

Gulfstream Aerospace Develops Pilot-in-the-Loop Aircraft Simulator with MathWorks Tools

Using flight tests to assess flight-control architectures, evaluate digital control law implementations, and develop advanced flight displays is both costly and time-consuming.

Engineers at Gulfstream Aerospace tackled these problems by using MathWorks tools to develop a pilot-in-the-loop aircraft simulation laboratory. The lab includes a cockpit emulator with pilot interfaces, flight-control displays, and window views. The controls and displays are linked to a real-time simulation based on high-fidelity Simulink® models of aerodynamic and engine forces and moments, equations of motion, aircraft sensors, control surface actuation, and flight control laws.

“Using Simulink and Aerospace Blockset we developed a modular and reconfigurable simulation environment,” says Nomaan Saeed, Flight Sciences Engineer for Gulfstream. “MathWorks tools enable us to evaluate control laws rapidly, modify our control systems, and immediately see the effects of those changes on handling qualities during simulation.”

THE CHALLENGE

Gulfstream engineers needed to build a flexible pilot-in-the-loop aircraft simulation facility, including a six-degrees-of-freedom simulation of the aircraft, in preparation for a scheduled flight test of a modified Gulfstream G550.

To accelerate development and meet their tight deadline, the team planned to divide the project into multiple parts and work on all parts simultaneously. The flight-control system development team required a highly interactive modeling and simulation environment to rapidly test and evaluate control laws. The team developing the air-



Cockpit of Gulfstream's aircraft simulator.

craft dynamics simulation needed to further divide the model into smaller high-fidelity subsystems—including the flap control unit, flight dynamics modeling, air data sensors and systems, inertial reference units, and angle-of-attack sensors—which would be developed concurrently and then integrated into a complete aircraft simulation.

THE SOLUTION

Gulfstream engineers used Simulink, Aerospace Blockset, and Real-Time Workshop® to develop the simulator and evaluate control law designs in real time during simulated flight.

They developed the aircraft dynamics model by translating existing equations for the aircraft into Simulink. Originally developed in Fortran, these equations were based on a traditional flat-earth model. The team used Aerospace Blockset to upgrade this model with round-earth equations of motion that incorporate the shape of the earth, its rotation, and the variation of gravity.

For the equations of motion and the wind and turbulence model, the engineers adapted pre-defined blocks in Aerospace Blockset.

THE CHALLENGE

To develop a pilot-in-the-loop aircraft simulation facility for real-time evaluation of control law designs and flight displays

THE SOLUTION

Use Simulink®, Aerospace Blockset, and Real-Time Workshop® to model and simulate the digital flight-control system and aircraft dynamics in real time

THE RESULTS

- Successful first flight
- Accelerated development
- Realistic flight-test preparation environment

The team also used Aerospace Blockset to perform coordinate transformation, converting Euler angles to directional cosine matrices. With Control System Toolbox they calculated eigenvalues, natural frequencies, and damping factors. Model referencing in Simulink enabled multiple teams to develop individual components independently and organize them hierarchically into a complete system.

After validating the aircraft dynamics model against flight test data, the team used Real-Time Workshop to automatically generate C code, which they compiled to create a real-time simulation of the aircraft.

A separate Gulfstream team developed the flight-control system model in Simulink. The two models, which communicated via shared memory, were then simulated together.

The simulation ran in interpreted mode, enabling Gulfstream engineers to analyze and debug the model as it ran by placing scopes on signals, introducing faults, and evaluating new algorithms.

Using a standard block from Aerospace Blockset, they connected the Simulink model to FlightGear flight simulation software to display window views based on aircraft state data.

The team used MATLAB® to post-process simulation results and to create a GUI for changing flight conditions, selecting an airport, and inducing failure modes during simulation.

Gulfstream continues to employ the simulation lab for a variety of aircraft. “Because of the flexibility of Simulink, we can use the lab for a wide range of purposes,” says Saeed. “It is highly modular and reconfigurable, so we can easily shift between different aircraft models, or evaluate different components.”

“On a tight schedule, we developed a pilot-in-the-loop simulation lab in which we can easily evaluate various control systems and rapidly adjust the feedforward path of the control laws if needed. Without MathWorks tools we would not have met our deadline.”

Nomaan Saeed, Gulfstream Aerospace

THE RESULTS

- **Successful first flight.** After implementing the control laws on the flight-control computer, the team flew the aircraft. “We had a deadline to meet and we met that deadline,” Saeed says. “When we flew the aircraft, everything went according to schedule.”
- **Accelerated development.** Without MathWorks tools, we would not have met our deadline,” notes Saeed. “By using the same tools to develop the aircraft dynamics model and the pilot-in-the loop simulation, we could rapidly develop and evaluate the control system.”
- **Realistic flight-test preparation environment.** Gulfstream used the simulation laboratory to prepare test pilots for flight testing. The pilots reported that the simulator closely matched the flight characteristics of the actual aircraft and provided an outstanding environment to prepare for flight tests.

To learn more about Gulfstream Aerospace, visit www.gulfstream.com

APPLICATION AREAS

- Aerospace and defense
- Model-Based Design
- Algorithm development
- Automatic code generation

PRODUCTS USED

- MATLAB®
- Simulink®
- Aerospace Blockset
- Real-Time Workshop®
- Control System Toolbox

www.mathworks.com