What Makes An Affordable and Reliable Launch System?

Corresponding Author Last Name: Holguin
AIAA-2006-7210
Session: 49-SE-3

The Space Operations Community: Other Views and Experiences

The Atlas and Centaur Programs have enjoyed a rich history as the trusted vehicle of choice for America's satellite programs. During that course of space launch development, the Atlas Expendable Launch vehicles have matured in both reliability and cost of operation of the system, due to evolutionary improvements that factored in all aspects of the mission, from design to manufacturing (including subcontractors) to assembly and test to operational launch. Launch costs have been reduced by over 50% from heritage Atlas, and launch turnaround from months to weeks. The flight proven Atlas has successfully launched payloads 79 consecutive times to their earth-synchronous or solar system bound trajectories, with increasing accuracy and reliability, lower cost and improved launch on time records. During the maturation from Atlas I to Atlas V, 8 evolutionary Atlas first flight vehicle configurations on 3 new or significantly modified launch pads provided a pathway to reduce cost and improve operational aspects of the launch system as a whole.

Atlas I	Atlas II	Atlas IIA	Atlas IIAS	Atlas IIIA	Atlas IIIB	Atlas V-400	Atlas V-500
AC-69	AC-102	AC-105	AC-108	AC-201	AC-204	AV-001	AV-003

The Atlas Evolutionary approach has successfully proven all 8 of 8 first flight vehicle configurations, with a current flight record of 77 consecutive successes.

This paper will address the evolutionary path that the Atlas Centaur program took to accomplish the goals of significantly reduced cost while improving all other aspects of the launch system. Because the success of any program is rooted in its ability to control its processes, evolve and grow to meet the ever-increasing need for lower cost while improving reliability and operability, it is important to understand how each of these variables affects the others – both positive and negative.

INTRODUCTION

Faster, Better, Cheaper. The mantra of NASA during the 1990's under NASA Administrator Dan Goldin's watch was tried and found to be wanting. You can have any two of the three in risky space endeavors but not all 3. As Einstein put it, "Make everything as simple as possible, but not simpler." The most dangerous approach to spaceflight is initiating a new design or taking steps to improve an old design and reduce cost without considering the full effect of the change, not only within the system that is being changed but to adjacent systems and operations. There are certain tenets of launch vehicle design that have developed over the years that if ignored or dismantled in order to try and get better somewhere else, carry large risks and heavy penalties for failure. It has been said that there are old pilots and there are bold pilots, but there are no old, bold pilots. For the simple reason that, in order to survive, the system must mature and incorporate the wisdom learned along the way. The Atlas V Launch Vehicle System has evolved in a disciplined and measured approach leading to success. Atlas V is the result of just such maturing over decades rather than months, and the systems and operational design has taken full advantage of that wisdom and maturity. The key is an Evolutionary approach to development that addresses not only performance, but cost (recurring and development) as well as reliability to strike a balance that gives proper weighting to each element.

As proof of the merits of the evolutionary approach, Atlas V has improved the performance of a launch by up to twice that of earlier vehicles while reducing cost up to 50% and achieving an unprecedented 8 successful first flight configurations, and an overall success of 79 in a row.

DISCUSSION

The Premise and Promise of EELV: The EELV program was undertaken in part, to reduce the cost of access to space, due to the high cost of the Titan IV launch vehicle for National Security payloads. In addition, the USG did not want to rely solely on a single LV for access to space, as the challenger disaster proved to be a difficult time in the nations launch capability. Prior to that he national policy required all payloads to be launched on the shuttle to increase launch rate to reduce costs; post disaster, these same payloads were put in limbo. Besides the EELV program goal of 25% cost reduction, 4 Key performance parameters (KPP's) were designed to be met by the EELV program A) performance capability , B) Design Reliability, C) Standardization , and D) Common payload interface were the most important parameters to be met by the EELV program. The Atlas V met and exceeded many of these KPP's in addition to meeting the goal of reducing cost by at least 25%, Atlas in some cases have reduced cost by up to 50% (reference figure 1) .

