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By

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Flutter Calculations on a Rudder with Trailing-Edge Spoiler

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SUMMARY

Flutter calculations made on a rudder with trailing-edge spoilers are described. The results obtained agree with the flight experience which has been acquired so far (except for the frequency of the flutter) in spite of the simplicity of the aerodynamic assumptions. It has been found that, as with tab flutter, a form of flutter involving the main surface (fin) occurs with an overmassbalanced spoiler.

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1 Introduction

Flight tests have been carried out recently on a Meteor aircraft to compare the effectiveness of a trailing-edge spoiler with that of the standard rudder tab. The calculations described below were made to investigate the flutter stability of the spoilers.

Two spoilers have been fitted to the rudder at different times. One replaced the tab and used the tab's control circuit, whilst the other was separate from the tab and enabled a direct comparison of the effectivenesses of the spoiler and tab to be made. Fig. 1 is a sketch of the arrangement of the first of these spoilers, referred to in the present paper as spoiler A.

Flutter calculations were made on each system. Those on the first system took account of only two degrees of freedom, rudder rotation and spoiler rotation, and showed that the spoiler should flutter at a speed proportional to the spoiler frequency; the flutter could be eliminated by spoiler massbalance. The aircraft flew with an unmassbalanced spoiler without experiencing any vibration. When the second spoiler was fitted a high-frequency vibration commenced at a low airspeed. A ternary flutter calculation involving rudder rotation, rudder torsion and spoiler rotation was made, and it was again shown that massbalance was an effective means of eliminating the flutter. A quaternary calculation, in which a fin flexural mode was added to the above ternary, was made to check whether an over-massbalanced spoiler would give rise to flutter similar to the 'ternary branch' type of tab flutter. Such a branch has been found.

An account of the calculations is given in section 2. The results are compared with the flight experience in section 3, the agreement being found to be reasonably good.

2 Details of Calculations

The aircraft to which the spoilers were fitted was a Meteor 7 with a Meteor 6 type rudder. The first spoiler, spoiler A, which replaces the tab, is connected to the tab circuit so that it is used for trimming, providing aerodynamic balance through a gearing, and is also connected. to an R.A.E. Type F autostabiliser. The second spoiler, spoiler B, which is on the top part of the rudder, is on a circuit of its own and is not used either for trimming or for balancing. In the flutter calculations both spoilers are considered to be directly attached to the rudder by springs and Lash-pots and no account is taken of the trimming and balancing duties of spoiler A.

The rudder is also fitted with trailing-edge strip, whose contribution to the aerodynamic hinge moment is not known accurately. In the binary and ternary calculations this contribution is varied, whilst in the quaternary the value that results in the lowest flutter speeds for the binary and ternary is used. Factors to represent the change in the direct rudder damping coefficient due to the trailing-edge strip are obtained from ReP.l.

No aerodynamic flutter derivatives are available for spoilers, and the only steady-motion derivatives available are those for the rate of change of lift with spoiler deflection and the rate of change of control-surface hinge moment with spoiler deflection. The other spoiler derivatives are taken to be negligible. This is so for the spoiler hinge-moment stiffness derivatives if they are of the same order as the spoiler static derivatives. All the derivatives are evaluated according to the recommendations of Minhinnick for surfaces of low aspect-ratio[2], viz:-

(1) estimated steady-motion values are assumed for the stiffness derivatives,

(2) the damping derivatives are assumed to be the same as the corresponding stiffness derivatives where possible (e.g. $\ell_{\dot{z}}$ assumed to be ℓ_α),

(3) the remaining damping derivatives are obtained from a comparison of the three-dimensional steady-motion derivatives and the turning-point values of the two-dimensional damping and stiffness derivatives.

All the derivatives are assumed to be independent of frequency parameter. The steady-motion derivatives used are low-speed estimates.

2.1 Binary Flutter Calculations

If we consider binary flutter involving rotations of the rudder and spoiler we arrive at the critical determinantal equation

$$\begin{vmatrix} -a_{11}\nu^2 + b_{11} i\nu + c_{11} + c_{11} y, & -a_{12}\nu^2 + c_{12} \\ -a_{21}\nu^2 & -a_{22}\nu^2 + y \end{vmatrix} = 0 \quad (1)$$

$(a_{21} = a_{12})$

where the symbols have their usual meaning and the first generalised coordinate is rudder rotation and the second is spoiler rotation. Structural damping has for the moment been neglected. It will be noted that all aerodynamic coefficients for the spoiler are zero except the cross stiffness c_{12}, rudder hinge moment due to spoiler rotation.

