Phase 2 EELV – An Old Configuration Option with New Relevance to Future Heavy Lift Cargo

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Abstract

In 2004, the Atlas program of Lockheed Martin created a vision for performance evolution of the Atlas V family focused on NASA growth missions, with performance options ranging up to 140t. The 5m diameter, 70t class Phase 2 Atlas Heavy, assuming dual RD-180s, was a key vehicle in this evolution. With Constellation, this configuration was put on the back burner, but there is now renewed interest with Augustine Commission identifying this vehicle on its short list of candidate Heavy Lift Launch Vehicles (HLLVs). With a dearth of publicly available data on this vehicle concept, this paper summarizes this configuration and its merits. The creation of United Launch Alliance has created important synergies with the availability of 5m tank hardware and production facilities from Delta IV, allowing ULA to incorporate the best of Atlas and Delta. The Phase 2 design leverages existing assets, including the Delta IV factory and the Atlas V launch pad, makes this a true EELV evolution. Newer upper stages alternatives now conceptually exist that might leverage NASA developments from the Constellation program to further enhance the Phase II EELV concept.

I. Introduction

In the late 1990s, Boeing was developing the Delta IV and Lockheed Martin the Atlas V as competitors for the Evolved Expendable Launch Vehicle (EELV) Program. In the midst of that activity, the focus was on getting the Delta IV and Atlas V fleets developed and flying. In 2004, NASA came out with the Jupiter Icy Moons Orbiter (JIMO) mission requiring a large increase in performance compared to either the Delta or Atlas Heavy vehicles. That spurred Atlas and Delta each to consider performance evolution roadmaps for their launchers.

The Boeing legacy Delta IV focused on a suite several different upgrades, including adding GEM-60 solids to the Heavy configuration, an RS-68 upgrade, a new upper stage, and propellant crossfeed, which when combined can remarkably double lift capacity while retaining the basic Delta IV Heavy configuration with three, 5m-diameter cores, the existing launch pad, and factory. The first step in this upgrade path, the RS-68A, is being realized today, with the first flight scheduled for late 2011. For lift requirements up to 45t, this remains a very appealing path, though not the topic of this paper.

The Lockheed Martin legacy Atlas V defined an evolutionary path with a new upper stage originally called Wide-Body Centaur, which was the Phase 1 evolution followed by an upscaled 5m-diameter Atlas booster powered by a pair of RD-180 engines that could lift over 70t of payload to LEO (called Atlas Phase 2). This concept shared significant design legacy from the Atlas V, and could even use the existing Atlas V launch pad.

JIMO was cancelled in 2005, and the subsequent Constellation architectures did not utilize EELV vehicles. With no other customers requesting significant EELV performance growth, these evolutionary concepts were moved to the back burner. The concepts originally defined in the JIMO activity remain the foundation for Delta IV and Atlas V evolution plans today. The merging of the Atlas and Delta programs in late 2006 into ULA created an opportunity for both programs to compare notes, find the best of both systems, and seek the best-combined evolutionary path. The Atlas Phase 2 has morphed into EELV phase 2, with an updated Atlas/Delta Advanced Common Evolved Stage (ACES) upper stage, and leveraging the tremendous Delta legacy factory capability for 5m tank manufacture in Decatur, Alabama, next door to NASA Marshall Space Flight Center (MSFC), to make the Phase 2 Atlas booster configuration even easier to implement. Given its dual legacy, the revised configuration is renamed Phase 2 EELV.

The 2009 Augustine Commission studied HLV vehicle options and endorsed EELV Phase 2 (under a generic name) as one of a handful of preferred concepts because of its obvious low cost and risk. Its most significant findings related to the affordability of the Constellation architectures, and this is where the Phase 2 EELV provides its greatest advantage. The configuration also represents low risk, the possibility of an early IOC, or the ability to phase in increased mission performance as mission requirements demand. Under the new Flexible Path Architecture, affordability will remain one of NASA greatest challenges just as it was in the earlier vision of Exploration, with the pace of Beyond-LEO missions likely driven by available funding. Figure 1 shows the merged ULA evolutionary vision.

