Innovation at ULA

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Since the dawn of the space age, Rocket Science has been synonymous with innovation. United Launch Alliance (ULA) has revolutionized reliable, global space access with our Atlas V and Delta IV rockets. The long history of innovation that resulted in these vehicles continues today at ULA as we invest in product line innovation to provide increased performance, additional capability and flexibility, and open up new and exciting markets. At the core of innovation are the people involved. Enabling an innovation culture at ULA creates boundless opportunities for innovation throughout the enterprise. Focusing on the nearer term, our Vulcan booster incorporates numerous new technologies including Methane/Oxygen propulsion, efficient structures, and additive manufacturing to make launch services more affordable and accessible. Next comes our newest upper stage known as ACES (Advanced Cryogenic Evolved Stage). This revolutionary design will incorporate highly innovative concepts to generate power, provide tank pressurization and reaction control, and enable long term cryogenic commodities storage. The resulting capabilities significantly expand performance and mission duration from hours to days, even weeks and months. Future concepts for reusability, distributed lift, and on-orbit refueling enable growth in an entire Cis-Lunar Econoshere. Exciting new markets for propellent (ie water) and material mining and solar power can become science fact instead of science fiction. This paper will explore a variety of the newest technologies being implemented on our next generation of launch systems.

1. INTRODUCTION

Innovation is perceived differently by different individuals. Many may think of innovation as building the next greatest widget. Some think of innovation in a much broader sense. The interpretation contained in this paper addresses a broader perspective in that innovation is in the way we think, conduct ourselves, and finally to develop products or services to meet the needs of our customers and of society in general.

United Launch Alliance (ULA) has portrayed this broader perspective since day one of its existence. This same perspective has increased in magnitude recently as ULA continues to re-invent itself to meet the needs of the future. In our view of the future, many of ULA innovations actually expand the potential opportunities of the future. However, given the broader perspective this paper will still limit the focus to three primary elements of ULA innovation: corporate culture that invigorates innovation, process innovation and the more traditional area of product innovation.

In the first element, ULA leadership stemming directly from the CEO is creating a vibrant atmosphere of innovation throughout the workforce. One example highlighted later called “Ignite Innovation” focuses attention on motivating lower level workscale, high potential employees with formal innovation training and associated projects. In the second element, ULA continues its engagement on continuous improvement with ULA leadership once again enabling the entire value stream to investigate innovations through multiple programs. Finally, in the third and more traditional sense of innovation, ULA is revolutionizing the space industry with ground-breaking technologies that will expand the future of the near-earth economy.

2. CORPORATE CULTURE AND INNOVATION

ULA leadership has truly embraced and enabled innovation from the top down. Similarly, ULA’s rocket scientist workforce has contagiously maintained and promoted a viral grassroots attitude of innovation. Both influences foster a culture that not only enables innovation yet ensures it will flourish throughout the entire enterprise value stream.

Transforming ULA requires a different way of looking at problems and developing new approaches that challenge conventional thinking. Being competitive will depend less on what we know and more on how we think. A new program called Ignite Innovation was created to provide employees the mind set, tools and processes to accelerate innovation and change in ULA. The program provides participants an understanding of how to engage in innovations and a process for understanding user needs and developing creative solutions. The program includes working on innovation projects with the guidance of innovation mentors over a two month timeframe and concludes with presenting project results and lessons learned to ULA executives. In this program, participants are taught a somewhat disciplined but flexible process for innovative thinking. Following the process based on Stanford University Institute of Design, we provide these exemplary employees the intellectual tools and training enabling innovation.[1] Figure 1 highlights this approach to innovation. Upon completing the classroom portion, small teams are formed and challenged with a project. These projects are often broadly defined to allow the team to drill down to facets of the project objective that appeals to them while also creating innovations. For example, one the recent project was to determine how to cut the cost of qualifications by 80%. In our very disciplined aerospace industry, qualification processes, analyses and testing can be quite costly. This team provided some very interesting approaches which are now being considered as part of the Vulcan Centaur development program.

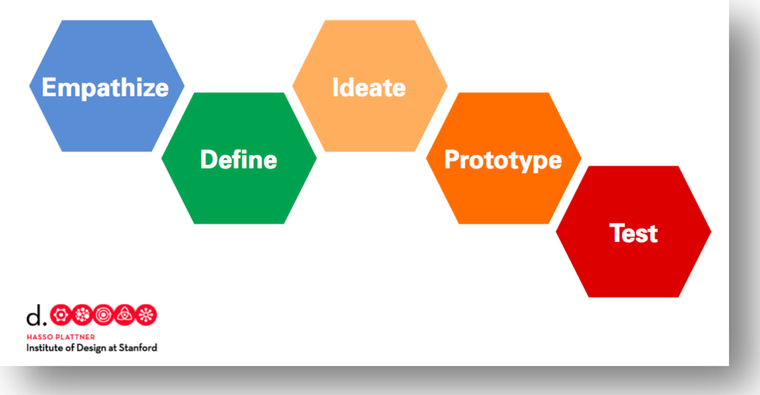

Figure 1: Design Thinking Process

3. PROCESS INNOVATION

ULA continues to focus attention on process innovation to create efficiencies throughout the enterprise value stream. At the very forefront of this effort is the continuous improvement ethic imbedded at ULA called Perfect Product Delivery (PPD)(Figure 2). PPD instills a persistent focus on quality in every aspect of ULA operations from business systems, analysis tools and products, supplier quality to production and launch execution. With PPD, employees are encouraged to suggest new and innovative ways to improve quality, reliability and efficiency. Proactive initiation of projects and accountability are also key features of ULA's PPD approach. Process change must be reliable, enhance first time quality, and provide for on time delivery of products.

In order to achieve this objective, once again, the company must have a work force which possesses the skills needed to continuously improve processes; skills which are obtained through Green and Black Belt training. Being a Green or Black Belt means that individuals have been trained to use a set of techniques and tools which help identify opportunities for innovative process improvement and to plan and execute projects, large and small, to change and improve those processes. ULA has close to 1000 Green Belts and closing in on 50 Black Belts.

