Atlas V Launch Vehicle for Commercial Crew: Development Progress Toward the Future

Michael Holguin,
United Launch Alliance (ULA)
9100 E. Mineral Avenue
Centennial, CO 80112

Abstract

The development of Commercial Crew transportation services is gaining momentum as the United States forges a path forward with US industry to develop a commercial approach to service the International Space Station. ULA was chosen by 3 of the 4 CCDev2 awardees to fill the role of the launch services provider. As the development of multiple spacecraft designs mature, ULA is developing core capabilities that add the safety features required for human spaceflight in conjunction with the flight proven, highly reliable Atlas V. ULA has received limited technical assistance from NASA using a Space Act Agreement under the Commercial Crew Development initiative to advance elements of its orbital commercial Crew Transportation System concepts. These additional elements include such items as an emergency detection system to identify and signal anomalies during ascent that will allow the crew to abort safely. In addition, facilities at the launch site that enable crew access and emergency egress, performance improvements to the launch vehicle, and information to support NASA's human spaceflight certification of the existing Atlas V rocket. This paper will present an overview of the elements under development and the status of that development activity.

I. Introduction

Since the early days of rocketry, Atlas has been the workhorse of the American space industry. Atlas has an incredible history. In additional to the hundreds of Delta launches, ULA recently marked several notable milestones

- ✓ 600+ launches of an Atlas vehicle including 30+ Atlas V launches
- ✓ 200+ Centaur flights
- ✓ 60+ launches since ULA was formed in December of 2006.

The Atlas V commercial crew design provides a straightforward path using the maturity of the vehicle design, plus the enhancements identified to meet the human rating plan. This effort has its roots more recently when significant progress on Human rating of the Atlas V was made during the OSP program in 2003 and 2004. During that effort, ULA and NASA worked very closely to understand the upgrades required to meet the approach under consideration at that time to fly humans on Atlas (and Delta). Numerous studies have been conducted over the last decade and cooperative agreements between NASA and various members of the spacecraft community have been performed to further increase this confidence.

Under the Commercial Crew Development program, Atlas V has been selected by 3 of the 4 CCDev2 Commercial Crew partners. The goal now is to evolve that same successful mature and disciplined approach into a low earth orbit transportation system that is safe enough to fly a human into space. This is achievable not only technically, but also within the visionary objectives of the NASA Commercial Crew program. These objectives include safety, as well as cost effectiveness, which when implemented, will open the door to the future. Figure 1 contains an illustration shows some representative flight configurations.

Figure 1 Atlas V Commercial Crew Flight Configurations

II. History

This amazing success story was not without its struggles. These successful attributes resulted from many years of hard lessons learned dating back to the trial and error period during early development of the program in the 1950's and 60's. Then, as late as the 1990s, Atlas experienced 3 near consecutive failures. After a complete halt to launches, detailed failure investigations and a revamped process discipline imperative, the Atlas program invoked an overwhelming transformation in how we controlled and analyzed the system design, as well as the processes and operations associated with the entire launch system. Since that time Atlas flight history has been virtually flawless.

During America's fledgling human-spaceflight program Atlas was chosen as the launch vehicle workhorse for Project Mercury. Within three years after the prime contract was awarded, the goal to orbit humans in space and return them safely to earth was completed successfully. The most historic mission was accomplished when John Glenn launched into space and successfully orbited 3 times over nearly a 5-hour period.[1] In total, the Project Mercury program conducted 6 manned flights, 2 suborbital Redstone and 5 Atlas orbital launches. Before John Glenn's flight in February of 1962, there were 61 flights, 23 of which were incomplete success or failures, two of the failures were Mercury program flights. In fact, a flight in January 1962 prior Glenn's was failure, but the project fixed and flew successfully.