The conditions for stability[3] are then:-

$$a_{11} y + a_{22}(c_{11} + c_{11} y) - a_{12} c_{12} > 0 \qquad (2)$$

$$a_{12}^2 y - a_{12} a_{22} c_{12} > 0 \qquad (3)$$

Both these conditions are fulfilled at all speeds if a_{12} and c_{12} have opposite signs, that is if the spoiler is dynamically overmassbalanced. The more critical of the conditions is (3) since from it, when a_{12} is zero i.e. when the spoiler is dynamically massbalanced, an oscillation of the spoiler will be maintained due to the elimination of the coupling from rudder to spoiler. The critical speed, $a_{12} \neq 0$, is given by

$$a_{12} y = a_{22} c_{12} \qquad (4a)$$

i.e.

$$V^2 = \frac{a_{12}}{a_{22} c_{12}} \cdot \frac{E_{22}}{\rho s c^2} \qquad (4b)$$

or

$$V = \left(\frac{a_{12}}{c_{12}}\right)^{\frac{1}{2}} \omega_2 c, \text{ for } E_{22} = \rho s c^4 \omega_2^2 a_{22} \qquad (4c)$$

The flutter speed of the spoiler decreases, therefore, as the mass-balance is increased until the spoiler is dynamically overbalanced, in which condition it is stable at all speeds. The flutter speed also depends directly on the frequency of the spoiler. The flutter frequency is given by the imaginary part of equation (1)

which is $$a_{22} \nu^2 = y \qquad (5a)$$

i.e. $$\omega = \omega_2 \qquad (5b)$$

At a critical flutter condition there is no rudder rotation in the flutter mode, and the spoiler oscillates at its own natural frequency. The effect of a typical massbalancing arrangement on the flutter speed of spoiler A is shown in Fig.2.

When the natural frequency of the spoiler was measured it was found that the spoiler was quite highly damped and the effect of structural damping on its flutter speed has been calculated. The marked effect of a small amount of structural damping on the shape of the flutter speed versus massbalance curve is shown in Fig.2. Fig.3 shows how the flutter speed of an unmassbalanced spoiler varies with the amount of damping in the spoiler circuit. It will be seen that over the normal part of the damping range the flutter speed varies little with the rudder hinge moment due to trailing-edge strip. If the spoiler's natural frequency is also that of the rudder the flutter speed for low values of the damping is about half that with the rudder free. The flutter frequency decreases at first with increasing damping when the rudder is free, the decrements being greatest for the rudder with least aerodynamic balance. When the flutter speed becomes higher, however, the frequency starts to Increase, presumably due to the increased aerodynamic stiffness of the rudder. With stiffness in the rudder circuit, the frequency Increases very slightly with Increase of damping. The critical frequency parameter for the undamped spoiler, based on the fin mean chord, is 2.9.

2.2 Quaternary and Ternary Flutter Calculations

The quaternary flutter calculation was made on spoiler B. The degrees of freedom added to those of the binary calculation are fin linear bending and rudder torsion. Rudder torsion is included as the natural frequency of spoiler B is higher than that of spoiler A and near to the natural frequency of the rudder torsion mode in which the top and bottom parts of the rudder move against each other as rigid bodies, all the twist being in their interconnection. The fin flexure mode is included to check whether flutter similar to the 'ternary' flutter of tabs is possible; in the circumstances the shape of the mode was not thought to be important and a linear mode was assumed for simplicity.

The curves of flutter speed versus spoiler massbalance for a wide range of fin frequencies are shown in Fig.4. The flutter equations were solved on the R.A.E. flutter simulator and 1 per cent of critical structural damping was included in all the modes. The rudder-spoiler ternary curves are generally similar to the rudder-spoiler binary curve of Fig.2 with spoiler damping included, in marked contrast to the binary curves (of Fig.2) without spoiler damping. The curves of Fig.4 for zero fin stiffness are based on extrapolated results, and whilst the flutter speeds are probably fairly accurate, since they are extrapolated from smooth curves, there may be large errors in the flutter frequencies. The quaternary flutter curve follows the ternary-rudder rotation, rudder torsion, spoiler rotation-flutter curve closely when the spoiler massbalance is less than static for all fin frequencies except the frequency pertinent to Fig.4d, when the quaternary curve is modified by a near coincidence of the fin and spoiler frequencies producing a low binary fin-spoiler flutter speed. From a ternary-fin bending, rudder rotation, spoiler rotation-flutter calculation which has been made and gives a higher flutter speed than the quaternary, it would seem that of the rudder freedoms the torsion, is the more important in this quaternary flutter.

