NASA's Top Model

Subscale UAV for test flights under extreme conditions

Aerobatic displays thrill spectators with maneuvers that push the aircraft to their limits. NASA is researching even more extreme flight situations with its unmanned aerial vehicle (UAV).

At its Airborne Subscale Transport Aircraft Research facility, called AirSTAR for short, NASA is using an unmanned aerial vehicle (UAV) to study flight situations that would be too dangerous and too expensive with a real aircraft. The role of the flight control computer is played by a dSPACE system which communicates by radio.

Scaling Effects: Smaller, Stronger, Faster

In an effort to improve aviation safety, engineers at NASA are looking to understand flight dynamics in abnormal and upset conditions and design automation systems that can help to maintain safe controlled flight. Loss of control can occur when events such as structural damage, hydraulic failures, or icing build-up have so changed the vehicle's performance that traditional autopilots fail and pilots are faced with highly coupled controls and oscillatory or even divergent handling characteristics. To study these flight conditions, a subscale UAV was designed and integrated with a highly automated ground station for piloted testing. Because the UAV is scaled down to 1:18 the size of a full-scale transport aircraft, the test model responds much more quickly to pilot inputs than a full-scale vehicle. However, with a careful structural design that scales the mass distribution and density along with the geometry, these subscale vehicles retain the dynamic coupling and response characteristics of the full-scale system. Flight test results from these vehicles can be scaled in time (by the square root of the scale factor) to predict full-scale dynamic behavior. This retains relevance to the target application of commercial transport aircraft, but allows experiments to be conducted which have more risk and may incur much larger structural loads than would be feasible on a full-scale aircraft.

Figure 1: Test flights with the UAV (here in front of the mobile ground station) serve to optimize the functions for flight control computers in passenger planes.

1. Navigation display, top-down view of location, heading and range limits
2. Aircraft configuration display, surface positions, engine settings, and test-card details and system status indicators
3. Primary heads-up display, a synthetic, out-the-window view overlaid with airspeed, altitude, g-load, flight-path information, and warning indicators
4. Secondary NAV display (redundant for safety)
5. Secondary HUD display (redundant for safety)
6. Analog ground-based tracker camera view
7. Analog in-flight nose camera view
8. Discrete mode selection switches, to invoke failure emulation and control algorithms

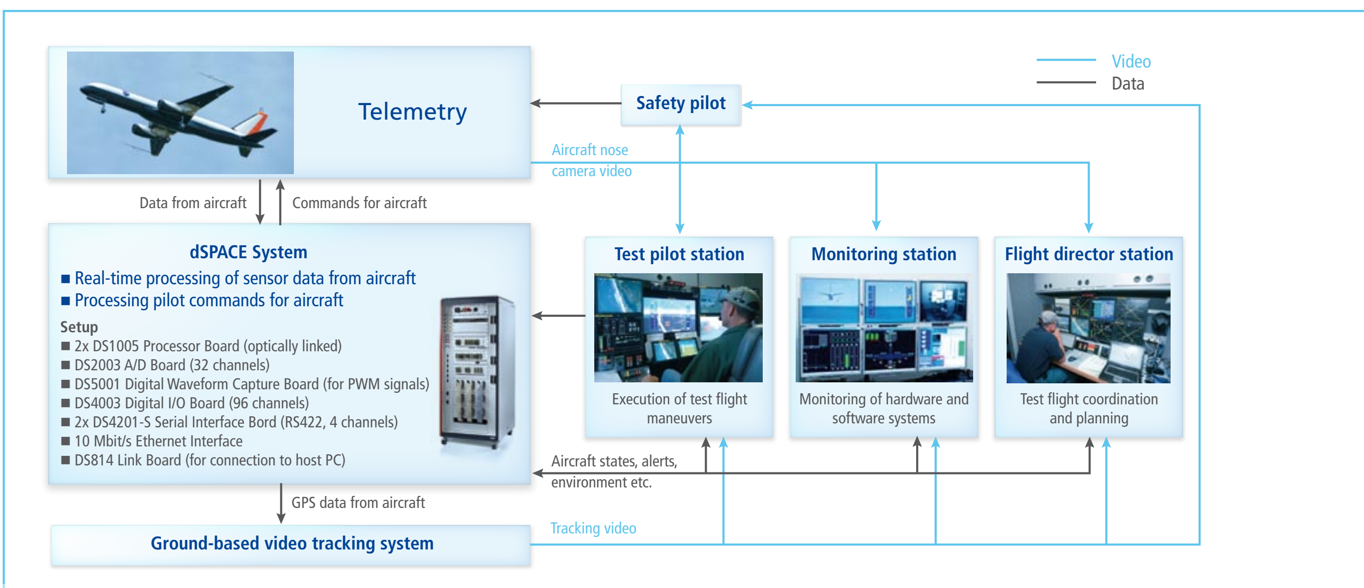
Figure 2: The test pilot's station. Communicating with the UAV by radio, the dSPACE system performs all the ongoing real-time computation tasks so that the test pilot can fly any desired maneuvers realistically from the ground.

Flight Control with the dSPACE System

Although the aircraft is small, the algorithms NASA is interested in testing can be quite large. Advances in control theory and real-time system identification are typically made at the researcher's desktop, with algorithm prototypes implemented in a model-based simulation tool like MATLAB®/Simulink®. One goal of the AirSTAR program was to reduce the amount of time required to rehost these algorithms to a real-time system for flight testing and provide ample computing power for researcher code. By doing this rehosting process quickly, it is possible to provide real-world test results during an early stage of technology development, where they can inform and influence the direction of ongoing research. This capability was provided by employing a dSPACE system on the ground that communicates with the vehicle over a high-bandwidth telemetry link.