As a follow on to Project Mercury, Project Gemini began early in 1961. The early Gemini program flew two unmanned Gemini missions in addition to the manned flights. Ten manned missions were conducted for Project Gemini between 1965 and 1966, which used the early Titan vehicle, also formerly and ICBM. [2] The Current Atlas V® launch vehicle incorporates the structurally stable booster-core design feature from the Titan program to enhance ground-processing operations. Both the Atlas Mercury and the Titan Gemini Program (see figure 2) proved that human spaceflight can be safely accomplished based upon expendable launch vehicles designs that were originally developed for other purposes.

Figure 2. Today's Atlas V® vehicle has its heritage in early launch vehicle developments that include the successful human-spaceflight versions used in Project Mercury and Gemini. (Images courtesy of NASA*)*

Centaur, the world's first in-flight ignited hydrogen powered vehicle began development in 1958 to launch NASA spacecraft on lunar and planetary missions. Centaur's design was based on the thin-walled pressure stabilized Atlas booster, but used liquid hydrogen (LH2) and liquid oxygen (LO2) for propellants. The RL-10 was chosen as a highly reliable upper stage engine. This configuration has proven its reliability on hundreds of successful flights.

---

[1] Project Mercury, A Chronology. NASA SP-4001. Prepared by James M. Grimwood, Historical Branch, Manned Spacecraft Center, Houston, Texas, as MSC Publication HR-1, Office of Scientific and Technical Information, National Aeronautics And Space Administration. Washington, D.C. 1963. http://history.nasa.gov/SP-4001/contents.htm

2 Project Gemini. Technology and Operations, A Chronology. Published as NASA Special Publication-4002. Prepared by James M. Grimwood and Barton C. Hacker with Peter J. Vorzimmer. http://history.nasa.gov/SP-4002/contents.htm

III. Atlas V Human Space Flight Capabilities Development

In 2010 ULA was awarded a CCDev1 Space Act Agreement to develop a prototype Emergency Detection System (EDS) that would enable the crewed spacecraft to abort in case of a launch vehicle or spacecraft failure, in addition to early integration subcontracts with various spacecraft providers. ULA successfully demonstrated the abort capability during the final demonstration effort performed in December of 2010. At that time ULA not only established that this capability was feasible using existing systems but was actually "flown" in a high fidelity Systems Integration Lab with various spacecraft configurations and various failure modes.

In 2011, ULA was selected by three of the four CCDev2 (Commercial Crew Development) spacecraft awardees to integrate the Atlas V launch vehicle - Boeing, Sierra Nevada and Blue Origin chose the Atlas V to provide launch services for their spacecraft. In addition, ULA elected to continue in parallel, the development of a few key elements to facilitate crewed space transportation. NASA also entered into a Memorandum of Understanding (MOU) to follow the design and certification efforts to provide limited technical guidance from the Commercial Crew Program Office (CCPO) as ULA evaluated the Atlas against the Crew Transportation System (CTS) 1100 series requirements set. Additional elements ULA continues to develop include 1) the EDS as the key enabling technology to allow humans to safely fly on Atlas; 2) taking advantage of the Atlas V CAT3 certification as a springboard for future human spaceflight; 3) Dual Engine Centaur which provides performance improvements to the launch vehicle to enhance abort capabilities; and 4) provisions at the launch site for accommodations such as crew access and emergency egress. This paper will describe the current approach to these elements under development and its status.

A. Emergency Detection System

Two key fundamental tenets of Human Space Flight are crew safety and mission success. The early Atlas Mercury program had it right; provide a simple yet robust system for detection of launch vehicle anomalies that would signal an abort to the crew capsule to allow the crew and capsule to safely abort. On the Mercury program it was called the Abort Sensing and Implementation System and consisted of 13 measurements monitoring vehicle performance at the highest level in order to detect an impending failure.