Employees are recognized and rewarded for their PPD projects. A quarterly and yearly process highlights the achievements from the many PPD project teams. These teams span all areas of business, yet one of the largest singularly focused set of projects has targeted launch span time reduction. In effect, this effort seeks to decrease the time it takes to execute a launch. Span time measures the launch campaign from start to finish of any particular mission, yet also reflects the time between launches. By reducing the span time, ULA can support increasing rates of yearly manifest launch requirements from all customers. Numerous employee-initiated projects have led to approximately 50% reduction in Atlas V launch span time. To support an increase in launch rate, it was also necessary to decrease the cycle time associated with

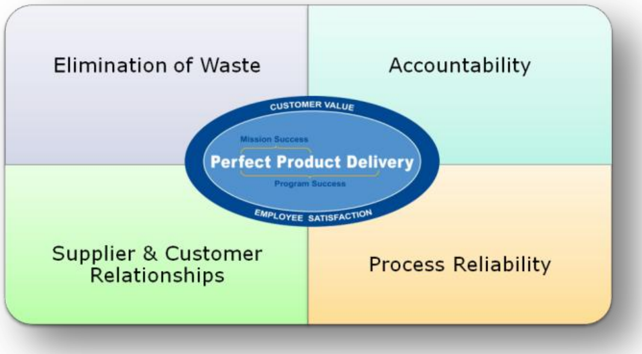

Figure 2: ULA Perfect Product Delivery (Continuous Improvement)

production. In this effort, employees initiated a set of projects that achieved over 20% reduction in Atlas V production cycle time. Together, these initiatives offer an increase in operational capability and efficiency for servicing what has been the highest launch demand in the history for ULA.

4. PRODUCT LINE INNOVATION

ULA is on the cusp of, once again, re-inventing our product line to meet the needs of the future. Dating back more than 50 years, the Atlas and Delta namesakes have been providing launch capabilities that have kept pace with the changing requirements of the US Government and other customers. Together, the current ULA fleet Atlas V and Delta IV launch vehicles meet the entire spectrum of customer requirements. However, now after more than a decade of 100% mission success performance, ULA is actively developing the next generation systems as portrayed in our product evolution roadmap Figure 3. The first Step of the roadmap is the most crucial with the development of the Vulcan Centaur system. Vulcan Centaur will adopt an American made engine with increased performance and capabilities. Next will be a significantly more capable upper stage called Advanced Cryogenic Evolved Stage (ACES). Further down the timeline more advanced concepts are planned for reuse, distributed lift, autonomous engine recovery, lunar surface access, and ultimately the concept for supporting a future Cis-Lunar economy. Spread throughout the various stages of the roadmap are innovative game-changing concepts and technologies. Each update has its own flavor of technical innovation. Many ongoing development activities focus attention on *game-changing* technologies intent upon revitalizing several major subsystem components. Each element of the roadmap will be explored in subsequent sections.

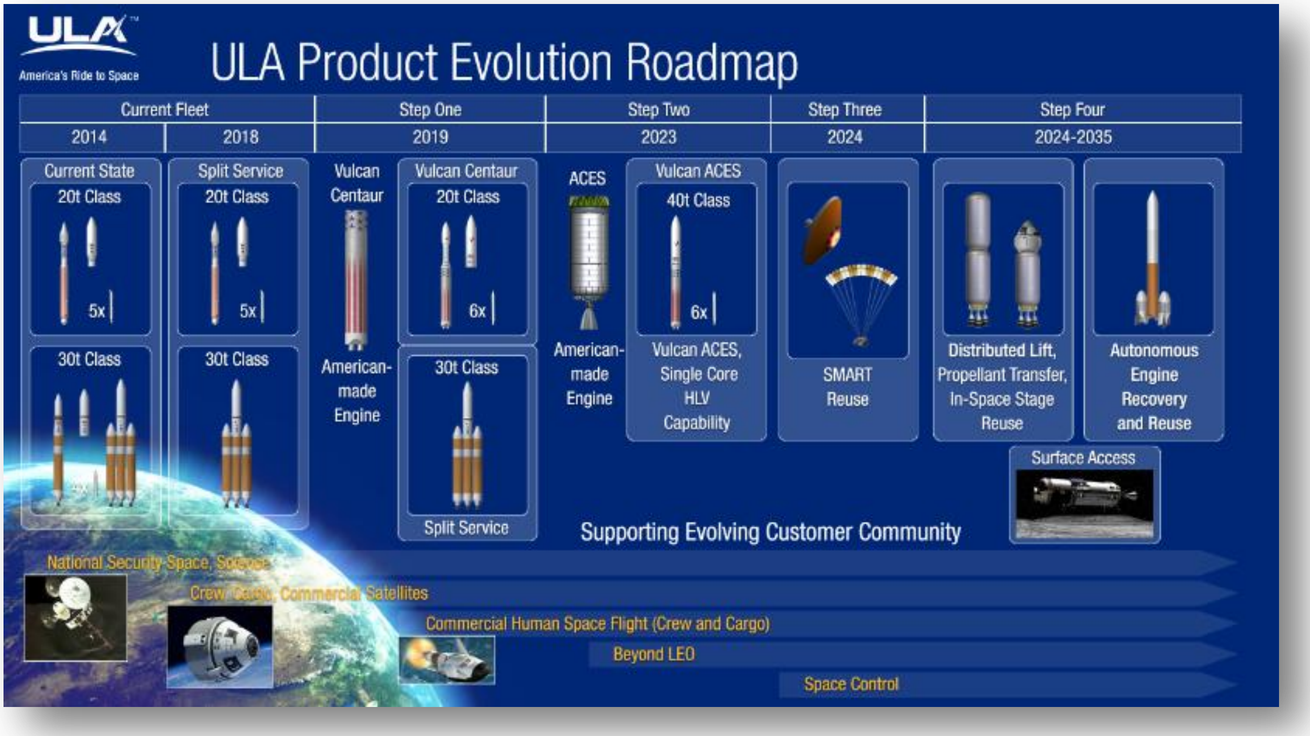

Figure 3: ULA Product Development Roadmap

Vulcan Centaur: With increasing cost of launch being highlighted by our National Security and NASA customers and with ULA's renewed attention to competing in the commercial market, ULA has embarked on developing the next generation launch vehicle called Vulcan Centaur (Figure 4) which is destined to provide increased capabilities at a much reduced cost. Vulcan Centaur will continue to provide levels of reliability embedded in ULA's DNA and expected by our most demanding customers. The additional benefit will be the national security imperative to eliminate dependency on Russian rocket engines. We are designing a rocket system from tip to tail that adopts innovative designs making it more affordable, capable, and competitive. [2]

