Excitations for Rapidly Estimating Flight-Control Parameters

Parameters are estimated, in nearly real time, from responses to these excitations.

Dryden Flight Research Center, Edwards, California

A flight test on an F-15 airplane was performed to evaluate the utility of prescribed simultaneous independent surface excitations (PreSISE) for real-time estimation of flight-control parameters, including stability and control deriva-tives. The ability to extract these derivatives in nearly real time is needed to support flight demonstration of intelligent flight-control system (IFCS) concepts under development at NASA, in academia, and in industry. Tradition-ally, flight maneuvers have been de-signed and executed to obtain esti-mates of stability and control deriva-tives by use of a post-flight analysis technique. For an IFCS, it is required to be able to modify control laws in real time for an aircraft that has been damaged in flight (because of com-bat, weather, or a system failure).

The flight test included PreSISE ma-neuvers, during which all desired con-trol surfaces are excited simultaneously, but at different frequencies, resulting in aircraft motions about all coordinate axes. The objectives of the test were to obtain data for post-flight analysis and to perform the analysis to determine:

- The accuracy of derivatives esti-mated by use of PreSISE,
- The required durations of PreSISE inputs, and
- The minimum required magnitudes of PreSISE inputs.

The PreSISE inputs in the flight test consisted of stacked sine-wave ex-citations at various frequencies, in-cluding symmetric and differential excitations of canard and stabilator control surfaces and excitations of aileron and rudder control surfaces of a highly modified F-15 airplane. Small, medium, and large excitations were tested in 15-second maneuvers at subsonic, transonic, and super-sonic speeds. Typical excitations are shown in Figure 1. Flight-test data were analyzed by use of pEst, which is an industry-standard output-error technique developed by Dryden Flight Research Center. Data were also analyzed by use of Fourier-trans-form regression (FTR), which was de-veloped for onboard, real-time esti-mation of the derivatives.

Figure 2 shows results, for one of the derivatives, from 9 PreSISE ma-neuvers at Mach 0.75. At this Mach number, the airplane is statically un-stable. The first set of data repre-sents results from the use of small PreSISE inputs, the second set from medium inputs, and the third set from large inputs. For the derivative
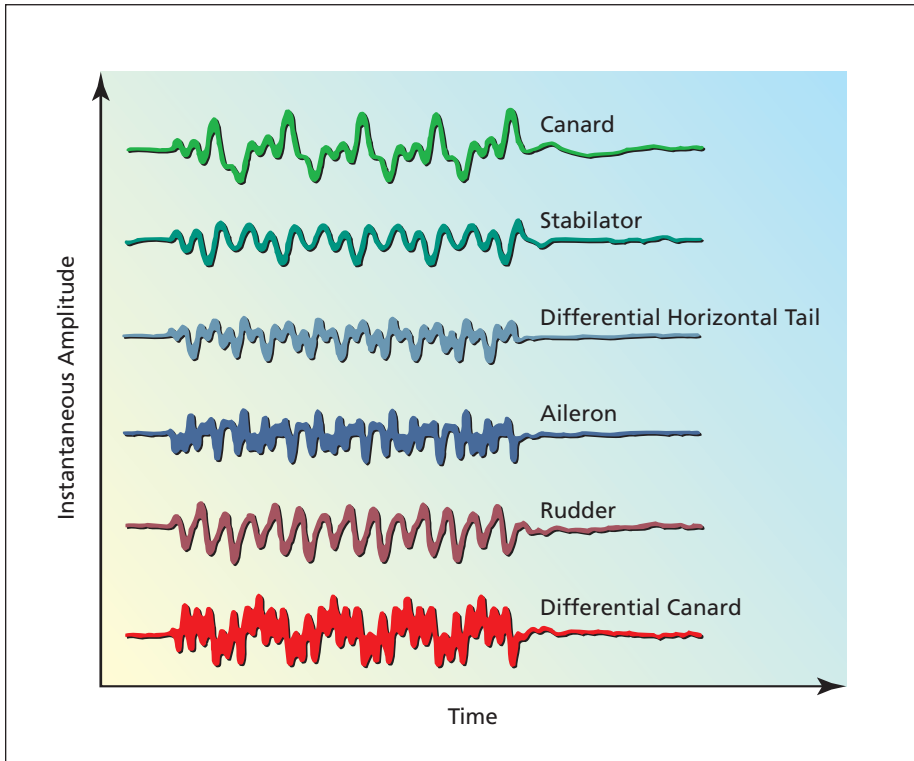

Figure 1. These **Control-Surface Excitations** were applied to an F-15 airplane to elicit responses from which stability and control derivatives could be estimated.
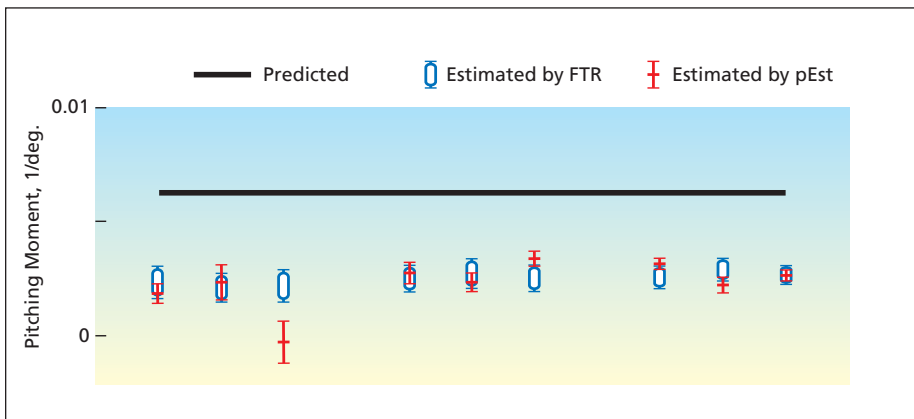

