Evolved Atlas To Meet Space Transportation Needs

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The Atlas Launch system has successfully supported space transportation endeavors for over 47 years with 485 successful launches. Beginning with the first launch in 1958, Atlas has been a workhorse for military, civil, human spaceflight and commercial launches. The Atlas commercial program, started in 1990, has fielded eight new configurations, all successful on their inaugural flights, and boasts a current world's best record of 76 consecutive successes. The Atlas success stems from a philosophy of low risk evolutionary development coupled with rigorous processes. Atlas V® is the current version of the Atlas line and has a perfect five-for-five record. Future Atlas evolution will adhere to the same proven philosophy of evolutionary development. Through a logical phased development approach, Atlas system performance can be increased to exceed Saturn V class performance. The first phase of this evolution develops a cryogenic upper stage evolved from today's Centaur that provides the foundation of a modular system of propulsive stages that can be used for a multitude of Earth-to-orbit and in-space applications. Each phase of the evolution provides single-body vehicles ideal for human spaceflight due to their simplicity and inherent reliability.

I. Introduction

In 1962, John Glenn became the first American to orbit the Earth. He traveled in a Mercury capsule launched by an Atlas rocket. Developed as an ICBM in the 1950's, Atlas has a long and storied history as a workhorse of America's space program. Among its 485 successful launches are the first human-made object to impact the moon (Ranger 1 in 1961), the first spacecraft to visit Mars (Mariner 4 in 1965), and the first spacecraft to Jupiter and beyond (Pioneer 10 in 1972). The Centaur upper stage made its debut in 1961 and together, the Atlas/Centaur combination has achieved 159 successful launches. As the world's first stage to be powered by high-energy LO2/LH2 propellants, Centaur has been a key contributor to many of our nation's most important space exploration missions including both Voyager missions, both Viking missions and recently, the spectacular Cassini mission to Saturn.

The modern era of the Atlas program began in the late 1980s with the initiation of the commercial Atlas program. Started by General Dynamics in response to the promise of the communications satellite market, the commercial program ushered in a new age for space launch. No longer funded by big government and without the scrutiny of government oversight, the commercial program got off to a rocky start. The Atlas I system experienced three failures in its first seven flights. As a result, General Dynamics Sold the Program to Martin Marietta (later to become Lockheed Martin), and moved from San Diego, California to Denver, Colorado. The combination of the early failures, the sale and relocation of the program resulted in an epiphany within program management. Engineering, manufacturing and operations processes were overhauled and infused with a new rigor. The formula for mission success was reestablished, this time as a purely commercial enterprise. Currently, the success record of the Atlas program is unmatched in the industry with 76 consecutive successes extending over more than a decade.

Equally impressive is the commercial program's record of first-flight successes. If you exclude Atlas, the overall launch-industry success record for first and second flights is somewhere around 65%, not great odds. The launch-insurance industry is well aware of this fact and severely inflates insurance rates for the first two flights of a new configuration. Looking at these data, the Atlas record truly stands apart—eight of eight first-flight successes. This success rate points to far more than mere luck. Given the 65% historical first flight success rate, the odds of achieving eight in a row by chance alone are less than 1 in 30. Figure 1 shows the overall success record of the Atlas commercial program.