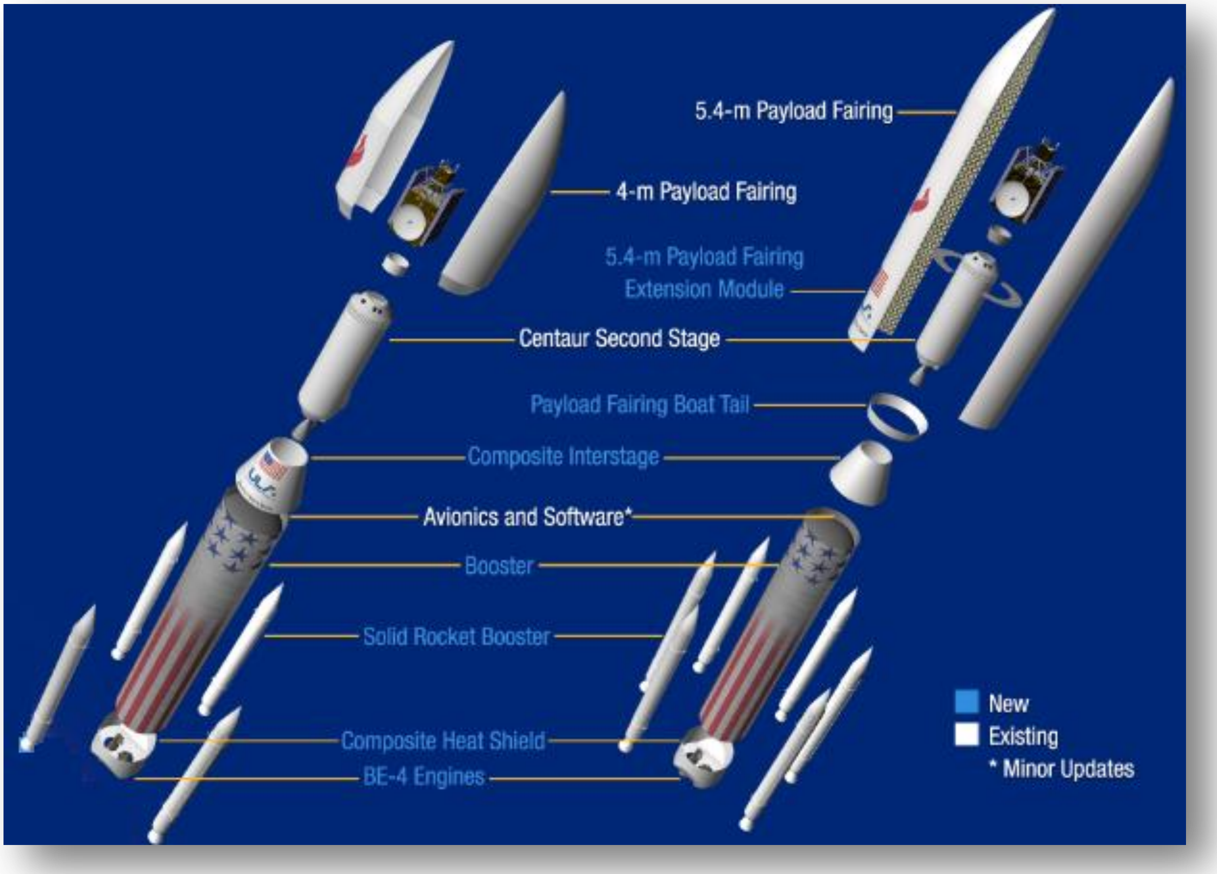

Figure 4: Vulcan Centaur Design Attributes

Figure 5: Blue Origin BE-4 Engine

The most critical part of any launch system is propulsion. For Vulcan, ULA's primary path is with the Blue Origin BE-4 booster engine system (Figure 5). This high-performance, oxygen-rich staged combustion engine produces a combined (two engines per stage) thrust of 1.1 Million lbs at sea level. The innovative approach to the design of the BE-4 Engine includes the never-before-used combination of Liquidied Natural Gas (LNG) and Liquid Oxygen (LOX). Use of LNG provides for low-cost readily available commodities. Additional benefits include the capability for autogenous tank pressurization and inherent chemical advantages for future engine reuse. The final financial benefit of the ULA and Blue Origin partnership is that the engine and bulk of Vulcan Centaur is developed and funded by private industry. ULA's backup engine plan includes the use of the Aerojet Rocketdyne AR-1. [2]

With the relatively lower density LNG, the booster tank structure diameter with a common bulkhead approach is larger that either Atlas V or Delta IV. One of the advantages in this respect is the capability to support up to six Solid Rocket Boosters (SRB). As with Atlas, individuals solids can be added asymetrically to enable a modular design that supports a broad range of customer performance requirements.[2]

Advanced Cryogenic Evolved Stage (ACES): With our new innovative upper stage concept, Advanced Cryogenic Evolved Stage (ACES), ULA will achieve performance and capability to sustain a future space economy (Figure 6). This 5.4 meter diameter stage has features to reduce costs of current mission designs and enable longer more complex missions previously unachievable.

