# RD-180 Engine: An Established Record of Performance and Reliability on Atlas Launch Vehicles

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*Abstract*— Expendable Launch vehicles remain the primary means of delivering payloads to orbit. [1 2] High reliability in these systems is vital to the safe delivery of the valuable payloads they carry. A considerable number of past launch vehicle failures can be attributed to propulsion subsystems. These subsystems contain combustion, control thrust levels, maintain vehicle stability, and withstand the dynamic loads associated with these processes. The high levels of complexity associated with propulsion subsystems often provide opportunities for failure.

It is crucial for launch vehicle providers to utilize reliable and robust propulsion systems to propel customer payloads to their final destination. Reliability is enhanced by establishing a mature design and is proven by demonstrating performance through testing and flight. Propulsion system improvements are inherent to any program where the ultimate goal is technical excellence and high reliability. The Atlas launch vehicle's main booster engine, the RD-180, has demonstrated consistent performance with predictable environments over the past decade. The RD-180 has substantially contributed to the established a record of high reliability on Atlas launch vehicles since its debut on the Atlas III in May of 2000.

The RD-180 is a LOx rich, closed cycle, staged combustion, LOx Kerosene engine, with throttle capability from 47% to 100% power level. The closed cycle engine with continuous throttling provides an unprecedented advantage to vehicle performance and mission profile flexibility, while still providing a very reliable engine design. To date, twenty-six engines have flown on missions out of Cape Canaveral Air Force Station, and three have flown on missions out of Vandenberg Air Force Base. These launches delivered payloads for commercial customers, NASA, NRO, and the USAF.

The engine integration to the Atlas V booster and subsequent testing is performed by United Launch Alliance (ULA) at the integration facility and launch sites. A greater understanding of the RD-180 engine system has been acquired by ULA, over the last twenty-nine launch campaigns. This understanding of operational characteristics including engine to engine variability associated with a family of engines has allowed development and implementation of enhanced ground testing, and operational risk reductions. The continuous mission performance demonstrated by the RD-180 has defined it as a mature, reliable, flight proven system.

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## 1. INTRODUCTION

In 1997 Lockheed Martin established an agreement with NPO Energomash, the leading Russian developer of liquid propellant rocket engines, to purchase engines for Atlas launch vehicles. The Russian American collaboration required to make these flights successful has surmounted significant challenges and withstood the test of time. RD-180s are delivered to ULA, a 50/50 joint venture owned by Lockheed Martin and The Boeing Company, via an American Russian joint venture company RD AMROSS. RD AMROSS is a 50/50 joint venture between Pratt & Whitney Rocketdyne (PWR) and NPO Energomash (NPO EM). NPO EM is the designer and manufacturer of the RD-180. PWR is the premier U.S. liquid rocket engine developer selected to collaborate with NPO EM in support of the RD-180 program. PWR and NPO EM both provide RD-180 integration and launch support services to ULA. Ten years after the debut of the first Atlas launch with an RD-180 twenty-nine engines have flown and have exhibited consistent performance.

## 2. HISTORY

In the early 1990s the closed cycle, LOx rich, staged combustion technology rumored to exist in Russia was originally sought out by General Dynamics because engines of this kind would be able to provide a dramatic performance increase over available U.S. rocket technology. Unlike its rocket building counterparts in the United States, Europe, China, and Japan, Russia was able to master a unique LOx rich closed cycle combustion technology which delivered a 25% performance increase[4].

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[2] IEEEAC paper#1457, Version 2, Updated 2011:1:13

**Figure 1 – AV-025 29th Atlas launch with an RD-180**

To achieve this additional performance, staged combustion engine designs require a much better understanding of the combustion process and the stages of that process. The engine is the subsystem responsible for containing and controlling combustion. For a LOx rich process, where environments include much higher pressures and temperatures, it is imperative to be able to limit where these processes take place. The unique technology developed for the RD-180 sets it apart from its counterparts designed in the United States not from a combustion understanding standpoint but by the technology developed to mitigate combustion.

Extensive development was necessary to create the combustion devices, the preburner and the chambers, that were able to consistently control continuous throttle from 47% to 100%. This technology was developed by the Soviet Union beginning in the 1970s at the height of the space race, and required significant resources. Learning how to control this type of process meant burning up a lot of hardware. With the space race in full effect the Russian designers had unlimited resources. They were able to develop this unique design though a pragmatic hardware based approach where important design questions were resolved after full system tests. [3]

After the fall of the Soviet Union, word of what the Russians had been able to accomplish made it into the global aerospace community and the technology was sought out by General Dynamics which later merged with Martin Marietta and eventually became Lockheed Martin. Twenty years after the technology had been developed it was still largely misunderstood by the global community and considered too risky.

