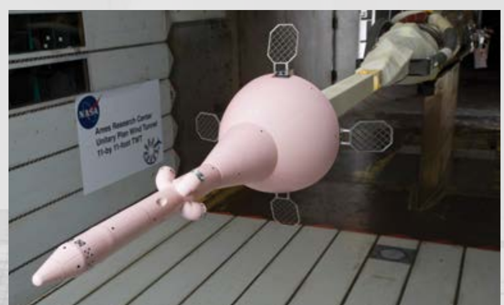
Changing the Shape of Launch Abort Systems

In December 2014, NASA's Orion Multi-Purpose Crew Vehicle (MPCV) Program successfully conducted Experimental Flight Test-1 (EFT-1), the first orbital flight test of the Orion spacecraft. Close observers may have noted that the spacecraft had an updated shape from the concepts included on the previous Ares I-X and Orion Pad Abort 1 flight tests. In reality, the Orion crew module (CM) shape has not changed substantially since these flights, but the Orion Launch Abort System (LAS) has changed.



Above: ALAS fairing mounted atop a United Launch Alliance Delta IV Heavy Rocket for the EFT-1 launch. *Below:* After developing the ALAS shape, the NESC performed further testing in the ARC Unitary Plan Wind Tunnel to investigate stability augmentation provided by grid fins.

Reducing structural loads

In September 2006, during a peer review of the NESC Composite Crew Module (CCM) Assessment, an Alternate Launch Abort System (ALAS) was conceived to reduce structural loads carried by the CCM during a flight abort. To further investigate the feasibility of the ALAS concept, Dr. Charles Camarda (then NESC Deputy Director for Advanced Projects) sponsored a study to evaluate promising approaches to improve overall Orion CM mission performance. This short, 5-week effort developed the concept of a multifunctional boost protective cover (MBPC) for the Orion CM, with analyses that demonstrated a system mass reduction due to the improved load transfer characteristics of the ALAS concept. An additional benefit the team discovered, which was not initially anticipated, was that the aerodynamically contoured forward fairing over the CM significantly reduced the overall launch vehicle drag – so much that the reduced drag provided even more payload-to-orbit increase than the improvement in structural load path.

Additional ALAS benefits investigated

Based on the promising phase 1 results, the NESC extended the effort designating Dr. Stephen Scotti, ALAS phase 1 lead, and Dr. David Schuster, NASA Technical Fellow for Aerosciences, to co-lead a second phase of the ALAS study team to further refine the concept. Starting in December 2006, they performed aerodynamic, structural and controls analyses, as well as a number of wind tunnel experiments, to obtain the data required to validate the concept.

"We found that adding a fairing improved the aerodynamic shape significantly," said Schuster. "It reduced drag during ascent, as well as weight by providing a separate load path around the crew module." In addition to better quantifying the aerodynamic, performance, and structural improvements, a major new focus investigated using the ALAS MBPC to reduce aeroacoustic loads on the Orion CM. "Current predictions of Orion acoustic loads far exceeded what was assumed in the design of the Orion subsystems," said Scotti. "And the project hoped that the ALAS approach would help solve that problem and eliminate the need to redesign and requalify all the subsystems."

The team developed a suite of aerodynamic shapes for the MBPC from a simple conic that would be easy to manufacture to the final Sears-Haack fairing offering the greatest drag reduction. A diverse family of ALAS configurations were evaluated using high fidelity computational fluid dynamics simulations in concert with wind tunnel testing. In total, 11 ALAS designs were evaluated along with 10 revisions to the 11th ALAS concept. Each design offered its own level of performance, stability, and acoustic advantages, but there were tradeoffs. For example, improvements in performance in some of the designs added additional complexity with the addition of fins and ducted abort motors. "The combination of high fidelity fluid dynamics analyses and the wind tunnel tests was essential to the design process because it positively identified the sources of noise in the flow" said Scotti. "We didn't have that capability during Apollo. Now instead of blindly trying design modifications, we knew exactly what changes would help and where to make them."

Mercury and Apollo spacecraft used launch abort towers without aerodynamically and structurally beneficial fairings.

The third revision of ALAS 11 made the final cut with the Orion MPCV Program and became the baseline configuration for the LAS design. Though other designs had higher performance improvements, ALAS 11 was a good compromise that offered considerable aeroacoustic load relief. “That’s the one that could fly without fins, yet remain controllable, and offer aeroacoustic protection and aerodynamic benefit. It was also relatively easy to incorporate,” said Schuster. Wind tunnel testing confirmed the ALAS-11 had the best blend of aerodynamic and aeroacoustic performance with the required launch abort vehicle stability characteristics.

