# REAL-TIME STABILITY MARGIN ESTIMATION FOR THE X-48B BLENDED-WING BODY

## Summary

A real-time stability margin (RTSM) estimation tool has been developed for in-flight robustness analysis of the X-48B (Boeing Phantom Works, St. Louis, Missouri) blended-wing body. The tool incorporates methods for generating excitation signals and the ability to analyze the open-loop frequency response during flight-testing. The excitation signals are mutually orthogonal and minimize the peak factors to provide multi-input excitation while avoiding excursions in flight condition. For in-flight analysis, an emphasis has been placed on comparison between flight data and simulation data in addition to estimated stability margins.

## Objective

The objective of RTSM estimation is to improve envelope clearance efficiency and provide an early indication of potential modeling errors. Efficiency gains for envelope clearance are accomplished by reducing the time required for excitation. This is done by exciting multiple signals simultaneously and reducing the peak factor of the multisine excitations. Analysis of the open-loop frequency response, and comparison with the anticipated frequency response provide unique insight into developing modeling discrepancies and trends throughout the flight envelope.

## Approach

A multisine signal is simply a sum of sinusoid signals, as indicated in eq. (1). The multisine signal is composed of sinusoids of various frequencies ($\omega_k$), phases ($\phi_k$), and relative power ($P_k$). To generate a mutually orthogonal set of multisine signals, the frequency components should vary linearly between the minimum and maximum frequency of interest. The relative power of each frequency component can be tuned to achieve a tailored power distribution for each channel of the multisine signal. The signal component phases are determined by minimizing the peak factor of each channel by use of an optimization routine, as described in reference 1.

$$u_j = \sum_{k=1}^{M} \sqrt{\frac{P_k}{2}} \cos(\omega_k t + \phi_k) \tag{1}$$

For the X-48B aircraft, multisine signals were developed to excite the roll, pitch, and yaw channels prior to the control allocation, as indicated in figure 1. The excitations vary in frequency between 1 rad/s and 75 rad/s, yielding a 19 s excitation signal. Each channel is composed of 25 individual frequencies. The power spectrum was tailored to increase vehicle response in a narrow bandwidth on a single channel. The peak factor of each channel is approximately 1.25.

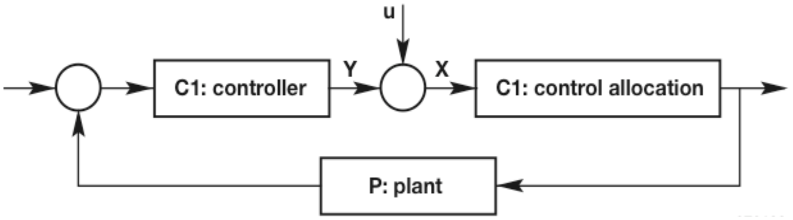

Figure 1. Block diagram indicating the excitation signal (u) location.

In-flight robustness is realized by estimating the transfer function response of the open-loop system, seen in figure 1. The excitation signals (*u*), and transfer function inputs (*X*) and outputs (*Y*) are all vectors of length 3, representing the roll, pitch, and yaw channels. Equation (2) represents the open-loop transfer function of interest.

$$\frac{Y}{X} = C_1 P C_2 \tag{2}$$

The vehicle open-loop transfer function can be estimated given closed-loop time-histories of both signals X and Y during excitation of signal *u*. Recorded data from the telemetry system will be used by the analysis tools during flight. While the multi-channel excitation enables analysis of the system as a multi-input, multi-output (MIMO) system, more insightful data can be garnered by analyzing the system as three single-input, multi-output (SIMO) systems. The analysis tools produce a series of time history plots, power spectral density plots for the inputs and outputs, and nine Bode plots including coherence and stability margin information.

### Status

Flights of the X-48B aircraft utilizing the RTSM excitation and analysis tools will be conducted in 2007.

### Reference

1. Morelli, Eugene A., "Multiple Input Design for Real-time Parameter Estimation in the Frequency Domain,"*13th IFAC Symposium of System Identification*, 2003.

## Contact

Chris Regan, DFRC, Code RC, (661) 276-5696