February 8, 2008

Why NASA Chose to Utilize a Shuttle-Derived Crew Launch Vehicle (CLV) Instead of Human Rating an Evolved Expendable Launch Vehicle (EELV)

Summary

NASA evaluated many launch vehicle options that could be utilized for human space exploration missions. The principal factors considered were the desired lift capacity, the comparative reliability, and the development and life-cycle costs of different approaches. Among these approaches, NASA considered existing vehicles, such as the EELV fleet, to meet crew and cargo transportation needs. This white paper outlines why NASA decided to move forward with the Ares launch vehicles after careful consideration and study of other launch alternatives.

Developing NASA's Exploration Architecture

NASA is developing the Exploration architecture to safely and affordably transport humans and cargo beyond low Earth orbit (LEO). This multi-purpose architecture is not simply a "ferry to the International Space Station (ISS)," or a "Shuttle replacement." Instead, by utilizing tested human space elements, it includes the Heavy Lift Launch Vehicle (HLLV) to deliver up to 70-75 metric ton (mT) of cargo to Trans Lunar Injection (compared to the Apollo/Saturn capability of approximately 47 mT).

NASA studied hundreds of commercial, Government and concept launch vehicle and architecture systems prior to 2005, culminating in the release of the Exploration Systems Architecture Study (ESAS). NASA studied Space Shuttle-derived, EELV-derived as well as "clean sheet" launch vehicle architectures in cooperation with the U.S. launch industry, and concluded that the Ares I and V system architecture provided the optimal solution for both LEO and beyond LEO applications. Figures of Merit (FOMs) used during the studies -- cost, reliability, human safety, programmatic risk, mission performance and schedule -- were applied to drive out the best alternative in the analysis. Additional considerations included legal requirements from the NASA Authorization Act of 2005 (P.L. 109-155), workforce skills and industrial capabilities. After a thorough analysis of the entire Exploration architecture requirements, EELV solutions were ultimately determined to be less safe, less reliable, and more costly than the Shuttle-derived solutions in development.

The ESAS concluded that NASA should adopt and pursue a Shuttle-derived architecture as the next-generation launch system for exploration missions due to their significant advantages, particularly with respect to safety, reliability, and cost. The extensive flight and test databases of currently flying hardware/software give a very strong technical and safety foundation with clearly defined and understood elements to anchor next-generation vehicles and minimize development costs and risks to flight crew. In addition, NASA's approach allows the Nation to leverage significant existing ground infrastructure investments (Kennedy Space Center (KSC); Michoud Assembly Facility (MAF), etc.) and personnel with significant human spaceflight experience. Overall, NASA's Shuttle-derived approach was found to be the most affordable, safe, and reliable approach, both by leveraging proven human rated vehicle and infrastructure elements and by using common elements across the architecture. While NASA continues to conduct trade studies aimed at refining the Ares V architecture for minimum development risks and operational costs, the Agency is committed to the fundamental Ares I/V approach established over two years ago.

The next section of this white paper explores some of the specific reasons why NASA chose the Ares architecture for future spaceflight missions, both manned and unmanned.

The Ares versus the EELV

Vehicle Performance: The EELV crew transport options examined were those of the Delta IV and Atlas V families. The study focused on the heavy lift versions of both Delta (currently flying) and Atlas families (drawings only), and confirmed that none of the medium versions of either vehicle had the capability to accommodate the Orion Crew Exploration Vehicle lift requirements. The Medium class EELVs, with no additional solid boosters, significantly under performed by approximately 40-60 percent. The option of using small, strap-on solid boosters was eliminated for safety reasons in the Orbital Spaceplane Safety Study conducted in 2004. Both EELV-heavy vehicles were assessed to require significant modification for human rating, particularly in the areas of avionics, telemetry, structures, and engine selection. Additionally, both the Atlas and Delta Heavy classes required development of new upper stages to achieve the lift performance required to launch Orion. Ares I is designed to launch the 23.3 mT Orion vehicle, which consists of the crew and service modules, into LEO. The Ares can also launch a 20.3 mT Orion to the inclination of the ISS.

The ESAS assessment showed that lunar missions requiring more than three launches dramatically reduced the probability of mission success. Therefore, NASA issued an architecture goal to minimize complex on-orbit assembly, and also placed a limit to no more than three launches for a mission. For lunar missions, this equates to a launch vehicle design with a lift capability near 100 mT or greater to LEO. Early in the trade study process, NASA identified the current EELV fleet, if used for lunar cargo missions, would require more than seven launches per lunar mission. This very high number of flights per mission is unacceptable from a mission success probability standpoint and did not meet the NASA goal of three launches maximum.