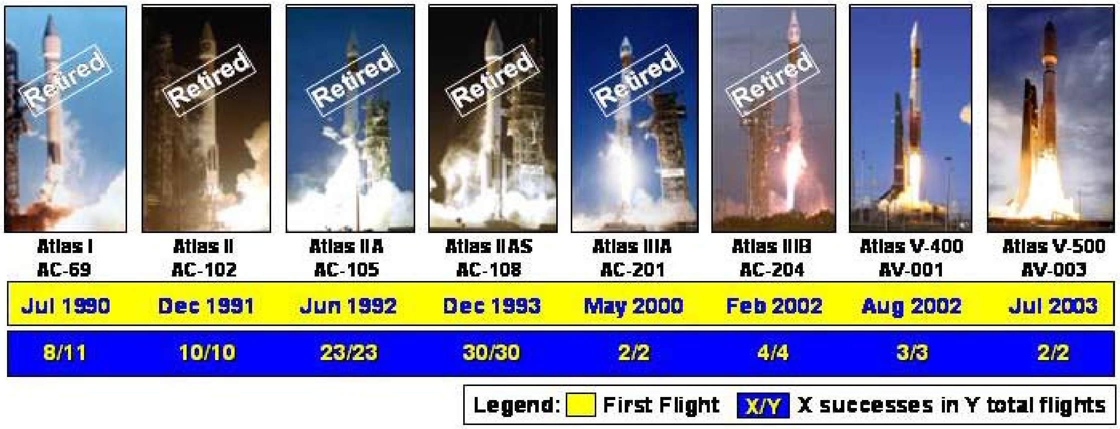

Figure 1 The Atlas Commercial Program Success Record

The success rate Atlas enjoyed on first flights is not due to good fortune, but to the excellence of the engineering processes, the experience of the design teams, and most importantly to the overarching development philosophy. Atlas has employed an evolutionary development approach, introducing significant system changes incrementally to minimize development risk. Figure 2 shows the last several steps in the Atlas evolutionary progression.

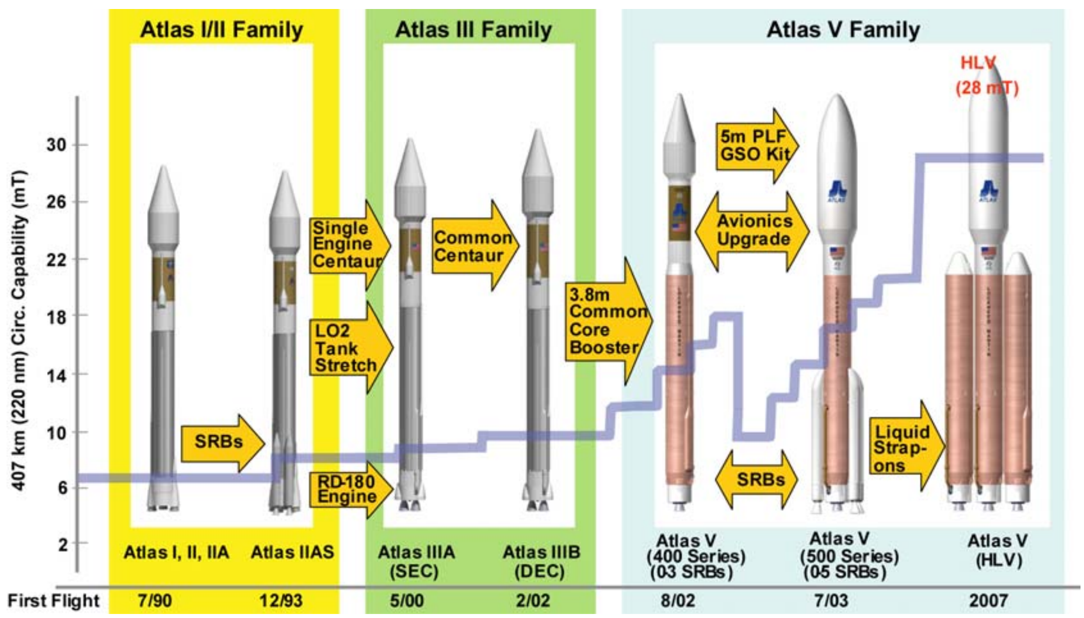

Figure 2 The Atlas Evolution

Atlas V® is the latest step in the Atlas evolutionary progress and is the most powerful and reliable Atlas to date. We based the Atlas V design on a set of modular elements that can be assembled to provide multiple configurations that maximize mission flexibility. The common elements allow for a tremendous range of performance while maintaining the efficiency and reliability of a common design. Major design improvements relative to previous Atlas configurations were implemented that resulted in a significant reduction in parts and active components. The smallest Atlas V® has more performance than any previous Atlas while reducing failure probability by a factor of almost three. The efficiencies in the Atlas V® system extend through to the program as a whole. Honed over 15 years of competition in the unforgiving commercial communications satellite launch market, Atlas V® is the only U.S. built system able to successfully compete with heavily subsidized foreign offerings. In fact, the five Atlas V® launches have been commercial. Atlas V® will also play an important role in space exploration—following in the footsteps of its venerable predecessors. Atlas V® will launch the Mars Reconnaissance Orbiter (MRO) in August 2005 and the Pluto mission in January 2006. Pluto is the last remaining planet to be visited by a human probe and Atlas V® will make the Pluto New Horizons spacecraft the fastest object ever to leave the Earth.

