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Binary Aileron—Spring-tab Flutter

By

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Summary.—This note deals with binary aileron–spring-tab flutter involving rotation of the aileron and spring tab about their hinge lines. The methods of R. & M. 1155[2] are used to calculate the variation of flutter speed with various parameters. Particular attention has been given to the magnitude and position of the tab mass-balance weight.

It is concluded that binary aileron–spring-tab flutter can be prevented by mass-balancing the tab provided the balance weight is not placed further than a certain distance ahead of the tab hinge. This distance is in agreement with the limit suggested by Frazer and Jones[4]. Although flutter can be prevented by adding mass at this limiting distance, the mass required is impracticably large ; it becomes practicable if the arm is reduced to about three-quarters of the limiting distance.

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1. *Introduction*.—The increasing possibility of the use of spring tabs–because they give light controls without any danger of aerodynamic overbalance–made it desirable that the flutter characteristics of aileron–spring-tab systems should be investigated. An investigation had previously been made by Duncan and Collar[1] into the flutter of a rudder fitted with a spring-connected servo-flap, a system mechanically identical with the aileron-spring tab system. The work, however, was chiefly concerned with a particular example, and the conclusion that ordinary mass-balance (product of inertia of ruddder and flap about their hinge lines zero) was adequate to prevent flutter was not theoretically justified for the general case. It was therefore decided to make some preliminary calculations on aileron–spring-tab flutter. These were suspended when Frazer began to investigate the problem, but were later resumed at Frazer's suggestion in order to provide a comparison with his results. Frazer's recommendations for the prevention of aileron–spring-tab flutter are :—

(*a*) The ratio of the aileron to tab density (for definitions *see* Appendix I) should exceed 1/2 if possible and preferably be of the order of unity or higher.

(*b*) Any addition of mass to the aileron only (*e.g.* by mass-balancing the combination in the usual way) is advantageous.

(*c*) The tab-balancing mass, if present, must be at a distance from the tab hinge less than $1/(N + 1)$ of the distance between tab and aileron hinge, where N is the ratio of tab angle to aileron angle when the system is displaced with the operating lever locked.

(*d*) If (c) cannot be satisfied tab mass-balance should not be attempted.

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* R.A.E. Report S.M.E. 3209,

The dimensions and densities for the aileron and tab discussed in the R.A.E. preliminary calculations were chosen to represent a typical fighter aircraft. Recommendation (a) was not satisfied, as the tab density was about three times that of the aileron; this value excludes any mass-balancing of the tab. Recommendation (c) was not satisfied either, since the chosen value of tab arm was equal to tab chord, *i.e.* greater than the value 0·78 tab chord as required by recommendation (c). The theoretical results showed that it was impossible to eliminate flutter by mass-balancing. It was decided to extend the calculations to a case in which the tab mass-balance was placed nearer the tab hinge. The calculations were accordingly repeated for a shorter length balance arm and, in addition, the critical lengths of balance arm, below which flutter could not occur, were determined for the case of a statically mass-balanced tab (C.G. of tab on tab hinge), and for a dynamically mass-balanced tab (product of inertia of tab and aileron about their hinge lines zero).

2. *Results.*—In these calculations the aileron and tab were each considered to be rigid and two degrees of freedom were assumed; namely, rotation of the aileron about its hinge and rotation of the tab relative to the aileron about the tab hinge. The methods of R. & M. 1155[2] were used to calculate the variation of flutter speed with three parameters:—

(1) The stiffness of the spring connecting the tab control lever and aileron.

(2) The amount of mass-balance weight applied to the tab; all the inertia terms were altered consistently as the mass-balance weight was changed.

(3) The distance ahead of the tab hinge at which the mass-balance weight was applied.

Flutter calculations for the following conditions were made,

(a) the control column fixed,

(b) the control column free,

(c) the control column held as in (a) but with backlash between the tab control lever and the tab, *i.e.* the tab effectively free.

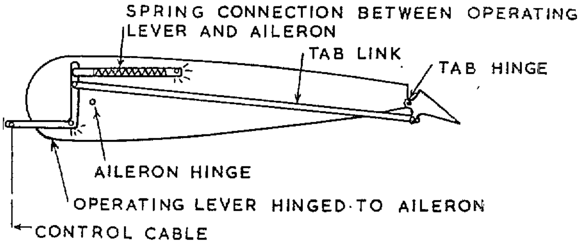

FIG. 1. Diagram of Spring-Tab System.*

The derivatives and the equations of motion used to obtain the flutter speeds are given in Appendix I. No account has been taken of preloading in the spring connection between the tab control lever and aileron.

Although the flutter speeds are all plotted in the diagrams as actual values in feet per second, the results should be considered as having qualitative rather than quantitative value, since theoretical calculations on control-surface flutter usually give results on the low side.

The results corresponding to variation of the three parameters are as follows:

(1) *Variation of flutter speed with stiffness of the spring connecting the tab control lever to the aileron.*—For condition (a) (control column held) the variation of flutter speed with spring stiffness appears to be small. Fig. 3 shows the slight increase in the flutter speed obtained by increasing the stiffness within practical limits. The balance arm is equal to the tab chord and three conditions of mass-balance have been taken; zero, static and dynamic. In view of the small variation obtained in the flutter speed with varying spring stiffness, and in order to simplify the work, the spring stiffness is henceforth taken as zero for all calculations relating to condition (a).

