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The Aerodynamic Effects of Aspect Ratio on Control Surface Flutter

by

H. Hall & E. W. Chapple

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The Aerodynamic Effects of Aspect Ratio on Control Surface Flutter

by

H. Hall
and
E. W. Chapple

SUMMARY

The report describes a series of low speed flutter tests to obtain a direct measurement of the aerodynamic effects of aspect ratio on wing-aileron flutter. The tests were made on rigid wings fitted with full span ailerons, the wings having root flexibilities in roll and pitch. Provision was made for massbalancing the ailerons. Some general conclusions are drawn concerning the effects of aspect ratio and massbalance on control surface flutter.

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1 Introduction

The tests described in this paper are the last of a series[1,2,3,4] using a technique, described in reference 1, whereby the aerodynamic effects of aspect ratio on flutter can be isolated. The procedure is to use wings that are virtually rigid, but have root flexibilities. By suitable adjustment of the inertia and elastic characteristics of the families of wings considered, it is possible to make any change in flutter speed between individual wings of these families dependent only on the aerodynamic effect of aspect ratio.

The technique was applied in this instance to a family of unswept, untapered wings, each wing having a full span aileron whose chord was 0.3 of that of the wing. The influence of massbalance on the control surface flutter characteristics was also investigated.

2 Experimental details

2.1 Description of the wings and mounting rig

All wings were of solid homogeneous construction, being made of spruce. Each wing was fitted with a full span aileron, whose chord was 0.3 of that of the wing and which operated on a plain bearing hinge. There was no stiffness between the wing and aileron. The wing section used throughout was R.A.E.101.

The rig allowed wing freedoms in modes of linear flexure (roll) and uniform pitch. A further degree of freedom was allowed, that of aileron rotation about its hinge line. The wing root was 0.075 span above the roll axis, and the pitching axis was 0.35 chord aft of the leading edge. Torsion bars of adjustable length provided the required stiffnesses, and sliding weights enabled the roll and pitch inertias to be adjusted.

The wing mounting was designed so that its product of inertia between roll and pitch was zero, but the mounting contributed to the direct inertias of the wings so that means of adjusting them were required. The moments of inertia of the rig (wing and mounting) about the axis of roll and pitch were adjusted by means of the sliding weights to vary as s^3 in roll and s in pitch, where s is the distance from roll axis to wing tip. Furthermore the wings were designed so that the products of inertia between roll and pitch and between roll and aileron rotation varied as s^2 and the product of inertia between pitch and aileron rotation and the moment of inertia of the aileron about its hinge line varied as s. The inertia values are given in the table accompanying Fig.1 together with the dimensions of the wings.

2.2 Massbalance arrangement

A massbalance rider was attached to a carrier arm at the outboard end of each aileron (Fig.2) and the massbalance contribution to the various inertias was such that the dependence of the inerties on the above functions of s (Section 2.1) was preserved. This was achieved by making all spanwise dimensions of the massbalance system vary as s, other dimensions being constant for all the wings. The carriers were made of steel and the riders of lead; the structural details of the massbalance system are given in the table accompanying Fig.2.

The massbalance system was effective in balancing out the dynamic cross inertia between wing roll and aileron rotation. When the c.g. of the rider was located 1.06" forward of the aileron hinge line the aileron was dynamically balanced in roll. However, when the rider was situated

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in its furthest forward position on the carrier, the rider c.g. then being 1.72" forward of the aileron hinge line, the cross inertia between wing pitch and aileron rotation was only reduced by 21% of its initial value.

The variation of massbalance conditions covered a range from 45% to 80% static balance of the aileron. The addition of mass balance had a pronounced effect on the pitching moment of inertia of the aileron. When the carrier only was added the inertia was increased by 15% of its basic value and when the rider was added at its furthest forward position it was increased by a further 73%.

2.3 Wind tunnel measurements

The tests were conducted in the 5 ft diameter open jet tunnel. All wings were mounted vertically above a reflector plate, to simulate the symmetric flow condition. The wing aspect ratios ranged from 2.0 to 6.0 being defined as 2 s/c where c, the chord of the wing, was constant for the whole series.

The wings were set up by adjusting the torsion bars so that for all the wings, the frequencies of the corresponding modes (with aileron fixed to the wing) were the same. The natural frequency of the wings in roll was 3.1 c.p.s. and in pitch 9.6 c.p.s. These frequencies were measured with the massbalance rider placed on the carrier with its c.g. 0.82" forward of the aileron hinge line.

For a particular massbalance condition i.e. aileron c.g. position, the various wings are so related that the flutter equations are identical apart from the aspect ratio effects on the aerodynamic coefficients. The fact that the natural frequencies of the wing in roll and pitch were measured at a particular massbalance condition does not imply that the relation holds only for this condition. The relation holds for all massbalance conditions but the equations for each massbalance condition will be different.

The tests were made with the aileron free and with various massbalance conditions. Readings were taken (1) with only the carrier fitted and (2) with the rider fitted on the carrier at various positions along the arm. For each of these conditions measurements were made of flutter characteristics for the binary types of flutter wing roll-aileron rotation and wing pitch aileron rotation and of the ternary wing roll-wing pitch-aileron rotation.

Flutter speeds and frequencies were measured for each wing, the speed being that at which the oscillation just died out as the tunnel speed was reduced. As some of the flutter speeds were unusually low and below the accurate calibrated value for the tunnel, measurements of all speeds were made using a Chattock gauge.

