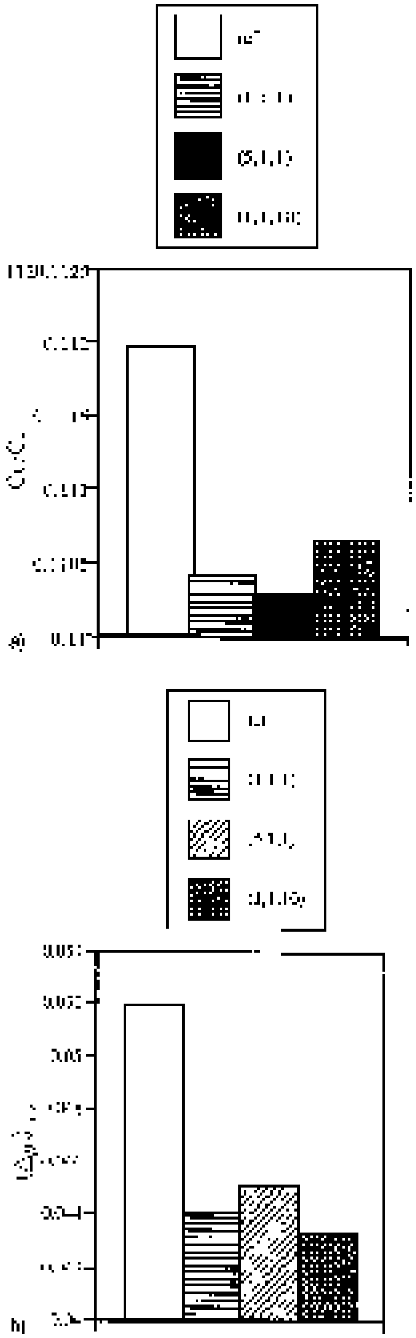

Fig. 2 Effect of weight factors on a) C_D/C_L and b) $(\Delta p_2)_{max}$.

application because of its ability to simultaneously address multiple objectives while incorporating the capability to emphasize specific objectives relative to the others. The procedure has been demonstrated, using a high-speed aircraft design problem, to be effective in achieving the desired goal of selectively emphasizing design objectives in the overall design process.

Acknowledgment

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Comparison of Aeroelastic Excitation Mechanisms

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Introduction

FLIGHT flutter testing relies heavily on measured aeroelastic flight data for safe and efficient envelope expansion. These data are used to determine the stability properties and predict the onset of flutter through algorithms to estimate damping parameters, transfer functions, and uncertainty descriptions for derived models.[1] The reliance on flight data presents a need for aeroelastic excitation mechanisms that can provide high levels of excitation across a wide range of frequencies. A recent AGARD conference identified such mechanisms as an important area of research for the aeroelastic and flight-test communities.[2]

This Note presents results from flight tests of the F/A-18 Systems Research Aircraft (SRA).[3] Flight data are recorded in response to three aeroelastic excitation mechanisms: atmospheric turbulence, pilot stick commands, and a wingtip exciter system. The performance of each mechanism is directly compared by analyzing power spectral information obtained from data recorded in response to each type of excitation at the same flight condition. This information demonstrates the level of excitation over a frequency range and the power of each modal response.

F/A-18 SRA

The F/A-18 SRA is being flown at NASA Dryden Flight Research Center as a testbed for flutter testing, advanced actuator concepts, smart structures, optical sensors and avionics systems. The SRA is a two-seat configuration fighter with production engines. Flutter testing was initiated on the SRA because of a major left wing structural modification to allow testing of several hydraulic and electromechanical aileron actuator concepts. The increased size and weight of these actuators required the replacement of a fitting called a *hinge-half* supporting the aileron hinge, the actuator, and a fairing with

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Table 1 Structural modal frequencies in Hz of the F/A-18 systems research aircraft for heavyweight condition

Mode	Symmetric	Antisymmetric
Wing 1st bending	5.59	8.84
Fuselage 1st bending	9.30	8.15
Wing 1st torsion	13.98	14.85
Wing 2nd bending	16.95	16.79
Wing outboard torsion	17.22	——
Fuselage 2nd bending	19.81	18.62
Fuselage torsion	——	24.19
Wing 2nd torsion	29.88	29.93
Aileron rotation	33.44	——
Aileron torsion	38.60	——

the larger and heavier items. These structural modifications changed stiffness and damping properties along with adding about 20 lb to the wing. Dependency of the aileron aeroelastic behavior on actuator dynamics warranted the flutter tests.

A partial list of calculated structural modal frequencies for the F/A-18 SRA after the modifications is given in Table 1.

Accelerometers are available at several points on the aircraft to record modal responses. Each wing has a sensor on the aileron and at the forward and aft position on the wingtip. Additional accelerometers are located on each vertical tail and horizontal stabilator.

