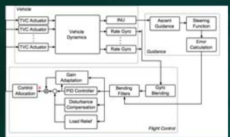
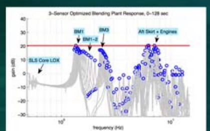
NASA Marshall Space Flight Center
Control Systems Design and Analysis Branch

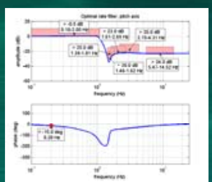
Launch Vehicle Dynamics and Control

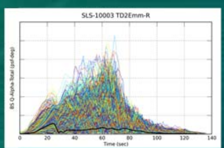
Advanced Dynamics

Marshall Space Flight Center maintains a critical national capability in the analysis of launch vehicle flight dynamics and flight certification of GN&C algorithms. MSFC analysts are domain experts in the areas of flexible-body dynamics and control-structure interaction, thrust vector control, sloshing propellant dynamics, and advanced statistical methods. Marshall's modeling and simulation expertise has supported manned spaceflight for over 50 years.


SLS Flight Control System


Structural Dynamics


Filter Optimization


Monte Carlo Analysis

Guidance, Navigation, and Control

Marshall's unparalleled capability in launch vehicle guidance, navigation, and control technology stems from its rich heritage in developing, integrating, and testing launch vehicle GN&C systems dating to the early Mercury-Redstone and Saturn vehicles. The Marshall team is continuously developing novel methods for design, including advanced techniques for large-scale optimization and analysis.

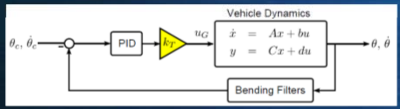
Advanced Control System Development

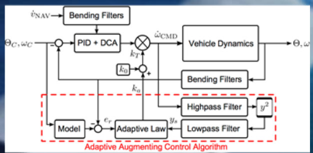
Adaptive Augmenting Controller Overview

The NASA Marshall Space Flight Center (MSFC) Flight Mechanics and Analysis Division developed an Adaptive Augmenting Control (AAC) scheme for launch vehicles that improves robustness and performance by adapting an otherwise well-tuned classical control algorithm to unexpected environments or variations in vehicle dynamics.

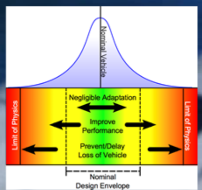
The philosophy that drove the formulation of the AAC algorithm was first and foremost to maintain nominal system performance and be compatible with classical stability criteria. The algorithm provides additional robustness using a simple architecture that can help recover from poor performance and prevent or delay aborts in extreme off-nominal conditions.

The AAC algorithm 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.





Control System Block Diagram with AAC

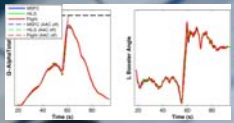


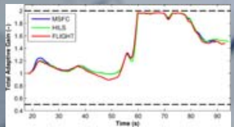
AAC Flight Regions

$$\dot{k}_T = p_{hi}(k_T)ae_r^2 - p_{lo}(k_T)\alpha y_s - \beta(k_T - 1)$$

Adaptive Law


NASA 853 Full-Scale Advanced Systems Testbed


Flight variables during extreme simulated low performance


Gain adaptation to increase performance

Flight Testing of the Adaptive Augmenting Controller

The Space Launch System (SLS) flight software prototype, including the adaptive component, was recently tested on a piloted F/A-18 aircraft at Dryden Flight Research Center (DFRC). Dryden's advanced technology for in-flight dynamic simulation on the Full-Scale Advanced Systems Testbed (FAST) was leveraged to conduct an extensive risk-reduction flight campaign. Scenarios were designed specifically to evaluate the AAC algorithm and ensure its ability to achieve the expected performance improvements with no adverse impacts in both nominal and off-nominal scenarios. Marshall developed an in-flight SLS model such that the controller "thought" it was flying SLS. 102 launch vehicle-like trajectories over six flight tests were completed in November and December 2013 at DFRC. All test objectives were successfully met and the AAC algorithm's capability, robustness, and reproducibility have been successfully demonstrated.

