Experimental methods of determining the mass, elasticity and damping properties of sailplanes

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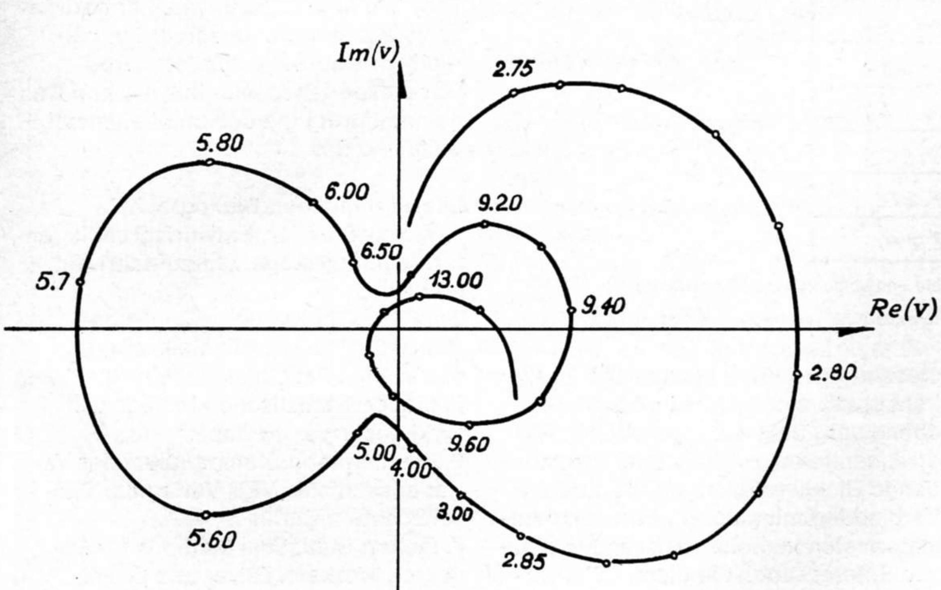
Introduction
During the first years when ground resonance tests were introduced they served mainly for the determination of natural frequencies and natural modes. At present, when we have to calculate more accurately the critical flutter speed of a sailplane, the range of these tests has been extended and the present task is the determination of all data necessery for the construction of the dynamic model of the sailplane. These data are: natural frequencies f_r, natural modes u_r, mass coefficients M_{rr} (generalized masses when r=s, and coupled masses when r≠s) and damping coefficients g_r.
The methods which will be discussed here, are based on the analysis of the records (fig. 1) obtained from the measurements of the amplitudes and phases (complex amplitudes) of deflections q or velocities v of the properly chosen points of the vibrating sailplane. These vibrations are excited by harmonic forces of variable frequency (usualy in the range 2 to 30 c/s) applied at selected points of the sailplane. From the point of view of accuracy, the measurement of the velocity of displacement is preferable.

Now we will discuss briefly the procedure applied in such tests.

Preparation of the sailphane for tests
During the tests the sailplane should be in conditions similar to these of free flight. Such conditions can be obtained as follows: 1. The sailplane is elastically suspended on rubber ropes at its centre of gravity. The stiffnes of the suspension has to be chosen in such a way that the natural frequency of the suspension—sailplane system should not amount to more than one—third of the lowest natural frequency of the sailplane (i. e. 0.5—1.0 c/s). The influence of such a suspension on the results is then negligible smaller than 5 %. 2. The pilot seat is loaded with a ballast weight (∾ 75 kg).
3. The control surface are locked in their neutral positions.

Determination of the natural frequencies
As is well known from the theory, the natural frequency f_r can be determined as the frequency for which either the amplitude is a maximum, or the phase between velocity and the exciting force is equal to 90° for deflection, or the derivative of arc length s (fig. 2) with respect to square of frequency, i. e. $ds/d(f)^2$ (in practice $\Delta s/\Delta f$) reaches its maximum value (fig. 3).



In our case the last requirement is used for the calculations, because, as tests have shown, it is very insensitive to the proximity of the resonance frequencies of different normal modes, damping, or distributions of points at which the pick—ups and exciters are located.