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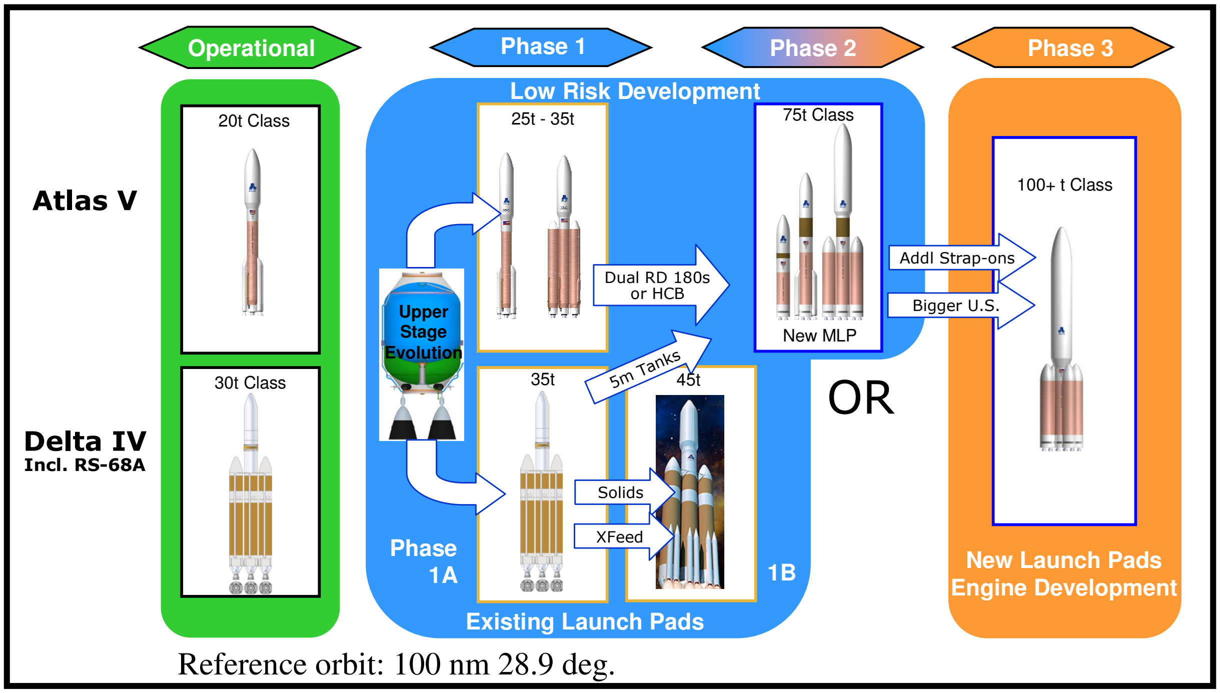


Figure 1. Merged EELV Evolution Plan

II. Value Proposition

Though the Phase 2 vehicle concept has been around for a number of years, it has new relevance in the discussion of the next NASA HLLV. The original estimates were for a Design, Development, Test & Evaluation (DDT&E) cost of $2.3B. Though assumptions regarding EELV-like development may need to be reassessed, and the need to account for cost escalation over the past 6 years is certainly required, the formation of ULA simplifies the Phase 2 development due to the ULA Decatur factory, with both tooling, and transportation infrastructure to create 5m tanks. Although ULA has not yet undertaken a revised cost estimate, we believe that EELV Phase II should have a compelling cost advantage compared to other vehicle options in the same performance class. These appear to be bold predictions, but they are grounded in actual costs and schedule experiences from the Atlas V and Delta IV programs, both for vehicle development, and the development of four associated operational launch pads. The Delta IV and Atlas V fleets were developed in a commercial environment, with limited oversight and insight from the USAF, but not with the same degree of U.S. Government design ownership seen on the Space Shuttle or as planned for on the Ares 1 and 5. The actual Delta IV development cost was $3.5B, including a $0.5B USAF investment, with multiple configurations including an HLLV configuration, RS-68 engine development, production factory, and two launch complexes. The Atlas V equivalent was $2B, including a $0.5B USAF investment, with a new launch fleet (without HLV configuration, new booster engine, or new factory), and two launch complexes. Atlas and Delta fleets each carry the legacy of over 50 years of continuous operational launch experience and a long history of evolutionary improvements.