3 Results

The results of the wind tunnel tests are plotted in Figs 3-8. In Figs 3-6 flutter speed and frequency are plotted against the reciprocal of aspect ratio and in Figs 7 and 8 flutter speed is plotted against massbalance position for each of the wings in turn.

The investigation was divided into three distinct parts, depending on the degrees of freedom of the system that were allowed. These were

(1) Wing roll and aileron rotation

(2) Wing pitch and aileron rotation

(3) Wing roll and pitch and aileron rotation

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3.1 Wing roll-aileron rotation

The variation of flutter speed and frequency with aspect ratio for this type of flutter is shown in Fig.3. It was found that the flutter was quite mild and could be allowed to continue right through its speed range so that an upper bound to the flutter was obtained. Flutter frequencies are only plotted for two massbalance conditions to avoid confusion in the figure.

It was found that the upper critical speeds were sensitive to damping in the aileron degree of freedom. The aileron amplitude near the upper critical speed is extremely small and the aileron inertia at similar amplitudes in the wind off condition is insufficient to overcome even the small amount of friction present in the aileron bearing. Too much significance should not therefore be attached to these upper critical speeds; the upper bounds are indicated by a broken line to indicate the uncertainty about the absolute values.

It can be seen that for certain massbalance conditions, as the aspect ratio increases there is a limit beyond which flutter of this type does not occur. The tests indicate that for increasing massbalance the limiting aspect ratio decreases. The limiting aspect ratio is slightly less than 4 when the aileron is 59% statically balanced decreasing to just greater than 3 as the balance rises to 64%. No nose to the flutter speed curve was found when the aileron static balance was less than 59%, the trend of the results indicates that limiting finite aspect ratios should exist but no values can be assigned to them.

It was considered that the extremely low Reynolds number at which the tests were conducted (between 3.5×10^4 and 24.5×10^4) could be producing some unwanted aerodynamic effect. The roll-aileron rotation flutter tests were accordingly repeated with transition wires fitted to the wing, this had the effect of increasing the width of the flutter band and making the flutter more violent. The general shape of the flutter speed curve is, however, unaltered and in particular for the higher values of mass balance a limiting aspect ratio exists above which flutter does not occur.

3.2 Wing pitch-aileron rotation

The variation of flutter speed and frequency with aspect ratio for this type of flutter is shown in Fig.4. Flutter speed increases linearly with decreasing aspect ratio; the frequency remains approximately constant as the aspect ratio increases from 2 to 4 but for larger values gradually decreases. In the range of aspect ratios examined the flutter speed can be expressed by a relation of the form $V = V_o f(A)$, where V_o is the extrapolated experimental value for the two-dimensional case* and $f(A)$ is a function of aspect ratio. The particular form to be assigned to the function f depends on the massbalance condition and several values are given in the figure. However, for the range of massbalance considered a reasonable average value of $f(A)$ is $f(A) = 1 + 4.25/A$.

Wing pitch-aileron rotation type flutter occurs at higher speeds than the other type for all the wings tested.

3.3 Wing roll-wing pitch-aileron rotation

When both of the wing degrees of freedom were allowed together with aileron rotation, two forms of flutter were obtained closely resembling the

* It should be noted that extrapolation of the results beyond those for the wings of highest aspect ratio tested may not be justified.

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types of binary flutter considered above. The mainly wing roll-aileron rotation type flutter was excited first, and then at higher speeds whilst this type of oscillation persisted, a further disturbance would excite the wing pitch-aileron rotation type flutter, which then became dominant. The variations of flutter speed and frequency of these types of flutter with aspect ratio are shown in Fig.5 and 6.

When the rider was fitted so that its c.g. was 1.12" forward of the aileron hinge line an instability of the roll-aileron rotation type was obtained involving large wing amplitudes. It was impossible to ascertain whether this was flutter or not as the rig immediately "hammered" against the amplitude limit stops. This phenomenon was not noticed for the binary system. Otherwise the flutter speeds and frequencies for the wing roll-aileron rotation type flutter are practically the same as the corresponding binary ones. The same doubts exist about the accuracy of the upper critical speeds for this type of flutter as were mentioned in connection with the binary flutter.

The results for the wing pitch aileron rotation type flutter are shown in Fig.6 and are very similar to those for the corresponding binaries. Flutter speeds for the ternary are greater than those for the binary having the same massbalance conditions. The slopes of the lines representing the increase in flutter speed with decrease of aspect ratio, decrease as the massbalance is reduced and they are greater than those of the corresponding binary case.

The regions in which the two types of flutter are possible are overlapping for certain massbalance conditions, and it is possible to have both types occurring at a particular speed. For an aircraft, only the lower bound is, in general, significant and there will be a transition from one form of flutter to another, the transition point being at a particular massbalance condition (corresponding to the nose of the wing roll-aileron rotation type flutter (Figs 7 and 8) of the tests) which depends on the aspect ratio of the wing in question.

3.4 Comparison with theory

The fact that a decrease of aspect ratio could increase the danger of a mild aileron flutter has been noticed previously by Jordan[5] in some flutter calculations on a similar system to this. To a certain extent this is confirmed by these tests i.e. for certain massbalance conditions a limiting aspect ratio exists above which flutter will not occur. Flutter calculations for the roll-aileron rotation binary using two dimensional derivatives[6] do not give agreement with the trends indicated by these measured results. These calculations show that a flutter speed exists for the infinite aspect ratio wing for all massbalance conditions between that in which no rider is carried and that in which the rider is 0.82" forward of the aileron hinge line. For more forward massbalance positions no flutter speed exists for the two dimensional case.

