Atlas and Delta Capabilities to Launch Crew to Low Earth Orbit

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The Atlas and Delta Launch Vehicle Families have enjoyed a rich history as trusted vehicles for launch of critical NASA Space Exploration missions. During that course of space launch development, the Atlas and Delta Expendable launch vehicles have matured well beyond the early days of spaceflight. This paper addresses the attributes of the Atlas V and Delta IV Heavy Expendable launch vehicles that makes them distinctively qualified to be highly reliable, robust earth-to-orbit transportation solutions for Crew launch to Low Earth Orbit (LEO). This paper details the Evolved Expendable launch vehicle system compliance to Human Rating requirements defined by NASA Standard 8705.2B "Human-Rating Requirements for Space Systems." In addition, the paper compares and contrasts various requirement options, some of which may drive highly complex, unreliable, and costly design solutions. Both Atlas and Delta have the unique capability to demonstrate the implementation of Human Rating requirements by validating designs on numerous uncrewed launches. The EELV flight rate of uncrewed missions quickly builds sufficient history to rely on flight demonstrated reliability, rather than paper reliability. Demonstrating these systems has the benefit of increasing reliability through commonality with commercial and government launches, in addition to continuing vehicle characterization due to the experience gained from higher flight and production rates. The Atlas and Delta EELVs are mature systems with demonstrated design robustness and processes discipline that provides a highly reliable, robust solution for Crew launch to LEO.

I. Introduction

TODAY"S Atlas and Delta have evolved to provide reliable assured access for critical NASA, Air Force and NRO missions. NASA embraced these designs by selecting the Atlas V and Delta IV to launch the crewed Orbital Space Plan (OSP) due to their robust, flexible designs, the reliability (calculated and demonstrated) and the confidence in these launch vehicles resulting from their evolutionary development approach, which minimized the historical first flight risk.

These systems offer the key to significantly reducing the Gap in US Human Spaceflight by providing flight-proven launch systems the offer the benefits of early Initial Launch Capability (ILC), lowest nonrecurring and recurring costs, and demonstrated reliability that meets or exceeds NASA Loss of Mission requirements. With the addition of a robust launch abort system, both Atlas and Delta can exceed stringent NASA Loss of Crew requirements. Both launch vehicles offer unique advantages for a commercial crew development program, or for the launch of the Orion Crew Exploration Vehicle.

II. Overview/Background

The Atlas and Delta Programs have been involved in human transportation studies beginning with the Orbital Space Plane (OSP) Program, NASA Exploration Launch Studies and Concept Evaluation and Refinement (CE&R) Studies, and continuing during early Crew Exploration Vehicle (CEV) Studies. Although Atlas and Delta engineers were not directly involved in NASA's Exploration Systems Architecture Study (ESAS), NASA recognized the benefits of using flight-proven systems for crew launch, and spent a considerable amount of effort on assessing these systems. Although the ESAS solutions did not appropriately reflect the design and capabilities of Atlas and Delta to

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meet Human Rating Requirements, NASA's acknowledgement that use of existing launch vehicles to meet human spaceflight needs was profound.

The Lessons Learned from those experiences has formed the basis for changes to the Atlas and Delta launch vehicles to provide crew transportation to Earth orbit. Atlas focused its efforts on providing launch for a number of commercial and entrepreneurial interests, while Delta responded to inquiries regarding its capability to provide launch services for the Orion Crew Exploration Vehicle. Numerous bidders for the NASA Commercial Orbital Transportation System (COTS) procurement recognized the significant advantages of using an existing launch vehicle for crew and cargo, and submitted proposals that utilized Atlas and Delta.

Existing launch vehicles offer a number of benefits, most notably the demonstrated reliability offered by continuing uncrewed launches during on-going operations. This is evident in the significant reduction in the historical infant mortality rate of new launch vehicles. Design flaws manifest themselves in early flights, which is minimized by the evolutionary design approach demonstrated by Atlas and Delta. This means that with a common fleet of launch vehicles, the uncrewed missions bear the first flight risk, thus significantly reducing the risk for crewed missions. Figure 1 illustrates the demonstrated reliability benefits of a common fleet of launch vehicles. Additionally, by 2015, the current Ares/Orion ILC, Delta IV will have flown over 50 Common Booster Cores, including 8 Delta IV-Heavy vehicles. Atlas V will have flown nearly 65 times.