Excitation Systems

Three different excitations are considered for the F/A-18 SRA flight tests. Atmospheric turbulence, pilot stick commands, and a wingtip system are utilized to generate aeroelastic response data.

Atmospheric turbulence and wind gusts can provide excitation over a broad range of frequencies because of random variations in the speed and direction of the airflow. This type of natural excitation is easily implemented because no changes or additions to the aircraft are required, although the level and frequency distribution of excitation may not be optimal as a result of insufficient turbulence at the test points.

Modal responses can also be excited by pilot commanded movements of the control surfaces through the stick. Several types of responses can be generated by stick raps, singlets, and doublets along with sinusoidal movements of the stick. The frequencies excited by such pilot stick commands are generally low frequency because of human bandwidth constraints and low-pass filters in the transfer function from stick to control surfaces to roll off any high-frequency commands.

The third excitation system was developed by Dynamic Engineering Incorporated (DEI).[4] The system consists of one or more wingtip exciters, an avionics box mounted in the instrumentation bay, and a cockpit controller. Several versions of this system are being used for flutter testing of military and commercial aircraft.[5] The version utilized for this project used a single exciter on each wingtip.[3]

Aerodynamic forces are generated by the wingtip exciter that consists of a small fixed aerodynamic vane forward of a rotating slotted hollow cylinder. Rotating the cylinder varies the forces on the vane. The cockpit controller commands sine sweeps to the rotating cylinder to determine the frequency and magnitude of the wingtip forces. The wingtip exciters are programmed to act in-phase (0 deg) or out-of-phase (90 deg) with each other to excite either symmetric or antisymmetric modes.

Flight-Test Results

Flight tests were conducted to measure data in response to each of the three aeroelastic excitation mechanisms at flight conditions of Mach 0.85 and an altitude of 10 kft. The test-point procedure for recording atmospheric turbulence responses consisted of level flight while data were collected for 30 s. The test-point procedure for the pilot stick commanded excitation consisted of lateral stick raps and singlets approximately every 5 s for 60 s. The test-point procedure for the DEI exciters utilized a 30-s linear sine sweep from 3 to 30 Hz with the exciters in symmetric mode.

Power spectral density (PSD) functions are computed for the flight data sets to determine the effectiveness of each excitation mechanism. The PSD is representative of the level of excitation across frequency because the integral over a frequency band of the PSD function is equal to the power of the signal in that band.

Figure 1 presents PSD functions for the forward wingtip accelerometer on the left wing. The wingtip sensors are used to observe symmetric and antisymmetric wing and fuselage modes that are often critical to identify for flight flutter testing.

The PSD function for atmospheric turbulence response data is given in Fig. 1a. No large peaks are present in the relatively flat PSD function to indicate that no modes are strongly excited by the turbulence. The turbulence excitation was strongest at low frequency with a decrease of approximately 5 dB after 20 Hz; however, even at low frequencies the energy in any modal response is no greater than the noise level in the measurement.

The PSD function for data measured in response to the lateral stick raps and singlets is given in Fig. 1b. The lateral stick raps and singlets are able to excite the symmetric and antisymmetric wing 1st bending modes; however, the energy in these modal responses is significantly less than the lateral rigid body roll mode response near 2 Hz. Stick commands poorly excite modal responses above 10 Hz because of bandwidth constraints of pilot movements and low pass filters in the transfer function from stick to control surface actuation as evidenced by Fig. 1b.

The PSD function for DEI excitation response data is given in Fig. 1c. Several modes are clearly excited during the flight test, which correspond to the predicted symmetric modes listed in Table 1. The symmetric wing 1st bending and wing outboard torsion are particularly evident in the response data.

Figure 2 presents PSD functions for the aileron accelerometer on the right wing. Information obtained from this sensor is important for stability monitoring of aeroservoelastic control surface modes. A particular concern is observing aileron modes during transonic flight to identify buzz phenomena.

Figures 2a and 2b present power spectral information for aileron responses to atmospheric turbulence and the lateral stick raps. Neither data set indicates these mechanisms are able