Attempts to predict the flutter characteristics for the finite aspect ratio wings using two dimensional derivatives factored by the previously determined aspect ratio correction[2] for the main surface and the full values for the control surface, gave generally poor agreement for the lower critical speeds and the upper critical speeds were very much lower than the measured ones. (There is doubt about the accuracy of the measured upper critical speeds though). The upper and lower bounds of the flutter speed curve are roughly parallel with the aspect ratio axis. The theoretical results obtained for the no rider case are indicated in Fig.3.

Speculation arises as to what is the cause of the discrepancy between calculation and practice. The introduction of structural damping into the flutter equations will eventually eliminate flutter in the infinite aspect

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ratio case but the amount of damping required in the aileron degree of freedom to achieve this is prohibitively large and such an amount of damping is certainly not present in practice.

Flutter calculations for the binary pitch-aileron rotation type flutter gave very poor agreement with the extrapolated experimental values for the infinite aspect ratio case and the theoretical work was not continued further than this.

4 Conclusions

Two types of ternary control surface flutter were characteristic of the system considered here, one in which the main motion was roll of the wing and control surface rotation and a second in which the main surface motion was predominantly pitch. For a particular massbalance condition both types exhibit an increase of flutter speed with decreasing aspect ratio, the increase being slight for the first type. A linear increase was found for the second type of flutter, which could be expressed in the form $V = V_o f(A)$, V_o being the extrapolated value for the two dimensional speed and A the aspect ratio, which was valid over the range of aspect ratios tested.

Some confirmation is provided by these tests of an earlier theoretical conclusion[5] that a decrease of aspect ratio can increase the probability of encountering a region in which a mild aileron flutter occurs. The limiting aspect ratio below which flutter occurs depends on the amount of massbalance carried by the control. Increase of percentage static balance has quite a marked effect on the first type of flutter, the flutter eventually being eliminated; for the wing of aspect ratio 2 this occurs at 70% static balance whilst for that of aspect ratio 4 it occurs at 59%. The effect on the second type of flutter is a gradual increase in flutter speed with increasing massbalance.

It is reasonable to expect that the results obtained will be applicable qualitatively to control surface flutter in general, where the aileron will not be free as in this case.

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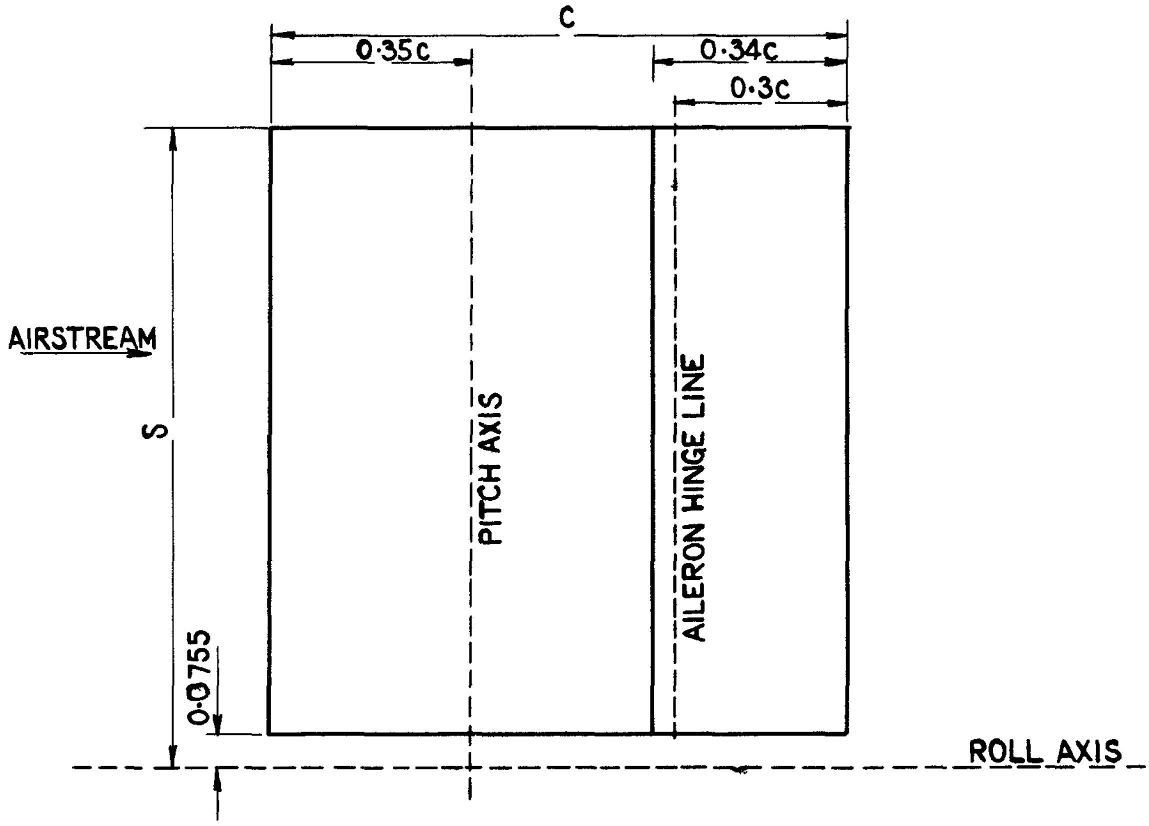