## 3. RD-180: UNMATCHED COMBINATION OF PERFORMANCE AND RELIABILITY

There was skepticism in the reliability of the newly found Russian technology as it was such a departure from designs in use in the United States; the LOx rich staged combustion cycle engine, although it delivered performance improvements, was considered too risky not only in the U.S. but around the world. The staged combustion cycle must achieve far higher combustion pressures in the chamber than open cycles because the main combustion chamber receives high pressure gaseous oxygen directly from the turbine exhaust. The end result is higher performance however the reward comes with additional risk.

For the RD-180, all of the oxygen flows through the preburner which drives the turbine. The gaseous oxygen that flows to the chamber requires much less energy to initiate a combustion process so the engine is more prone to consuming itself given an ignition source. NPO Energomash, the leading designer of engines in Russia, had gone through hundreds of designs, each an improvement on the last, to harness the power of LOx rich combustion. This required a very careful approach to how the fuel is burned in the preburner so that the temperature field is uniform. It also required improvements in materials and production techniques. They found a way to take the chamber pressures to new limits while protecting the internal components from fire risks. This required a new class of high temperature resistant stainless steel invented to cope with the risks of the LOx rich environment[3].

The RD-180 designed and built by NPO EM was specifically tailored for the Atlas launch vehicle. It is a two chamber derivative of the RD-170 which later evolved into the RD-171 and RD-171M. Before agreeing to purchase these engines United Launch Alliance had to be persuaded that it worked and could work reliably. This was achieved through rigorous development and certification testing that was agreed upon by all parties involved. Since each side had a vested interest in the success of the engine, it was imperative that each side had the answers to their questions and were satisfied with the level of testing conducted.

The demonstrated performance established during this process was beyond anything achieved in the United States. The RD-180 reaches chamber pressures up to 3,722psia which was more than double the chamber pressures achieved by comparable U.S. engines. Exposure to Russian design philosophy and the success of a high performance engine made U.S. engine designers question their own methods. This dual sided cross-cultural engineering approach which has persisted through the life of the RD-180 program adds depth to the understanding of engine capability and operational characteristics.

In Russia the manufacturing organization is allowed more flexibility in recommending changes to the design process.

This allows for greater innovation in process and manufacturing techniques. In the U.S., in general, designs are delivered to the factory floor and the manufacturing engineer must meet the requirements specified on the drawing with substantial oversight by the designers. This increases time to delivery, scrap rate, requires higher precision manufacturing, and ultimately increases cost.[3]

Understanding and acceptance of differences in design and manufacturing methods was established during development and certification testing and has been solidified by the successful launches over the last decade. With proof of consistent performance from test, and established reliability in flight, the Atlas program has been able to leverage off of the best rocket engine technology in the world. To date there have been twenty-nine Atlas vehicles flown with the RD-180. Those launches accumulated a total of 6,973 seconds, almost two hours, of booster engine run time.

## 4. RD-180 Continues to Improve

No development program or new program performs consistently and with perfection. But the RD-180 development was fortunate in that most of the design deficiencies had been worked out on its predecessor engine which, at the time of the development of the RD-180, had already gone through the growing pains of its own development and had flown upwards of twenty-six flights on the Zenit launch vehicle.

The current version of the RD-180 flies at 100% of its thrust capacity and has slightly higher chamber pressures than its predecessor engine[4]. It is built from 70% similar components. The other roughly 30% are scaled versions of the RD-170 components. The RD-180 reliability is enhanced not only by its heritage but also by its current place in a family of NPO Energomash engines the RD-171M and the RD-191. Under the license agreement between NPO EM and the ULA, there is very limited scope on the ability to convey information from the other programs. However continuous hardware and process improvements are inherent to any program where technical excellence and product success are key factors. This is a benefit to RD-180 because not only does it improve from the knowledge gained by its own tests and flights but also by the testing and flights of the RD-171M and RD-191. Although ULA and PWR do not have insight into what design improvements are conducted on the other programs, it is quite clear based on the understanding of engineering practice and the history of success at NPO Energomash that product improvements cross program lines.