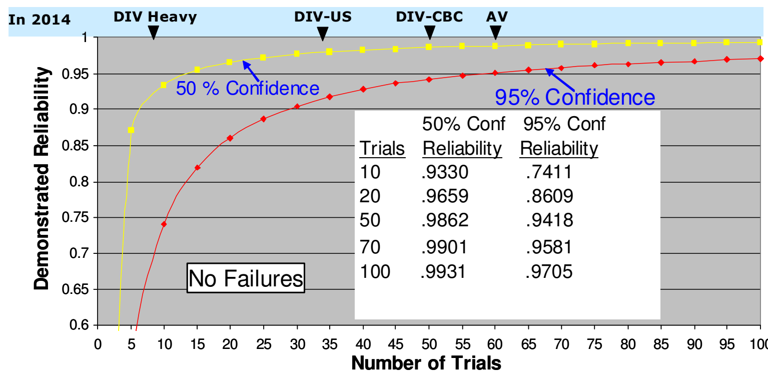

Figure 1. A common family of launch vehicles providing crew launch demonstrates reliability sooner than a unique vehicle

ULA believes that a Human Rating should be comprised of three primary factors: 1) Launch vehicle reliability, 2) Addition of an Emergency Detection System, and 3) Intact abort capability. The combination of these three elements provides a common-sense, system-level approach to accomplish the goal of safe, reliable transportation to LEO.

1. Launch Vehicle Reliability

Probably the single most important factor for human spaceflight is demonstrated reliability. Atlas and Delta have used an evolutionary approach to enhancing the capabilities of the systems, and it is evident in a long history of launching successfully. This record has not been achieved by accident. Rather it is the reliance on experienced people; robust, repeatable processes; single-fault tolerant systems where reliability is enhanced; robust vehicle designs and vehicle characterization; and finally, rigorous, closed loop test as you fly processes. These advantages are a direct result from ongoing launch operations.

2. Addition of an Emergency Detection System (EDS)

Historically, launch systems have incorporated some level of EDS that would monitor critical systems and issue status, warning and abort commands. For Atlas and Delta, the EDS would be common and scalable, and utilize existing sensors within an architecture that used an independent, fault tolerant failure sensing system. Operational systems such as Atlas and Delta offer the advantage of flying the EDS on all missions, in addition to having flight environments that are well known and well characterized.

3. Intact Abort Capability

Liquid propulsion systems offer the key advantages of minimal catastrophic failures (compared to solid systems) and thrust termination prior to any abort. The resulting benign environment created will maximize the ability of the crewed vehicle to successfully abort and return the crew safely. Finally, in conjunction with the crew vehicle design, Atlas and Delta can meet NASA Human Rating requirements specified in NASA-STD-3000 for Crew Loads Limits without any abort Black Zones OR significant reduction in performance.

III. Requirements Compliance

Atlas and Delta have a wide variety of Specifications, Standards, and Handbooks that have been instituted in the design of the respective systems. Additionally, these launch vehicles have over 50 years of unparalleled launch vehicle experience that provides the basis for the basis for changes we believe are required to safely and reliably transport commercial crew to LEO. ULA engineers have performed detailed assessments of their systems' ability to meet the requirements detailed in NASA Procedural Requirements 8705.2B "Human-Rating Requirements for Space Systems" (May 6, 2008). For commercial crew, a key groundrule was to minimize modifications to the Atlas system to maintain commonality while minimizing development and operational costs. For Delta IV-Heavy launch of Orion, we assumed a more extensive compliance would be required by NASA, so the compliance tends to be broader and affects more systems. In both cases, engineers were mindful of the benefits of leveraging the demonstrated reliability benefits of a common fleet while maximizing safety for the passengers. Atlas and Delta engineers performed a line-by-line review of NPR 8705.2A requirements and allocated each to the appropriate system responsible for demonstrating compliance (Launch Vehicle and Crew Vehicle, Launch Vehicle only or Crew Vehicle only). Once that was determined, the engineers assessed compliance of their systems to the requirements allocated to the system and the Launch Vehicle. Table 1 shows the results of that assessment.

		Atlas & Delta Compliance			
	Total Requirements	Meets/ Exceeds	Meets Intent	Non-compliant	Not Applicable (Crew Vehicle only)
Chapter 1 – Human-Rating Certification Process	28	28	0	0	0
Chapter 2 – Human-Rating Certification Requirements	50	50	0	0	0
Chapter 3 – Technical Requirements for Human Rating	31	9	4 (Atlas) 3 (Delta)	0 (Atlas) 1 (Delta)	18

Table 1: Atlas and Delta 8705.2B Requirements Assessment Process

The Delta IV non-compliant requirement is for the fault tolerance requirement (3.2.2) which reads *"The space system shall provide failure tolerance to catastrophic events (minimum of one failure tolerant), with the specific level of failure tolerance (one, two or more) and implementation (similar or dissimilar redundancy) derived from an integrated design and safety analysis (per the requirement in paragraph 2.3.7.1)."* For Delta IV, this means that some added redundancy in subsystems is required unless the Technical Authority deems otherwise. (These potential redundancy enhancements are discussed in Section VI of this Paper.) In addition to the redundancy inherent in Atlas and Delta, both meet the intent of this requirement by utilizing "abort" as the second leg of fault tolerance for all credible failure modes, which will further enhance the level of fault tolerance provided by these flight-proven systems.

