[111] can be specifically tailored to include as much or as little of the traditional government-unique contract clauses as the parties prefer, but are generally used to avoid including these terms.[112] If the Vulcan is developed under an OTA, it may not be required to

[110] U.S. Congress, "Hearing to Receive Testimony on Military Space Launch and the Use of Russian-Made Rocket Engines, Senate Armed Services Committee," January 27, 2016, 14, http://www.armed-services.senate.gov/imo/media/doc/16-06-1-27-16.pdf.
[111] Other Transaction Authority (OTA) agreements are a mechanism developed to allow the government to enter into business arrangements without the usual panoply of detailed contract terms. OTAs were originally developed to enter into research and development agreements with non-traditional suppliers. Their use has been expanded over time to include initial production stages and a wider range of suppliers. Statutory authority for DoD to enter into OTA agreements is codified at 10 U.S.C. 2371b.
[112] This arrangement gives rise, however, to the question of what rights will be obtained by the government for its contribution to the public-private partnership, which is likely to be a substantial share of the development cost. A

track its development and operational costs using traditional government-unique accounting standards. This would allow both SpaceX and ULA to operate under the same contracting mechanism once the Vulcan becomes operational. In the alternative, however, it seems unlikely that SpaceX would ever agree to accept traditional government-unique contract terms. So if a level playing field in space launch is to be adopted, it will almost certainly require the use of commercial contract terms.

In some respects, this approach mirrors the original EELV strategy, which also used OTAs to develop the Atlas V and Delta IV launcher families, rather than traditional contracts, because of the expectation that commercial launches would compose a significant share of EELV payloads. However, this expectation proved to be flawed in the late 1990s and early 2000s. While there were many emerging commercial space companies in the 1990s, compared to today, there were few commercially-oriented space launch companies with significant private-sector financing. The apparent development of a commercial space launch market in recent years, at least at an early stage, suggests a higher likelihood that the era of commercial launch is arriving.

Managing Risk

The last major ingredient in the next national security space launch acquisition strategy is an approach to managing risk, including both technical and business risks. In most defense acquisition programs, technical risk is the predominant risk, as development programs are seeking to push the technological boundaries of performance. Technical risk in the next national security space launch acquisition strategy, however, is likely to be limited, as the basic Falcon 9 launcher is already developed, and its Heavy variant is approaching initial launch. The development required for a competing system is more substantial but does not appear to require any pioneering of technical advances. Indeed, the more pressing concern for a new launch vehicle today is cost, rather than performance. A critical factor will be determining the mission assurance levels necessary to achieve the launch certification for competing systems that was given to SpaceX.

Business risk can also have a profound effect on programs, especially those that are dependent on, or highly influenced by, outside market forces from overlapping or adjacent commercial markets. Both under and over performing markets can affect the acquisition strategy. In the late 1990s, the risk of under performance in the commercial market was realized. Commercial market under performance will remain a risk going forward, but there is also risk in the coming years that today's growing commercial space market may develop quickly in directions that undermine the next acquisition strategy (for example, by creating stiff competition for launch capacity between the government and commercial launch customers). A form of business risk undermined DoD's Joint Tactical Radio System (JTRS) program when commercial communications developments rapidly overtook the government's effort to develop software-defined radios and made elements of the JTRS program obsolete before they were completed.

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variety of outcomes are possible including ownership rights in the design, government purpose rights, stock warrants (as sometimes obtained in return for investments by In Q Tel), or a share in revenues.

A related form of business risk is the potential for the failure of key market participants. Launch providers and their key suppliers will need to have continued market viability, likely including some degree of commercial viability, for the next strategy to succeed. An important method for managing this risk will be how the competition between launch providers is designed. This design will have to strike a balance between ensuring the viability of full service national security launch providers and ensuring DoD's ability to access new entrants that are offering new capabilities.

