Flutter Prediction Involving Trailing-Edge Control Surfaces

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Abstract

A FLUTTER incident occurred during flight testing of the T-46A that was not predicted by analyses. The flutter mode consisted largely of wing bending and aileron rotation. Further calculations showed that the predicted effectiveness of the trailing-edge control surfaces had to be decreased in order to accurately predict flutter.

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An unexpected flutter incident occurred during flight flutter testing of the T-46A jet trainer. The static unbalance of the ailerons had been changed in order to avoid a flutter mode predicted by analyses, and the intention was to fly up to 200 knots and excite the plane via stick raps. At approximately 205 knots, the pilot displaced the stick to excite the ailerons; this action was enough to induce flutter. Onboard measuring equipment showed oscillations of approximately 8 Hz. The flutter mode apparently involved the first bending mode of the wing coupling with an aileron rotation mode. The pilot was able to slow the plane quickly, and flutter stopped at approximately 150 knots. For this effort, the experimental flutter speed was assumed to be 150 knots.

The T-46A is interesting to the dynamicist and the flutter analyst. The ailerons are not directly connected to the stick and are not connected to each other. Instead, they are supported by soft springs and driven by a small tab at the trailing edge of each aileron. The tabs are, in turn, connected to the stick via a cable arrangement. The result is that ailerons are quite free to move independently, and also that the first vibrational mode of the aircraft is the symmetrical aileron rotation mode at about 1.8 Hz. The next two modes both involve large amounts of wing bending and occur at about 8.2 and 8.9 Hz, respectively. The proximity of an aileron rotation mode and wing bending modes is unusual in an age of aircraft whose control surfaces are driven by very stiff electrical or hydraulic actuators.

Military requirements state that aircraft must be free of flutter up to 115% of the design limit speed. The limit speed of 400 knots for the T-46 meant that the plane had to be free of flutter up to 460 knots. Analyses performed prior to the flight test in question indicated that a 33 Hz mode was present below 460 knots for aileron mass balance values above about 58%; 58% mass balance in this case means that weight was added ahead of the hinge line to equal 58% of the static unbalance of the aileron. These analyses also predicted an 8 Hz flutter mode in the 150–200 knot range at mass balance values of less than about 53%. In response, the mass balance was set at 55% for a series of flight tests. Previous testing had taken place at low speeds with a mass balance of 70% in order to avoid the 33 Hz mode, which was predicted to exist at higher speeds. A 280 knot placard was placed on the aircraft for the early series of flight tests.

Previous analyses used a beam model of the aircraft structure coupled with a strip-theory model of the aerodynamic surfaces. The fuselage was modeled structurally, but not aerodynamically. The beam structural model was tuned using data from ground vibration tests. The strip theory was modified with an elliptical spanwise pressure distribution to account for planform effects. In addition, the effectiveness of the ailerons and tabs was assumed to be that predicted by strip theory.

Following the flutter incident, two analyses were conducted at Wright-Patterson Air Force Base. Both used the beam structural model with some modifications following a ground vibration test of the aircraft after the flutter incident. The first used a strip-theory aerodynamic representation of the aircraft with the same elliptical spanwise pressure distribution and one further modification. The control surface effectiveness was decreased by multiplying the section aerodynamic coefficients involving the aileron and tab by a constant. For instance, a 30% reduction in effectiveness is obtained by using 0.70 as the multiplication factor.

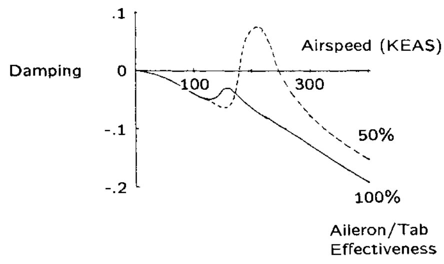

Fig. 1 Damping vs velocity as predicted by strip theory.

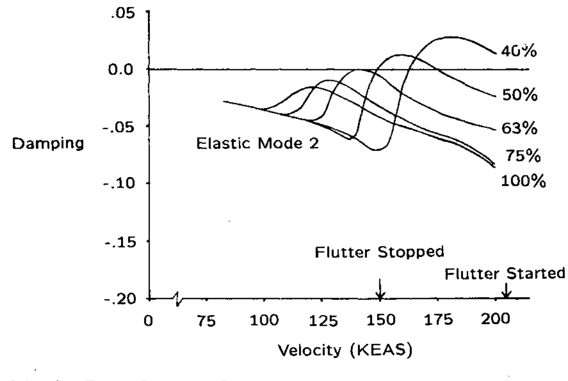

Fig. 2 Damping vs velocity as predicted by doublet lattice.

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The control surface effectiveness was varied, and damping vs velocity plots from two representative cases are presented in Fig. 1. It can be seen that assuming 50% effectiveness results in a prediction of flutter at about 170 knots.

The second analysis used the doublet lattice method to find generalized aerodynamic forces. In this case, the reduction in control surface effectiveness was accomplished by multiplying the real and imaginary components of the pressure coefficients over the control surfaces by a reduction factor. Effectiveness was defined as for the strip-theory calculations. Again, effectiveness values were varied, and damping vs velocity data is presented in Fig. 2. It can be seen that an effectiveness of 50% results in a prediction of flutter at about 150 knots.

Although there are few aircraft being designed with relatively flexible aileron-tab control systems, such configurations were common in the past. It has been known for some time that linear aerodynamic methods overpredict the effectiveness of trailing-edge control surfaces. This is largely because linear codes do not account for boundary-layer effects, which can cut down the effectiveness of such a surface. Many designers have schedules of effectiveness for given deflections, which are used for trailing-edge surfaces in steady flow. The effectiveness is likely to drop off further in an unsteady flow.

This effort should serve as a reminder to experienced flutter analysts, and a word of caution for those with less experience. Any analyses in which trailing-edge control surface rotation could play a part in the flutter mode should include some type of variation in the control surface effectiveness. The exact amount of variation depends on the aircraft configuration and the reduced frequency involved, and so no value can be given here. However, any flutter result that is significantly influenced by a change in effectiveness of a trailing-edge surface should receive careful consideration. Effectiveness values should be varied to see if reducing the effectiveness results in a prediction of flutter within the flight envelope.

References

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