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Interrogative Testing for Nonlinear Identification of Aeroelastic Systems

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Introduction

SIMULATION and testing of aeroelastic systems are usually performed over a wide range of parameters without the conceptual or mathematical basis that is needed to specifically characterize differences in nonlinear aeroelastic responses. In general, this approach is very expensive and may not completely yield the required data for a comprehensive analysis or prediction capabilities of aeroelastic responses in different flight regimes. Furthermore, because these responses are characterized by jumps and bifurcations, generic procedures that are based on blind or wide variations of input parameters are extremely ineffective and, to a certain extent, precarious. In this Letter, we present an example of testing and data analysis procedures that can yield significant information about different aeroelastic aspects in different flow regimes. Particularly, differences in nonlinear response characteristics of a high-speed civil transport flexible semispan model (FSM) over the subsonic and transonic flight regimes are identified. This identification is achieved through time/frequency analysis of response data to sine sweep excitations in experiments performed at the NASA Langley Research Center's Transonic Dynamics Tunnel. The overall goal is to address the issue of how simulation or testing procedures could be employed to determine proper physics and response characteristics of aeroelastic systems over different operational regimes. Such a characterization is essential for the development of inexpensive mathematical models that embody these physics and enable the prediction and/or control of aeroelastic responses.

Experimental Setup and Data Analysis

The FSM experiments were conducted in the Transonic Dynamics Tunnel at the NASA Langley Research Center. The model planform was a 1/12th-scale configuration based on an early design known as the reference H configuration. A detailed diagram of the FSM is presented by Silva et al. [1], Hajj and Silva [2], and Chabalko et al. [3,4]. This work focuses on the forced-response tests that were performed to investigate the response of the model to different forcing conditions. Two different forcing procedures were used to excite the model. In the first procedure, referred to as *sweep* tests, the forcing signal was a swept sinusoid with a frequency that was varied between 5 and 25 or 30 Hz while maintaining a constant amplitude for 30 s. In the second procedure, the forcing signal consisted of a sinusoid with a frequency near that of the response frequency over different ranges of the sweep tests. This procedure is referred to as a *dwell* test and was used to force the model near one of its natural frequencies. In this work, acceleration data from the sweep excitations in the subsonic- and transonic-tunnel conditions are analyzed. The tunnel conditions and excitation signals for the analyzed runs are presented in Table 1. The wing-response characteristics to the varying excitation conditions are determined from a time/frequency analysis of the wingtip accelerations. This analysis is performed by applying the continuous wavelet transform to the wingtip-acceleration signals. Details of the implementation of the wavelet analysis are similar to those presented by Chabalko et al. [3,4].

Results and Discussion

The response time series as measured by the trailing-edge accelerometer near the wingtip under sweep excitation in the subsonic regime is presented in Fig. 1a. The corresponding contour plot of the magnitudes of the wavelet coefficient is presented in Fig. 1b. Three black lines are superimposed on the plots of the

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Table 1 Run numbers and test conditions

Run number	Mach number	Dynamic pressure, psf	Control surface deflection
911	0.7	162.34	0.5 deg
980	0.948	159.99	0.5 deg

magnitude of the wavelet coefficients. The middle and thickest line represents the instantaneous forcing frequency, the top line represents twice the forcing frequency, and the bottom line represents half the forcing frequency. Obviously, the highest response is observed at the onset of the excitation between 1 and 3 s. As the excitation frequency is varied in the range of 5.5–6 Hz, a strong response is observed near twice this range of frequencies, indicating a superharmonic response. The importance of this result lies in the fact that the maximum response is nonlinear. As such, a dwell test with an excitation frequency near 5.5–6 Hz would have enabled a better characterization of the nonlinear aeroelastic characteristics in the subsonic regime than a dwell test with a frequency near that of the model's response.