Figure 2 EDS unit testing in the high fidelity Systems Integration Lab

During CCDev1, ULA demonstrated an Emergency Detection System (EDS) prototype to the Commercial Crew community. The EDS is architected to monitor the launch vehicle (LV), detect anomalous conditions that will result in a crew safety critical situation, and send a signal to the crewed spacecraft in sufficient time for the spacecraft to abort and get safely away. The system also allows the crew to initiate an abort on the spacecraft side of the interface. In each case the EDS will also shut down the LV liquid propulsions system to allow the crew and spacecraft to abort. EDS monitors only those potential LV events that are Criticality 1 crew safety hazards. These were determined based on investigation of failure modes and assessment of the resulting hazard and criticality of the event. The Atlas V design is single fault tolerant, with redundancy management and reconfiguration functions are already designed into the current system and subsystem architecture. EDS is not required to manage those interactions, keeping the system simpler and more reliable. The EDS is also kept simple by integration into the existing architecture with minimal intrusions, not interacting with the guidance and control system of the launch vehicle during normal flight. EDS must be reliable enough to ensure an inadvertent abort is not initiated, so it must be able to distinguish a failed sensor vs. a true system failure. A corroborating set of measurements will be used to validate anomalous readings. A key attribute of using the existing Atlas V rocket is that it flies several times a year, and the operation of EDS can be validated over many flights if it is flown in passive mode, piggybacking on current non-crewed flights.

Current development progress is primarily in two areas. The overall system architecture and "box" development, and secondly the measurement set and associated thresholds to detect failures. The box development effort uses our existing single board computer (SBC) flown on the fault tolerant inertial guidance and navigation unit, and therefore is a much simpler and less costly development effort than starting from scratch. This SBC is integrated into the box level design and the overall design is currently headed to SRR/SDR in June 2012, and scheduled to be thru CDR by May 2014. An initial set of measurements were designed during a first pass evaluation of failure modes during 2010 and 2011, and this is being refined this year based on evaluation of the hazards those failure modes cause in order to settle on a final measurement set. Existing design standards, practice, and experience are being used to development the EDS, which leverages proven design-to-production engineering and manufacturing processes.

B. Atlas V Human Space Flight Certification

The Commercial Crew Transportation System will be certified at the system level using the HSF certification process currently specified within the NASA CST 1100 series documents. The Launch vehicle will not achieve certification on its own, as the spacecraft significantly contributes to safety with its own systems. For example, the capability to abort during ascent off the top of the rocket is critical to certification, a capability the original Mercury, Gemini and Apollo as well as Soyuz programs relied on, but the shuttle system did not have. The overall certification approach is being developed to balance NASA insight and oversight.

Atlas V has been certified to the highest levels by NASA as part of the qualifications required to fly the most important and expensive NASA science missions. Since science missions are "one of a kind" and extremely expensive and valuable scientifically, NASA policy dictates an extensive certification process. This highest level of certification is referred to as Category 3 and is based on a combination of successful flights and access to the body of evidence including design, test and flight data. Launch Vehicle Certification is part of a comprehensive Mission Assurance process that is based on decades of experience and lessons learned over hundreds of missions. The Certification process is executed by NASA's Launch Services Program at KSC, with support from other organizations. The certification process used to certify Atlas V at the Category 3 level is extensive and includes:

- Launch Vehicle Certification
- Insight & Approval (NPD 8610.23)
- Engineering Review Process / Board
- Flight Anomaly Resolution
- Mission Analysis
- Verification Process
- Resident Offices
- Reviews
- Safety & Flight Assurance and Risk Management
- Launch Readiness Reviews
- Launch Operations
- Lessons Learned Process

In addition, the Atlas V has been certified to fly nuclear science payloads, which underscores the confidence placed on the reliability and safety of the launch vehicle. It is important to note that because many mission have been flown this way for many years, the launch services program office has become deeply knowledgeable not only of the current vehicle configuration but is also engaged in the ongoing upgrades and improvements to the vehicle in order that the vehicle continues to maintain its certification. As such, those government level certification processes parallel and complement ULA processes throughout the product lifecycle.