Development risk is lowered by leveraging operational EELV systems for an HLLV. The Phase 2 EELV could be ready to fly as early as 2016, sooner than potentially any other HLLV concept. More importantly, the interim capability provided by putting the new upper stage on EELVs as an interim Phase I capability buys time for the Phase 2 HLLV booster and a new U.S.-built hydrocarbon booster engine to be developed, without delaying NASA's ability to perform beyond LEO crewed missions. NASA's use of EELVs allows early crewed, beyond-LEO missions starting as early as 2016 in an environment of constrained NASA budgets that could delay the larger HLLV.

III. Evolution Plan vs Point Design

It is easy to compare and contrast individual vehicles, but the real comparison needs to be made based on the best evolutionary plan. NASA's Flexible Path Architecture will have a mission model of ever-escalating challenge and performance requirements, starting with relatively easy Lunar Flyby's and Lagrange Point mission, moving to more challenging Asteroid Rendezvous and Lunar Landing, followed by very challenging Mars moon and Mars surface missions. A single point launch vehicle design vehicle solution that satisfies the ultimate Mars Surface requirement can be huge overkill for interim missions, and it represents a large burden on NASA's budget if developed a decade before it is really needed. Although this paper is about the Phase II EELVs, this 70t vehicle is a part of a larger evolution starting with the 35t Phase 1 Advanced Common Upper Stage on an existing EELV, followed by the 70 to 80 t Phase 2 Booster, and upgraded to become the 100+ t Phase 3 vehicle with added liquid strap-ons. Given uncertainty in the mission requirements, and our flawed ability to predict 20 years into the future of space, we believe the next generation of HLLV needs to be flexible and modular.

Our evolutionary approach allows the nation to build lift capacity cost effectively and reliably on an incremental basis, utilizing the existing infrastructure and investing in only what is required, when it is required.

IV. Phase 1 Development – New Upper Stage

The heart of the EELV-derived heavy lift architecture is not in the powerful booster stages, but in the often-overlooked upper stage. Regardless of the payload or the booster configuration, modern missions demand a very high performance upper stage. The upper stage is far more complex and has more variation in operation than the booster whose entire function is completed in less than 5 minutes. Upper stages today operate for up to 8 hours. Exploration missions demand operation ranging into the weeks and months. To achieve the required high performance, the upper stage is powered by cryogenic hydrogen and oxygen, which demands subtle design considerations. Taken as a whole, the upper stage drives the design of the entire vehicle and contains the bulk of the design risk.

ULA currently operates three high-performance cryogenic stages (Figure 2). We have accumulated an extensive knowledge of how these vehicles operate under real-world conditions on 204 missions with cryogenic upper stages.

