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Adaptive Augmenting Control Flight Characterization Experiment on an F/A-18

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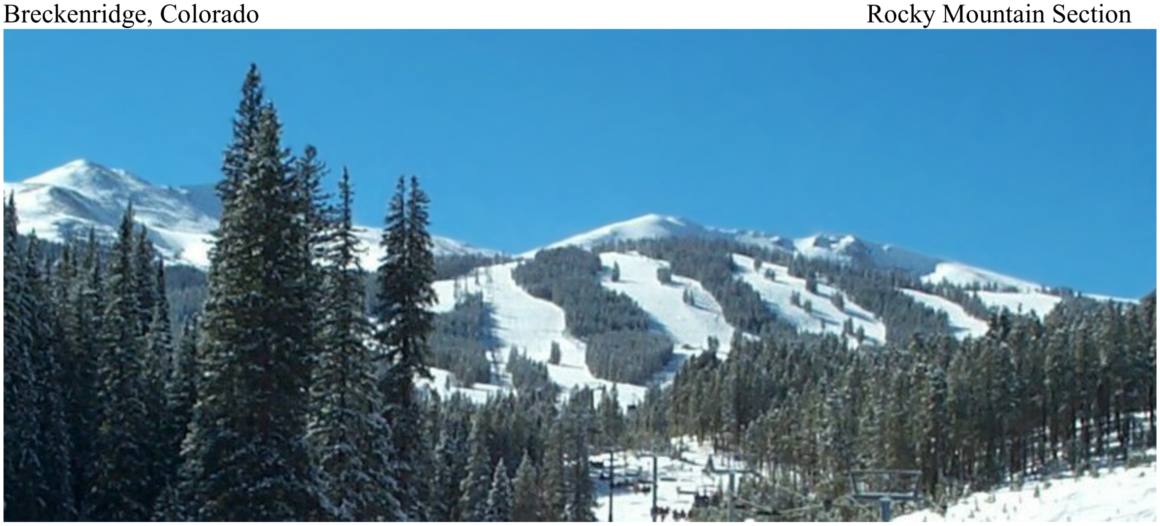

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Abstract

This paper summarizes the Adaptive Augmenting Control (AAC) flight characterization experiments performed using an F/A-18 (TN 853). AAC was designed and developed specifically for launch vehicles, and is currently part of the baseline autopilot design for NASA's Space Launch System (SLS). The scope covered here includes a brief overview of the algorithm (covered in more detail elsewhere), motivation and benefits of flight testing, top-level SLS flight test objectives, applicability of the F/A-18 as a platform for testing a launch vehicle control design, test cases designed to fully vet the AAC algorithm, flight test results, and conclusions regarding the functionality of AAC.

The AAC algorithm developed at Marshall Space Flight Center is a forward loop gain multiplicative adaptive algorithm that modifies the total attitude control system gain in response to sensed model errors or undesirable parasitic mode resonances. The AAC algorithm provides the capability to improve or decrease performance by balancing attitude tracking with the mitigation of parasitic dynamics, such as control-structure interaction or servo-actuator limit cycles. In the case of the latter, if unmodeled or mismodeled parasitic dynamics are present that would otherwise result in a closed-loop instability or near instability, the adaptive controller decreases the total loop gain to reduce the interaction between these dynamics and the controller. This is in contrast to traditional adaptive control logic, which focuses on improving performance by increasing gain.

The computationally simple AAC attitude control algorithm has stability properties that are reconcilable in the context of classical frequency-domain criteria (i.e., gain and phase margin). The algorithm assumes that the baseline attitude control design is well-tuned for a nominal trajectory and is designed to adapt only when necessary. Furthermore, the adaptation is attracted to the nominal design and adapts only on an as-needed basis (see Figure 1). The MSFC algorithm design was formulated during the Constellation Program and reached a high maturity level during SLS through simulation-based development and internal and external analytical review.

The AAC algorithm design has three summary-level objectives:

1. "Do no harm;" return to baseline control design when not needed.
2. Increase performance; respond to error in ability of vehicle to track commands.
3. Regain stability; respond to undesirable control-structure interaction or other parasitic dynamics.

