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Fatigue Loadings in Flight: Loads in the Tailplane and Fin of a Jet Provost

by

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FATIGUE LOADINGS IN FLIGHT: LOADS IN THE TAILPLANE AND FIN OF A JET PROVOST

by

Anne Burns, B.A.

SUMMARY

Data are presented on the fluctuating and steady loads measured during flight in the tailplane and fin of a Jet Provost. Conditions include take-off, landing, taxying, flight in turbulence, aerobatics and the use of airbrakes and flaps. The relative importance of the loads in the different conditions is assessed with reference to the use of the aircraft in the basic trainer rôle.

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1 INTRODUCTION

In January, February and March, 1958, flight tests were made in a Mk.T2 Jet Provost G-AOUS to obtain information on the fatigue loads in the tailplane and fin. The tests were made as part of a general survey of ground and flight loads in the tail units of aircraft[1,2,3]. A more particular objective was to provide information for assessing the fatigue life of the Mk.T3 Jet Provost in its future rôle as a basic trainer for the R.A.F. The information obtained is presented in this note.

2 DESCRIPTION OF FLIGHT TESTS

A brief account of the instrumentation and flight tests is given in Appendix 1. The main load measurements were bending moments about the tail-plane and fin roots; measurements of bending moments halfway out along the tailplane and of shear loads at the fin root were also made as a check on load distribution. Gauge installations at the tailplane root were duplicated so that, by electrically combining the signals from each side, antisymmetric loads as well as the separate loads in each side could be recorded simultaneously.

Two accelerometers were mounted rigidly near the aircraft c.g. to cover the different ranges of acceleration experienced in aerobatics (-2g to +5g) and in turbulence (0g to +2g). The smaller range accelerometer read in steps of 0.1g. The readings of these accelerometers are, for convenience, referred to throughout the note as c.g. accelerations. It should be understood, however, that any dynamic effects due to flexibilities of the structure are included.

Strains and accelerations were recorded in conditions that represented, as far as possible, those experienced during training. Since, however, the aircraft was being flown by experienced test pilots, the loads, especially those in aerobatics and during the initial landing impact, are unlikely to be as large as when the aircraft is flown by trainee pilots. The aircraft was also subject to more severe 'g' restrictions than those applicable to Mk.T3 Jet Provosts; for this reason again loads in aerobatics may be slightly smaller than those experienced by Mk.T3 aircraft in training. Loads measured on the ground included loads in take-off, landing and taxying, both on grass and on tarmac; and loads measured in flight included loads in aerobatics, and in atmospheric turbulence at heights of from 500 ft above ground to 2000 ft above mean sea level. Attention was confined mainly to fluctuating loads but, in the case of the tailplane, some load measurements were made in steady flight with and without air-brakes and with varying amounts of flap.

3 PRESENTATION OF RESULTS

The fluctuating loads in the tailplane and fin during take-off, landing, taxying and turbulence have been analysed in terms of numbers of ranges exceeding certain magnitudes[1,2,4]. Loads during the buffeting which occurs in spins, stalls and when the airbrakes are open have also been analysed in similar terms. All these results are shown in Tables 1 to 7. For aerobatics other than spins, maxima and minima loads only are given since buffeting does not occur (Table 8). Tail loads in steady flight at various speeds with and without airbrakes are shown in Fig.4, and tail loads when operating the flaps and undercarriage in Table 9.

The analysis is confined mainly to the bending moments at the fin and starboard tailplane roots although some results for loads at other stations indicating the distribution of load are also given. All loads refer to the sections at which the strain gauges are attached (see Figs.2 and 3). Loads are sometimes given as a percentage of ultimate load; in this case the ultimate load is taken to be the design load at the section in question times the calculated reserve factor. Values used are 55,250 lb in. and 105,700 lb in. for the fin root and tailplane root ultimate bending moments respectively. The value of 105,700 lb in. refers to the ultimate down-load on the tailplane but is used regardless of whether the measured load acts upwards or downwards.

In order to summarise the information the number of load ranges exceeding certain magnitudes are shown in Figs.5 and 6 for the component conditions of a complete 120 hour training course. It was estimated from information obtained from R.A.F. Stations Hullavington and Little Rissington (Central Flying School) that a typical flying course on a Jet Provost comprises the following operations:- 330 take-offs and landings, 10% on grass and the rest on metalled surfaces; 19 hours taxying with the same division between grass and metalled surfaces; 101 hours flight at various heights and speeds, for $5\frac{1}{2}$ hours of which the airbrakes are open; and 220 aerobatics including 62 spins. Details of the estimation of the loads for these component conditions are given in Appendix 2.

The graphs of Fig.7 have been prepared so that the tail and fin loads in turbulence can if required be related to operational data on gust frequencies. The curves show the relationship between the load and gust velocity ranges that are exceeded the same number of times during normal cruising at a speed of 160 kts, and while flying in the circuit at a speed of 110 kts with 30° flaps. The gust velocities are derived from the measured c.g. accelerations using standard alleviation factors[5].

4 DISCUSSION OF RESULTS

4.1 Loads in spins

The most striking result is the severity of the buffeting both of tailplane and fin during the spin. Buffeting occurs throughout the period of rotation so that the number of fluctuations counted depends on the duration of the spin. Results given refer to spins of from $2\frac{1}{2}$ to $3\frac{1}{2}$ turns, the normal duration in training. The tailplane and fin oscillate in a rather erratic manner at from 13 to 15 c.p.s., the motion of the tailplane being mainly anti-symmetric. The oscillation is most severe towards the end of the spin; moreover at this stage it is superimposed on manoeuvre loads associated with the recovery. In the case of the tailplane the manoeuvre load acts upwards mainly on one side (see Fig.8a) and, combined with the buffet loads can produce root bending moments as large as 35% of the ultimate bending moment. Maximum loads of similar severity occur in the fin due to the combination of manoeuvre and buffet loads; in this case the direction of maximum load depends on the direction of turn (Fig.8b).

4.2 Ground loads

Ground loads in the tailplane when operating on tarmac tend to be very small (maximum load range usually less than 8% ultimate); this is probably due to the absence of buffeting from the jet efflux since the jet exit is situated behind the tail. This supposition is confirmed by the lack of buffeting both of the tailplane and fin when the engine is run at various R.P.M. with the aircraft stationary. Ground loads in the fin are, if considered as a percentage of ultimate load, slightly larger than those in the tailplane (maximum bending moment range usually less less than 16% ultimate); they appear to be caused by the use of rudder and by small oscillations of the structure excited by wheel rotation and by the application of brakes.

When operating on grass, oscillations of the tailplane are excited by the unevenness of the ground and the loads are about twice the magnitude of those when operating on tarmac (compared on a basis of equal numbers of occurrences). For the fin there is little difference between operation on grass and on tarmax except during taxying when the loads on grass are no longer negligible.

Mean loads for the tailplane are very small except during those parts of the take-off and landing when the nosewheel is held clear of the runway; in this condition the fluctuating loads are superimposed on a mean down-load of the order of 6% ultimate.

When considering the significance of the ground loads in the training rôle, the smallness of the loads in individual take-offs and landings together with the associated taxying is to some extent counteracted by the large number of take-offs and landings performed. Thus for the tailplane the ground loads are next in importance to the loads in spins although still comparatively insignificant from the fatigue aspect.

4.3 Loads in aerobatics (other than spins)

Loads in the tailplane during aerobatics other than spins are very small; the maximum root bending moment due to down-load is only 8.7% of ultimate occurring in a vertical roll, and the maximum root bending moment due to up-load only 6.2% of ultimate occurring in a Derry turn*. Loads in the fin are on the whole somewhat larger; the maximum root bending moment is, however, only 23% of ultimate occurring in a vertical roll. Loads in aerobatics flown by trainee pilots are likely to be slightly more severe but even if doubled would still be unimportant compared with those in spins.