Options

While there are countless potential approaches to the next space launch acquisition strategy, there are a few dominant options that have emerged, with most other approaches being variations on those. The main options center around whether to focus on maintaining one to two full-service, integrated launch providers or whether to open up the market more broadly to new entrants, potentially including competition from launch providers who may be interested in serving only part of the national security launch market.

Table 2: DoD Options for Competition

	Block Buy with Limited Competition	Allocated Competition	IDIQ[113] Competition	Full & Open Competition
Objective	Ensure One Full Service Launch Provider	Ensure Two Full Service Launch Providers	Obtain Full Service Launch with Enhanced Competition	Maximize Competition and Access to Commercial Launch Market
Competitive Cycle	Compete once for five year or longer block buy contract. Compete reserved launches annually	Compete once for five year or longer contract	Compete once for minimum awards and during contract for additional launches	Launches competed at least annually
Minimum Award	Enough launches to ensure viability of main launch provider and obtain some	Close to but less than half the total number of launches over contract period	May vary somewhat by awardee but all minimum awards are a relatively small	None

[113] Indefinite Delivery/Indefinite Quantity (IDIQ) is a business arrangement (and a type of contract) where a company agrees to supply materiel or services to the government over a period of time but the exact quantities and timing of delivery are specified over the course of the arrangement in task or delivery orders.

	economic order quantities. No minimum for other launch providers		share of total number of launches	
What DoD is Buying	Product/Service Hybrid	Product/Service Hybrid	Mostly Service	Service
Market DoD Accessing	Mostly DoD	DoD/Commercial Hybrid	DoD/Commercial Hybrid	Commercial
Scope DoD is Buying	Block Buy Integrated/Competition Federated	At Least Two Integrated Providers	Two or More Integrated Providers	Federated
Mechanism for Buying	Traditional DoD Contract for Block Buy/Commercial Contracts for Competed Launches	Traditional DoD or Commercial Contracts	Mostly Commercial Contracts with limited DoD-unique Clauses	Commercial Contracts
Primary Risk DoD is Managing	Potential Cost Growth of Main Launch Provider	Potential Divorce from Commercial Space Launch Market	Potential Emergence of Monopoly Launch Provider	Existence of Sustainable Commercial Launch Market
Prime Example	Current National Security Space Launch	Navy Shipbuilding Destroyers	NASA Commercial Resupply Service 2	TRANSCOM[114] Airlift

Block Buy with Limited Competition

An approach using a block buy with limited competition ensures that DoD has at least one full service provider, while providing the opportunity for other launch providers to compete for a limited number of launches. The initial block buy contract would be a multi-year contract of at least five years in duration, which would be competed on a combination of technical merit and price. The number of launches in the block buy would be determined by the minimum number required to ensure the viability of one full-service launch provider and to obtain some economies of scale by committing to multiple launches. Launches would be reserved outside the block buy to ensure that some launches are available for competition. The technical merit evaluation would include considerations such as the reliability of the supplier and their ability

[114] United States Transportation Command (TRANSCOM) is the combatant command responsible for providing full-spectrum global mobility solutions to its supported customers who are largely other DoD components.

to service the full range of the government's needs. This approach would be similar to the current acquisition strategy, except that, unlike the current system, the initial block buy would be awarded after competition. For example, if the number of launches planned over the course of the contract is 20, the block buy would include 12-14 launches chosen to ensure the winner maintains the full range of required government launch capabilities, and 4-6 launches would be reserved for competition. The reserved launches would be separately awarded after competition, with price as the determining factor. This option focuses on achieving efficient production rates on at least one full service family of launch vehicles but runs the risk of cost growth if the winning government launch provider is not also competing in the commercial launch market—or other markets where price competitiveness is required.

