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United Launch Alliance – Delivering Perfectly on the NRO's Most Aggressive Launch Schedule in Over 25 Years

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On the 14th of April, 2011, an Atlas V roared off its launch pad from Vandenberg Air Force Base in California and successfully delivered into orbit the NROL-34 payload. This represented the final mission in a five-mission/seven-month aggressive launch campaign for the National Reconnaissance Office (NRO). This was a remarkable achievement, and in order to make it happen, United Launch Alliance (ULA), in partnership with industry and customer, had to integrate and launch the first Delta IV Heavy vehicle from the West coast and simultaneously process launch vehicles on three launch pads on the East and West coasts. This paper will discuss the recipe of Mission Success that led to delivering perfectly on the NRO's most aggressive launch schedule in over 25 years.

Figure 1. Three of the Five NRO Missions Delivered During the 2010-11 Aggressive Launch Campaign

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Introduction

Formed in December 2006, United Launch Alliance (ULA) is a 50-50 joint venture owned by Lockheed Martin and The Boeing Company. ULA brings together two of the launch industry's most experienced and successful teams – Atlas and Delta – to provide reliable, cost-efficient space launch services for U.S. government launch customers including the Department of Defense, NASA, and the National Reconnaissance Office (NRO).

Atlas and Delta expendable launch vehicles have supported America's presence in space for more than 50 years, carrying a variety of payloads including weather, telecommunications and national security satellites that protect and improve life on Earth, as well as deep space and interplanetary exploration missions that further our knowledge of the universe.

With three families of launch vehicles – Atlas V, Delta II, and Delta IV – ULA continues the tradition of supporting strategic U.S. space initiatives with advanced robust launch solutions to provide assured access to space and 100 percent mission success. Launch operations are located at Cape Canaveral Air Force Station (CCAFS), FL, and at Vandenberg Air Force Base (VAFB), CA. Reference website: http://ulalaunch.com/site/. The following section describes the Atlas V and Delta IV launch vehicles.

A. Atlas V

The Atlas program has logged more than 600 launches to date, from the early days of America's manned spaceflight to the recent return to the Moon. As illustrated in Fig. 2 and Fig. 3, the Atlas V Family of Launch Vehicles consists of:

1) A common booster core powered by the RD-180 engine. Produced by RD AMROSS, the RD-180 engine is throttleable over a wide range and develops a liftoff thrust of 3.8 MN.
2) Up to five Aerojet Atlas V strap-on solid rocket boosters. The solid rocket boosters, the largest monolithic solids in the world, enable the Atlas V to flexibly and competitively meet varied performance requirements for missions from low-Earth to geosynchronous orbit and beyond.
3) A Centaur upper stage configured with either one or two Pratt & Whitney Rocketdyne-manufactured RL10 engines to optimally meet various spacecraft mission requirements.
4) The option of either a 4.2-meter diameter Atlas-heritage design payload fairing or a 5.4-meter diameter Oerlikon-manufactured payload fairing. Both flight-proven fairings are offered in three lengths to more precisely accommodate customer requirements.

Figure 2. Atlas V Family

Performance

	401	431	551	HLV
GTO	4,750 kg (10,470 lb)	7,700 kg (16,970 lb)	8,900 kg (19,260 lb)	13,000 kg (28,660 lb)
LEO	9,800 kg (21,600 lb)	15,720 kg (34,650 lb)	18,810 kg (41,480 lb)	29,400 kg (64,820 lb)

GTO (Geosynchronous Transfer Orbit): 35,786 x 185 km (19,323 x 100 nmi) at 27.0°;
LEO (Low-Earth Orbit): 185 km (100 nmi) circular at 28.5°

Figure 3. Atlas V Payload Performance

B. Delta IV

Since its launch in 2002, the Delta IV has successfully demonstrated its ability to launch high-priority USAF, NRO, NASA and commercial payloads to orbit. With the Heavy Launch Vehicle (HLV) variant, Delta IV has the highest mass-to-orbit performance capability of any available U.S. Expendable Launch Vehicle.