While elements of current EELVs can be utilized to develop a 100 mT LEO equivalent launch vehicle (boosters, engines, etc.), the lack of acceptable EELV boost stage performance (compared to Shuttle-derived hardware) drives the need for an additional Liquid Oxygen (LOX)/Liquid Hydrogen (LH2) stage to reach orbit. The EELV-derived solutions required two upper stages as well as additional strap on core boosters to provide the necessary lift capability to minimize launches for on-orbit assembly. These characteristics were deemed to decrease mission safety and reliability while increasing costs to unacceptable levels based on NASA requirements. NASA did not pursue “clean sheet of paper” designs because it was deemed too risky and expensive.

Crew Safety/Reliability: The current EELVs were designed to carry unmanned payloads. Modifying the EELV design to meet the Human Rating Requirements would require changes in areas such as flight termination system changes to add a time delay for an abort scenario and in-flight crew control/abort capabilities. The use of EELVs for crew transportation would also require NASA to invest significant funds into pad modifications required for crew access/emergency egress that currently does not exist at the EELV launch site. Based on ESAS assessments, the Shuttle-derived launch vehicle was highest-rated in terms of crew safety by about a factor of two over other options (Loss of Crew approximately 1/2000). This confidence for crew safety is driven by the extensive history of the Shuttle system, which far surpasses the experience base for any other existing system. To add to the reliability of the system, the Ares I hardware is recovered and inspected for any system anomalies. In addition, Shuttle propulsion systems are already "human-rated" which mitigates one of the highest programmatic risks for a launch vehicle. Leveraging systems that are already human rated reduces the uncertainties and risks associated with human rating the new CLV. In addition, the current EELVs have a booster structural Factor of Safety (SF) of ≤1.25, where NASA requires that all structures have a 1.4 Factor of Safety (NASA Standard NASA-STD-5001). If the Agency were to accept the reduced SF of the EELVs, a large engineering and development effort would be required to validate structural integrity relative to NASA Standard and would likely eventually lead to some structural redesign of select systems. In addition, main propulsion systems would require modification, for example, the RL-10 upper stage engine would also require human rating in areas such as: Redundancy upgrades; increased subsystem robustness; fault detection; isolation and recovery; engine redlines; safe in-flight shutdown mode; and, any design changes from structural assessments. For Atlas V, RD-180 American co-production and human rating would be required adding greater challenges. From a human rating perspective, the RD-180 will require additional redundancy and increased robustness in select systems. Finally, for Delta IV, several modifications would be required to human rate the RS-68 including extensive health monitoring, increased robustness of subsystems, and elimination of the fuel-rich environment at liftoff which would pose a crew hazard.

Life Cycle Costs: The Ares I and Ares V combination for lunar missions provides significantly lower non-recurring cost than that of the current EELV launch vehicle families. The Shuttle-derived launch vehicle combination allows for a "1.5 launch" solution whereas the EELV architectures required two HLLV launches with more expensive hardware costs. It was determined that the total EELV-derived CLV plus EELV-derived Cargo Launch Vehicle (CaLV) Design, Development, Test, and Evaluation (DDTE) costs are approximately 25 percent higher for EELV-derived versus selected Shuttle-derived architecture.

The launch cost for human rated, EELV-derived systems is significantly higher than the current cost of a medium-class EELV. This launch cost also does not include the non-recurring development investment required to meet the Orion's lift requirements and human rate these systems, which has been estimated to cost in the several billions of dollars. In order for the unmanned payload customers to not incur the unnecessary additional costs for human-rated systems on the EELV, the EELV providers would likely need a unique human-rated variant which would increase the costs.

NASA continued to refine its launch recommendations post-ESAS. In early 2006, NASA modified the architecture from a four-segment Reusable SRB (RSRB)/single Space Shuttle Main Engine (SSME) upper stage CLV, and a five-segment RSRB/Expendable SSME Core/J-2X Earth Departure System (EDS) CaLV to a five-segment RSRB/single J-2X upper stage CLV, and five-segment RSRB/RS–68 Core/J-2X EDS. After careful analysis, NASA elected to forgo the modification of the SSME for altitude-start and proceed directly to development a common J-2X engine for both the Ares I upper stage and the Ares V Earth departure stage, which sends the Orion crew capsule/lunar lander combination to the Moon. This new approach eliminates a top ESAS-identified risk — SSME altitude start — and addresses another risk — J-2X development — sooner thereby lowering overall Exploration risks and costs. In addition, the inordinate expense of using five SSMEs with each cargo launch made the selection the relatively simple (and much less costly), utilizing the expendable RS-68 engine with the added advantage of using a common engine to meet both Department of Defense and NASA needs. With this approach, engine development for the Ares I provides a significant and direct "down payment" on the Ares V test and development plan. Selecting common hardware not only maximizes nonrecurring investments and reduces overall lifecycle cost; it also gets NASA closer to enabling a lunar transportation system. Concentrating efforts on two major propulsion developments rather than on five, as was originally proposed, will reduce development costs by hundreds of millions of dollars and save billions in operations costs. These combined changes represented a projected savings of over $5 billion in life cycle costs over the initial ESAS recommendations.