Based on the success of the RD-180 since its debut over ten years ago, NPO Energomash has not only continued to establish their superiority in engine design but they have also shown an ability to be successful in foreign markets, not only with the Atlas program but with Boeing's Sea Launch and South Korea's Naro 1. International cooperation in technical programs does have risks and challenges, but based on the consistent performance of the Atlases powered by the RD-180, those challenges have not impacted the most important end result – mission success. This has established that leveraging off of foreign technologies which are either superior or better suited to a specific system can provide significant benefits to a program.

For the Atlas those benefits include a 47%-100% throttle capability and up to 860,000 lbs of thrust. Aside from the original benefits delivered with the engine, long term benefits have also become apparent. The RD-180 engine has shown repeatable ignition and cutoff, stable combustion, predictable thermal and dynamic environments, as well as consistent engine control accuracy in mixture ratio, thrust levels, and trajectory. This consistency in engine performance adds confidence to vehicle margins, component assessments, and performance models.

## 5. Reliability Through Atlas Evolution

When the RD-180 was chosen as the boost phase propulsion system for the Atlas III, the overall reliability of the Atlas rocket increased from 0.9876 to 0.9955. This increase was largely due to the reduction in the number of engines on the booster. The Atlas IIAS vehicle relied upon six MA-5 engines during the boost phase. When the number of propulsion systems was reduced from six to one during the evolution from Atlas II to Atlas III, the reliability coefficient improved dramatically. There were changes to the Centaur upper stage and the RL10 that were also improvements in reliability, but these were very minor in comparison to the transition to a single propulsion system on the first stage. Every successful launch improves the overall reliability number by a very small amount. More important than this small improvement is the confidence in the original numbers and the assumptions used to establish them.

The reason for the Atlas vehicle success is largely due to the deep roots and hard won maturity in the areas of system design robustness and process discipline that are results of an evolved vehicle design[4]. Like our Russian counterparts, this type of evolved process comes from experience. That experience being mostly a result of understanding and recovery from past failures in addition to past successes.

Years of monitoring both in ground test and flight has provided a substantial family of data. The process for data collection and review is rigorous; new data compared to an established family applies directly to improved reliability. Continuous post flight analysis leads to corrective actions, lessons learned, and model refinements.

While there are improvements on the engine supplier side, there are also improvements related to integration and launch. When the RD-180 is delivered the thrust frame and the gimbal actuators for thrust vector control are already installed. This makes for a very simple integration process. Streamlining and adding improvements to these processes have occurred over the life of the program and were a real benefit to ULA during the move of its production facility from Denver Colorado to Decatur Alabama.

improvements to the Russian company that builds the engine. The RD-180 program must adhere to international traffic in arms regulations or ITAR. ITAR restrictions on the RD-180 program limit the constant operational improvement that naturally occurs on other domestic programs. In order to do business with a foreign company, United Launch Alliance and its counterparts at Pratt & Whitney Rocketdyne must operate under a license agreement with NPO Energomash approved by the United States Government. The purpose of this agreement is to protect sensitive technology that is available in the United States but not available in Russia. NPO EM has a similar agreement with the Russian Government that only allows

