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An Investigation of
Wing-Aileron Flutter
Using Ground Launched
Rocket Models

by

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SUMMARY

Control surface flutter of the wing torsion-control rotation type has been investigated for an unswept wing with an under-massbalanced, half span, outboard aileron. Thirteen pairs of wings were tested, using ground launched rocket driven vehicles, and a range of values of aileron natural frequency was covered. The test results showed considerable scatter, but enabled upper and lower limits of a flutter boundary to be determined approximately. It was established that aileron flutter could be eliminated on the models tested provided the aileron frequency exceeded the wing torsional frequency by 20 per cent or more. In this condition the models were also free from single degree of freedom flutter (control surface "buzz").

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1 INTRODUCTION

The effect of Mach number, particularly in the transonic region, on control surface flutter for finite wings has not been widely investigated experimentally. The theoretical treatment of the problem is made difficult by the lack of knowledge of the aerodynamic forces associated with control oscillation at speeds where compressibility is important. Accordingly, an experimental investigation of wing aileron flutter has been made using ground launched rocket driven test vehicles, and the results are given in this Note.

A series of thirteen pairs of nominally identical models was tested, each model having an outboard aileron. The ailerons were under-massbalanced, and provision was made for variation of hinge stiffness. It is characteristic of under-massbalanced controls that, for low values of hinge stiffness, flutter will occur at low speeds, and the wing motion will be predominantly flexural. If the hinge stiffness is raised, this type of flutter will be eliminated. At higher speeds the aileron will couple with torsion of the wing to give a new flutter condition. It is principally this second type of wing-aileron flutter that has been investigated in the present tests.

There is, however, a third type of oscillation that may be expected to occur at high subsonic speeds. This is single degree of freedom flutter of the control surface (aileron 'buzz') and it is possible that flight records of this type of oscillation would be indistinguishable from records of wing-aileron flutter. Nevertheless, for aileron hinge stiffnesses greater than a certain value, neither coupled flutter nor 'buzz' occurred, and this value was, in fact, very much lower than the value obtained from a criterion which has been suggested as a general guide in design for the avoidance of buzz¹.

2 EXPERIMENTAL PROGRAMME

2.1 Wing details

Thirteen pairs of wings were used in the tests, each pair consisting of two root-to-tip half wings which could be clamped to a central rocket motor representing the fuselage. Each half wing (Fig.1) was untapered and unswept with a span of 2 feet and chord of 1 foot. Quarter chord ailerons were carried on the outboard half of each wing giving aileron dimensions of 1 foot span and 3 inches chord. The aerofoil section was R.A.E. 101 with a thickness/chord ratio of 0.10. A fairing was carried at the wing tip, extending over the total chord with a semi-circular cross section in the plane normal to the line of flight.

The wing construction was of spruce with an insert of lead strip along the leading edge. The aileron was carried on a 20 S.W.G. steel tube with a brazed strip in the aileron plane (Fig.2). The aileron, which was screwed and glued to the tube and strip, was also of spruce. The aileron hinge consisted of two plain bearings at the inboard and outboard ends of the aileron, the hinge brackets being attached to the wing so that there was no disturbance of the contour. The inboard end of the aileron tube carried a plug with a splined hole on the tube centre line. An aileron torque bar with splined ends was fitted between the aileron tube and the wing root; the layout being shown in Fig.2. The torque bar was held at the wing root in a steel block which was attached to the bracket clamping the wing to the rocket motor. Variation of the material and cross-section of the aileron torque bar enabled the stiffness of the aileron hinge to be varied.

* This method of providing control circuit stiffness is representative of some aircraft systems with manual control. For other manually operated systems and for power operated systems a stiffness would be required between the control and an outboard wing section.

2.2 Laboratory tests

The weight, centre of gravity position, and pitching moment of inertia of each wing-aileron assembly was measured. Owing to the difficulty of removing the ailerons from the wings after manufacture, spot checks were made on four ailerons before assembly to determine aileron centre of gravity and moment of inertia about the hinge line. The models were manufactured in two batches and it was found that differences in aileron inertia characteristics existed between batches. Stiffness tests were made on each wing to obtain the flexural and torsional stiffnesses in the line of flight at 0.7 span with the root end of the wing held rigidly. The aileron hinge stiffness was also measured with the wing held rigidly. Resonance tests were made under the same conditions, the nodal lines of the first three normal modes of the wing being obtained by means of the sand pattern technique.

2.3 Wind tunnel and flight tests

In order to determine the minimum value of control hinge stiffness necessary to avoid aileron flutter of the wing flexure type, a series of low speed wind tunnel tests was made in the R.A.E. 5 ft wind tunnel. In these tests, a half wing was rigidly clamped at the root and the flutter speeds and frequencies were measured for a range of aileron torque bar stiffnesses. The maximum air speed reached in these tests was 270 feet per second.

In the rocket tests each pair of wings was rigidly clamped to a 5 in. "Thrush" boost motor. A four fin tail assembly of standard pattern was attached to the motor at the venturi and a telemetry transmitter was carried at the front of the motor.

Instrumentation consisted of an accelerometer near the tip of each wing oriented to respond to acceleration normal to the plane of the wing. The transducers were at 0.95 of the semi-span and 0.23 of the chord aft of the leading edge, and had a maximum range of ± 17 g. Leads from the transducers were taken to the wing root within the wing contour, and thence through conduit along the side of the boost motor to the telemetry transmitter. The transmitter was a miniature, multi-channel unit operating on a carrier frequency of 465 megacycles/second. The two accelerometers in a test vehicle were each sampled every six-hundredth of a second.

