The RD-180 Replacement and the Future of the U.S. Rocket Motor Industrial Base

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Introduction

The United States was one of the two initial space-faring countries. Without assured access to space, the United States will cease to be a Great Power. It is almost impossible for those who have grown up in the era of Apollo, Moon landings, the Shuttle and missions to the International Space Station to imagine a time in which this country's ability to launch payloads and people into space would be severely limited. Yet, that time is right in front of us.

The reason why is because of our dependence on a Russian-made engine, called the RD-180, to boost one of our two available rockets, the Atlas V, into space. Guaranteed access to supplies of the RD-180 has fallen victim to Moscow's aggression against its neighbors and Congress's unwillingness to reward the Kremlin for its bad behavior.

The immediate crisis over availability of the RD-180 is symptomatic of a broader problem in the space industrial base. A combination of failures by both the Air Force and NASA to successfully manage the development of new launchers and space vehicles, the termination of the Shuttle replacement program, delays in defining intercontinental (ICBM) and submarine-launched (SLBM) ballistic missile modernization and inaccurate predictions regarding the size of the space launch market combined to severely damage this sector. A significant reduction in demand for most classes of rockets and missiles left the industry with excess capacity with respect to the addressable market.

In recent years, NASA and the Air Force have taken steps to improve U.S. access to space. The Air Force has opened up the market for launch of national security payloads to new commercial competitors, provided they can meet stringent certification standards. NASA recently awarded contracts for the development of a new crew vehicle to carry U.S. astronauts into space. The Minuteman missile force recently completed a major refurbishment program.

The one glaring deficiency in this good news story is the continuing dependence on the RD-180. The U.S. space program needs to free itself from this potential albatross. This means developing and producing domestically a new engine for the Atlas V.

Fortunately, there are a number of companies that could do the job, assuming they get the opportunity to compete for the job. Indeed, it is rather remarkable that since the issue of the RD-180 emerged, no fewer than five companies have come forward to indicate their interest and demonstrate their capability to compete for the work.

Decisions taken some two decades ago put this country's assured access to space at risk. Those responsible today both in government and Congress need to be sure that decisions taken in the near term regarding the choice of an alternative to the RD-180 do not result in similar problems. In particular, there needs to be a process that clearly and openly balances tradeoffs between time, cost, risk and capability. Also, decisionmakers must not be shortsighted in their desire for a solution that appears rapid and cheap, thereby throwing away the opportunity not only to ensure reliable access to space but advance the state-of-the-art in rocket engine design, reinvigorate a part of the U.S. aerospace and defense industry that is in decline, create jobs and promote national security more broadly.

How we got to where we are

Following the end of the Cold War and the resulting decline in defense budgets, the U.S. Air Force faced the daunting challenge of maintaining assured access to space, modernizing both launch systems and space craft, and reducing the costs for both hardware and operations. In addition, it had become obvious that less reliance than had been anticipated could be placed in the Space Shuttle to lift critical national security payloads. The Air Force needed to find means of lifting heavy payloads to orbit without incurring the high initial costs and potential reduction in reliability associated with the development of a new rocket.

After the collapse of the Soviet Union, Western scientists and engineers were able to acquire access to and, hence, a better understanding of Russian advanced technology. As a consequence, U.S. experts discovered that Russia had developed an expertise in closed cycle, liquid oxygen (LOx) rich, staged combustion technology that offered as much as a 25 percent increase in performance over available U.S. rocket engine technology. Working closely with U.S. aerospace companies, the Russian entity responsible for this technology, NPO Energomash, designed a version of this type of engine, designated the RD-180, specifically for the U.S. Atlas booster.[1] At the time, the RD-180 was possibly the world's most advanced rocket engine.

By permitting the RD-180 to be deployed as the first stage of the Atlas rocket, the U.S. government achieved a number of objectives. First, it acquired a more capable heavy lift vehicle than what was available at the time domestically without the expense and risks associated with an attempt to duplicate the research and development (R&D) that NPO Energomash had already done. In addition, given the collapse of the Soviet military-industrial complex, the price charged for the RD-180 was incredibly cheap; early sales were on the order of $10 million a copy and even today, the price is said to be around $70 million. Finally, by providing work for Russian aerospace engineers and workers, the risk that some would sell their services to rogue regimes could be reduced.

