

Flutter characteristics of a sailplane wing

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Foreword

The flutter problem in aeronautical structures is not a new one: it became more and more important as the aircraft speed increased but it cannot be disregarded even in slow flying aircraft particularly when structural stiffnesses are low. Sailplanes, with their light wings of high aspect ratio, have flexibilities much higher than any conventional motor plane of the same maximum speed, and may undoubtedly run more easily into aeroelastic troubles. Some recent incidents possibly due to flutter occurred on various sailplanes, and a number of computations have been carried out at the CVT to clarify some aspect of the phenomenon, and test the susceptibility of sailplane structures to flutter.

At the present time no adequate criteria are available in this field and of course the designer is not expected to face flutter computations, always expensive and time consuming; it is nevertheless important that he knows the problem, and is able to introduce into his design those points useful to avoid or cure possible instabilities.

The aim of this paper is to point out some of the flutter characteristics of a sailplane wing, of course without pretending to reach definite general conclusions.

General data

The wing under investigation is shown in Fig. 1. It is a wing of the standard class with a 15 m² area. Taper ratio is 1:3, and the root chord is 1.5 m. The aileron runs through half a span with a chord equal to 25% of the wing local chord. Elastic axis was assumed at 25%, this being a reasonable figure for wood construction with a single spar and a torsion box leading edge. The weight of a half wing is 49 kg (surface weight 6.6 kg/m²), and the CG is at 50% of the chord. The aileron structural weight is 4.2 kg, and the CG is 0.3 of the aileron chord aft of its hinge line. The radius of gyration about CG for the wing and aileron was taken 25% of the chord of wing and aileron respectively. Span weight distribution was assumed proportional to the chords.

All these data, although not pertinent to any specific sailplane, are however average values, checked on various standard sailplanes.

As far as stiffnesses are concerned, some tests made at the CVT made it possible to approximately compute the wing bending and torsion modes, associated with a bending frequency $\omega_b = 2$ cps and a torsion frequency $\omega_t = 15$ cps. Uncertainties in the determination of such frequencies may certainly alter the absolute value of the results, but cannot change the flutter general trends.

Flutter calculations

Calculations have been carried out in three degrees of freedom, by considering the wing free to vibrate in bending and torsion and the aileron free to rotate, without torsion, about its hinge line with an adequate elastic restraint to define its frequency. In the calculations, the wing torsional stiffness, the aileron restraint and the aileron massbalancing have been varied.

Oscillatory aerodynamic coefficients are those of Theodorsen and Küssner, taken from the qualified bibliography.

All results are expressed in the form familiar to aeroelasticians, in diagrams where damping g and frequencies ω of pertinent modes are plotted in terms of the flight speed V . (Structural damping is a function of the vibration amplitude and not of the frequency. It may be considered as a force in phase with the vibration speed and proportional to the elastic restoring force; the coefficient g is the proportionality factor. Mathematically, a free linear vibration of an elastic system of mass M and natural frequency ω_0 , may be described by the equation

$$M\ddot{x} + M\omega_0^2(1 + ig)x = 0$$

where i is the imaginary unit.)

A wing, at zero speed, has a number of vibration natural modes, each one associated to a certain frequency and a certain structural damping. While speed increases, damping of these modes also increases, due to the aerodynamic action; the frequency may increase or decrease. This increase in damping continues up to a certain speed, where it begins to decrease: the damping may even change sign at a definite speed, which means that the oscillation is no longer stable but becomes oscillatory divergent. The critical flutter speed has been reached. We shall not enter here into the nature of the phenomenon, this being beyond the scope of the present study; we shall only add that the instability or instabilities always occur from the interaction or "coupling" of two different vibration modes: therefore a wing bending-aileron flutter will be an instability rising from the coupling between the wing bending mode and the aileron rotation, although a certain minor contribution of other modes may be present.

