Advancing the technology readiness of SLS adaptive controls

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NASA Armstrong's highly modified F/A-18A Full Scale Advanced Systems Testbed aircraft No. 853 validated the effectiveness of the Adaptive Augmenting Controller developed by NASA Marshall engineers for the Space Launch System. Credit: NASA / Carla Thomas

Can a rocket maneuver like an airplane? And can an airplane act as a surrogate for a maneuvering rocket?

NASA engineers demonstrated just that when they used a NASA F/A-18 aircraft recently to simulate a rocket in its early flight phase to test adaptive software for NASA's new rocket the Space Launch System (SLS), the largest, most powerful launch vehicle for deep space missions.

The tests are helping engineers working on the development of the SLS at NASA's Marshall Space Flight Center in Huntsville, Ala., ensure the rocket can adjust to the environment it faces as it makes its way to space.

Engineers reviewed the root causes of historical launch vehicle failures and found that although guidance, navigation and control systems were rarely the cause of the incidents, they discovered that advancements in this technology could result in expanded capabilities to keep the rocket on track in the face of anomalies that might occur in flight.

"When NASA develops new technology for launch vehicles like Adaptive Augmenting Control, we want to test it in order to mature the technology and build our confidence in it," said Tannen VanZwieten, NASA Marshall's SLS flight control lead. "But in lieu of a launch vehicle flight test, we need to find creative ways to mature it through testing in a relevant environment.

"With our flight software, the SLS program at Marshall partnered with NASA's Engineering and Safety Center, Armstrong Flight Research Center at Edwards, Calif., and the Space Technology Mission Directorate's Game Changing Development Program to test our algorithm on a NASA F/A-18 airplane," added VanZwieten.

An early version of an adaptive control system was used on the last X-15 rocket plane that was built in the 1960s. As the X-15 reached thinning atmosphere at the edge of space, the adaptive control system automatically responded to the changing conditions by increasing the responsiveness of the control surfaces to commands.

"An adaptive control system is any type of control system that changes its parameters in flight to adjust to information that it learns about the vehicle that is different from what was predicted before flight," explained Jeb Orr of the Charles Stark Draper Laboratory.

NASA Armstrong's F/A-18A Full Scale Advanced Systems Testbed aircraft pitches up during an LVAC Adaptive Augmenting Control validation flight. Credit: NASA / Carla Thomas

"Conventional control systems are designed or 'tuned' using models on the ground," he added. "Naturally, the way the vehicle behaves in flight is never exactly the same as modeled, so the control system must be robust—that is, able to tolerate flying a vehicle that is a bit different from what the designers expect."

Large rockets like the SLS have complex computers and software that swivel the rocket engines to steer the vehicle along its flight path. NASA's new software algorithm will make real-time adjustments as the vehicle pushes toward space, helping improve performance and enhancing crew safety in the particularly stressful parts of the flight.

In November and December 2013, the team of engineers, technicians and pilots completed two series of test flights to assess the adaptive augmenting controller software planned for the rocket on a modified NASA F/A-18 at NASA Armstrong.

"The multi-center NASA team worked together seamlessly, yielding a major advance in launch vehicle flight control technology and substantially accelerating the application of adaptive control to manned systems," Orr said.

One of first project tasks for engineers at NASA Armstrong was the development of a mission trajectory that an aircraft could fly that would simulate the SLS launch. Other responsibilities were the implementation of the software on the F/A-18 and mission planning. Part of that mission plan called for the pilot to engage the adaptive controller to mitigate the simulated effects of extreme scenarios, like bending instability during the simulated rocket trajectory.

"The engineers at Marshall were developing a simple adaptive control law, and wanted to flight test it," said Chris Miller, chief engineer for the Launch Vehicle Adaptive Control (LVAC) project at NASA Armstrong. "They considered their options and the available platforms, including sounding rockets and the F/A-18. Our engineers worked with them to determine what aspects of their control law we could test in a meaningful way on the F/A-18.

"They recognized very early the importance of flight research for gaining the necessary experience, confidence, and acceptance of any new technology," added Miller. "Performing that kind of research in flight is part of our DNA at NASA Armstrong, and we were excited to contribute our capabilities and skills to help the Marshall team test their technology on our F/A-18 aircraft."

In one of the innovative tests, the F/A-18 flew a sequence of test points that maximized the bending excitation of the actual airplane based on data collected from earlier flights and prior structural tests. The bending response was isolated and the key features were reproduced in simulation, allowing the control variables to be modified accordingly to induce a real structural instability that the adaptive controller would have to mitigate.

NASA Armstrong research test pilot Jim Less climbs aboard the center's F/A-18A Full Scale Advanced Systems Testbed for one of the Launch Vehicle Adaptive Control test flights. Credit: NASA / Tom Tschida

Subsequent tests used that data to intentionally place the airplane in structural resonance, which causes the aircraft to vibrate while in flight. The adaptive augmenting control system then responded to these vibrations, suppressing them when they were large, meeting one of the major objectives of the adaptive controller.

The adaptive controller experiment was tested on six research flights.

During these flights, almost 100 SLS trajectories and over a dozen straight-and-level airframe structural amplification tests were successfully executed, many of which were to collect additional data regarding the interaction of the pilot, the simulated SLS vehicle dynamics, and the adaptive augmenting control algorithm.

"The goal of the F/A-18 flights was to advance the technology readiness of the SLS adaptive control design by operating it in a relevant environment while introducing a wide variety of unusual launch scenarios," said Curtis Hanson, NASA Armstrong's principal investigator for the project.

"These tests helped to validate the Marshall team's design philosophy that the controller only adapts when necessary, and that it works to maintain acceptable trajectory tracking and structural resonance characteristics throughout a wider operational envelope than the traditional design alone," Hanson added. "The tests also helped to identify any adverse interactions between the pilot and the adaptive controller in a proposed manual steering mode for the SLS."

Collaborative efforts among the different NASA organizations is one of the ways the Space Technology Mission Directorate is seeking to rapidly develop and demonstrate high-payoff technologies that potentially offset mission risk, reduce costs and advance enabling technologies for NASA.

"Space Technology's Game Changing Development Program is happy to work with NASA centers on innovative technology development, such as the LVAC work," said Stephen Gaddis, Game Changing Development program manager. "We are expecting the results to aid in the control algorithms for NASA's Space Launch System."

Provided by NASA

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