As illustrated in Fig. 4 and Fig. 5, the Delta IV launch vehicle family consists of:

1) A common booster core powered by the Pratt & Whitney Rocketdyne RS-68 first-stage engine. Designed with reduced complexity and costs, it runs off liquid oxygen/liquid hydrogen propellants for high performance.
2) Three common booster cores for Heavy Launch Vehicle variant for maximum mass-to-orbit performance.
3) Use of proven heritage hardware, software, and processes from Delta II, the industry workhorse.
4) Efficient launch site processing, with off-pad horizontal integration of the vehicle and parallel processing of the payload.
5) Second stage powered by the Pratt & Whitney Rocketdyne-manufactured RL10 engine. The engine possesses a 3D carbon-carbon extendible nozzle designed for improved performance and longer second-stage burn durations.
6) The Medium-Plus variants with a Common Booster Core (CBC) and either two or four 1.5-m-diameter graphite-epoxy solid propellant strap-on motors. These motors are designed and manufactured by Alliant Techsystems and have both fixed and vectorable nozzle configurations.
7) The option of either a 4- or 5-m-diameter fairing.

Figure 4. Delta IV Family

Performance

	Medium	M+(4,2)	M+(5,4)	Heavy
GTO	4,300 kg (9,480 lb)	6,030 kg (13,290)	7,020 kg (15,470 lb)	12,980 kg (28,620 lb)
LEO	9,150 kg (20,170 lb)	12,240 kg (26,980 lb)	13,360 kg (29,440 lb)	22,560 kg (49,470 lb)

GTO (Geosynchronous Transfer Orbit): 35,786 x 185 km (19,323 x 100 nmi) at 27°;
LEO (Low-Earth Orbit): 407 km (220 nmi) circular at 28.7°

Figure 5. Delta IV Payload Performance

I. Delivering Perfectly on the National Reconnaissance Office (NRO)

With the launch of the NROL-34 payload on 14 April, 2011, ULA delivered perfectly on the NRO's most aggressive launch schedule in over 25 years.

This represented the final mission in a five-mission/seven-month aggressive launch campaign. This was a remarkable achievement, and in order to make it happen, ULA, in partnership with industry and customer, had to integrate and launch the first Delta IV Heavy vehicle from the West coast and simultaneously process launch vehicles on three launch pads on the East and West coasts. Two heavy launch vehicles, NROL-32 and NROL-49, each consisting of port, core, and starboard common booster cores, were launched during this campaign.

The launches included, in chronological order, NROL-41, NROL-32, NROL-49, NROL-27, and NROL-34. In addition, during this same time period, ULA successfully launched COSMO-4 on a Delta II, and OTV-2 on an Atlas, as noted in Fig. 6.