4.4 Gust loads

Loads in the tailplane due to gusts are very small; the tailplane load corresponding to a gust cycle of ±10 ft/sec is only ±2% of ultimate at 160 kts, 2000 ft. Loads in the fin due to gusts are somewhat larger; the fin load corresponding to a ±10 ft/sec gust is ±8% of ultimate at 160 kts, 2000 ft. It is apparent from the records that the fin loads contain a large component of oscillation at a frequency of 1 cycle every 2 to $2\frac{1}{2}$ seconds. This is attributable to a lateral oscillation of the whole aircraft initiated by horizontal gusts. This oscillation, sometimes called the "Dutch roll", appears to be only lightly damped (see Fig.9).

Fig.7 shows that a simple relationship exists between tailplane load divided by E.A.S. and gust velocity when these two quantities are compared on a basis of equal numbers of occurrence. This relationship appears not to vary significantly with the different conditions under which the measurements were taken - i.e. cruising at 160 kts, 2000 ft and 500 ft, and circuiting at 110 kts, 30° flap, with and without undercarriage lowered. The relationship between fin load and gust velocity (vertical) on the other hand is not the same for cruising and flight in the circuit. Had the fin loads been directly attributable to aerodynamic loading from horizontal gusts and the turbulence been isotropic, a simple relationship might have been expected; since however, the fin loads are largely attributable to lateral oscillations of the whole aircraft, a simple relationship is not to be expected in view of the effect on such oscillations of changes in aerodynamic damping with airspeed.

5 LOAD DISTRIBUTION

5.1 Tailplane

The ratio of the fluctuating bending moments at the tailplane root to those halfway out along the tailplane is 2.2:1 in spins, 2.5:1 for ground loads and 2.9:1 in gusts. These values are compatible with the calculated design figure of 2.5:1. The ratio of the mean bending moments at different speeds, with and without airbrakes, shows very different values however.

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*Defined in Appendix 1, page 9.

With airbrakes open ratios of the order of 5:1 are obtained while with air-brakes shut the indications are that the ratios are even larger, although the outboard bending moment is too small to justify numerical estimation. It appears that in steady flight there is a concentration of the load inboard; this could be due to variation in the angle of downwash across the tailplane span.

The ratio of the antisymmetric bending moment at the tailplane root to the total bending moment is of the order 0.75:1 in spins, 0.55:1 in take-offs and landings and 0.65:1 in gusts.

5.2 Fin

Information on the distribution of the fin loading is obtainable from the shear loads measured in the front and rear posts. The ratio of the front to rear shear load is an indication of the chordwise position of the c.p., and the ratio of bending moment to total shear load of the spanwise position. The variation in the c.p. of the load in the calibration tests was insufficient to allow much accuracy in the analysis of flight test results. The indications are, however, that in the spin the c.p. is well back probably near the hinge line of the rudder and about 33 in. above the rear fin post attachment pin. For loads in gusts the indications are that the c.p. is forward near the front post and some 28 in. above the rear fin post attachment pin. The loads in other conditions were considered too small to warrant determination of their distribution.

6 CONCLUSIONS

Information on loads likely to produce fatigue damage in the tailplane and fin of a Jet Provost during training flying has been obtained in special flight tests. The results indicate that when the aircraft is used in the training rôle the loads in the spin are the most important from the fatigue aspect both for the tailplane and fin. The loads are mainly due to buffeting which occurs throughout the period of rotation. During recovery the buffet loads are superimposed on manoeuvre loads and this combination may result in root bending moments due to up-load as large as 35% ultimate in the tailplane and side loads of similar magnitude in the fin.

Loads in other conditions are comparatively insignificant from the point of view of fatigue of the Jet Provost. Points of more general interest with regard to these loads are summarised below:-

6.1 Ground loads

(a) Ground loads in the tailplane i.e. loads in take-off, landing and taxying, are very small, (maximum load ranges less than 8% ultimate) when operating on tarmac probably because the configuration of the aircraft precludes ground buffeting of the tailplane from the power plant.

(b) Ground loads in the tailplane when operating on grass are roughly twice the size of those when operating on tarmac (compared) on a basis of equal numbers of occurrences).

(c) Ground loads in the fin are roughly comparable when operating on grass and on tarmac (maximum load ranges less than 16% ultimate) except during taxying when significant loads are produced only when operating on grass.

6.2 Loads in aerobatics (other than spins)

(a) Loads in the tailplane during aerobatics are small; the maximum load measured is only 8.7% ultimate (down-load on one side in a vertical roll).

(b) Loads in the fin during aerobatics are slightly larger than in the tailplane; the maximum load measured is 23% ultimate during a vertical roll.

6.3 Loads in gusts

(a) Gust loads in the tailplane are very small. The load which occurs the same number of times as a 10 ft/sec gust at 160 kts, 2000 ft is only 2% of ultimate.

(b) Gust loads in the fin are slightly larger than in the tailplane. The load which occurs the same number of times as a 10 ft/sec gust at 160 kts, 2000 ft is of the order 8% ultimate. The fin loads are only in small part caused by the direct action of horizontal gusts; they are mainly attributable to the airloads induced by the almost continual lateral oscillation of the whole aircraft, frequency $\frac{1}{2}$ c.p.s. approximately, which occurs in turbulent conditions.

(c) Results indicate that a simple relationship independent of airspeed exists between gust velocity and tailplane load divided by equivalent airspeed. No simple relationship is found between gust velocity and fin load divided by airspeed.

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4	York, E.J.	Maths. Services Department. Series B. No.261
5	Zbrozek, J.K.	Gust alleviation factor. R.& M. 2970. August 1953.

APPENDIX 1

FLIGHT TESTS

INSTRUMENTATION

British Thermostat strain gauges were attached and water-proofed with Araldite special strain gauge cement at the stations shown in Figs.2 and 3. The signals from the gauges were fed into a Films and Equipment 6 channel carrier wave amplifier and recorded after amplification on a New Electronic Products 6 channel recorder. Because of the rather narrow width of the recording paper (only 60 mm) it was unusual to record more than 3 or 4 strain gauge signals simultaneously.

Two accelerometers were rigidly mounted on the floor of the engine bay near the aircraft c.g. These were a Structures Type 4 accelerometer with a range of 0g to 2g which read in steps of 0.1g, and a Hussenot J.53 accelerometer range -3g to +5g, which provided a continuous trace on the Hussenot recorder in which it was mounted. The signal from the stepped accelerometer was also recorded on the Hussenot recorder.

CALIBRATION

The strain gauge signals were calibrated directly in terms of load by means of ground tests in which vertical loads were applied to the tailplane by loading it with shot bags, and side loads to the fin by means of a contoured frame (see Fig.10). The calibration tests indicated that the tailplane and fin* root bending moments were virtually independent of chordwise centre of pressure. The ratio of shear load in the front fin post to that in the rear varied according to the chordwise centre of pressure, the total shear load being given by the formula

$$S = 488 \, (S_R + 5.1 \, S_F)$$

where S_R, S_F are the signals from the rear and front fin post shear gauge bridges respectively expressed as a proportion of the calibration signal

$$\frac{\delta R}{R} = \frac{1}{1000}$$

and S is measured in lb. The shear load is taken mainly by the rear post and is opposed by a small shear load of opposite sense in the front post. The value of this front post shear increases as the c.p. moves back. This opposing shear load arises from the fact that the front post is pin-jointed whereas the rear is encastré. Because of the lightness of the front post it is forced by the ribs to conform to some extent with the distortion of the rear post and this will produce a shear load in the sense observed.

Calibration tests were made before and after the flight tests and were in reasonable agreement except for a few of the early pre-flight calibration tests in which the signals from the fin root bending moment were some 20% greater than in later tests. A mean value weighted in favour of the latter tests was used for interpreting the flight results.

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*Bending moment was measured in the rear post only since the front post is pin-jointed at the root and thus cannot transmit bending moment.