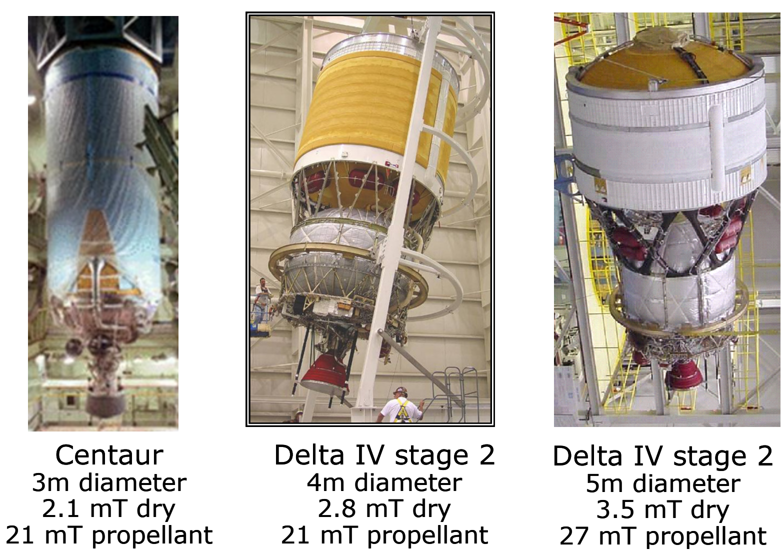


Figure 2. ULA currently operates three high energy LO2/LH2 stages.

ULA has been focusing on common Atlas and Delta upper stage upgrades as the next steps in our EELV evolution. Some confusion can exist because ULA is pursuing two separate upper stage upgrades. The Common Centaur is focused on the Air Force, NASA science, and commercial requirements with the goal of replacing the Delta IV 4m Upper Stage with the Centaur to achieve greater commonality and to realize cost savings across the EELV fleet. Tied to this upgrade is the rework of the large number of inventory RL10B-2 engines into a new common RL10C variant that captures the best of the B-2 and A-4, and can be used on Atlas V, and potentially the Common Centaur. Though the Delta missions realize a small amount of performance gain, this is primarily a commonality upgrade focused on affordability, flexibility, and a streamlined supplier chain for the DoD customer. At this time, the 5m Delta Upper stage is not included.

With the above plan for reworking RL10B-2s for Atlas the inventory, RL-10 engines run out in the 2018 timeframe. ULA sees this as an opportunity to cut in a brand new 25klb thrust class upper stage engine option, and it has approached an array of engine vendors for concepts. A newly manufactured block of RL-10Cs remains an option. Larger than 25klb thrust creates challenges for the existing EELV fleet, including a particular challenge for a key Heavy GEO missions, which are essentially thrust insensitive, but would be penalized for the higher weight associated with a higher thrust engine.

The proposed 5m-diameter ACES upper stage is being pursued in addition to the Common Centaur. ACES is designed to support NASA and DoD heavy lift missions, and it would fly on both Atlas V and Delta IV. This is a 5m-diameter stage with four of the 25Klb class engines for LEO with a propellant capacity approximately 41t, twice the Centaur or 4m Delta Cryogenic Second Stage (DCSS) propellant providing a large performance boost compared to our existing upper stages. The ACES is a thin walled, monocoque, common bulkhead stage that is about the same length as ULA's existing upper stages. ACES is intended as foundation for a modular system of stages to meet the launch requirements of a wide variety of users.

ACES is a capabilities driven stage that offers substantial LEO payload increase, and engine-out reliability benefits. Flying the ACES upper stage on the existing Delta IV Heavy booster becomes the Phase 1 EELV upgrade and offers up to 35t class LEO performance. It also becomes the planned upper stage for the scaled-up 70t class Phase 2 and Phase 3 EELVs booster discussed later. Initial operational capability for the ACES stage (Phase I EELV) could be accomplished in as little as 5 years.

ACES is based on a simple modular design (Figure 3). Use of multiple barrel panels, similar to Centaur, provides a straight forward means to building multiple-length (propellant load) stages that are otherwise common. The common equipment shelf derived from the Delta upper stage accommodates two, or four 25Klb class engines (either new engines, or newly manufactured RL-10Cs). As future larger upper stages become available, they can be incorporated. ACES takes advantage of the existing Centaur and Delta subsystems such as avionics, pneumatic, and propulsion elements. The majority of these subsystems are directly transferable with little or no changes required.