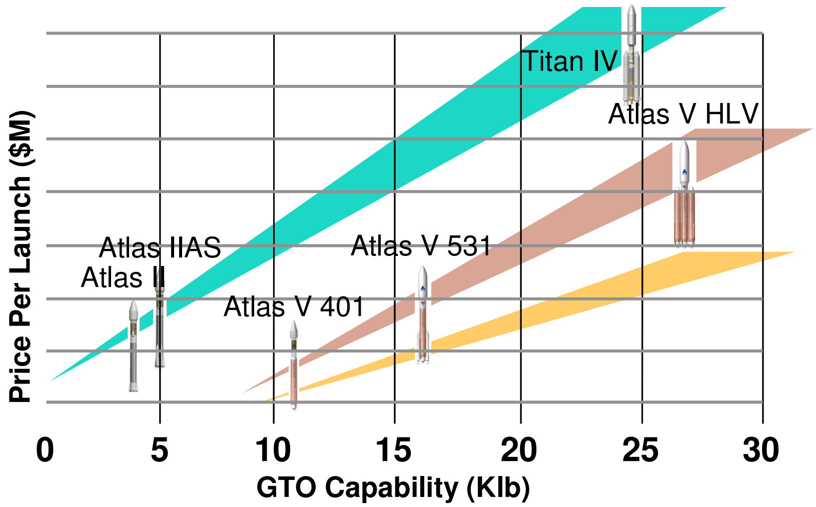
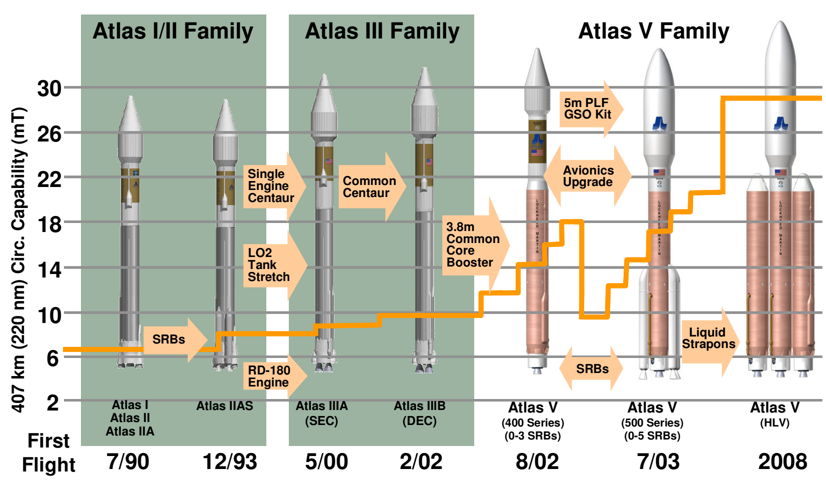


Figure 1: The Atlas V/EELV Family Successfully Reduced Cost to Orbit by up to 50%