The decision to allow the RD-180 to be employed on a U.S. space launch vehicle occurred in the context of the effort begun in 1995 to develop a family of Evolved Expendable Launch Vehicles (EELV). The purpose of the EELV program was to reduce the cost of operational space launch by 25-50 percent and to improve reliability over existing launch systems. The EELV program eventually produced two families of launch vehicles, the McDonnell Douglas/Boeing Delta IV and

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[1] Brooke Mosley, *RD-180 Engine: An Established Record of Performance and Reliability on Atlas Launch Vehicles*, United Launch Alliance, at http://www.ulalaunch.com/Education_PublishedPapers.aspx#Evolution.

the Atlas V, developed by Lockheed Martin. Each company was awarded a certain number of launches in a block buy, thereby allowing the companies to acquire materials and subsystems in an advantageous manner and manage the workflow in a way designed to reduce labor costs.

The ongoing effort to reduce launch costs and the limited size of the space launch market eventually resulted in the creation of a single entity, akin to a lead system integrator, to provide the launch vehicles and manage the launch process. In 2005, Boeing and Lockheed Martin announced their intent to form a joint venture, the United Launch Alliance (ULA), to provide space launch services to the U.S. government at reduced cost.

The EELV program and ULA have a remarkable record of successfully delivering payloads into space. The Atlas V has achieved 50 successful launches. At the same time, it has experienced criticism for what are alleged to be high costs. Recently, a potential competitor in the EELV space, SpaceX, has challenged the decision by the Air Force to award a large block of launches to ULA without competition, asserting that it can perform the same mission far more cheaply.[2]

The Problem: Ending U.S. Dependence on a Russian Rocket Engine

While the attention of the American people and their government was focused elsewhere, a new Cold War between Russia and the West has begun. In many ways it has been a replay of how the last Cold War came about. Disagreements over "spheres of influence" in Eastern Europe led to efforts by Moscow to expand its control through subversion, coups and outright military aggression. Anyone remember their history? Czechoslovakia, 1948? Ukrainian separatists aren't just being armed and trained by the Russian military. They are being controlled from Moscow. Now Russian forces have operated in eastern Ukraine to prevent the government in Kiev from reasserting control over "rebellious" provinces. President Vladimir Putin has responded to Western economic sanctions with some of his own, intended not just to send a message but also to reduce his economy's dependence on Western goods. Moscow also is expanding economic and military ties with China, much as Stalinist Russia did in the late 1940s and early 1950s with the Chinese Communists, in order to open a second front against the West. In addition, it is now reported that Russia has for several years been violating a vital nuclear arms treaty. Can a new arms race be far behind?

The handwriting is on the wall. Russia is not backing down from its campaign to dominate Ukraine and from there much of Eastern Europe. Nor can it back down. To do so would be disastrous for President Putin's regime domestically, particularly once tougher Western sanctions begin to hurt his country's economy. Moreover, Russia minus Ukraine is a declining power, demographically as well as economically and militarily. If you believe, as Putin apparently does, that the West, in general, but the United States, in particular, is trying to undermine your political system, then you need all the resources, territory and leverage you can get for the struggle to come.

As relations with Russia have deteriorated in the wake of that country's aggression against Ukraine, the situation has become potentially dire. The United States and the European Union have imposed

[2] Mike Gruss and Dan Leone, "SpaceX Formally Protests Initial EELV Block Buy Contracts," *Space News*, April 25, 2014; Mike Gruss, "News from the 30th Space Symposium: Responding to Critics, ULA Discloses Pricing Information," *Space News*, May 20, 2014.

sanctions on a number of senior Russian officials, including high-ranking members of the government and on critical sectors of the Russian economy.

Russia has imposed its own countervailing sanctions on Europe and the United States. More ominously, in May, when the U.S. last imposed sanctions on Russia, Russian Deputy Prime Minister Dmitry Rogozin, a close associate of President Putin and on the list of individuals sanctioned by the United States and the European Union, announced that his country would no longer provide U.S. astronauts with rides to the International Space Station. In addition, Rogozin declared that his country might prohibit use of the RD-180 for U.S. military launches and could even refuse to sell it to ULA.[3]

The U.S. is scrambling to respond to this serious threat to our access to space. ULA reported that it had at least a two year supply of RD-180s on hand. This time period could be extended by a year or more with careful management of EELV launches. In addition, the company is said to be negotiating for a large new purchase of RD-180s. At the time of the original decision to employ the RD-180 on the Atlas, the U.S. insisted that an American company acquire the license to produce the RD-180 domestically. However, it would take at least four years and $1 billion to build a production line, and the Russian government would still control use of the engine. Some payloads could be shifted to the other ULA launcher, the Delta IV. But heavier payloads would still require the Atlas V. The recent accident experienced by the Orbital Sciences' Antares vehicle underscores the danger associated with relying on a single launch vehicle for either system for commercial or military payloads.