Flight critical software is defined in 3.2.6 "*The space system shall provide the capability to mitigate the hazardous behavior of critical software where the hazardous behavior would result in a catastrophic event."* Originally, this requirement drove a solution that could include a Back-up Flight Software system similar to that flown on the Space Shuttle. Existing, flight proven Atlas & Delta flight software satisfies the intent of this requirement by the elimination of the potential for common cause failures, and has instituted a robust testing routine to prove out all aspects of the software pre-flight. Our experience is that the root cause of software failure in human error, caused by requirements and/or coding errors, or the hardware to software interaction is not understood. Mitigating the errors means eliminating the potential for single human error opportunities by conducting independent reviews, analyses, and testing (to include independent requirements development) of the software.

Atlas and Delta meet the intent of the Manual Control During Ascent requirement (3.4.1) *"The crewed space system shall provide the capability for the crew to manually control the flight path and attitude of their spacecraft, with the following exception: during the atmospheric portion of Earth ascent when structural and thermal margins have been determined to negate the benefits of manual control."* Human control of these systems will be limited to abort or abort targeting, which is similar to what is currently available on the Space Shuttle. There may be an opportunity to maximize the unique capabilities of Atlas and Delta and enhance some abort conditions by offering more manual control during aborts. This will have to be investigated in more detail once the specific capabilities of the crew vehicle are determined.

Several requirements drive enhancements to the existing EELV systems. Obviously the current systems would have to be modified for crew ingress. However, paragraph 3.6.1.1 states *"The space system shall provide the capability for unassisted crew emergency egress to a safe haven during Earth prelaunch activities."* This drives the need for emergency crew egress. Both Atlas and Delta have concepts to modify the existing pads infrastructure to accommodate this requirement.

The last enhancement is driven by *"3.6.1.2 The space system shall provide abort capability from the launch pad until Earth-orbit insertion to protect for the following ascent failure scenarios (minimum list):a. Complete loss of ascent thrust/propulsion; b. Loss of attitude or flight path control."* and *"3.6.1.3 The crewed space system shall monitor the Earth ascent launch vehicle performance and automatically initiate an abort when an impending catastrophic failure is detected."* Atlas & Delta will comply with this requirement by incorporating an Emergency Detection System and design ascent trajectories that eliminate "Black Zones."

IV. Schedule

Atlas and Delta have a long history of successful launch vehicle development and launch pad activation. ULA has built on that experience by developing a detailed plan and schedule to provide crew launch services for NASA and commercial providers. Based on our understanding of the requirements, we believe that that an Atlas V can be ready for commercial Human Spaceflight in less than 4 years and that the Delta IV-Heavy can be ready to launch Orion in 4-1/2 years. These schedules are consistent with the US experience during the Mercury-Atlas and Gemini-Titan Program experience, both of which flew the first manned mission within 4 years of the selection of the launch vehicle. They are analogous because in both cases existing expendable launch vehicles (ICBMs) were human rated.

ULA has experience in developing launch systems that span the spectrum of new launch vehicle development to modifications of existing systems. For example, Table 2 shows the launch vehicle development spans for the Atlas launch vehicle from Atlas 1 through Atlas V and Delta IV. The average span of these developments has been approximately 4-1/2 years.

	ATP – CDR	CDR – ILC	Total Span
Atlas I	9	27	36
Atlas II	20	30	50
Atlas IIA	30	22	52
Atlas IIAS	35	23	58
Atlas III	27	21	48
Atlas V	42	22	64
Delta IV	28	37	65

Table 2 – Launch vehicle development span times

Human Rating Schedule Elements

Whether the U.S. pursues a Low Earth Orbit (LEO) Commercial Crew Program or traditional NASA Orion Crew Exploration Vehicle Program, there are several common aspects to human rating the Atlas and Delta expendable launch vehicles such as the Emergency Detection System (EDS). Some elements are unique, such as added redundancy initiatives are only anticipated for the Delta launcher.

1. Emergency Detection System (EDS)

We anticipate that this system will be similar for either Atlas or Delta, and will use the recent Atlas V Fault Tolerant Inertial Navigation Unit (FTINU) as the point of departure for design and development. The FTINU was developed in less than 3 years and was launched on and Atlas 551 for the NASA Pluto New Horizon mission in 2006. With EELV vehicle subsystem highly characterized, and with added flights-of-opportunity to check out the EDS (without its LAS) EELV has lowered schedule, technical, and cost risk for EDS development.