For the low fin frequencies the quaternary flutter speed remains practically coincident mth the ternary-rudder rotation, rudder torsion, spoiler rotation-speed until at 185% static spoiler massbalance, where the ternary flutter has almost disappeared, a second branch of the quaternary flutter appears. (The spoiler is dynamically massbalanced for rudder rotation at twice the value for static balance). In this second branch the critical speed decreases as the massbalance is Increased, and the important rudder motion is rotation. As the fin frequency is increased the transition to the second branch first occurs with less mass-balance and then the overbalance branch disappears completely, the addition of the fin bending mode leading only to minor modifications of the ternary rudder-spoiler curve.

3 Comparison of Results of Calculations and Flight Experience

No evidence of vibration was obtained in flight when the aircraft flew with the unmassbalanced spoiler A. The effectiveness tests were made at speeds up to 250 knots and the aircraft was fitted with vibration measuring equipment.

The frequency of the spoiler was measured on the ground and was found to be 25 c.p.s. when the spoiler was oscillating with small amplitude. The oscillations were observed to be quite heavily damped, the damping being estimated to be at least 10% of critical. Referring to Fig.2, it is *seen* that, for this value of damping, the calculated binary flutter speed when the undamped frequency of the spoiler is 25 c.p.s. and the rudder is free is at least 325 knots. This theoretical speed is consistent with there being no evidence of vibration in flight.

When spoiler B was fitted and flown without massbalance a persistent high-frequency vibration started at low airspeeds. The vibration was not severe but increased in severity on one occasion when the spoiler operating rod broke due to fatigue. The frequency of the vibration was measured as 52 c.p.s. 50% static massbalance made little difference *to* the vibration but when the massbalance was increased to 100% the vibration disappeared and has not occurred since.

This behaviour is explained to some extent by the left-hand branches of the quaternary flutter curves. The theoretical flutter speed? agree reasonably well with flight evidence but the theoretical flutter frequency does not. The theoretical flutter frequency of the unmassbalanced spoiler is 41.7 c.p.s., which is the natural frequency of the spoiler, while the frequency measured in flight is 52 c.p.s. Arbitrary changes in the direct spoiler structural damping and aerodynamic stiffness that have been investigated in an attempt to improve the agreement between the theoretical and practical frequencies give no better results. The spoiler seemed to have little damping when its frequency was measured, and reasonable amounts of structural damping were included when the flutter equations wore solved on the R.A.E. flutter simulator.

4 Conclusions

Calculations have given reasonable explanations of the flutter behaviour of two spoilers but have not accurately predicted the flutter frequency in the case where flutter was experienced in flight.

Flutter in which both the main surface and main control-surface play necessary parts is possible when the spoiler is overmassbalanced.

LIST OF SYMBOLS

a_{rs}, b_{rs}, c_{rs}	respectively the non-dimensional total inertia, aerodynamic damping and stiffness coefficients in the flutter equations
b2	the rate of change of the static rudder hinge moment with rudder angle
c	fin *reference* chord
c_{11}	ratio of stiffness in rudder rotation mode to that in spoiler rotation mode (E_{11}/E_{22})
s	fin reference length
Y	$E_{22}/\rho sc^2V^2$
E_{rr}	direct structural stiffness in r^{th} mode
V	critical flutter speed
ζ	negative b_2 due to rudder trailing-edge strip
ν	critical frequency parameter
ω	critical flutter frequency
ω_1	uncoupled still-air frequency of fin
ω_2	uncoupled still-air frequency of spoiler

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3	H. Templeton	The Technique of Flutter Calculations. Current Paper X0.172 April, 1953