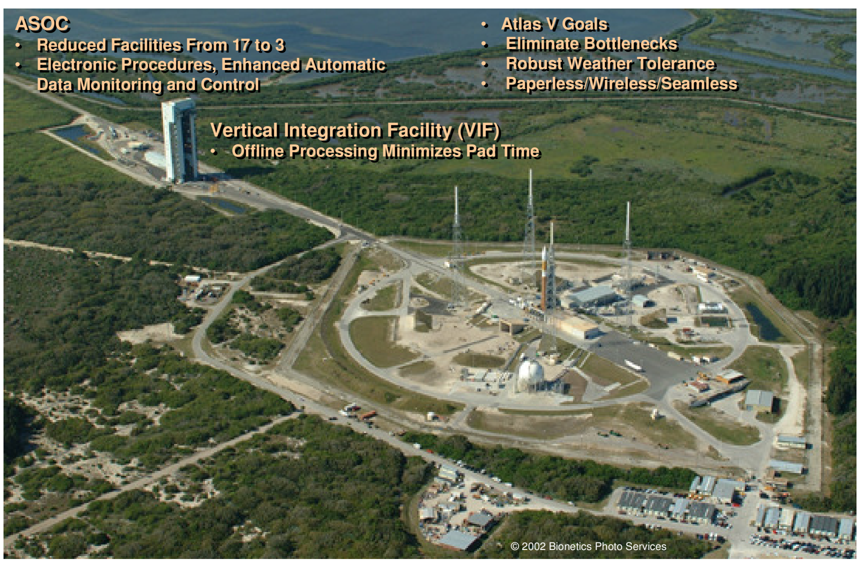
The Atlas Evolution approach began during the early days of the Atlas program. The concept was simple and straightforward: Test the technology that improves the cost and or performance and/or reliability of the launch system like you fly it, and make incremental changes to ensure maximum mission success. Atlas V record has been successful to the point that paying customers have been aboard every single first flight of a new configuration. Figure 2 outlines this incremental approach and highlights the incremental changes along each variant. Of particular note is the Atlas II configuration, which paved the way for EELV Atlas V. This new engine in the Atlas III configuration combined the world's most powerful LO2/Hydrocarbon engine with the safety and reliability of the Atlas heritage systems resulting in a highly reliable and affordable launch vehicle. Once proven on Atlas II, it was a significantly less risky step to evolve to Atlas V launch vehicle. The DoD, as support to the panel of experts discussing the future National Security Space launch requirements, commissioned the RAND National Defense Research Institute to support this panel. The RAND Institute published the National security Space Launch Report, where the assessment concluded that the "space launch capability inherent in the two EELV family of U.S. rockets (Atlas V and Delta IV) are state of the art technology achievements gained through combined industrial and DoD investment"[1].



[1] National Security Space Launch Report, Copyright 2006, RAND National Defense Research Institute, Forrest McCartney et. al.

Figure 2: ***Demonstrated Low Risk Evolutionary Development by Introducing and Improving Upgrades One Step at a Time***

Fixed Cost (Infrastructure) and Launch Rate Drives Overall LV Cost – When More is Better: It has long been recognized that the high cost of the infrastructure for maintaining the capability to provide space access is the single overriding cost factor. The fixed cost for the production capacity, launch site and engineering and technician support is needed for a single launch or a dozen launches a year, with only a marginal increase in the human support required for a higher launch rate. So ultimately, the launch rate determines the how much fixed cost is allocated to the price for any single launch. Cannibalization of the launch rate with new launch systems can have the unintended effect of exacerbating an already low rate per launch system with capacities of a dozen or more per year, each. The EELV's have the capacity to launch significantly more than they are currently slated to launch, even with capture of the entire USG market in the EELV class. The proposed United Launch Alliance is intended to bring additional benefits by combining some of the launch infrastructure associated with the EELV systems. A NASA funded study conducted by the Space Policy Institute on Launch vehicles, and Economic Perspective[2], concluded among other things that because of the inelasticity of price due to demand, existing and new entrants in the markets place face significant hurdles to overcome to be successful. Some of the most significant factors as identified in this study are: 1) overly optimistic demand curves that rely on very cheap access to space, neither of which have materialized, and in fact have been thwarted by other non-related economic factors (e.g. the telecom boom of the 1990's went bust), 2) basing development of new vehicles on overly optimistic technological assessments rather than a rigorous economic analysis, 3) Politics can overwhelm economics even in mature market economics, and 4) too few launches in any particular year.



[2] Launch Vehicles: An Economic Perspective, Henry R. Hetrtzfeld, Ray A. Williamson, and Nicolas Peter, eorg Washington University Space Policy Institute, September 2005.