The test vehicles were fired over the R.A.E. Larkhill range at an elevation of 15° . Ground instrumentation at the range comprised radio reflection Doppler, giving the variation of velocity with time, telemetry receiver giving the variation of transducer response with time, kine-theodolite tracking giving trajectory, and high speed cinematography.

3 TEST RESULTS

3.1 Laboratory and wind tunnel tests

Details of the inertia, stiffness and resonance tests are given in Table 1 and Fig.3. The values of aileron frequency are those of the flight test condition. Lower values of aileron frequency were used in the wind tunnel tests, which were all made on wing number 3. These were zero (no torque bar) 12.0, 22.3 and 27.1 cycles/second. With the first three of these frequencies flutter was obtained and was observed to be of the wing bending-aileron rotation type. At the highest aileron frequency no flutter occurred up to a tunnel speed of 270 feet/second. The 'nose' of the wing bending-aileron rotation branch of the flutter curve could be assumed therefore to be in the region of 25 to 30 cycles/second as is shown in Fig.6

and a minimum value of aileron frequency for the flight tests of 40 cycles/second was chosen. The maximum value was determined by the effectiveness of the aileron torque bar end fittings, and this value proved to be in the region of 90 cycles/second.

3.2 Flight tests (first series)

In the first series of flights, six models were tested, having aileron natural frequencies of 42, 48, 62, 68, 84 and 93 cycles/second (Models 1-6, Table 1).

Model 1 (aileron frequency 42 cycles/second). A very clear telemetry record of flutter was obtained for both wing transducers. The starboard wing began to flutter at a slightly lower speed than the port wing (Fig.4(a)) and about seventeen cycles of the flutter oscillation occurred before the ailerons broke away from the wing.

Model 2 (aileron frequency 48 cycles/second). Neither the telemetry record (Fig.4(b)) nor the high speed cine films indicate a clear case of wing-aileron flutter up to 1840 feet/second, but at 918 feet/second the telemetry record indicates a few cycles of an oscillation with a frequency of 84 cycles/second. As the model was instrumented in the starboard wing only, this oscillation could have been due to flutter of the port aileron, which would be unlikely to show up clearly on the opposite wing. At 1846 feet/second a body freedom type of flutter occurred causing wing failure².

Model 3 (aileron frequency 62 cycles/second). The telemetry record (Fig.4(c)) shows a clear case of flutter of the starboard wing at 791 feet/second with a frequency of 79 cycles/second. Both ailerons broke away from the wings at about 970 feet/second.

Model 4 (aileron frequency 68 cycles/second). This model was instrumented in both wings, and flutter occurred at 727 feet/second with a frequency of 82 cycles/second (Fig.4(d)). The amplitude of oscillation increased rather more rapidly on the port than on the starboard wing, but both maintained a steady amplitude for about nine cycles of oscillation after the initial build-up, until aileron failure occurred at a speed of 920 feet/second.

Model 5 (aileron frequency 84 cycles/second). This model suffered a failure in the telemetry transmitter at the moment of launching. Examination of the high speed camera records showed that aileron flutter occurred, followed by aileron failure, during the deceleration phase of the flight. Owing to the difficulty of detecting an aileron oscillation from the camera records it is impossible to say with certainty that flutter did not occur during acceleration. The flutter speed obtained from the camera records was 950 feet/second with aileron failure at 905 feet/second.

Model 6 (aileron frequency 93 cycles/second). The records showed no flutter oscillation up to a speed of 1600 feet/second when body freedom flutter occurred, resulting in wing failure. A few cycles of oscillation are shown on the telemetry record (Fig.4(e)) at a speed of 720 feet/second, but the frequency was approximately 30 cycles/second, and the oscillation was probably due to random excitation of the fundamental bending mode of the wing.

3.3 Flight tests (second series)

The tests on models 1 to 6 yielded three definite cases of wing-aileron flutter during the acceleration phase of the flights (Model 1, 3 and 4). It was decided, therefore, to repeat the tests of Models 2, 5 and 6 with Models 7, 8 and 9.

Model 7 (aileron frequency 49 cycles/second). This reached a high speed with no clear indication of wing aileron flutter (Fig.4(f)). Unfortunately, there was a loss of signal from the port wing accelerometer at the moment of launching; the starboard accelerometer continued to function and gave a record very similar to that obtained from Model 2. There is a very slight indication of an oscillation at a speed of 860 feet/second, with a frequency in the region of 70 cycles/second, which could (like Model 2) be accounted for as flutter of the port wing which does not appear as a clear oscillation on the starboard transducer. At 1840 feet/second a body freedom type of flutter occurred which ultimately caused model failure.

Model 8 (aileron frequencies 80 and 82 cycles/second). Aileron flutter occurred at a speed of 970 feet/second during deceleration (Fig.4(g)). The flutter frequency was 73 cycles/second. Failure of the ailerons took place after 8 cycles of increasing amplitude when the speed was 950 feet/second. There was some slight indication from the telemetry records of a condition of low damping during acceleration at a speed of 975 feet/second and frequency 70 cycles/second.

Model 9 (aileron frequencies 89 and 93 cycles/second). The maximum velocity of 1915 feet/second was reached without any clear indication of aileron flutter. The telemetry record showed that throughout the flight, oscillation of the starboard wing occurred at a frequency of 180 cycles/second. This frequency is close to that of the overtone bending natural frequency (175 cycles/second) and it is probable that excitation of this mode was caused by some sort of aerodynamic disturbance. Oscillations of this type are a fairly common feature of rocket flutter tests, although it may be noted that the telemetry record gives, at first glance, a rather misleading picture of the amplitude of the oscillation (Fig.4(h)). Since the accelerometer signal is proportional to the square of the frequency, oscillations of high frequency tend to obscure those of lower frequency; in Fig.4(h) the oscillations at 180 cycles/second represents amplitudes of a few thousandths of an inch at the transducer, which, for the overtone bending mode, is close to an antinode. There is however, some slight evidence of an oscillation at 980 feet/second having a frequency of 70 cycles/second. It is probable that this is a condition of low damping due to the proximity of the flight path to the nose of the flutter boundary (Fig.5).