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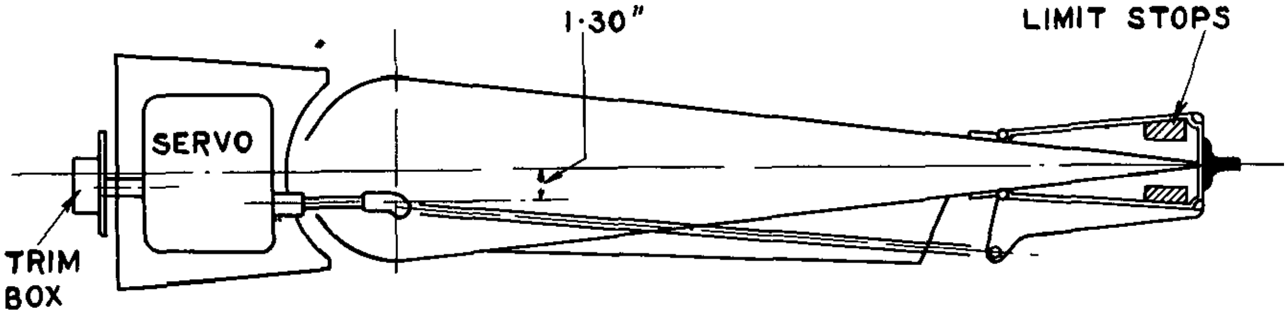
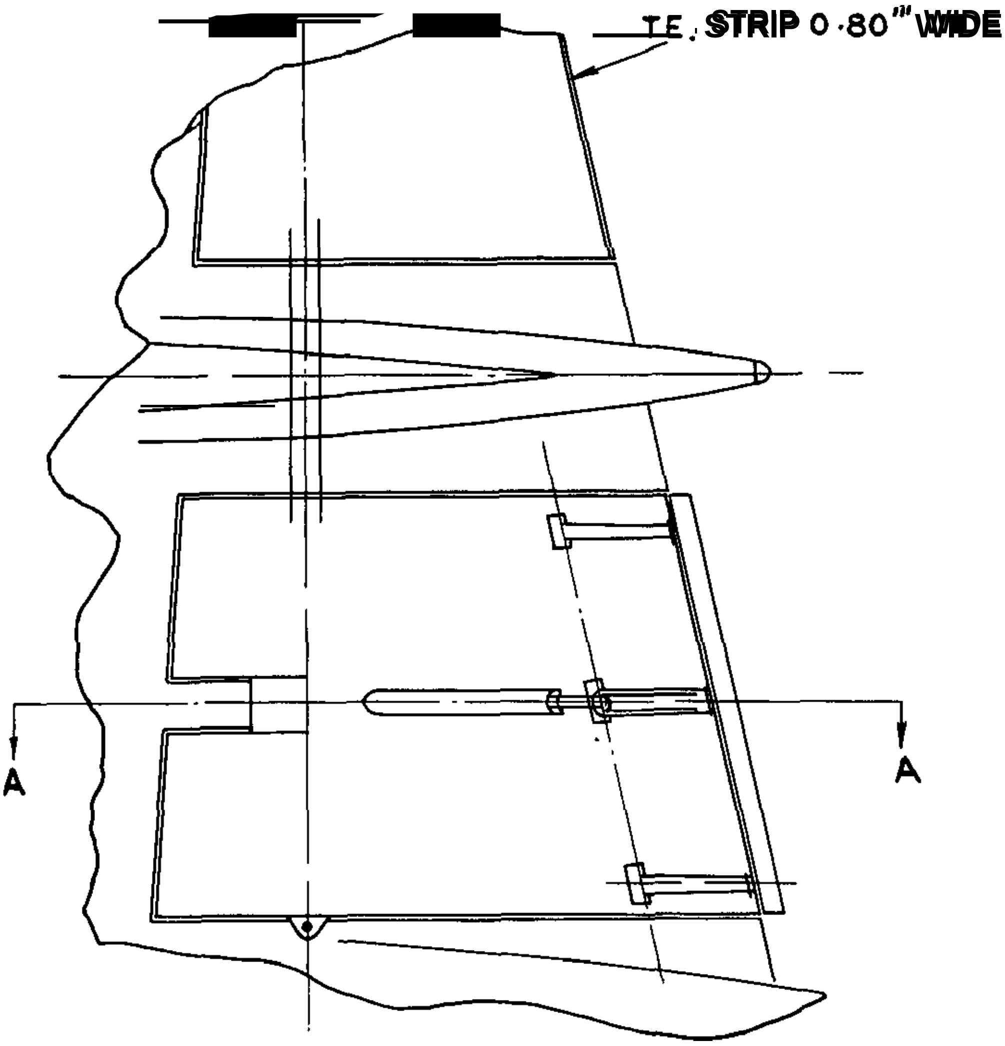
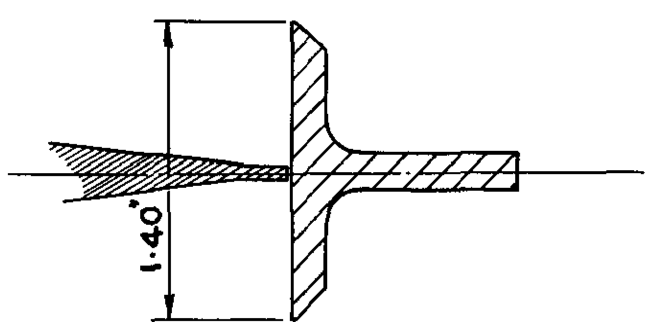