Figure 3 - ***Atlas V Clean Pad Concept Delivers Operational Simplicity and Flexibility***

Atlas V is a launch system that doesn't rely on overly optimistic projections, but can handle them if and when they materialize without additional investment in infrastructure. Figure 3 shows an example of infrastructure reduction that allows an increased launch rate at the Atlas V launch site. Built around a clean pad concept, all of the processing is done offline, allowing multiple launches in consecutive days. Recognizing the alternate build on pad approach, the Atlas V clean pad requires a minimum amount of time on pad with the minimal amount of infrastructure with the

Commonality in the LV system design also allows the fixed costs to be absorbed over a much larger flight rate. By modularly adding common components such as boosters, upper stage engines, solids or fairing components, the infrastructure cost per LV comes way down, thus achieving rate synergy to the maximum extent. Figure 4 indicates the components in the Atlas V family of vehicles with Common components.

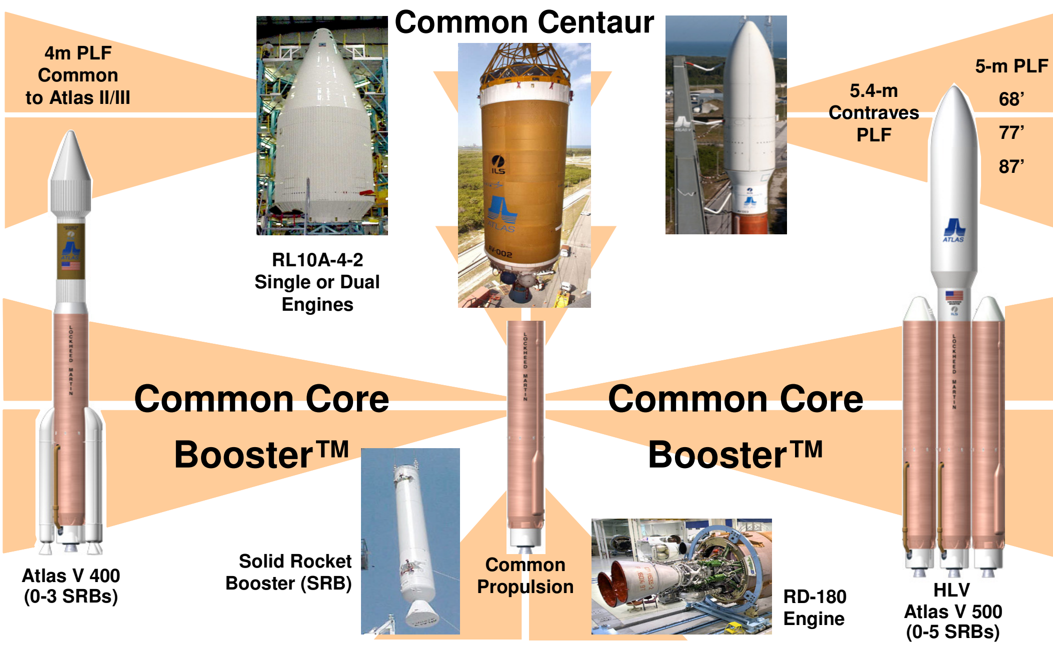


Figure 4 – The Atlas V Family Designed in Significant Commonality Between Vehicle Configurations to Minimize Unique Operations and Maximize Synergy

The potential for increase of launch rate stems mostly from the current USG manifest – both NASA and DoD. The Space Transportation Policy provided the premise for this sharing, recognizing the benefits of a shared launch system. Some of the benefits for the USG if DoD and NASA use a common Space Transportation System are as follows:

- **Assured Access**

– **Shared Infrastructure—Manufacturing, Engineering, Management, Launch Site**
– **High Flight Rate—Demonstrated Reliability, Lower Costs, Resiliency**

