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# Wind Tunnel Tests on the Flutter of a Swept and Un swept Wing with Ailerons

by

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ROYAL AIRCRAFT ESTABLISHMENT

WIND TUNNEL TESTS ON THE FLUTTER OF A SWEEP AND  
UNSWEEP WING WITH AILERONS

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H. Hall

and

J.A. Rein

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SUMMARY

Details are given of low speed flutter tests on an unswept and  $40^\circ$  sweptback wing, each wing having a half span, quarter chord aileron. The aileron massbalance and hinge stiffness were varied in the tests. Flutter calculations were made for both wings and show general agreement with the experimental results.

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## 1 INTRODUCTION

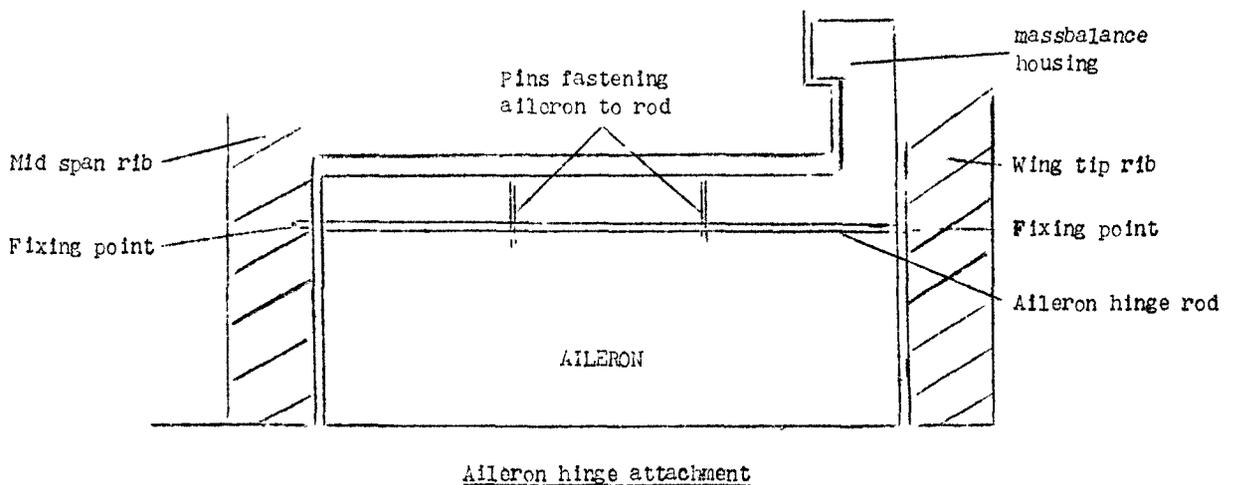
Wind tunnel tests have been carried out to investigate the low speed flutter characteristics of an unswept and sweptback wing having a half span aileron. The wings were to be used, in conjunction with rocket propelled vehicles, in a research programme to investigate wing-aileron flutter at transonic and supersonic speeds. The tests described in the paper were made to assist in planning the research programme.

Flutter calculations have been made, and some empirical corrections to the two dimensional derivatives were needed in order to obtain good agreement with the measured flutter characteristics. The modifications to the derivatives are discussed in the paper.

## 2 THE EXPERIMENTS

### 2.1 Model details and laboratory tests

The unswept wings are of constant 1 ft chord and have a semi-span of 2 ft. The thickness:chord ratio is 4% with a modified bi-convex section. A steel spar occupies the forward 5" of the wing chord, and aft of this the wing is entirely of balsa. The ribs are of light alloy, those at mid span and the tip being thicker as they carry the aileron hinge attachments. The aileron is pinned to a torsion rod which spans the aileron and is embedded at each end in the wing ribs. The rod thus provides both aileron hinge and circuit stiffness, and by varying the position of the aileron pins a variation of hinge stiffness may be obtained. A sketch of the arrangement is shown below. The ailerons are of 25% chord and 50% span, the aileron section being a complete box. Provision is made for aileron massbalance on an arm at the outboard end of the aileron.



The swept wings are derived from the unswept by shearing all sections in the line of flight to a sweepback of  $40^\circ$ .

Resonance and stiffness tests were made on the fixed root wings. The nodal lines and frequencies of the first three modes for the unswept and swept wing are given in Fig.1, together with the appropriate aileron uncoupled natural frequencies. Tests were made for two values of hinge stiffness for each wing. Results of the stiffness tests are given in Table 1.

### 2.2 Tunnel tests

The tests were carried out in the R.A.E. 5 ft diameter open jet tunnel. The unswept wing was mounted on a structure which roughly

represented the rocket body and was presumed to be rigid. In fact the structure used was much more flexible than had been supposed and the frequency of the wing fundamental mode was somewhat reduced from the fixed root value. The significance of this is discussed in Section 3.2.

