

The RD-180 Rocket Engine Policy Issue Guide

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Preface

The *Issue Guide Series* is a series of reports researched and written by the George C. Marshall Institute. The series examines current issues facing the space community while providing background information on important problems and policy decisions.

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Introduction to the RD-180 Engine Policy Issue

One of the most reliable rockets for launching spacecraft is the United Launch Alliance (ULA - a joint venture between Boeing and Lockheed Martin) Atlas V launch vehicle.¹ The Atlas V is a two-stage expendable launch vehicle that relies on two separate types of engines, one Russian-made RD-180 engine for the first stage and the domestically produced RL-10 engine for the second stage. Currently, the Atlas V is one of three launch vehicles families certified in the Air Force's Evolved Expendable Launch Vehicle (EELV) Program for the launch of national security payloads.² As a result, the Atlas V is relied upon heavily to launch national security satellites. After Russia threatened to ban the export of the RD-180 engine to the United States in May 2014, the wisdom of relying on the engine seems less obvious. This Issue Guide reviews the history of the Russian engine in U.S. launch vehicles, examines how use of the RD-180 engine became problematic, and considers the potential results of a ban of the RD-180 engine.

History of the United States Use of the RD-180 Engine

The integration of the RD-180 engine into the Atlas launch vehicle began in April 1993 when Vice President Al Gore and Russian Prime Minister Victor Chernomyrdin agreed to technical cooperation with the United States that allowed Russia to partner in building the International Space Station (ISS). One major goal for cooperation was to

prevent Russian scientists from immigrating to countries such as Iran and North Korea interested in developing ballistic missiles.³ This agreement provided the Russians with a \$400 million contract to continue to develop space hardware and employ the Russian space industry.⁴ On September 2, 1993, the United States and Russia entered into a trade agreement that created commercial opportunities with the Russian military-industrial complex and consequently the ability to launch American-made satellites.⁵ Through these agreements, Lockheed Martin and Pratt & Whitney were able to work with Russia and obtain the rights to use the Russian-made RD-180 engine.

At this time the Department of Defense (DoD) was searching for a new generation of launch vehicles through the EELV Program (the primary program of launch vehicles for U.S. defense satellites) to assure access to space for government satellites at an affordable rate.⁶ The Gore-Chernomyrdin Commission and the trade agreement allowed Lockheed Martin to search in the former Soviet Union for a more powerful engine to use on the Atlas IIAR launch vehicle. In 1995, Lockheed Martin opened a competition for a new engine and selected the RD-180 rocket engine.⁷ There were three main reasons for selecting the RD-180:

- 1) The RD-180 is a liquid, oxygen-rich, closed-cycle combustion technology that delivered a twenty-five percent performance increase, a great improvement over U.S. rocket technologies at the time.⁸
- 2) The costs were lower. NPO Energomash, which is majority-owned by the Russian government, produced sixty-three engines that were sold to the United States for half of their real production value of \$11-15 million each.⁹ The agreement also allowed for domestic U.S. development of the engine, but while this was technically feasible, the costs were prohibitive.¹⁰
- 3) The production of the RD-180 would employ under-utilized space and defense workers in Russia.

Sanctions

After Russia forcibly annexed Crimea from Ukraine in early 2014, President Obama issued two Executive Orders, on March 6 and March 17, 2014, that placed sanctions on individuals or entities operating in Russia's arms or armament-related industrial sector.¹¹ Deputy Prime Minister Dmitry Rogozin, who is also head of the Russian space industry, was among the targets of these Executive Orders.

Mitchell Report

Previously, Russia had no significant objections to the U.S. using the engine for launching national security space satellites. With the sanctions in place, however, then Secretary of Defense Chuck Hagel asked the U.S. Air Force to review the U.S. use of the RD-180 and the implications of using the engine, including supply interruptions.¹² The review, also known as the Mitchell Report, concluded:

- neither the Delta IV nor a new entrant can fully replace the Atlas V through FY2017;
- near-term actions are required to mitigate the potential loss of the RD-180;
- disruption to the RD-180 supply limits competitive options; and
- reliance on the commercial markets cannot meet the needs of the Department of Defense and intelligence community.¹³

According to the report, the United States will rely on the RD-180 for more than fifty-six percent of future EELV launches between FY 2014-FY 2020. Absent another vehicle to make up those launches, the RD-180 will continue to play a major part in U.S. national security space launches.