- **New Capabilities, Shared Investment and Mission Assurance**
  – **Reliability Enhancements**
  – **Responsive Launch Through Additional Infrastructure**
  – **Additional Performance Including WTR heavy lift capability**
  – **Large Payload Fairings (PLF)**
  – **In-Space Transportation, Proximity Operations**
  – **One Team approach to management of processes and products**

Reliability, the Proof Is in the Pudding: For a new design, design reliability is really the only predictor of future success, and is a relatively uncertain one. Reliability is ultimately measured by the success of the system over a statistically significant number of launches. Additionally, for technology insertion on an existing launch system, the Probabilistic Risk Assessment (PRA) approach provides a rational and realistic assessment of the risk of the new technology based on the extensive use of existing proven subsystems, components and operational procedures, and the human elements with experience that design and operate all of those aspects of the system. Atlas V benefited significantly from the use of a significant amount of new and heritage technology and systems that were upgraded incrementally, then flight proven prior to the next technology insertion. Infant mortality failure rates are mitigated by the ability to fly changes (hardware, operations or both) on a proven vehicle, pre-empting the infant mortality syndrome (see figure 5).

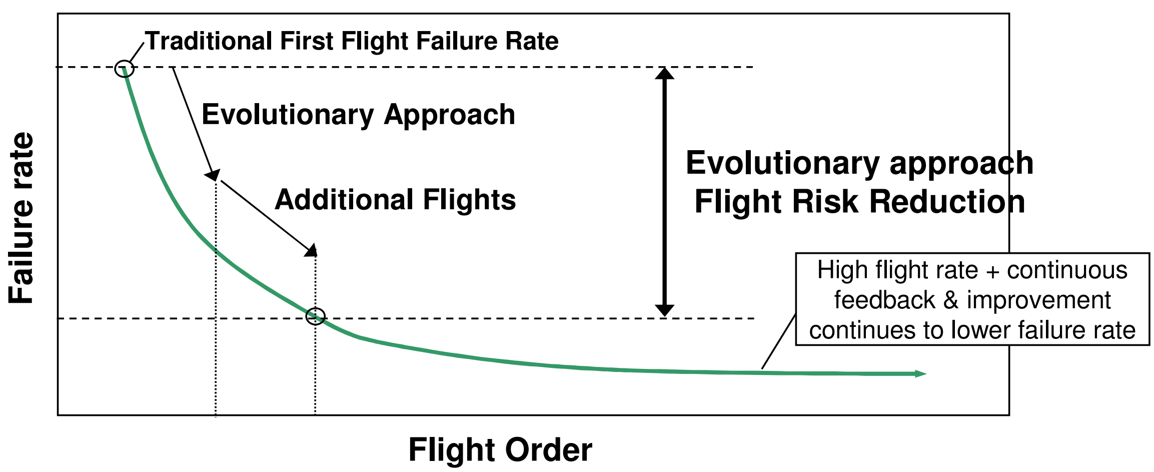


Figure 5 - Design flaws manifested in early flights are minimized by the evolutionary development approach, and process flaws (quality, human error) are mitigated by continuous improvement driven by flight & test results

The Atlas V family reliability also benefits from a common family of vehicles used to fly all missions, including commercial, AF, NRO, and NASA science payloads. The same components fly on multiple vehicle configurations with a flight rate from 6 to 10 per year, thus proving the same system and components over and over. This approach demonstrates reliability much sooner than a unique vehicle with a low flight rate. The recurring flight data provides system characterization, and lessons learned from each flight in all 3 critical areas of people, process, and product are acted upon prior to the next flight. Figure 6 shows this effect.