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* The operating lever hinge coincides with the aileron hinge in this report.

Fig. 4 shows a check made on this simplification with a balance arm of 0·58 times the tab chord; the difference in flutter speeds obtained by changing the spring stiffness from zero to 0·005 of the control-circuit stiffness is seen to be small, and the zero value gives the worse case. The spring stiffness is the moment about the tab hinge required to give unit tab rotation when the aileron is fixed and the aileron control circuit disconnected.

For condition (b) (control column free), and approximately for condition (c) (backlash in tab link), the flutter speed varies with the square root of the spring stiffness, so that for all three conditions it is advantageous to have the spring as stiff as is practicably possible. In practice there will probably be little choice in spring stiffness, since it will be determined by aerodynamical considerations.

(2) *Variation of flutter speed with mass balance.*—Fig. 5 shows the results of the initial preliminary calculations made with the balance arm equal to the tab chord. Although a mass-balance weight slightly greater than that giving static mass-balance prevents flutter altogether in conditions (b) and (c), no amount of over-mass-balance prevents flutter in condition (a); in fact increase of mass-balance weight merely lowers the flutter speed. This result is fully in accordance with Frazer's results. The calculations were then repeated for a very much shorter balance arm of length 0·1 times the tab chord and again were in agreement with Frazer's results. The variation of flutter speed is shown in Fig. 5; static mass-balance is now more than adequate to prevent flutter in conditions (a) and (b) and a mass-balance weight very slightly greater than the static mass-balance weight prevents flutter in condition (c). It should be noted that in this case the weight required for static mass-balance is impracticably large (about three times the tab weight).

(3) *Variation of flutter speed with length of balance arm.*—Since, in view of other requirements, spring tabs will probably be statically mass-balanced about their hinges, it seemed desirable to determine the longest length of balance arm (and hence the smallest mass) for which static mass-balance will prevent flutter. Condition (a) was chosen as being the critical one, as it was thought that flutter in condition (c), where it is due to backlash in the tab-connecting link, could probably be prevented by careful design (otherwise a mass-balance weight slightly in excess of the static mass-balance weight would be required to cover this condition). Condition (b) was not considered, since no flutter had occurred in that condition when the tab was statically mass-balanced, either with a balance arm of length 1 times the tab chord or of length 0·1 times the tab chord. Accordingly the variation of flutter speed with balance arm was calculated in condition (a) with the tab statically mass-balanced about its hinge. The result is shown in curve (1) of Fig. 7; curve (2) shows the result of repeating the calculation with the tab mass-balanced to make the product of inertia of the tab and aileron about their hinges zero; this required a slightly greater amount of balance weight than the static mass-balancing. If flutter is to be prevented the maximum permissible length of the mass-balance arm is 0·58 times tab chord when the tab is statically mass-balanced (*see* curve (1)) and 0·68 times tab chord when the tab is dynamically mass-balanced (*see* curve (2)).

Finally the variation of flutter speed with mass-balance was calculated for a balance arm of 0·58 times the tab chord. The results are plotted in Fig. 8. Static mass-balance of the tab, which requires a mass 0·575 times tab mass, is now, of course, just adequate to prevent flutter in condition (a). Flutter in condition (b) is prevented as for the previous arm lengths of 1·0 and 0·1 times the tab chord by statically balancing the tab. In condition (c) a slightly greater mass-balance weight (about 0·7 times tab weight) is required to prevent flutter, but this condition will not arise if the system is designed to cut out backlash between the tab control lever and tab.

3. *Conclusions.*—It can be deduced from Frazer's results that provided the balance arm is less than a certan length (depending on the ratio of tab angle to aileron angle when the system is displaced with the operating lever locked), then flutter can be prevented if sufficient balance mass is added to the tab.

The calculations of this report show that flutter occurs for a mass-balance arm slightly greater than Frazer's critical length, whatever the mass-balance weight, but indicate that a decrease in the mass-balance arm would eliminate flutter if the mass-balance weight were very large; on the other hand the mass required decreases very rapidly with further decrease in arm length. The critical length of balance arm below which flutter can be prevented by mass-balancing the tab agrees with that given by Frazer and Jones, but it should be noted that this critical length is not practical, since the mass-balance weight required to prevent flutter is very great. From general considerations (*e.g.* ternary flutter) it will probably be necessary for spring tabs to be statically mass-balanced; it is found (in this report) that if static mass-balance is to be sufficient to prevent flutter (except in the backlash case) then the mass-balance arm must not be greater than about $0 \cdot 75$ of the critical length given by Frazer. In the backlash case, flutter will be prevented if the tab mass-balance weight is slightly greater than that required for static mass-balance. It seems, therefore, that in order to prevent flutter of spring tabs, the tab mass-balance weight should exceed, by about 20 per cent., that required for static mass-balance (*i.e.* C.G. slightly ahead of the hinge line) and the mass-balance arm should not exceed $0 \cdot 75$ times the length given by Frazer, *i.e.* the arm is to be not greater than $3/4\ (N + 1)$ of the distance between tab and aileron hinges, where N is the ratio of the tab angle to the aileron angle when the system is displaced with the operating lever locked.