A much more rigid structure was devised for the tests on the swept wing and no difference was found between the fundamental frequency of the wing fixed root or when mounted on the support.

Tests were made for various massbalance conditions, flutter speed and frequency being measured for each case. Frequency measurements were made by synchronising a Strobflash with the oscillating wing and the output of a photocell placed near the Strobflash was used to trigger a Dekatron counter<sup>1</sup>.

### 2.3 Results

The results for the unswept wing with the lower aileron hinge stiffness are shown in Fig.2 together with the corresponding calculated values. The tunnel tests show that as massbalance,  $m$ , is increased the critical speed of the wing flexure-aileron rotation type flutter decreases until a minimum occurs at approximately  $m = 0.04$  lb. Further increase of massbalance results in a slight increase of critical speed and above  $m = 0.08$  lb this type of flutter is eliminated completely. No flutter was found for the unswept wing with the stronger aileron spring.

The results for the flexure-aileron rotation flutter of the sweptback wing with the weaker aileron spring fitted are shown in Fig.3 together with the corresponding calculated values. The tests show a slight decrease in critical speed with increase of massbalance up to  $m = 0.02$  lb and then an increase of speed with increased massbalance up to approximately  $m = 0.09$  lb, where the nose of the curve occurs. With the stronger aileron spring fitted, no flutter was obtained but a poorly damped oscillation persisted from 110 to 240 ft/sec at a frequency of about 14 c.p.s., indicating a near flutter condition.

## 3 THE CALCULATIONS

### 3.1 Aerodynamic derivatives

The modification to the main surface derivatives used in the calculations are based on some work done to determine the aerodynamic effects of aspect ratio on wing flutter in which virtually rigid wings were used<sup>2</sup>. The application of this work to flexible wings, such as those used in the present tests, had not been tested before.

Static values of  $b_1$  and  $b_2$  were measured on the unswept wings and from these, values of the oscillatory derivatives  $h_\alpha$  and  $h_\beta$  were found. The corresponding damping derivatives were determined by Minhinnick's method<sup>4</sup> from these i.e. multiplying by the ratio of the asymptotic values of the two dimensional damping to stiffness derivatives. The methods of finding the other derivatives and their values are given in Table 2.

### 3.2 The unswept wing

A ternary calculation using two arbitrary wing modes and aileron rotation was performed. The arbitrary modes of distortion assumed for the wing were those of uncoupled uniform beam bending and torsion. The elastic coefficients in the flutter matrix were chosen so that the still air coupled frequencies derived from them were equal to the measured coupled frequencies obtained in the resonance tests on the wing with a rigid root mounting.

The results of the calculations are shown in Fig.2. Using the measured fixed root frequencies the calculations show a steady increase in critical speed with increasing massbalance until the flutter is eliminated at  $m \doteq 0.075$  lb. This result is in reasonable agreement with the experimental result for the location of the nose of the curve but the overall trend of flutter speed with massbalance is different.

Flutter of wing torsion-aileron rotation type is to be investigated in the rocket tests and the calculations were extended to cover this type of flutter in order to plan the tests. The results of this calculation are shown in Fig.4. There is an increase in critical speed with increasing massbalance up to  $m = 0.13$  lb where the nose of the curve occurs. Calculations based on two dimensional derivatives exhibit this trend but no nose to the curve is found up to  $m = 0.24$  lb. A further type of flutter is found in the supersonic range involving wing flexure, wing torsion and aileron rotation. The critical speed decreases with increasing massbalance up to the largest value considered.

The calculation for the wing fitted with the stiffer aileron spring agrees with the experimental result that flutter of wing flexure-aileron rotation type does not occur. The torsion-aileron flutter characteristics are practically unchanged with the increase of aileron circuit stiffness.

In view of the discrepancy occurring between theory and experiment for the wing flexure-aileron rotation flutter of the wing fitted with the weaker aileron spring, repeat resonance tests were made with the wing fitted on the tunnel mounting. These showed that because of flexibility in the mounting the wing fundamental frequency was somewhat reduced. Calculations using the amended value for the fundamental frequency give very good agreement with the measured flutter characteristics.

### 3.3 The swept wing

A quaternary calculation was made using three arbitrary wing modes and aileron rotation. The third wing mode was included in these calculations because in the resonance tests the fundamental torsion mode occurred at a higher frequency than that of the overtone bending mode. The arbitrary modes of distortion assumed were again those of a uniform beam. Elastic coefficients were put equal to the appropriate direct inertia multiplied by the square of the measured natural frequency in that mode.

The results for the flexure-aileron rotation flutter are shown in Fig.3 and show in general an increase in flutter speed with massbalance after a slight initial decrease. These results are in reasonable agreement with those measured except that the nose of the curve occurs at a smaller value of massbalance in practice. A possible reason for this discrepancy is that the assumption of modes of uniform beam bending and torsion for the swept wing may not be a sufficiently representative one.