This Category 3 certification provides a significant springboard for the Commercial Crew Program to leverage for Human Space Flight Certification. Significant time and resources have been invested over the years to provide an independent technical and risk assessment of the Atlas V. This has helped ensure mission success for every planetary mission launched, and Atlas V has launched most interplanetary missions. As illustrated in Figure 3, the body of evidence and technical penetration by the risk assessments through multiple decades of cooperative efforts between our customer and ULA is substantial. Beyond that, the additional documentation and technical assessments required for Nuclear Certification form a solid basis for HSF certification and allows ULA to provide a requirements and processes gap assessment for Commercial Crew. This is a significant advantage of using flight proven rocket, which can reduce the burden on the Commercial Crew Program Office.

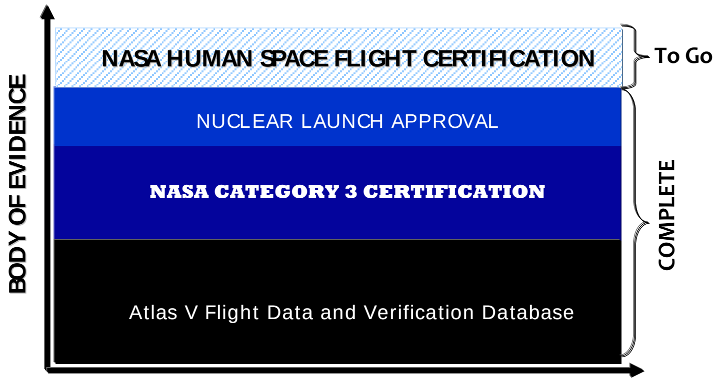

Figure 3 The Existing Body of Evidence from Previous NASA Category 3 and Nuclear launch approval efforts provides a significant dataset for Human Spaceflight Certification of Atlas V

Progress on certification has consisted of evaluating the CST 1100 series requirements series against the current Atlas V design. These requirement dispositions were reviewed at the tailored Systems Requirements and Design Review in December 2011 with the Commercial Crew spacecraft community. The full Systems Requirements and Design Review is scheduled to complete in June 2012, which will clear the way toward PDR and CDR. In addition, ULA is developing hazard assessments for both ground and flight as well as a Probabilistic Risk Assessment for the Atlas V commercial crew configuration, which is scheduled to be provided to the Commercial Crew spacecraft community during CCDev2.

C. Dual Engine Centaur

The commercial crew program places primary emphasis on crew safety. The Dual Engine Centaur (DEC) effort proposed for the commercial crew development program improves performance and enables a trajectory that improves safety in the event of an abort. The DEC configuration has flown over 160 times starting with AC-1 in 1962 and has a long and very successful flight history and has been a staple in the ULA family of vehicles for decades (See figure 4).

.

Figure 4 DEC in the factory

Because of the significant flight heritage, the remaining development effort is almost entirely upgrades to DEC to incorporate recent Centaur system improvements since the last time it was flown. As such, it is not a full fledged development effort. The existing Centaur III DEC was designed and qualified for the Atlas V vehicle, so technical risk is considered low based on very successful flight heritage with DEC on Atlas IIIB. This configuration successfully flew both the single & dual engine Centaur III configurations.

Progress during 2011 and 2012 to date consists of trade studies, system level requirements definition and preliminary design and analyses. These efforts were reviewed at ULA engineering review boards and at the tailored System requirements and design review in December 2011. The next major milestone is a full Systems Requirements and Design review scheduled for June 2012, with PDR and CDR to follow in 2013 in time to incorporate changes to the production line.

D. Launch Site Accommodations

Access for the crew to the spacecraft while at the launch pad is currently not available on Atlas V launch complex 41 and is a key facility addition. Because Atlas V uses the “Clean Pad” approach at SLC-41 there are no existing towers or facilities that can be used to provide that access. The “Clean Pad” concept has been a key program advantage as launch complex equipment and facilities are relatively simple yet robust. The incorporation of crew ingress /egress was first studied with NASA during the Orbital Space Plane (OSP) effort in 2004.