APPENDIX 1

Fundamental Equations and Data

Notation.—

ξ_1	Angle of rotation of aileron measured in radians from neutral position, positive when trailing edge is depressed.
ξ_2	Angle of rotation of tab relative to aileron, measured in radians, positive when trailing edge is depressed.
α	Ratio of stiffness of spring connection between tab control lever and aileron-to-aileron control circuit stiffness; for stiffness definitions *see* X and Y below.
β	Ratio of tab mass-balance weight to tab weight.
γ	Ratio of length of balance arm used for tab mass-balance weight to tab chord; the balance arm is the distance ahead of the tab hinge at which the mass-balance weight is applied.
c_A, c_T	Length in feet of aileron and tab chord respectively, assumed constant along span.
S_A, S_T	Area in square feet of aileron and tab respectively.
s_A, s_T	Length in feet of aileron and tab span respectively.
M_A, M_T	Weight in slugs of aileron and tab respectively.
Y	Aileron control circuit stiffness measured in lb ft/rad.; defined as elastic moment about aileron hinge per unit angle rotation of aileron when tab control lever is fixed relative to aileron and the control column is fixed in the cockpit.
X	Spring stiffness measured in lb ft/rad; defined as elastic moment about tab hinge per unit angle rotation of tab with aileron held fixed and Y and Z infinite.
Z	Elastic stiffness of tab link measured in lb ft/rad; defined as elastic moment about tab hinge per unit angle rotation of tab when aileron and tab control lever are fixed. Two values only, $Z = 0$ or ∞, are considered.

ρ Density of air at normal temperature and pressure, $= 0 \cdot 002378$ slug/cu ft.

V Airspeed measured in ft/sec.

N Ratio of tab angle to aileron angle when the system is displaced with the control column held and the control cable and tab link infinitely stiff.

The following data was assumed as being representative of a fighter plane. The densities have been obtained by averaging known values of aileron and tab densities for certain fighters.

$c_A = 1 \cdot 4$ ft.

$c_T = 0 \cdot 35$ ft.

$s_A = 10$ ft.

$s_T = 3\frac{1}{3}$ ft.

$N = 1/0 \cdot 35$.

$\frac{M_A}{s_A c_A^2} = 1 \cdot 1g$ slug/cu ft, defined as aileron density.

$\frac{M_T}{s_T c_T^2} = 3 \cdot 5g$ slug/cu ft, defined as tab density.

$Y = 2000$ lb. ft/rad.

Aspect ratio of wing $= 6$.

Ratio of wing chord to aileron chord $= 5$.

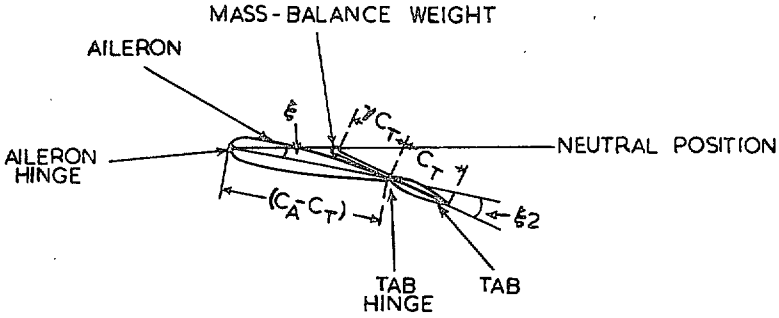

FIG. 2. Diagram Illustrating Notation.

Equations of Motion.—It is assumed that the motion impressed on the wing by the aileron-tab flutter can be neglected; and that the tab and aileron are both rigid, and that the inertia of the moving parts of the aileron and tab control system is small enough to be neglected. Then there are two degrees of freedom which can be specified by the following two co-ordinates; rotation of the aileron plus tab about the aileron hinge, denoted by ξ_1, and rotation of the tab relative to the aileron about the tab hinge, denoted by ξ_2. Two equations of motion are obtained by equating moments about the aileron hinge and about the tab hinge.

The equation of moments about the aileron hinge gives

$$A_1\ddot{\xi}_1 + B_1\dot{\xi}_1 + C_1\xi_1 + D_1\ddot{\xi}_2 + E_1\dot{\xi}_2 + F_1\xi_2 = 0 \, ,$$

and similarly about the tab hinge

$$A_2\ddot{\xi}_1 + B_2\dot{\xi}_1 + C_2\xi_1 + D_2\ddot{\xi}_2 + E_2\dot{\xi}_2 + F_2\xi_2 = 0 \, .$$

A and D are inertia coefficients, B and E are aerodynamical damping coefficients, and C and F are aerodynamic plus elastic stiffness coefficients. The flutter speeds are obtained from these equations by the classical methods of R. & M. 1155[2].

Inertia Coefficients.—The mass distribution for both aileron and tab is assumed to be constant along the span and to decrease linearly from a positive value at the aileron and tab hinges to a zero value at their respective trailing edges. The inertia coefficients can be obtained as in Appendix I of R. & M. 1155[2] or from first principles by integration of the moments of the inertia forces on every element. With the assumed distribution of aileron and tab mass and with the tab mass-balanced by a bob-weight βM_T on an arm of length γc_T forward of the tab hinge it is found that—

$$A_1 = M_A \frac{c_A^2}{6} + \left(M_T - \frac{M_A}{47}\right)\left(\frac{c_T^2}{2} + c_A^2 - \frac{4c_A c_T}{3}\right) + \beta M_T \left(c_A - c_T \,.\, \overline{1 + \gamma}\right)^2 ,$$