Leveraging design and operations experience with Atlas Centaur and Delta Cryogenic Second Stage (DCSS), ACES continues with hydrogen and oxygen as the propulsion commodities. The number of engines is flexible to meet the need of the specific mission with four engines illustrated in the figure. Likewise, the fuel load can be adjusted to the specific performance need to optimize the mission. At a full fuel load of 68 tons of LO2 and LH2, ACES can carry three times the load of centaur. Coupled with Vulcan, this single "stick" configuration exceeds the performance of the Delta IV Heavy at about one fourth the cost. Similarly, this magnitude of fuel load enables longer and more complex missions. At 15 meters long, the structure is composed of a steel, pressurized tank design that at 0.92 will exceed even Centaur's best-in-the-world stage mass fraction. Even with innovation in the basic design, it is the additional innovative game changing technologies that truly enhance the broad capabilities of ACES.[3]

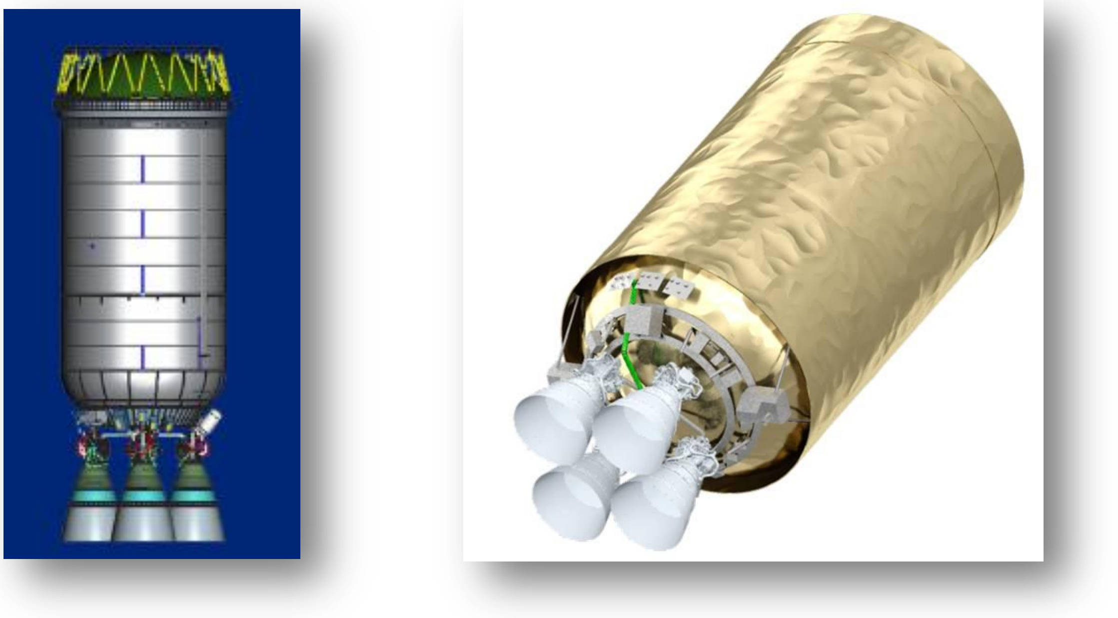

Figure 6: Two Renditions of the ACES Upper Stage Configuration

Game Changing Technologies: ULA is investing in a variety of innovative, game-changing technologies that enhance performance, simplify design, increase capabilities and reduce overall cost. These technologies include Integrated Vehicle Fluids (IVF), Hydrogen (H2) and Oxygen (O2) thruster, Cryogenic Fluid storage and management, and additive manufacturing. Each of these technologies will have a profound impact on system capabilities and open up incredible future mission opportunities.

Integrated Vehicle Fluids (IVF): ULA is developing the IVF system, a single system, to replace three independent upper stage subsystems; the helium pressurization system, the reaction control system and the electrical power storage subsystem. This capability is revolutionary and is a departure from the incremental evolution of the existing Evolved Expendable Launch Vehicle cryogenic upper stages. Current Centaur and DCSS system's approach for power, pressurization, and reaction control requires complex plumbing, control systems and power to operate. IVF combines these functions in an elegant solution that relies on the use of existing propellants, O2 and H2, which drive the upper stage engines. Figure 7 shows the aft bulkhead of ACES with redundant IVF modules and a more detailed rendition. Not only does the IVF system reduce weight and complexity but it can be built and tested offline and then integrated onto the upper stage which simplifies production and testing operations at the factory and launch site.[4]

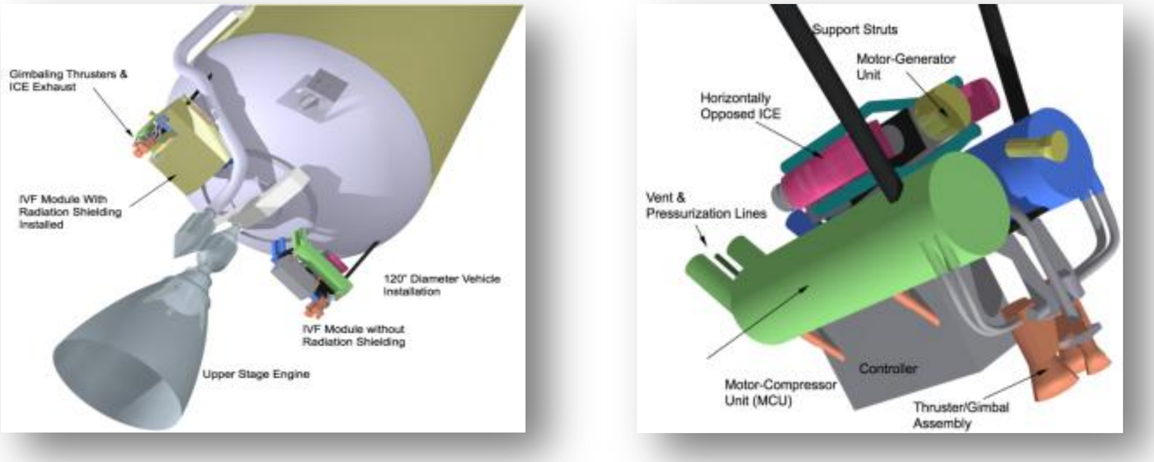

Figure 7 The IVF module is a compact single integrated module that contains all 3 systems in a single unit.