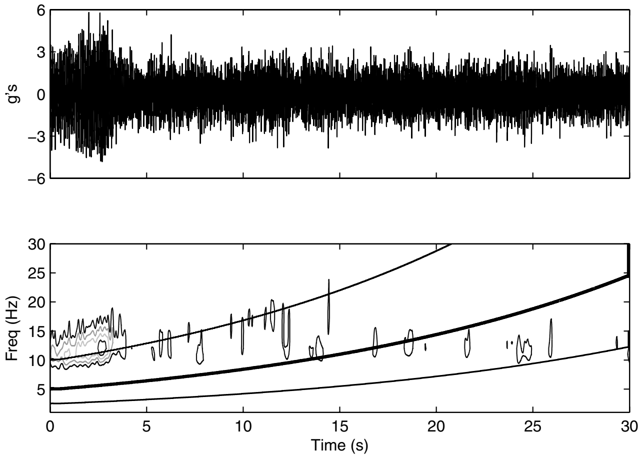

Fig. 1 Time series: a) corresponding contour plot of the magnitudes of the wavelet coefficient and b) response of the wingtip under sweep excitation in the subsonic regime; run 911.

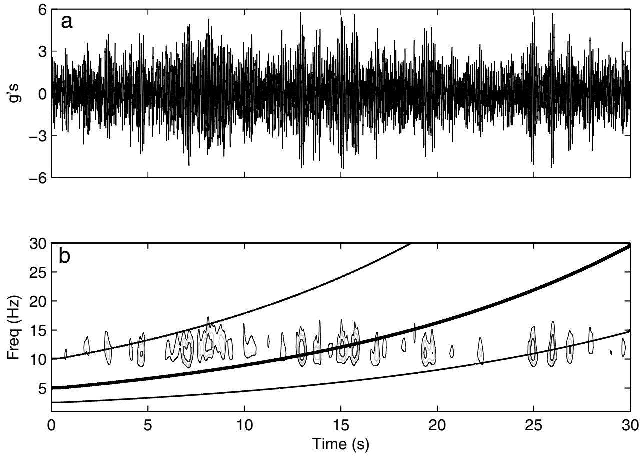

Fig. 2 Time series: a) corresponding contour plot of the magnitudes of the wavelet coefficient and b) response of the wingtip under sweep excitation in the transonic regime; run 980.

In the transonic-flow regime, the model was forced with a sweep between 5 and 30 Hz at the same amplitude of the sweep forcing in the subsonic regime. The response time series as measured by the trailing-edge accelerometer near the wingtip under sweep excitation is presented in Fig. 2a. A contour plot of the corresponding magnitudes of the wavelet coefficients of the time series is presented in Fig. 2b. The results clearly show a different response from the one observed in the subsonic regime. Particularly, a strong linear response over different frequency modes between 10.5 and 12.75 Hz, identified as hump modes by Silva et al. [1], is noted. Moreover, a strong subharmonic response over the same range of the hump mode is noted when the excitation frequency is near twice this range, indicating a subharmonic response. A third region of high response frequency is also noted over the excitation range between 7.2 and 8.4 Hz, yielding a response over the range of the hump mode near $3/2$ the excitation frequency. Such a combination of resonance can certainly be associated and should be expected in an aeroelastic system, which can have multiple (i.e., aerodynamic and structural) excitation sources. Again, dwell tests with excitation frequencies near twice and $3/2$ of the response frequency would have yielded a good characterization of the nonlinear aeroelastic characteristics in the transonic regime.

Conclusions

A comparison of the responses of the FSM model over the subsonic and transonic regimes shows that the nonlinear responses observed in these regimes are significantly different from each other. Because the structure properties and excitation amplitude did not change, the different nonlinear responses in the transonic and subsonic regimes should be associated with differences in aerodynamic nonlinearities. Consequently, dwell tests that exploited these nonlinearities and further analysis of the data from these tests could have been used to characterize the different types of nonlinearities, develop models for both structural and aerodynamic nonlinearities, and determine the effectiveness of the control surface in the different flight regimes.

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