The final step in the Atlas V® family is the Heavy Lift Vehicle (HLV), representing a relatively minor change and introducing *no* major new systems. Over 95% of the hardware elements inherent in the three-body version of Atlas V® have flown on pervious flights. The Atlas V® HLV design embodies all the lessons learned over decades of launching three body Titan rockets, as well as the simplicity inherent in Atlas V® overall.

II. Future Atlas Evolution

In January 2004 President Bush announced the Vision for Space Exploration, providing focused exploration goals for the nation. Meeting the vision will require even more capable space transportation systems. The Atlas program is uniquely positioned to meet these challenges with its unparalleled development record (8 for 8 first-flight successes) and operational record (76 consecutive successes). The Atlas development team is intact, fresh from the successful Atlas V development, and provides the experience and credibility in affordable development so critical for the exploration vision.

The Atlas evolution philosophy includes 4 key tenets. 1) Evolutionary (spiral) development lowers cost and risk. This has been proven throughout Atlas history. Clean sheet or revolutionary design have been plagued by first-flight failures and do not connect with the success and lessons learned from the past. 2) Each evolutionary step creates a family of launch vehicles to serve all customers. A system that serves all customers is uniquely positioned to leverage the efficiencies of common infrastructure, processes and personnel.

With the reality of today's constrained budgets, NASA cannot afford to go it alone, paying for a unique system and ignoring the substantial synergy to be gained from shared requirements with other Government agencies and the commercial marketplace. 3) The launch system family is built from a set of common modular elements. This enables maximum synergy with other launch customers and provides affordability through increased production rate. 4) Reliability enhancements benefit all customers. Human spaceflight requires very reliable systems. Yet all customers benefit from reliable access to space. The DoD launches critical national security missions and even commercial launches carry the dreams and investments of the satellite operators.

Following this philosophy, Atlas evolution proceeds in three low-risk phases, eventually delivering greater than Saturn V class performance, as shown in Figure 3. The first phase focuses entirely on the upper stage, creating a modular design of increased diameter (5.4m) and multiple lengths. It also provides multiple engine configurations of 1, 2, 4, or 6 RL-10 engines. No new engine development programs are required. The tank-diameter change is a modest change in keeping with other Centaur modifications over the years. However, to increase the producibility of the tank and reduce weight, the tank construction will be changed from spot-welded stainless steel to friction-stir welded aluminum. This will also allow the tank to be structurally stable for ground handling. The phase 1 evolved family can deliver up to 40 mT to LEO in the three-body configuration and reaches back to capture all the existing Atlas V® missions at the same or even reduced costs.

