Flutter of Asymmetrically Swept Wings

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Theme

RECENT interest in the use of an asymmetrically swept, high aspect ratio wing to achieve high lift-to-drag ratios has focused attention on the aeroelastic stability characteristics of this oblique-winged aircraft. The undesirable static aeroelastic divergence characteristics of symmetrically swept forward wings has led to serious questions as to the feasibility of such a design. Jones and Nisbet[1] have presented data that tend to allay some misgivings about the aeroelastic stability characteristics of oblique wings. Prominent among their findings, based upon a quasi-static aerodynamic model, is the discovery that the rigid-body roll degree of freedom appears to have a stabilizing influence on flutter.

The present study further explores the aeroelastic stability of obliquely swept wings. From these studies, it is found that the ratio of wing-to-fuselage roll moment of inertia significantly affects the aeroelastic stability of the aircraft. In addition, two fundamental types of instability are found to occur; the first, termed body-freedom flutter, is associated with significant rolling motion of the aircraft, whereas the second, fixed-root flutter, is relatively unaffected by the rigid-body roll freedom.

Contents

In order to assess the significance of the rigid-body roll degree of freedom to the aeroelastic stability behavior of an oblique-winged aircraft, a simple model was defined first. This model, which is discussed fully in the backup paper, consisted of a uniform wing in incompressible flow. The wing was given freedom to roll as a rigid body, and also freedom to bend along a straight elastic axis. Analysis of this model revealed that, if freedom to roll was eliminated, the swept-forward portion of the oblique wing undergoes aeroelastic divergence at relatively low speeds. When the fuselage was freed so that the model could roll, the mode of instability changed from static divergence to flutter, the flutter speed being larger than the previously found divergence speed for any given sweep angle. These results tend to confirm the results in Ref. 1.

This model had several deficiencies, the most serious being the use of a limited number of modes of deformation (bending only) and the assumption of quasi-steady aerodynamics. In order to remedy these deficiencies, a finite-element model of a flexible wing, free to roll, was developed. This model takes into account both bending and torsional flexibility, and allows wing structural, inertial, and aerodynamic characteristics to vary along the span. A flutter analysis was conducted, using a matrix equation approach, with assumed mode methods as described by Rodden.[2] The aerodynamic influence cofficient matrix is computed using the doublet-lattice theory.[3] Structural stiffness and mass matrices are computed, using conventional finite-element theory applied to beam bending and torsion behavior. The aerodynamic influence coefficients are functions of Mach number, and reduced frequency, $k=\omega b_r/2V$, where ω is the frequency of oscillation, b_r is a reference semichord, and V is the airspeed. The familiar V-g method of flutter analysis (Ref. 4, pp. 565–568) was used to ascertain the velocity at which flutter occurs.

An analysis of the wing studied previously, using strip theory aerodynamics, was conducted, this time employing doublet-lattice aerodynamics and the first 20 natural modes of the system. The results of this study are shown in Fig. 1. The wing, with its fuselage clamped, experiences static aeroelastic divergence at $k\cong 0$, signifying that the instability is aperiodic with time when roll freedom is disallowed.

However, with the aircraft free to roll, aeroelastic instability occurs as flutter. More importantly, the analysis reveals two basic modes of flutter instability. The first type is characterized by a bending-torsion oscillation, coupled with a significant amount of rigid-body roll oscillation. The second type of flutter oscillation resembles classical, swept-wing, bending-torsion flutter with little, if any, rigid-body roll motion. Depending upon the sweep angle, one of these modes will occur first as airspeed is increased.

Figure 1 reveals that the bending-torsion-roll mode does not become critical until the sweep angle is nearly 15 deg. The cusp in the V_f vs Λ curve indicates that the mode of instability changes at this point. Associated with this changeover is a discontinuous change in flutter oscillation frequency.

Gaukroger[5] has noted similar phenomena for bilaterally symmetric aircraft. A phenomenon termed "body-freedom" flutter is found to occur if the fuselage pitch moment of inertia is small enough. This body-freedom flutter involves significant coupling between the elastic degrees of freedom and rigid-body pitching oscillation. For large values of pitch inertia, the mode of flutter instability changes to "fixed-root" wing flutter in which the wing behaves as if pitching freedom were not allowed, i.e., the wing root is clamped. Gaukroger also notes that the same type of phenomenon is possible theoretically if the fuselage roll moment of inertia is either ex-

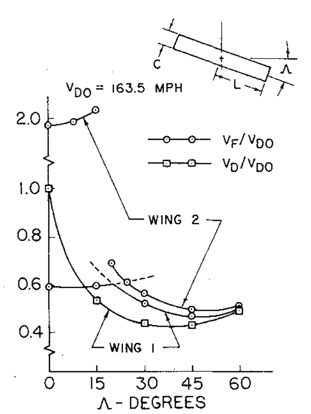

Fig. 1 Uniform property wing; ratio of fixed-fuselage divergence and roll-free flutter velocities to the fixed-fuselage divergence velocity at zero sweep angle, V_{DO}; doublet-lattice aerodynamics; torsional stiffness distribution of wing 2 is 10 times that of wing 1.