SECTION A-A.





SPOILER SECTION (FULL SIZE.)

FIG. 1. TRAILING-EDGE SPOILER(A) FITTED TO METEOR MK.8 TYPE RUDDER.

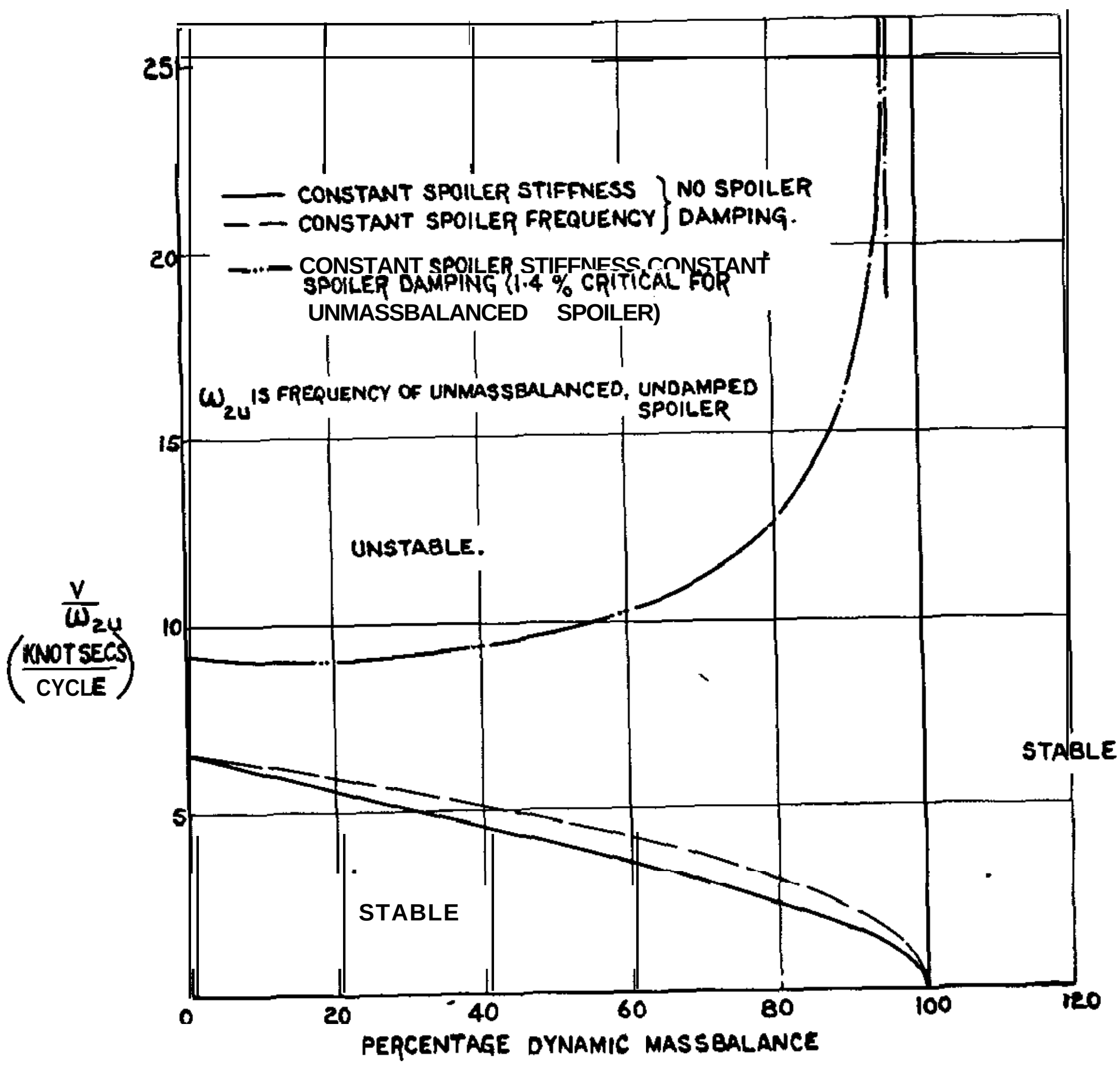


FIG.2. VARIATION OF FLUTTER SPEED WITH MASSBALANCE (RUDDER -SPOILER BINARY)