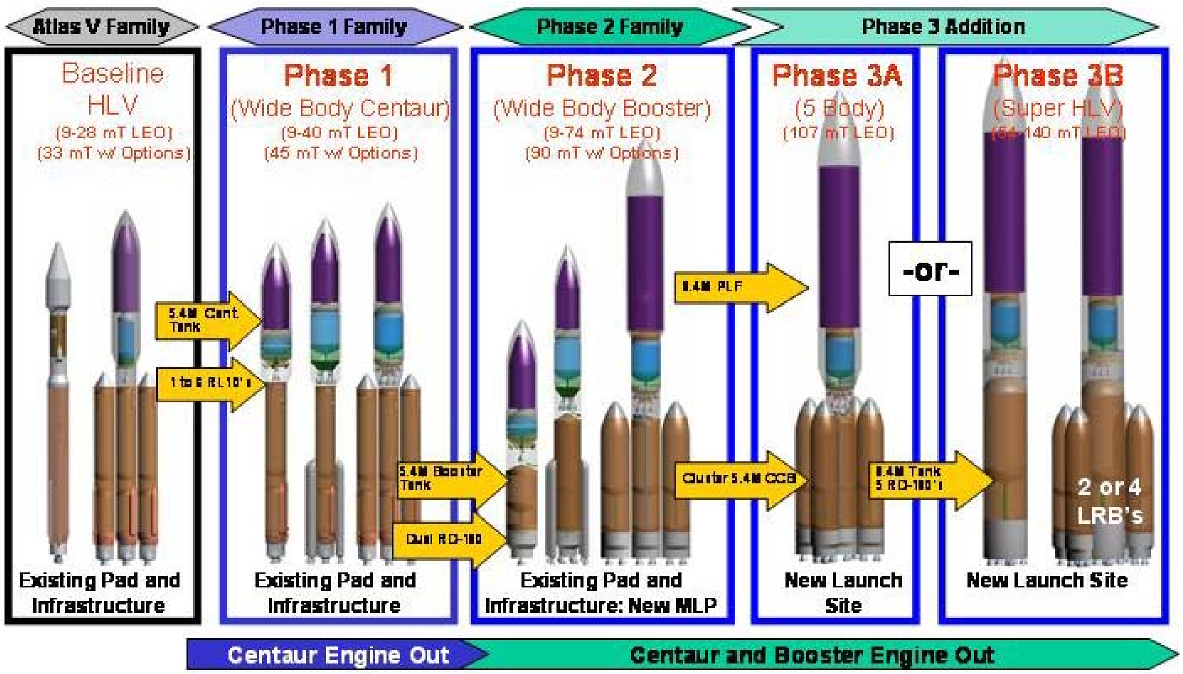

Figure 3 Future Atlas Evolution

The second phase increases the booster-tank diameter to the same 5.4m and allows either 1 or 2 RD-180 engines. Again, no new engine development programs are required. This new booster tank will be made from the same aluminum alloy as the current Atlas V® tank. Again, to aid producibility and lower cost, the tank-welding process will be changed from TIG welding to friction-stir welding. This new boostertank development is actually less of a change than the new Atlas V® tank where the switch was made from stainless steel at a 10ft diameter to aluminum at a 12.5-ft diameter. The phase 2 system can lift up to 80 mT in the three-body configuration, more than adequate for most lunar mission architectures. Yet it continues to reach back to capture the existing commercial and national security launch markets at equivalent of lower prices.

Both the new upper stage and booster tanks would be built at the Michoud, Louisiana facility where the friction-stir weld process has been perfected for the STS external tank by NASA and the transportation infrastructure is already in place. In addition, both phase 1 and phase 2 evolved Atlas systems can be launched using the existing Atlas V® launch pad infrastructure at LC-41. Phase 1 requires only some simple platform modifications in the Vertical Integration Facility (VIF) and an augmentation of the propellant storage vessels at the pad itself. Phase 2 requires some additional platform modifications, additional augmentation of propellant storage, and a new mobile launch platform. Even the phase 2 modifications represent far less infrastructure than was done for Atlas V® where LC-41 was essentially rebuilt from the ground up. For human spaceflight, phase 1 delivers engine-out capability for the upper stage. Phase 2 delivers engine-out capability for the booster. Section IV covers human rating in detail.

The third phase (if required) consists of two options. If a 100-mT performance level is required with little prospect for even higher requirements in the future, the phase 3A option is recommended. It combines five phase 2 LRBs into a cluster with the phase 1 upper stage. However, if even greater performance is required or anticipated sometime later, phase 3B is recommended. Phase 3B increases the booster-tank diameter again to 8.2 meters (the same as used in the STS ET) and includes up to five booster engines and four Liquid Rocket Boosters (LRB). The booster engines are the RD-180 and the LRBs are the same as phase 2. The upper stage is again the same as phase 1. The beauty of this approach to Saturn V class performance is that all the investment made in phases 1 and 2 are directly applicable to the phase 3 solution allowing intermediate configurations that can be fielded soon for moderate investment, but that are on the path to the super heavy vehicle. For example, a moon mission can be easily performed using phase 2 vehicles. If the super heavy vehicle is needed later for Mars, only the large booster need be developed (the upper stage and LRBs being on hand and proven).