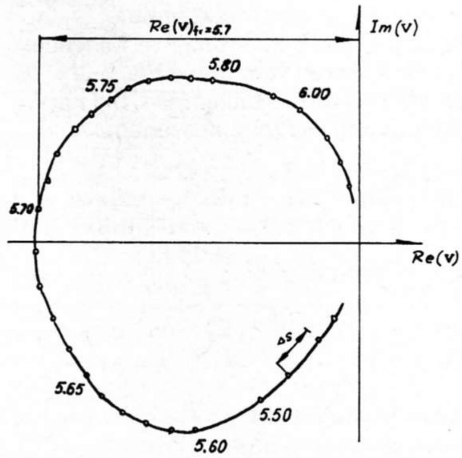


Fig. 2

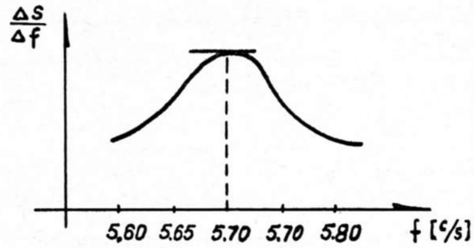


Fig. 3

Determination of damping coefficients
In the neighbourhood of the resonance frequency the plot of the imaginary part of the complex amplitude of velocity (the real part for deflection) versus the frequency is approximately linear (fig. 4). According to the theory, the damping coefficient (fig. 5) can be calculated from the formula:

$$g_r = \frac{2 \cdot \Delta f \cdot Re\,(v)\; f = fr}{fr \cdot \Delta\, Im\,(v)} \quad \text{or}$$

$$g_r = \frac{2 \cdot \Delta f \cdot Im\,(q)\; f = fr}{fr \cdot \Delta\, Re\,(q)}$$

where the values necessary for calculations are taken from the amplitude plots (fig. 2).

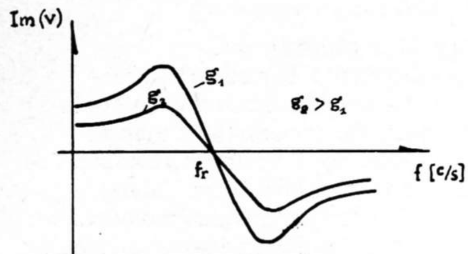


Fig. 4

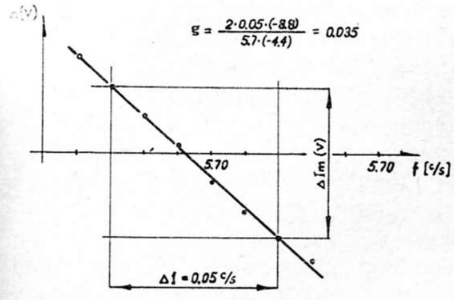


Fig. 5

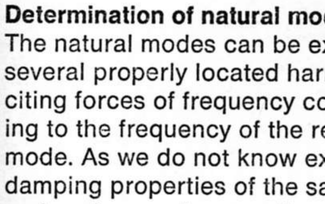
Determination of generalized masses
After adding small (0.25–0.50 km) masses in properly chosen points x_k of the sailplane (for example on the tips of wings), natural frequencies and generalized masses of the sailplane are changed. If we suppose that the shape of modes have not changed, we can calculate the growth of the generalized masses from the following relations:

$$\triangle M_{rr} = \sum_{K=1}^{n} m_k \cdot u_r^2 (x_k).$$

After finding the new natural frequencies f_{rm} of the sailplane with added masses, the generalized masses can be obtained in the same manner as for systems with one degree of freedom (fig. 6).

Determination of the coupled masses due to the control surfaces
These masses can be calculated if we know the natural modes of the sailplane, the masses of the control surfaces, their centres of gravity locations, and their moments of inertia around the hinge axis.