Power Generation/storage - Internal Combustion Engine (ICE) – One facet of innovation is to use traditional technologies in new ingenious ways. IVF is hugely innovative in leveraging more than a century of development of the internal combustion engine. At the core of IVF is a small piston engine (750cc) manufactured by Roush Industries, that runs on waste gases from the liquid oxygen and hydrogen tank fed into the engine intake (Figure 8). The system operates very similar to a car in that the IC engine powers a generator to create current which charges a relatively smaller battery (much smaller than current main vehicle batteries). The small battery is used to level power and not for long term power storage. Peak power generated can be regulated from 30V to 300V. The IVF controller will turn various subsystems on and off as needed. Unlike current main vehicle batteries which are heavy and constrained by limited life, IVF with the ICE can operate as long as there are H2 and O2 tank ullage gas available – days to weeks without refueling and longer with refueling.[4]

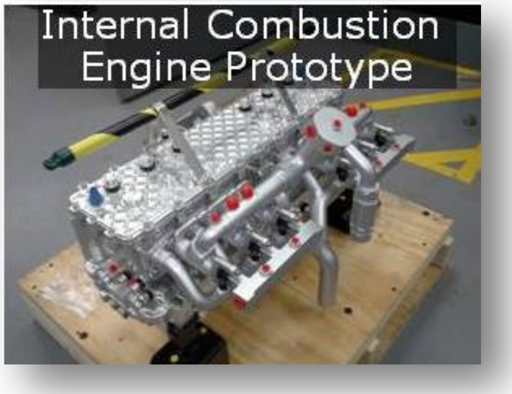

Figure 8: Roush Prototype ICE

Tank Pressurization – Heat Exchanger: IVF provides another substantial advantage by utilizing the heat generated in the combustion process for pressurizing the upper stage tanks. This alternate source of pressurization obviates the need for helium for this purpose (current approach), and thus enables the removal of large helium bottles. Even with complete IVF system redundancy, overall system weight is reduced with a corresponding increase in performance and payload capability in the range of 400 to 800 lbs. Without the requirement for high pressure Helium bottles, ground crew operations are simplified and significant weight savings are realized.[4]

Attitude Control - H2/O2 Thruster: As part of the IVF system, ULA is developing a hydrogen and oxygen thruster pictured in Figure 9. This six-to-nine pound thruster uses gaseous hydrogen and oxygen from the IVF system. Use of existing commodities readily available is an efficiency theme that should be obvious at this point. The actual design of the thruster has been through several iterations already with extensive test fire demonstrations at upper stage propellant inlet conditions. This highly efficient thruster will replace all of the current hydrazine-based reaction control thrusters and thus enable removal of Hydrazine bottles. Removal of Hydrazine and related bottles is not only a significant weight reduction opportunity, but also provides safety and operational efficiency as well. Mounting the thrusters on a gimbal platform that can slew in virtually almost any direction allows propellant settling operations, stage attitude control and thermal control maneuvers to be executed from a single set of

Figure 9: H2/O2 Thruster Hot Fire Test

thrusters on each module. The thruster gimbal system has been designed to allow gimbaling in a slightly forward direction, which will allow the stage to back away slowly form a separated payload, possibly eliminating the need for a complicated and expensive payload separation system that uses springs or other devices to ensure no stage re-contact. Additionally, the thruster can support new mission capabilities for multi-payload deployment and much longer coast missions.

Cryogenic Storage and management. One of the challenges of upper stage operations is loss of cryogenic propellants due to boiloff. Current stages are limited in part by boiloff to up to 12 hours in total mission duration. ULA has extensive experience in developing innovations that reduce boiloff by two orders of magnitude. These technologies imbedded in a program called CRYOTE have been developed over many years and verified in a series of tests at NASA's Marshall Spaceflight Center (MSFC). Being passive, these innovative technologies do not require any power. Examples include design of the tank to reduce penetrations or attachments and minimize surface area, enhanced multi-layer insulation, and a common bulkhead between the H2 and O2 tanks to enable the hydrogen to cool the oxygen.[4]

ACES Performance Enhancements: With the above mentioned innovations, ACES performance, capability and flexibility is increased substantially. Numerous main engine starts, virtually unlimited reaction control and tank pressurization, extended duration power generation combine to enable mission opportunities that can extend for days to weeks. Upper stage disposal is also no longer an issue. Many of these technologies also increase safety and relibility. IVF extended duration power can also be provided to the payload which likewise overcomes payload power limitations. With stage refueling mentioned later, many new mission opportunities can become a reality.

Additive Manufacturing. Addititive Manufacturing (synonomous with 3D printing) is finding a home in aerospace like many industries since attributes of AM are perfectly matched to aerospace applications. AM is well suited for low-volume, higher cost product lines like launch vehicles where reducing weight is also an objective. As such, ULA has quickly adopted AM throughout the enterprise value stream. One of the often unsung high-payoff applications of AM is simple tooling. With the ability to rapidly and very cheaply produce a tool perfectly designed to the requirements, ULA can immediately show a return on the investment. To date, literally hundreds of tools designed and produced from Ultem and ABS polymer material are being used on the production floor. Numerious other shop aids like fit check and mockups aid efficiencies in the production process. A few examples are illustrated in Figure 10.[5]