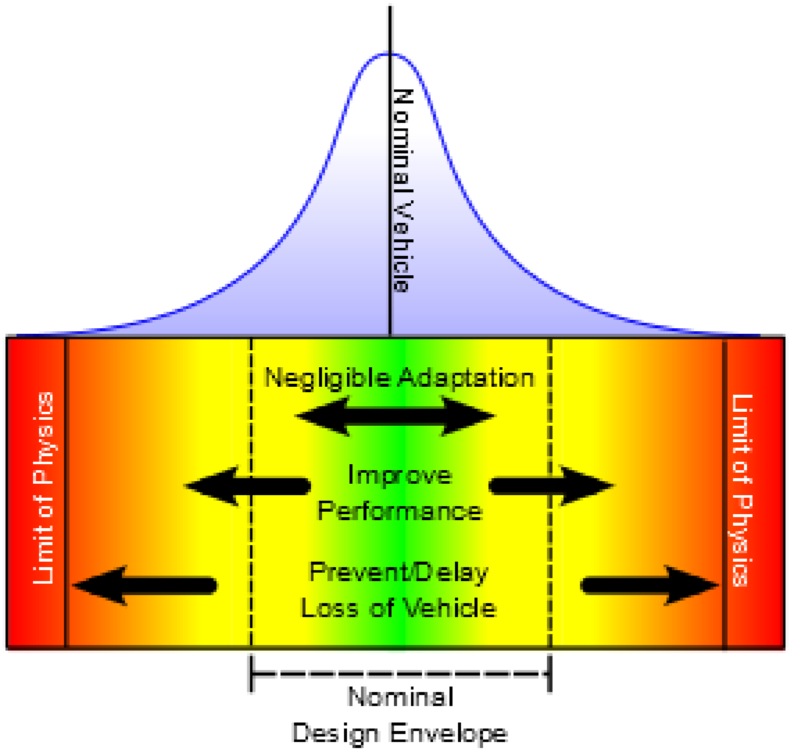

Figure 1. The AAC Algorithm Design Paradigm is Adaptive on an As-needed Basis

AAC has been successfully implemented as part of the Space Launch System baseline design, including extensive testing in high-fidelity 6-DOF simulations the details of which are described in [1].

The Dryden Flight Research Center's F/A-18 Full-Scale Advanced Systems Testbed (FAST) platform is used to conduct an algorithm flight characterization experiment intended to fully vet the aforementioned design objectives. FAST was specifically designed with this type of test program in mind. The onboard flight control system has full-authority experiment control of ten aerodynamic effectors and two throttles. It has production and research sensor inputs and pilot engage/disengage and real-time configuration of up to eight different experiments on a single flight. It has failure detection and automatic reversion to fail-safe mode. The F/A-18 aircraft has an experiment envelope cleared for full-authority control and maneuvering and exhibits characteristics for robust recovery from unusual attitudes and configurations aided by the presence of a qualified test pilot.

The F/A-18 aircraft has relatively high mass and inertia with exceptional performance; the F/A-18 also has a large thrust-to-weight ratio, owing to its military heritage. This enables the simulation of a portion of the ascent trajectory with a high degree of dynamic similarity to a launch vehicle, and the research flight control system can simulate unstable longitudinal dynamics. Parasitic dynamics such as slosh and bending modes, as well as atmospheric disturbances, are being produced by the airframe via modification of bending filters and the use of secondary control surfaces, including leading and trailing edge flaps, symmetric ailerons, and symmetric rudders. The platform also has the ability to inject signals in flight to simulate structural mode resonances or other challenging dynamics. This platform also offers more test maneuvers and longer maneuver times than a single rocket or missile test, which provides ample opportunity to fully and repeatedly exercise all aspects of the algorithm.

Prior to testing on an F/A-18, AAC was the only component of the SLS autopilot design that had not been flight tested. The testing described in this paper raises the Technology Readiness Level (TRL) early in the SLS Program and is able to demonstrate its capabilities and robustness in a flight environment.

REMARK: FLIGHT TEST SCHEDULED TO COMMENCE ON 27 AUG 2013, WITH THE 4-5 TESTS SCHEDULED TO BE COMPLETED BY THE END OF SEPTEMBER 2013. THIS SHOULD PROVIDE ADEQUATE TIME FOR INCLUSION OF THE FLIGHT TEST RESULTS IN THE PAPER.