WING CHORD = 0·5 FT.
WING THICKNESS/CHORD = 0·15
WING SECTION = R.A.E. 101

WING Nº	WING SPANS INS.	ASPECT RATIO	INERTIAS WING & MOUNTING - LB. IN². ROLL INERTIA	ROLL-PITCH INERTIA	PITCH INERTIA	INERTIAS AILERON - LB. IN². ROLL-ROTATION INERTIA	PITCH-ROTATION INERTIA	ROTATIONAL INERTIA
1	6	2·00	7·90	0·570	0·794	0·0870	0·0812	0·0251
2	7	2·33	12·73	0·722	0·924	0·1136	0·0922	0·0294
3	8	2·67	18·99	1·172	1·060	0·1532	0·1076	0·0335
4	9	3·0	26·70	1·237	1·195	0·2088	0·1274	0·0376
5	10	3·33	37·68	1·547	1·326	0·2428	0·1357	0·0417
6	12	4·00	64·83	2·030	1·600	0·3610	0·1665	0·0501
7	15	5·00	122·7	3·064	1·996	0·5768	0·2115	0·0627
8	18	6·00	214·8	5·004	2·401	0·8074	0·2485	0·0749

FIG. 1. GEOMETRICAL AND STRUCTURAL DETAILS OF THE WINGS.

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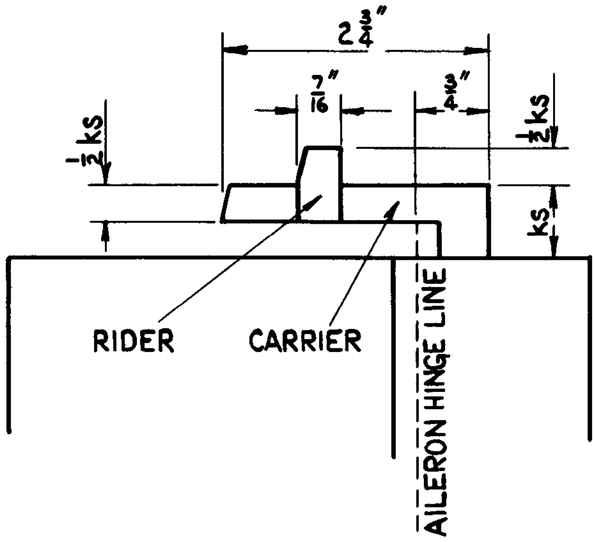

k = 0·02083

WING Nº	CARRIER WEIGHT x 10² LB.	RIDER WEIGHT x 10² LB.
1	1·777	0·617
2	2·090	0·672
3	2·372	0·787
4	2·650	0·974
5	2·972	1·080
6	3·574	1·226
7	4·460	1·565
8	5·368	1·918

FIG. 2. THE AILERON MASSBALANCE SYSTEM.

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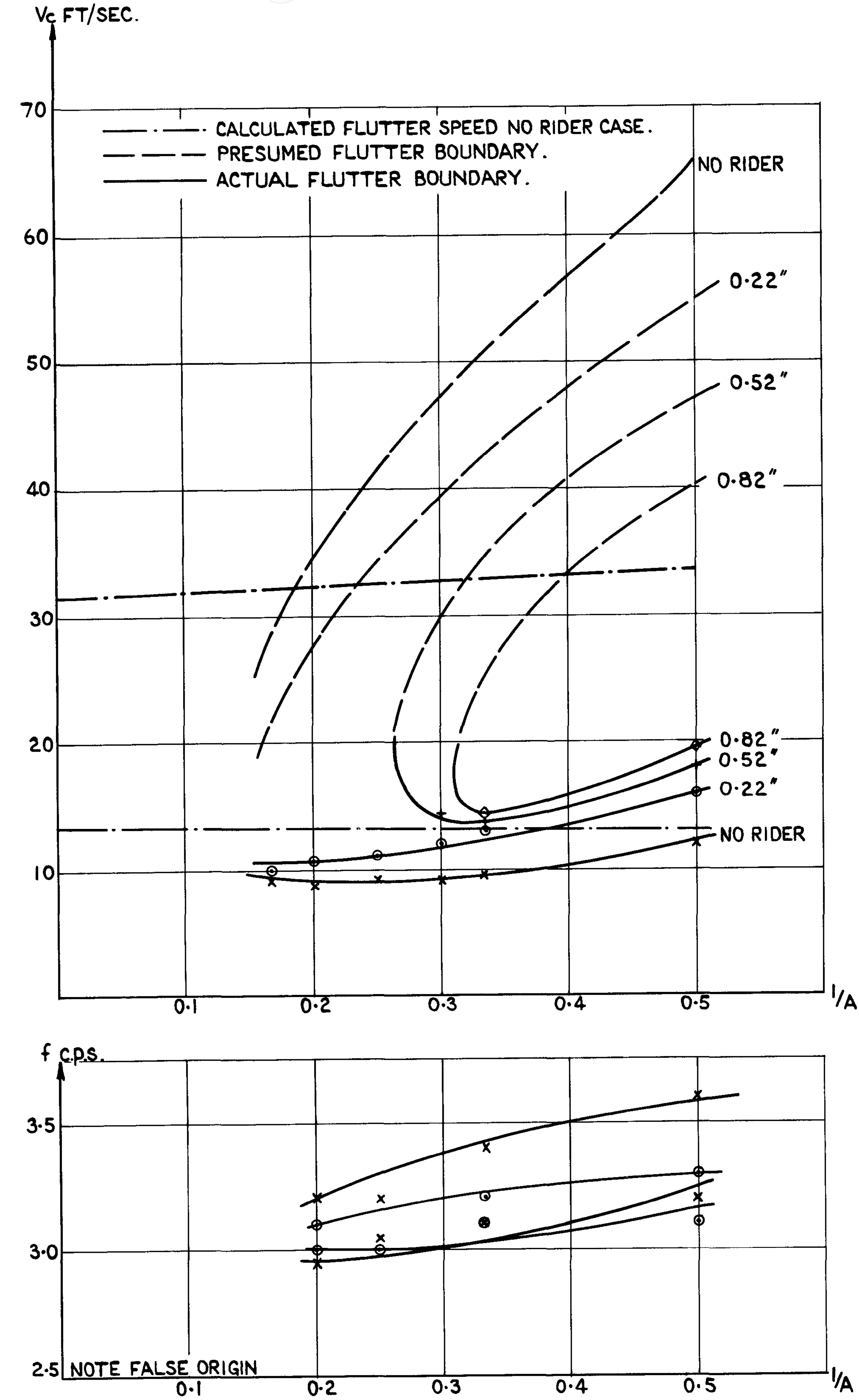