$$D_1 = A_2 = M_T \frac{c_T^2}{6} + M_T \frac{c_T}{3}(c_A - c_T) + \beta M_T \gamma^2 c_T^2 - \beta M_T \gamma (c_A - c_T) c_T ,$$

$$D_2 = M_T \frac{c_T^2}{6} + \beta M_T \gamma^2 c_T^2 .$$

On insertion of the values for the tab and aileron densities and the tab dimensions as multiples of the aileron dimensions these expressions reduce to

$$A_1 = [2{\cdot}897 + 0{\cdot}2383\, \beta\, (1{\cdot}5 - 0{\cdot}5\gamma)^2]\, \rho S_A c_A^3 ,$$
$$D_1 = A_2 = (0{\cdot}06951 - 0{\cdot}1788\beta\gamma + 0{\cdot}05959\beta\gamma^2)\, \rho S_A c_A^3 ,$$
$$D_2 = (0{\cdot}009931 + 0{\cdot}05959\beta\gamma^2)\, \rho S_A c_A^3 ,$$

Aerodynamical Derivatives.—Since no experimental data were available the derivatives were estimated with the aid of R. & M. 1171[3] which gives expressions for the hinge moments per unit span for an aerofoil with multiple-hinged flaps. The moments are expressed in terms of coefficients depending on the aspect ratio and flap to aerofoil chord ratios, and tables for the coefficients are given at the end of the report. The required aerodynamical stiffness coefficients are the hinge moments per unit rotation of the aileron and tab, so that if the wing is considered as an aerofoil with two hinged flaps, the aileron and tab, the aerodynamical stiffness coefficients can be obtained directly by putting the appropriate coefficients into the expression for the hinge moment and multiplying by the span of the flap concerned. The aspect ratio of the wing is taken as 6, the ratio of aileron to wing chord is $0{\cdot}2$, and the ratio of tab to wing chord is $0{\cdot}05$. The hinge moments are multiplied by an efficiency factor of $0{\cdot}8$ to allow for differences between theory and practice. The final values are

$$M_{\xi 1} = -\,0{\cdot}34\rho S_A c_A V^2 , \qquad H_{\xi 1} = -\,0{\cdot}0028\rho S_A c_A V^2 ,$$
$$M_{\xi 2} = -\,0{\cdot}17\rho S_A c_A V^2 , \qquad H_{\xi 2} = -\,0{\cdot}0070\rho S_A c_A V^2 ,$$

where $M_{\xi 1}$, $M_{\xi 2}$ are aerodynamic moments about the aileron hinge per unit angle rotation of the aileron and tab respectively, and $H_{\xi 1}$, $H_{\xi 2}$ are aerodynamic moments about the tab hinge per unit angle rotation of the aileron and tab respectively; the tab rotation is to be measured relative to the aileron

The aerodynamical damping terms were obtained on the basis that the aerodynamical moment on a hinged rotating aerofoil, due to the angular velocity, is the same as that on a static aerofoil whose incidence is some constant times the ratio of the aerofoil chord multiplied by aerofoil angular velocity to the airspeed. If the flap angular velocity is $\dot{\xi}$ and the airspeed is V then a brief investigation shows that the velocity $\dot{\xi}$ could be regarded as producing an incidence change of about $0{\cdot}8c\ \dot{\xi}/V$, and hence the aerodynamical damping coefficients can be estimated in the same way as the aerodynamical stiffness coefficients. The final results are

$$M_{\dot{\xi} 1} = -\,0{\cdot}34\rho S_A c_A^2 V , \qquad H_{\dot{\xi} 1} = -\,0{\cdot}0028\rho S_A c_A^2 V ,$$
$$M_{\dot{\xi} 2} = -\,0{\cdot}043\rho S_A c_A^2 V , \qquad H_{\dot{\xi} 2} = -\,0{\cdot}0018\rho S_A c_A^2 V ,$$

where $M_{\xi 1}$, $M_{\xi 2}$ are aerodynamic moments about the aileron hinge corresponding to unit angular velocity of the aileron and tab respectively, and $H_{\xi 1}$, $H_{\xi 2}$ are aerodynamic moments about the tab hinge corresponding to unit angular velocity of the aileron and tab respectively. The tab velocity is to be measured relative to the aileron.

The values of the aerodynamical derivatives obtained here may be considerably in error, especially the damping coefficients. The results of the calculations using these derivatives can therefore only be regarded as qualitative.

Elastic Coefficients.—The elastic coefficients have been obtained by differentiation of the total elastic potential energy. The stiffness of the spring connection between the aileron and operating lever is X and the control-circuit stiffness is Y (for exact definitions *see* Notation). It has been assumed that the operating lever is infinitely stiff, but the tab link has been given a stiffness Z (for definition *see* Notation). A value of 2,000 lb. ft/rad has been taken for Y throughout the calculations. X is varied from 0 to $0 \cdot 01 Y$; Z has either the value infinity when the tab link is infinitely stiff or zero when there is backlash between the tab and operating lever (*see* Fig. 1).