2. Launch Site

The existing launch infrastructure must be modified to allow crew ingress and egress at the pad, plus address launch rate. For Delta IV-H launching Orion, this equates to a new, dedicated launch pad – LC-37A – and with the exception of crew ingress/egress would be virtually identical to the existing LC-37B. ULA believes that LC-37A could be built in approximately 39 months. With the fundamentals of the pad design already validated from the existing 37A pad, the pad represent low technical risk and a nearly build-to-print design allowing for less design and checkout time than our 37B actuals.

For Commercial Crew on Atlas, crew ingress/egress would be provided by a modification of the Mobile Launch Platform (MLP). In addition, ULA recommends that a dedicated Vertical Integration Facility (VIF) and MLP be built to support the increased flight rate, and provide a dedicated human spaceflight processing facility. The VIF would be virtually identical to the existing VIF at LC-41. ULA believes that the dedicated VIF/MLP would be completed in approximately 36 months. For Atlas or Delta, the pad construction or modifications are not in the critical path for human space flight.

The projected pad span times for launch site modifications and activations are clearly within our previous experience, as noted in Figure 2, which shows recent pad activation spans to construct brand new launch sites from groundbreaking through certification of Site Readiness.

Development	**Year completed**	**Time to Complete (Months)**
SLC40 Titan IV	1992	36
SLC3E Atlas IIAS	1194	65
SLC36A Atlas IIAS Mods	1996	12
SLC36B Atlas III Mods	1998	18
SLC41 Atlas V	2002	36
SLC37 Delta IV	2002	52
SLC3E Atlas V	2004	18
SLC6 Delta IV	2004	54
SLC6 Delta IVH	2008	30
SLC6 Delta IV L49	2008	51

Figure 2 - New launch pad construction span times

3. Redundancy Initiatives

The Delta IV has an array of on-going redundancy and robustness upgrades to support our current customer's needs. ULA has developed an array of potential upgrades for human spaceflight that addresses redundancy and other potential NASA safety requirements. These typically focus on eliminating avionics and ordnance single point failures, and adding redundancy in the pneumatic and hydraulic systems. All of these potential upgrades are individually achievable in the required timeframe, assuming subsystem and component requalification is completed before assembly of the first manned flight vehicle in mid 2014, with many also able to support the uncrewed Orion demo flight in late 2013.

4. Production Hardware Delivery

A surprising critical path item is production engine fabrication and delivery. The current build cycle for RS-68s is four years from contract complete, to engine delivery, with additional time needed for vehicle assembly in the factory, and pad checkout and processing. This creates challenges with new block changes of the engine occur, such as the switch from RS-68 to RS-68A, or the anticipated change from an RS-68A to an RS-68A+ that adds startup H2 release mitigation. Interestingly, the engines required to support certification for the first flight of the RS-68A in 2012 are already on order with minimal risk associated with RS-68A.

5. Delta Human Rating Schedule

The overall Delta IV Human Rating activity is summarized in Figure 3, and reflects the primary elements including EDS development, Redundancy and other Safety initiatives, Pad Development, and Production Hardware Delivery. Overall the proposed 4-1/2 development timelines is relatively low risk.

6. Atlas Human Rating Schedule

The overall Atlas 40X development schedule is based on the simplified scope of effort for a Commercial Crew Program. There is essentially no need for added redundancy initiatives on Atlas (unlike Delta) with complete single fault tolerance throughout Atlas V (with the exception of main propulsion). The ground support equipment is also simpler and more redundant. The Atlas schedule is summarized in Figure 4. With a late 2013 initial launch capability for crew on Atlas we believe the commercial crew vehicle development, which has not begun in earnest as of mid 2009, will become the true pacing item with very low risk related to the launch vehicle development becoming a driver. As such, the Atlas launch vehicle should support the earliest credible commercial ILC.