The Mitchell report concluded that immediate actions are required to mitigate current risks while preserving future options. The authors' urged the United States to develop a new engine to replace the RD-180 and to power a next generation launch vehicle.

Lawsuits

On April 30, 2014, SpaceX filed a lawsuit against the U.S. Air Force on the grounds that it entered into an unlawful contract with ULA for the provision of satellite launches.¹⁴ The suit argued that the contract was illegal since the majority of ULA launch vehicles use the RD-180 rocket engine, which is made by NPO Energomash, headed by Deputy Prime Minister Rogozin who is sanctioned by President Obama's Executive Orders. The preliminary injunction prohibited the Air Force and ULA from making any purchases from, or paying money to, NPO Energomash or any other entity subject to Rogozin's control.¹⁵ This injunction highlighted the U.S. dependence on a hostile foreign power in order to launch vital defense systems into space.

The preliminary injunction was lifted on May 8, 2014, based on the legal responses by the U.S. Departments of Treasury, Commerce, and State. The sanctions targeting Russia are enforced by the Department of the Treasury, which alone decides when to implement the "owned or

controlled by” prohibitions. In this case, the Department of the Treasury made no such determination to trigger the prohibitions on NPO Energomash, so the Air Force and ULA had neither directly nor indirectly contravened the sanctions.¹⁶ The preliminary injunction was lifted and ULA continued to purchase the RD-180 engines and use the Atlas V launch vehicle.

The Twitter Declaration

After the sanctions were imposed against Russian individuals and entities, and the U.S. denied export licenses for high-technology items that could support Russian military forces, Russia threatened to suspend delivery of the RD-180 engines. On May 13, 2014, Deputy Prime Minister Dmitry Rogozin announced on Twitter that, “Russia is ready to continue deliveries of RD-180 engines to the U.S. only under the guarantee that they won’t be used in the interests of the Pentagon.”¹⁷ Despite this threat, and the knowledge that the loss of the RD-180s would significantly delay national security space launches, ULA continues to receive original RD-180 orders for national security launches.¹⁸

Policy for Developing a New Engine

The threat of a ban on the RD-180 drew a quick response from the U.S. Congress. In April 2014, the House of Representatives passed legislation for the domestic development of a new engine to replace the RD-180 by 2019¹⁹ and in late May 2014, the Senate Armed Service Committee endorsed a similar plan.²⁰ In December 2014, Congress announced a deal that included \$220 million for a new liquid rocket engine to replace the RD-180 by 2019.²¹ Congress additionally banned the future use of the RD-180 for the EELV Program after ULA completes its thirty-six, block-buy launches, which are scheduled until 2018.²²

When the RD-180 became a policy issue, the White House did not publicly support or oppose the development of an indigenous engine to replace the RD-180. Several congressional leaders sent a letter urging the White House to join in their support for a new engine.²³ In mid-June 2014, the White House wrote to Representative Hal Rogers (R – KY) in reference to the Department of Defense Appropriations Act, 2015, objecting to the House proposal of \$220 million for a new rocket engine. The White House argued that such an action would be premature, and the engine would take eight years to develop, could cost up to \$4.5 billion, and would not reduce American reliance on the RD-180 engine for at least a decade.²⁴ The White House also believes that developing a new engine independent of the rest of the launch system risks millions of dollars without ensuring an operational launch system.²⁵

Extension of the RD-180

ULA, Secretary of Defense Ashton Carter, Director of National Intelligence James Clapper, and Secretary of the Air Force Deborah Lee James have asked Congress for an extension on allowing ULA to use additional RD-180 engines for national security launches that were ordered, but not paid for, before the invasion of the Crimea.²⁶ The additional fourteen engines are required for ULA to continue launching until a new engine is ready. The House supports the extension of the fourteen engines, but the Senate only supports the extension of nine more engines because it wants to prevent funding Russia's military industrial base.²⁷ The White House supports the continued use of the RD-180 and argues that restrictions will inhibit the Department of Defense's assured access to space.²⁸

Launch Gap

Although Congress wants a replacement engine by 2019, Air Force Secretary Deborah Lee James told Congress that this date is unrealistic because it takes six to eight years to develop an engine and one to two years to integrate the engine with a rocket.²⁹ There are no true replicas of the RD-180 being domestically developed because it would cost around \$1 billion and take five years.³⁰ There are also no other engines that can be quickly installed into the Atlas V because it requires alterations to the vehicle. A new engine integrated into an existing launch vehicle would effectively be a new rocket and would need to go through a new certification process.³¹ The certification process for new launch vehicles is not quick and requires several reviews by the Air Force.