The following are the values obtained for the elastic stiffness coefficients.

$$m_{\xi 1} = \frac{N^2 (X + Z) Y}{N^2 (X + Z) + Y},$$

$$m_{\xi 2} = h_{\xi 1} = - \frac{NYZ}{N^2 (X + Z) + Y},$$

$$h_{\xi 2} = \frac{Z (N^2 X + Y)}{N^2 (X + Z) + Y}.$$

$m_{\xi 1}$, $m_{\xi 2}$ are the moments about the aileron hinge of the elastic stiffness forces per unit angle rotation of the aileron and unit rotation of the tab relative to the aileron respectively; $h_{\xi 1}$, $h_{\xi 2}$ are the moments about the tab hinge of the elastic stiffness forces per unit angle rotation of the aileron and unit rotation of the tab relative to the aileron respectively. N depends on the geometry of the control system and is defined in the Notation list; a value of $1/0 \cdot 35$ is taken in this case. Flutter calculations were made for the following three conditions—

(a) the tab link is rigid, *i.e.* Z is infinite and the control column is fixed; the stiffness coefficients are then

$$m_{\xi 1} = Y,$$

$$m_{\xi 2} = h_{\xi 1} = - 0 \cdot 35 Y,$$

$$h_{\xi 2} = X + 0 \cdot 1225 Y.$$

(b) Z is infinite as in (a) but the control column is free *i.e.* $Y = 0$; the stiffness coefficients are

$$m_{\xi 1} = m_{\xi 2} = h_{\xi 1} = 0,$$

$$h_{\xi 2} = X.$$

(c) if there is backlash in the tab link $Z = 0$ and with the control column held the stiffness coefficients are

$$m_{\xi 1} = \frac{XY}{X + 0 \cdot 1225 Y},$$

$$m_{\xi 2} = h_{\xi 1} = h_{\xi 2} = 0.$$

The standard values for the coefficients used in the equations can now be written down in terms of α, β and γ; they are as follows.

Coefficient	Standard Value		Coefficient	Standard Value	
A_1	$[2 \cdot 897 + 0 \cdot 2383\beta(1 \cdot 5 - 0 \cdot 5\gamma)^2]\ \rho S_A c_A{}^3$		A_2	$(0 \cdot 06951 - 0 \cdot 1788\beta\gamma + 0 \cdot 05959\beta\gamma^2)\ \rho S_A c_A{}^3$	
B_1	$0 \cdot 34\ \rho S_A c_A{}^2 V$		B_2	$0 \cdot 0028\ \rho S_A c_A{}^2 V$	
C_1	$0 \cdot 34\ \rho S_A c_A V^2 + 2000$	(condition (a))	C_2	$0 \cdot 0028\ \rho S_A c_A V^2 - 750$	(condition (a))
	$0 \cdot 34\ \rho S_A c_A V^2$	(condition (b))		$0 \cdot 0028\ \rho S_A c_A V^2$	(condition (b)
	$0 \cdot 34\ \rho S_A c_A V^2 + \dfrac{2000\alpha}{\alpha + 245}$	(condition (c))		$0 \cdot 0028\ \rho S_A c_A V^2$	(condition (c))
D_1	$(0 \cdot 06951 - 0 \cdot 1788\beta\gamma + 0 \cdot 05959\beta\gamma^2)\ \rho S_A c_A{}^3$		D_2	$(0 \cdot 009931 + 0 \cdot 05959\beta\gamma^2)\ \rho S_A c_A{}^3$	
E_1	$0 \cdot 043\ \rho S_A c_A{}^2 V$		E_2	$0 \cdot 0018\ \rho S_A c_A V^2$	
F_1	$0 \cdot 17\ \rho S_A c_A V^2 - 750$	(condition (a))	F_2	$0 \cdot 0070\ \rho S_A c_A V^2 + 2000\alpha + 245$	(condition (a))
	$0 \cdot 17\ \rho S_A c_A V^2$	(condition (b))		$0 \cdot 0070\ \rho S_A c_A V^2 + 2000\alpha$	(condition (b))
	$0 \cdot 17\ \rho S_A c_A V^2$	(condition (c))		$0 \cdot 0070\ \rho S_A c_A V^2$	(condition (c))

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No.	*Author*	*Title, etc.*
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4	R. A. Frazer and W. P. Jones	Wing-aileron-tab Flutter. A.R.C. 5668. (To be published).

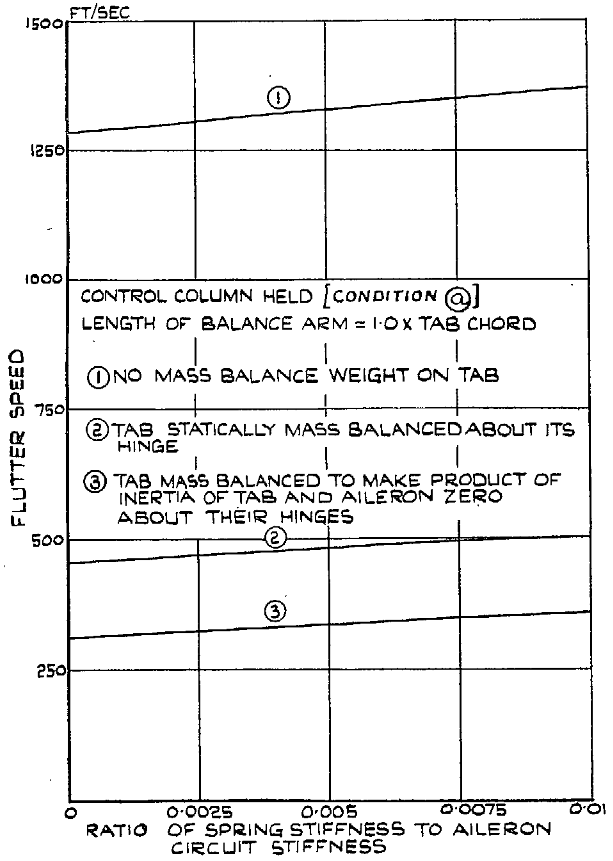
FT/SEC
1500
1250
1000
750
500
250
FLUTTER SPEED
CONTROL COLUMN HELD [CONDITION ⓐ]
LENGTH OF BALANCE ARM = 1·0 X TAB CHORD
① NO MASS BALANCE WEIGHT ON TAB
② TAB STATICALLY MASS BALANCED ABOUT ITS HINGE
③ TAB MASS BALANCED TO MAKE PRODUCT OF INERTIA OF TAB AND AILERON ZERO ABOUT THEIR HINGES
①
②
③
0
0·0025
0·005
0·0075
0·01
RATIO OF SPRING STIFFNESS TO AILERON CIRCUIT STIFFNESS