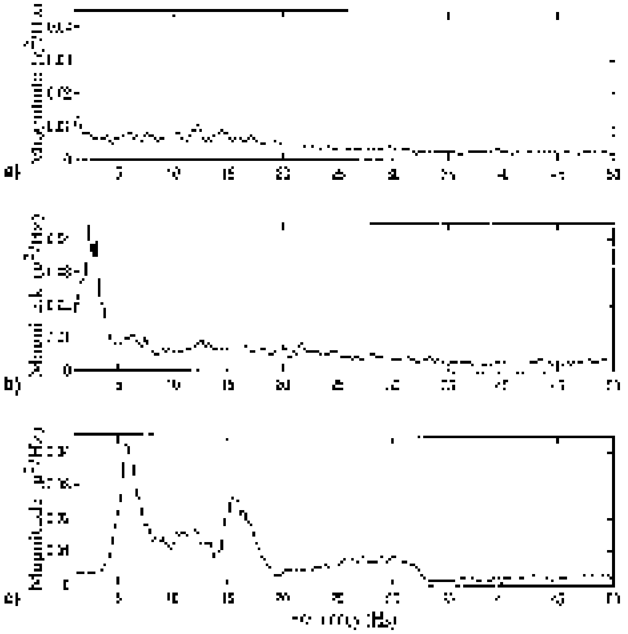

Fig. 1 PSD in g^2/Hz of left wing forward wingtip accelerometer data in response to a) atmospheric turbulence, b) pilot-commanded lateral stick raps, and c) wingtip excitation system.

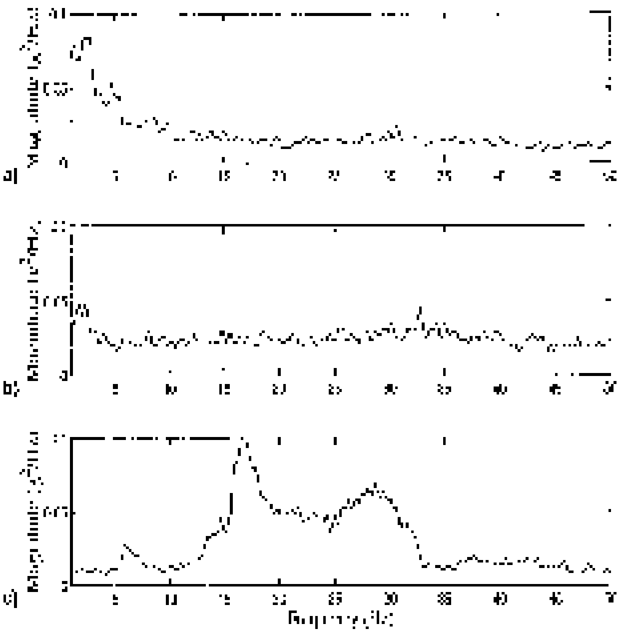

Fig. 2 PSD in g^2/Hz of right wing aileron accelerometer data in response to a) atmospheric turbulence, b) pilot commanded lateral stick raps, and c) wingtip excitation system.

to excite the aileron modes. Figure 2c presents the power spectrum density function for aileron responses to the DEI excitation. These data indicate an aileron Rotation mode is excited at 29 Hz along with the wing 1st bending and wing outboard torsion modes.

Comparing the power in modal responses of each PSD function is an accurate means of comparing the performance of each excitation method. Clearly the DEI excitation system excited aeroelastic modal responses with higher power than the pilot stick commands or atmospheric turbulence with the observed symmetric modal responses consistently more than 5 dB higher for the DEI excitation. The symmetric wing 1st bending mode is representative of this behavior with −3.8 dB in the response as a result of the DEI excitation, but only −9.0 dB for the pilot stick commands and −10.3 dB for the atmospheric turbulence excitation.

The power measured by the aileron sensor below 5 Hz is greater for responses to pilot stick command than for the DEI excitation as shown in Fig. 2. This power indicates stick commands to the control surfaces that agrees with the observation that pilot commands are limited to this frequency range as evidenced by Fig. 1b. Similar behavior is reflected in the turbulence response data, where spectral information from the roll stick data indicates some pilot commands were constantly input to the aileron in this frequency band.

Also, power levels measured by the aileron in Fig. 2 are greater than for the wingtip sensor in Fig. 1 because of movement of the aileron. The aileron is usually undergoing some motion because of the control system maintaining trim along with some amount of freeplay in the surface.

The effective operation of the DEI excitation system is indicated by Figs. 1c and 2c. Modes are strongly excited up to the commanded maximum sweep frequency of 30 Hz, with a sharp decrease in power above this frequency. The frequency sweep is the commanded linear function that allows the high-frequency modes to be as strongly excited as the low-frequency modes. Additionally, the observed modes match well with the symmetric modes listed in Table 1 to indicate the exciters maintained nearly 0 deg of phase difference during the commanded symmetric sweep.

The DEI exciters did not sweep above 30 Hz, and so any excitation above that frequency is a result of atmospheric excitation, as evidenced by the comparable power levels above this frequency in subplots a and c of Figs. 1 and 2. The lateral stick commands were most effective at exciting modes below 10 Hz, although the power level in the measured data between 10 and 30 Hz is higher than that obtained from atmospheric turbulence. Above 30 Hz the power measured in response to pilot stick commands is similar to that measured using atmospheric turbulence.

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