The calculations give a somewhat different result from the unswept wing for the torsion-aileron rotation type flutter (Fig.5). At small values of massbalance the flutter, whilst having much the same appearance on the simulator as the torsion-aileron rotation type i.e. the motion is mainly in the torsion and aileron degrees of freedom, has a frequency approximately the same as that of the overtone bending mode. There is an increase in flutter speed with increasing massbalance.

Increase of aileron natural frequency to 12 c.p.s. is sufficient to suppress the wing flexure-aileron rotation type flutter; the damping in the aileron mode being quite high at all speeds. This result is not in

complete agreement with the experiment where, although no flutter occurred a poorly damped oscillation of the aileron was found at certain windspeeds (see section 2.3).

#### 4 CONCLUSIONS

The low speed flutter characteristics of an unswept and swept wing with aileron, designed for investigation of transonic and supersonic control surface flutter, have been investigated in the wind tunnel. The limiting value of massbalance, above which flutter of the wing flexure-aileron rotation type does not occur, has been determined. This fact has been used in planning the transonic and supersonic tests.

Flutter calculations have been made which give very good agreement with the measured characteristics of the unswept wing and reasonable agreement with the swept. It is thought that agreement for the swept wing is slightly worse because of the assumptions made about the distortion modes for this wing. Pseudo three-dimensional derivatives were determined for the wings using a combination of measured and calculated results. The aspect ratio correction factor determined from tests on rigid wings has been applied to find the main surface derivatives for these flexible wings and appears to give satisfactory results.

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TABLE 1

The measured flexural and torsional stiffnesses of the wings

Wing	$m_{\theta}$ lb ft/rad.	$e_{\phi}$ lb ft/rad.
Unswapt	1660	3560
40° swapt	1200	2700

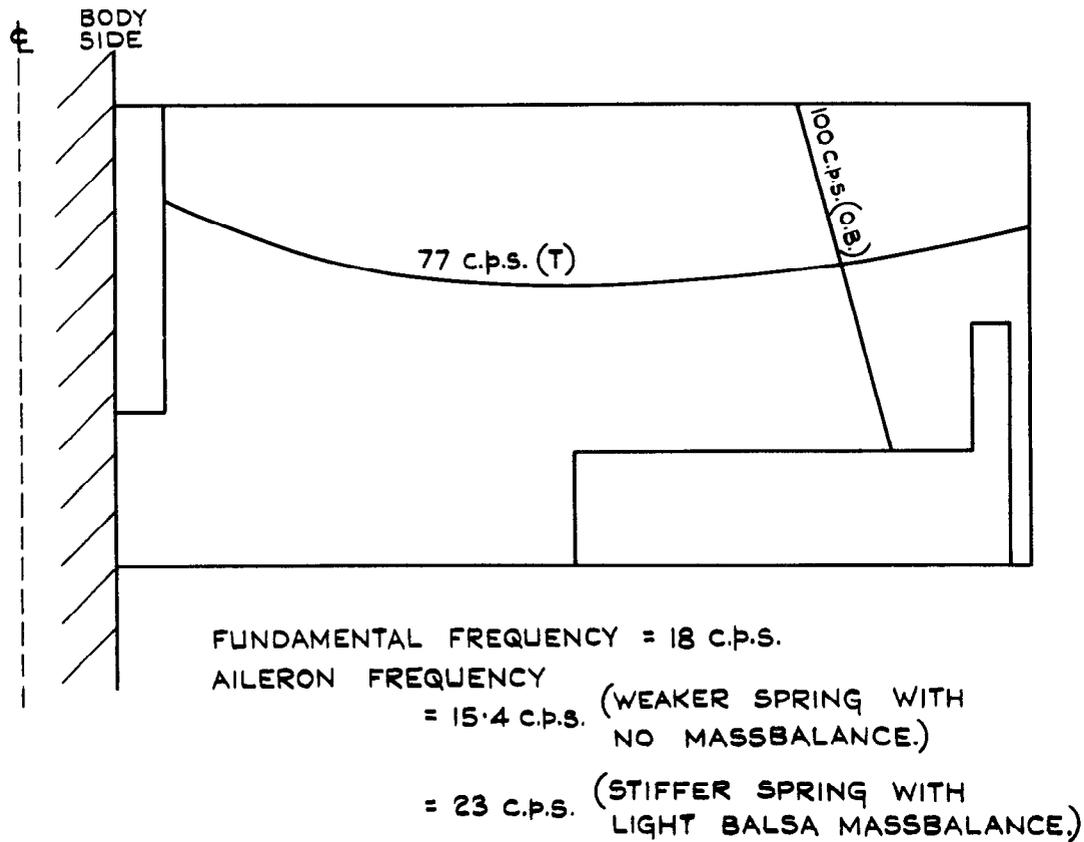
N.B. All stiffnesses measured at 0.7 span in the line of flight.