III. Integrated Cryogenic Evolved Stage (ICES)

The Centaur upper stage has been the mainstay for high-energy missions for several decades. Overall, there have been 159 successful Centaur missions including such notable exploration missions as Mariner, Viking, Voyager, Cassini, and SOHO. The key to successful usage of the high-energy LO2/LH2 propellants for upper stages is cryogenic propellant management, especially for missions requiring long-coast durations between burns, and multiple burn missions. Fundamental to flying these missions is a thorough understanding of the non-equilibrium cryogenic thermodynamics and low- and zero-gravity behavior. Centaur is the only cryogenic stage that has demonstrated this long-coast capability, both with 10-foot and 14-foot diameter configurations. LH2 and LO2 both have unique behaviors in low gravity, and a detailed understanding of the complex interaction of the fluid dynamics of the propellant on the tank thermodynamics for pressure control during the coast is critical to ensure efficient use of the reaction control propellant and to ensure that the engine conditions are met for each burn.

For Centaur, the thermodynamic understanding began with several full-duration firing tests in NASA's Plumbrook vacuum chamber in the early 1970s. For these tests, arrays of specially designed temperature sensors were installed inside the liquid hydrogen tank so that the extent of stratification near the liquid-vapor interface could be properly characterized while realizing that a misprediction would result in either excessive pressurant usage or dropping below the minimum net positive suction pressure required by the RL10 engine. These data were further anchored to flight when two Centaurs were flown during the mid-1970s with the same complement of internal temperature sensors. One of these Centaurs demonstrated seven burns, one that occurred following a 5.25-hour coast. The mission provided critical data that is still used today to assess the non-equilibrium conditions that exist during the mission. Many of the phenomena that occur during these long coasts still elude classical equilibrium thermodynamic modeling, so semi-empirical models anchored to the Plumbrook testing and these fully instrumented missions, updated with the large amount of flight data, are critical

As discussed above, the first phase of the future Atlas evolution will develop a new wider diameter stage based on the successful Centaur heritage. Called the Integrated Cryogenic Evolved Stage or ICES, the stage can become the foundation for a modular system of stages satisfying a wide variety of uses for space exploration from upper stages to in-space stages to in-space propellant depots. Figure 4 depicts the ICES concept. ICES places the tremendous efficiencies of cryogenic propellants into the hands of the moon and Mars mission architects, allowing a significant reduction in launch mass required relative to Saturn, which relied on the much lower efficiency storable propellants.

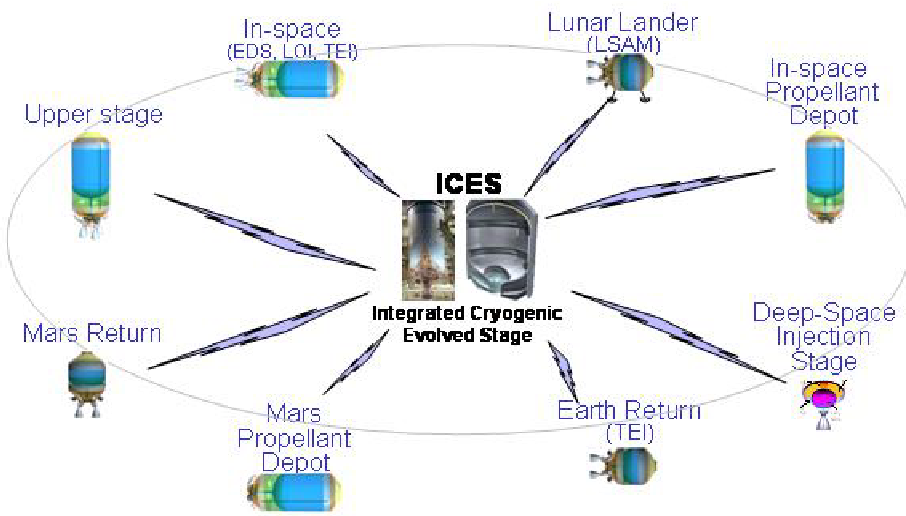

Figure 4 Integrated Cryogenic Evolved Stage (ICES)