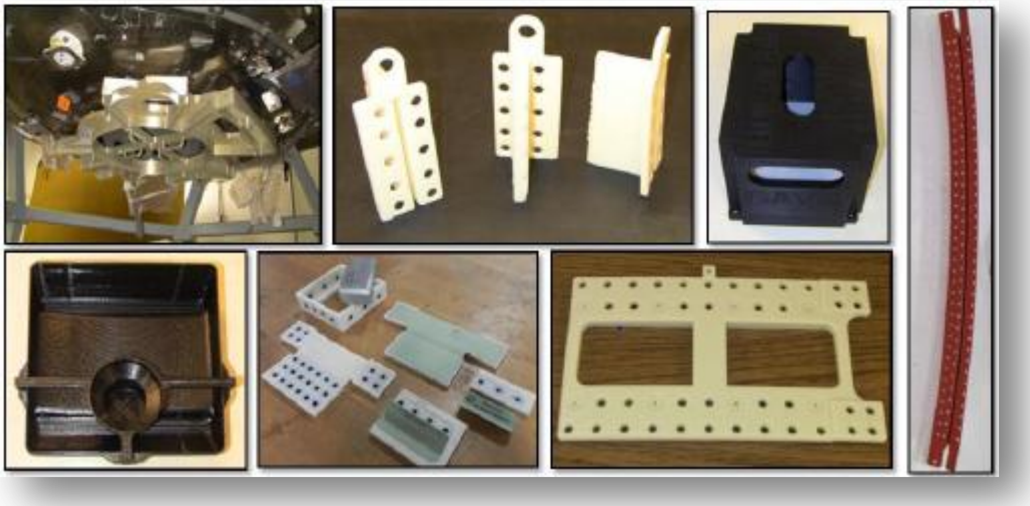

Figure 10: Additive Manufacturing Shop Tools, Mockups, and Installation Tools

The more prevalently highlighted applications of AM are product line uses. ULA sees a huge potential for application on our launch vehicle systems. However, aerospace companies like ULA with existing products like our Atlas V and Delta IV find it challenging from a business case standpoint to redesign and requalify AM components to retrofit existing components. However, we are still finding numerous opportunities that cut cost and reduce weight. The initial thrust was utilizing Fused Deposition Modeling (FDM) of Ultem Polymer for flight applications. Yes, many parts of a rocket can effective be made from a high strength polymer. One notable example planned to fly soon is highlighed in Figure 11. In this particular application, the benefits of AM really shine in that we were able to reduce the part count from 140 to 14, reduce the cost 57%, and significantly reduce both component lead time and rocket production processing time. Other similar examples are flying today.

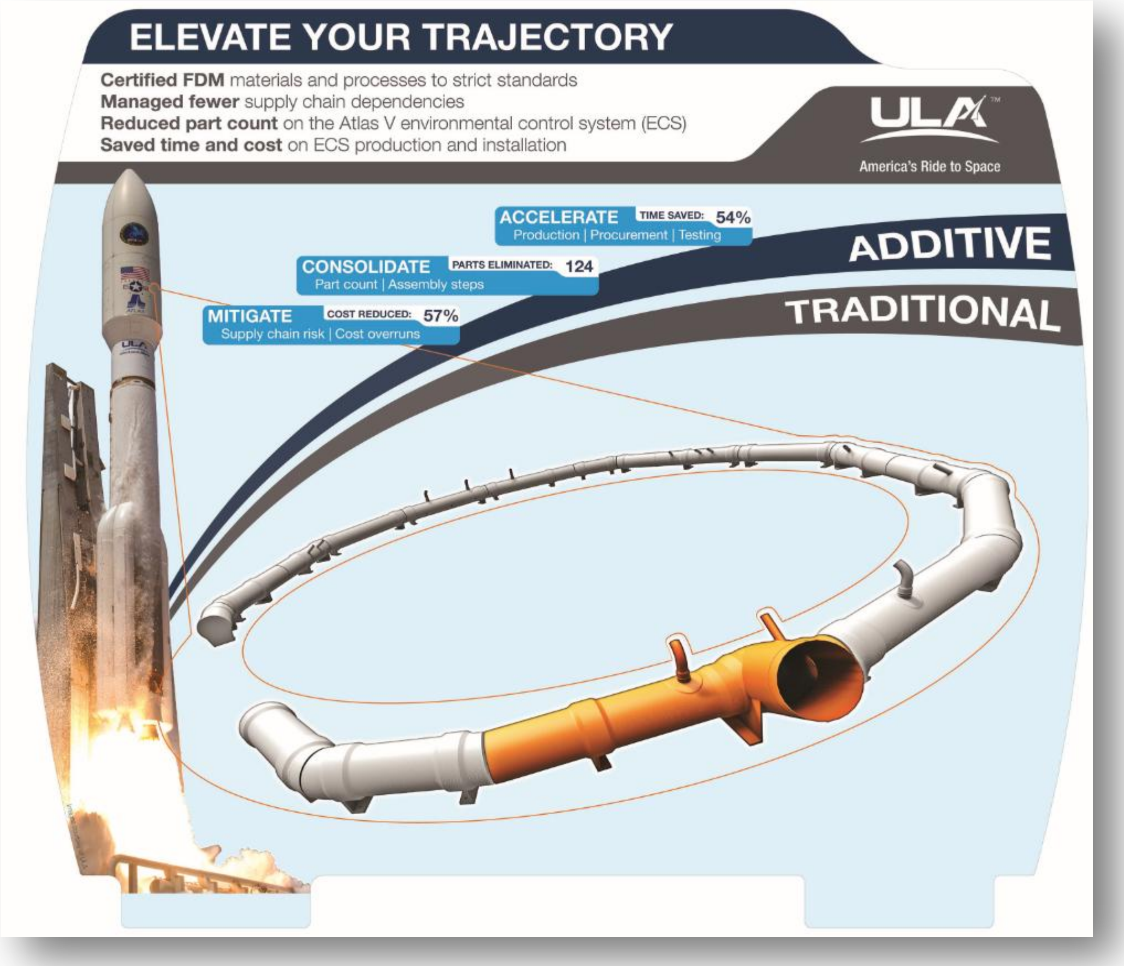

Figure 11: Additively Manufactured Flight Component System (Credit Stratasys)

With the opportunity for a new launch vehicle design, the Vulcan Centaur and ACES developments create a perfect environment for more expansive exploitation of AM applications. AM is exquisite in the capability to enable design to the specific purpose unencumbered by traditional design for manufacturing constraints. Also, in this environment, we are already committing to design and qualification time and costs so bringing in AM can be considered a wash. Like many aerospace companies, we still require extensive training and material testing of AM techniques especially as we adopt metal AM. We are quickly progressing through those activities already. Qualification approaches are also a challenge in the industry but many collaborative efforts will aid in this effort. ULA leadership is placing high expectations on AM adoption for these major developments and the teams are finding numerous innovative applications. AM has the strong potential of changing the face of launch vehicle design and production, and ULA is taking a huge leap into this innovative technology.