TABLE 2

The derivatives used in the calculation and their derivation

Derivative	2D value x Sec $\Lambda$ for $E_{\beta}=0.25$ $\nu=1.0$ $M=0$	Value used x Sec $\Lambda$	Derivation
$l_z$	0.4735	0.3288	2D value/ $\{f(A)\}^2$ (Method of Ref.2)
$l_{\dot{z}}$	1.878	1.565	2D value/ $\{f(A)\}$ (Method of Ref.2)
$l_{\alpha}$	2.234	1.5514	2D value/ $\{f(A)\}^2$ (Method of Ref.2)
$l_{\dot{\alpha}}$	1.721	1.4342	2D value/ $\{f(A)\}$ (Method of Ref.2)
$l_{\beta}$	1.193	0.6734	Measured value on wing of AR = 4, $E_{\beta} = 0.2$ (Ref.3), factored by ratio of 2D derivatives at $\nu = 1$ for $E_{\beta} = 0.25$ and 0.2.
$l_{\dot{\beta}}$	0.05939	0.09756	Stiffness derivative x $\frac{2D \text{ damping derivative}}{2D \text{ stiffness derivative}}$ (Method of Ref.4)
$(-m_z)$	0.1184	0.08222	2D value/ $\{f(A)\}^2$ (Method of Ref.2)
$(-m_{\dot{z}})$	0.4696	0.3913	2D value/ $\{f(A)\}$ (Method of Ref.2)
$(-m_{\alpha})$	0.5584	0.3878	2D value/ $\{f(A)\}^2$ (Method of Ref.2)
$(-m_{\dot{\alpha}})$	0.8229	0.6858	2D value/ $\{f(A)\}$ (Method of Ref.2)
$(-m_{\beta})$	0.6230	0.2982	Measured 2D value (Ref.5), corrected for AR and $E_{\beta}$
$(-m_{\dot{\beta}})$	0.1457	0.08443	Stiffness derivative x $\frac{2D \text{ damping derivative}}{2D \text{ stiffness derivative}}$ (Method of Ref.4)
$(-h_z)$	0.002641	0.001834	2D value/ $\{f(A)\}^2$ (Method of Ref.2)
$(-h_{\dot{z}})$	0.01056	0.009906	= $(-h_{\alpha})$ (Method of Ref.4)
$(-h_{\alpha})$	0.01256	0.009906	From measured value of $b_1$
$(-h_{\dot{\alpha}})$	0.03232	0.02642	Stiffness derivative x $\frac{2D \text{ damping derivative}}{2D \text{ stiffness derivative}}$ (Method of Ref.4)
$(-h_{\beta})$	0.02544	0.01472	From measured value of $b_2$
$(-h_{\dot{\beta}})$	0.01534	0.009341	Stiffness derivative x $\frac{2D \text{ damping derivative}}{2D \text{ stiffness derivative}}$ (Method of Ref.4)

$f(A) = 1 + \frac{0.8}{A}$  and for these wings with AR = 4,  $f(A) = 1.2$   
For the swept wing  $\Lambda = 40^{\circ}$ .