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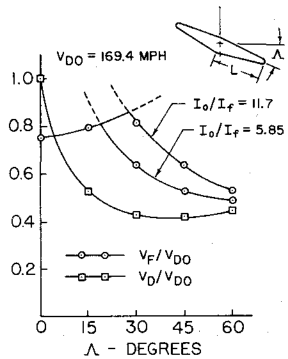

Fig. 2 Nonuniform property wing; ratio of fixed-fuselage divergence and roll-free flutter velocities to the fixed-fuselage divergence velocity at zero sweep angle, V_{DO}; doublet-lattice aerodynamics; wing-to-fuselage roll moment of inertia ratios differ by a factor of 2.

tremely small or mathematically negative. For these small hypothetical values of fuselage roll inertia, body-freedom flutter at low values of reduced frequency k is found to be possible for symmetrical aircraft.

This behavior of symmetrical aircraft is in contrast to the results shown here for the oblique-winged aircraft. In this latter case, if the fuselage roll inertia is large enough, in comparison to the wing roll inertia, the body-freedom type of flutter will become critical. This occurs if the wing is swept such that its roll moment of inertia becomes small enough. Body-freedom flutter is seen to be undesirable because, as Λ increases, the flutter speed decreases.

An additional example of this type of flutter behavior is seen in Fig. 2. Again, a small wind-tunnel model is analyzed at Mach number equal to zero. This model has a variable chord and is constructed of thin, aluminum sheet-metal. Two cases were studied; in the first case, the wing-fuselage combination had a wing-to-fuselage roll moment of inertia ratio I_o/I_f (in the unswept position) of 5.85. In the second case, the fuselage moment of inertia was reduced by a factor to two so that $I_o/I_f = 11.7$. Figure 2 displays the results of the aeroelastic stability analysis of each wing-fuselage combination.

With the wing root clamped, not free to roll, the mode of instability for both combinations is bending-torsion divergence. With freedom to roll, stability behavior is encountered similar to that seen for the uniform property wing. For small values of Λ, both wing-fuselage combinations undergo "fixed-root" flutter at nearly identical speeds. It is seen that the cusp in the V_f vs Λ curve is moved to the right if the fuselage roll inertia is decreased. In addition, decreasing the fuselage roll inertia is seen to cause a wider separation between the clamped divergence speed and the roll-free flutter speed, even in the body-freedom mode.

As a final example, consider again the uniform property wing that was first discussed. The effect of greatly increasing the torsional stiffness distribution was studied to discover its effect on oblique wing flutter. The results are shown superimposed on Fig. 1. Wing 1 refers to the uniform property wing, analyzed previously with doublet-lattice aerodynamic theory. Wing 2 is identical to Wing 1 in all respects, except that the torsional stiffness distribution GJ of Wing 2 is ten times that of Wing 1.

Figure 1 reveals that the relation between flutter speed and Λ has an apparent discontinuity near $\Lambda = 15$ deg. Increasing the value of GJ is found to have a pronounced effect on flutter speed at low sweep angles, but has little effect on flutter at high sweep angles when flutter is of the body-freedom type.

The results presented in this paper indicate that: with the rigid-body roll freedom included, loss of aeroelastic stability occurs, not as divergence, but as flutter; flutter of asymmetrically swept or oblique wings can appear either as fixed-root flutter or as body-freedom flutter. Fixed-root flutter is characterized by relatively high reduced frequencies of the order of $k = 0.3$; body-freedom flutter is characterized by low reduced frequencies, $k = 0.03$, and significant coupling between rigid-body roll and elastic deformation oscillations. Body-freedom flutter leads to relatively low flutter speeds as compared with fixed-root flutter (except for small values of Λ). As a result, any method that can delay the appearance of body-freedom flutter will enhance the stability characteristics of the aircraft.

The models analyzed represented low-cost, sheet-metal, wind-tunnel models. These models have considerably more bending and torsional strength than real aircraft; they also have wing sectional shear centers that are coincident with the centers of mass. Analysis of strength-designed wings may reveal characteristics somewhat different than those shown here. Dynamic or elastic "wing tailoring" may be possible such that the body-freedom instability can be avoided altogether.

References

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