3.4 Flight tests (third series)

The tests on Models 7, 8 and 9 tended to confirm the results of the tests on Models 2, 5 and 6. On the other hand it appeared unlikely that aileron flutter should occur at much higher speed with aileron frequencies of 48 (Model 2) and 49 (Model 7) than frequencies of 42 and 62 (Models 1 and 3). It is probable that the experimental results are misleading although no reasonable explanation for this has been found. Delay in the onset of flutter could be caused by any one of a number of factors, although it seems an unlikely coincidence that both Models 2 and 7 should be similarly affected. It was decided, therefore, to test another model (Model 10) having an aileron frequency between those of Models 2 and 3. On the basis of the results of Models 5 and 8, both of which failed during deceleration, it appeared probable that the tests had been made close to the 'nose' of a flutter region such as that indicated in Fig.5 and this is to some extent confirmed by the apparent condition of low damping in Model 9, which was mentioned above. The acceleration through the flutter region could have allowed insufficient time for the flutter oscillation to have started, particularly if the region extended only over a limited speed range. In this case flutter would be expected to occur during deceleration - because the deceleration is lower than the acceleration, so giving

more time for a flutter oscillation to build up. In order to examine the flutter boundary in more detail in this region two models were tested (Models 11 and 12) having aileron frequencies of 70 and 77 cycles/second. Finally, although Models 6 and 9 (aileron frequencies of more than 90 cycles/second) had been flutter free (excluding the body freedom flutter of Model 6) it was felt that the aileron torque bar attachment might be unreliable at these frequencies, with a possibility of slip at the inboard attachment point, and it was decided to use the final model (Model 13) to repeat the tests of Models 6 and 9.

Model 10 (aileron frequencies 56 (port) and 54 (starboard) cycles/second)

An oscillation of 39 cycles/second developed at 400 feet/second. At 570 feet/second the oscillation of the starboard wing changed to a frequency of 79 cycles/second; at the same time the port wing oscillation died away and at 655 feet/second it too changed in frequency to 79 cycles/second. (In fact, there was a slight difference in frequency between the two wings as may be seen in Fig.4(i).) The amplitude of oscillation of both wings remained practically constant once the initial build-up had taken place, until at speeds of 1070 and 1140 feet/second on the port and starboard wings respectively the oscillations started to decrease in amplitude and eventually died away completely. The vehicle reached a maximum speed of 1892 feet/second and shortly afterwards, when the speed had dropped to 1840 feet/second, the starboard wing and aileron broke away leaving the port wing and aileron still attached to the boost. Later in the deceleration phase the port wing started to oscillate again at 1050 feet/second (frequency 90 cycles/second) and the oscillation continued until at 963 feet/second the port aileron failed.

Model 11 (aileron frequencies 70 (port) and 71 (starboard) cycles/second)

A very clear telemetry record of flutter was obtained (Fig.4(k)). The flutter began on the starboard wing at a speed of 659 feet/second and frequency 78 cycles/second; the port wing fluttered at 765 feet/second and frequency 74 cycles/second. Both ailerons broke off at approximately 970 feet/second.

Model 12 (aileron frequency 77 cycles/second). On the telemetry record (Fig.4(l)) the behaviour of the port wing was obscured by bursts of oscillation in the overtone bending mode at 180 cycles/second (see Note on Model 9). However, flutter of both wings occurred at speeds of 949 and 970 feet/second for starboard and port wings respectively, the frequency being 77 cycles/second for both wings. Aileron failure occurred at approximately 1020 feet/second.

Model 13 (aileron frequency 93 cycles/second) showed no indication of flutter throughout its flight (Fig.4(m)) and reached a speed of 1997 feet/second, when body freedom flutter occurred, causing wing failure.

4 DISCUSSION OF TEST RESULTS

4.1 Examination of all the rocket test results (Fig.5) shows that there is considerable scatter, and a definite flutter boundary cannot be established. The basis on which the flutter boundary indicated by the dotted curve in Fig.5 has been drawn is as follows. It can be argued that flutter of a rapidly accelerating model may apparently occur at a higher speed than the critical flutter speed; this may be due to insufficient aerodynamic disturbance to start the oscillation at precisely the critical speed, or to structural damping in the system delaying the onset of flutter. In either case, a time delay of, say, 0.2 of a second at an acceleration of 30g is equivalent to a speed change of nearly 200 feet/second. There is some

justification, therefore, for drawing the lower boundary of the flutter curve so that it passes through the points of lowest critical flutter speed. It also seems clear that there is a limiting value of aileron frequency above which wing aileron flutter does not occur. Models 6 and 13 were completely free from flutter, whilst the records of Model 9 indicated a region of low damping, which would indicate the proximity of a flutter region, or perhaps that the model passed through a narrow flutter region but with insufficient time for a flutter oscillation to build up. However, Models 5 and 8 both fluttered in deceleration only and the shape of the flutter boundary in this region can be drawn as shown in Fig.5 so that it passes through the results of Models 5 and 8 and leaves Model 9 as a case of low damping. It is relevant to consider here the effect of acceleration on the effective aileron frequency of these models (see Appendix 1). During acceleration the effective frequencies were 83.2, 85.1 and 90.2 for still air frequencies of 82, 84 and 89 cycles/second. Thus for the flutter boundary shown in Fig.5 both Models 5 and 8 passed through the flutter region during acceleration, and the telemetry signal of Model 8 does show a trace of oscillation during acceleration, although at a speed which is slightly higher than the critical speed obtained during deceleration. The remainder of the upper boundary of the flutter region may be drawn on the basis of the results for Model 10. With this model the upper boundary is determined by the speeds at which both wings ceased to flutter during acceleration and that at which the port wing started to flutter during deceleration.