FIG. 3.

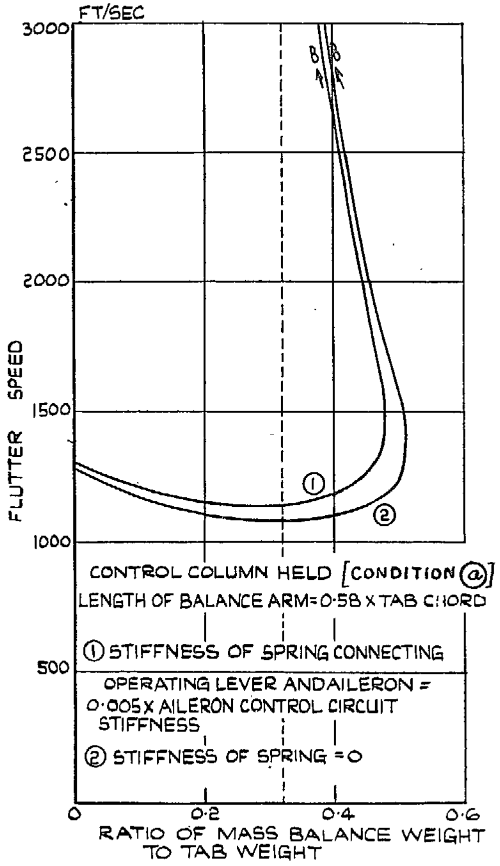
FT/SEC
3000
2500
2000
1500
1000
500
FLUTTER SPEED
B
B
A
A
①
②
CONTROL COLUMN HELD [CONDITION ⓐ]
LENGTH OF BALANCE ARM = 0·58 X TAB CHORD
① STIFFNESS OF SPRING CONNECTING OPERATING LEVER AND AILERON = 0·005 X AILERON CONTROL CIRCUIT STIFFNESS
② STIFFNESS OF SPRING = 0
0
0·2
0·4
0·6
RATIO OF MASS BALANCE WEIGHT TO TAB WEIGHT

FIG. 4.

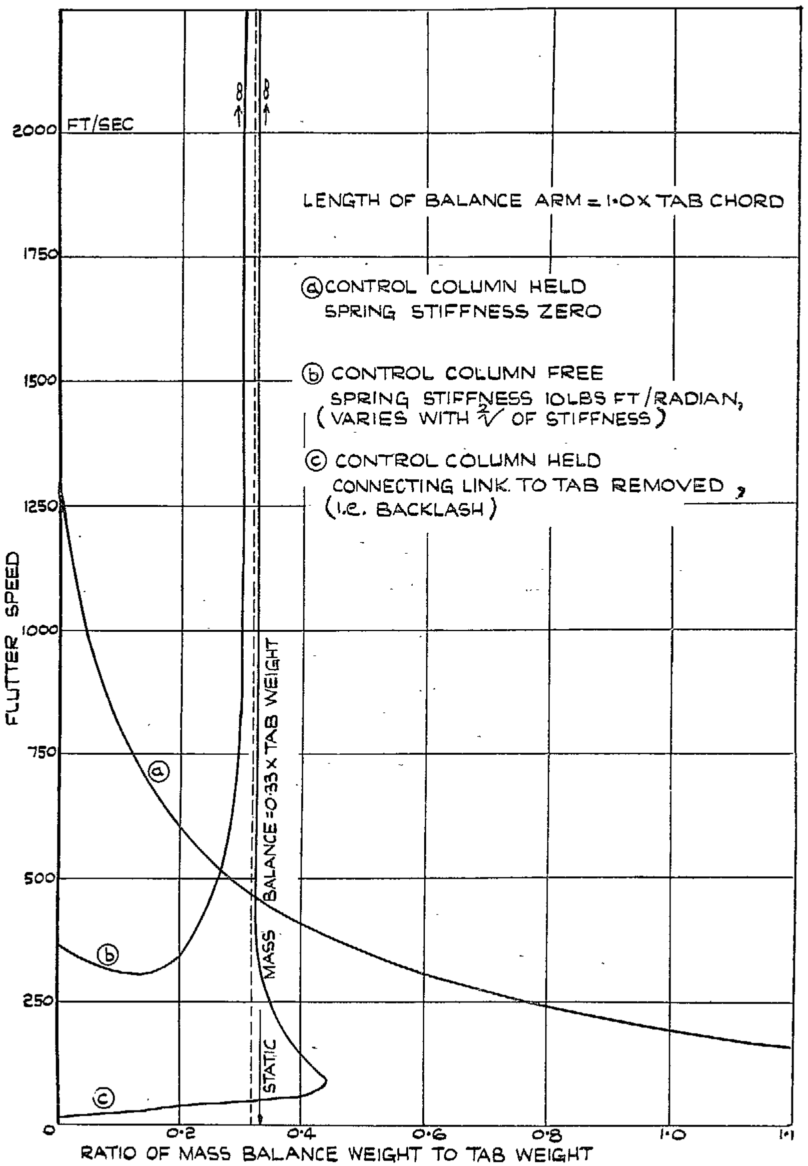
2000 FT/SEC
1750
1500
1250
1000
750
500
250
0
FLUTTER SPEED
0·2
0·4
0·6
0·8
1·0
1·1
RATIO OF MASS BALANCE WEIGHT TO TAB WEIGHT
∞
∞
LENGTH OF BALANCE ARM = 1·0 X TAB CHORD
ⓐ CONTROL COLUMN HELD
SPRING STIFFNESS ZERO
ⓑ CONTROL COLUMN FREE
SPRING STIFFNESS 10LBS FT/RADIAN,
(VARIES WITH ∛ OF STIFFNESS)
ⓒ CONTROL COLUMN HELD
CONNECTING LINK TO TAB REMOVED,
(I.E. BACKLASH)
STATIC MASS BALANCE = 0·33 X TAB WEIGHT
ⓐ
ⓑ
ⓒ