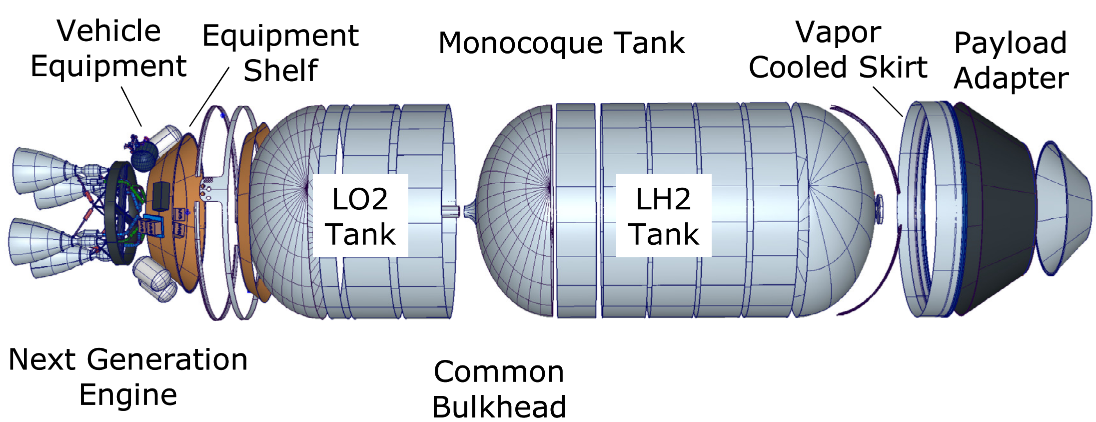


Figure 3. ULA's planned Advanced Common Evolved Stage (ACES) will fly on both the Atlas V and Delta IV boosters, enhancing mission capability while reducing costs through commonality. ACES design encompasses intended variations supporting upper stage and in-space applications.

The ACES structure and systems are a melding of the Atlas and Delta design lessons learned. If a particular function cannot be met by the baseline 41t propellant mass, then the tanks can be stretched with minimal redesign effort as demonstrated by numerous past Centaur stretches. These stretched variants continue to share the fundamental components, structures, and systems. Variations with propellant capacities in excess of 120t have been explored, with stretched variants particularly valuable as propellant tankers in depot scenarios or to enhance Earth departure stages.

The ACES design is optimized with long-duration cryogenic applications in mind. A number of passive-thermal management features are incorporated into the stage at the system level. The tank geometry is designed to minimize the exposed surface area. Through the use of a thermally isolated equipment shelf tank penetrations are being minimized. Vapor-cooling, where vented hydrogen is used to intercept the remaining high-load heat paths, is integrated into the tank structure.

Mission reliability is a key requirement of our payload customers. ACES will continue to place a top priority on reliability across the entire life cycle, including design, component, and process levels. ACES will incorporate single fault tolerance at least equivalent to our existing stages. Significantly, the dual and quad engine ACES variants incorporate engine-out. Engine-out capability provides the single largest lever to improving system reliability (Figure 4). It is a key basis for ULA's desire for multiple smaller (25Klb) class engines rather than a single larger upper stage engine.

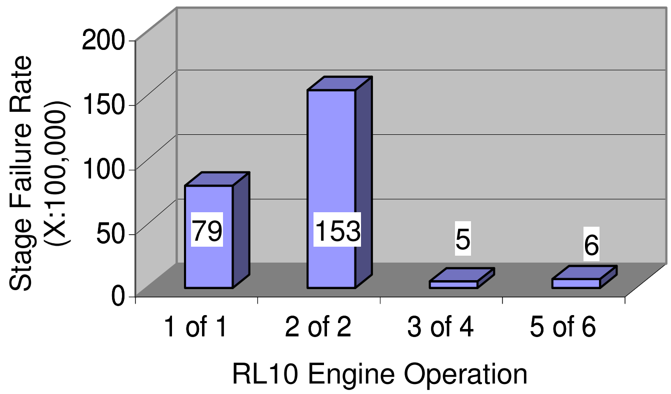


Figure 4. ACES significantly improves mission reliability by incorporating engine out accommodation.