O.B. = OVERTONE BENDING  
T = TORSION

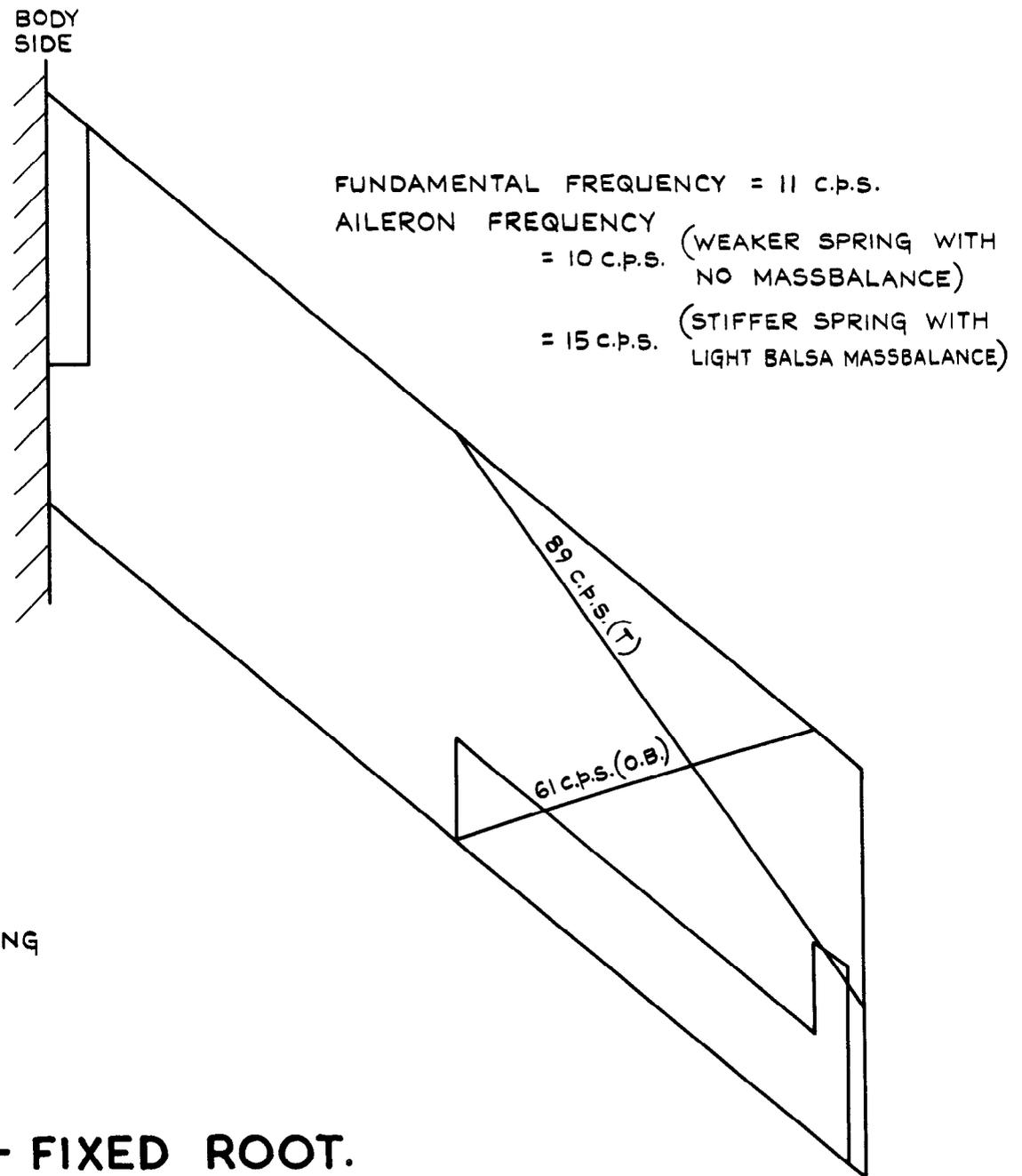


FIG. I. NORMAL MODES - FIXED ROOT.

+ DERIVATIVES WITH ASPECT RATIO CORRECTIONS.  
 x TWO DIMENSIONAL DERIVATIVES ( $M=0$ )  
 o EXPERIMENTAL POINTS.

----- DERIVATIVES WITH ASPECT RATIO CORRECTIONS AND MODIFIED WING FUNDAMENTAL FREQUENCY.

