Closed-Loop Flight Vehicle Qualification Testing

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Theme

IN the design of mechanical systems for re-entry vehicle roll rate control, the problem of modeling system nonlinearities such as friction and motion limitation is severe. In the absence of effective mathematical models for the controller, preflight qualification testing is indicated. This paper presents a technique for exercising the prototype control system hardware in a realistic way and describes the application of that technique to a flight test program. The test is conducted by incorporating the hardware and a flight angular motion simulator in a hybrid-computer simulation of the trajectory.

Contents

As the laboratory testing conceptualization (Fig. 1) shows, the motion simulator is slaved to the analog computer, which solves the six-degree-of-freedom motion of the flight vehicle in real time.‡ The test hardware responds to the motion of the simulator, and its responses are used as inputs to the analog simulator.§ The fact that the loop is closed through the hardware is central to the laboratory concept in that the hardware controls the simulation in the same way that it will control the flight vehicle.

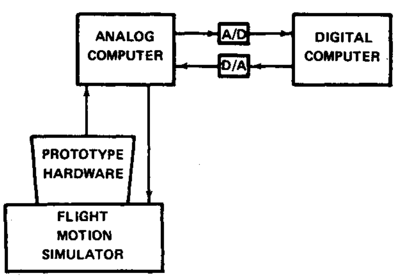

Fig. 1 Laboratory concept showing how hardware "closes the loop" with real-time simulation.

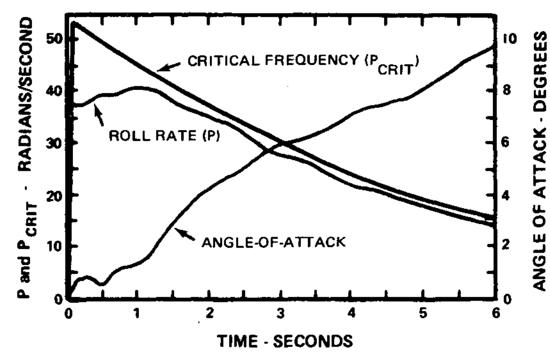

Fig. 2 Time histories of vehicle roll resonance with angle-of-attack divergence.

The vehicle aerodynamic coefficients are stored as multidimensional tables in the digital computer; and interpolation in these arrays is based upon converted analog signals representing the vehicle attitude, rates, Mach number, and control surface deflection. The results of the aerodynamic function determinations are returned to the analog computer by fast digital-to-analog converters. The digital subsystem is also used to set up, check out, and document the testing.

To minimize analog computer equipment, the trajectory equations are written in body-fixed axes with arbitrary dynamic and static unbalance. A single-coordinate transformation is made to determine the relative wind direction. To determine atmospheric density and speed of sound, flight along a straight-line path at the initial re-entry angle is assumed.

The simplified trajectory model was validated by comparison with flight test data and with a large, all-digital trajectory program. Figure 2 gives a representative trajectory simulation for a flight test in which small, purposely introduced asymmetries drove the vehicle into pitch-roll resonance with a resulting divergence in angle of attack. Because a good reproduction of the

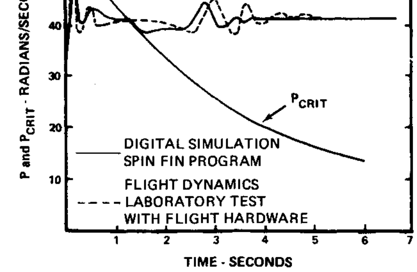

Fig. 3 Vehicle spin rate from digital and laboratory simulations.

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Index categories: LV/M Simulation; LV/M Dynamics and Control; Computer Technology and Computer Simulation Techniques.

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‡ Motion simulator tracking accuracy is monitored to insure that no dynamic errors are introduced by the flight table. For stable flights, the simulator's response capability is not highly taxed.

§ In the present program, the controller converts angular velocities to corrective deflection of small aerodynamic control surfaces. An instrumentation system converts these deflections to properly scaled voltages for transmission through slip rings to the analog computer.

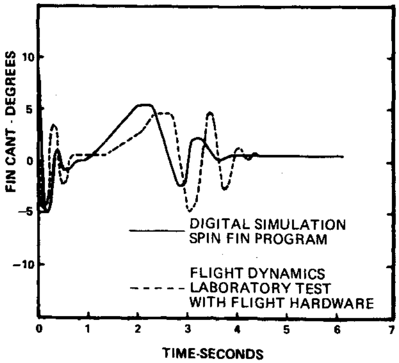

Fig. 4 Control-system fin cant from digital and laboratory simulations.

flight test results was obtained with the model, hardware qualification was initiated.

Figures 3 and 4 show typical results of the hardware-in-the-loop qualification testing. For comparison, plots of the detailed trajectory simulations are included as well, their discrepant character indicating the difficulty of modeling the controller. These results show satisfactory controller performance for which the acceptable limits were established by many experimental runs with a variety of vehicle and launch parameters. When these limits had been determined to lie outside the expected variations in aerodynamic uncertainties and launch conditions, the controller was committed to flight testing.

Figure 5 shows the flight data and postflight simulations conducted with flight-derived aerodynamic coefficients. It is concluded from the agreement between the flight test data and the simulation that the closed-loop testing technique provides a realistic exercise for the prototype controller.

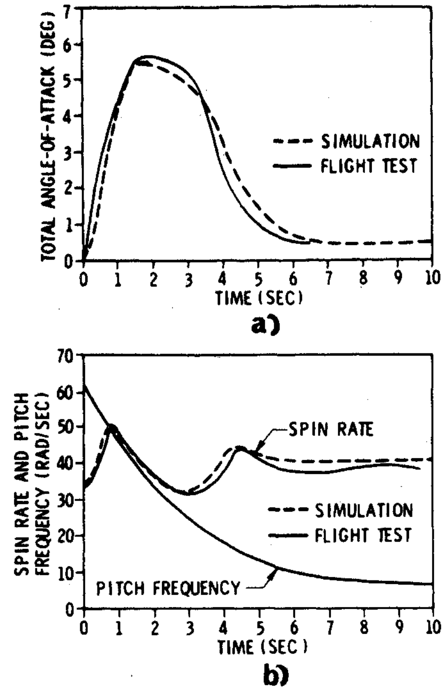

Fig. 5 Fin-roll control-vehicle flight test data and comparison with simulation. a) Total angle of attack. b) Spin rate and pitch frequency.