ICES is based on a simple modular design as shown in Figure 5. Common domes are joined to barrel panels through the friction-stir welding process. The barrel panels come in multiple lengths that allow stages of variable propellant capacity. The common-thrust structure accommodates either 1, 2, 4, or 6 RL-10 engines. The longer ICES versions with four or six engines would be suitable for upper-stage applications carrying very large masses into low-Earth orbit. Shorter ICES versions with one or two engines would be used for traditional GTO missions, interplanetary missions, or in-space stages such as an Earth departure stage (EDS) or trans-earth injection stage (TEI).

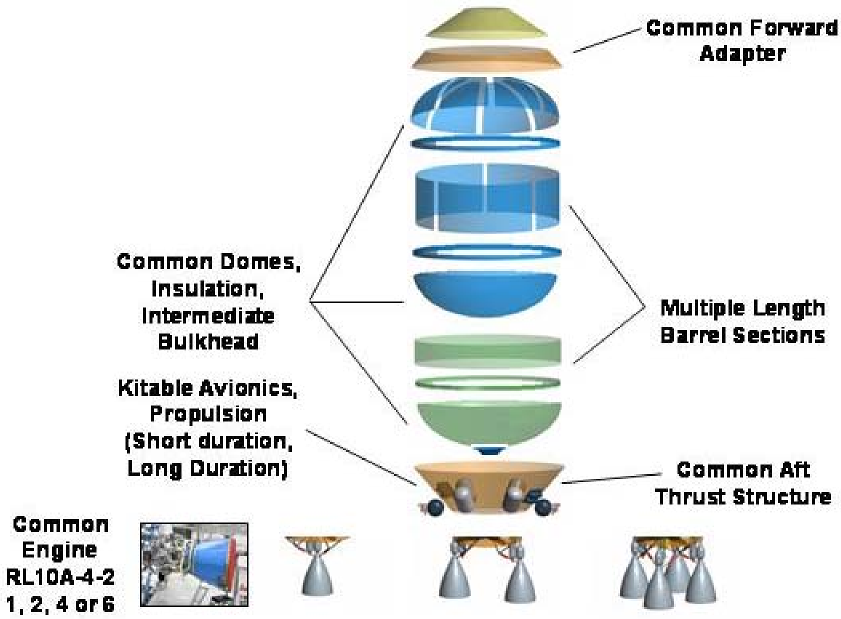

Figure 5 ICES Modular Design

These last two applications require cryogenic storage of days (EDS) up to months (TEI). The ICES design is optimized specifically for these long-duration cryogenic applications in mind. We incorporated a number of passive thermal management features into the stage at the system level. The number of conduction paths into the tank has been minimized by placing all propulsion and avionics hardware onto dry structure. The tank geometry in the short versions is nearly spherical, the optimum shape to minimize surface area to volume ratio. Perhaps most important is the common bulkhead, a feature of all Centaur tanks and carried over to ICES. Due to inherent thermodynamic properties, it is far more efficient to vent hydrogen, in terms of amount of heat removed per pound, than oxygen. With a common bulkhead, heat input into the oxygen can be removed by venting hydrogen. In other words, the hydrogen is used to cool the oxygen, precluding the need to ever vent oxygen.

Additional passive thermal-management features can be incorporated into a particular ICES as a kit. These include propellant management devices, vapor cooling features (using vented hydrogen to cool hot spots), and sun shields. The ICES avionics would also be modified for long-duration applications, incorporating solar panels and other power system components common in satellites.

IV. Human Launch

The phased Atlas evolutionary approach also offers significant capabilities for human spaceflight. Safety is paramount in human spaceflight and Atlas begins with its best-in-industry reliability record. Already embodied in the Atlas V® is design reliability 2.6 times better than the Atlas II which delivered 63 of 63 successful flights. This improvement was achieved by a dramatic simplification if the design, replacing eight propulsion systems with two and cutting parts by large factors. Further improvements were gained through the incorporation of redundancy. Other than the engines, there are five single-point failures on an Atlas V® 401 vehicle and these can be easily eliminated going forward. The Atlas V® is by far the most reliable Atlas vehicle ever fielded.