TEST FLYING

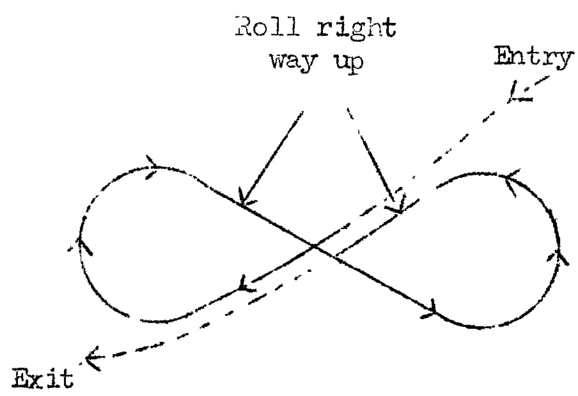
The aircraft was flown for most of the tests at an initial all-up-weight of 6,300 lb and with the c.g. 15.7 in. aft of the datum (limits 14 in. to 19 in. aft of datum. For the first four flights, however, the initial all-up-weight was 6,170 lb and the c.g. 18 in. aft of datum. The Jet Provost carries 200 gallons of fuel so that the all-up-weight decreases by up to 1,500 lb during a flight. Account was taken of the fuel contents when estimating total weight for flight in turbulence but not in other cases.

Take-offs and landings were recorded during the course of the tests and no special requests made for heavy landings. The take-offs, landings and taxying on grass were carried out at White Waltham Aerodrome, those on hard surface at R.A.E.

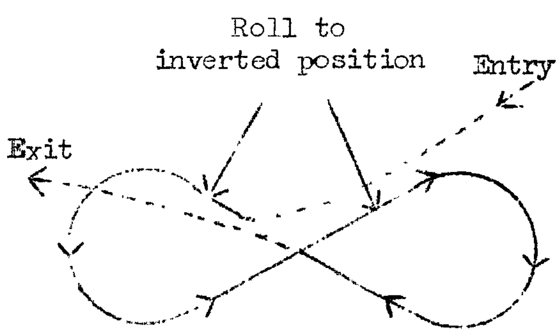
Turbulence was recorded flying straight and level at 160 kts, at altitudes of 500 ft above ground and 2000 ft above mean sea level. It was also recorded at 110 kts, 800 ft above ground, 30° flap, with and without undercarriage lowered, to represent conditions in the circuit. No restrictions were placed on the movements of the controls by the pilot.

Steady loads in the tailplane with and without airbrakes were measured within the height band 5,000 to 10,000 ft above mean sea level. It was necessary to dive the aircraft in order to attain the higher speeds.

Aerobatics were performed at altitudes of 3,000 ft to 8,000 ft above mean sea level and at the speeds recommended in Pilot's Notes. The aerobatic referred to as a Derry Turn consisted of a figure of eight in a horizontal plane, the two halves of which were linked by a fast roll through the inverted position. The scissors and Cuban figures-of-eight were performed in the vertical plane as shown below:



Scissors Figure-of-Eight



Cuban Figure-of-Eight

The Cuban figure-of-eight is more correctly performed with the eight standing vertically but this form could not be flown in the Jet Provost.

APPENDIX 2

ESTIMATION OF LOAD OCCURRENCES IN A 120 HOUR TRAINING COURSE

An estimation of the loads occurring in a typical 120 hour training course was made from information obtained from R.A.F. Stations Hullavington and Little Rissington (Central Flying School). This information referred to Jet Provost Mk.T2's and consisted of a detailed break-down of the flying syllabus into times spent taxying, flying at different airspeeds and heights, number of aerobatics performed etc. A brief account of the estimation of load occurrences for the different conditions is given in this appendix.

GROUND LOADS

It was estimated that on average 330 take-offs and landings were made per flying course, 10% on grass and the rest on metalled surfaces; the associated time spent in taxying was estimated at 19 hours 10 minutes (i.e. $3\frac{1}{2}$ minutes per sortie) with the same division between grass and metalled surfaces. Although the loads per individual take-off and landing plus associated taxying were more severe when operating on grass, both cases had to be considered because of the much greater proportion of operation on metalled surfaces.

Average values were taken for the occurrences of tail and fin loads during take-off, landing and taxying in the flight tests and the results scaled up. It should be noted that, because only a few take-offs and landings and only short periods of taxying were analysed, the scaled-up average values can only give a very rough prediction of the loads occurring in a flying course. Because of the insignificance of the loads however, it was not thought worthwhile to attempt a more accurate prediction.

LOADS IN GUSTS

The flying hours of the syllabus were broken down into hours spent at various speeds and heights, and an estimate of the numbers of gusts encountered at the different conditions made from the curve and data of Fig.11. Of the 2,500 gusts of 10 ft/sec or greater, up or down, encountered, some $\frac{3}{4}$ were found to occur in the height band 0 to 2000 ft. Since information relating to other height bands was not available from the flight tests the relationship between gust velocities and tail unit loads of Fig.7, relating to the height band 500 ft to 2000 ft was used to deduce the corresponding tail unit loads for all heights. The occurrences of tail unit loads in the different conditions were then added to give the totals shown in Figs.5 and 6.

A correction factor was included in the above calculation to allow for the difference in numbers of gust cycles obtained from a consideration of gust levels exceeded and from the method of analysis used in this report. In the former method positive and negative gust velocities of equal magnitudes are associated together to give cycles, geometric means being taken if the numbers of occurrences are unequal; whereas, in the method of the report, adjacent maxima and minima are paired in ascending order of magnitude regardless of mean value. The correction factor was obtained from Fig.12 which shows accelerations measured in the flight tests analysed in terms of cycles by the two methods. Since the factor was small a constant value of 0.95 was used at all gust levels.

LOADS IN AEROBATICS

Aerobatics other than spins

It was estimated that the following aerobatics would be performed per average 120 hour training course:- 24 loops, 22 slow rolls, 22 barrel rolls, 12 rolls off the top, 12 vertical rolls, 12 stall turns, 12 Derry turns, 12 inverted turns, 24 figure eights (scissors and Cuban) and 12 steep turns. Results were available from the flight tests for about half this number of aerobatics and the numbers of occurrences were scaled up accordingly. Only one load range was taken for each aerobatic consisting of the difference between maximum and minimum loads. Some smaller load variations did occur but in view of the insignificance of the aerobatic loads from the fatigue aspect a more detailed analysis was not thought worthwhile.

This method of analysing the loads in terms of ranges takes no account of mean load. Average mean loads and load ranges for each type of aerobatic are given in Table 10.

Spins

It was necessary to treat the loads in spins in more detail than those in other aerobatics because of the severe buffeting which occurred. This necessitated a detailed analysis of the load cycles throughout the spin. The tail loads in four spins and the fin loads in three were analysed in this manner; not much variation was found in the number of cycles for the different spins and an average was taken. The results were then scaled up to give the number of cycles occurring in 62 spins, the estimated number of spins per course.

LOADS DUE TO USE OF AIRBRAKES

The conditions under which airbrakes are used in a flying course vary considerably. The two main uses are (i) short bursts for reduction of speed in which there is considerable variation in the speeds at which the airbrakes are opened and shut and (ii) longer periods of use during let-down in which the aircraft is descending at constant Mach Number or indicated airspeed. Altogether it was estimated that the airbrakes are open for 5 hours 40 minutes of the 120 hours flying course, some two-thirds of the useage occurring during let-down.

During the flight tests load measurements were taken mainly during short bursts in which the speed was falling off. By cross plotting these results and allowing for the fall-off in speed, graphs were constructed showing the variation of numbers of load cycles with speed at certain load amplitudes. Estimates of the use of airbrakes in the flying syllabus were broken down to give periods at different speeds and the numbers of load cycles then estimated. The total number of cycles are shown in Figs.5 and 6; it should be appreciated, however, that the mean loads for these cycles vary considerably with airspeed. A break-down into mean loads and associated cycles is given in Table 11.