If the ban on the RD-180 were to remain, the U.S. would have only one launch provider for national security launches beginning around 2019 and lasting until 2022, which would be the earliest opportunity to fly a newly certified launch vehicle.³² The Delta IV launch vehicle is scheduled for retirement; it cannot compete financially against the Falcon 9, built by SpaceX.³³ Thus, the Falcon 9 would be the only certified national security launch vehicle available to the Department of Defense and the intelligence community.³⁴ Having SpaceX as the only domestic launch provider would contradict the 2013 National Space Transportation Policy, which requires at least two U.S. space transportation vehicle families capable of reliably launching national security payloads and introduces competition to lower the costs of launching satellites.³⁵

The second gap will be between the retirement of the Delta IV heavy launch vehicle and a new heavy lift vehicle. Currently the Delta IV heavy costs between \$300-400 million per launch. If

ULA cannot use the RD-180 after 2018, the Delta IV heavy costs will rise to nearly \$1 billion per launch as ULA launch rates to maintain this price would collapse. With a limited amount of launches, the cost per launch would increase. The U.S. Congress would be wary of paying this much for a launch and the Delta IV heavy would be retired due to the high costs³⁶ While Congress is reluctant to pay such a high price for a launch, it previously paid a high amount during the 1990s with the Titan rocket family.³⁷ The alternative heavy lift vehicle is the SpaceX Falcon Heavy launch vehicle, but there are doubts about whether SpaceX can meet their expected certification date of 2018, leaving a gap of unknown time before a launch vehicle replacing the Delta IV is available.³⁸ The first test launch of the Falcon 9 heavy will occur in 2016, and the certification process will follow.³⁹ But, while SpaceX shows promise with its launching abilities of the Falcon 9 and experience with the certification process, the 2018 date is a very aggressive deadline for a very demanding rocket.⁴⁰

Replacement Engines and Other Launch Vehicles

Despite the Russian threat to ban some exports of the RD-180, ULA is receiving engines as scheduled and expects to carry on taking delivery of them through 2017 for the block-buy.⁴¹ As noted, the Air Force has requested proposals for the development of a domestically produced engine to replace the RD-180.⁴²

Though it will take years to develop a new engine, several companies have expressed interest in the undertaking. ULA and Blue Origin agreed to jointly develop the BE-4 engine and create the Vulcan rocket. Blue Origin began development of the BE-4 in 2011, and it has plans for quicker production rates, greater capacity, and better affordability.⁴³ Testing of the engine is planned for 2016, with the first flight in 2019.⁴⁴ Certification would take place by 2022 or 2023.⁴⁵

Aerojet Rocketdyne joined in the development race as a contingency plan to the Blue Origin and ULA partnership.⁴⁶ Aerojet Rocketdyne and ULA will explore using the AR1, an existing Aerojet Rocketdyne booster engine, as a replacement of the RD-180.⁴⁷ Each pair of AR1 engines would reportedly cost between \$20-25 million.⁴⁸ The AR1 is a comparable engine to the RD-180 as both engines use liquid oxygen/kerosene fuel. A consortium of Aerojet Rocketdyne, Dynetics Incorporated, and Schafer Corporation want to obtain the data rights to the Atlas V in order to adapt the AR1 to it in order to create a low-risk, affordable rocket. The companies believe the AR1 and a repurposed Atlas V could possibly gain certification in 2019.⁴⁹ ULA and Lockheed Martin, who own a significant portion of the data rights, are not interested in selling these rights to another company.⁵⁰

Orbital ATK offered the Air Force a replaceable solid propulsion rocket motor that could be available within three years and at a lower cost than other U.S. engines.⁵¹ But replacing the liquid-fuel RD-180 with a solid-fuel engine would be difficult, time consuming, and require a significant redesign to the launch vehicle.

SpaceX will compete against ULA to launch national security payloads with the Falcon 9, as it became certified to launch them on May 26, 2015.⁵² The Falcon 9 will compete against the remaining Atlas V launch vehicles for national security space launches that are not associated with the block-buy contract. With the certification -- and if a ban on the future purchase of the RD-180 engine were to remain intact -- the Falcon 9 would provide launching capabilities for most national security payloads.