Fig. 5.

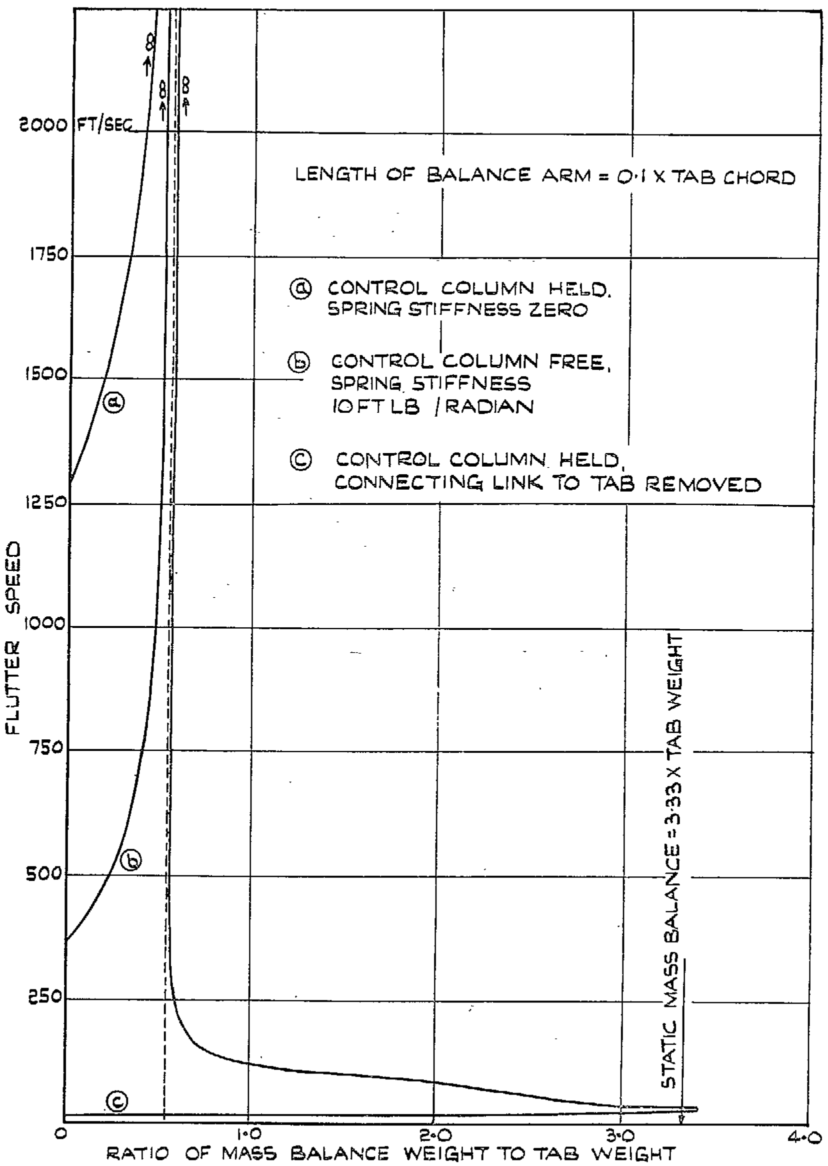
2000 FT/SEC
1750
1500
1250
1000
750
500
250
0
FLUTTER SPEED
1·0
2·0
3·0
4·0
RATIO OF MASS BALANCE WEIGHT TO TAB WEIGHT
∞
∞
∞
LENGTH OF BALANCE ARM = 0·1 X TAB CHORD
ⓐ CONTROL COLUMN HELD.
SPRING STIFFNESS ZERO
ⓑ CONTROL COLUMN FREE.
SPRING STIFFNESS
10 FT LB / RADIAN
ⓒ CONTROL COLUMN HELD.
CONNECTING LINK TO TAB REMOVED
STATIC MASS BALANCE = 3·33 X TAB WEIGHT
ⓐ
ⓑ
ⓒ

Fig. 6.