Future Atlas evolution offers even greater improvements. Single-body configurations are the safest configurations, in general, with the fewest number of stages and separation events. Each phase of the Atlas evolution offers single-body configurations ideal for human spaceflight. Figure 6 shows single-body configurations for both phase 1 and phase 2. The phase 2 single-body vehicle can lift 23.9 mT to LEO using 4 RL-10s on the upper stage and 29 mT using 6 RL-10s. These performance numbers accommodate the potential for passive re-entry in the case of abort, while meeting the appropriate g-level requirements and eliminating the so-called black zones.

The presence of multiple engines on the evolved Atlas vehicles allows for engine-out capability. This is important in mitigating the effects of the least reliable part of a rocket, the engine. With four or more upper-stage engines, the ICES can achieve orbit should any one of the RL-10 engines fail to operate. Similarly, with the phase 2 booster, for about two thirds of the trajectory, orbit can be achieved with a RD-180 engine failure.

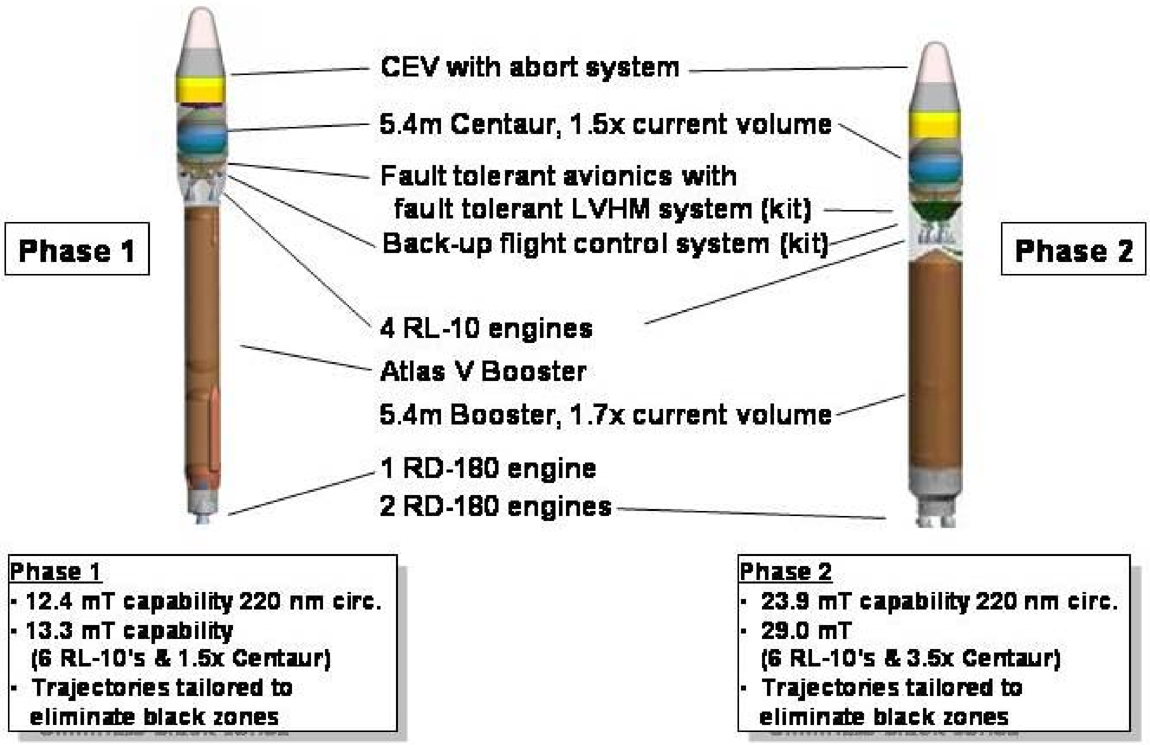

Figure 6 Single Body Configurations for Human Spaceflight

The Atlas approach to human rating relates back to the days when the Mercury astronaut first flew on Atlas. It begins with the most reliable system in industry augmented by the benefits of engine out. It then incorporates a vehicle-health monitoring system (as used on Mercury). This system closely monitors critical launch-vehicle parameters, such as engine turbine speed, vehicle rates and accelerations, and system pressures. Should an anomalous state be detected, the system initiates an abort. Rudimentary versions of vehicle-health monitoring are flown today on Atlas V®. For example, if the RD-180 turbine speed is out of tolerance at ignition, the launch is aborted. The crew exploration vehicle (CEV) includes an intact abort capability, such that the CEV can separate from the launch vehicle and safely return the crew to earth. The overall human-rating approach is depicted in figure 7.