With a new Cold War looming, it is madness to be dependent on Russia for critical resources, contracts and technologies. Western Europe must begin now to reduce its dependence on Russian energy. NATO has to bite the bullet, so to speak, and increase defense spending as well as redeploy forces to ensure the security of its eastern frontier with Russia. France must be saved from itself by being encouraged to cancel the sale of a Mistral amphibious assault ship to Russia.

Congress has sent the clear message that the Air Force needs to free itself from the current dependence on the RD-180 as soon as possible. Responding to Russian threats, the House Armed Services Committee amended the 2015 National Defense Authorization Act to direct that "The Secretary of Defense shall develop a next-generation liquid rocket engine that enables the effective, efficient and expedient transition from the use of non-allied space launch engines to a domestic alternative for national security space launches." To that end it proposed initial funding of $200 million for a replacement engine.

The United States must end its dependence on Russia for rocket engines. This is particularly important with respect to the Atlas V which carries so many national security payloads.[4] As the former head of Air Force Space Command stated in his recent testimony before Congress on the subject of assured access to space: "If you consider space a national security priority, then you

[3] Mike Gruss, "Rogozin Calls for Ban on U.S. Military use of RD-180," *Space News*, May 13, 2014.
[4] This was the conclusion reached in the Congressionally-mandated RD-180 Mitigation Study otherwise known as the Mitchell Study. See Major General Howard J. Mitchell (USAF, Retired), Testimony to the Committee on Commerce, Science and Transportation and the Subcommittee on Strategic Forces of the Committee on Armed Services Joint Hearing, July 16, 2014.

absolutely have to consider assured access to space a national security priority. ... Given that we have a vulnerability here, it's time to close that hole."[5]

Critical considerations in a Domestic Rocket Engine Program

It is clear to all responsible parties that the United States needs to free itself from dependence on Russian rocket motors. The question is how to accomplish this end within the time frame required without injecting unacceptable risk into a critical national security program or incurring excessive costs?

Overall, the current EELV program has been very successful, conducting more than 70 launches without a failure since the program began a dedicated focus on Mission Assurance in 2002. More specifically, there have been some 50 successful launches of the Atlas V using the RD-180 engine. This is extremely important since the program involves the deployment into space of vital national security satellite systems that can cost $1 billion or more. The importance of these military and intelligence payloads makes it imperative that the reliability of the rockets and associated launch activities be of the highest attainable standard. Reliability is a priority even if this requires paying a higher price. In the military space launch business there is no room for such acquisition standards as "lowest cost, technically acceptable."

This is the chance for the United States to take a leap forward in space launch capabilities. It is up to the Air Force to decide how to proceed. In doing so it must balance considerations of time, risk, cost and innovation. Of these four factors, time and risk are paramount. The time factor is a function of how many RD-180s ULA currently has, whether any more will be acquired but most significantly, whether exogenous events such as additional Kremlin misadventures will create another crisis in U.S.-Russian relations. A new certified engine needs to be available before ULA runs out of its stockpile of RD-180s in approximately three years.

The Atlas V carries some of the Nation's most sensitive national security payloads, so the risk associated with the development of a new engine itself, as well as its integration with the launch vehicle, must be low. It took years of hard work for Lockheed Martin and NPO Energomash to overcome doubts regarding the viability of the RD-180 engine itself and the feasibility of integrating it into what was then the Atlas III.

In addition, the current plan is to employ the Atlas V as the launch vehicle to return U.S. astronauts to space aboard the Boeing winner of NASA's competition for a Commercial Crew Transportation Capability. Sierra Nevada Corporation with its Dreamchaser lifting body vehicle, which was the loser in the competition, also planned on using the Atlas V as its launcher. Clearly, when it is a matter of transporting human beings, the margins for acceptable risk are quite low.

It is important to recognize that several candidate replacement engines rely on novel approaches to achieving the desired power levels but have never been demonstrated at the required thrust levels. Even advocates for these systems admit that significant risk reduction work and testing would be

[5] General William Shelton, U.S. Space Command, Testimony , cited in http://thehill.com/policy/technology/212440-pentagon-warns-of-vulnerability-in-space-program.

required before one or more of these could be flown on an Atlas V. Nevertheless, a number of experts believe that the new technologies are sufficiently well understood to support the transition away from the Russian engine on the required timeline (approximately four years) and for a price equal to or less than that which would be needed to build a U.S. factory to produce RD-180s (about $1 billion).[6]

The risk and costs associated with providing an alternative engine also depend on the extent to which modifications must be done to the rocket body itself. It may be possible to swap a domestic engine – or even two – of lower power onto an Atlas V with minimum integration requirements. There are candidate engines which could provide the required thrust but would necessitate a redesign of the Atlas V thereby increasing cost, time and potentially the complexity of system integration. What the Air Force should be looking for is a new rocket engine as nearly equal as possible to the RD-180 in size, power and performance and which would require the least modification to the Altas V booster.