The clean pad processing starts with the launch vehicle horizontally at the Atlas Space Operations Center. The vehicle is then transported to the dedicated Vertical Integration Facility (VIF) and mounted onto the Mobile Launch Platform (MLP), then integrating the crewed spacecraft onto the vehicle at the VIF. The fully integrated launch vehicle and spacecraft are rolled out on the MLP to the launch pad immediately before launch. Crew loading occurs during the final countdown and hatch closure and all systems verified go prior to launch. In case of an emergency on the pad, the crew has three options,

1) Abort off the top of the rocket using the spacecraft abort system, or
2) Remove the hatch and egress down the tower using nominal egress means, or
3) Remove the hatch and egress using an alternative emergency egress capability such as a slide wires that the shuttle program developed in order to allow the crew to escape from the top of the tower to a safe haven a distance away from the pad. .

Option 1 is undesirable due to the damage to the rocket and pad as well as an undesirable use of the spacecraft during that situation; it would only be used as a last resort. Options 2 and 3 depend on the severity of the hazard and associated timing to criticality.

Progress to date has consisted of defining the preliminary requirements and design concepts which were reviewed at the tailored SRR/SDR in December of 2011. The hazards criticality and timing associated with each as part and parcel of the overall requirements for the system design are continuing to be developed and will be reviewed at the full SRR / SDR in June of 2012. In addition, ULA continued to develop multiple options from simple to complex. Current concepts for crew access and emergency egress using various approaches under consideration as shown in figure 5.

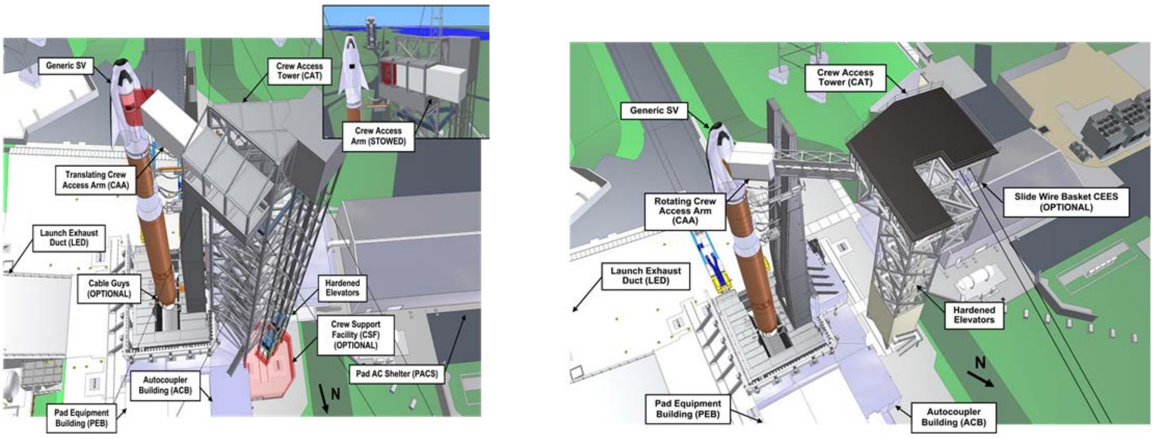

Figure 5 Crew Access & Emergency Egress Concepts

IV. Summary

ULA provides an Atlas V system with significant flight heritage and an existing infrastructure that provides a significant benefit to the Commercial Crew program. EDS is a key component of the safety equation, and a simple yet robust system provides confidence that the crew can abort when required and while avoiding false abort. The EDS takes advantage of an existing highly reliable avionics architecture and suite of sensors, with flight proven computing power to provide the most reliable system overall. ULA works in conjunction with NASA and other potential spacecraft providers to demonstrate the ability to detect anomalous conditions on the LV and provide a timely abort signal to the crew. Human Space Flight Certification will benefit from a mountain of evidence already provided to NASA for category 3 certification. ULA and NASA maintain a healthy partnership to provide continuous and ongoing detailed penetration and access to design, analysis, test, qualification and flight data for verification purposes. The performance improvements achieved with reimplementation of the flight heritage Dual Engine Centaur capability provides additional performance and safety margin. The accommodations for crewed spacecraft at the launch site are the key to providing our spacecraft customers and NASA with the safest possible ride to orbit for our future commercial crew astronauts.