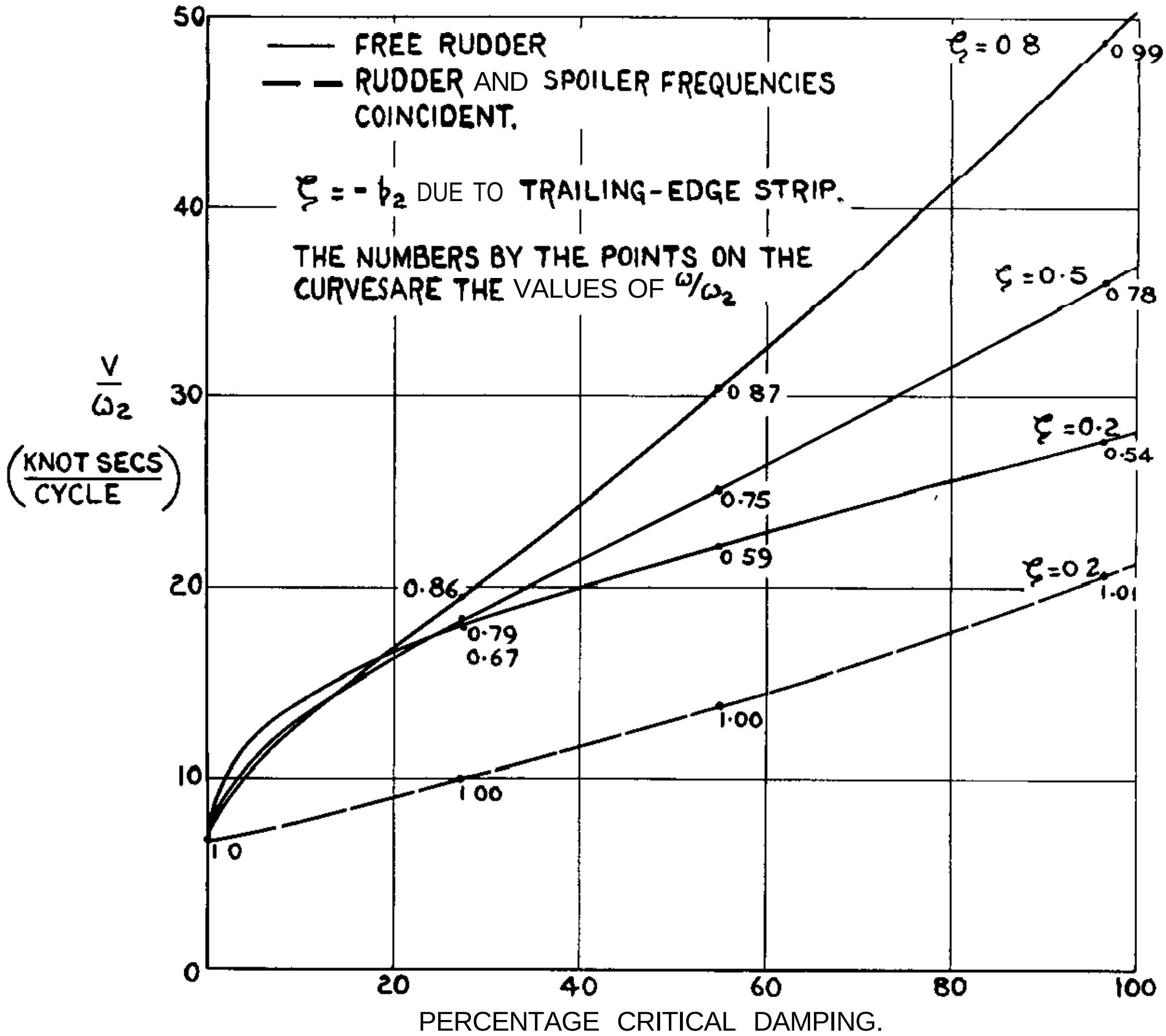


FIG.3. EFFECT OF SPOILER DAMPING ON RUDDER- SPOILER FLUTTER SPEED.