In Fig. 2 a typical damping diagram is plotted for the wing considered. The aileron frequency was assumed 2 cps. The aileron has no massbalance. The following considerations may be drawn. The damping for the wing bending

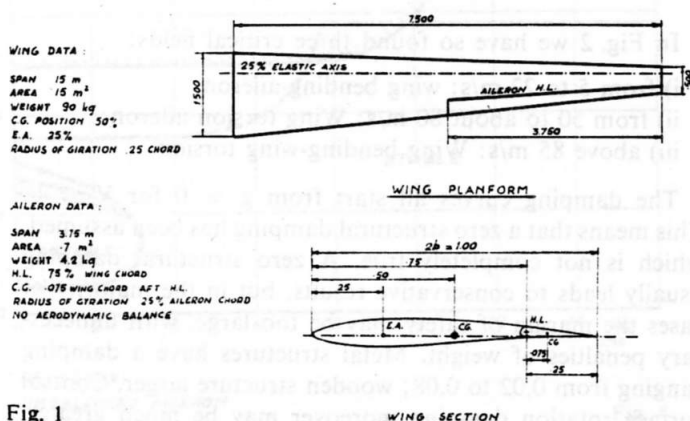
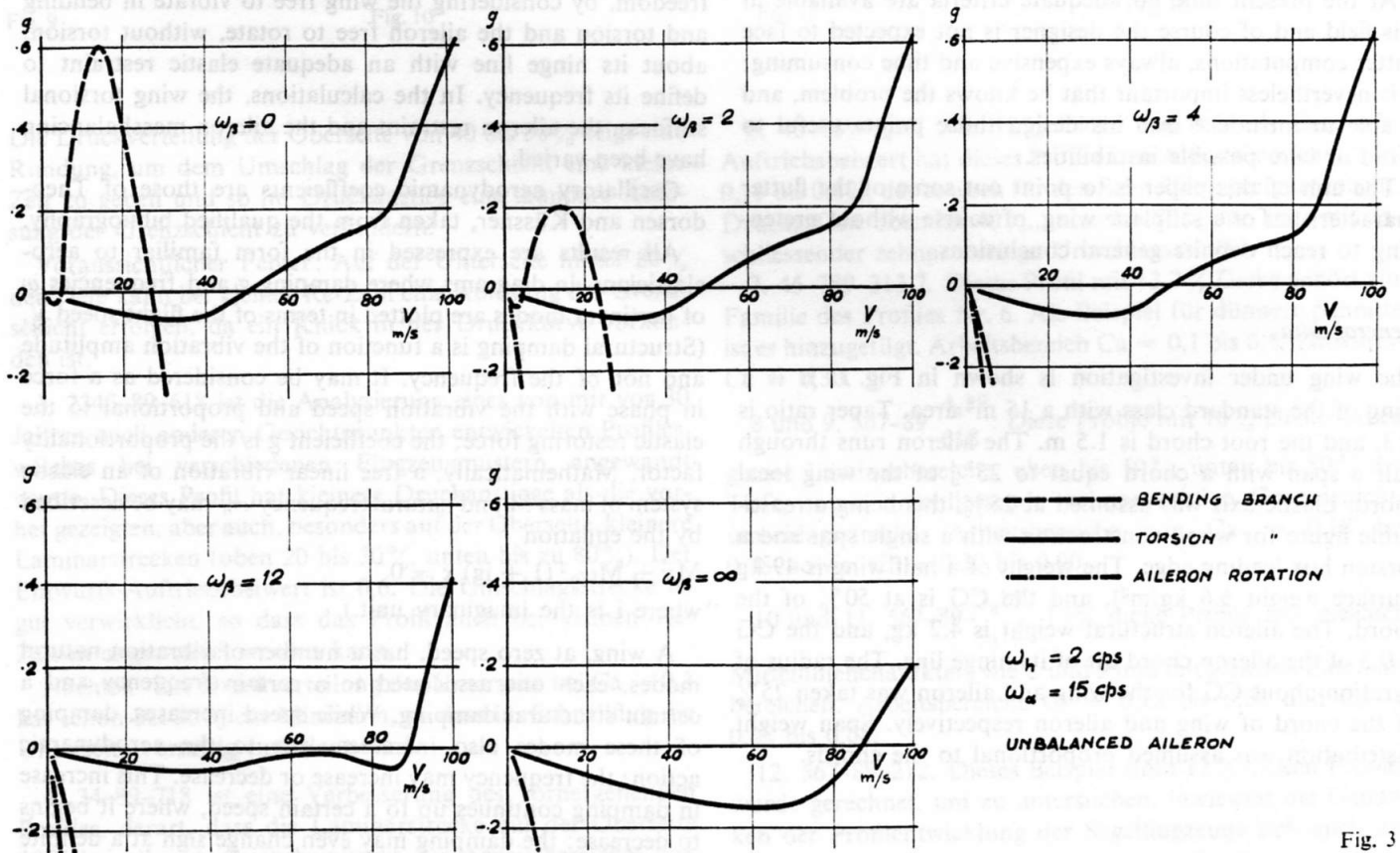
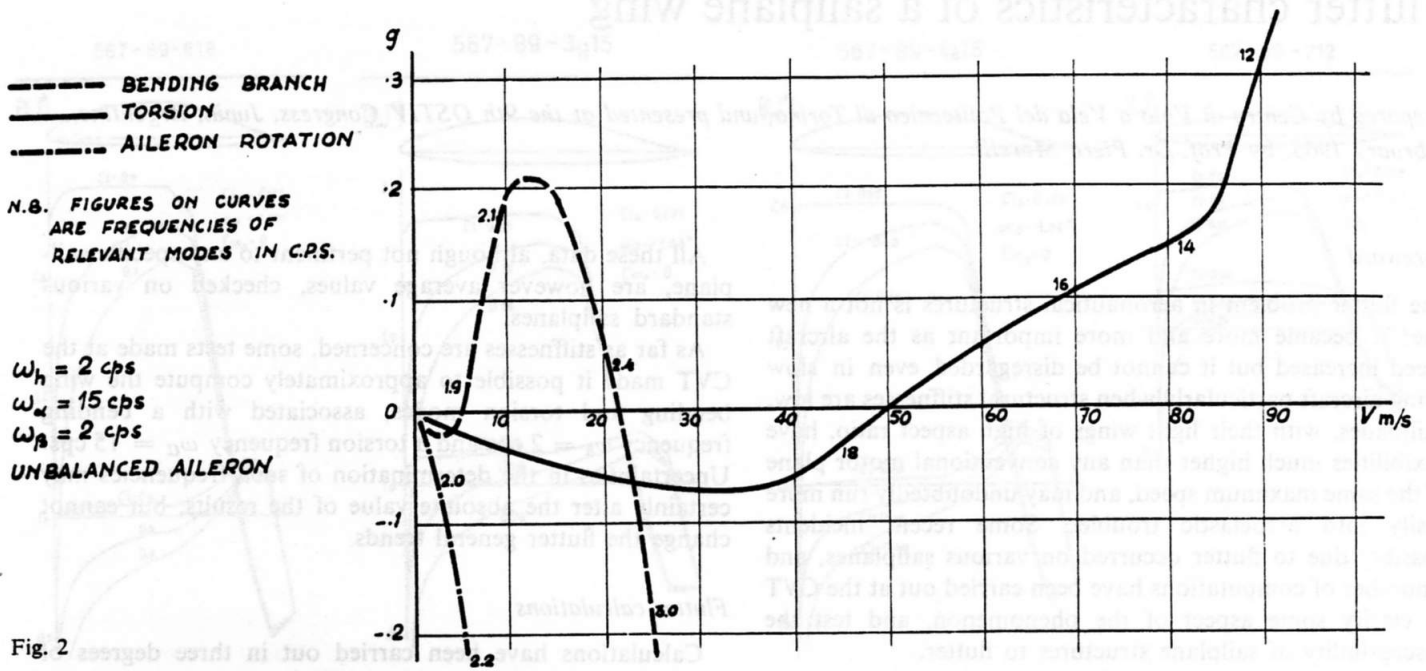


