USAF Test Pilots School Vets Safer Adaptive Flight Controller

Guy Norris *Aviation Week & Space Technology*

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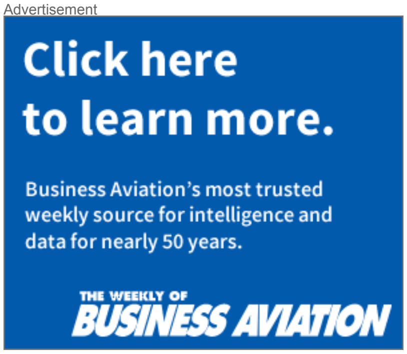
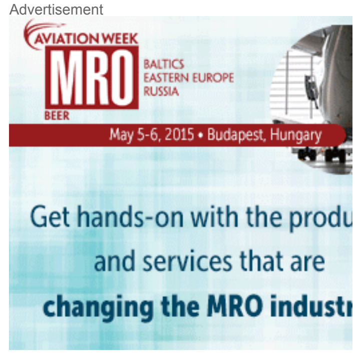


An adaptive flight controller that could help pilots save a critically damaged or out-of-control aircraft is being proposed for possible commercial development following a rigorous evaluation by U.S. Air Force Test Pilots School (TPS) students here, using Calspan's variable-stability Learjet 24 test aircraft.

The L1 controller is designed to automatically intervene in the case of control problems, immediately reconfiguring the flight control system to compensate for degraded flying qualities from mechanical failure or battle damage to a control surface, or even the unintended result of shifting center-of-gravity inflight for better cruise performance. Acting as a backup to the standard flight control system, the L1 is designed to provide safe, predictable, reliable and repeatable responses that would free up pilots to deal with the emergency and further compensate for reduced performance.

In development for more than a decade by researchers at the University of Illinois at Urbana-Champaign, the L1 controller architecture differs from most previous approaches to adaptive control systems. Until now, the standard has been gain-scheduled control systems in which the flight control computer selects the appropriate preprogrammed gains to suit current flight conditions and vehicle configuration. However, the L1 works in real-time to predict transient behavior and estimates lumped uncertainties, rather than every individual parameter that can affect system dynamics; it compensates for them within the bandwidth of a control channel.

The L1 controller comprises three blocks: a state predictor, a fast estimation scheme and a control law. The fast estimation scheme includes a state predictor and a fast estimation law which together approximate the dynamics of the aircraft to generate estimates of the uncertainties. These estimates are provided as input to a bandwidth-limited filter which generates a control signal to the flight control system.



Tests of the controller in Calspan's variable-stability Learjet included dealing with roll-coupled yaw while simulating a lifting body and high adverse aileron yaw while replicating an F-100 Super Saber. Credit: Calspan

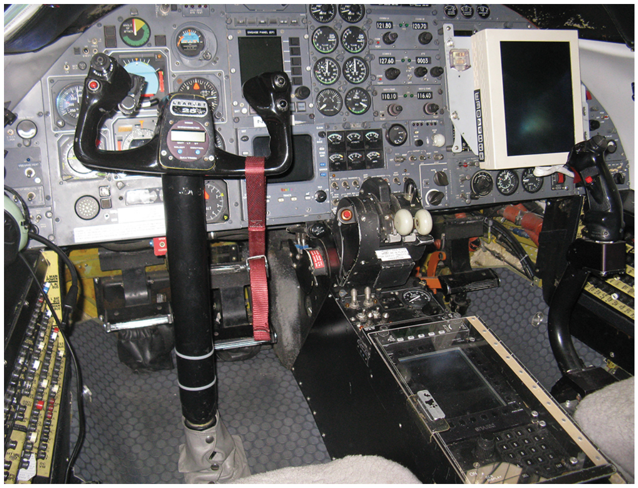
Unlike other adaptive controllers that use the estimated values of uncertain parameters directly as control gains, the L1 system decouples the estimation loop from the control loop. This architectural change, which is achieved through the presence of the bandwidth limited filter in the control structure, avoids the high-gain response of earlier adaptive systems, making it safer, robust and easier to certificate, say developers.