The effect of acceleration on the natural frequencies of all the models has been calculated. For Model No.1 (natural frequency at rest 42 cycles/second) there is an increase of 6%, and for Models Nos.6 and 13 (natural frequency 93 cycles/second) the increase is just over 1%. These adjustments have not been included in drawing Figs.5 and 6 since at the higher values of control natural frequency where the most rapid variation in flutter speed occurs the corrections are small enough to be ignored.

4.2 There is a distinct possibility that single degree of freedom flutter (control surface 'buzz') may have occurred in the flight tests. The grounds on which this possibility is based are that buzz is known to have occurred on flutter models of an identical planform but having a thinner section (thickness/chord ratio of 0.06). The models of the present series had a thickness/chord ratio of 0.10 and the effect of thickening increases the likelihood of buzz. It is also known that increase of control surface hinge stiffness reduces the likelihood of buzz, and Broadbent¹ has suggested a criterion based on the natural frequency of the control. The criterion (for the avoidance of buzz) is that -

$$\frac{n c}{100} > 1$$

where n = natural frequency of control (cycles/second)

c = control mean chord (feet).

In the present tests c = 0.25, and therefore none of the models comes near to satisfying the criterion. However, Models 6 and 13 (n = 93 in both cases) were free of oscillation throughout their speed range (other than body freedom flutter) and it would seem, therefore, that there are circumstances in which the criterion may be very pessimistic in terms of the control hinge stiffness required to avoid buzz.

4.3 It may be pointed out that the instrumentation of the rocket models, with a single transducer in the wing, would be insufficient to detect a single degree of freedom oscillation of the aileron. This is theoretically true, but in practice there will be some motion of the wing as a result of the inertia coupling of wing and control, although the wing motion is not an essential component of the buzz oscillation. Previous experience of buzz phenomena on rocket and wind tunnel models has shown that sufficient motion of the wing generally occurs for wing transducers to indicate the oscillation.

4.4 For a number of the models, reference has been made to a body freedom type of flutter that caused model failure. This has been investigated theoretically², and was found to be due to a coupling between wing bending and the symmetric body freedoms of pitch and normal translation. As this type of flutter is unaffected by the control surfaces, or vice versa, no further reference is made to it in this Note.

5 CALCULATIONS

5.1 Flutter calculations were made to compare with the experimental results. Although all the models were nominally to the same design, the laboratory tests showed that differences did exist (Table 1). It was decided, however, in order to make a general comparison between experiment and calculation, to assume in the calculations that all the models were structurally and aerodynamically identical. An "average" model was chosen, for which the inertia details are given in Table 2. Three wing distortion modes were used in the calculations (i) a fundamental bending mode at a frequency of 29 cycles/second (ii) a fundamental torsion mode - frequency 72 cycles/second - having a nodal line at 0.338 chord (iii) an overtone bending mode - frequency 195 cycles/second. The modes were those for a uniform cantilever beam. The fourth mode was, of course, aileron rotation. The aerodynamic derivatives were those appropriate to two-dimensional incompressible flow³ for a frequency parameter of unity with a correction factor for wing aspect ratio⁴. The correction applied was to multiply the stiffness derivatives by $\left(\frac{1}{f(A)}\right)^2$ and the damping derivatives by $\left(\frac{1}{f(A)}\right)$ where:-

A is the full span aspect ratio

and

$$f(A) = \left(1 + \frac{0.8}{A}\right).$$

The control surface and cross coupling derivatives were unfactored.

5.2 The results of the calculations are shown by the full line of Fig.6. The left-hand branch of the flutter curve corresponds to the wing flexure-aileron rotation flutter of the wind tunnel tests. Reasonable agreement is obtained with the wind tunnel tests in which flutter occurred, but the value of aileron frequency which is necessary to eliminate this type of flutter is higher in the calculations than in the tests. The right-hand branch of the flutter curve - the wing torsion-aileron rotation branch - shows poor agreement with the rocket test results. No upper boundary of the flutter region could be found in the calculations, and there was no limiting value of aileron frequency for this type of flutter in the range examined (up to 110 cycles/second). Since the aerodynamic derivatives used in the calculations are appropriate to zero Mach number good agreement between calculation and experiment would not be expected in the high subsonic region. Nevertheless, the discrepancies at lower Mach numbers (for instance, in the region of aileron frequency up to 50 cycles/second) indicate the need for further theoretical investigation. This is being undertaken, and will form the subject of a separate report.

6 CONCLUSIONS

6.1 The rocket tests as a whole show the limitations of the technique in an investigation of this type. Because of the high scatter in the results, the determination of the flutter boundary cannot be made with accuracy. One would expect that a wind tunnel test would establish the lower flutter boundary of wing torsion - aileron rotation flutter with much more precision, although it is unlikely that an upper boundary could be determined easily. Moreover, tunnel interference effects in the transonic region could lead to inaccuracies. Nevertheless, the advantage of control over the test, and the facility for more comprehensive instrumentation of models give the wind tunnel technique a major advantage over the rocket technique.