V. Phase 2 Development

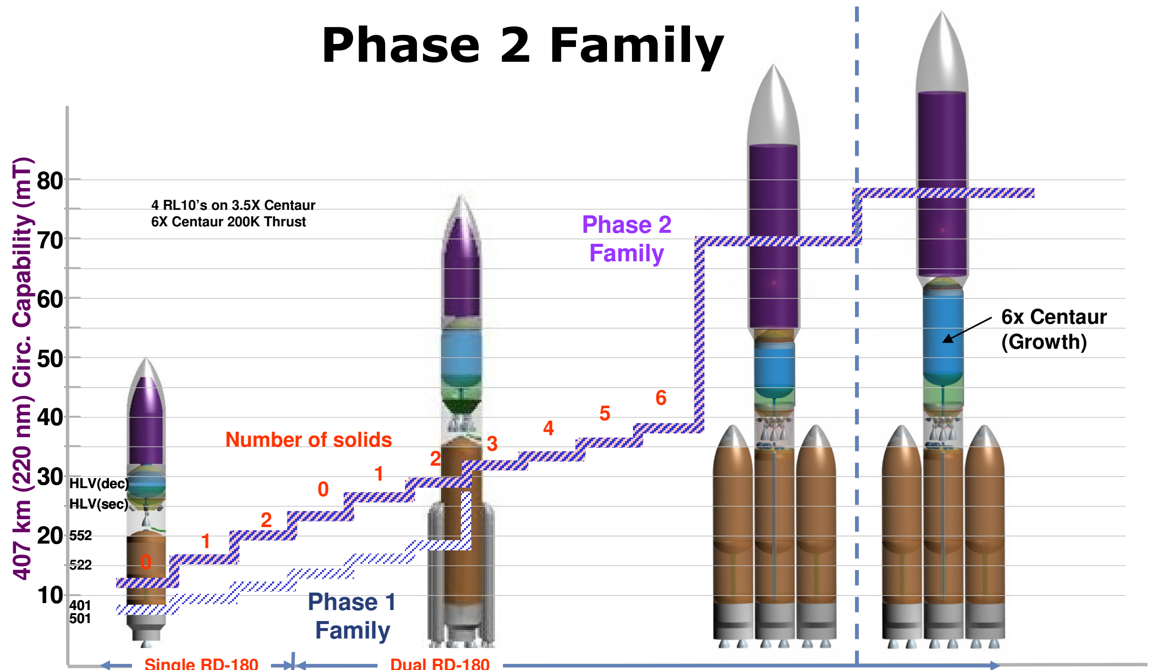
The Phase 2 booster takes the 5m-Delta booster tank structure, converts it to store LO2 and kerosene, and mates a new thrust structure to two RD-180 class engines. Because of the higher density of the Kerosene/LOX propellant, 1.08 Mlb of propellant can be carried in each shorter than the current Delta IV tanks. This booster core can be flown with two strap-on boosters in a classic HLV configuration, or can be mated to 1-6 Atlas-class solid rocket boosters for modular, intermediate capabilities. These boosters would all be mated to the common ACES upper stage discussed previously. In its least energetic configuration (without solids), this vehicle can equal the performance of an existing Atlas 521. In the HLV configuration, shown in Figure 5, performance can exceed 70t to LEO. The Phase 2 vehicle family allows ULA to maintain a broad band of operating performance while extending the peak performance level. The EELV Phase 2 is especially effective with stretched ACES stages.

The Baseline EELV Phase 2 is based on a pair of RD-180s, but a new Hydrocarbon Boost Engine could be perfect match with this concept. Performance can scale from near the current HLV performance with 1Mlb thrust, up to the quoted 70 to 80t with a 2Mlb thrust HCB engine (or dual 1Mlb engine installation for better Atlas V compatibility). Phase 2 booster vehicles could even initially incorporate the existing RD-180 with the first flight of the Phase 2 booster in 2017 or 2018. These new boosters could then be matured over several years before they would be evolved to incorporate the HCB engine.