Fig. 1



branch becomes positive (unstable) at a very low speed. The first critical flutter speed is attained at about 5 m/s, with a frequency of 2 cps. This instability is due to the wing bending - aileron coupling; it vanishes at 22 m/s, where the wing is stable again. At 50 m/s the wing torsion branch becomes unstable by the coupling with the aileron rotation. The new flutter frequency is about 17 cps. Between 80 and 90 m/s the damping of the torsion branch exhibits a sudden rise, which implies that a new kind of instability is taking place. In fact, the wing bending - torsion coupling is now responsible for this critical area. The large positive values of g , indicate that the vibration amplitude amplifies quite abruptly.

In Fig. 2 we have so found three critical fields:

- i) from 5 to 22 m/s: wing bending-aileron;
- ii) from 50 to about 80 m/s: Wing torsion aileron;
- iii) above 85 m/s: Wing bending-wing torsion.

The damping curves all start from $g = 0$ for $V = 0$. This means that a zero structural damping has been assumed, which is not completely true. A zero structural damping usually leads to conservative results, but in the majority of cases the margin of safety may be too large, with unnecessary penalties of weight. Metal structures have a damping ranging from 0,02 to 0,08; wooden structure larger. Control surface rotation damping moreover may be much greater.

to take into account the effect of damping we can as first approximation shift the abscissa axis upward according to the value chosen for the damping: on the same diagram we shall read the new values for the critical speeds.

The frequency ω_β of the control surface rotation, has a fundamental importance on the stability curves. This frequency is often quite difficult to determine, and it is not at all constant during the aircraft life. Altitude, wear, cable tension, are all elements which may change it and often the pilot, by tightly gripping the stick, may somewhat alter the stiffness conditions (and therefore the frequency) of the control. Because of all these uncertainties, it is preferred in the calculations to consider all possible values of ω_β and verify that no frequency may lead to critical configurations. Therefore, in Fig. 3, the calculations are plotted for different ω_β from zero to infinity. The case $\omega_\beta = 0$ corresponds to a completely free aileron with no elastic restraint; the $\omega_\beta = \text{infinite}$ case corresponds to an aileron rigidly clamped to the wing; the intermediate cases correspond to different stiffnesses between aileron and control stick. (In the symmetrical oscillations the stick is a nodal point and the pilot is unable to affect the frequency of the aileron.)

From the diagrams we can see that the first instability areas vanish by stiffening the control line, leaving the last instability (85 m/s) which depends, as already mentioned, no longer on the aileron but only on the wing structure. At $\omega_\beta = 4$ cps the instability wing bending - aileron fades away; at 12 cps the wing torsion-aileron has gone. Values likely to be met for the aileron frequencies in a sailplane are about 5 cps, but, as said before, such a datum simply indicates an order of magnitude.

In Fig. 4 the results obtained with different wing torsional stiffnesses are reported. From the curves we see that, while

the first low instability remains practically unaltered varying ω_α , the upper limit shifts upward and to the right by increasing the torsional frequency, more or less proportionally to this. Note that the curves for increasing ω_α partly overlap, and therefore indicate, for certain ω_β a reduction in the flutter critical speed against a limited increase in torsional stiffness. Elimination of the lower instability would have occurred, should an increase in the wing bending frequency have been considered. A powerful means for eliminating control surface flutter is massbalancing. Masses are placed concentrated or distributed along the span ahead of the aileron hinge line. The mechanism through which masses are effective in reducing the flutter boundaries, is that they strongly decrease the inertia coupling between the wing and aileron modes. In Fig. 5 the flutter boundaries in terms of the aileron natural frequency ω_β are shown for zero massbalance, for a 25% static massbalance and for a 50%. Total static massbalance occurs when the aileron + masses center of gravity falls right on the hinge line. Massbalance has the effect of shrinking the critical areas due to an aileron-wing coupling and, if sufficiently high, can completely sweep them off. Of course the instability due to wing modes coupling still persists and, if dangerous, must be attacked with quite different means. However, the low speed flutter instabilities can positively be fixed by a properly mass-balanced control surface.