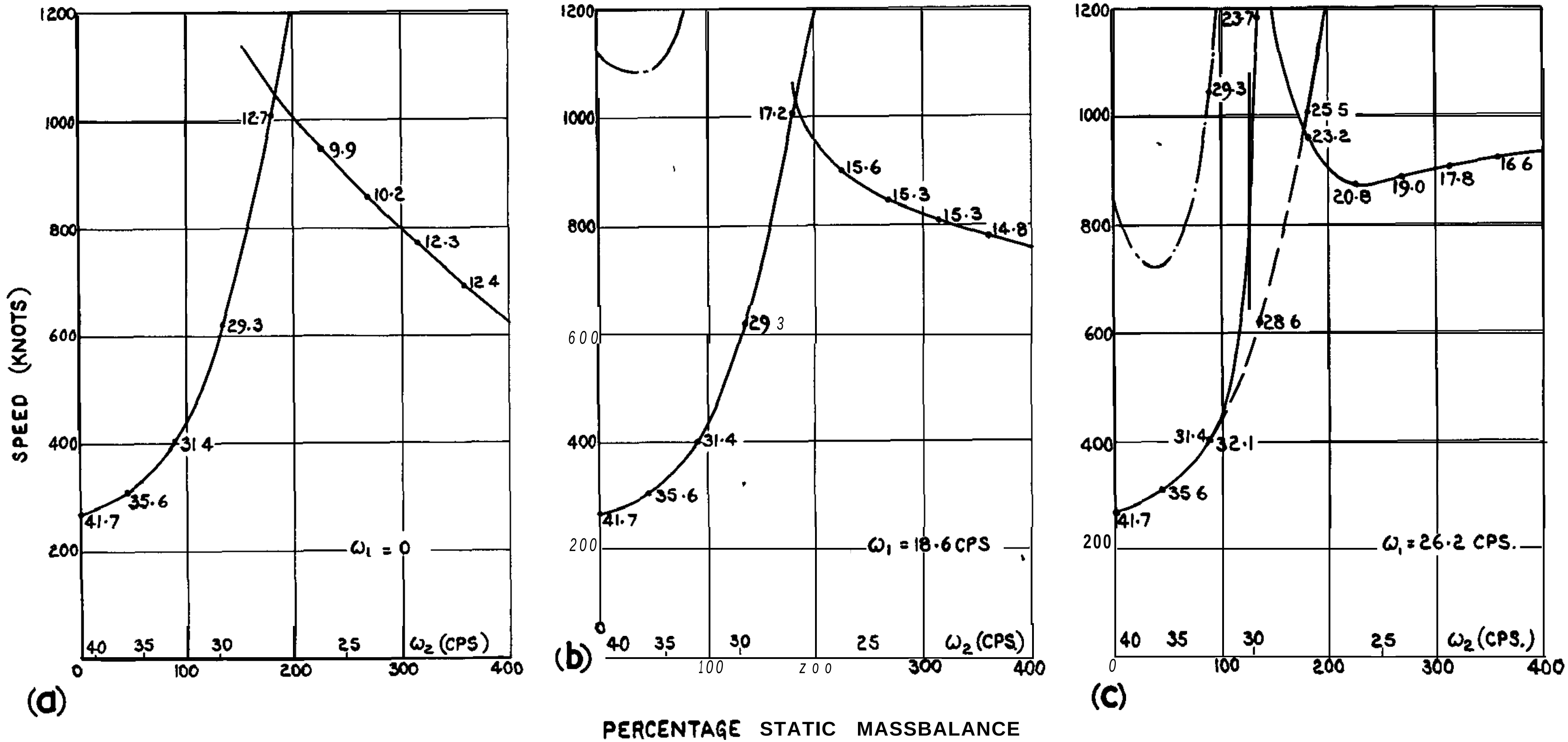


FIG. 4 (a-c) EFFECT OF SPOILER MASSBALANCE ON FLUTTER SPEED.