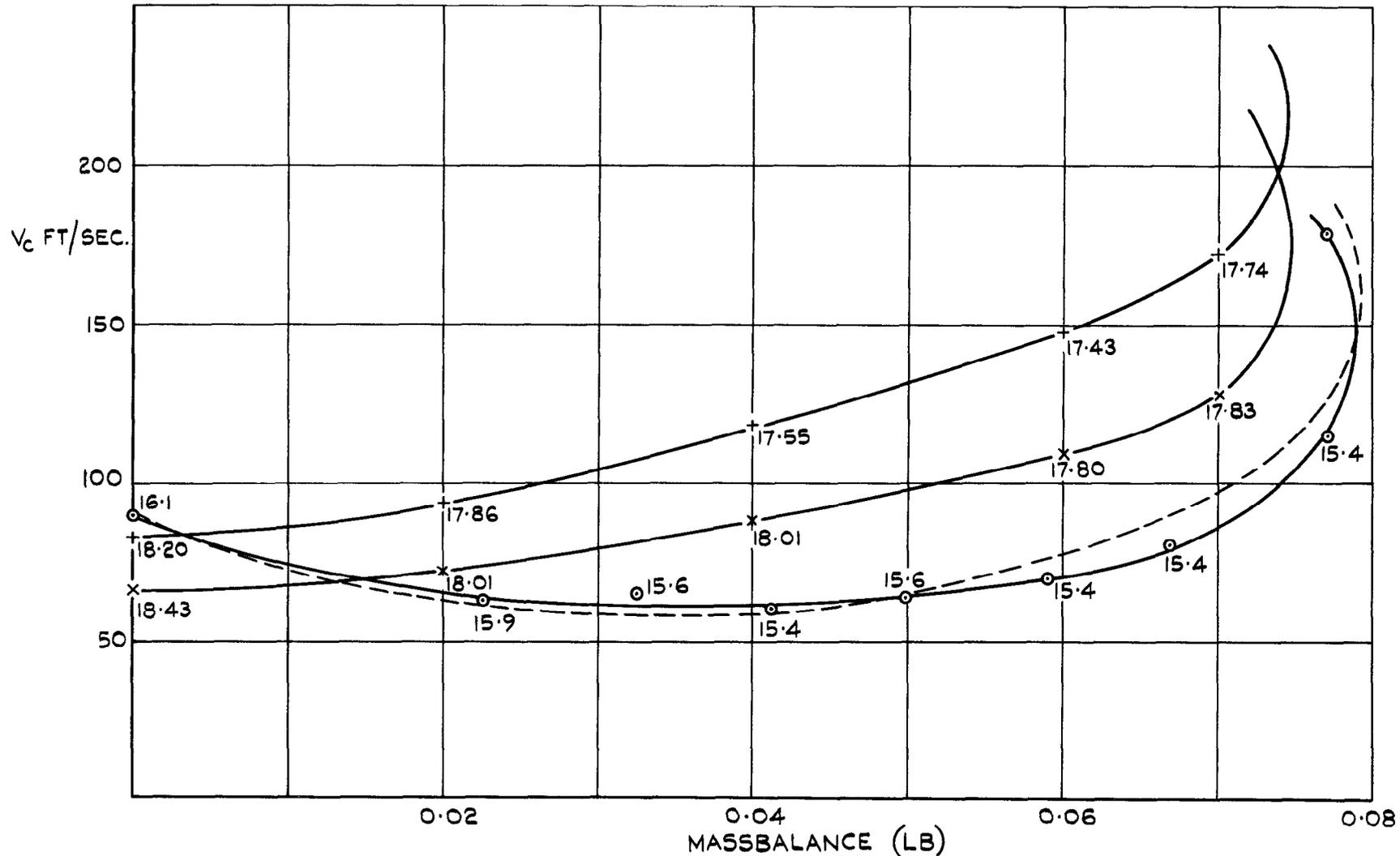
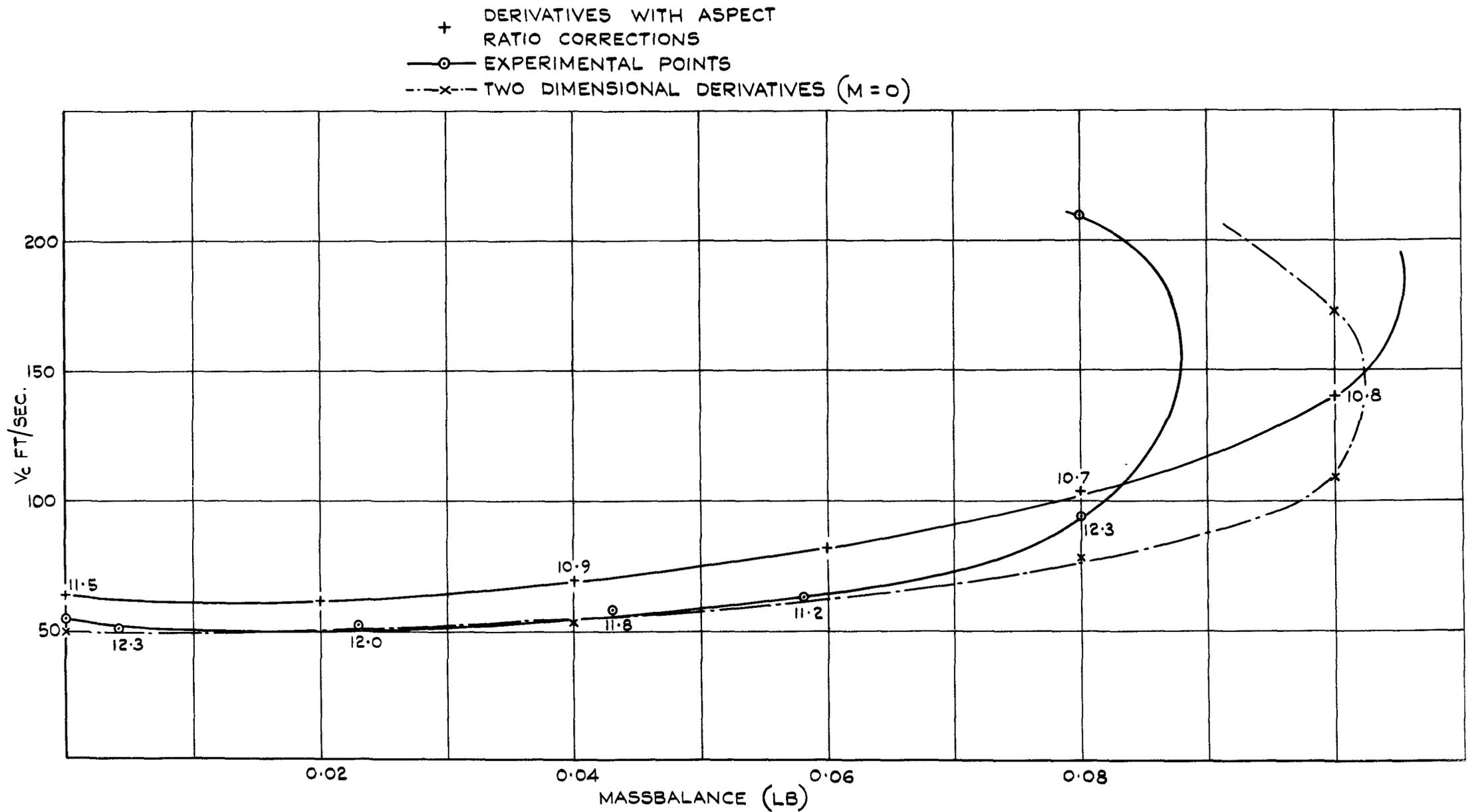