6.2 One unknown in the tests described has been the effect of control surface buzz. Whilst it has been possible to establish that buzz has not occurred for the models with a high value of aileron natural frequency, it has not been possible to establish a positive region in which buzz does occur. This is in any case difficult, even in a wind tunnel test, but there would seem to be a case in control surface flutter investigations at high subsonic speeds, for making a preliminary investigation of buzz characteristics. This could be done either by using a model with a very stiff wing (so that coupled flutter will not occur) or by bracing the actual flutter model so as to increase the wing stiffness. Clearly the second method is unsuitable for a rocket test but the first may be possible.

6.3 The test results showed that there was a value of control surface natural frequency above which flutter involving the aileron did not occur. This value was some 10 to 20 per cent higher than the frequency of the fundamental torsion mode of the wing.

6.4 Flutter calculations using two-dimensional incompressible flow aerodynamic derivatives showed reasonable agreement at the low speeds associated with wing flexure - aileron rotation flutter, but compared poorly with the rocket test results for wing torsion - aileron rotation flutter. In particular the calculations did not indicate a value of control natural frequency above which this type of flutter would be eliminated.

ACKNOWLEDGMENT

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APPENDIX

THE EFFECT OF LONGITUDINAL ACCELERATION ON CONTROL FREQUENCY

Consider a wing carrying a control surface which is restrained by a torsion bar on the hinge line of stiffness K . Let the mass of the control be m and its moment of inertia about the hinge line be I . Let x be the distance of the control centre of gravity aft of the hinge line.

If the wing is accelerating in a forward direction with acceleration 'a' then for a rotation β of the control about the hinge line there is a restoring moment M due to the acceleration where:-

$$M = m.a.x \sin \beta$$

$$\approx m.a.x\beta \text{ if } \beta \text{ is small}$$

The stiffness due to acceleration is therefore given by $\frac{M}{\beta} = m.a.x$. and the natural frequency of the control ω (ignoring aerodynamic forces) is given by:-

$$\omega^2 = \frac{K + m.a.x}{I} = \omega_n^2 + a \frac{x}{k^2}$$

where ω_n is the natural frequency at rest in still air, and k is the radius of gyration of the control about the hinge line.

For an accelerating wing ('a' positive) the natural frequency of the control ω will be increased over the static value ω_n if the control is under-massbalanced (x positive) and decreased if it is overmassbalanced (x negative). During deceleration ('a' negative) the opposite occurs.

For a typical rocket vehicle the acceleration increases rapidly at boost ignition and then remains virtually constant until the boost motor is fully burnt. Subsequently there is a deceleration, so that the acceleration-time curve for the vehicle will be as shown in Fig.7. If now a control surface flutter test is being made for which the flutter characteristics are as shown in Fig.8 and the control under test has a natural frequency of ω_1 the effective natural frequency during the various stages of the flight is indicated by the dotted lines of Fig.8. Thus, in this example, flutter will be avoided during acceleration but will occur at the upper boundary during deceleration.

Longitudinal acceleration will also have an effect on the torsional stiffness of the main surface. There will be an effective increase in stiffness if (as is usual) the inertia axis lies aft of the flexural axis.

In practice, the wing stiffness is so large that the acceleration contribution to wing stiffness is usually negligible, but this may not be so in the case of control hinge line stiffness.