SMART Reuse: ULA has constructed an innovative approach to reusing launch vehicle components we call Sensible Modular Autonomous Return Technology (SMART). Pictured in figure 12, our SMART approach focuses on recovering the most expensive part of any launch system, the rocket engine. Much of the other components such as large structure are relatively inexpensive to produce but have a very large impact on performance with other approaches involving returning the entire booster. Returning just the engine portion preserves performance by not requiring the system to use substantial propellent as part of the re-use approach. The cost of refurbishing components after high speed re-entry and exposure to salt water (in the case of a Shuttle SRBs) can also be substantial. The ULA approach mitigates these issues with a simple, yet inventive solution.[6]

Figure 12: Sensible Modular Autonomous Return Technology (SMART)

Our concept of operations starts when the 1st stage engine is detached after completion of that portion of flight. Reentry is accomplished by utilizing the atmosphere to decelerate the engine via aerodynamic drag. In conjunction with NASA, ULA's method for aerodrag uses the Hypersonic Inflatable Aerodynamic Decelerator (HIAD) design (Figure 13). The HIAD design is based primarily on an innovative inflatable structure that is densely packed during ascent then inflated exo-atmospherically to create a large heat shield for re-entry. Soon after max deceleration, the HIAD is ejected and a parafoil is then deployed to slow descent further. The final step is for Mid-Air Recovery and return to ground. Utilizing a large helicopter, the parafoil and engine components are gently captured and returned to a precise location. Each of these technologies have been tested in subscale and are mature and scaleable. This approach also benefits from limiting any major impacts of deceleration or salt water contamination. Without going into extensive detail, the economics of this approach are much more appealing than other methodologies that significantly impact performance and cost. Looking even farther into the future, ULA has concepts for autonomous engine recovery which is similar in concept to this simple but innovative approach but will take further development.[6]

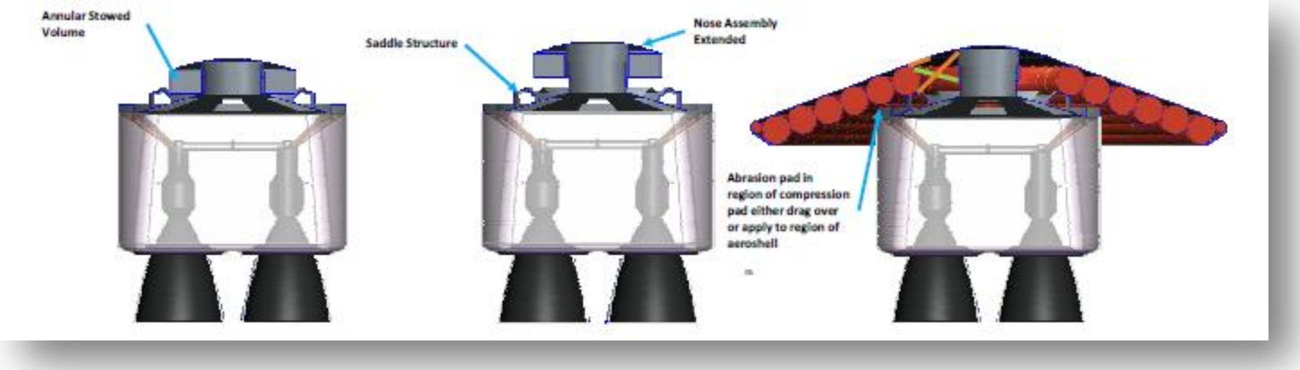

Figure 13: Hypersonic Inflatable Aerodynamic Decelerator (HIAD) Design

Distributed Lift: Distributed lift is a fairly simple yet innovative approach. Instead of utilizing one very large, singular launch vehicle, this method spreads the lift performance needed across two or more missions (Figure 14). The primary payload is launched to orbit aboard one launch vehicle. This vehicle consumes all of its propellent to achieve low earth orbit for the payload. A second launch supplies additional propellents via a disposable "Drop Tank". The first upper stage (ACES) and payload then rendesvous' in orbit with the second. Propellents are transferred to the first via a robotically coupled process. Once all of the propellants have been transferred the two systems separate. The first vehicle upper stage and payload perform one or more main engine burns to achieve the desired end trajectory. The second upper stage/ and depleted Drop Tank perform a deorbit burn to dispose of the system in Earth's atmosphere.[7]

Distributed Lift can be shown more than double the performance of available launch vehicles without the cost burden of additional fixed infrastructure, such as a permanent orbital propellant depot or cost of an exquisitely designed larger single launch vehicle.[7]