TABLE 1 – Tailplane starboard root bending moment cycles

Load Range lb in. x 10^{-3}	Number of times load range is exceeded																								
	Take-off			Landing					Taxying		Airbrakes (10 Second Records)					Spins				Stalls					
	Grass	Tarmac		Grass	Tarmac				Grass	Tarmac	kts 160	210	260	310	360	Left	Right	Left	Right	Clean	Clean	Clean	T.O. Flap	T.O. Flap	T.O. Flap U/C down
	Mean of 6	Mean of 3	Rec.No. 10.01	Mean of 6	Mean of 5	Rec.No. 10.10	16.17	17.19	160 secs	60 secs	17.03	17.04	17.05	17.07	27.01	27.03	27.04	27.06	27.07	10.05	10.06	17.15	10.03	10.04	17.16
2.1	253	15	8	352	90	68	101	129	1077	No	47	53	80	99	101					33	50	35	24	42	9
3.1	139	2	1	234	12	9	20	15	384	Counts	3	13	37	68	85					15	17	15	10	27	2
4.2	70	1	1	136	4	3	5	4	1122		1	4	15	42	63	129	108	105	135	9	12	8	2	18	
5.2	31	1	1	78	2	3	1	2	50			1	5	19	43	119	102	102	126	7	4	7	1	8	
6.3	14	1	1	46	1	2	1	1	24				1	6	27	102	87	86	108	4	3	4	1	6	
7.3	8	1	1	24	1	1	1	1	8					2	12	86	73	74	96	1		2	1	3	
8.4	5		1	14					5					1	8	73	56	65	83	1		1		2	
9.4	3		1	7					1						4	65	51	58	78					1	
10.5	3			4											1	56	37	52	69					1	
11.5	2			2											1	51	29	46	60						
12.6	1			2											1	41	26	41	53						
13.6	1			1											1	33	24	34	43						
14.6	1			1												30	21	31	37						
15.7																27	19	24	34						
16.7																25	18	20	30						
17.8																23	16	19	23						
18.8																20	12	18	20						
19.9																18	11	16	18						
20.9																14	10	13	18						
22.0																13	9	13	17						
23.0																10	5	12	15						
24.1																8	5	8	8						
25.1																7	4	6	6						
26.2																5	4	6	6						
27.2																5	4	4	4						
28.2																4	3	4	3						
29.3																3	3	4	3						
30.3																3	3	3	3						
31.4																2	3	3	3						
32.4																2	3	3	2						
33.4																2	2	3	2						
34.5																2	1	1	2						
35.5																1	1		2						
36.6																1	1		1						
37.6																1	1		1						
38.7																	1		1						
39.7																	1		1						
40.8																	1		1						
41.8																	1		1						
42.9																	1		1						
43.9																	1		1						
45.0																	1		1						
46.0																	1		1						
47.1																	1		1						
48.1																	1								

Load Range lb in. x 10^{-3}	Number of times load range is exceeded								
	Turbulence								
	110 kts 800 ft			160 kts 200 ft		160 kts 2000 ft			
	T.O. Flap		T.O. Flap and U/C Down						
	1 min 38.3	1 min 39.2	1 min 38.4	1 min 38.2	1 min 27 secs 9.1	1 min 39.1	1 min 39.3	1 min 39.4	1 min 38.1
2.1	46	56	49	232	179	73	87	73	66
3.1	13	19	11	88	76	22	31	23	22
4.2	4	7	4	43	26	8	12	8	6
5.2	3	4	3	21	11	4	7	4	2
6.3	1	1	2	12	5	1	2	1	
7.3			1	5	3	1	1		
8.4				1	2		1		
9.4				1	1				

Table 2

Tailplane starboard outboard bending moment cycles

Load Range lb in. x 10^{-3}	Number of times load range is exceeded: Turbulence, 110 kts 1000 ft, T.O. Flap 1 min	Turbulence, 110 kts 1000 ft, T.O. Flap and U/C Down 1 min	Turbulence, 160 kts 200 ft 1 min	Turbulence, 160 kts 2000 ft 1 min	Airbrakes (10 Second Records) 160 kts	Airbrakes 210 kts	Airbrakes 260 kts	Airbrakes 310 kts	Airbrakes 310 kts	Airbrakes 360 kts	Stalls T.O. Flap	Stalls T.O. Flap	Stalls T.O. Flap U/C Down	Stalls Clean	Stalls Clean	Stalls Clean	Take-off Tarmac	Landing Tarmac	Landing Tarmac	Landing Tarmac	Taxying Tarmac 30 sec
Rec. No.	38.03	38.04	38.02	38.01	17.03	17.04	17.05	17.07	20.14	17.09	10.03	10.04	17.16	10.05	10.06	17.15	10.01	10.10	16.17	17.19	22.1
1.0	26	26	193	35	16	40	72	110	78	109	21	37	8	30	36	35	4	33	83	57	No Counts
1.5	7	5	53	4	3	7	33	62	38	68	10	23	2	13	11	16	1	6	12	4	
2.0	2	1	12			1	7	28	12	48	3	11		6	2	9	1	3	1	2	
2.5		1	5				2	12	4	22	1	6		4	2	6	1	3	1	2	
3.0			2				1	3	1	13	1	3				3	1	2	1	1	
3.5								1	1	6		1				2					
4.0									1	3		1									
4.5										1											
5.0										1											
5.4										1											
5.9										1											

Table 3

Tailplane port root bending moment cycles

Load Range lb in. x 10^{-3}	Number of times load range is exceeded: Turbulence, 110 kts 1000 ft, T.O. Flap 1 min	Turbulence, 110 kts 1000 ft, T.O. Flap and U/C Down 1 min	Turbulence, 160 kts 200 ft 1 min	Turbulence, 160 kts 2000 ft 1 min	Airbrakes (10 Second Records) 160 kts	Airbrakes 210 kts	Airbrakes 260 kts	Airbrakes 310 kts	Airbrakes 310 kts	Airbrakes 360 kts	Stalls T.O. Flap	Stalls T.O. Flap	Stalls Clean	Stalls Clean	Take-off Tarmac	Landing Tarmac
	38.03	38.04	38.02	38.01	20.04	20.05	20.07	20.09	20.11	20.12	10.03	10.04	10.05	10.06	10.01	10.10
2.3	32	35	158	34	26	47	91	102	95	103	37	47	26	34	14	46
3.4	9	11	64	14	4	14	41	61	56	69	18	27	12	11	1	8
4.6	6	4	32	5	1	2	11	23	28	34	111	14	5	3.	1	3
5.7	2	2	19	1		2	1	11	13	19	5	9	2		1	1
6.8	2	2	10			1	1	4	7	12	2	3	2		1	1
8.0	1	1	6				1	1	3	6	1	1	2		1	11
9.1			2					1	2	4	1:	1	1			
10.2			1					1	1	1	1	1				
11.4								1	1							
12.5								1								
13.7								1								

Table 4

Tailplane antisymmetric bending moment cycles

Load Range (B.M. per side) lb in. x 10⁻³	Number of times load range is exceeded																
	Turbulence				Airbrakes (10 Second Records)						Stalls				Spin	Take-off	Landing
	110 kts 1000 ft T.O. Flap 1 min	110 kts 1000 ft T.O. Flap and U/C Down 1 min	160 kts 200 ft 1 min	160 kts 2000 ft 1 min	160 kts	210 kts	260 kts	310 kts	310 kts	360 kts	T.O. Flap	T.O. Flap	Clean	Clean	Left	Tarmac	Tarmac
	38.03	38.04	38.02	38.01	20.04	20.05	20.07	20.10	20.11	20.12	10.03	10.04	10.05	10.06	43.03	10.01	10.10
1.0	146	187	481	221	69	78	114	116	109	125	76	90	46	57	218	12	60
1.5	38	63	278	64	23	45	91	99	97	108	40	44	26	30	201		8
2.0	18	18	142	17	9	25	65	67	74	88	26	32	18	19	192		5
2.5	7	8	73	4	3	6	38	54	55	74	21	27	12	14	181		4
3.0	2	4	39	2		2	25	39	40	56	12	22	9	7	169		4
3.4	1	2	21				14	21	28	39	9	17	7	4	164		3
3.9			8				6	12	19	27	4	9	4	3	155		2
4.4			5				3	7	12	21	2	5	3	1	142		2
4.9			3				1	3	7	13	2	4	3		129		2
5.4			2				1	1	4	9	2	4	1		123		2
5.9								1	3	7	1	2			117		2
6.4								1	3	4		2			106		
6.9									1	2		1			97		
7.4									1	1		1			86		
7.9									1	1					75		
8.4									1	1					68		
8.9										1					61		
9.4										1					58		
9.8															54		
10.3															50		
10.8															46		
11.3															44		
11.8															37		
12.3															33		
12.8															31		
13.3															30		
13.8															24		
14.3															20		
14.8															18		
15.3															13		
15.7															12		
16.2															12		
16.7															9		
17.2															8		
17.7															6		
18.2															6		
18.7															3		
19.2															1		

