Table 1 AFW technology flutter suppression system wind-tunnel model digital control loop stability margins

Control loop (at actuator)	Dynamic pressure, psf	
	300	250
Symmetric	−4 dB ≤ Gain ≤ 4 dB	−13 dB ≤ Gain ≤ 8 dB
	−35 deg ≤ Phase ≤ 32°	−70 deg ≤ Phase ≤ 60°
Antisymmetric brake on	−3.3 dB ≤ Gain ≤ 3.3 dB	−7.5 dB ≤ Gain ≤ 7.5 dB
	−26 deg ≤ Phase ≤ 24°	−32 deg ≤ Phase ≤ 70°

Table 2 AFW technology flutter suppression system TEI control surface performance during brake-off March 1991 wind-tunnel test results

Dynamic pressure, psf	rms position, deg	rms rate, deg/s	Maximum position, deg	Maximum rate, deg/s
200	0.12	6.97	0.52	33.85
250	0.18	10.91	0.82	52.08
265	0.19	11.56	0.81	46.88
275	0.20	12.27	0.79	49.48
290	0.23	14.23	0.86	57.29

(260) 11% beyond flutter speed. In addition, the roll trim system (RTS) rolled the model at 290 psf (which was 23% beyond flutter speed).

Conclusions

FSS control laws were designed and tested for the AFW technology wind-tunnel model. The design approach was to use torsion moment strain gauges and bending moment strain gauges as the feedback sensors instead of the standard accelerometers. The synthesis method was the classical single-input/single-output using direct digital design in the frequency domain applying the Nyquist criterion. The model entered the TDT at NASA Langley Research Center during March 1991 for testing. The significant results of the wind-tunnel test are that both the symmetric and the antisymmetric flutter modes were successfully stabilized at 23% beyond flutter speed, and that the symmetric flutter mode was successfully stabilized at 11% beyond flutter speed during high roll rate maneuvers through 90 deg and 23% beyond flutter speed during low rate roll trim maneuvers. The control authority of the FSS did not interfere with either the RRTS or the RTS during the wind-tunnel tests. The conclusion that bending moments and torsion moments are good candidates for feedback sensors in FSS is supported by these results. Future study of the application of these sensors in FSS should include sensor location and control law design methods to take advantage of these sensors.

Acknowledgments

This work was supported by Independent Research and Development (IR&D) TPA 150 from January 1990 through September 1990, and by IR&D TPA 128 from October 1990 through March 1991 at North American Aircraft Division, Rockwell International, El Segundo, California.

References

[1]Perry, B., III, Cole, S. R., and Miller, G. D., "A Summary of the Active Flexible Wing Program," AIAA Paper 92-2080, April 1992.

[2]Irving, A., "An Analytical Technique for Predicting the Characteristics of a Flexible Wing Equipped with an Active Flutter-Suppression System and Comparison with Wind-Tunnel Data," NASA TP 1367 (N79-17264), Feb. 1979.

Maneuver Load Control Using Optimized Feedforward Commands

Doug Moore*
Rockwell International Corporation,
Los Angeles, California 90009

Introduction

A MANEUVER load control (MLC) system has been designed for and tested on the active flexible wing (AFW) wind-tunnel model.[1] The MLC system was designed to constrain wing bending and torsion loads, while maintaining roll performance. Successful MLC systems will allow designers additional options in the aerodynamic and structural design of wings. The objectives of this work were to provide design and test experience in MLC systems and in the integration of MLC systems with flutter suppression systems.

Control Law Design

The method used for the MLC design was to treat the roll-load situation as a constrained optimization problem. Simplifying assumptions included treating the wind-tunnel model as a rigid body and neglecting load feedback. From previously obtained wind-tunnel data of wing loads and model response due to surface deflection, a multidimensional gradient problem was formulated that maximized roll performance without exceeding load limits. The optimization procedure minimized total control-surface deflection while producing required roll acceleration and roll rate without exceeding wing loads or control-surface deflection constraints. Optimization proceeds until conflicting load and/or deflection constraints exist; this defines the maximum possible roll performance subject to the design constraints. The final product of this design method was a set of look-up tables of control-surface deflection as functions of roll rate and roll rate error. The purpose of the MLC portion of the AFW wind-tunnel test was to evaluate the performance of the look-up tables generated by the optimization algorithms.

Test Results

Testing on the AFW wind-tunnel model in the NASA Langley Transonic Dynamics Tunnel confirmed the concept of optimized feedforward commands as a basis for an MLC system. Projected roll rates of 300 deg/s were achieved with reductions in torsion and bending moments (compared to tests conducted without the MLC system at the same high roll rates).

Received May 7, 1992; revision received March 7, 1994; accepted for publication Sept. 19, 1994. Copyright © 1994 by the American Institute of Aeronautics and Astronautics, Inc. All rights reserved.

*Member Technical Staff, Vehicle Dynamics and Control, North American Aircraft Division, P.O. Box 92098.

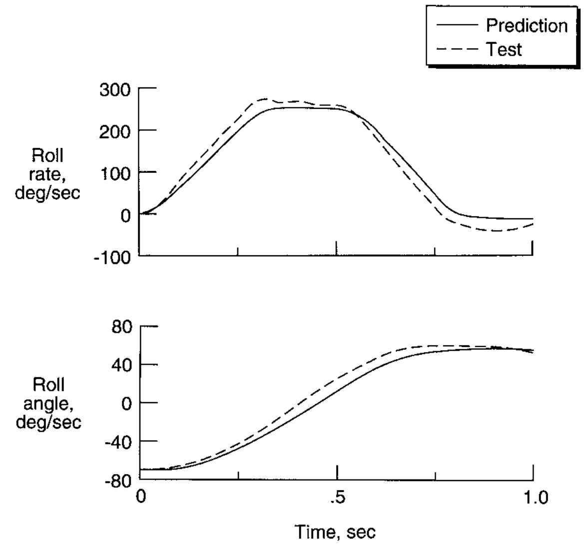

Fig. 1 Roll performance.