Allocated Competition

This option focuses on achieving and maintaining two full service launch providers. It would establish a competition for launch service providers to develop and deliver families of launch systems that meet the full scope of the government's needs. Contracts of at least a five-year duration would be awarded to two teams after a competition. The competition would include consideration of both price and technical merit. Technical merit would be the main determining factor in selecting the launch service providers and would include the same considerations as in the block buy option. Limited price competition would be achieved by awarding a larger number of launches to the winning bidder that submitted the lower price. The second bidder selected would receive a smaller, but still substantial, number of launches. For example, if the contract is expected to include a total of 20 launches, the winner might receive 12 launches, and the second awardee might receive 8 launches. This approach would be similar in many respects to the 1997 EELV competition,[115] NASA's initial commercial resupply service competition,[116] and the way that the Navy has allocated destroyers between its two destroyer shipyards for a number of years. It focuses on obtaining assured access to space through maintaining two full service launch providers, but runs the risk of divorcing DoD from the commercial space market, with this risk increasing over time.

IDIQ Competition

Indefinite Delivery/Indefinite Quantity (IDIQ) Competition option allows for more competition, additional entrants, and provides less protection to the market position of competitors. It would establish a competition for launch service providers capable of meeting the full scope of the government's needs. Two or more launch service providers would be selected based on a combination of technical merit and price and then awarded IDIQ contracts for multiple launches. Each selected provider would be guaranteed a relatively modest minimum number of launches. For example, if the total number of launches during the period of the contract is expected to be 20, there may be 3 total awardees, each receiving

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[115] In October 1998, the United States Air Force awarded Initial Launch Services contracts to two providers, Boeing and Lockheed Martin for a total of 28 launches. Boeing was awarded 19 launches and Lockheed Martin was awarded 9.

[116] John Yembrick and Josh Byerly, *Nasa Awards Space Station Commercial Resupply Services Contracts*, National Aeronautics and Space Administration, December 23, 2008, https://www.nasa.gov/offices/c3po/home/CRS-Announcement-Dec-08.html.

a minimum award of 4 launches, with the remaining 8 launches competed over the course of the contract. The most competitive bidder could obtain significantly more launches than the minimum number, up to a total of 12. This approach would be similar to NASA's second commercial resupply service competition. It focuses on ensuring that DoD has access to the best services available on the market and encouraging competition in the short term, but it runs the risk of allowing a dominant market actor to emerge, potentially limiting future competition.

Full and Open Competition

A full and open competition option allows for the most price competition and greatest access to the commercial space launch market. It would allow launch service providers to bid to service the entire scope of government launch or to bid for only portions of the launch portfolio. Multiple launch service providers would be selected based on how well they meet the government's needs and with a heavy emphasis on price. Competition would be annual, and there would be no minimum awards. For example, if the total number of planned launches in a year was 20, there might be a total of 6 awardees, with one receiving 6 launches, two receiving 4 launches each, and 3 others receiving only 2 launches each. This approach would be similar to how TRANSCOM awards airlift contracts.[117] It focuses on maximizing competition and innovation in offering launch services, but it runs the risk of undermining the government's ability to ensure that there are at least two launch providers that can service the entire scope of the government's needs if the market becomes highly federated.

Evolving the National Security Space Launch Acquisition Strategy

The most likely outcome is that the national security space launch acquisition strategy will need to evolve over time. As NASA demonstrated with its commercial resupply service (CRS) contracts, the government can modify its approach in successive contracts as the market matures. NASA's initial CRS contract was designed to establish initial commercial resupply service providers and used an allocated competition approach to ensure that NASA achieved that objective. The second CRS contract built off the success of the first, and it also took advantage of additional competitors working on other NASA launch efforts to allow for more competition, like the IDIQ competition option. The space launch market doesn't currently match the level of maturity that exists in the air cargo market, but is necessary to support an option like the full and open competition model. However, it is possible that it could reach such a stage in the future if the commercial space launch market experiences rapid growth. In the near term, given the challenges confronting national security space launch, allocated competition between SpaceX and ULA may be the most viable option until a more competitive market emerges. The key decision in the near term will be how many public-

[117] Daniel Wilson, "FedEx, Others Get $545M In DOD Airlift Services Contracts," Law360, October 2, 2014, https://www.law360.com/articles/583517/fedex-others-get-545m-in-dod-airlift-services-contracts.

private partnerships DoD will establish to develop potential competitors to create a more competitive approach in the 2020s.