In parallel to the development of ALAS, the NESC was also pursuing a towerless LAS, known as the Max Launch Abort System (MLAS), to tackle development challenges with regard to the tower design on the Orion MPCV. While those challenges were later overcome, the MLAS, based on the new ALAS shape, pushed the boundaries of the LAS design even further. ***See “Launch Abort System Evolution” - page 24.***

ALAS proven on EFT-1

Ultimately, ALAS offered benefits beyond what was expected and in December 2014, ALAS successfully flew for the first time on EFT-1. “Something that was effectively a research study became the baseline—the main geometry—for the Orion vehicle,” said Schuster, who didn’t realize back in 2006 that ALAS would help redefine the concept of the LAS at NASA. Since timing of the ALAS development didn’t mesh with either the ARES 1-X test flight or the first pad abort test for the Orion MPCV Program, “The Orion EFT-1 was the first time flying with the ALAS design,” Schuster said. This would finally allow the Orion MPCV Program and the NESC team to collect and analyze real-time flight data on the new configuration. It was a big moment for everyone involved, he said. “We could point to the top of the vehicle and say ‘We designed that shape.’” □

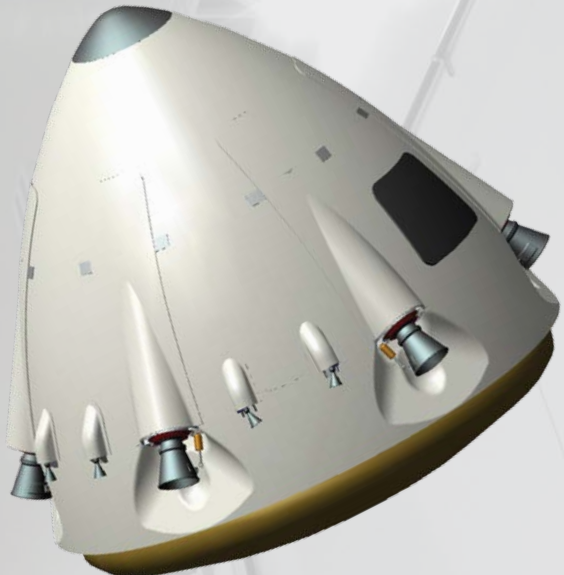
Reference NASA/TM-2014-217155

Lockheed Martin

Unpainted ALAS fairing used to protect the Orion crew module during Exploration Flight Test-1.

Launch Abort System Evolution

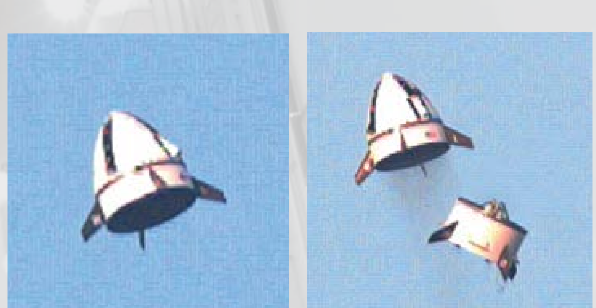
A critical component of crewed spacecraft, the launch abort system (LAS), allows for rescue of the crew in the event of a catastrophic malfunction while the spacecraft is sitting on the launch pad or on its way into orbit. For a successful rescue, however, the LAS must perform several critical maneuvers in rapid-fire succession. First, the launch abort motors must be powerful enough to fly the fairing and crew module (CM) to a safe distance away from the launch vehicle. Next, it must reorient and fly in a carefully controlled heat shield-forward attitude. Finally, it must release the CM, enabling the CM's parachute landing system to deploy for a safe return of the crew.



Propulsively stabilized MLAS concept.

LAS begins with Project Mercury

Since the time of Project Mercury and the Apollo Program, the LAS has maintained its traditional tower configuration. But as spacecraft design has evolved, so has the need for a new LAS. The Orion Multi-Purpose Crew Vehicle launched on December 4, 2014, featured a new Alternative Launch Abort System (ALAS) shape and structure that enhanced the aerodynamic and aeroacoustic performance of the spacecraft. But while the NESC was spearheading efforts on the ALAS design, it was also developing the Max Launch Abort System (MLAS), a follow-on to the ALAS design that incorporated the ALAS shape while fundamentally changing the LAS from a tower to a towerless design.



Left: Successful launch abort test of the passively stabilized MLAS flight test vehicle. *Right:* Spent test booster can be seen falling away after launch.

Named in honor of Maxime Faget, developer of the original Mercury launch escape system, MLAS was a 2-year effort that culminated in a full-scale flight demonstration. The initial goal of MLAS was to keep the ALAS advantages while pursuing a LAS concept that eliminated the tower and did not require active attitude control or stabilization following escape motor burnout. A key design constraint was avoiding structural changes to the CM if MLAS was substituted for the launch abort tower.

From napkin sketch to flight test

From a napkin sketch design drawn by the NASA Administrator at the time, which featured six side-mounted escape motors attached to the service module, the NESC team focused on key issues such as the number and placement of motors, separation dynamics, stability following motor burnout, and CM extraction from the fairing. This concept became the basis for the MLAS flight test vehicle, which would be boosted to abort test conditions to prove MLAS was passively stable, could be reoriented with parachutes, and safely release the CM for crew recovery. Launched from NASA Wallops Flight Facility in July 2009, the MLAS successfully demonstrated all flight test objectives.

During the flight test, dummy motors were incorporated into the MLAS fairing alongside the CM. This preserved space for the next flight test concept, which was to use the six abort motors with thrust vector control to perform active stabilization and eliminate the large exterior fins used on the first flight test. Thrust vector control would allow the MLAS to steer in the best direction for safety during the boost phase of an abort, then reorient for safe release of the CM. This MLAS objective system design was completed to a point where it could be built and tested if needed in the future.

More than 150 people from across NASA, as well as industry partners, had a hand in bringing the MLAS flight test to fruition, not only meeting the mission objectives, but developing and building a full-scale prototype vehicle from which invaluable experience was gleaned for future NASA projects. □