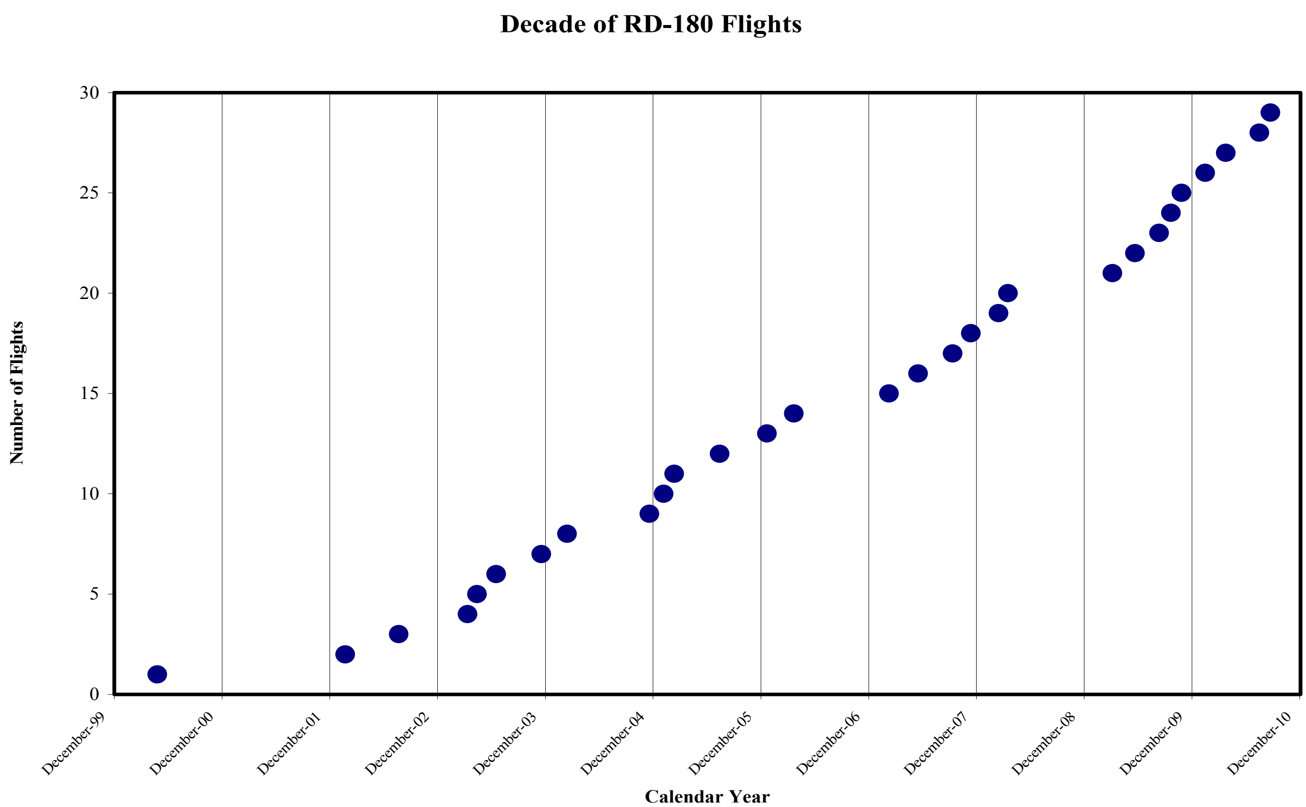


**Figure 2 – RD-180 engines flown between 2000 and 2010**

## 6. TURNING PROGRAM LIMITATIONS INTO PROGRAM SUCCESSES

A better understanding of the engine system over time has led to the development of enhanced testing, support equipment, and test hardware. Despite the enhanced understanding and comfort that come with a mature program, there are known disadvantages associated with a foreign supplied engine.

*ITAR Restrictions*

Although ULA is the end user of the engine, as a U.S. company, it is not authorized to suggest technical them to provide information and data specific to the RD-180 engine. The U.S. license must be agreed upon by NPO EM the U.S. government and ULA. Likewise, the PWR license must be agreed upon by NPO EM and the U.S. government. This document is what defines the scope of technical assistance and discussions that may be provided by ULA and PWR to NPO EM in order to deal with issues associated with integration and launch of the engines.

Often times the license and ITAR regulations limit the type of discussions and data transfers that take place between NPO Energomash, United Launch Alliance, and Pratt & Whitney Rocketdyne.

Despite this challenge, there has been an enhancement of communication since the program began. Over time the license or technical assistance agreement has undergone revisions and improvements. These revisions have not necessarily increased or decreased the scope of what is allowed, but the restrictions have become better defined and better understood by all parties. Typically a technical license defined or agreed upon by the U.S. government expires between ten and twelve years. Revisions are added, relationships between companies, and relationships between governments change. After sixteen years, the RD-180 technical assistance agreement expired, and was replaced with a new re-baselined consolidated license in 2009.

The RD-180 program adheres to the restrictions that are intended to control the export and import of sensitive technical information between countries. To ensure that this is done, there has been involvement of the Defense Technology Security Administration or DTSA. In the past all operations that required support in the production factory from Russian foreign nationals and meetings conducted in Russia had a DTSA representative present. Over time ULA and its partners have been proactive in training and self monitoring which has led to less oversight by DTSA. Most meetings in the factory in Decatur Alabama and at NPO Energomash in Khimki Russia are conducted under company internal monitoring and the DTSA monitor requirement is waived. This has delivered considerable cost savings to the United States Government.

