Autonomous Flight Safety System – Phase III

Decision/Data Models and Analysis

The Autonomous Flight Safety System (AFSS) is a joint KSC and Wallops Flight Facility project that uses tracking and attitude data from onboard Global Positioning System (GPS) and inertial measurement unit (IMU) sensors and configurable rule-based algorithms to make flight termination decisions. AFSS objectives are to increase launch capabilities by permitting launches from locations without range safety infrastructure, reduce costs by eliminating some downrange tracking and communication assets, and reduce the reaction time for flight termination decisions.

The AFSS flew on a Terrier Improved-Orion two-stage sounding rocket at White Sands Missile Range on April 5, 2006. Two GPS sensors and two independently programmed processors were used, each with a different set of mission rules. The mission rules set for one processor were configured so that a nominal flight would not result in any flight termination actions. The mission for the other processor included three additional rules so that multiple destruct activations would occur during a nominal flight. Because the AFSS was not connected to a flight termination system, it could not initiate any destruct actions.

Preflight loading and verification went smoothly. However, the Ashtec G12 GPS receiver lost lock on liftoff and did not regain it until after the flight was over. The Javad GPS receiver maintained lock throughout the flight. The rocket behaved nominally, the nominal processor did not execute any unplanned destruct actions, and the errant processor successfully initiated three destruct actions as planned. Both processors provided navigation and status messages to observers via the vehicle telemetry stream. These messages were also stored in the nominal processor's nonvolatile (flash) memory for the entire operation. The errant processor's flash memory chip became partially dislodged during the flight and stopped recording at T+335 s. Otherwise, the system performed as expected.

An improved AFSS test article flew on the SpaceX Falcon 1 from the Kwajalein/Reagan Test Site on March 21, 2007. The test item consisted of a single chassis with redundant flight processors, a custom-built voting circuit, a power supply module, and a GPS receiver. An externally mounted GPS receiver and a 10-W Low-Cost Tracking and Data Relay System (TDRS) Transceiver (LCT2) for a space-based range demonstration were also flown. The LCT2 was to transmit the status messages from one of the processors and the messages from the other processor were transmitted in the vehicle telemetry stream. Unfortunately, a concern was raised on launch day that the LCT2 might interfere with the vehicle GPS, and the Falcon 1 launch management team decided to fly with the LCT2 powered off. This meant that data from only one of the processors was available for postflight analysis.

First AFSS sounding rocket test flight.

Even with the loss of the LCT2 data, the AFSS met all the minimum success criteria. These included performing properly before the launch, maintaining at least one GPS solution, transmitting valid navigation data from at least one GPS receiver, transmitting mission rule evaluation status from at least one processor for the entire flight, and evaluating the full set of mission rules on at least one processor from launch to orbit insertion (or end of flight).

Falcon 1 launch vehicle at liftoff.

An anomaly in the navigation solution of the externally housed GPS receiver, caused when marginal satellites swapped in and out of track, led one processor to improperly flag first-stage burnout and second-stage ignition events. Because of a setup error, the system used the elapsed time from second-stage ignition as the time reference for tabulated, moving-gate coordinates instead of time from launch. These errors caused the two processors to issue ARM/FIRE commands at different times. In the future, acceleration data from one or more IMUs will be used for in-flight ignition and burnout event detection. Despite these anomalies, the inability to use the LCT2, and the rocket's failure to reach its desired orbit, the testing was a valuable experience and will lead to an improved AFSS.

Continuing efforts to improve the AFSS include making the chassis more rugged, formalizing the requirements and design, and adding a loosely coupled GPS/Inertial Navigation Solution (INS) to improve the reliability of the AFSS sensor suite. A prototype of this GPS/INS was flown on an F-104 at Kennedy Space Center on November 8, 2007. The equipment was integrated on the F-104 and recovered undamaged, but the GPS receiver did not function properly for reasons still being investigated. Consequently, the data collected was not sufficient to determine how the GPS/INS system performed. A second set of flights is planned for 2008.

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