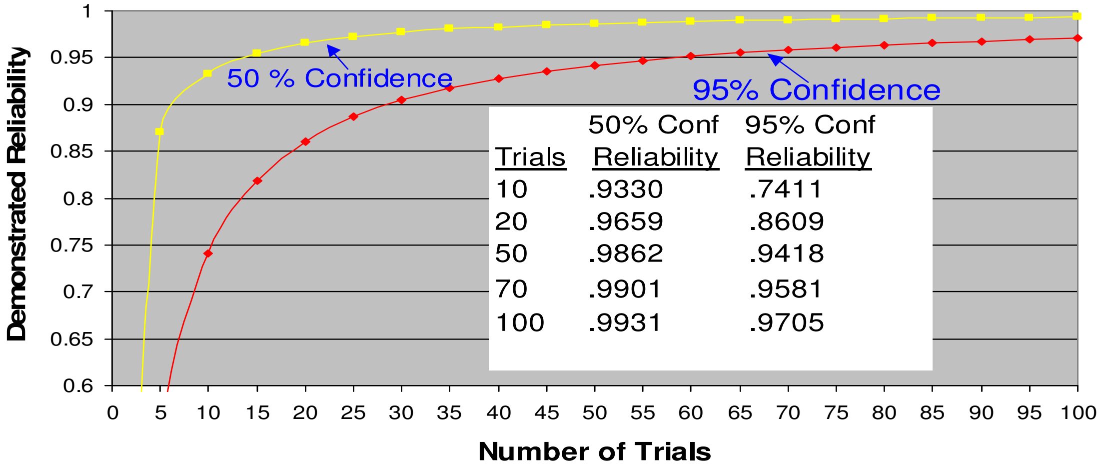


Figure 6 – the reliability of a LV system achieves a high reliability much sooner using common systems and processes.

Learning Curves Aren't Always Straightforward: Learning curve effects are felt both in the cost and reliability variables of the launch vehicle system equation. In a study conducted by General Dynamics in 1988[3], traditional learning curve estimating for LV production was not directly applicable, but rather a rate learning curve approach will more accurately predict the future cost of a launch vehicle fabrication and assembly. This is primarily due to rate sensitivity as a result of varying launch manifest (flights per year) affecting the buildup, falloffs and gaps in the production schedule.

The Cost of Reliable Component Technology – Penny Wise and Pound Foolish: The prices of individual subsystems and associated technology have largely been defined by the Mil-Std specifications on level of redundancy and/or test associated with each individual component. Reliability is paramount for launch systems, as the cost of the payload, often in the billions of $$'s for both NASA science and security payloads, far outweighed the cost of the launch system underneath it. For example, a single failed component, such as a gasket that might have cost $1.39, could bring down a $1.5B launch, as well as the loss of science or national security and years of dedication and hard work that preceded it, as well as the loss of priceless information that would have been gained from it. The cost of failure was and is still high, and countless scientists and war-fighters rely on the $1.39 gasket doing its job properly and reliably, and that comes at a price that includes extensive test, review of the performance of the system at every level. Similarly, the technology in rad-hard processors lags years behind the computing power into days PC's, but the reliability far outweighs the benefit of being able to stuff more lines of code through a faster processor, only to be deep-sixed by an Single Event Upset.

[3] The Production Cost Surface, Thomas H. Merrill, Manager, Engineering and Operations Estimating, and Curtis C. Ruesser, Senior Cost Development Engineer, General Dynamics Space Systems Division, April 25-27, 1998 for the 25th Joint Meeting of The Institute of Management Science/Operations Research Society of America.

SUMMARY

What makes an affordable and reliable launch vehicle? The Atlas V evolutionary approach provides a safe and reliable way to inject new technologies that enhance cost, performance and/or reliability into an existing platform. The clean sheet approach, ambitious at first, often fails to have the benefit of multiple flights and decades of testing, and the wisdom of knowing what works and what doesn't and how to know that early on prior to flight. An evolutionary approach, while not foolproof, provides the best safeguard against simple, stupid but costly mistakes. The cost of the launch goes up by an order of magnitude when you factor in a failed launch and useless payload into the cost. That lesson has been learned the hard way too many times.