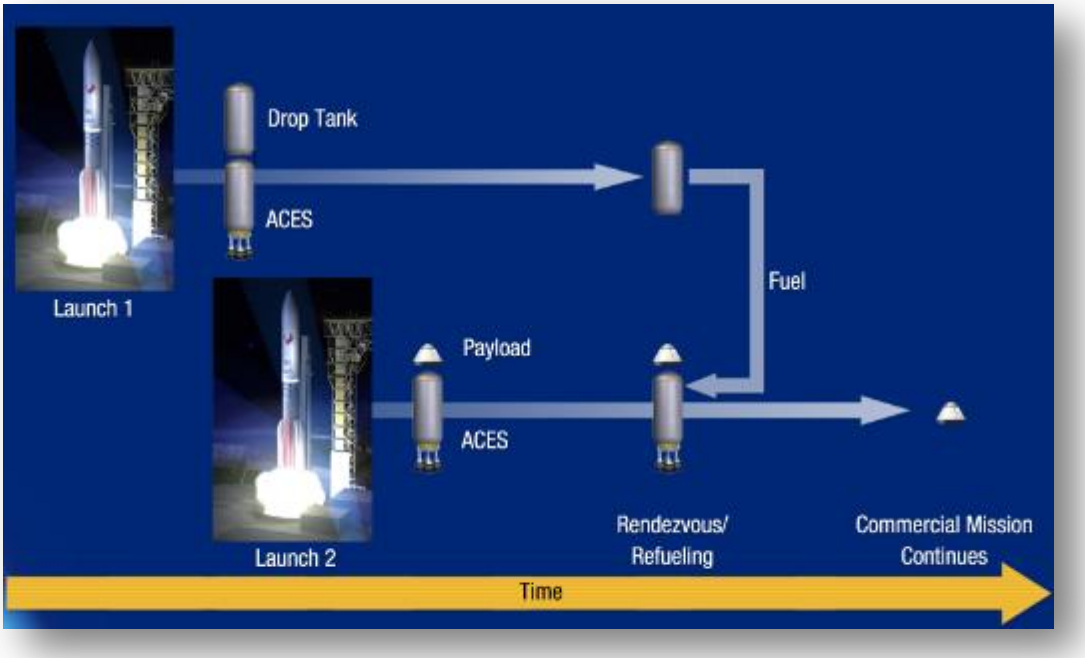

Figure 14: Distributed Lift Approach Using Two Missions

Cis-Lunar Economy: The key to a sustaining an enduring space economy is to generate wealth not consume it. The two major elements of wealth generation in today's commercial space economic model are communications and GPS related terrestrial applications. Government sponsored space activities are not subject to free market dynamics thus provide limited addition to a commercial model. Yet together it's clear the primary economic benefits of space occur in the vincinity of Earth which is where all the consumers live. As such, the next great free market opportunity in space is to go beyond earth orbit into the cis-lunar environment. The enormous distances beyond cis-lunar are prohibitive to generate wealth for the foreseeable future.[8]

The initial step in developing a cis-lunar economony is to determine all of the potential business opportunities to exploit. Figure 15 highlights both the transportation routes and potential activities associated in each regime. Most are familiar with existing earth orbit commercial activities. There are still growth opportunities identified in the red colored future market list. The Earth Moon Langrange (EML) points represent the "transportation hub" bridging the distance between earth and the moon. The first likely resource extracted on the moon would be water ice to enable human habitation as well as fuel chemical propulsion that makes transportation possible to and from the moon. Abundant sunlight near the lunar poles supplies power for a lunar economy. Mining rare elements provides for wealth generation.[8]

The overall challenge is transportation costs. Like how lower cost, high capacity rail to the western United States open it up to industry, cheaper more capable access to cis-lunar space will open up its economic potential. This is where the innovation, attributes, capabilities and low cost of ACES make it perfectly suited to be the railroad of the cis-lunar economy. First and foremost, ACES utilizes H2 and O2 as its source of chemical propulsion. Thus water effectively powers transportation via ACES. It can be shown that a business case reusing and refueling multiple ACES stages will sustain an cis-lunar transportation economy.[8]

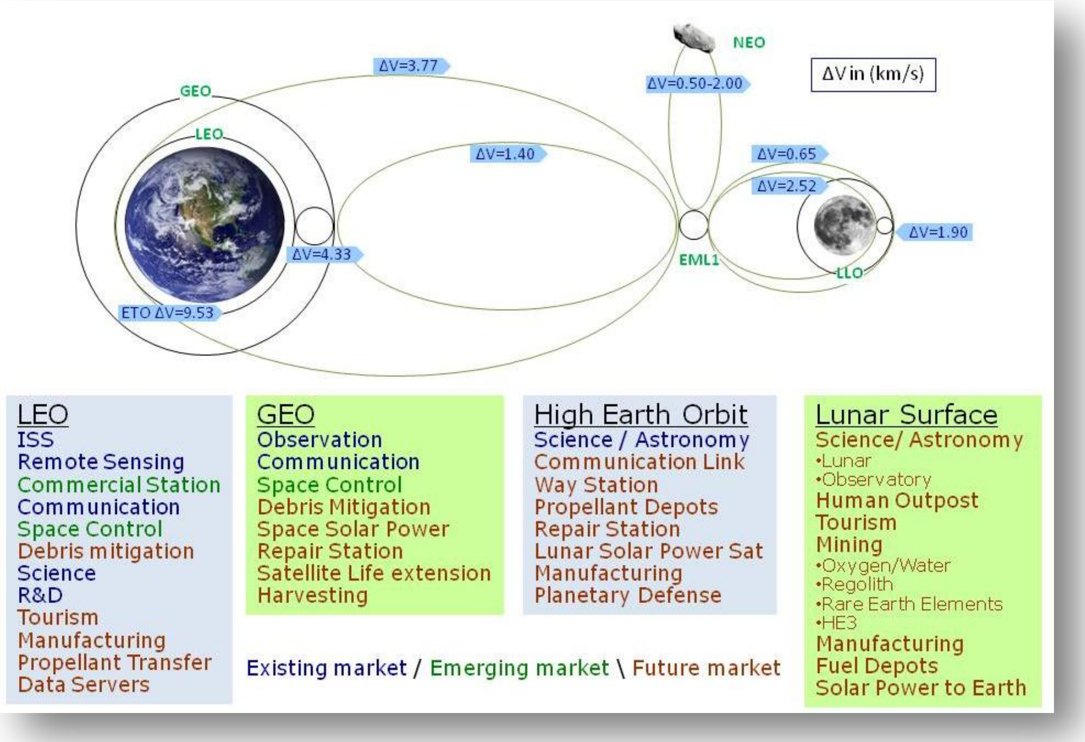

Figure 15: Cis-Lunar Economy Orbit and Market Opportunities

CONCLUSION

"Is ULA an innovative company?" the answer is an unequivocal yes! We infuse innovation stemming from a corporate philosophy into every facet of our value stream. Future challenges do exist. As a company, ULA faces uncertainty in future market predictions and growth of competition both national and international. Yet, with flight-proven reliability, decades of experience, and continued focus on innovation, ULA will continue to provide unmatched launch capabilities to our entire customer base. The innovations imbedded in Vulcan and then significantly expanded in ACES will truly open up future economies that will fuel the future of space.

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