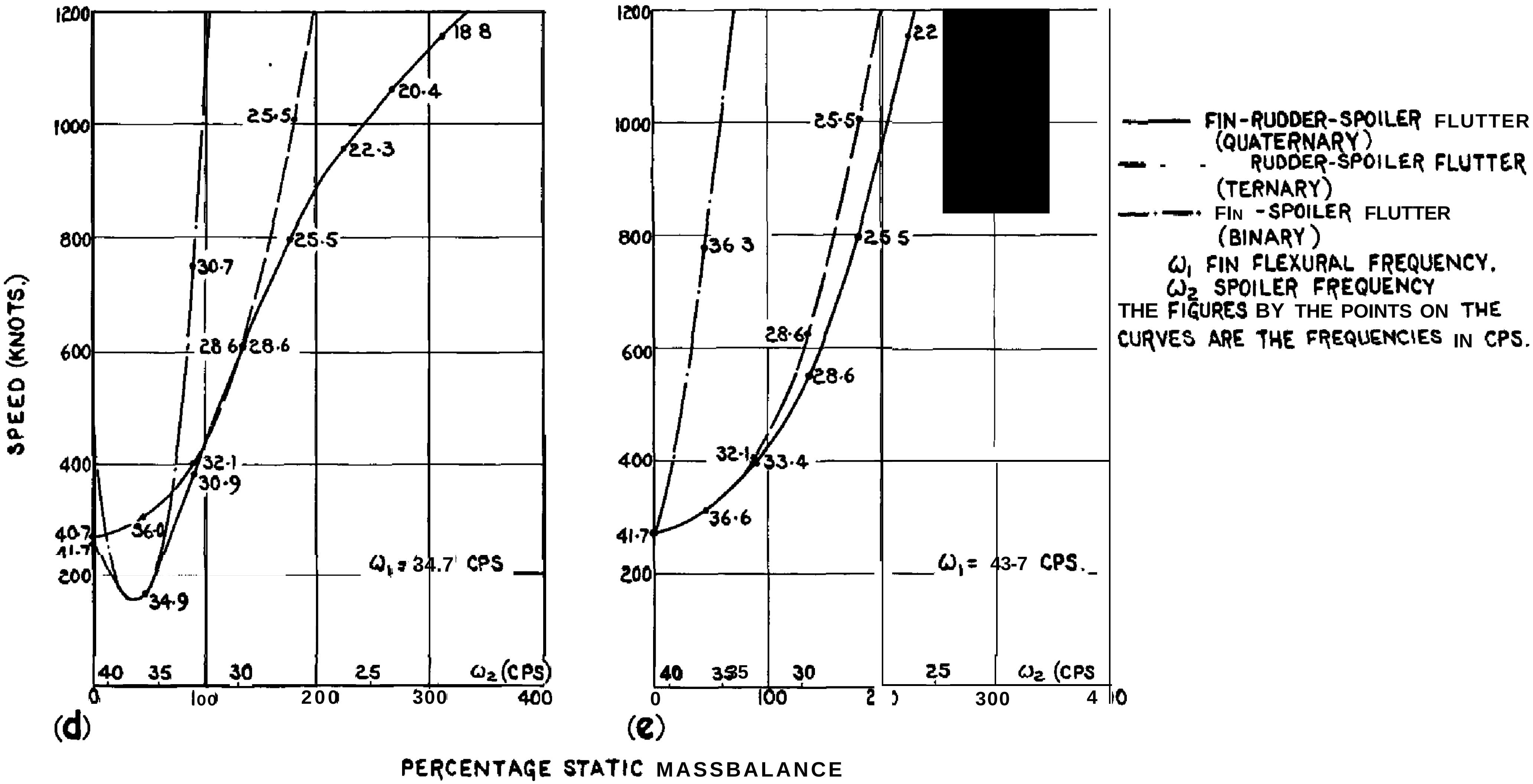


FIG.4(d&e) EFFECT OF SPOILER MASSBALANCE ON FLUTTER SPEED.

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