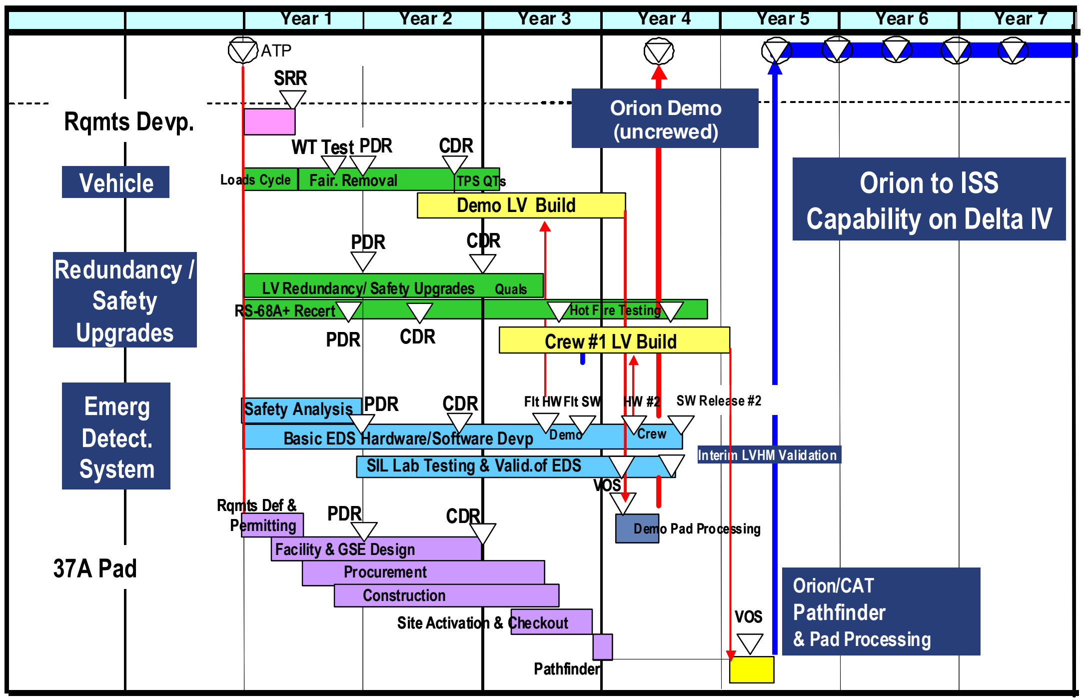

Figure 3: Delta IV-Heavy Development Schedule Supports Orion for ISS Crew

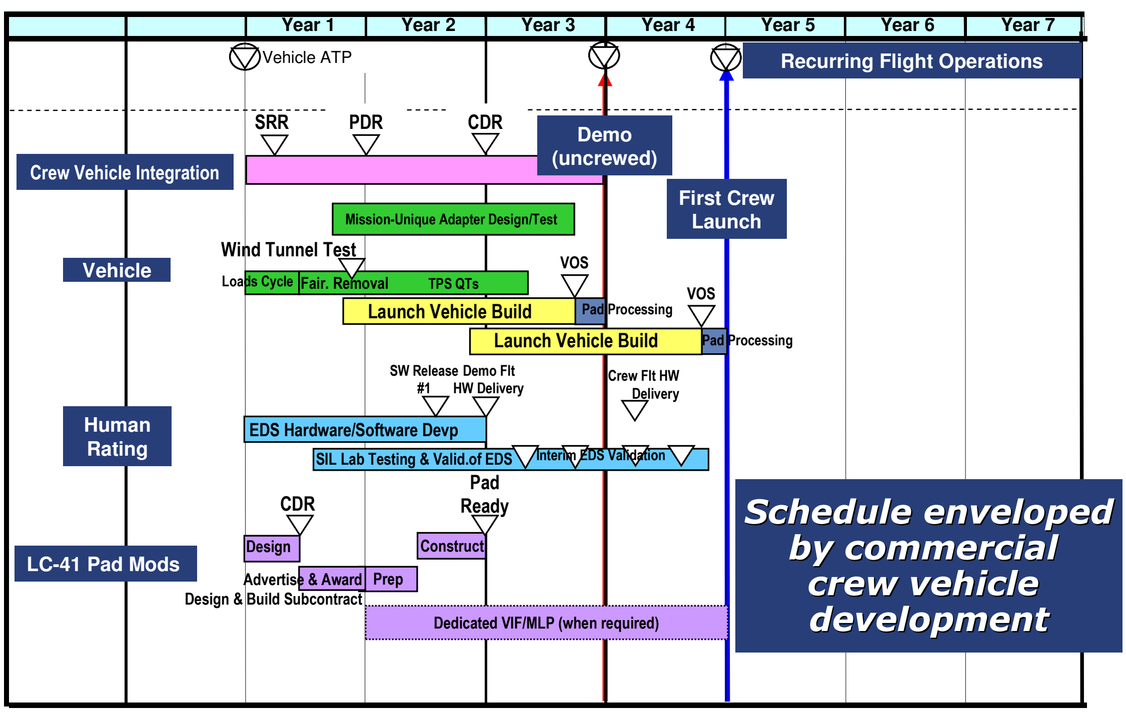

Figure 4: Atlas Human Rated Launch Vehicle Development Schedule for Commercial Crew

V. Loss of Mission/Loss of Crew

System reliability was one of the most important design considerations for the EELV systems, Atlas V and Delta IV. It was one of only four critical performance parameters specified by the Operational Requirements Document (ORD). As such, a tremendous amount of effort was expended to develop credible reliability estimates to prove that the requirements were met. Probabilistic Risk Assessment (PRA) type analysis was used to determine so-called design reliability. But mission reliability, what the program called the true reliability, was calculated by applying a

Bayesian update to incorporate actual flight experience of similar systems or subsystems. This approach was arrived at through lengthy technical interchanges between the EELV contractors and the Aerospace Corporation, representing the Air Force customer. The results of the analysis are shown in Table 3 below along with the associated LOC numbers assuming the probability of a failed abort is 1/10.