In addition to the UAV itself, the AirSTAR test facility includes a mobile ground station for piloting and monitoring the vehicle. The ground station's computer systems consist of a multi-CPU dSPACE unit and several connected workstations for display generation and data logging. One CPU of the dSPACE system has the "ship systems", which handle pilot inputs (discrete, analog and PWM I/O), manage the telemetry stream to and from the aircraft (RS422 serial), and calibrate and process data to drive real-time displays (UDP). The second dSPACE CPU is dedicated to research control algorithms which are invoked during the flight under both nominal and failed vehicle configurations. These control algorithms are routinely swapped out for different flight experiments, and implement code developed and prototyped in Simulink using a simulation model for

Figure 3: Schematic of the mobile AirSTAR test facility. The flight control system installed on the dSPACE system receives telemetric data from the UAV and sends pilot commands and other parameters to the UAV. For a closer look at one of the three control stations (the test pilot station), see figure 2.



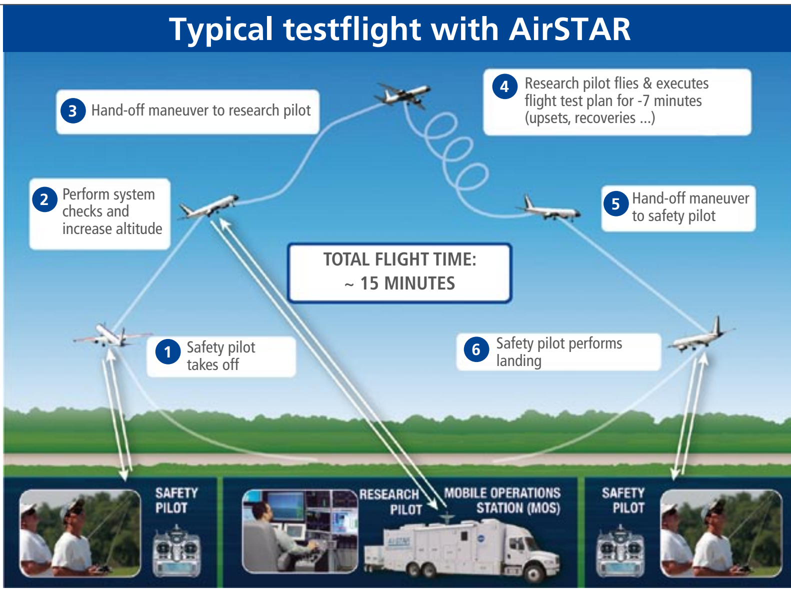


Figure 4: A typical test flight procedure. The main focus is on investigating loss-of-control scenarios and appropriate recovery maneuvers.

the vehicle. The use of a secondary CPU for this code not only provides a high level of computing power but also allows the master CPU to monitor and isolate any software faults, including code lockup, segmentation faults, or unbounded behavior, and automatically revert to a ship-system controller. The telemetry stream provides over 70 channels of raw data at 200 Hz, but with real-time calibrations, corrections and the calculation of derivative variables, this data set grows considerably. Over 500 variables at 200 Hz are streamed to disk via the dSPACE host PC optical link, including 75 variables provided to document internal variables to study the control algorithms during flight. This data set is available as a MATLAB file within minutes of landing, providing researchers with an opportunity to understand test results and if necessary modify test plans during flight test deployment.

A Typical Test Flight Procedure

The UAV can make flights lasting about 15 minutes. A second pilot, the safety pilot, in visual contact with the vehicle, performs the take-off and landing phases, and hands off the UAV to the test pilot only after a specific altitude has been reached. The test pilot runs through the flight program in the remaining time, piloting the vehicle from the simulator-like displays in the mobile ground station. As part of the NASA Aviation Safety Program, the declared aim of the test flights is to especially analyze what are called loss-of-control scenarios – extreme flight situations combined with the failure of onboard systems – and to evaluate suitable recovery maneuvers. The test pilot can choose to fly with the support of the flight control system or without it. He or she can also feed in freely configurable failure scenarios, which lock up control surfaces or destabilize the vehicle's dynamic response. To avoid exceeding the UAV's structural strength, a load protection algorithm monitors thrust and control surface settings and can limit inputs in emergency situations. In addition, the safety pilot always has overriding control of the test flight – the ability to intervene at any time and take over control of the UAV from the test pilot.

> "The dSPACE system provides the performance required by the complex real-time computations during test flights with the UAV."
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> *Tommy Jordan, NASA Langley Research Center*

Summary and Outlook

NASA uses the AirSTAR test facility to perform test flights with a UAV for investigation of abnormal flight situations, including loss of control, that cover a large proportion of fatal accidents in commercial aviation. The ground-based flight control system is implemented as a dSPACE system. It processes the measurement values collected by the UAV and also the test pilot's flight commands in real time, supports the generation of data for flight displays, and records test data for post-flight analysis. Future plans for the system include an expansion of test conditions, algorithm complexity, and the introduction of different vehicles into the system. Due to its flexible design, the ground processing system can accommodate these changes with very little modification to its architecture and software. ■

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