Infrastructure and Capability Retention: While NASA will continue to use existing U.S. expendable launch vehicles for the robotic exploration missions (five to eight launches per year), the Ares V system leverages heritage human-rated systems such as the Shuttle Solid Rocket Motor; the Solid Rocket Booster, as well as heritage infrastructure, including the MAF in Louisiana; and the Vertical Assembly Building and crawler and launch complex 39 at KSC in Florida. To sustain the manufacturing infrastructure capability required for the Ares V between Shuttle retirement and the first human lunar launch, NASA's Exploration architecture (Shuttle-derived Ares I) ensured America's industrial base for production of large solid rocket systems, high-performance liquid engine systems, large lightweight stages, large-scale launch processing infrastructure, and the current production level of solid propellant fuels is available to support the Ares V. If NASA selected the EELV-based CLV options, this would have required a significant amount of "keep alive" costs to maintain the industry and Center infrastructure and skills assets for eventual use on Ares V development.

External Reviews: Several external reviews have been conducted with regard to NASA's launch vehicle selection, with all reviews to date supporting the direction of the Agency. NASA's conclusions regarding the Space Shuttle-derived Ares I and V vehicles have received agreement by the Department of Defense (DoD) and results were validated by Congressional Budget Office (CBO) and Government Accountability Office (GAO) reports. In 2005, the DoD reviewed NASA's analysis and concurred with NASA's approach. A joint recommendation was formally submitted in a memorandum to the Director of the Office of Science and Technology Policy, Dr. John Marburger, in August 2005.

In October 2006, CBO concluded a study on the NASA's selection of the Ares I and Ares V launch vehicles ("Alternatives for Future U.S. Space Launch Capabilities Report"). The CBO report contrasted CBO's analysis with the recent NASA ESAS report and resulting implementation approach and identified a number of observations, highlighting four main points:

1. Fewer launches per exploration mission increases overall mission reliability;
2. NASA's Shuttle-derived launch vehicle approach is the most economical option when minimizing the number of launches;
3. Since CBO cost results are consistent with NASA's ESAS conclusions, and since NASA also based its launch decisions on safety and reliability (not assessed by CBO), NASA's selection of a Shuttle-derived launch vehicle is further validated by the CBO study; and
4. The CBO estimates for the NASA-selected launch vehicles are within NASA budget projections."

And the most recent report from the GAO in November 2007 ("Agency Has Taken Steps toward Making Sound Investment Decisions for Ares I but Still Faces Challenging Knowledge Gaps Report") noted that "NASA has taken steps toward making sound investment decisions for Ares I." The GAO report also noted that:

> "Furthermore, NASA's decision to include the J–2X engine and five-segment booster in the Ares I design in order to reduce long-term operations and support cost is in line with the practices of leading commercial developers that give long-term savings priority over short-term gains. The Ares I project was also proactive in ensuring that the ongoing project was in compliance with NASA's new directives, which include elements of a knowledge-based approach. NASA's new acquisition directives require a series of key reviews and decision points between each life cycle phase of the Ares I project that serve as gates through which the project must pass before moving forward…We found that the Ares I project had implemented the use of key decision points and adopted the recommended entrance and exit criteria for the December 2006 Systems Requirements Review and the upcoming October 2007 Systems Definition Review."

Summary: NASA is designing transportation architecture, not just a point solution for access to LEO. In deciding on this architecture, NASA considered principal factors such as performance, reliability and development and life cycle costs when comparing alternatives. NASA also took into consideration the growth path to heavy lift capability which results from the choice of a particular launch vehicle family. To grow significantly beyond today's EELV family for lunar missions requires essentially a "clean sheet of paper" design, whereas the Ares V design makes extensive use of existing elements, or straightforward modifications of existing elements, which are also common to Ares I. The Shuttle-derived launch vehicle architecture selected by NASA meets all of the goals and objectives to achieve the exploration mission, while also:

- Providing the best possibility of meeting stakeholder and customer requirements, including legal mandates, within the funding available and timeframe desired;
- Providing the safest, most reliable and cost effective launch vehicle for NASA missions;
- Maximizing leverage of existing, human rated systems and infrastructure;
- Leveraging collaboration between the retiring Shuttle Program and emerging Constellation projects by sharing lessons learned and transitioning valuable resources, ranging from a specialized workforce to a unique launch infrastructure;
- Creating the most straightforward growth path to later Exploration launch needs; and
- Ensuring the industrial base for production of large solid rocket systems, high performance liquid engine systems, large lightweight stages and critical, large scale launch processing infrastructure.