The baseline EELV Phase 2 assumes a new mobile launch platform and vertical integration facility flying from the current Atlas V LC-41 pad. However, operation from the Space Shuttle legacy Vehicle Assembly Building (VAB) and Pad 39 is an entirely reasonable alternative that could offer NASA a more familiar operations concept and utilize existing support contractors.

Another interesting possibility is using an Ares-1 like upper stage with the J-2X on the Phase 2 EELV. A J-2X powered stage is much too big for the existing EELVs, but is reasonably sized for the larger Phase 2 EELV boosters for LEO delivery. Although ULA has received many inquiries on the compatibility of a J-2X upper stage on existing EELVs, it actually provides less performance, requires more booster modifications, and a stage less compatible with higher energy GTO and GEO missions (losing synergy with National Security Space) than the existing upper stages or the ACES stage. A more promising alternative scenario is one where the ACES becomes the upper stage for the Phase I EELV using existing boosters, then a new J-2X stage becomes a LEO 2nd stage for the Phase 2, and subsequent Phase 3 phases, with the ACES evolving to become the (in-space) 3rd stage for beyond LEO on these vehicles, where its high Isp, excellent mass fraction, and low-boiloff design provide the greatest benefits.

Figure 6 shows past performance trades showing the potential evolution paths of Phase 1, 2, and 3 EELVs. Capabilities with J-2X upper stages are not yet included, but can be interpolated from data on the table.



100nm Circ	-	-	-	24.8	27.3	29.8	32.3	34.8	37.0	39.2	71.0	80.2
220nm Circ	-	-	-	24.1	26.5	29.0	31.4	33.8	35.9	38.0	68.5	77.9
GTO	-	-	-	12.6	14.0	15.3	16.6	17.9	19.0	20.2	35.3	43.2
C3=0	-	-	-	9.7	10.7	11.8	12.8	13.8	14.7	15.6	27.5	33.8
GSO	-	-	-	6.3	7.1	7.9	8.7	9.4	10.1	10.8	19.3	24.1
C3=20	-	-	-	6.8	7.7	8.5	9.3	10.1	10.8	11.5	20.5	25.5
C3=80	-	-	-	1.7	2.2	2.6	3.0	3.5	3.9	4.2	9.0	11.7