According to a Government Accountability Office study, none of the commercial companies vying for work that at present is exclusive to the EELV program have the ability to configure their vehicles so as to be able to launch the full range of EELV-class payloads.[7] For example, SpaceX, which has presented itself as a competitor for EELV launches, would be required to provide a new, as yet not built booster, the Falcon Heavy, in order to service the full range of payloads.

None of the proposed alternatives to the RD-180 could be made ready for flight without significant investments of money. The Air Force is desperately short of resources at present, which suggests it might prefer a solution that minimizes its upfront costs. The rise of a private space launch industrial base funded at least in part by entrepreneurs such as Jeffrey Bezos, Elon Musk and Richard Branson has opened up interesting new possibilities for advancing the state of technology in this field while minimizing actual government expenditures.

But even deep pockets do not ensure that the technology will be ready on time or that it will meet stringent government performance and reliability requirements. The Air Force must not forget NASA's unfortunate experience pursuing an acquisition strategy based on Faster, Better, Cheaper.

Finally, the Air Force should consider the long-term value of investing in the domestic rocket engine industrial base, generally, and in addressing the long-standing gap in our capabilities to design and build high performance LOx/hydrocarbon engines. Encouraging the industry to be more innovative could reduce launch costs long-term and serve as a base for revitalizing the U.S. commercial space industry.

[6] Frank Morring, Jr. and Amy Butler**, "**Engine Makers Pushing AM, Other Technologies For RD-180 Replacement: RD-180 prototype replacement could be ready to test in 2.5 years," *Aviation Week & Space Technology*, September 15, 2014.

[7] Stew Magnuson, "Costs, Benefits of RD 180 Rocket Engine Replacement Program Debated," *National Defense* July, 2014.

Options to Replace the RD-180

It is important to begin this section by pointing out that the Congressionally-mandated RD-180 Mitigation Study (also known as the Mitchell Study) concluded that a "healthy environment exists for competition" for a replacement for the RD-180. However, it was recommended that the Government invest in critical technologies to mature LOx/hydrocarbon engines and make that technology available to industry.[8]

The candidate that most closely approximates a direct replacement for the RD-180 would appear to be the Aerojet-Rocketdyne AR-1. The AR-1 is a 500,000-lb., thrust oxidizer-rich, staged-combustion engine fueled by a combination of LOx and kerosene. The current concept is to employ two AR-1s in lieu of a single 800,000-lb. thrust RD-180 on the Atlas V. Twenty years of R&D investment by the Air Force and NASA has produced advances in a host of component technologies. Company sources assert that the AR-1 development program could be completed for a cost of $800 million to $1 billion over four years after a contract award and that they have targeted a full-production cost of $20-25 million for each two-engine set of AR-1s.[9]

Aerojet-Rocketdyne has been spending scarce independent research and development dollars to improve the manufacturing processes associated with its rocket engines. The company has been experimenting with additive manufacturing, also known as 3-D printing, to reduce the time and cost associated with producing complex motor parts. "'Going to additive manufacturing is going to be one of the biggest cost and time savers on this engine.' …The team has built a key rocket engine part, known as the pre-burner, with a new manufacturing process for this type of part. What typically takes 15 months …they did in 15 days."[10]

SpaceX has proposed their Merlin engine currently deployed on the Falcon family of rockets. The Merlin uses LOx/kerosene and the most advanced design, the 1D configuration is capable of generating approximately 170,000-lb. thrust. The Falcon 9, the competitor for a place in the EELV program, employs nine Merlin 1D engines in its first stage. The Falcon Heavy will require 27 Merlin engines between Stage 0 and Stage 1. The Falcon 9v1.0 and successor v1.1 have made more than half a dozen successful space flights.

It must be noted that the Merlin engine has not been integrated on the Atlas V. It is likely that there would be considerable additional work necessary to ensure that the nine engine configuration could perform as well as the single RD-180. In addition, the use of the Merlin on the Atlas V would meet the need for a domestically produced engine but create a potential critical vulnerability due to the fact that both the Falcon and the Atlas V would be dependent on the same engine.