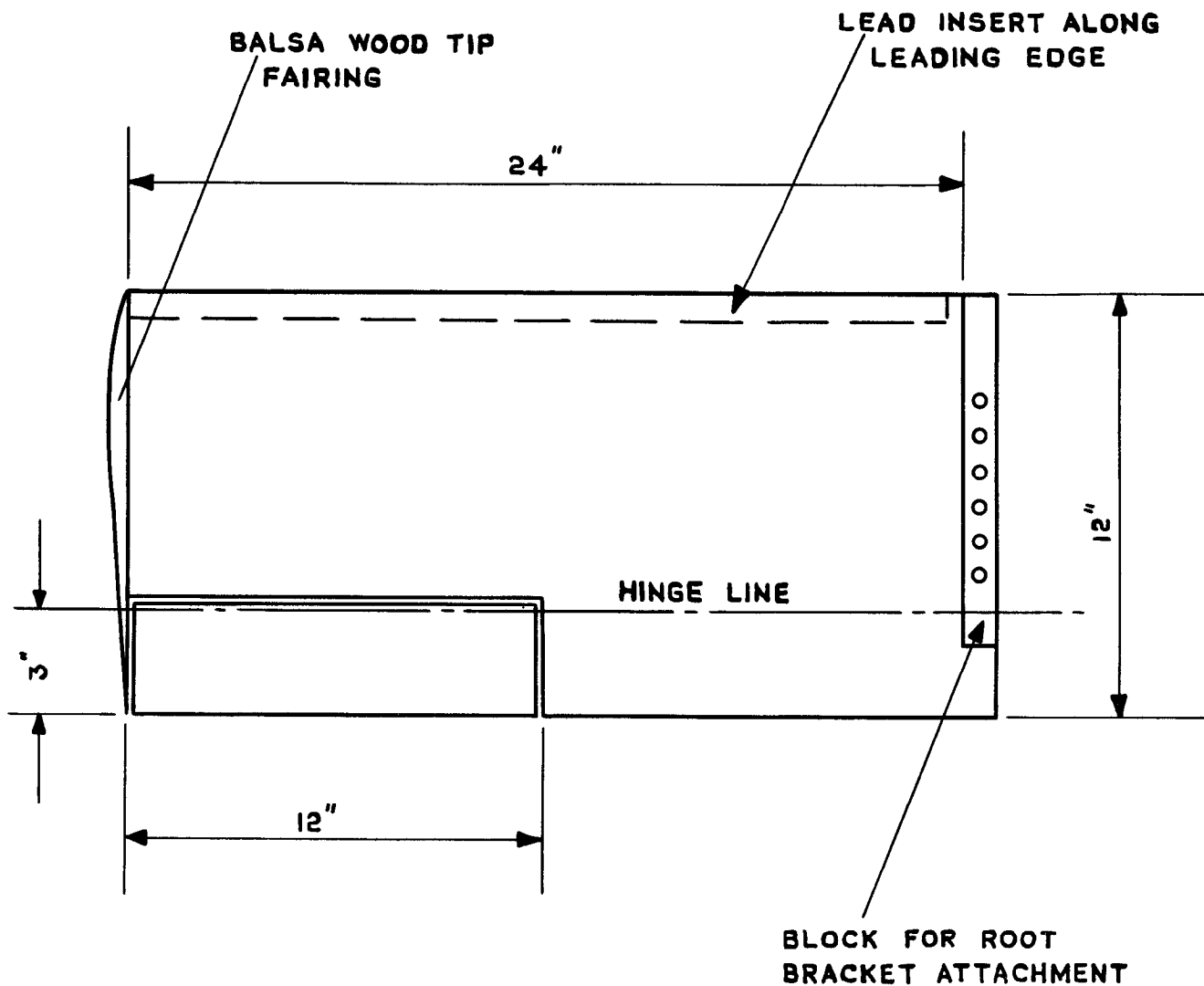
TABLE 1
 Summary of test results

Model No.	ℓ_{ϕ} lb ft/ rad	m_{θ} lb ft/ rad	Flexural axis	Wing weight lb	Wing C.G.	Wing pitching K in.	Aileron weight lb	Aileron mass moment lb in.	Aileron moment of inertia lb in ²	Fundamental bending frequency c/s	Fundamental torsion frequency c/s	Overtone bending frequency c/s	Aileron frequency c/s
1 P S	7865 7270	1900 1927	0.392 0.396	5.71 5.55	0.361 0.366	3.23) 3.28)	0.662	0.357	0.504 (	36 34	68 68	188 144	42 42
2 P S	12560 11420	1880 1850	0.340 0.340	5.92 5.92	0.364 0.364	-) -)	0.662	0.357	0.504 (	33 33	70 70	150 150	48 48
3 P S	9350 9100	1600 1640	0.280 0.320	5.55 5.55	0.358 0.360	3.40) 3.37)	0.662	0.357	0.504 (	29 30	70 70	210 215	62 62
4 P S	7809 7809	2056 1683	0.337 0.348	5.81 5.78	0.363 0.357	3.29) 3.23)	0.662	0.357	0.504 (	26 27	70 70	- -	68 68
5 P S	7780 7390	1910 1910	0.375 0.372	5.34 5.30	0.379 0.375	3.54) 3.57)	0.662	0.357	0.504 (	29 29	80 82	180 174	84 84
6 P S	8720 11760	1900 1970	0.400 0.393	5.71 5.73	0.364 0.358	3.39) 3.41)	0.662	0.357	0.504 (	27 27	73 73	200 195	93 93
7 P S	9900 9520	1930 1740	0.310 0.340	5.71 5.74	0.366 0.370	3.40) 3.38)	0.662	0.357	0.504 (	27 27	72 72	197 202	49 49
8 P S	9180 10300	1710 2280	0.348 0.352	5.81 5.81	0.358 0.360	3.35) 3.40)	0.662	0.357	0.504 (	31 31	70 72	170 172	80 82

ℓ_{ϕ} = flexural stiffness at 0.7 span
 m_{θ} = torsional stiffness at 0.7 span

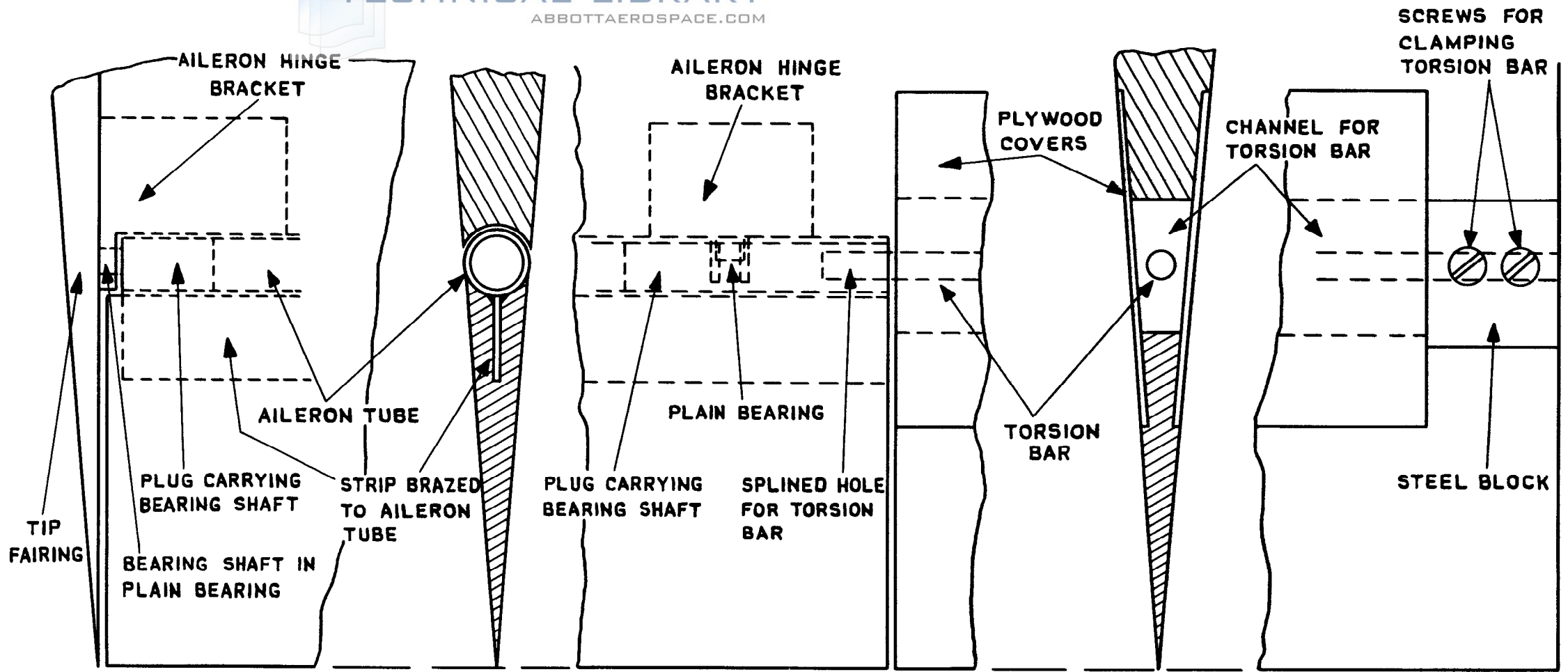
TABLE 1 (Contd.)