Determination of natural modes
The natural modes can be excited by several properly located harmonic exciting forces of frequency corresponding to the frequency of the required mode. As we do not know exactly the damping properties of the sailplane and we have only a small number of exciters, we cannot obtain pure modes.



$$\omega_r^2 = 4\pi^2 f_r^2 = \frac{C_r}{M_{rr}}; \qquad \omega_{rm}^2 = \frac{C_r}{M_{rr}+\Delta M_{rr}}$$

$$M_{rr} = \frac{\Delta M_{rr}}{\frac{f_r^2}{f_{rm}^2} - 1} = \frac{0.50}{0.035} = 14.2\ kg$$

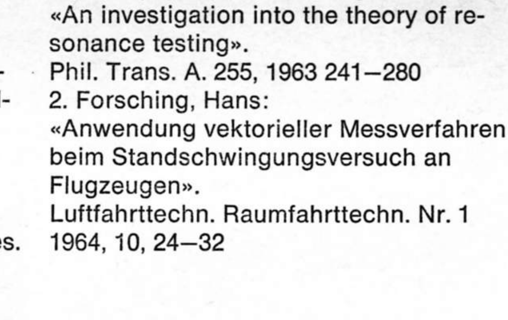


Fig. 6

After recording the complex amplitudes of velocities (deflections) of the properly chosen points of the sailplane (fig. 7 presents the amplitudes of points located along the wing span) we take into consideration only either the real parts of the complex amplitudes of velocities of the imaginary parts for deflections (fig. 8). This method, which is much simpler and requires less instrumentation than other methods (for example that proposed by O. N. E. R. A.), has given good results in actual sailplane tests.

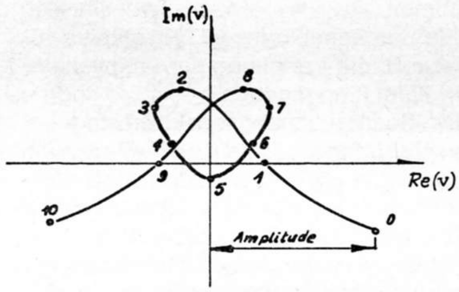


Fig. 7

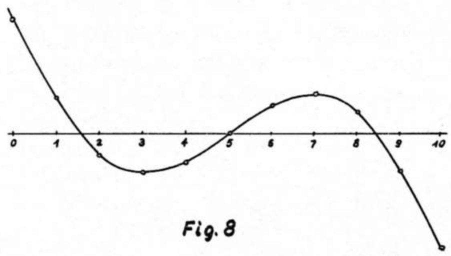


Fig. 8

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Zusammenfassung

Bodenresonanztests, die früher für die Bestimmung der Eigenfrequenzen und Eigenschwingungsformen verwendet wurden, werden jetzt erweitert, um auch Massen-Koeffizienten und Dämpfungs-Koeffizienten zu liefern. Die beschriebene Methode verwendet die Analyse von Amplituden und Phasen der Durchbiegung und der Geschwindigkeit (Figur 1).
Für die Versuche sollte das Segelflugzeug in seinem Schwerpunkt an einem Gummiseil frei aufgehängt sein. Die Eigenfrequenz der Aufhängung sollte 1/3 der niedrigsten Eigenfrequenz des Segelflugzeuges nicht überschreiten. Der Pilotensitz sollte mit 75 kg Ballast versehen und die Steuerorgane in Neutrallage festgelegt werden.
Die Eigenfrequenz wird durch die Ableitung ds/d(f)² (in der Praxis: △s/△f) bestimmt (Figur 2 und 3).
Der Dämpfungs-Koeffizient wird berechnet aus den Linearanteilen der Kurven des Imaginärteiles der komplexen Geschwindigkeits-Amplitude (oder im Falle der Durchbiegung aus dem Realteil) (Figur 4 und 5).
Die generalisierten Massen werden bestimmt durch die Änderungen der Eigenfrequenz, die aus der Addition kleiner Massen – beispielsweise an den Flügelenden – hervorgeht (Figur 6).
Die Kopplungsmassen (infolge Rudermassen) werden berechnet aus den Eigenschwingungsformen des Segelflugzeuges und aus den Rudermassen, Schwerpunktlagen und Trägheitsmomenten um ihre Drehachsen.
Die Eigenschwingungsform wird erhalten durch Erregung bei den Eigenfrequenzen. In der Praxis ist die Zahl der Erreger begrenzt und reine Schwingungsformen werden nicht erzielt. Die komplexen Amplituden der Geschwindigkeit (Realteile Figur 7) und Durchbiegung (Imaginärteile Figur 8) entsprechender Punkte werden aufgezeichnet. Die Methode ist einfacher als einige andere und hat in der Praxis gute Ergebnisse erzielt.

VERNON/ZACHER