Figure 5. EELV Phase II Family

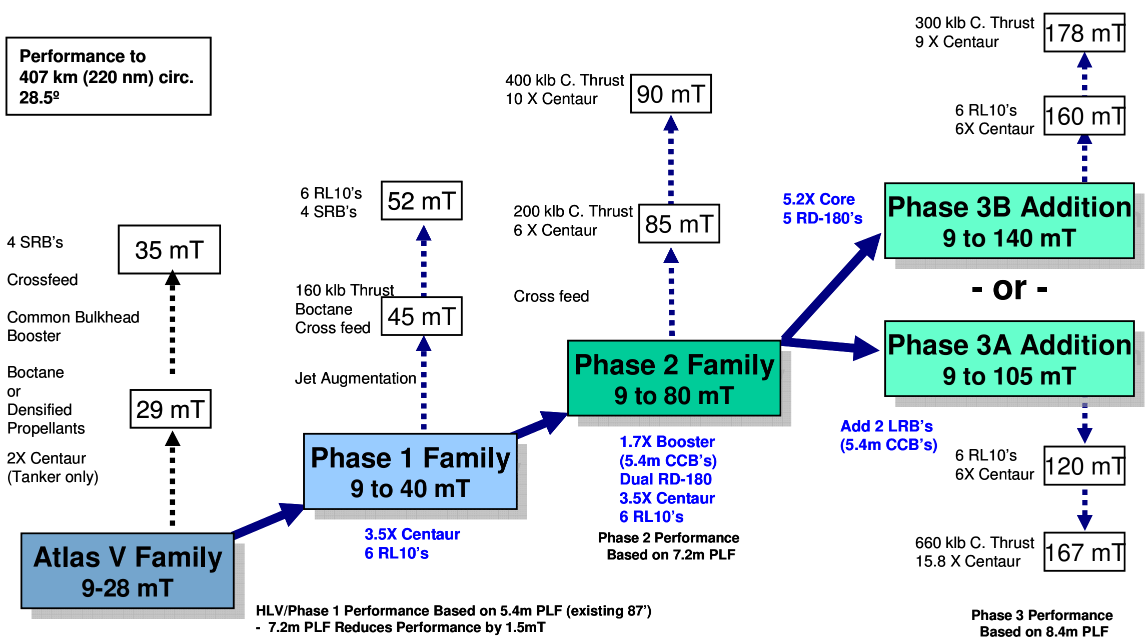


Figure 6. EELV Evolution Options

VI. Phase 3 Development

Even greater lift capability can be obtained by strapping on two additional common core boosters and upsizing the upper stage. The Atlas Phase 3 vehicle, Figure 7, performance can grow to well over 100t. While this Phase 3 vehicle demands a larger launch complex shut as the Shuttle's VAB/LC-39, it is still composed of the same modular elements that are used in Phase 2. It remains connected to the manufacturing and design infrastructures and thus shares the economic and reliability benefits.

Propellant crossfeed could further enhance performance beyond 100t, provide strap-on engine-out capability to enhance reliability and optimize acceleration levels by allowing two of the strap-ons to be jettisoned earlier. As the booster evolves to this larger size, the notional J-2X powered upper stage provides increasing performance vs the ACES upper stage. Preliminary analysis shows performance growth well beyond 150mT as shown in figure X. Phase 3 remains connected to the manufacturing and design infrastructures on the earlier variants and thus shares the economic and reliability benefits, and may share the launch complex if a Pad 39 launch solution is used for the Phase 2.

Figure 7. Atlas Phase 3 can support well over 100t of LEO performance while incorporating large payload fairings.

VII. Summary

ULA firmly believes that the development of the next generation of heavy lift systems will require the partnership of NASA development expertise with the operational experience of industry. This cooperative development should be the foundation of the program management philosophy. Equally important is the development of partnerships across U.S. Government agencies. The greatest opportunities for reliability improvements, cost reduction, and industrial base sustainment lie in the consolidation of requirements across U.S. Government agencies. ULA looks forward to an ongoing dialogue and development of a working partnership with NASA/ MSFC.

A modular approach to the launch systems architecture should be pursued to mitigate the unique and large cost of a dedicated heavy lift system. We believe the HLLVs should be a variant of a family of vehicles built upon common elements that can be produced at high rate encompassing missions besides NASA heavy lift. The greatest cost, reliability, and industrial base benefits for the entire national launch community can be drawn from a space launch architecture which builds upon the existing EELV systems.

The next generation of booster engines should build upon the legacy of the RD-180 family. The engine must be capable of being integrated into the Atlas V architecture. To minimize risk and speed development times, the program should consider some level of international involvement in the development program. A 1Mlb class, hydrocarbon-boost engine is compatible with the existing Atlas V and a Phase II EELV in a dual engine installation.

The EELV-derived evolution suppresses the non-recurring investment. Both the Delta and Atlas vehicles are substantially evolved from prior vehicles. Atlas redesigned the Atlas III booster tanks but retained the RD-180 engine and Centaur upper stage. The Delta IV upper stages evolved from the prior Delta III configuration. This allowed the design teams to focus on what was needed to gain the new capabilities and not design wholly new elements that merely replicated existing capability. In the end, the combination of modular construction and evolutionary design enabled the deployment of two separate launcher systems within 5 years and for less than a combined $5.5B, and can offer similar economies when expanded to the HLLV.

The use of a multi-step evolution, rather than a point design vehicle allows NASA to only buy launch capability as needed, against the backdrop of an ever-escalating flexible path mission model. The first step in this path, the Phase I EELV, allows early crew missions to take place without waiting for the new heavy lift booster.