FIG. 3. THE VARIATION OF FLUTTER SPEED AND FREQUENCY WITH ASPECT RATIO FOR THE ROLL-AILERON ROTATION TYPE FLUTTER.

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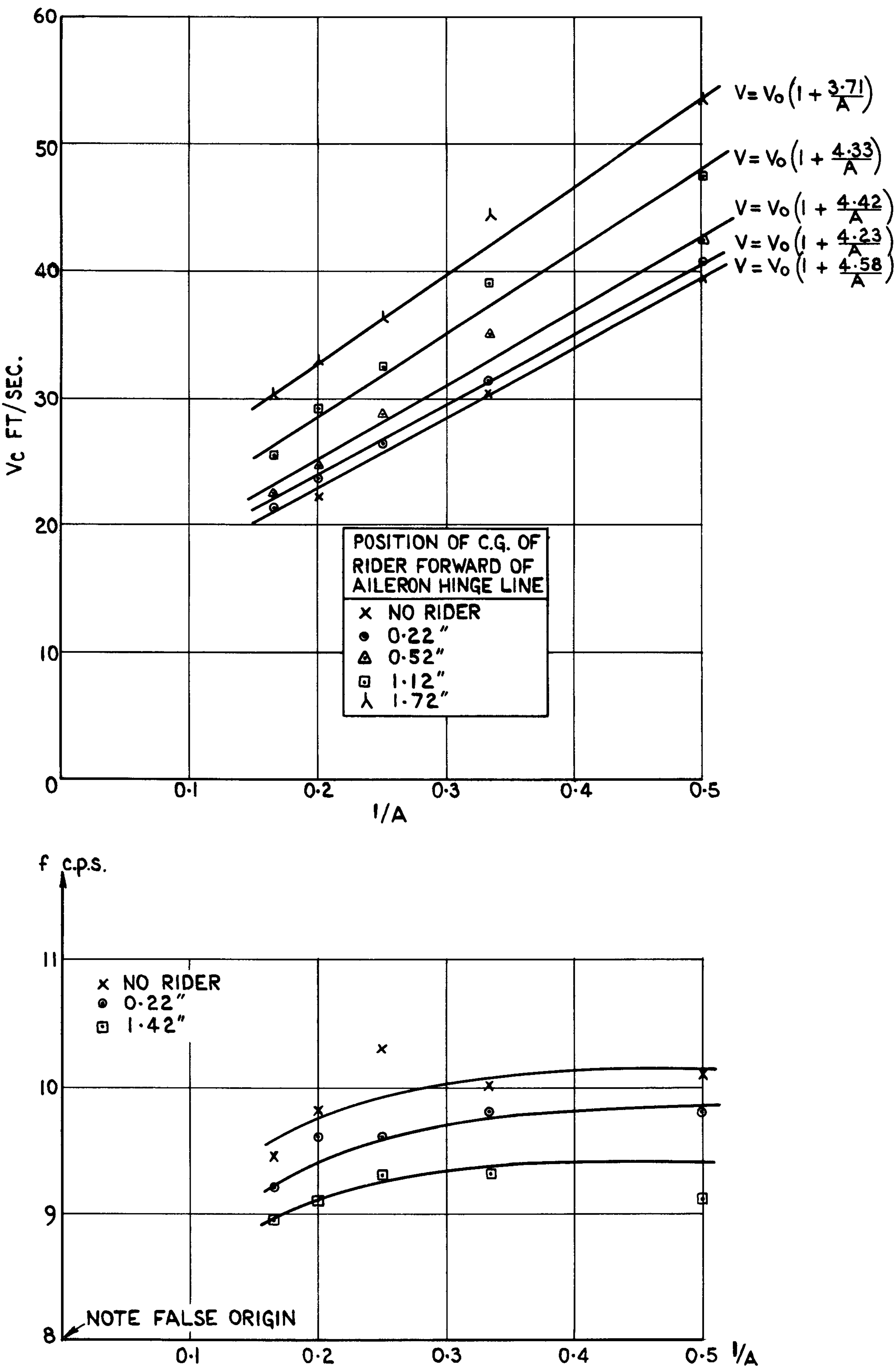

FIG.4. THE VARIATION OF FLUTTER SPEED AND FREQUENCY WITH ASPECT RATIO FOR THE PITCH-AILERON ROTATION TYPE FLUTTER.