Table 5

Fin root bending moment cycles

Load Range lb in x 10^{-3}	Number of times load range is exceeded																					
	Take-off		Landing		Taxying		Turbulence						Airbrakes (10 Second Records)					Spins			Stalls	
	Grass Mean of 2	Tarmac Mean of 3	Grass Mean of 3	Tarmac Mean of 4	Grass 1 min 33 secs	Tarmac 30 secs	110 kts 800 ft T.O. Flap 1 min	160 kts 1700 ft 1 min	160 kts 1700 ft 1 min	160 kts 1700 ft 1 min	160 kts 500 ft 1 min	160 kts 500 ft 1 min 20 secs	160 kts	210 kts	260 kts	310 kts	360 kts	Right	Right	Left	Clean	T.O. Flap U/C Down
							Rec. No. 39.02	39.01	39.03	39.04	45.01	45.02	18.01	18.02	18.03	18.04	18.06	18.08	18.14	18.09	18.10	18.11
2.2	107	41.3	166	65	352	No Counts	124	96	148	135	98	237	9	10	20	41	41	135	150	133	24	15
3.3	19	12.7	51	15.5	100		58	63	74	66	39	108			2	9	15	132	131	119	21	10
4.4	3.5	4.7	13	4.0	32		30	36	43	35	25	63			1	3	8	114	110	94	10	5
5.5		2.0	3	3.75	7		21	26	30	26	21	42					4	90	93	76	8	2
6.6		1.0	0.3	1.5	1		13	19	25	17	8	32					2	68	77	60	2	1
7.7		0.3	0.3	0.5			7	10	19	9	3	22					1	47	65	43		
8.7		0.3					3	5	10	7		13					1	39	52	35		
9.8							1	4	8	4		9						31	41	26		
10.9								1	6	2		5						25	32	22		
12.0								1	5	1		4						21	25	15		
13.1									1	1		2						17	21	10		
14.2									1	1		2						13	18	9		
15.3												1						11	15	7		
16.4												1						10	13	5		
17.5																		8	11	4		
18.6																		8	9	4		
19.7																		7	7	3		
20.8																		7	6	2		
21.9																		3	4	2		
23.0																		3	3	1		
24.0																		3	2	1		
25.1																		1	2	1		
26.2																		1	1	1		
27.3																				1		
28.4																				1		
29.5																				1		

TABLE 6

Fin rear post shear load cycles

Load Range lb	Number of times load range is exceeded														
	Take-off Tarmac Mean of 2	Landing Tarmac	Taxying Tarmac	Spins			Stalls		Airbrakes (10 Second Records)					Turbulence	
				Right Rec. No. 18.08	Left 18.09	Right 18.14	Clean 18.10	T.O. Flap U/C Down 18.11	160 kts 18.01	210 kts 18.02	260 kts 18.03	310 kts 18.04	360 kts 18.06	160 kts 500 ft 1 min 45.01	160 kts 500 ft 1 min 20 secs 45.02
150	6	11	No Counts	123	117	131	18	8	No Counts	No Counts	2	7	15	38	119
220	4	9		109	94	109	8	5			1	2	5	28	62
295	1	5		89	75	84	7	2					3	21	43
370	0.5	3		66	55	67	3						1	12	40
445	0.5	2		49	44	51								7	31
515				40	36	44								3	26
590				31	27	32								1	19
665				27	18	26									15
740				22	15	19									8
810				19	8	17									5
885				12	5	16									3
960				10	5	11									2
1035				9	4	9									1
1110				6	4	7									1
1180				6	1	4									
1255				2	1	2									
1330				1	1										
1400					1										
1475					1										

TABLE 7

Fin front post shear load cycles

Load Range lb	Take-off Tarmac	Landing Tarmac Mean of 2	Taxying Tarmac	Spins: Right Rec. No.18.08	Spins: Left 18.09	Spins: Right 18.14	Stalls: Clean 18.10	Stalls: T.O. Flap U/C Down 18.11	Airbrakes (10 Second Records): 160 kts 18.01	Airbrakes: 210 kts 18.02	Airbrakes: 260 kts 18.03	Airbrakes: 310 kts 18.04	Airbrakes: 360 kts 18.06	Turbulence: 160 kts 500 ft 1 min 45.01	Turbulence: 160 kts 500 ft 1 min 20 secs 45.02
	Number of times load range is exceeded														
80	No Counts	7	No Counts	117	103	127	14	3	No Counts	No Counts	No Counts	1	4	No Counts	No Counts
125		5		95	77	101	5	1							
165		4		73	56	74	3								
205		2		54	43	53									
245		1		36	33	44									
290				27	26	32									
330				23	10	24									
370				18	10	20									
410				12	8	17									
450				10	6	14									
495				7	4	9									
535				3	4	8									
575				3	2	4									
615				2	2	1									
660				1	1										
700				1											

TABLE 8

Maximum and minimum loads and accelerations in aerobatics, spins and stalls

Aerobatic	Tailplane root B.M.				Fin root B.M.		C.G. Acceleration		Flight and Record No.	Direction of turn or roll	Comments
	Starboard		Port								
	Up-load lb in. x 10^{-3}	Down-load lb in. x 10^{-3}	Up-load lb in. x 10^{-3}	Down-load lb in. x 10^{-3}	To port lb in. x 10^{-3}	To stb'd lb in. x 10^{-3}	Maximum g	Minimum g			
Loop	3.7_5	-2.1	3.9	-2.0			3.23	0.77	4.14		
	2.7	-4.5	1.6	-2.9			3.85	0.88	7.17		
					3.3_5	1.3_5	3.58	0.88	11.12		
					1.0	2.5_5	3.77	0.69	24.20		
					1.8_5	4.8	3.77	0.96	24.20		
	2.9	-3.1_5			3.5_5	1.3_5	3.46	0.35	28.02		
	3.5	-1.6			3.0	2.3	3.46	0.93	28.02		
	2.4	-3.9			1.3	1.7	4.00	0.38	28.08		
Slow roll	4.6	-2.6_5	4.0	-1.8			2.38	-0.69	4.13		
	4.1_5	-1.0_5	0.7	-3.9			2.73	0.27	7.11		
	6.5_5	-2.6	1.5	-6.1_5			3.39	-0.12	7.12		
	0.7	-2.1	0.6	-4.5_5			1.81	-0.69	19.11	Right	
	0.9	-4.6	1.5	-3.4			2.42	-0.73	19.11	Left	
					5.4	6.0	1.98	-0.65	24.09	Left	
					5.3	4.4	2.19	-0.55	24.09	Right	
	2.2	-2.0			1.5_5	4.5_5	1.96	-1.12	28.06	Left	
	1.3	-3.6			3.3	2.4	2.11	-1.05	28.06	Right	
	0.8	-4.9			4.8	2.5_5	3.70	-1.46	28.09	Right	
	2.3	-2.7			4.1	2.5_5	2.54	-0.58	28.10	Right	
Barrel roll	3.3	-2.2	3.1	-1.1	3.6_5	2.5	2.11	0.15	4.12	Right	
	1.0	-1.0_5					2.50	1.00	7.09		
	1.5_5	-1.1_5					2.69	0.77	7.10		
					6.2	2.0	2.27	0.92	11.07	Right	
					2.1_5	7.5	2.35	0.88	11.08	Left	
					5.4	0.7	3.12	0.92	24.02	Right	
					5.8	0.7	2.38	0.27	24.02	Right	
	2.4	-1.8			3.8	0.1_5	2.85	0.81	28.05	Right	
	1.1	-1.8			1.4	3.8	2.92	0.31	28.05	Left	
	1.2	-1.8			1.0	3.5_5	2.00	0.62	31.02	Left	
	0.8	-1.9			0.8_5	3.0	2.15	0.54	31.03	Left	
Roll off the top	3.8	-3.6	3.4	-3.1			3.12	-0.12	4.16		
					4.0	3.75	3.48	0.73	11.13		
	5.8	-5.3_5	5.3_5	-4.4			4.31	0.62	19.04		
					2.0	5.25	3.04	0.04	24.12		
					2.7	1.5_5	3.27	0.31	24.13		
	3.2	-3.4			1.3	3.1	3.46	0.31	28.07		
	1.9_5	-4.5			2.5_5	1.5_5	3.70	0.50	28.07		
	2.8	-6.1			3.7	2.7	3.44	0.65	31.04		
	3.4	-4.5			3.4	2.0	3.56	0.54	31.07		