For sake of clearness, in Fig. 6 the flutter boundaries have been plotted in terms of the aileron massbalance, for three different values of the frequency ω_β . Let us examine the case $\omega_\beta = 0$, the most critical of the three. Also here the low speed instability shrinks when massbalance is increased, but a 70% massbalance must be attained to be sure that we are beyond the instability area. In this study this same mass-

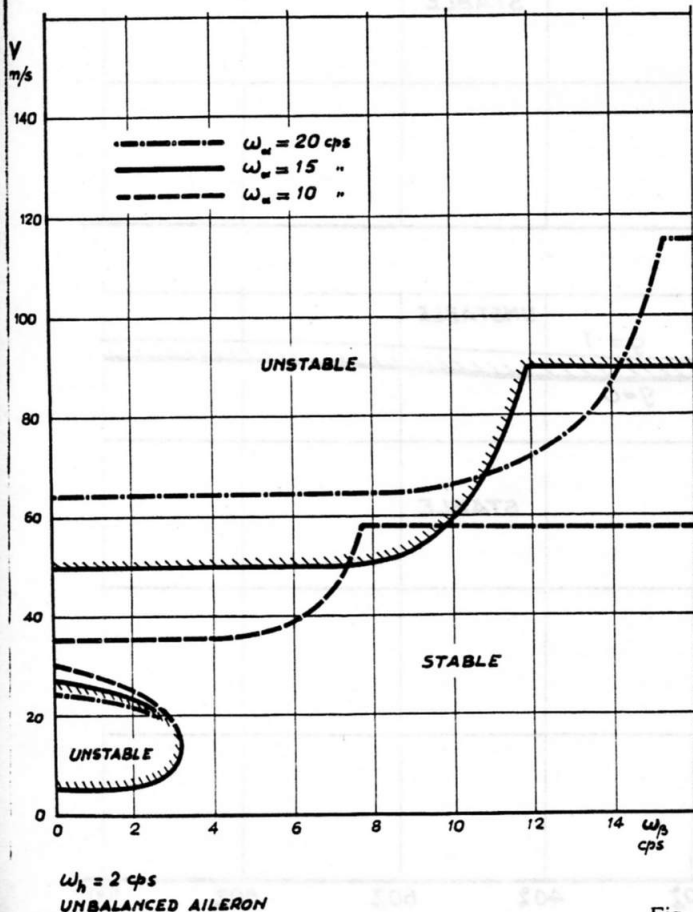


Fig. 4

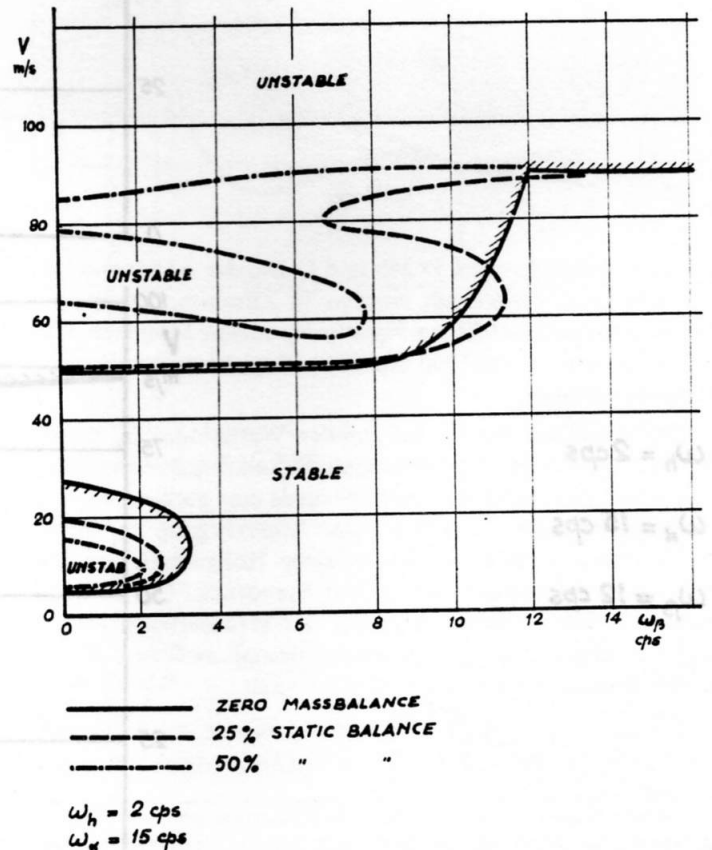
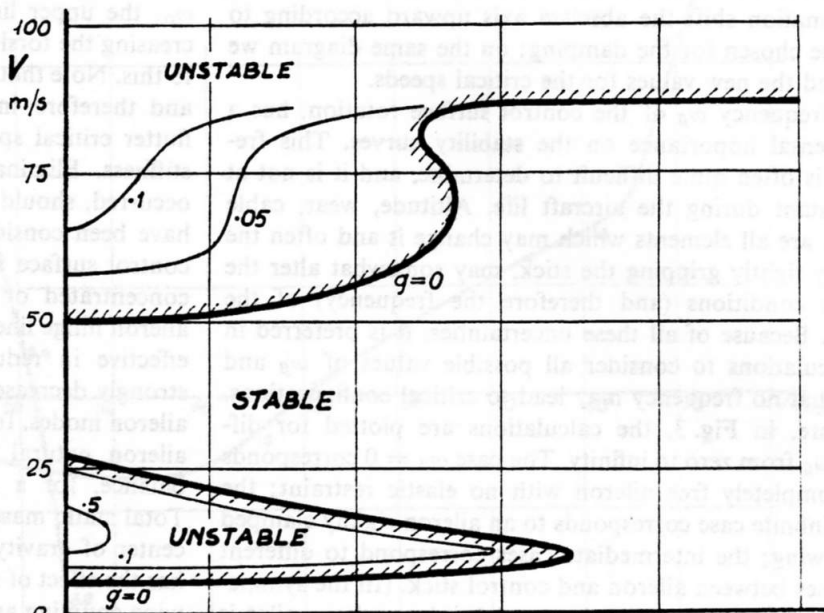