FIG.2. THE EFFECT OF MASSBALANCE ON WING FLEXURE - AILERON ROTATION FLUTTER OF THE UNSWEPT WING.



**FIG.3. THE EFFECT OF MASSBALANCE ON WING FLEXURE -  
 AILERON ROTATION FLUTTER OF THE SWEEP WING.**

- + DERIVATIVES WITH ASPECT RATIO CORRECTIONS
- x TWO DIMENSIONAL DERIVATIVES (M=0)

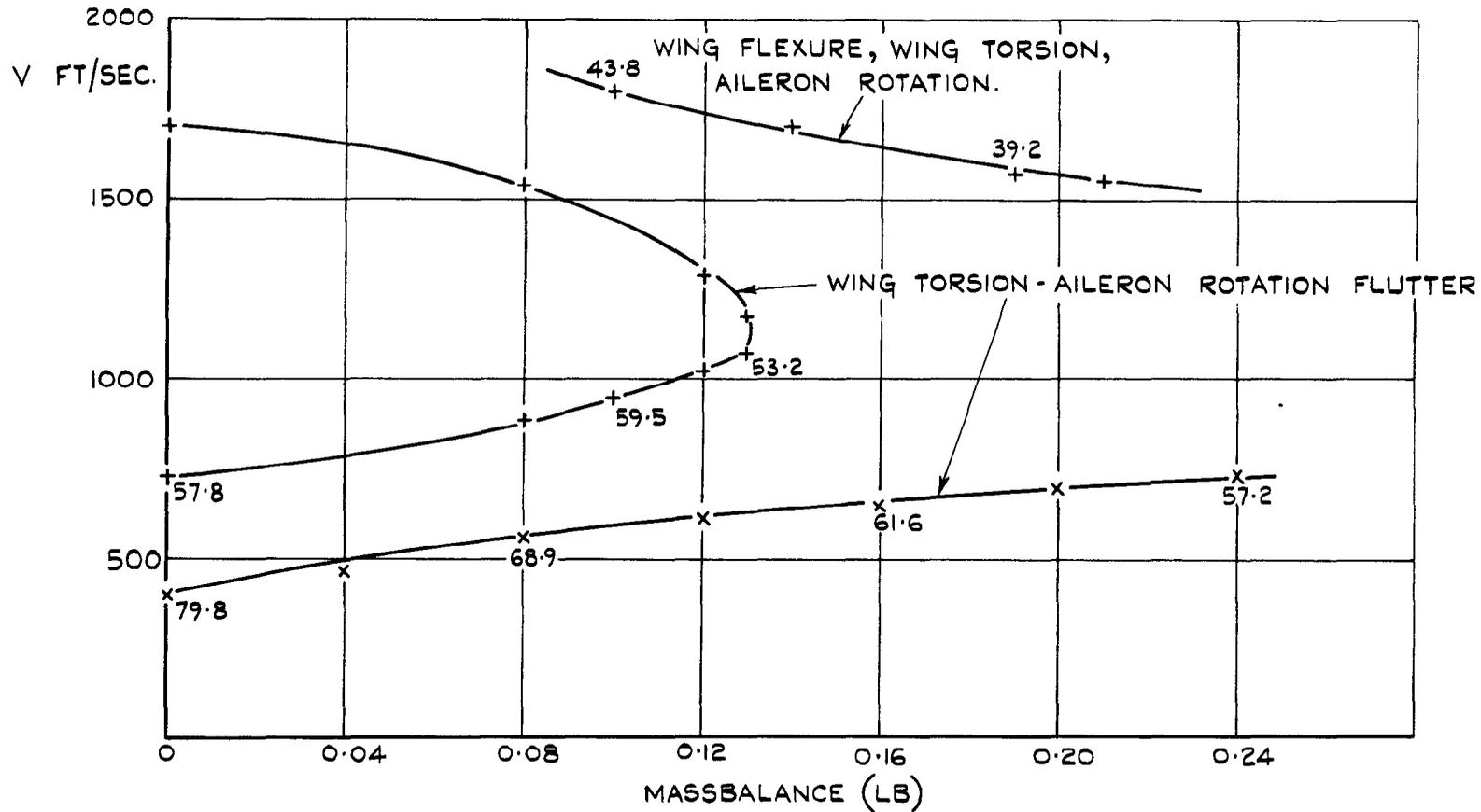


FIG.4. THE EFFECT OF MASSBALANCE ON WING TORSION - AILERON ROTATION FLUTTER OF THE UNSWEPT WING.