Vehicle	Loss of Mission		Loss of Crew	
Delta IV Heavy	0.9875	1/80	0.9987	1/800
Atlas V Heavy	0.9900	1/100	0.9990	1/1000
Atlas V 401	0.9960	1/250	0.9996	1/2500
Atlas V 402	0.9942	1/170	0.9994	1/1700

Note: All values represent 50% confidence level

Table 3: EELV Loss of Mission and Loss of Crew calculations based on PRA developed mission reliability.

Another approach using demonstrated reliability as the anchor point has been used for the Atlas V system. In this method, the starting point is the demonstrated Atlas II success rate of 63 of 63. This information is then combined with the PRA result that the Atlas V 401 configuration is a factor of 2.65 more reliable than Atlas II. This is due to the dramatic reduction in engines, staging events and parts going from Atlas II to Atlas V. This makes use of the PRA as a relative measure between systems rather than as an absolute value. The final step includes the fact that Atlas III and Atlas V are a combined 21 of 21 successes. This analysis yields the cumulative distribution shown in Figure 5. The 50% confidence value of 0.996 is remarkably close to the value in the preceding table though the calculation methods were completely different. The 95% confidence value is 0.984. These results are illustrated in Figure 6.

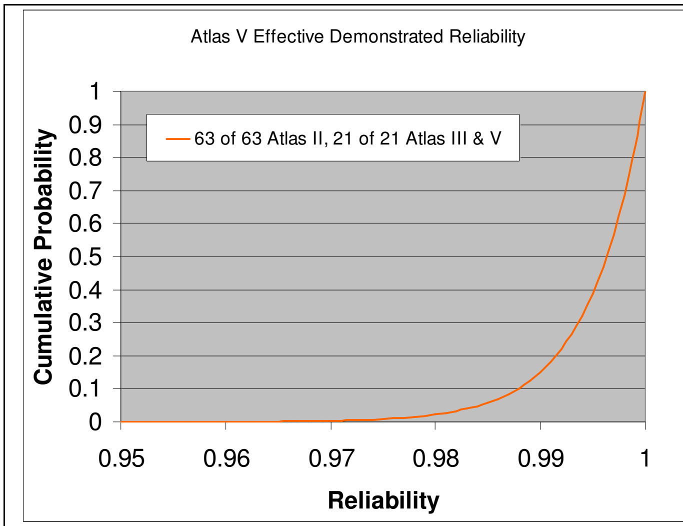

Figure 5. Cumulative probability of Atlas V reliability based on Atlas II, III and V success records.

A similar approach for Delta IV is more problematic. The Delta II has enjoyed a long string of success, but the design similarities between Delta IV and Delta II are few. The Delta IV system itself has flown ten times with 100% success in nine operational missions. The one non-operational mission, the DIV heavy demo, did not achieve its intended orbit although it did complete a full mission duration. This emphasizes the risk of first flight which historically have experienced about a 50% success rate. However, if DIV heavy is chosen as a human spaceflight vehicle, it will have a substantial track record by the time of the first human mission in 2014. Assuming continued success, the DIV system will have accumulated the flights of 50 cores and 35 upper stages and will have climbed substantially up the demonstrated curve. This is shown in Figure 7.

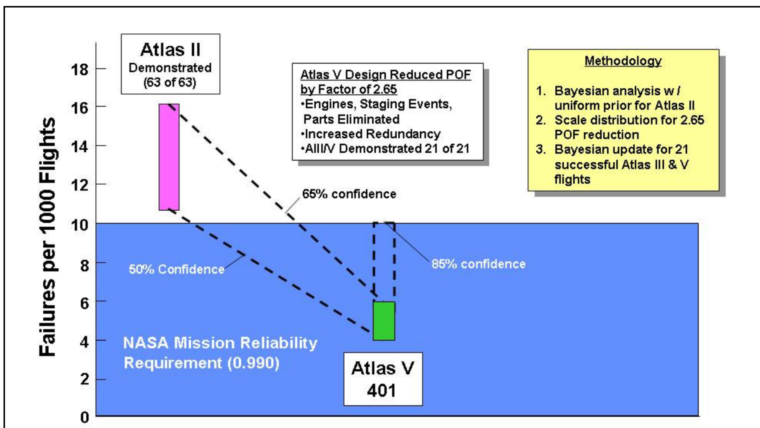

Figure 6. Atlas V 401Estimated Reliability.

