USER STORY

MathWorks Tools Help Land Unpiloted Boeing Spacecraft

THE CHALLENGE

Design a guidance, navigation, and control system that could land an unpowered, unpiloted, reusable spacecraft on a standard runway

THE SOLUTION

Design, test, and automatically generate code for the GN&C system using tools from The MathWorks

THE RESULTS

- Rapid development within budget
- A successful flight test
- A contract to continue development

At Holloman Air Force Base, New Mexico, Boeing and the U.S. Air Force conducted a successful first test flight of the X-40A Space Maneuver Vehicle (SMV). "We wanted to validate low-speed handling qualities and demonstrate autonomous approach and landing capability," said John Fuller, Boeing Phantom Works SMV project manager. "We did that today."

The X-40A is a 90-percent scale reusable experimental space vehicle, a prototype for a new generation of highly maneuverable spacecraft that will perform tasks such as satellite deployments, surveillance, logistics, and Space Station support.

Key to the success of the X-40A was a guidance, navigation, and control (GN&C) system designed and modeled using tools from The MathWorks.

THE CHALLENGE

A small group of engineers at Boeing was tasked with designing a GN&C system that would allow the X-40A to land and come to a full stop on a standard runway without either power or a pilot. The project had to be completed within strict time, funding, and resource limits. The software needed to be reusable in operational SMVs.

The X-40A has a 22-foot-long fuselage, a 12-foot wingspan, and a weight of about 2,600 pounds. It is guided by the control surfaces on the wings, which perform roll and braking functionality, and those on the tail, which control pitch and yaw. There is no propulsion system, and the vehicle must be lifted to its maneuvering position.

The team needed to develop, model, and simulate flight-control laws for the X-40A and then test them in real-life drop tests. The flight-control laws needed to be flexible enough to adjust to any changes made to the vehicle's design during the development cycle. Lateral and directional control laws had to provide feedback for the roll and yaw rates that would permit the bank-to-turn command for runway centerline steering. The longitudinal control laws had to provide feedback for the pitch rates that would enable the command for flight path tracking.

This project also involved prototyping software for avionics, sensors, actuators, and controllers and validating the software development metrics and processes.

THE SOLUTION

The Boeing team chose MATLAB®, Simulink®, Real-Time Workshop®, Control System Toolbox™, Robust Control Toolbox™, Statistics Toolbox™, and Simulink Design Optimization™. They knew that these products would streamline software implementation, shorten the design-to-software-to-verification cycle, and enable them to make late changes as the vehicle's design matured.

The engineers used Simulink and the MATLAB toolboxes to create, block-diagram, and simulation-test the flight-control laws. Real-Time Workshop was used to automatically generate C code for the GN&C system. They then modified an independent Fortran simulation of the Space Shuttle autoland algorithm to fit the X-40A configuration. Finally, they validated

> *I am very pleased with the results of this flight test. It is a significant step in the development phase.*
>
> **John Fuller, Boeing**

the C and Fortran codes against each other until the results matched identically.

In the model analysis phase, the team used MATLAB and the Monte Carlo simulation technique to test the GN&C code. They also used MATLAB and Statistics Toolbox to develop a tool to process and analyze the Monte Carlo data.

The X-40A was tested in three phases: ground testing, to check subsystems and verify and refine models; captive flight testing, to check dynamic sensors, verify tow stability, and collect pressure data; and free-flight testing. The engineers refined the Simulink models during the first two tests. Then they used MATLAB and the toolboxes to analyze the test data in preparation for free-flight testing.

The initial implementation of the GN&C took six weeks—two weeks for the Simulink modeling and four weeks for the unit testing. Each subsequent update, including verification and analysis, took one week.

THE RESULTS

- **Rapid development within budget.** The GN&C system was completed on schedule and in accordance with Boeing's mandate to demonstrate low cost and rapid development.

- **A successful test flight.** A U.S. Army UH-60 Black Hawk helicopter took the X-40A to an altitude of 9,000 feet to initiate free-flight testing of the GN&C system. Upon release, the flight-control system took over and smoothly and accurately guided the vehicle to a runway landing.

- **A contract to continue development.** The success of the GN&C software helped Boeing win a contract to develop an unpiloted, autonomously operated space plane that is capable of reaching speeds of up to Mach 25 while demonstrating aircraft-like operations.

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APPLICATION AREAS

- Aerospace and defense
- Verification, validation, and testing
- Code generation

PRODUCTS USED

- MATLAB®
- Simulink®
- Real-Time Workshop®
- Control System Toolbox™
- Robust Control Toolbox™
- Statistics Toolbox™
- Simulink Design Optimization™

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