(96127) Wt. 14/806 K.5 2/51 Hw

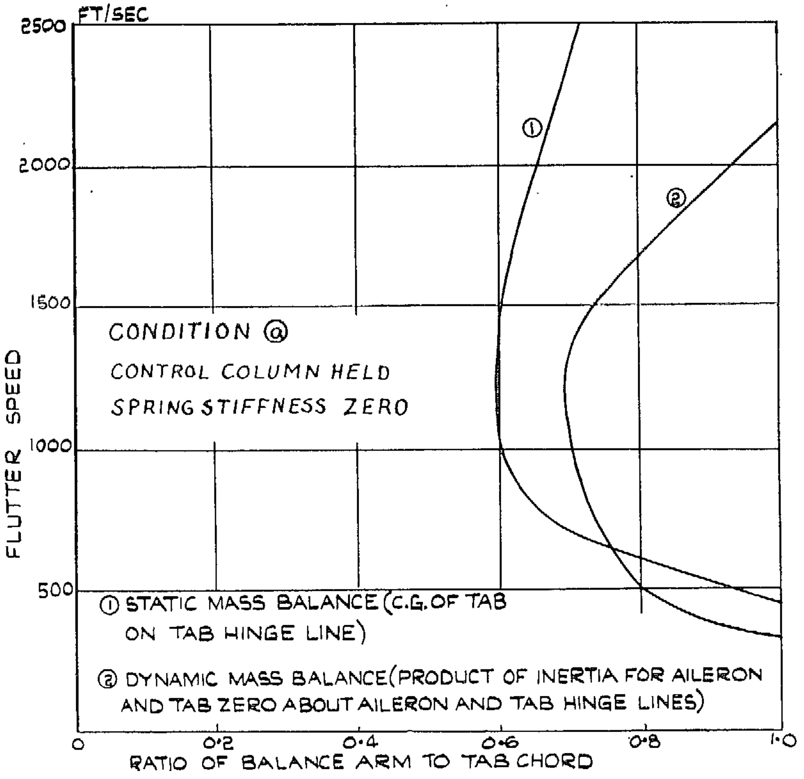

FIG. 7.

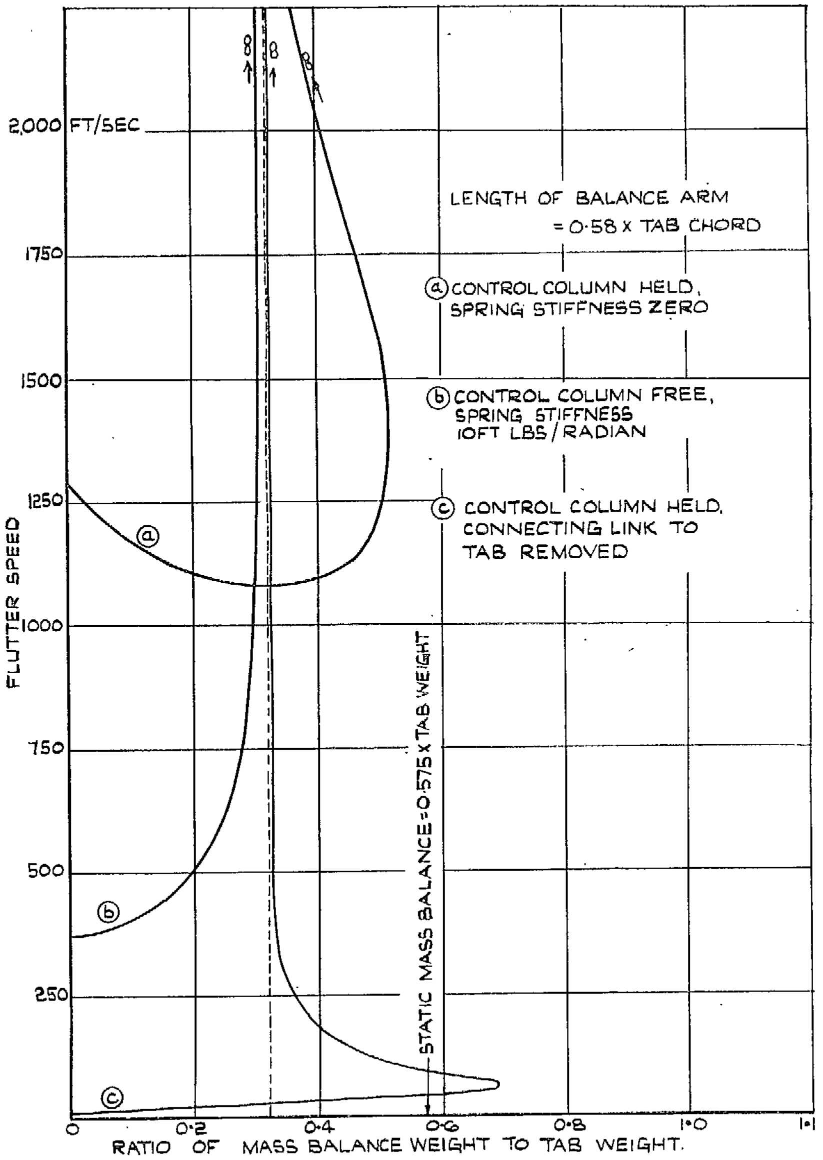

FIG. 8.

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