Model No.	lb ft/ rad	lb ft/ rad	Flexural axis	Wing weight lb	Wing C.G.	Wing pitching K in.	Aileron weight lb	Aileron mass moment lb in.	Aileron moment of inertia lb in ²	Fundamental bending frequency c/s	Fundamental torsion frequency c/s	Overtone bending frequency c/s	Aileron frequency c/s
9 P S	4714 4567	1822 1697	0.390 0.330	5.40 5.45	0.343 0.342	3.28) 3.30)	0.550	0.258	0.272 (	24 25	73 72	170 175	93 89
10 P S	8500 8257	1998 1858	0.400 0.371	5.73 5.61	0.360 0.363	3.23) 3.29)	0.662	0.357	0.504 (	27 25	69 73	189 176	56 54
11 P S	4944 4386	1927 1631	0.383 0.291	5.44 5.40	0.345 0.345	3.22) 3.07)	0.550	0.258	0.272 (	23 23	73 72	170 175	70 71
12 P S	5224 4829	1786 1780	0.312 0.320	5.52 5.43	0.347 0.343	3.21) 3.22)	0.550	0.258	0.272 (	22 22	68 72	174 175	77 77
13 P S	5810 4304	1753 1842	0.330 0.390	5.47 5.40	0.342 0.350	3.30) 3.22)	0.550	0.258	0.272 (	24 24	72 74	166 168	93 93



WING SECTION: R.A.E. 101 $t/c = 0.10$

FIG. I. WING DETAILS.



(a) OUTBOARD HINGE. (b) MID-AILERON SECTION. (c) INBOARD HINGE. (d) INBOARD WING SECTION. (e) ROOT FIXING.

NOT TO SCALE

FIG. 2(a-e). DIAGRAM OF AILERON AND TORSION BAR LAYOUT.