TABLE 8 (Contd)

Aerobatic	Tailplane root B.M. Starboard Up-load lb in. x 10^{-3}	Tailplane root B.M. Starboard Down-load lb in. x 10^{-3}	Tailplane root B.M. Port Up-load lb in. x 10^{-3}	Tailplane root B.M. Port Down-load lb in. x 10^{-3}	Fin root B.M. To port lb in. x 10^{-3}	Fin root B.M. To stb'd lb in. x 10^{-3}	C.G. Acceleration Maximum g	C.G. Acceleration Minimum g	Flight and Record No.	Direction of turn or roll	Comments
Upward or vertical roll	1.9_5	-3.9					3.12	0.81	7.14		Upward roll
					3.35	10.2	3.12	0.58	11.14		"
	3.9_5	-9.2	2.7	-7.3			4.43	0.19	19.05		"
					3.0	9.1	3.46	-0.19	24.10	Left	"
	2.1_5	-6.5			5.1	7.4	4.04	0.65	28.12	Left	Vertical roll
	2.7	-6.7			2.9	11.9	4.08	0.15	28.12	Left	"
	2.9	-4.9_5			5.5	12.6	3.78	0.50	31.10	Left	"
					12.5	3.5_5	3.81	0.33	31.11	Right	"
Stall turn	3.9_5	+0.4	1.3	-0.9			1.96	0.77	7.13		
	5.0	-0.5_5	4.3_5	-0.6			2.69	-0.18	19.03		
	5.3	+0.1	4.4	-0.6_5			2.73	0	19.03		
	4.7	-0.3_5	5.1	+0.1			2.73	-0.08	19.03		
					4.7	3.3	2.75	0.04	24.08	Right	
					4.0	3.2	2.73	0.04	24.08	Left	
					2.1	5.1	3.20	-0.04	24.10	Right	
					1.7	5.0	3.08	0.04	24.20	Right	
	4.6	+0.3			5.7	3.1	2.42	0.04	28.03	Left	
	3.4	-2.1			4.1	3.8	2.81	0.19	28.03	Right	
Derry turn	6.6	-4.2	6.0	-5.3			3.50	-0.38	4.17		
	3.6	-1.3	1.75	-4.1			3.54	0.69	7.15		
	3.1	-1.4	2.5	-3.1			3.54	0.85	7.16		
					6.2	4.3	3.18	0.50	11.09	Left	
					4.3	4.4	3.36	0.42	11.10	Right	
	3.0	-3.4					3.88	0.88	19.10		
	6.3_5	-1.7					3.81	1.00	19.10		
					3.1	11.7	3.46	-0.73	24.19	Left	
					6.1	4.7	4.08	-0.58	24.19	Right	
	4.4_5	-2.3			3.4	7.5	3.70	-0.54	28.15	Left	
	4.0_5	-4.0			10.5	2.4	3.92	-0.23	28.15	Right	
Inverted turn	1.1	-3.4	1.1	-3.7_5			1.65	-1.58	19.08		
	1.6_5	-3.6	1.9	-4.7			1.77	-1.70	19.09		
					7.1	2.8	2.46	-1.65	24.16		
					2.8	4.3	2.23	-1.62	24.17		
					4.7	3.1	2.31	-1.79	24.18		
	1.2	-1.7			4.8	5.4	1.58	-1.42	28.17		
	2.2_5	-2.1			7.4	1.9	2.00	-1.42	28.18		
	1.6_5	-1.7			4.7	3.1	1.81	-1.38	28.19		
	2.7	-2.7_5			3.4	3.2_5	1.69	-2.08	31.12		

TABLE 8 (Contd)

Aerobatics	Tailplane root B.M.				Fin root B.M.		C.G. Acceleration		Flight and Record No.	Direction of turn or roll	Comments
	Starboard		Port		To port lb in. x 10^{-3}	To stb'd lb in. x 10^{-3}	Maximum g	Minimum g			
	Up-load lb in. x 10^{-3}	Down-load lb in. x 10^{-3}	Up-load lb in. x 10^{-3}	Down-load lb in. x 10^{-3}							
Figure 8					4.6	3.3_5	2.77	0.92	11.11		Horizontal 8
(various)	3.1	-3.2_5					3.80	0.62	19.02		"
					4.2_5	1.7	3.54	0.18	24.03		"
					4.1^5	3.0	3.27	-1.27	24.04		Cuban 8
	1.5	-2.8			3.1	5.8	3.50	0.08	28.11		"
	2.2_5	-3.6^5			2.3	4.7	3.50	0.73	28.11		Spectacles
	2.5	-3.8			3.1	0.7	3.35	0.31	31.09		"
Steep	1.7_5	+0.3			1.4	3.5_5	3.08	0.88	31.14	Left	
turn	2.8	+0.1			3.8	4.7	3.42	1.00	31.15	Right	
Spin	22.8	-8.3							17.12	Left	
					10.9	18.3			18.08	Right	
					12.5	17.2			18.09	Left	
					18.5	15.6			18.14	Right	
	26.1	-14.1							27.03	Left	
	40.6	-8.3							27.04	Right	
	24.6	-13.0							27.07	Left	
	37.2	-10.2							27.08	Right	
Stall	9.7	-0.8							17.15		Clean
	8.1	-1.5							31.21		Clean
	2.3	-3.4							17.16		U/C Down, 20^{o} Flap
	3.4	-1.3							31.22		" " " "
	6.0	-4.8							31.23		U/C Up, 20^{o} Flap

TABLE 9

Tailplane loads when operating flaps and undercarriage in circuit

Condition	Change in tailplane root B.M. (starboard)	
	1st circuit lb in.	2nd circuit lb in.
Landing		
Lowering flaps to 30°	+1,500 to -8,600	+1,500 to -8,900
" undercarriage	-6,300 to -4,800	-6,800 to -5,100
" flaps from 30° to full	-4,900 to -7,400	-5,000 to -7,600
Take-off		
Raising undercarriage	-1,800 to -3,250 -3,450 to +2,800	-2,400 to -3,900 -3,650 to +2,300

TABLE 10

Tailplane and fin root bending moments in aerobatics expressed in terms of mean and cyclic load

	Average mean and cyclic load per aerobatic								
	Slow roll	Barrel roll	Vertical roll	Loop	Roll off top	Figure 8	Stall turn	Derry turn	Inverted turn
Tailplane root B.M. - lb in. x 10^{-3}									
Mean*	-0.2	0	-1.8	0	-0.5	-0.5	-2.1	+0.9	-0.4
Cycle**	$\pm 2.6_5$	$\pm 1.6_5$	± 4.5	$\pm 3.0_5$	$\pm 4.0_5$	$\pm 2.8_5$	$\pm 2.4_5$	$\pm 3.5_5$	$\pm 2.1_5$
Fin root B.M. - lb in. x 10^{-3}									
Mean *	0.7_5	1.75	3.3_5	0	0.7	1.0_5	0.65	1.95	2.2
Cycle**	± 3.9	± 3.0	$\pm 7.2_5$	$\pm 2.3_5$	± 2.8	± 3.4	$\pm 3.7_5$	$\pm 5.6_5$	± 1.1