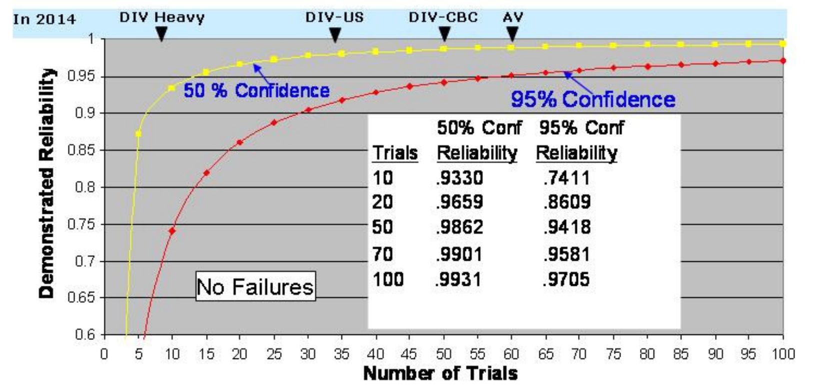

Figure 7. Demonstrated reliability improvement over time.

VI. Atlas Human Rating

The Atlas V 401 and 402 vehicles are well suited for commercial human spaceflight. They are simple, low cost, reliable systems with a long successful heritage. They use two flight proven propulsion systems (RD-180 & RL-10), with only two engine starts, and two separation events. They have benign, well characterized environments, robust margins, and high demonstrated reliability (100% for the 401) and design reliability (.9960 for the 401 and .9942 for a 402). Atlas 401 and 402 can provide up to approximately 27,500lbs of performance to LEO, depending on the specific configuration of the crew vehicle. Trajectories can easily be shaped to eliminate "Black Zones" with no appreciable impact to performance. ("Black Zones" are defined as any period of flight when an abort would result in unsafe landing conditions if: 1) the aborting capsule falls into hostile terrain; or 2) High-g loads occur during a re-entry. Table 3 depicts the comparison of performance and the impacts to account for the Black Zone considerations.

	PSW (kg)	Mission Margin
GTO Commercial	5,170	2.33 sigma + Full LVC
Std Mission Planners Guide Optimized ISS Performance	11,180	3.0 sigma + Full LVC
ISS Trajectory Shaped to Close Black Zones	11,180	3.0 sigma + Full LVC
Difference	0	

- Injection Orbit 200 km at 51.6 deg
- Maximum boost acceleration of 4 g's
- Impact point trace
  - No North Atlantic, no Alps
  - No constraint on Q and heating (covered by capsule)

PSW = Payload Systems Weight (capsule plus all supporting HW)
LVC = Launch Vehicle Contingency

Table 4: Atlas 402 can close Black Zones without impacting performance.

Atlas V can accommodate commercial human spaceflight with no changes to the existing vehicles. The only enhancements will be the addition of the Emergency Detection System and changes to the Mobile Launch Platform to allow crew ingress and egress. Once a particular crew vehicle is selected, Atlas V will conduct a series of analyses and system testing to integrate vehicle on a 401 or 402. These include Hazard Analyses, Design Margin Analyses and Mission Unique Analyses specific for the Crew vehicle configuration. In addition, we may conduct wind tunnel tests and subsequent aerodynamics and loads analyses to ensure that we maintain our existing vehicle margins.

The Atlas V 4XX offers the lowest risk, lowest cost solution for commercial crew. The demonstrated reliability record and robust vehicle design allows Atlas the flexibility to meet the needs of a variety of commercial crew vehicles currently being contemplated and designed.

VII. Delta Human Rating

The Delta IV has ample performance margin. For the ISS crew mission, based on current Orion weight allocations, the Delta IV Heavy has 4.8t of margin for lifting the Orion capsule to the ISS delivery orbit. This drops to 4.3t of margin for the Lunar Crew delivery mission. These 20% margins are very healthy, especially given that Orion would be flying on a demonstrated launch vehicle. These margins are after depressing the trajectories to close all Black Zones. (Performance margins would have been ~1t higher if this had not been done.) These performance margins are so big that they can cover almost any conceivable human rating penalty, or combination of penalties, including a 1.40 safety factor, and significant RL-10 derating. NASA has now acknowledged that they believe that the Delta IV Heavy has adequate performance margin and no Black Zones. This should refocus any questions about EELV compatibility onto human rating, reliability, and schedule.

The human rated Delta IV Heavy fundamentally is the same Delta IV vehicle that has flown successfully three times, and is expected to fly 10 times by the projected mid 2014 IOC date. (32 total Delta IV CBC booster elements are projected to have flown by this same date.). This is a huge benefit from a crew safety standpoint. Though there are many measures of reliability, demonstrated reliability is the least subjective measure. Even with an analytic reliability which is higher, the EELVs cumulative launch total before the 2014 IOC, and additional accumulation of launches including DoD, means that the Ares-1 or another new vehicle might effectively never catch up with Delta's demonstrated reliability. The EELV system will be fully "de-bugged" (for example achieving successful 30 flights a decade before a new crew launcher could.