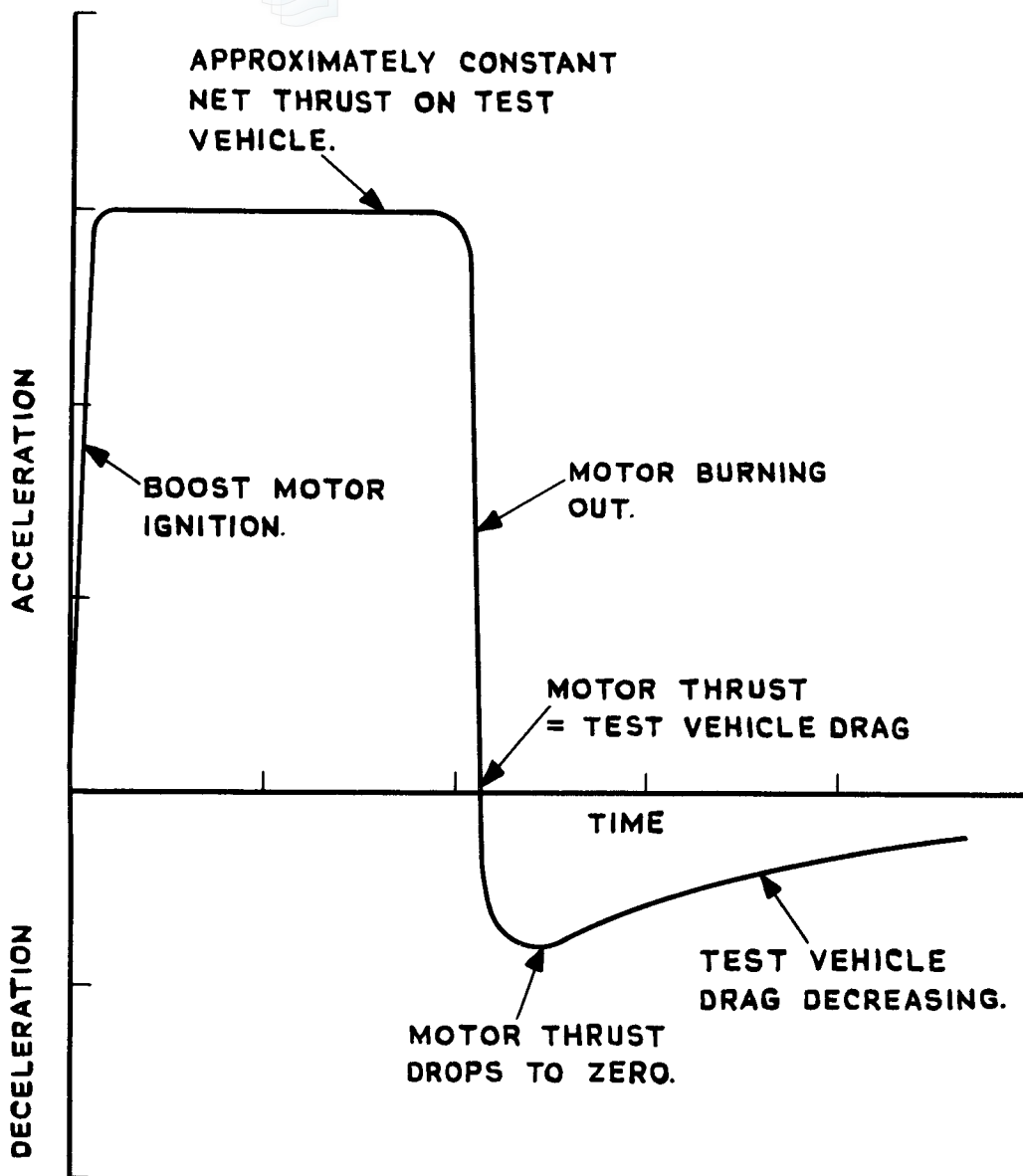


FIG. 7. ACCELERATION OF TEST VEHICLE.

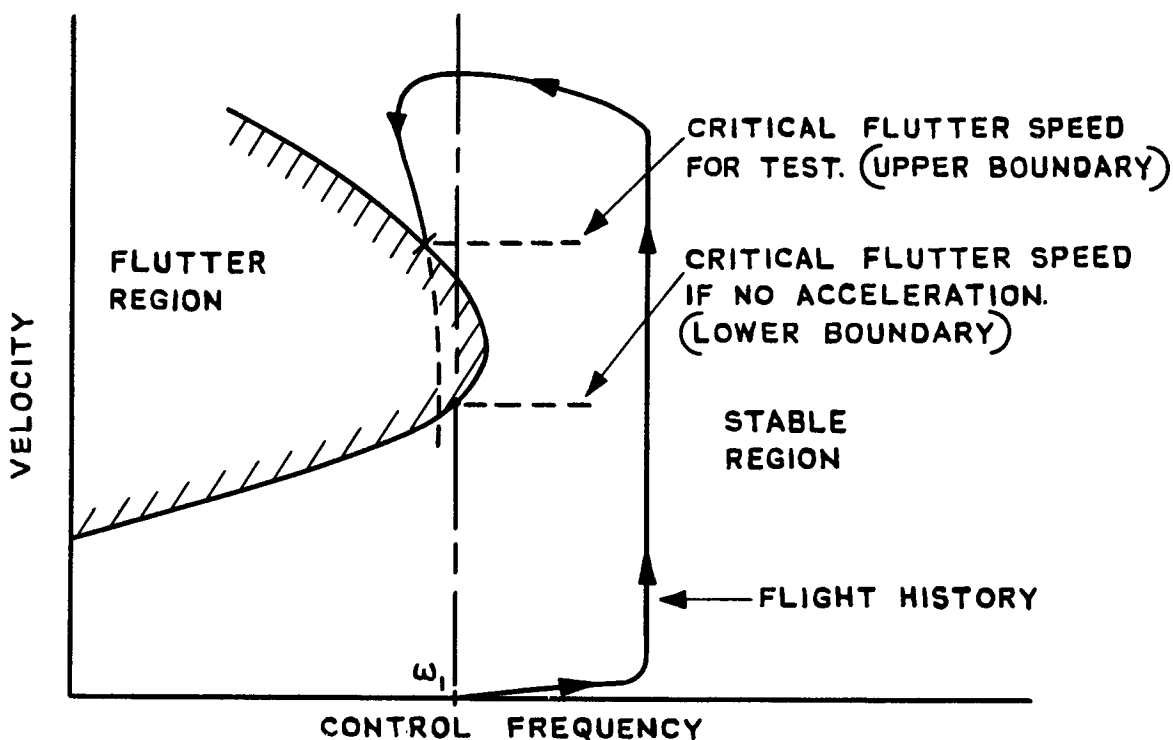


FIG. 8. ILLUSTRATION OF ACCELERATION EFFECT ON CONTROL SURFACE FLUTTER INVESTIGATION.

A.R.C. C.P.No. 627

AN INVESTIGATION OF WING-AILERON FLUTTER USING GROUND
LAUNCHED ROCKET MODELS. Gaukroger, D. R. and
Curran, J. K. February, 1962.

Control surface flutter of the wing torsion-control rotation type has been investigated for an unswept wing with an under-massbalanced, half span, outboard aileron. Thirteen pairs of wings were tested, using ground launched rocket driven vehicles, and a range of values of aileron natural frequency was covered. The test results showed considerable scatter, but enabled upper and lower limits of a flutter boundary to be determined approximately. It was established that aileron flutter could be eliminated on the models tested provided the aileron frequency exceeded the wing torsional frequency by 20 per cent or more. In this condition the models were also free from single degree of freedom flutter (control surface "buzz").

533.6.013.422 :
533.693 :
533.694.511 :
533.6.055

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