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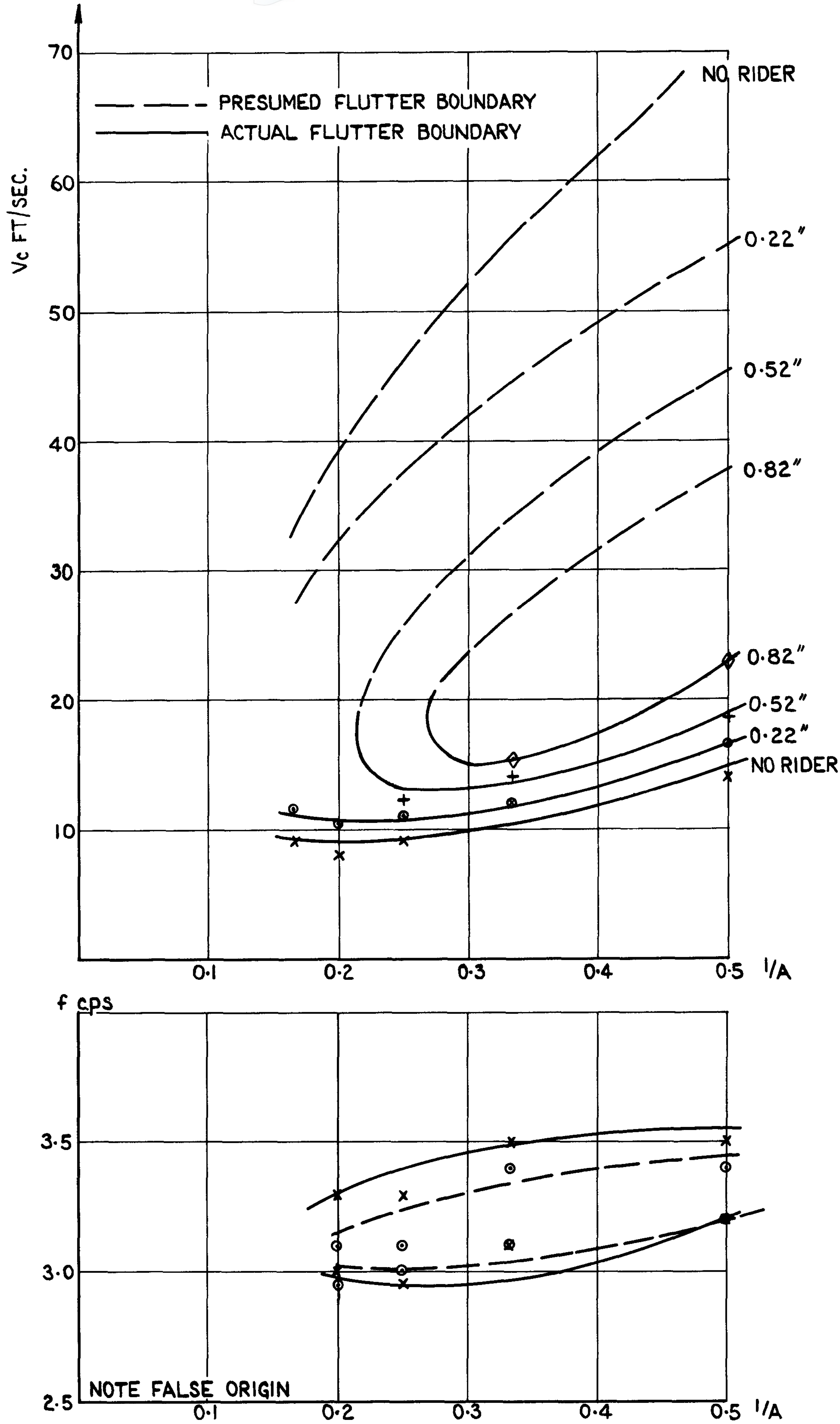

FIG. 5. THE VARIATION OF FLUTTER SPEED AND FREQUENCY WITH ASPECT RATIO FOR THE TERNARY TYPE FLUTTER OF ROLL-AILERON ROTATION CHARACTER.