The Vulcan Launch Vehicle

On April 13, 2015, ULA announced that the Vulcan Rocket would become their main launch vehicle of the future.⁵³ Vulcan will be based on previously successful ULA work, but with new designs. The first stage will use heritage Delta IV technologies because of the BE-4's need for a large diameter booster.⁵⁴ The new designs, coupled with cutting-edge manufacturing technologies incorporated into the first stage, should lower costs, but it may still be costly since it will be derived from the expensive Delta IV.⁵⁵ With increased production and launches, the price per launch should decrease, but the actual costs are not yet known. Vulcan will need a high production rate to be commercially competitive; it would not be competitive with only two launches per year.⁵⁶ The rocket would initially incorporate the Atlas V second stage, but then it would use a new second stage with the RL-10: a BE-3 or XCOR engine.⁵⁷ The rocket is being funded on a quarterly basis by Lockheed Martin and Boeing -- an indication that there are some doubts about the program on their part.⁵⁸

ULA is also investigating the use of reusable engines for Vulcan.⁵⁹ If this plan is implemented Vulcan would jettison the BE-4 engines after the first stage is complete. The joined engine would then re-enter Earth's atmosphere using a hypersonic inflatable aerodynamic decelerator. Once the engine slowed to low subsonic speed, a parafoil would deploy and a Chinook helicopter will capture the engines mid-air.⁶⁰ This method is similar to the satellite capture method that was used on spy satellites before digital imaging and downloading capabilities were available.

Reusable engines can lower costs if there is a large enough demand for launch services, but the number of launches is not expected to increase enough to justify a Vulcan reusable rocket or engines.⁶¹ While there will be an increase in private launches, the majority of future launches of

small satellite constellations are attached to ULA competitors. Companies creating constellations, such as Planet Labs, Google's Skybox Imaging, or OneWeb, will be inclined to use competitors, as these companies have invested in other rocket companies and the satellites are scheduled for launch before the Vulcan Rocket is operational.⁶² Small, cube-, nano-, and micro-satellites are being launched more frequently, but Vulcan cannot rely on these satellites to justify the costs of the reusability concept.

Conclusion

The RD-180 has been a stalwart engine for the Atlas V rocket, but it may become unavailable at any time due to the continuing deterioration of U.S.-Russian relations. To ensure U.S. access to space, another launch vehicle and engine is needed. There are a few engine options available, but they will require several years to develop, test, and certify. Retiring the Delta IV put the U.S. in a difficult situation, since it forces U.S. policymakers to choose between extending the use of the RD-180 or relying only on SpaceX for national security launches for an unknown period of time. There is no clear path or risk-free solution to this complex issue. Whether it is extending the use of the RD-180, creating a brand new engine, relying on SpaceX as the sole commercial provider until another vehicle is available, reversing the retirement decision on the Delta IV launch vehicle while lowering costs, or a combination of these options, the U.S. will still need to launch national security payloads and is now facing a truly wicked problem that will endure for years to come.

¹Note: The Atlas V has a 100 percent launch rate, but NRO Payload NROL-30 launched on June 15, 2007 had the Centaur upper stage and experienced a fuel leak which resulted in the two satellites being placed into a lower than intended orbit. The Air Force still considered the launch a success.

Gunter's Space Page, *Atlas V*, Last Accessed on August 18, 2015 http://space.skyrocket.de/doc_lau/atlas-5.htm
Stephen Clark, "New Engine Valves Installed on Atlas and Delta Rockets," *Spaceflight Now*, August 16, 2007, <http://www.spaceflightnow.com/news/n0708/16r10valve/>

² Note: The other two are ULA's Delta IV and SpaceX's Falcon 9.

³ Note: The cooperation was done through the Commission on U.S.-Russia Technical Cooperation. Marcia S. Smith, "NASA's Space Station Program: Evolution and Current Status," Testimony before the House Science Committee, *Congressional Research Service*, April 4, 2001, 3, <http://history.nasa.gov/isstestimony2001.pdf>.

⁴ U.S. Department of State, *Fact Sheet: Gore-Chernomyrdin Commission*, June 20, 1995, Last Accessed December 10, 2014, <http://dosfan.lib.uic.edu/ERC/bureaus/eur/releases/950620Gorer.html>.

⁵ Senator Daniel Akaka, *Has the Russian Space Launch Quota Achieved its Purpose?*, International Security, Proliferation, and Federal Services Subcommittee of the Committee on Governmental Affairs for the United States Senate, 106 Congress, July 21, 1999. <http://www.gpo.gov/fdsys/pkg/CHRG-106shrg59455/html/CHRG-106shrg59455.htm>.