Robotic Lander Test Bed

Mighty Eagle Warm Gas Test Article

The Mighty Eagle Warm Gas Test Article (WGTA) is a robotic lander testbed based at the Marshall Space Flight Center that is used to inexpensively test algorithms and sensors that could be implemented in future space programs. Originally designed and built in 2010 to support risk reduction of the International Lunar Network program, the vehicle has been adapted for additional testing of optical Autonomous Rendezvous and Capture technology as well as Hazard Avoidance software using an off-the-shelf stereo camera system.

The WGTA's propulsion system (mono-propellant, pressure regulated) uses 90% pure hydrogen peroxide and silver screen catalyst beds to achieve flight times of around 45 seconds. The lander, about the size of a pool table, weighs ~200 kg dry and ~300 kg with a full load of fuel and has 16 thrusters: 12 Attitude Control System (ACS) thrusters that orient the vehicle, 3 Descent thrusters that are responsible for vertical velocity control and 1 Earth Gravity Cancelling (EGC) thruster. The EGC continuously throttles to offset 5/6ths of the vehicles weight as fuel is burned in order to simulate lunar gravity, 1/6th that of Earth.

Spacecraft GN&C

Advanced On-Orbit Guidance, Navigation, and Control

Marshall Space Flight Center's guidance, navigation, and control expertise extends to the support of orbital mission operations, including trajectory optimization, autonomous rendezvous and docking (AR&D), on-orbit control system algorithm design, analysis of low-G propellant slosh, navigation analysis, and the development of novel and enabling guidance algorithms for emerging mission concepts such as asteroid rendezvous and autonomous on-orbit assembly. Marshall expertise is backed by a rich heritage of supporting manned orbital missions, including Apollo, Shuttle, and the International Space Station.


Interim Cryogenic Propulsion Stage (ICPS) and the Orion Multi-Purpose Crew Vehicle (MPCV)

CubeSat Integration and Testing


Portable SPRITE hardware-in-the-loop simulation

Small Projects Rapid Integration & Test Environment

The Small Projects Rapid Integration & Test Environment (SPRITE) Lab at Marshall Space Flight Center aids in the development and verification of cubesat flight software in a real-time simulation. Engineers at SPRITE partner with universities and other third parties to provide cubesat expertise and simulation capabilities.

SPRITE has a modular, layered design that evolved from the Systems Integration Laboratory (SIL), developed for Ares I and SLS for avionics and software integration and testing. This design supports rapid reconfiguration for satellites and robotic systems. SPRITE's plant models, algorithms, and flight software development is based on experience with the Fast, Affordable, Science & Technology Satellite (FASTSAT).

A portable version of SPRITE's hardware-in-the-loop simulation capability has been developed. It is in the form factor of a small suitcase and can thus be taken to the customer's location. In addition, the SPRITE's hardware can be customized to meet the customer's flight computer hardware interfaces.

Flight Robotics Lab

Flight Robotics Laboratory Overview

The Flight Robotics Lab (FRL) at Marshall Space Flight Center provides a full scale, integrated simulation capability for the support of the design, development, integration, validation, and operation of orbital space vehicles.

The FRL is built on developed technologies such as air bearing floors, servo drive overhead robotic simulators, precision targets, gimbals, 6 degrees-of-freedom mobility units, and a manipulator and visual system evaluation facilities.

The facility is centered around a 44' x 86' precision air bearing floor – the largest of its kind.

Small and large air sleds are used on the air bearing floor. The air sleds hold a 400 lb. payload. An 8 DOF overhead gantry, called the Dynamic Overhead Target Simulator, provides an 800 lb. payload capability for simulating relative motion with respect to a fixed target on the facility floor. A computer system provides inverse kinematics and allows the gantry to act as a target or as the 6 DOF rendezvous vehicle. The target reaction dynamics are simulated through force/torque feedback from sensors mounted at the payload interface.


Flight Robotics Lab and precision floor


Air bearing spacecraft simulator