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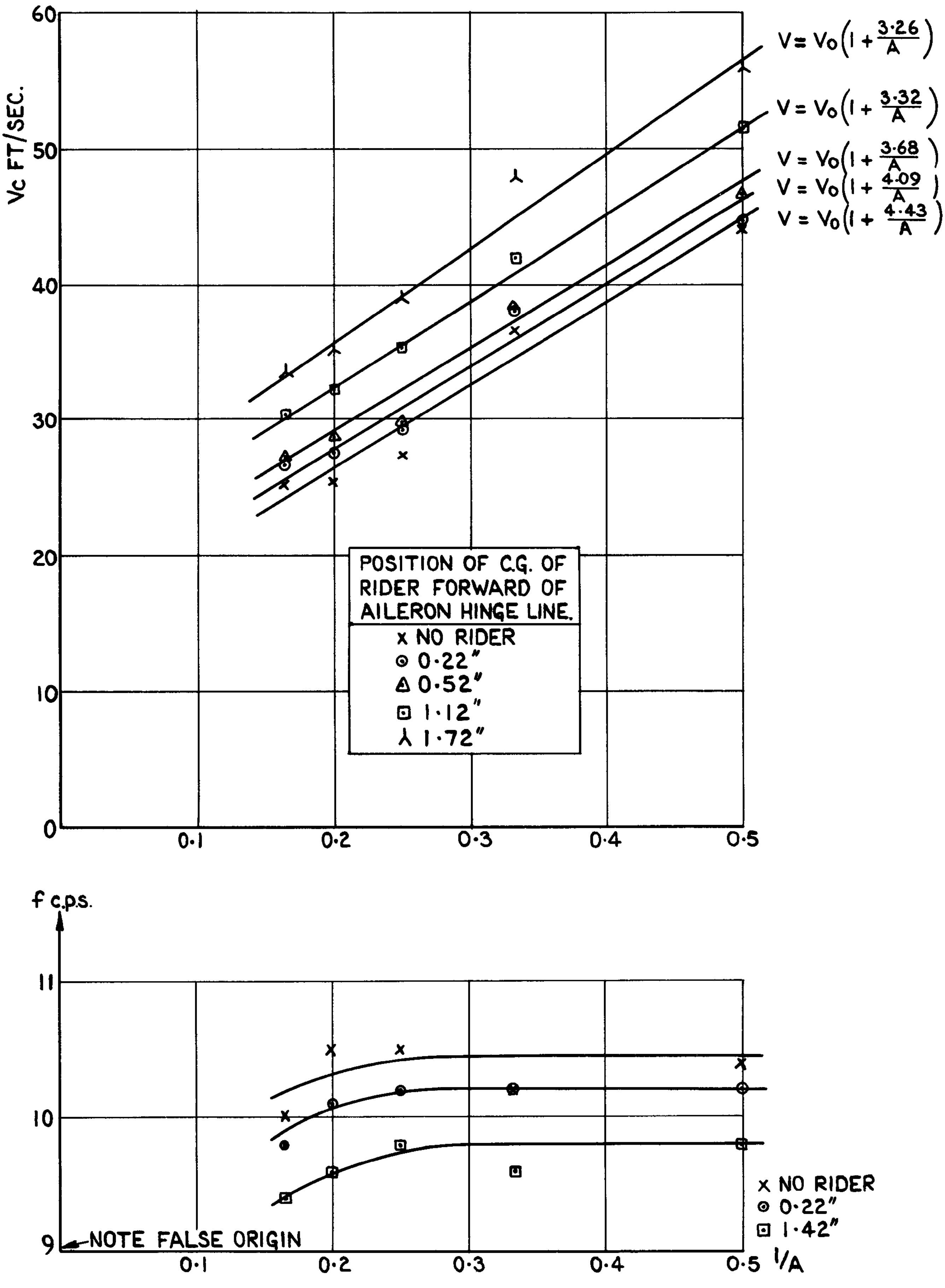

FIG. 6. THE VARIATION OF FLUTTER SPEED AND FREQUENCY WITH ASPECT RATIO FOR THE TERNARY TYPE FLUTTER OF PITCH-AILERON ROTATION CHARACTER.

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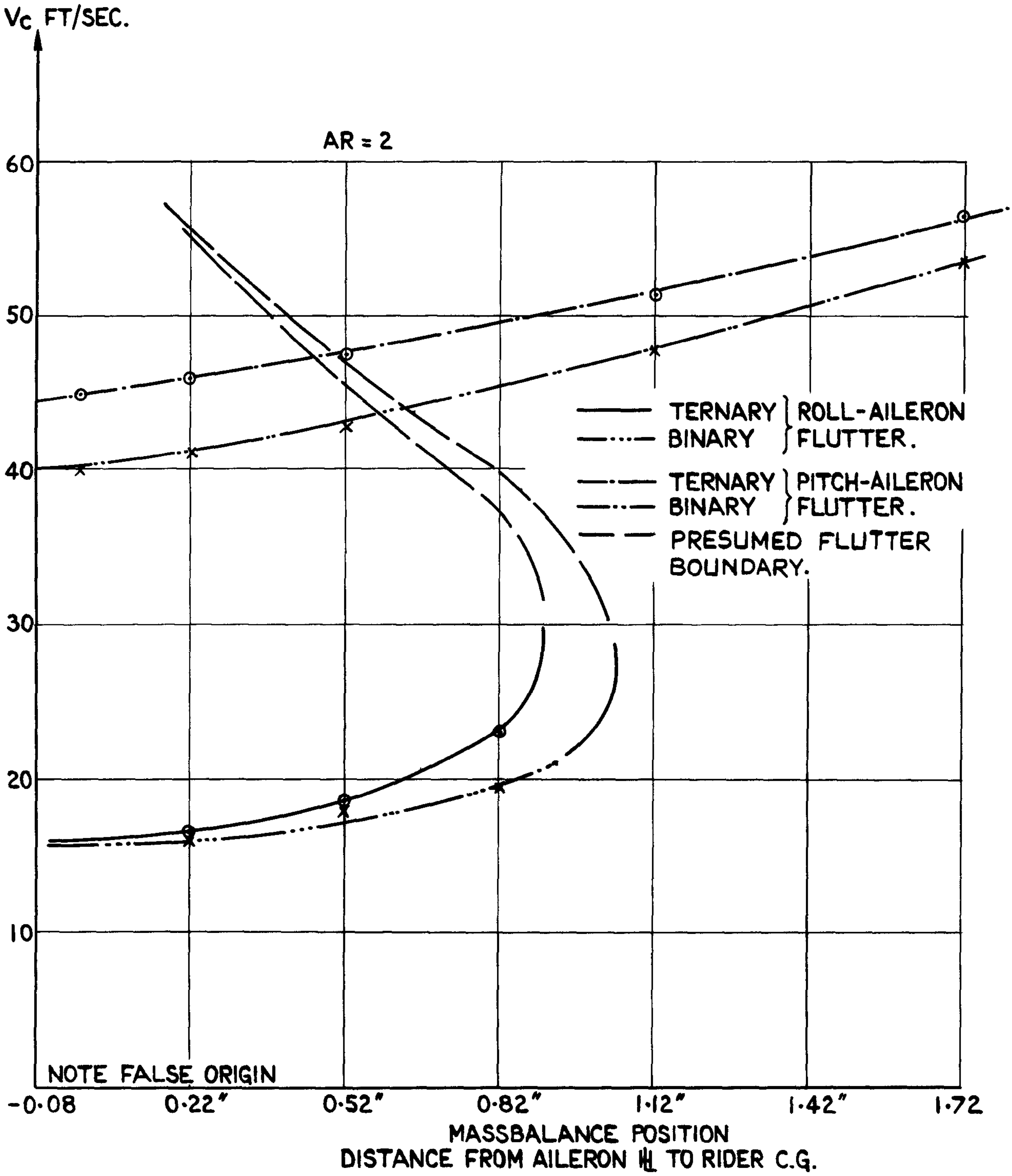