* Mean of maximum and minimum load

** One cycle per aerobatic

TABLE 11

Tailplane root bending moments when using airbrakes during flying course

	Mean loads and numbers of load cycles per flying course									
	<160 kts 57 mins	160 kts 23 mins	180 kts 155 mins	200 kts 65 mins	220 kts 5 mins	240 kts 10.5 mins	260 kts 0.6 mins	280 kts 0.6 mins	300 kts 0.6 mins	320 kts 0.6 mins
Tailplane root B.M.	Negligible									
Mean load % ultimate		-1	-2.5	-4.1	-6.0	-8.2	-10.3	-12.4	-14.6	-18.2
No. of cycles of ±4% ultimate		0.4	5.0	7.4	1.3	7.2	0.9	2.2	5.4	12.9
" " " " ±2½% "		35	336	339	47	181	19	34	61	113

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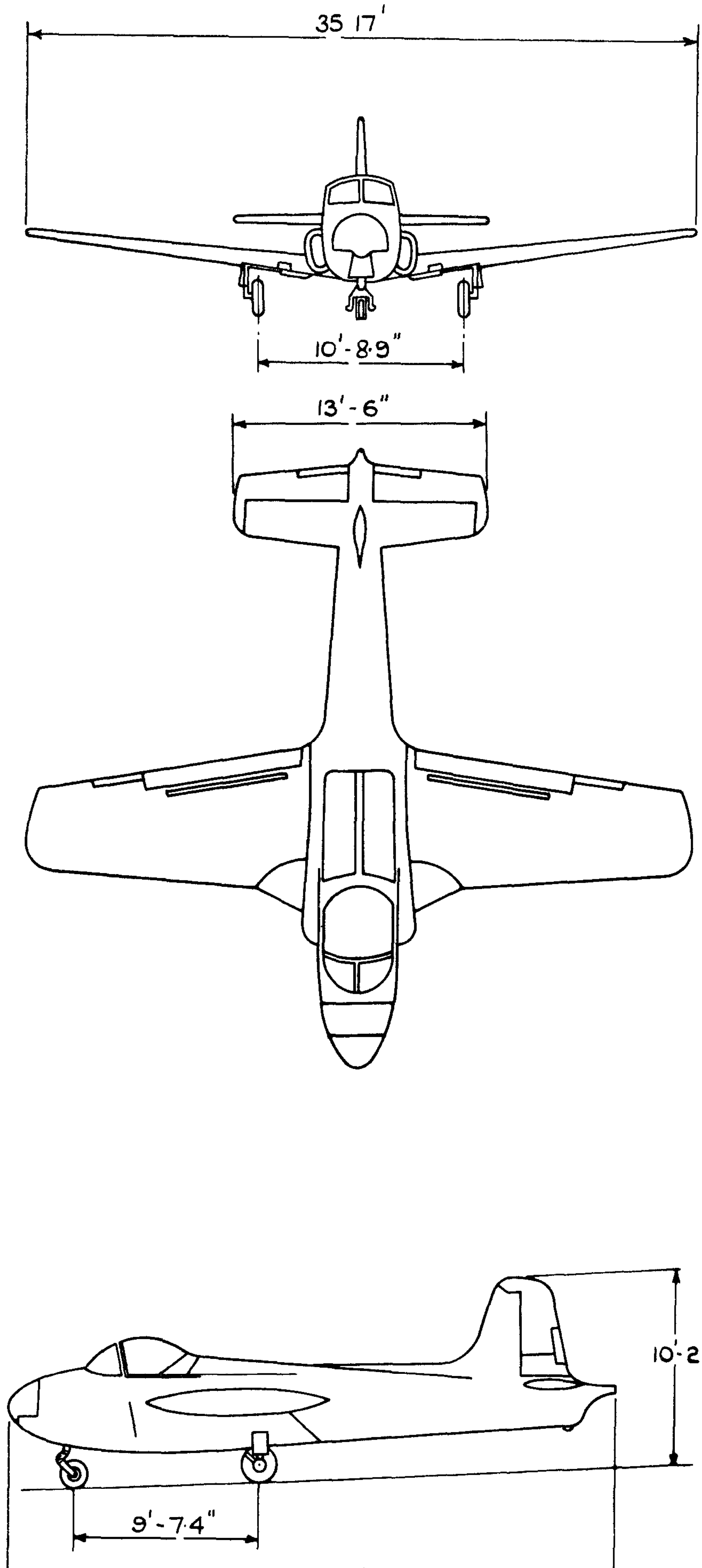

FIG.1. GENERAL ARRANGEMENT OF JET PROVOST
G-AOUS.