# 40° SWEEP WING

## WING TORSION - AILERON ROTATION TYPE FLUTTER

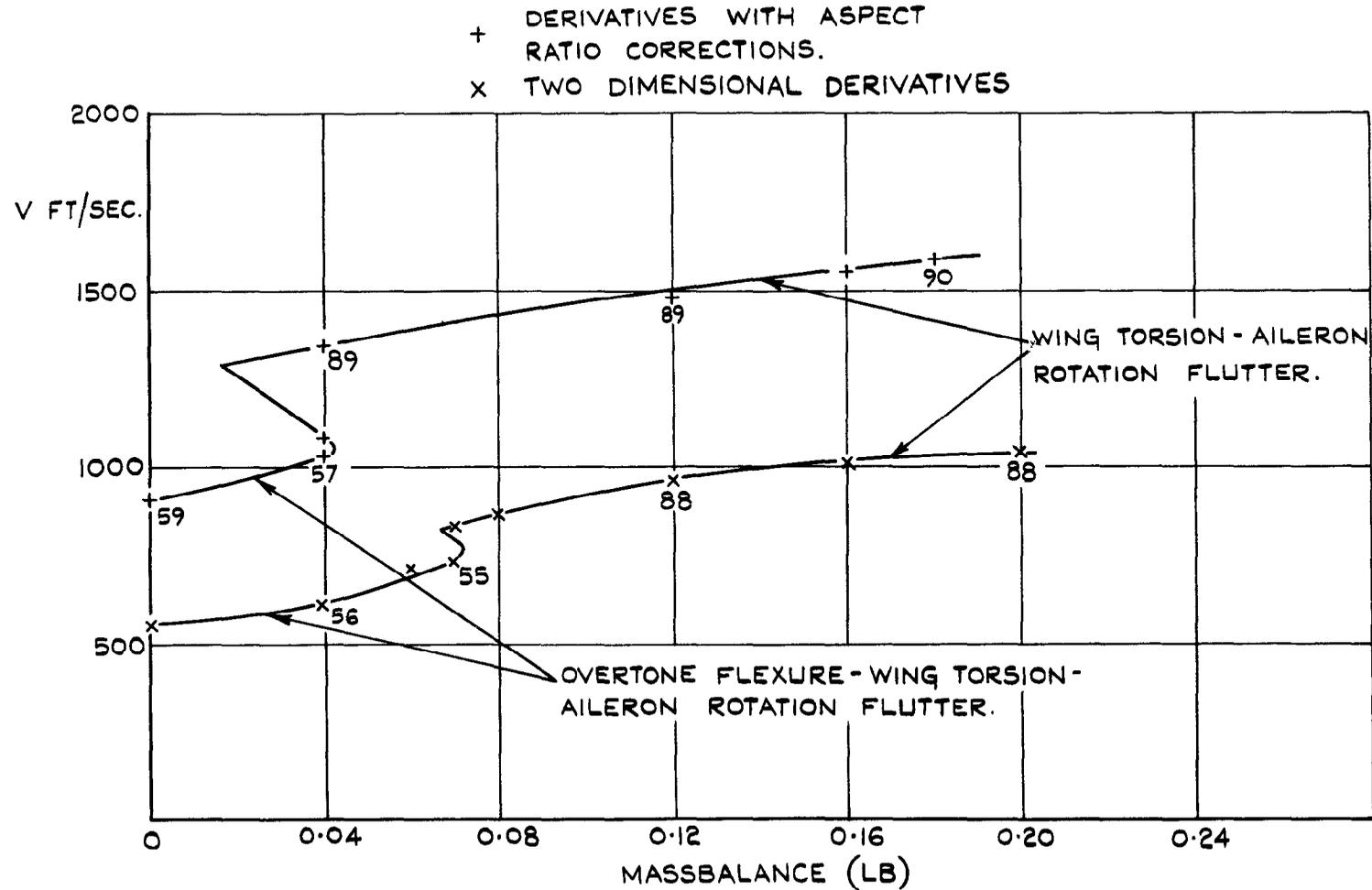


FIG.5. THE EFFECT OF MASSBALANCE ON WING TORSION - AILERON ROTATION FLUTTER OF THE SWEEP WING.





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