Conclusion

The Russian RD-180 rocket engine has been an integral part of the U.S. military's space launch capabilities since the 1990s. The RD-180 was chosen for the Atlas V because it was an advanced rocket engine with unmatched technical capabilities. The decision to use the RD-180 was influenced by many other non-technical factors as well, such as the United States' geopolitical goal of easing the former Soviet Union's transition from communism and U.S. industry's desire to remain competitive in the global launch market. And despite the EELV program's cost overruns and program restructurings, the RD-180 has helped the U.S. military achieve its goal of mission assurance for the launch of national security payloads.

From the beginning, the U.S. government and its industry partners planned to eventually transition production of the RD-180 to the United States. However, after costs began to rise on the EELV program, this goal was repeatedly delayed. In 2007, the government decided to forego the goal of producing the RD-180 domestically, and instead chose to stockpile enough engines to mitigate the risk of a supply disruption. This approach held until the 2014 Russian invasion and annexation of Crimea. With the imposition of U.S. sanctions against Russia and Russian threats to retaliate by possibly withholding sales of the RD-180, policymakers made breaking the reliance on Russian engines a top priority.

Under current law, DoD must end its dependence on the RD-180 by 2022. It also remains the policy of the United States to maintain two independent launch vehicle families capable of launching all national security space payloads. Assuming that the Falcon 9 and Falcon Heavy (once certified) will be one of the two launch vehicle families, DoD must still have an alternate launch vehicle family that does not utilize the RD-180.

The Aerojet Rocketdyne AR1 engine currently under development is the closest to being a drop-in replacement for the RD-180. However, because it is heavier, has a higher thrust, and has a lower I_{sp}, the AR1 would require modifications to the existing Atlas V launch vehicle that would lower the vehicle's overall performance. The same AR1 engine could also be used on the new Vulcan launch vehicle, which would achieve higher performance than the current Atlas V. The Vulcan could also be powered by Blue Origin's new BE-4 engine, which is further along in development than the AR1 and largely self-funded by Blue Origin. All three of these options have some level of technical risk because they are new development programs, and each launch option would take several years before it is certified to launch national security payloads.

Alternatively, the existing Delta IV and Ariane 5 families of launch vehicles could be used to launch payloads currently serviced by the Atlas V. Both would involve less technical risk and would be available immediately because they are already in production and have well-established safety records. However, the Delta IV family of vehicles is much more expensive than the Atlas V and Falcon 9, which means it is not a viable competitor in the long-term. And because the Ariane 5 is a European-made launch vehicle, its use would create a host of security and political challenges. Policymakers must weigh each of these options and consider a range of factors, such as schedule, cost, technical risks, and the long-term competitiveness of the U.S. space launch industrial base.

Simultaneously, the Defense Department will need to reconsider its acquisition strategy for the next phase of the EELV program. As public-private partnerships continue to evolve, DoD should consider the critical ingredients necessary to make its acquisition strategy successful, including: 1) the nature of the acquisition; 2) the health of the commercial space launch market; 3) the range and scope for purchasing launch services and how integrated or federated this needs to be; 4) the mechanism for purchasing launch; and 5) the management of risk in space launch acquisition.

With these ingredients in mind, there are several different ways to have successful, but varying, amounts of competition in the national security space launch market. Block buys allow for limited competition that assures some access to space with one launch provider while allowing for competition for a smaller, but still significant, number of launches. Allocated competition focuses on achieving and maintaining assured access to space through two launch providers. IDIQ competition obtains full service launch with enhanced competition. Lastly, the most price-competitive option comes from full and open competition.

The global space market is poised to grow significantly over the coming decade, and the U.S. government should position itself to support and reap the benefits of this growth. This will require some flexibility and perhaps new approaches for how the government buys space launch. The transition away from the RD-180 is an opportunity for the U.S. government to remake the EELV program so that it avoids mistakes from the past and supports a robust and innovative national security space program.

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