Engineering Notes

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Ride Quality Flight Testing

Robert L. Swaim*
Purdue University, West Lafayette, Ind.

Introduction

OTHER than seating density, physiological factors, and cabin environmental factors, the ride quality that airplane passengers receive is a function of airframe rigid-body and elastic dynamic responses produced by atmospheric turbulence and pilot, autopilot, and stability augmentation system control inputs. These responses result in vertical and lateral normal accelerations of the cabin, and the amplitudes and frequencies of the corresponding load factor distributions are the primary variables affecting ride.

A number of analytical methods are available for predicting ride quality that utilize amplitude and/or frequency data.[1-4] In order to assess the worth of analytical methods, flight test data should be obtained to compare with analysis. This Note describes a frequency response method that can be used to select sinusoidal elevator input time histories which yield vertical load factor distributions, within desired minimum and maximum bounds, as a function of fuselage station.

Method

The vertical load factor in g's is given by Eq. (1), where U_0 is the trim airspeed, γ and θ are the perturbation flight path and pitch angles, ξ_i the ith elastic mode generalized coordinate, and $\phi_i(l_x)$ the mode shape at fuselage station l_x.[4] l_x is positive when it is forward of the center of gravity and negative aft.

$$n_z(l_x,t)=\frac{1}{g}\left[U_0\dot{\gamma}+l_x\ddot{\theta}-\sum_{i=1}^{n}\phi_i(l_x)\ddot{\xi}_i(t)\right] \tag{1}$$

The amplitude and frequency content of n_z can be studied by considering a sinusoidal elevator input given by

$$\delta_e(t)=\delta_{e_{\max}}\sin\omega t \tag{2}$$

In the frequency domain, n_z is given by

$$n_z(l_x,\omega)=|n_z(l_x,\omega)/\delta_e(\omega)|\,\delta_{e_{\max}}\sin(\omega t+\psi) \tag{3}$$

where ψ is the phase angle and $|n_z(l_x,\omega)/\delta_e(\omega)|$ is the magnitude of the transfer function $n_z(l_x,s)/\delta_e(s)$ evaluated at $s=j\omega$. The transfer function amplitude can be evaluated for a range of excitation frequencies that goes from below the short-period frequency to above the highest frequency elastic mode included in the aircraft dynamic model. Examination of plots of the amplitude ratio, as a function of fuselage station, will allow selection of the most appropriate excitation frequency and elevator amplitude $\delta_{e_{\max}}$ to avoid exceeding fuselage structural limitations. To avoid overstressing wing and tail surfaces, the load factor amplitude would need to be calculated at selected wing and tail stations as well.

Example

The two-degree-of-freedom short-period, plus the first symmetric elastic mode equations of motion for the B-1 airplane at a Mach 0.85 sea level flight condition, are given by Eq. (4) in Laplace form.[5]

$$\begin{bmatrix} s+1.21 & -0.94 & 0.00021s+0.0091 \\ 0.48s+7.65 & s+1.57 & 0.0075s+0.19 \\ -2.26s+735.19 & 135.40 & s^2+1.14s+177.43 \end{bmatrix} \times \begin{bmatrix} \alpha(s) \\ \dot{\theta}(s) \\ \xi_1(s) \end{bmatrix} = \begin{bmatrix} -0.29 \\ -15.19 \\ -2228.40 \end{bmatrix} \delta_e(s) \tag{4}$$

First, considering only the rigid-body dynamics by deleting the elastic mode, the fuselage load factor transfer function is

$$\frac{n_z(l_x,s)}{\delta_e(s)}=\frac{(8.52-0.47\,l_x)s^2-(8.08+0.50\,l_x)s-474.41}{s^2+3.23s+9.10} \tag{5}$$

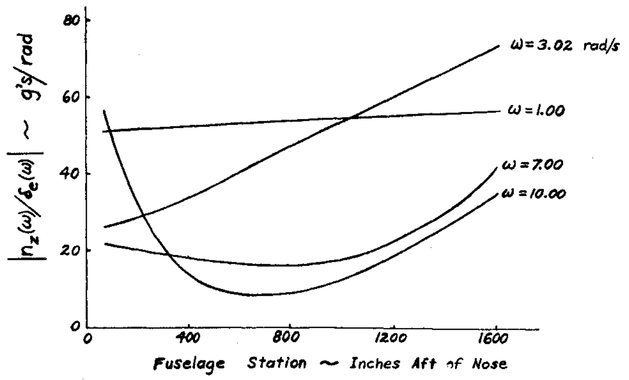

Fig. 1 Rigid-body load factor steady-state amplitude ratio for B-1.

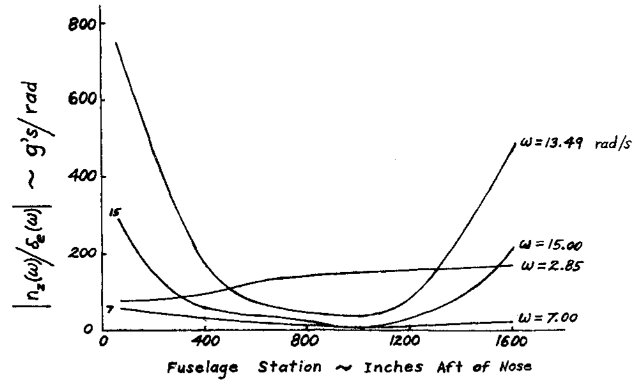

Fig. 2 Elastic load factor steady-state amplitude ratio for B-1.

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*Professor and Associate Head, School of Aeronautics and Astronautics.

The frequency response amplitude plots are shown in Fig. 1. The short-period undamped natural frequency is 3.02 rad/s. Notice the considerable change in curve shape and mean level with frequency. If, for example, we wish to hold the maximum load factor at all stations below 0.5, then we could use a $\delta_{e_{max}}$ amplitude of 0.01 rad and frequency of 7 rad/s.

If we include the elastic mode, the transfer function is

$$\frac{n_z(l_x,s)}{\delta_e(s)} = \frac{[8.52-0.47l_x+69.23\phi_I(l_x)]s^4+[-12.20-1.07l_x+154.32\phi_I(l_x)]s^3+[-94.64-70.21\,l_x+224.63\,\phi_I(l_x)]s^2+[-1977.87-75.84\,l_x]s-71{,}968.00}{s^4+4.36s^3+190.08s^2+570.79s+1473.14} \tag{6}$$

The plots are in Fig. 2. The coupled short-period frequency is now 2.85 rad/s, and the coupled elastic mode frequency is 13.49 rad/s. Note the very large amplitudes at these two resonant frequencies. It would appear that 7 rad/s would still be a good choice for excitation frequency. Of course, more than one elastic mode would be included in an actual analysis.

Acknowledgment

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References

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