FIG.7. THE VARIATION OF FLUTTER SPEED WITH MASSBALANCE POSITION.

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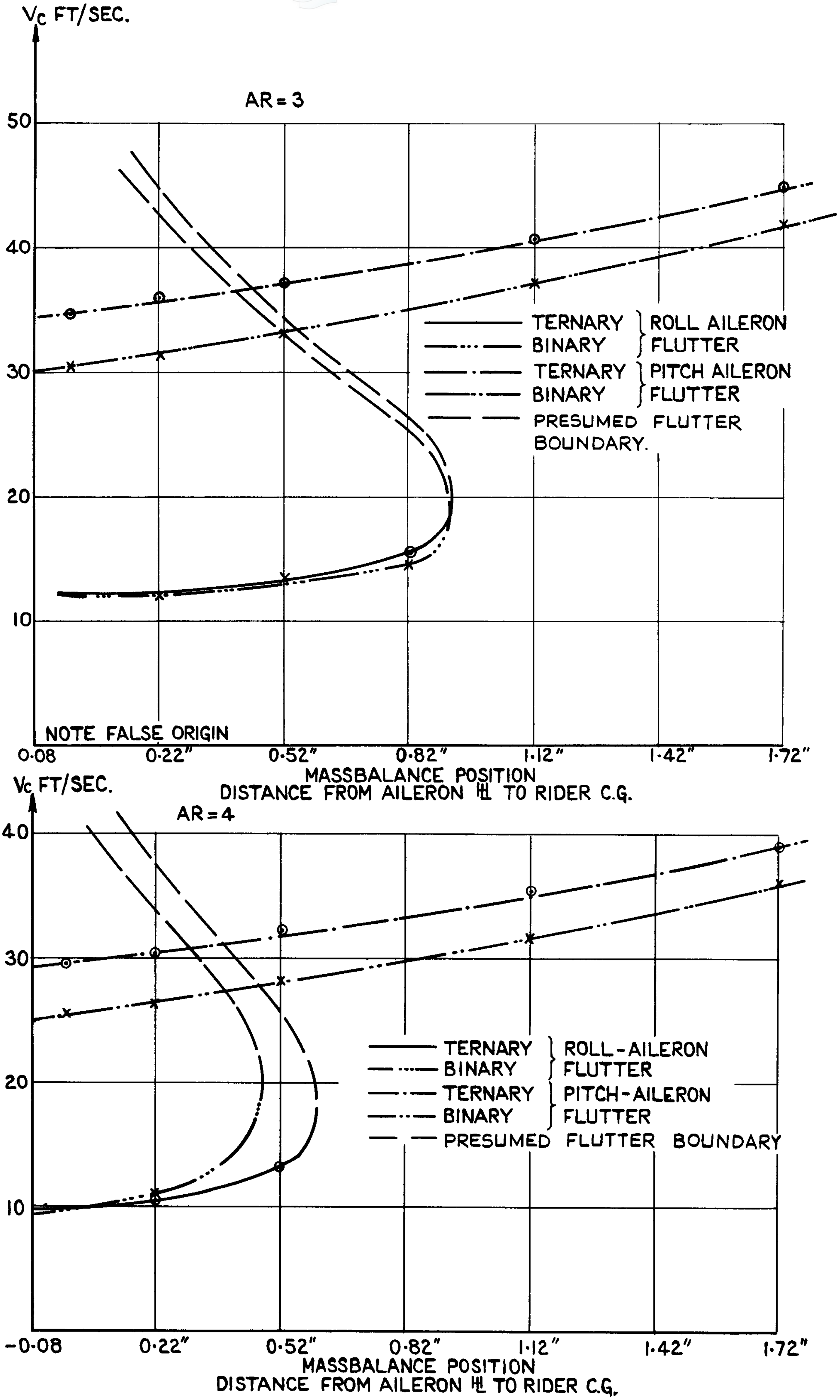

FIG.8. THE VARIATION OF FLUTTER SPEED WITH MASSBALANCE POSITION.

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