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*, September 2, 1993, <http://www.gpo.gov/fdsys/pkg/FR-1994-03-10/html/94-5498.htm>

⁶ Christina Chaplain, “Evolved Expendable Launch Vehicle: Introducing Competition into National Security Space Launch Acquisitions,” *United States Government Accountability Office*, GAO-14-259T, March 5, 2014, 3, <http://www.gao.gov/assets/670/661337.pdf>.

⁷ Note: Pratt & Whitney was selected by NPO Energomash to represent the marketing production, application and sales of the engine to the US. NPO Energomash, “Projects,” *NPO Energomash*, Last Accessed on December 8, 2014, <http://www.npoenergomash.ru/eng/dejatelnost/ved/>

⁸ Brooke Mosley, “RD-180 Engine: An Established Record of Performance and Reliability on Atlas Launch Vehicles,” *United Launch Alliance*, August 2011, 1, http://www.ulalaunch.com/uploads/docs/Published_Papers/Evolution/RD180EstablishedRecord201108_0201.pdf.

⁹ Majority Owned: Peter B. de Selding, “Profile: Leonard R. Dest, Chief Executive, RD Amross,” *SpaceNews*, January 4, 2010, <http://www.spacenews.com/article/leonard-r-dest-chief-executive-rd-amross>

Cost of Engine: RT News, “Russian Rocket Engine Export Ban Could Halt US Space Program,” RT News. Last Accessed December 10, 2014. <http://rt.com/news/russian-rocket-engine-ban-039/>.

¹⁰ Jeff Foust, “The Case for Kerolox,” *The Space Review*, October 14, 2013, <http://www.thespacereview.com/article/2384/1>

¹¹ Note: The Executive orders for the sanctions are Executive Order 13660 and 13661. They can be found at the Office of the Press Secretary, “Background Briefing by Senior Administration Officials on Ukraine,” *The White House*, March 17, 2014, <http://www.whitehouse.gov/the-press-office/2014/03/17/background-briefing-senior-administration-officials-ukraine>

¹² Tony Capaccio, “Pentagon Asks Air Force About Russia Rocket Engine,” *Bloomberg*, March 20, 2014, <http://www.bloomberg.com/news/print/2014-03-20/pentagon-asks-air-force-about-russia-rocket-engine.html>

¹³ H.J. Mitchell, Michael Griffin, Thomas Moorman, Erik Krystkowiak, Jim Norman, Pat Youngson, Rob Bongiovi, and Curt Khol, “RD-180 Availability Risk Mitigation Study Summary,” May 2014, 13-18, http://www.spacepolitics.com/wp-content/uploads/2014/05/Mitchell_Report_May2014.pdf

¹⁴ Susan Braden, “Space Exploration Technologies Corp. v. The United States and United Launch Services, LLC Order Issuing Preliminary Injunction,” (In the United States Court of Federal Claims, No. 14-354 C, April 30, 2014), 1

¹⁵ Susan Braden, “Space Exploration Technologies Corp. v. The United States and United Launch Services, LLC Order Issuing Preliminary Injunction,” (In the United States Court of Federal Claims, No. 14-354 C, April 30, 2014), 3

¹⁶ Susan Braden, “Space Exploration Technologies Corp. v. The United States and United Launch Services, LLC Order Dissolving Preliminary Injunction,” (In the United States Court of dFederal Claims, No. 14-354 C, May 8, 2014), 3

¹⁷ Dmitry Rogozin, Twitter Post, May 13, 2014, 11:12 a.m., <https://twitter.com/DRogozin/status/466234541611311104>

¹⁸ Alissa de Carbonnel, “Russia Targets Space Station Project in Retaliation for U.S. Sanctions,” *Reuters*, May 13, 2014, <http://www.reuters.com/article/2014/05/13/ukraine-crisis-russia-usa-idUSL6NONZ4EA20140513>

¹⁹ Mike Gruss, “Draft House Bill Recommends \$220 Million Next Year for RD-180 Alternative,” *SpaceNews*, April 29, 2014, <http://spacenews.com/article/military-space/40404draft-house-bill-recommends-220-million-next-year-for-rd-180-alternative>

²⁰ Andrea Shalal, “U.S. Senate Panel Backs Plan for Alternative to Russian Rocket Engine,” *Reuters*, May 22, 2014, <http://www.reuters.com/article/2014/05/23/us-russia-usa-rockets-idUSBREA4M00F20140523>

²¹ Mike Gruss, “Compromise Appropriations Bill Includes \$220 Million for New Rocket Engine,” *SpaceNews*, December 11, 2014, <http://spacenews.com/compromise-appropriations-bill-includes-220-million-for-new-rocket-engine/>.