"We can quantify ahead of time the transient steady-state performance specification and robustness margin in an aircraft and set guidelines for the trade-off between performance and robustness and the adaption piece," says TPS Flying Qualities Master Instructor Chris Cotting. "If I have a stability augmentation system I can make it incredibly stable but not very maneuverable, or very maneuverable but not very stable. L1 [allows you] to make those kinds of trades with this adaptive controller."

L1 development from theory to flight test has been led by Naira Hovakimyan, a professor of mechanical science and engineering at Illinois, who worked on the concept under Air Force funding between 2004 and 2008 at Virginia Tech with postdoctoral fellow Chengyu Cao (now at the University of Connecticut). The TPS evaluation was the first time the controller had been flown on a manned aircraft and was a vital step toward implementing L1 as a flight safety system, says Hovakimyan. "This is just a pure flight control system like an autopilot, but you can augment it with additional features such as envelope protection, different pilot interfaces and so on." NASA is funding that endeavor, "and now we are focused on revolutionizing the fight control system of commercial aviation."

Although studies into adaptive flight control systems in the U.S. go back to the X-15 program in the late 1950s, the L1 originated with lessons learned from the Boeing/Air Force Research Laboratory X-36 Restore program, says Hovakimyan. Under this effort, which ran from 1996 to 1999, researchers attempted to stabilize an unstable, tailless unmanned air vehicle (UAV) with several simulated control-system failures.

"Predictability is the key word," Hovakimyan says. "In the Restore program, when they tested it with adaptive controllers they didn't know how to tune it. It was stable but not predictable and every time they got different transients. Adaptation can help, but the architecture itself had deficiencies. It was good for slow adaptation but it was not correctly structured to maintain robustness in the presence of fast adaptation." Subsequent studies focused on development of a fast-adapting controller that could also maintain robustness. "That's what we nailed down architecturally," she adds.



The L1 was evaluated by the pilot in the right seat using a joystick. The left seat, with the conventional Learjet controls, is for the safety pilot. Credit: Guy Norris/AW&ST

The L1 was flown for the first time in 2006 in the Rascal UAV at the Naval Postgraduate School and again starting in 2009 when NASA evaluated the controller on the AirSTAR Dynamically Scaled Generic Transport Model research aircraft. In 2011, L1 was tested on the Simona motion-based research simulator at the Delft University of Technology in the Netherlands. Versions of the L1 controller are used in marine autopilots and industrial machines, and are being studied for UAVs and missiles.

Flight tests were conducted at Edwards AFB under one of the school's Test Management Projects, which provide students and staff with the opportunity for short-duration, real-world flight tests. Industry, academia or other military customers provide the research concept and any required funding while the school provides test aircraft, a team of test pilots and engineers as well as resources ranging from the Edwards airspace to flight-test data and analysis (*AW&ST* Dec. 1/8, 2014, p. 57).

Testing was conducted over two weeks in February and March on a Calspan Learjet 25D modified with a variable stability simulator (VSS). This feature changes the apparent stability of the aircraft, allowing it to be used as an inflight simulator of other aircraft types. The L1 was overlaid on top of the VSS, which simulated various aircraft in up-and-away flight at 250 kt. and 15,000 ft., and powered approach with gear down and flaps at 20 deg. If the Learjet approached dangerous flight conditions, a series of safety trips disengaged the VSS, returning control to the safety pilot in the left seat.

"The VSS puts in the good or bad dynamics we want, and the L1 was designed to restore the reference set," says Cotting. "If we make the VSS better than the L1, it will degrade it to the reference model, or if we make it worse, the L1 will make it better," he adds. Students assessed flying and handling qualities over 14 hr. of test time at the two test conditions, as well as measured the robustness of the adaptive controller. Data also was collected for offset approaches and straight-in landings.

Specific failures—applied either individually or in combination—included reduced pitch damping, aft center of gravity for neutral static longitudinal stability, reduced yaw damping, high adverse and proverse aileron yaw, reduced roll damping and a coupled roll-spiral mode. During simulations of a lifting body, the L1 overcame lateral direction and oscillation control issues, and while representing an F-100 Saber at high angles of attack, the system enabled normal roll control.

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