In September, 2014 ULA announced that it had formed a strategic partnership with Blue Origin for the purpose of using the latter's BE-4 engine, under development for some four years, as a replacement for the RD-180. The BE-4 uses a unique combination of LOx and liquefied natural gas (LNG) as its fuel in an oxygen rich, staged combustion cycle to produce approximately 550,000-lb. of thrust. To date, Blue Origin has only built and tested a smaller, less powerful version of its

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[8] Major General Howard J. Mitchell, *op. cit.*
[9] Frank Morring, Jr. and Amy Butler, *op, cit.*
[10] Marcus Weisgerber, "How 3D Printing Could Help Replace Russian Rockets," *DefenseOne*, October 21, 2014.

LOx/LNG design, the 110,000-lb. thrust BE-3. The BE-3 has never actually powered a payload into space.

Because LNG is not as dense as the kerosene fuel that powers the RD-180, a BE-4 rocket will require a less complex and cheaper system for pressurizing the fuel tanks. However, for the very same reason, the BE-4 will require larger fuel tanks than those currently used on the Atlas V. This could require ULA to undertake significant design changes to the Atlas V in order to accommodate not only two BE-4 engines but different fuel tanks and associated plumbing.[11] Perhaps this is why ULA publicly suggested that the BE-4 was not intended to replace the RD-180 but instead to provide the power for a new space launch vehicle.

> The BE-4 is not a direct replacement for the RD-180 that powers ULA's Atlas V rocket, however two BE-4s are expected to provide the engine thrust for the next generation ULA vehicles. The details related to ULA's next generation vehicles – which will maintain the key heritage components of ULA's Atlas and Delta rockets that provide world class mission assurance and reliability – will be announced at a later date.[12]

Blue Origin is not the only company proposing a different, potentially even revolutionary, approach for replacing the RD-180. Sierra Nevada Corporation recently completed acquisition of Orbital Technologies Corporation, the developer of an innovative vortex-combustion rocket engine. The new engine holds forth the promise for greater efficiency, reliability, reusability and reduced costs.

Finally, Alliant Techsystems, the premier maker of solid rocket motors for the Space Shuttle program, is reported to have been working on a new solid rocket motor for the Atlas V. Company sources assert that a competitive offering could be available within three years.[13]

The Air Force's decision to seek information from industry regarding their potential ability to provide alternatives to the RD-180 produced a veritable cornucopia of possibilities, many involving promising, innovative technologies. The challenge for the Air Force is to ensure close oversight over the selection process and to balance the requirements of time, risk, cost and technological innovation.

> No matter how difficult the Air Force's budget circumstances may be and how appealing it finds the idea of relying on commercial launch providers, the service's space community needs to be intimately involved at each step in this process, with an eye to getting rid of those Russian engines in a reasonable timeframe. That's what Congress wants, and that's what national security demands.[14]

[11] Warren Ferster, "ULA To Invest in Blue Origin Engine as RD 180 Replacement," *Space News***,** September 17, 2014.
[12] Anthony Young, "ULA, Blue Origin and the BE-4 Engine," *Space News*, October 20, 2014.
[13] Christian Davenport, "Jeff Bezos isn't the only one who says he can end U.S. reliance on a Russian-made engine," *The Washington Post*, September 23, 2014.
[14] Dr. Loren Thompson, "Air Force Can't Let Budget Woes Abort Search For A Reliable Successor To Russian Rocket Engines," at http://www.lexingtoninstitute.org/air-force-cant-let-budget-woes-abort-search-for-a-reliable-successor-to-russian-rocket-engines/.

The Importance of a Full and Open Competition

Where we are today with respect to the Nation's ability to reliably access space, in general, and the RD-180 engine, specifically, is a function of a series of decisions which at the time seemed reasonable and without serious negative second and third order consequences. The negative impacts – dependence on critical technologies from an increasingly unreliable supplier, a series of failed programs to produce next generation space systems, and reduced funding that resulted in the decline of the domestic rocket engine industrial base – have become apparent over time.

Now the Department of Defense and the Air Force are faced with the need to make a tough choice in a period of strategic uncertainty and severe budget stringency. The natural temptation to pursue a low cost solution, while understandable, conflicts with the absolute requirement to minimize technical and programmatic risks in order to ensure reliable access to space.

The only way to arrive at an acceptable answer – one that balances time, risk, cost and innovation – is by holding a full and open competition. Defense Department acquisition officials continually trumpet their desire to increase the role of competition in the procurement process. With a significant and growing number of candidate companies offering different solutions, the RD-180 replacement program appears to be a poster child for a competitive procurement process.

Acronyms

EELV	Evolved Expendable Launch Vehicles
ICBM	Intercontinental Ballistic Missile
LOx	Liquid Oxygen
LNG	Liquified Natural Gas
NASA	National Aeronautics and Space Administration
R&D	Research and Development
SLBM	Submarine Launched Ballistic Missile
ULA	United Launch Alliance

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