²² Note: This law allows ULA to use the RD-180 that it purchased and paid for.

U.S. Congress, Senate, Armed Services Committee, *National Defense Authorization Act for Fiscal Year 2015*, 113th Cong., 2nd sess., December 2, 2014, 22. <http://www.armed-services.senate.gov/imo/media/doc/CPRT-113-HPRT-RU00-S1847.pdf>.

²³ Robert B. Aderholt and others, “Letter Supporting the Development of a New, American, Liquid-Fueled Hydrocarbon Rocket Booster Engine,” *Members of the U.S. House of Representatives*, September 17, 2014.

²⁴ Office of Management and Budget, *Statement of Administration Policy: HR 4870 – Department of Defense Appropriations Act, 2015 (Rep. Rogers, R-KY)*, June 17, 2014, 3.

²⁵ Office of Management and the Budget, “Statement of Administration Policy,” *Executive Office of the President of the United States*, June 2, 2015, 6,

https://www.whitehouse.gov/sites/default/files/omb/legislative/sap/114/saps1376s_20150602.pdf.

²⁶ Aaron Mehta, “ULA to Retire Delta IV, Push for More RD-180s,” *Defense News*, March 15, 2015, <http://www.defensenews.com/story/defense/air-space/space/2015/03/15/ula-delta-iv-retire-rd180-russia-spacex/70231994/>.

Andrea Shalal, “McCain Rejects Pentagon Push for More Russian Rocket Engines,” *Reuters*, May 13, 2015, <http://www.reuters.com/article/2015/05/13/us-usa-military-space-russia-idUSKBN0NY1LJ20150513>.

Brian Everstine, “AF Asks Congress to Let it Use More Russian-Made Rocket Engines,” *AirForceTimes.com*, April 29, 2015, <http://www.airforcetimes.com/story/military/capitol-hill/2015/04/29/air-force-asks-congress-more-russian-engines/26589639/>.

²⁷ Andrea Shalal, “McCain Rejects Pentagon Push for More Russian Rocket Engines,” *Reuters*, May 13, 2015, <http://www.reuters.com/article/2015/05/13/us-usa-military-space-russia-idUSKBN0NY1LJ20150513>.

²⁸ Office of Management and the Budget, “Statement of Administration Policy,” *Executive Office of the President of the United States*, June 2, 2015, 6,

https://www.whitehouse.gov/sites/default/files/omb/legislative/sap/114/saps1376s_20150602.pdf.

²⁹ Andrea Shalal, “Air Forces Seeks Rethink of 2019 Deadline for New U.S. Rocket Engine,” *Reuters*, February 25, 2015, <http://www.reuters.com/assets/print?aid=USKBN0LT23S20150225>.

³⁰ Jeff Foust, “Replacing the RD-180,” *The Space Review*, May 12, 2015, <http://www.thespaceview.com/article/2512/1>.

³¹ Courtney Albon, “AFSPC Chief Confident SpaceX will be Certified by Year’s End,” *Inside Missile Defense*, December 10, 2014, 7.

³² Tory Bruno, “Assuring Assured Access to Space Committee Hearing,” *United States House Armed Services Committee Hearing*, March 17, 2015.

³³ Tory Bruno, “Assuring Assured Access to Space Committee Hearing,” *United States House Armed Services Committee Hearing*, March 17, 2015.

³⁴ Note: The Delta IV launch vehicle was retired due to its inability to compete commercially. Further information elaborating about the Delta IV competing commercially at an increased launch rate was not given. It’s believed that that costs of the Delta IV would drop with increased production and use of the rocket. It is also not known if the planned cost saving measures and new manufacturing techniques would significantly lower costs of the Delta IV to make it commercially competitive. There are some missions that the Delta IV would not be able to perform compared to the Atlas V and would require a much more expensive heavy lift version. There are significant difficulties coming to a decisive conclusion with regards to the Delta IV, as a lot of vital information regarding costs, are not available. Retiring the vehicle was a pure business decision. The author assumes that ULA and Boeing have both completed internal reviews that reached an assessment that even with an increased production rate and the implementation of planned costs saving measures, the Delta IV was so costly and didn’t meet all mission needs that it only existed to meet policy needs and have two commercial launch vehicles instead of one. The government paid a higher price for the vehicle and to meet its policy goals. It is also possible that this was a pure business decision and ultimatum to the U.S. government. The ultimatum was for the U.S. to choose between having one launch provider, SpaceX, or to continue following the two launch provider policy and allowing ULA to continue using the RD-180. If successful, ULA will continue to use the RD-180, despite the ban that was initially overwhelmingly supported by Congress.