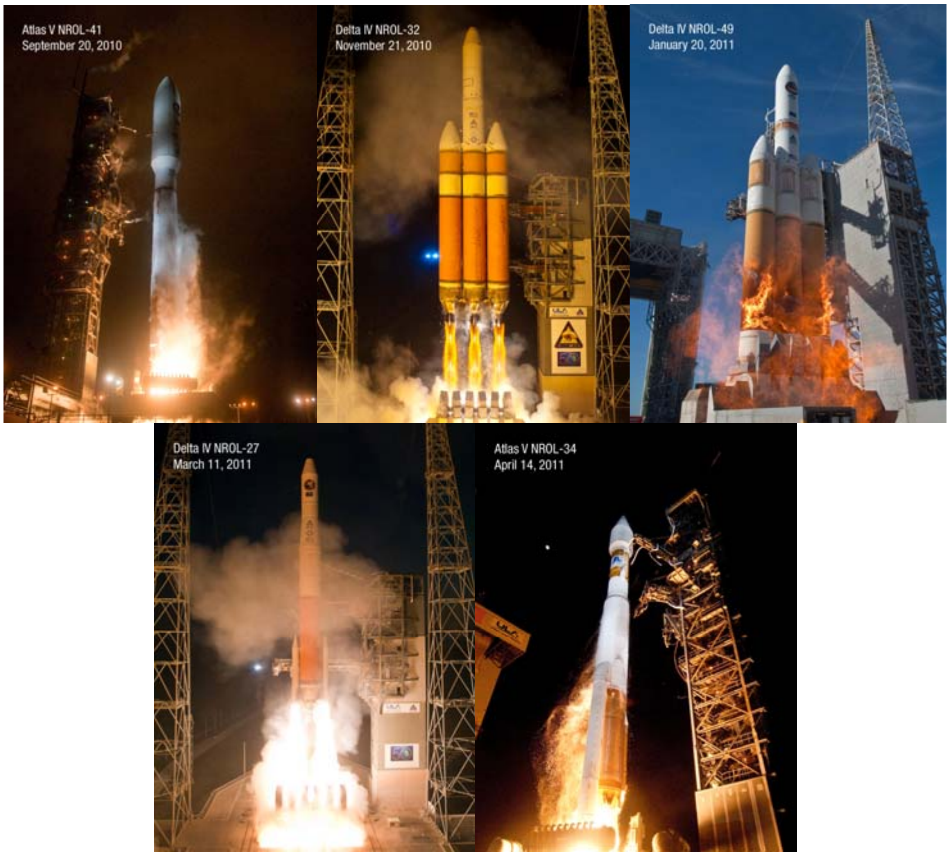

Figure 6. NRO's Most Aggressive Schedule in Over 25 Years

This enormous success can be attributed to a successful partnership with the Air Force – the Office of Space Launch (OSL), and Launch Systems Directorate. More details on this will be included in the following sections, but the Air Force teams contributed significantly to mission success and the ultimate delivery of critical space capabilities to the United States in the form of independent review teams and hardware pedigree reviews.

Delivering perfectly on the NRO can also be contributed to ULA's higher standard of quality of service and a proven recipe for mission success.

II. ULA's Higher Standard of Quality of Service Defined

ULA's higher standard of quality of service is defined as:

1) Invested performance capability to cover all the Nation's payloads
2) Invested, redundant launch site infrastructure on both coasts to ensure uninterrupted access to space and maximum schedule flexibility
3) Demonstrated flight reliability
4) Predictable, stable vehicle behavior through anchored flight characterization across the whole spectrum of possible missions and payloads
5) Mission success recipe built on mature, proven, and disciplined processes and best practices, learning and improving continuously
6) Highest mission success standards developed through lessons learned from past failures, recoveries and recurring learning events

7) Verified unique spacecraft accommodations to handle and protect any payload

This paper will focus on the mission success recipe, lessoned learned, and unique spacecraft accommodations.

III. Mission Success Recipe Built on Mature, Proven, and Disciplined Processes and Best Practices, Learning and Improving Continuously

ULA's mission success record is our key strength, which cannot be taken for granted; and we must continue to improve. Small missteps are noticed as our customers expect excellence and hold ULA to a higher standard.

The mission success recipe that has brought 100% mission success to ULA is difficult to define, as there are many elements that work together to make it happen. One cannot forget that our people set us apart, with more than 100 years of combined experience. Great people plus process focus leads to ULA and customer mutual success.

Nevertheless, there are key ingredients to the mission success recipe which include:

1) Systems Engineering
2) Operational Excellence
3) Certified Responsible Engineer program
4) Causal Analysis
5) Independent Review Teams
6) Test Like You Fly
7) Closed-loop Data Review
8) Error Prevention Program
9) Supplier Partnership
10) Operational Fishbone Process
11) Continuous Improvement

Some of the ingredients above will be touched upon in more detail in the following sections.

A. Independent Reviews and Hardware Pedigree Reviews

The contributions of the Air Force – the Office of Space Launch (OSL), and Launch Systems Directorate, in partnership with ULA, are extremely important and are a key element to mission success. One important way that they contribute is through independent reviews and hardware pedigree reviews.

The customer independent review teams include:

1) Pedigree Review Team
2) Independent Readiness Review Team (IRRT)
3) Mission Integration Group (MIG)
4) Mission Assurance Team (MAT)
5) Independent Verification and Validation (IV&V)

ULA also employs independent review teams, including:

1) ULA Independent Review Team (IRT)
2) ULA Independent Readiness Review Team (IRRT)

All these teams participate in a closed-loop data review that look at product build, test, and flight records, which are maintained and configuration-controlled (pedigree). All data are independently reviewed for trends, comparison to family and component acceptance criteria, compliance to spacecraft interface requirements, and comparison to preflight predictions. Test levels are also reviewed and compared against maximum expected flight levels plus margin.

Independent reviews and hardware pedigree reviews are key to *preventing* mission failure and potential disastrous consequences to the Nation's space capability and war fighting capabilties.