*International Challenges*

The RD-180 program deals with several real every day challenges. The time zone is a perfect example. There is a ten hour time difference between U.S. Mountain Time in Denver, Colorado and Russian Moscow Time in Moscow, Russia. Meetings and correspondence must be arranged at specific times in order to support this significant time difference. Travel to the supplier or supplier travel to ULA facilities involves overcoming significant jetlag prior to showing up for work.

International travel comes with its own difficulties and expenses, with business visas, customs, and long plane rides. Thus, travel is limited to what is absolutely necessary.

Language barriers limit the ability to communicate issues and ideas. Engineers are forced to get creative with the words used to communicate in order to get a point across or must find more than one way to convey a particular idea. Sometimes it is difficult to understand how or why something is done in a particular way because of differences in cultures. We do things very differently both in business and in engineering. Effective communication is often about relationships. Some of the best communication happens when the conversation or the relationship is less formal. The frame of the RD-180 program with ITAR, contractual obligations, time differences, and a translator in between makes the conversation very formal. The time to develop relationships is harder, it takes longer, and requires considerably more effort from all parties. Fortunately everyone has the same goal: success of the hardware. When that success comes to fruition the reward is more personal in spite of or even because of the challenges that are overcome along the way.

## 7. Success in Data Sharing

One very common misperception related to the RD-180 program is that our Russian colleagues are prone to withholding or guarding information; this would be understandable if it did occur this way. It would be a natural reaction to protect technology that you know far surpasses that of your competitors however quite the opposite is true. An agreement was made to provide engines, along with their data, and engineering support that leads to their successful use and consistent performance. True to that agreement over the past ten years, that delivery has been made. Information that is critical to successful engine operation is always provided.

*NPO Energomash Supplier Visits*

Russian culture and American culture are quite different. At the same time, the engineering communities are very similar on many levels. It is a skeptical community, one where solutions to problems are based on analysis rooted in math and physics or results of testing and inspections. NPO EM has been very gracious in their willingness to share information in order to help its customer succeed. Non-technical visits to NPO EM suppliers in more recent years have provided an increased transparency. In 2008 ULA, PWR, and the USAF customer were able to visit the RD-180 thrust vector control actuator supplier, Arsenal in St. Petersburg. In 2010 a similar visit was coordinated with the chamber manufacturers at Metalist in Samara. This increased openness has allowed more opportunity for dialogue, and has enhanced not only the relationship with NPO EM but their suppliers as well.

*History of Transparency: Co-Production*

It is important to note that transparency is not new to the RD-180 program. In September of 2003 all of the documents required to build the RD-180 engine were delivered to RD AMROSS and PWR in West Palm Beach in support of U.S. co-production of the RD-180. The shipments included more than 100,000 documents that represented the data required to produce the engine. That data included engineering drawings, design specifications, certification design documentation and manufacturing documentation, in addition to materials data, test data and tooling documentation[5].

This information did two things. First it allowed U.S. engineers insight into the design techniques, practices, and metallurgy which led to a better understanding and a greater appreciation of the RD-180 engine system. Second and more importantly the delivery of all the RD-180 documentation reinforced the relationship between Pratt & Whitney Rocketdyne and NPO Energomash. There was a promise made to deliver the data and the extensive amount of data was delivered. The value of the intellectual property rights transferred was enormous. This both exposed and established mutual trust between the companies. It solidified their ability to establish international cooperation, trusting that there would be protection of very valuable intellectual property.

## 8. SUMMARY

The RD-180 program has established that international cooperation, involving valuable intellectual property, is possible and can be beneficial to all parties involved. Using a powerful, efficient, reliable engine on an already mature launch vehicle has created a pairing which has led to years of mutual success.

This was accomplished despite the initial skepticism that came with a foreign technology. The risks both in international relations and the lack of technical understanding by ULA were accepted or mitigated to allow use of what was advertised as superior technology. Testing demonstrated performance which has remained consistent throughout a decade of Atlas flights. Partners at NPO EM, PWR, RD AMROSS and ULA have established a strong understanding of the engine not only technically but programmatically. Continuous improvements, built upon a strong heritage with growing experience and enhanced openness and communication are well recognized throughout the RD-180 program.

ITAR restrictions, DTSA involvement, and Language Barriers, to name a few, are the hurdles that had to be overcome by ULA and its partners to leverage the power of the RD-180 engine. A history of well developed engines, proven performance, and substantial support from the engine supplier has set precedence for international program cooperation. This cooperation was formed in order to give the Atlas rockets increased performance and reliability through use of the RD-180 as the main booster engine.

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