³⁵ President of the United States, “National Space Transportation Policy,” *The White House*, November 21, 2013, 3.

³⁶ Note: Currently, the Delta IV Heavy maintains its price because of the infrastructure and sales of the RD-180 engine. The price of the Delta IV heavy would increase if ULA were unable to use the RD-180 sales to help support and make the Delta IV heavy competitive.

Tory Bruno, “Assuring Assured Access to Space Committee Hearing,” *United States House Armed Services Committee Hearing*, March 17, 2015.

³⁷ Note: During the Titan Rocket era, the U.S. government was paying between \$500-\$550 million per launch in the 1990s. Accounting for inflation a \$500 million dollar launch in 1995 would be around \$775 million prelaunch in

2015. If the system is deemed vital, the U.S. government will pay a high price for launching the system. Inflation calculation completed on <http://data.bls.gov/cgi-bin/cpicalc.pl> on June 9, 2015.

Howard “Mitch” Mitchell, “Assuring Assured Access to Space Committee Hearing,” *United States House Armed Services Committee Hearing*, March 17, 2015.

³⁸ Note: U.S. government space launch experts believe that the certification will most likely occur in mid 2019 or 2020 if all launches are successful. Howard “Mitch” Mitchell, John Hyten, William LePlante, Katrina McFarland, “Assuring Assured Access to Space Committee Hearing,” *United States House Armed Services Committee Hearing*, March 17, 2015.

³⁹ Stephen Clark, “First Flight of Falcon Heavy Delayed Again,” *Spaceflight Now*, July 21, 2015, <http://spaceflightnow.com/2015/07/21/first-flight-of-falcon-heavy-delayed-again/>

⁴⁰ Note: Outside of testing, SpaceX has successfully launched 18 out of 19 launches and the certification process took around two years to complete since SpaceX and the Air Force signed a Cooperative Research and Development Agreement to certify the Falcon 9 rocket. One Falcon 9 had one partial failure on October 12, 2012, when it placed a secondary payload, an Orbcomm prototype satellite, into an incorrect orbit. The satellite gathered enough data for the company to move forward on their constellation the following year. The one Falcon 9 rocket failure was on June 28, 2015, during an ISS resupply mission.

Alicia Garges, “SMC Enters into Cooperative Research and Development Agreement with SpaceX,” U.S. Air Force, June 11, 2013, <http://www.losangeles.af.mil/news/story.asp?id=123352061>.

⁴¹ Dan Leone, “Notwithstanding Sanctions, ULA Standing By for RD-180 Deliveries through 2017,” *SpaceNews*, August 6, 2014, <http://spacenews.com/article/military-space/41507notwithstanding-sanctions-ula-standing-by-for-rd-180-deliveries-through>

⁴² Brian Everstine, “Air Force Issues Call for Next-Gen, U.S.-Made Space Launch System,” *Military Times*, June 2, 2015, <http://www.militarytimes.com/story/military/tech/2015/06/02/air-force-industry-call-space-launch/28365087/>.

⁴³ Jason Rhian, “Insider Interview: ULA’s Tony Bruno Talks Next Generation Launch System,” *SpaceFlightInsider.com*, January 26, 2015, <http://www.spaceflightinsider.com/organizations/ula/insider-interview-united-launch-alliances-tony-bruno-next-generation-launch-system/>

⁴⁴ Jad Mouawad, “A Bezos Company Will Make Engines for Rockets,” *The New York Times*, September 17, 2014, http://www.nytimes.com/2014/09/18/business/18rocket.html?partner=yahoofinance&_r=1

⁴⁵ Tory Bruno, “Assuring Assured Access to Space Committee Hearing,” *United States House Armed Services Committee Hearing*, March 17, 2015.