Delta IV vehicle changes include removal of the fairing, and replacement with the Orion System, including service module and launch abort system and adapters. The Emergency Detection System will be incorporated into the launcher. An array of relatively small redundancy and safety modifications have been identified based on NASA requirements, but these remain modest in scope compared the legacy design. We anticipate these upgrades to be acceptable to the DoD customers, and expect these to be incorporated fleetwide with no need for a unique NASA vehicle design apart from the EDS kit. Currently 1.40 safety factor has been removed from NASA requirements, though a return to this requirement driving some regauging and requalification could be accommodated within the same proposed schedule.

The details of redundancy upgrades on Delta remain an area of interest. A summary of candidate upgrades is shown in Figure 8. Of note is that quite a few of the requirements are not driven by explicit redundancy requirements, but on other anticipated safety criteria as the desire to reduce the release of burning H2 at RS-68 start. Also, in some cases different redundancy upgrades (RS-68 backup valves, feedline prevalves, and hydraulics redundancy) need to be traded off to find the smartest implementation path. This makes the final suite of upgrades somewhat uncertain. However, the anticipated total scope and cost of these safety upgrades is programmatically small, with engine mods the most expensive due to high intrinsic recertification cost. Generally speaking, schedule impacts on IOC (effecting the US human spaceflight "gap") is a more significant consideration.

System	Initiative	Reason
RS-68A	ECU Upgrade (Lower Prob)	EDS
	Startup H2 Mitigation (duct / start sequence)	Robust
	Added Potentiometer	Redund
	Pneumatic Valve Backup (Lower Prob)	Redund
RL-10B-2	Dual Spark Igniter (DDSI) - Free- AF funded	Redund
	Improved Gear Set - Free - AF funded	Robust
	B/C Cone & NEDS Elimination (Lower Prob)	Robust
	Main Fuel Shutoff & TCV redesign	Robust
	Redundant Solenoids	Redund
	Beef up due to 5012 Spec (Lower Prob)	Robust

System	Initiative	Reason
Avionics	Emergency Detection System	EDS
	RIFCA Upgrade (Lower Prob)	EDS
	EPAC (Engine TVC Controller)	Redund
	Redundant RGEA (Lower Prob)	Redund
Ordnance	Ord Box Upgrade (Elim Mech relays)	Robust
	Dual Sept Nuts for Fwd CBC Attach	Redund
CBC Propulsion Feed System	Fuel Pre-valve	Redund
	LOX Pre-valve (Lower Prob)	Redund
Booster Pneumatics	Redundant CBC He Supply	Redund
	Redundant He Reg and Press Control Valves	Redund
	3rd Stage 1/2 Sep thruster assy (Lower Prob)	Redund
Hydraulics	CBC Hydraulics Cross Strapped	Redund
	Upgrade to Full Redundancy (Lower Prob)	Redund
US Pneumatics	Redun.He regulator & tank press valve assy	Redund
	Slosh Baffle / Hardware Mods (Lower Prob)	Robust

Figure 8. Candidate Delta IV Human Rating Upgrades

Delta IV avionics and ordnance systems are already single fault tolerant, so a few modifications are required to patch single point failure "holes". Pneumatics mechanical redundancy is also quite easy, with Atlas design approaches, and legacy hardware from Delta and Atlas existing. The booster hydraulics TVC system could require a more extensive redesign, which should be traded against the merits of retaining the flight proven mechanically non-redundant system. This is a question of flight safety trading theoretical reliability for demonstrated reliability, not of cost or schedule related to the hydraulics redesign.

Interestingly, there is no comparable list of redundancy upgrade for Atlas, since Atlas already has comprehensive single fault tolerance, and no other safety and robustness upgrades yet identified. Though we assume Orion on Delta IV, and commercial crew capsules on Atlas, the difference in human rating is intrinsic to the launch vehicles, and not to assumed differences in human rating requirements.

VIII. Summary

The EELVs are ready to support crew lift with flight proven vehicles that will have an even longer legacy of flights by the crewed IOC date with superior demonstrated reliability compared to any new system. Our schedules are grounded by ULA's unmatched legacy of vehicle development and modifications programs and launch pad developments.

The Atlas V, with the relatively minor addition of an Emergency Detection System and a dedicated NASA Vertical Integration Facility (VIF) and Mobile Launch Platform (MLP), is ready for commercial human spaceflight and complies with NASA human rating standards. The 3 1/2 year integration span is likely shorter than the development for any new commercial capsule that might fly on it.

The Delta IV has ample performance to support the existing Orion vehicle, without Black Zones. The Delta IV can support a mid-2014 Crewed IOC, which is superior to Orion launch alternatives. The proposed 37A pad is a look-alike counterpart to the existing 37B pad with low development risk. Human rating the Delta is a relatively modest activity, with the addition of an Emergency Detection System, an array of relatively small redundancy and safety upgrades, both in the vehicle and the engines that are almost trivial compared to the original development of the Delta IV.