B. Systems Engineering

In close partnership with our customers, ULA developed a robust systems engineering process, evolved from heritage systems and learned principles from past failures. Below is a summary of the chronology:

1) Post 1990s launch failures, incorporated evolutionary development of vehicle technology and capability, learned principles from previous failures embedded into processes.
2) 1998-2002 Extensive requirements development and verification process, designed to most stressing conditions, incorporated new technologies and tools and design principles that directly supported mission success. ULA employees lived, learned, and leveraged previous customer-directed Broad Area Review (BAR) directives.

3) 2002-Present closed loop process of incorporating latest launch data into system in preparation for next launch.

ULA's systems engineering for the U.S.'s Evolved Expendable Launch Vehicle (EELV) program is a key ingredient to the mission success recipe.

C. Operational Excellence

Operational success results from process design and control, skilled personnel, and continuous improvement. Important elements on the production floor include situational awareness, reliable and repeatable processes, process discipline, and a world class 5S workplace (sorting, simplifying, sweeping, standardizing, and self-discipline).

ULA's program for continuous improvement can be summed up in perfect product delivery, the relentless pursuit of perfection to achieve excellence in everything we do. It applies our passion for mission success to continuously improve every process and product, to completely meet the needs of every customer and it inspires all employees to dedicate our innovative talents to deliver program success and develop a world-class work environment.

Part of perfect product delivery is ULA's error prevention program, which is setting the standard for error prevention in operations and business practices. Through this robust closed-loop process, ULA demonstrated a significant reduction in operational mishap frequency and severity.

Another piece of operational excellence is the implementation of operational fishbones. This is a variation of the traditional Ishikawa cause-and-effect analysis tool that includes the risk rating concepts of Failure Modes and Effects Analysis. This is developed for each critical process and is a reliable method for developing and implementing actions to eliminate or mitigate risks.

D. Certified Responsible Engineer (CRE)

Another ingredient to mission success is ULA's CRE program. The program ensures mission success through individual ownership and certification of critical products throughout the product lifecycle.

Key principles include:

1) Critical products must have a single owner who has responsibility, accountability and authority for the product throughout its lifecycle
2) Critical products must undergo comprehensive certification to ensure readiness for each mission
3) Critical product owners must prioritize technical issues and solutions over cost and schedule
4) Critical product owners must meet minimum qualifications and be certified in the product certification process

E. Test Like You Fly

ULA has learned from past failures the importance of testing the vehicle like you fly. What that means is that you test first all expected flight functions, environments, and stresses before first flight. Data from measurements, video, etc. are independently reviewed. The data is reviewed for out of specification requirements, predictions, or family.

Rigorous system-level testing at maximum expected flight levels are essential to success.

An important ingredient to mission success is not only protecting the spacecraft while in flight, but also while being processed and integrated to the launch vehicle at the launch site. The next section will describe ULA's unique spacecraft accommodations.

F. Unique Spacecraft Accommodations

ULA has a catalogue of demonstrated spacecraft accommodations which can be tailored for any customer.

ULA's proven capability include:

1) Continuous payload environmental monitoring and control during transport, hoist, mate, integrated testing and checkout, countdown, and launch, as in Fig. 7
2) Fully redundant environmental control system
   a) Temperature set-point control given to spacecraft
   b) Environmental Control System (ECS) Flow up to 4000 SCFM capability
   c) Humidity control
   d) Class 5000 cleanliness
3) Vertical spacecraft and launch vehicle integration
4) Shielded portable clean environmental shelter to access payload

5) Radio-frequency protection shelters
6) Continuous space vehicle instrumentation purge
7) Demonstrated spacecraft on-pad propellant loading
8) Dedicated spot-cooling system to accommodate localized spacecraft cooling

IV. Conclusion

The proven recipe of mission success that brought mutual benefits to both ULA and its customers is difficult to define. Even so, there are key ingredients to the mission success recipe that include customer and ULA independent review teams, systems engineering, operational excellence, certification of responsible engineers, testing like you fly, and payload protection and accommodation during ground integration activities.

It is important to emphasize the contributions of the Air Force – the Office of Space Launch (OSL), and Launch Range Directorate, in partnership with ULA, to the overall mission success culture.

This mission success recipe led to perfect product delivery of five missions over an aggressive seven-month launch campaign for the NRO.

Figure 7. Payload Environmental Control and Cleanliness Maintained During Transport