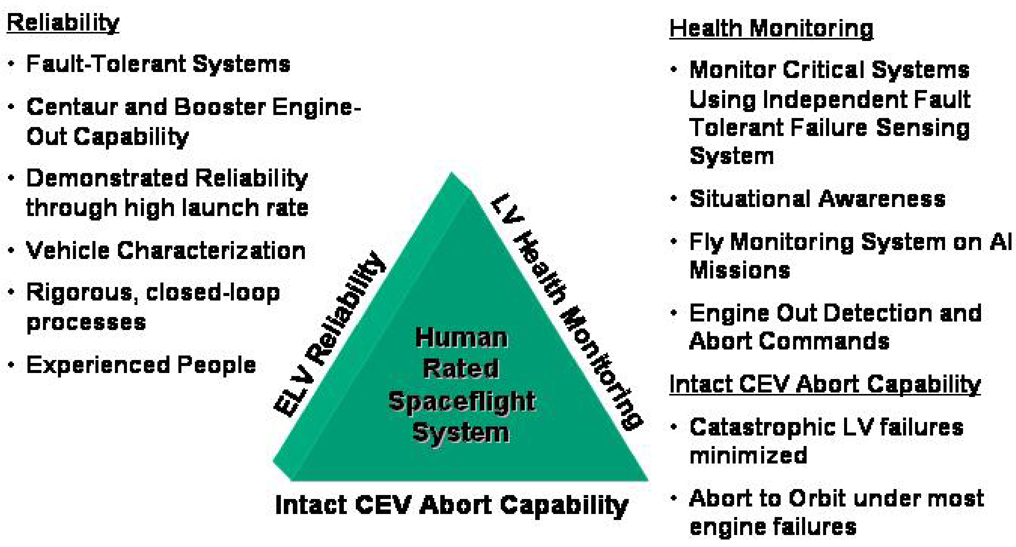

Figure 7 System Level Human Rating Concept

V. Conclusion

President Bush's vision for space exploration sets important and inspiring goals for America's space program. Key to achieving this vision is reliable and affordable space transportation. The Atlas evolution program offers a simple and logical series of steps to obtain Saturn V class or greater performance, long duration cryogenic stages for in-space applications, and human launch systems. These steps involve only tank structural modifications, and modest launch infrastructure improvements, but no new engine developments or risky technology. These steps are well in keeping with the evolutionary modifications executed by the Atlas commercial program over the past 15 years with an unprecedented eight-for-eight-success record for first flights. Just as important in our budget constrained world is the Atlas record of on-cost, on-schedule developments. The Atlas development team is intact, coming off the Atlas V® vehicle development and most recently, the SLC-3E launch site activation.

The affordability of Atlas cannot be matched by any credible alternative. Atlas has been honed by 15 years of competition in the commercial marketplace, and is the only domestic rocket still in the market. The price per pound launched is factors lower than the shuttle system, for example. The emerging entrepreneurial systems, so lauded by the press, have yet to put even one ounce into orbit, and will undoubtedly be greatly humbled by the time they do—if they do.

The dream of many of us involved in the space program is to launch humans to another planet. Humanity will go to another planet for the first time only once. It will be the most important event in human history. We need to spend our precious resources wisely. Space transportation should be a small fraction of the overall cost, and can be—if Atlas is the solution.