⁴⁶ Jason Rhian, “Insider Interview: ULA’s Tony Bruno Talks Next Generation Launch System,” *Spaceflight Insider*, January 26, 2015, <http://www.spaceflightinsider.com/organizations/ula/insider-interview-united-launch-alliances-tony-bruno-next-generation-launch-system/>

⁴⁷ Doug Cameron, “Aerojet Joins Race to Replace Russian Rocket Engine,” *The Wall Street Journal*, October 1, 2014, <http://online.wsj.com/articles/aerojet-joins-race-to-replace-russian-rocket-engine-1412197065>

⁴⁸ Amy Butler, “Aerojet Rocketdyne Targets \$25 Million Per Pair for AR-1 Engines,” *Aviation Week*, June 3, 2014, <http://aviationweek.com/defense/aerojet-rocketdyne-targets-25-million-pair-ar-1-engines>.

⁴⁹ Andrea Shalal, ed. Christian Plumb, “Aerojet Rocketdyne, Others Look at Keeping Atlas 5 Rocket in Use,” *Reuters*, May 11, 2015, <http://www.reuters.com/article/2015/05/11/usa-military-space-idUSL1NOY230T20150511>.

⁵⁰ Amy Butler, “Options Open?,” *Aviation Week & Space Technology*, May 25-June 7, 2015, 26.

⁵¹ Andrea Shalal, “Alliant says Can Replace Russian Launch Engine for U.S. Satellites,” *Reuters*, September 23, 2014, <http://www.reuters.com/article/2014/09/23/usa-rocket-atk-idUSL2N0RO1KK20140923>.

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⁵³ Tory Bruno, “NGLS Press Conference,” 31st National Space Symposium, April 13, 2015, <https://www.youtube.com/watch?t=224&v=pCceCh68oos>.

⁵⁴ Travis Cottom, E-mail conversation with Jessica Rye, June 8, 2015.

⁵⁵ George Sowers, “I am George Sowers, VP of Advanced Concepts & Technologies for United Launch Alliance. Ask Me Anything!,” *Reddit.com*, April 15, 2015, https://www.reddit.com/r/IAmA/comments/32qe61/i_am_george_sowers_vp_of_advanced_concepts/.

⁵⁶ Andrea Shalal, "Lockheed-Boeing Rocket Venture Needs Commercial Orders to Survive," *Reuters*, May 21, 2015, <http://www.reuters.com/article/2015/05/21/lockheed-martin-boeing-ula-idUSL1N0YC2DV20150521>.

⁵⁷ Tory Bruno, "NGLS Press Conference," 31st National Space Symposium, April 13, 2015, <https://www.youtube.com/watch?t=224&v=pCceCh68oos>.

⁵⁸ Colin Clark, "ULA CEO Thinks RD-180 Waiver Likely; Gap of 5 Engines Between House, Senate," *Breaking Defense*, May 22, 2015, <http://breakingdefense.com/2015/05/ula-ceo-thinks-rd-180-waiver-likely-gap-of-5-engines-between-house-senate/>.

⁵⁹ Note: When Vulcan was unveiled, Tory Bruno announced that they were going to introduce the reusable concept, but after an E-mail with Jessica Rye, the concept was changed to a possibility determined by a business case for such a need.

Travis Cottom, E-mail conversation with Jessica Rye, June 8, 2015.

⁶⁰ George Sowers, "NGLS Press Conference," 31st National Space Symposium, April 13, 2015, <https://www.youtube.com/watch?t=224&v=pCceCh68oos>.

⁶¹ Andrea Shalal, NGLS Press Conference," 31st National Space Symposium, April 13, 2015, <https://www.youtube.com/watch?t=224&v=pCceCh68oos>.

⁶² Note: Planet Labs plans on developing a large remote sensing constellation and a board member, Steve Jurvetson, is also a SpaceX board member. While this does not mean that SpaceX will automatically receive the launching contract, the author is feels inclined to acknowledge that there is a financial interest in Planet Labs to launch with SpaceX. Mike Wall, "Planet Labs Raises \$95 Million for Tiny Earth-Observation Satellites," *Space.com*, January 23, 2015, <http://www.space.com/28341-planet-labs-investment-cubesats.html>.

OneWeb signed a contract with Arianespace to begin launching their constellation in 2017. Skybox Imaging selected Arianespace's Vega launch vehicle to launch a block of their satellite constellation in 2016. Skybox Imaging, may eventually select a larger launch vehicle, but it would be likely that they go with SpaceX as, Google invested a significant amount of money in SpaceX at the beginning of 2015.

Dana Hull, Brian Womack, and Serena Saitto, "SpaceX Scores \$1 Billion from Google, Fidelity," *Bloomberg.com*, January 20, 2015, <http://www.bloomberg.com/news/articles/2015-01-20/musk-s-spacex-sells-10-stake-to-google-fidelity-for-1-billion>.