Fig. 5

$$\omega_h = 2 \text{ cps}$$

$$\omega_\alpha = 15 \text{ cps}$$

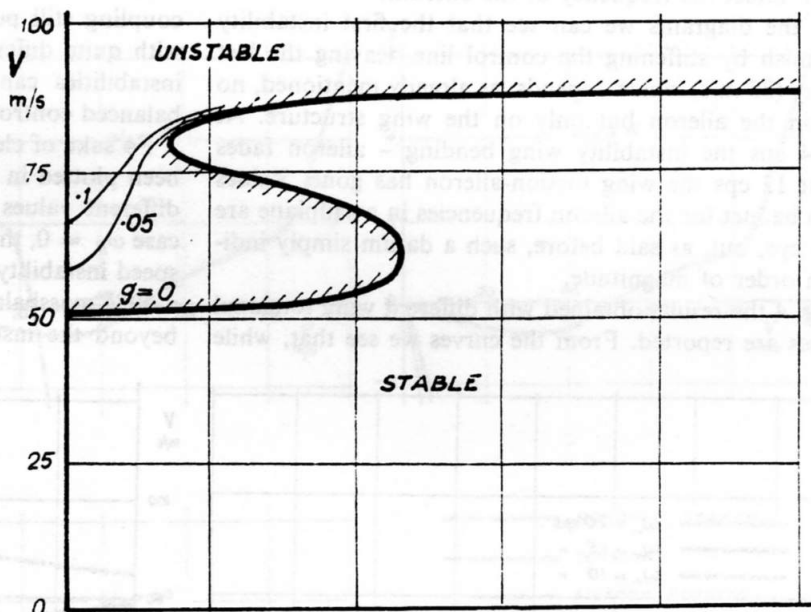
$$\omega_\beta = 0$$



$$\omega_h = 2 \text{ cps}$$

$$\omega_\alpha = 15 \text{ cps}$$

$$\omega_\beta = 8 \text{ cps}$$



$$\omega_h = 2 \text{ cps}$$

$$\omega_\alpha = 15 \text{ cps}$$

$$\omega_\beta = 12 \text{ cps}$$

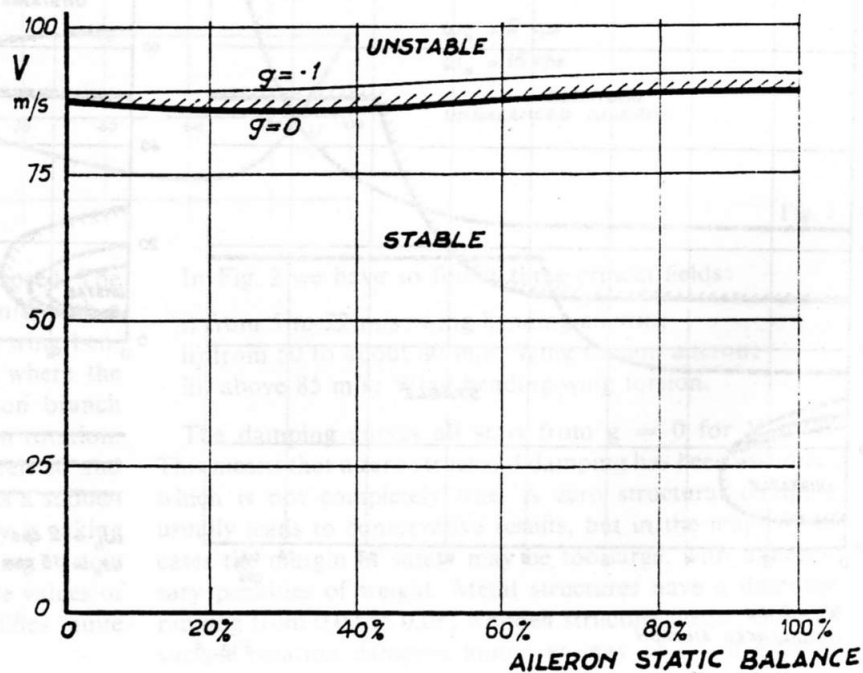


Fig. 6

balance is sufficient to eliminate the instability due to wing torsion-aileron, but this is not always so, as a higher degree of massbalance should be often adopted in wing torsion-aileron cases.

Another parameter can modify the general flutter trend: the structural damping of the vibration modes. For this purpose, on the same diagrams the curves for other values of damping are plotted; we see how the flutter boundaries are seriously affected by this, and we see how important its influence is. Unfortunately, as already mentioned, extreme care must be taken when damping is intended to stabilize a critical area, because a reduction in damping, if it occurs, may lead to disastrous effects.

The two other diagrams show the same things for $\omega_p = 8$ cps and 12 cps.

Conclusions

The calculations carried out and here presented may give an idea of the complexity of the problems to be faced when

entering the dynamic aeroelastic domain. From this study a few conclusions may be drawn:

1. Critical flutter speeds, even very low, are actually possible on a sailplane.
2. Such speeds generally result from the coupling between main structure and control surface vibration modes.
3. These flutter boundaries may be completely eliminated by properly massbalancing the control surface or by increasing the natural frequency of the control line.
4. The use of an artificial damping may be a powerful means to eliminate such instabilities.
5. Structural damping present in the wing or in the control line cannot be ignored, but careful attention must be paid to possible variations of damping during the aircraft life.

(Swiss Aero Review 1964/3)



Das Diagramm zeigt die beiden Flugzustände...

Die Messflüge wurden bei stabilen Wetterlagen in Höhen...

Für jede Geschwindigkeitsstufe wurde eine große Zahl von...

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