Figure 2. A **Pitching Moment** due to the angle of attack was predicted and was estimated from responses to PreSISE at small, medium, and large magnitudes.

in question, the estimate was the same, independent of input size or analysis technique. Typically, the longitudinal derivatives were estimated with acceptably high accuracy and, using FTR, converged to final values after about 5 seconds of inputs. Some lateral-directional derivatives were not estimated as accurately, because signal-to-noise ratios were low. Efforts to optimize the inputs for increased accuracy in estimation of the derivatives are underway.

✪ Estimation of Stability and Control Derivatives of an F-15

Parameters can be estimated in nearly real time for use in adaptive flight control.

Dryden Flight Research Center, Edwards, California

A technique for real-time estimation of stability and control derivatives (derivatives of moment coefficients with respect to control-surface deflection angles) was used to support a flight demonstration of a concept of an indirect-adaptive intelligent flight control system (IFCS). Traditionally, parameter identification, including estimation of stability and control derivatives, is done post-flight. However, for the indirect-adaptive IFCS concept, parameter identification is required during flight so that the system can modify control laws for a damaged aircraft.

The flight demonstration was carried out on a highly modified F-15 airplane (see Figure 1). The main objective was to estimate the stability and control derivatives of the airplane in nearly real time. A secondary goal was to develop a system to automatically assess the quality of the results, so as to be able to tell a learning neural network which data to use.

Parameter estimation was performed by use of Fourier-transform regression (FTR) — a technique developed at NASA Langley Research Center. FTR is an equation-error technique that operates in the frequency domain. Data are put into the frequency domain by use of a recursive Fourier transform for a discrete frequency set. This calculation simplifies many subsequent calculations, removes biases, and automatically filters out data beyond the chosen frequency range.

FTR as applied here was tailored to work with pilot inputs, which produce correlated surface positions that prevent accurate parameter estimates, by replacing half the derivatives with predicted values. FTR was also set up to work only on a recent window of data, to accommodate changes in flight condition.

A system of confidence measures was developed to identify quality-parameter estimates that a learning neural network could use. This system judged the estimates primarily on the basis of their estimated variances and of the level of aircraft response.

The resulting FTR system was implemented in the Simulink software system and autocoded in the C programming language for use on the Airborne Research Test System (ARTS II) computer installed in the F-15 airplane. The Simulink model was also used in a control room that utilizes the Ring Buffered Network Bus hardware and software, making it possible to evaluate test points during flights.

In-flight parameter estimation was done for piloted and automated maneuvers, primarily at three test conditions. Figure 2 shows results for pitching moment due to symmetric stabilator actuations for a series of three pitch doublet maneuvers (in a doublet maneuver, a command to change attitude in a given direction by a given amount is followed immediately by a command to change attitude in the opposite direction by the same amount). A time window of 5 seconds was used. The portions of the curves shown in red are those that passed the confidence tests.

The technique showed good convergence for most derivatives for both kinds of maneuvers — typically within a few seconds. The confidence tests were marginally successful, and it would be necessary to refine them for use in an IFCS.

Figure 1. The **F-15 #837 Airplane** was used in a flight demonstration of the real-time parameter-estimation technique.
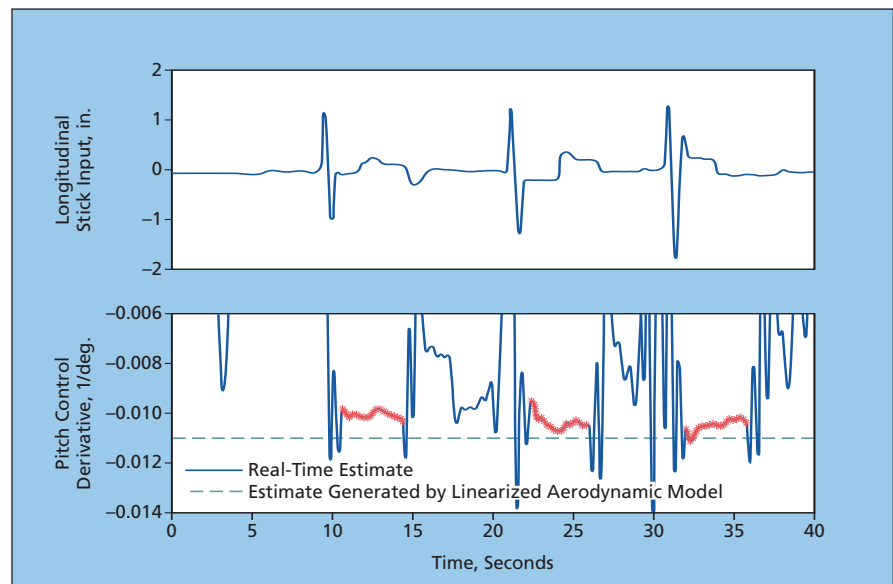

Figure 2. These **Results Derived From a Pitching-Moment Test** involving three pitch-doublet maneuvers illustrate the capability afforded by the real-time parameter-estimation technique.