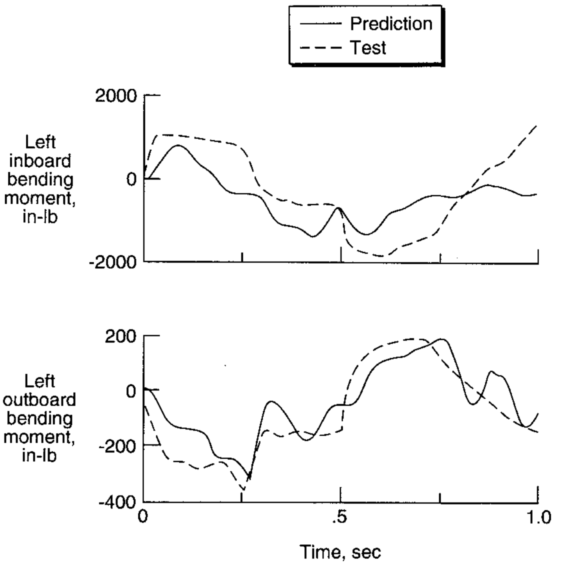

Fig. 2 Wing bending moments.

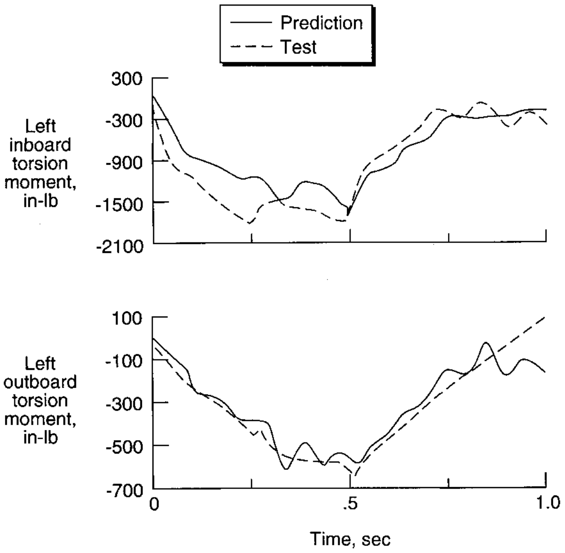

Fig. 3 Wing torsion moments.

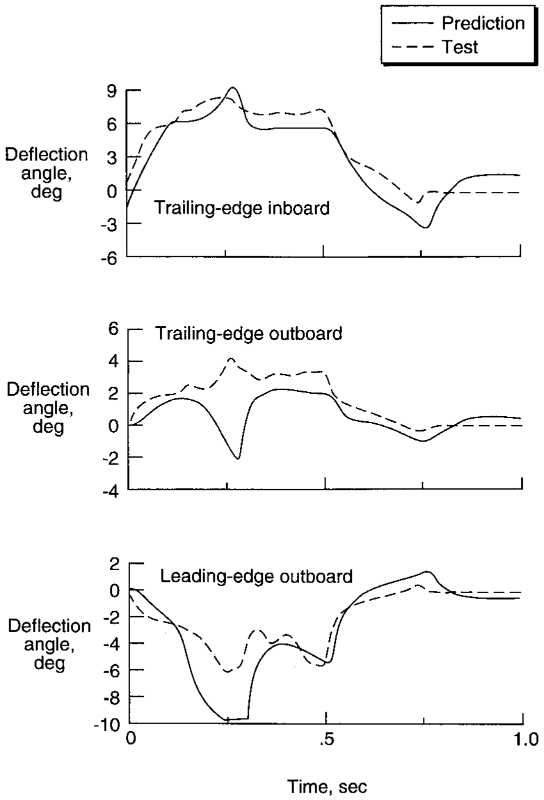

Fig. 4 Control-surface deflections on left wing.

Figures 1–4 contain comparisons of analytically predicted and experimentally measured performance of the MLC system. In each figure the solid lines represent the prediction and the dashed lines represent test results. Test conditions were Mach number of 0.4 and dynamic pressure of 250 psf. In Fig. 1 roll rate and bank angle results are in good agreement with the predicted values. The load results in Figs. 2 and 3 show good agreement with the predicted trends. Most of the discrepancies are due to the assumption of neglecting the higher order dynamics of the wing. Figure 4 shows control surface deflections from test and simulation. Notice how the trailing edge surface moves in a load control direction during the acceleration phase of the roll maneuver.

Concluding Remarks

The design and implementation of a feedforward MLC system, based on constrained optimization techniques, was successfully tested on the AFW wind-tunnel model. The lessons learned from this work include: the viability of nonlinear load control schemes; the requirement to augment the a priori knowledge represented by the feedforward control with feedback control; and the requirement to model the higher order dynamics of the plant. Knowledge gained in the design and test of the MLC system and a Rockwell-designed flutter suppression system[2] are currently being used to solve the aeroservoelastic challenges in high speed civil transport (HSCT) designs.

References

[1] Perry, B., III, Cole, S. R., and Miller, G. D., "A Summary of the Active Flexible Wing Program," AIAA Paper 92-2080, April 1992.

[2] Klepl, M., "A Flutter Suppression System Using Strain Gauges Applied to Active Flexible Wing Technology: Design and Test," AIAA Paper 92-2098, April 1992.