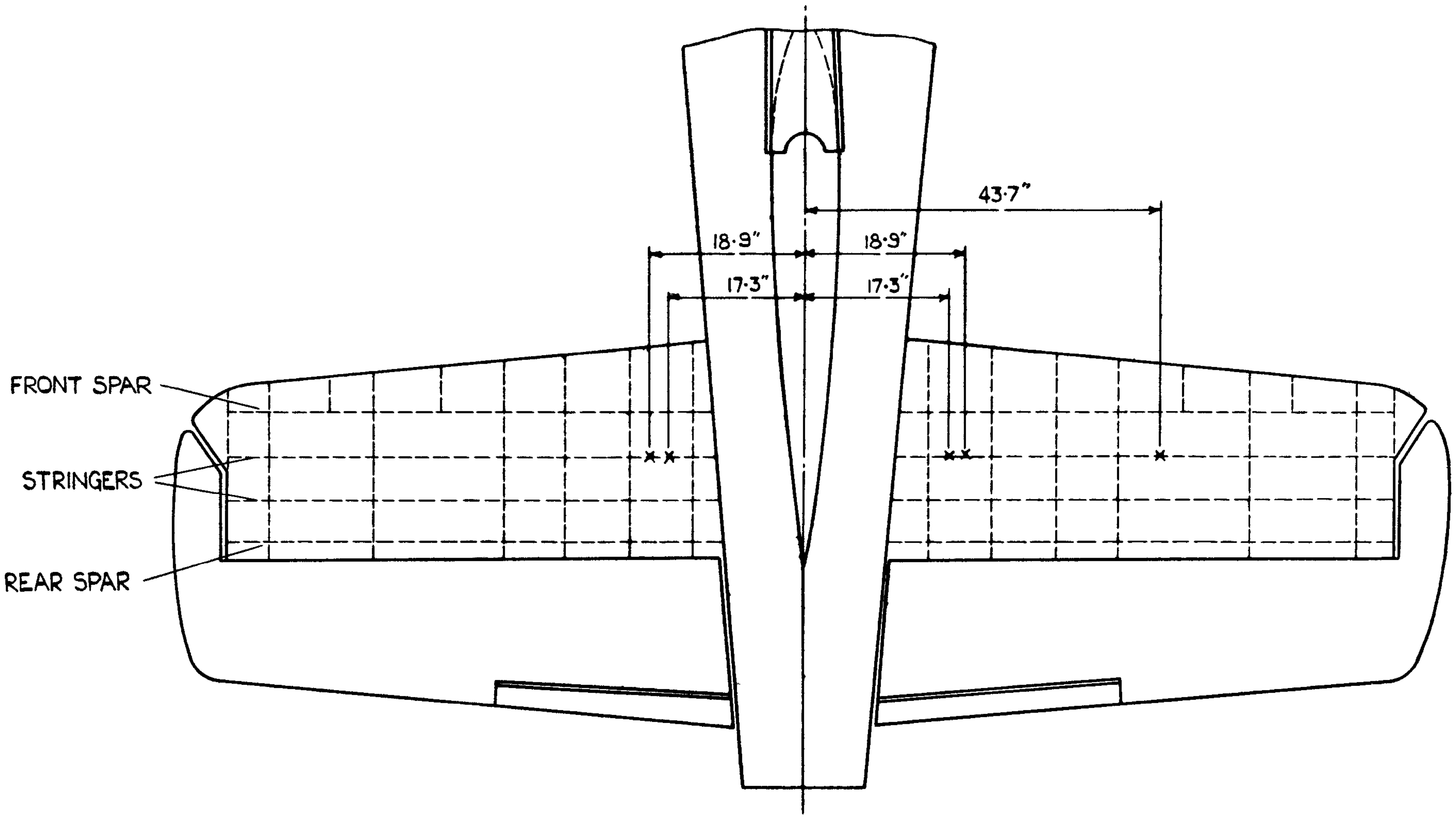

FIG. 2. POSITION OF STRAIN GAUGES ON TAILPLANE OF JET PROVOST

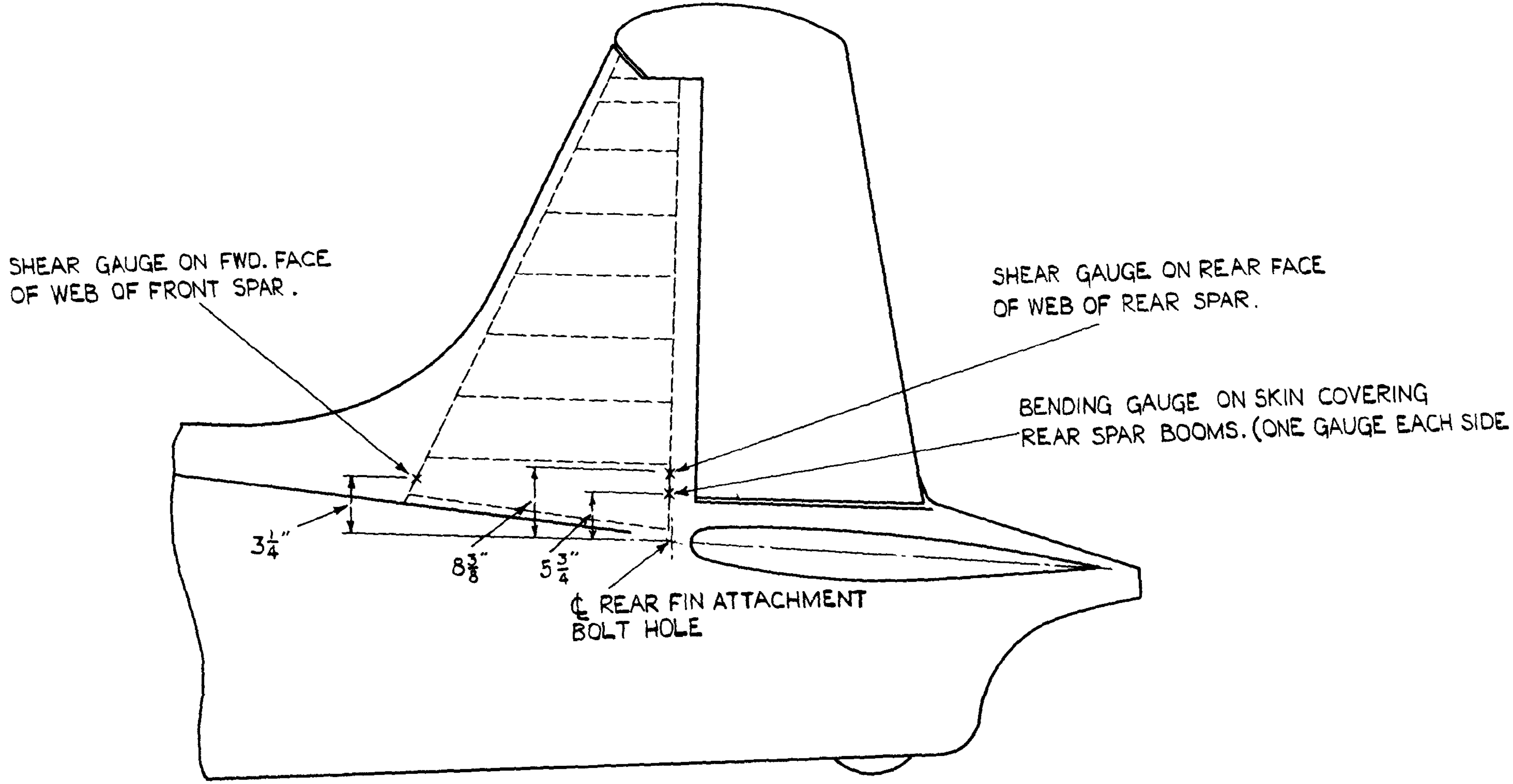

FIG. 3. POSITION OF STRAIN GAUGES ON FIN OF JET PROVOST.

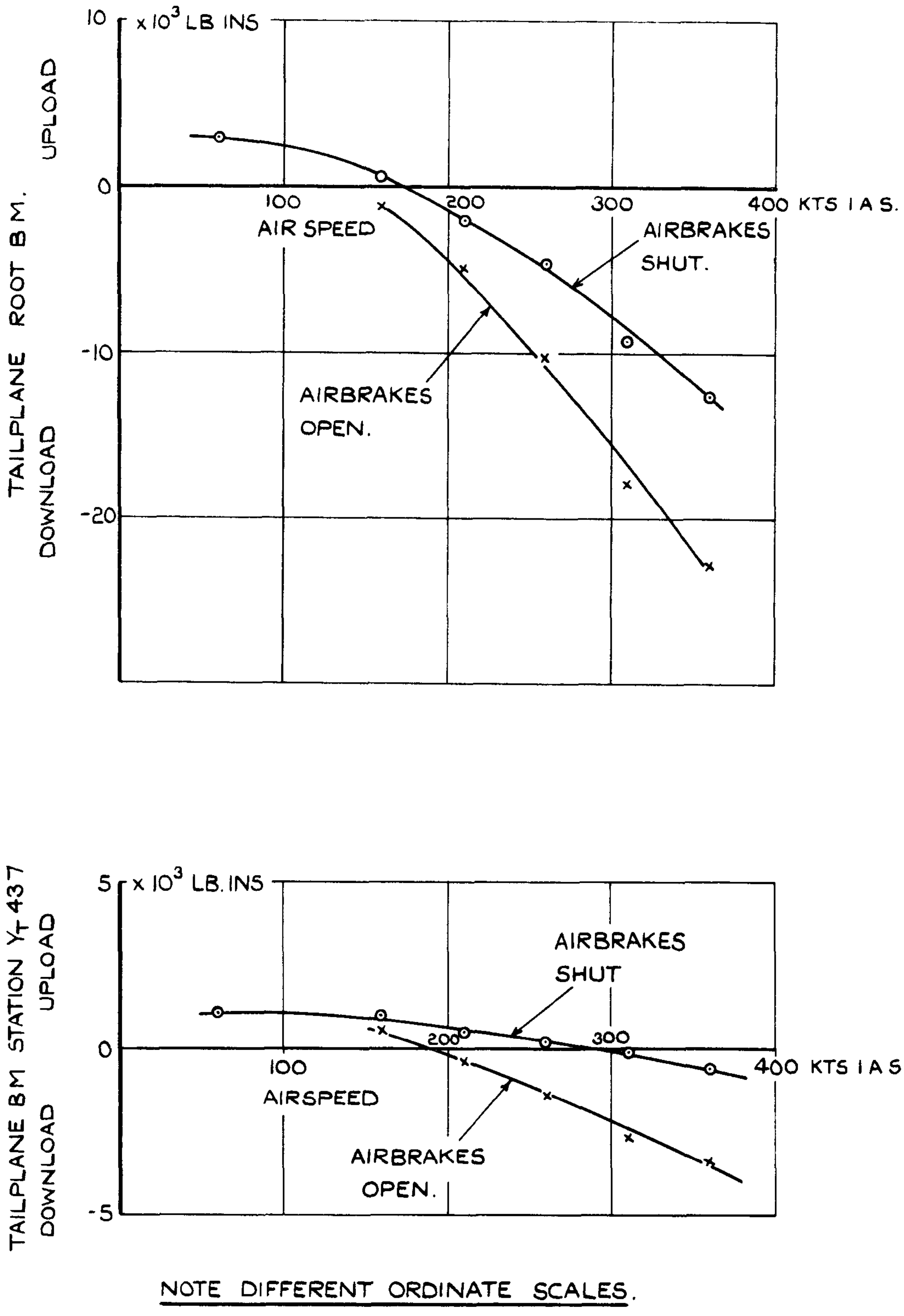

FIG. 4. TAILPLANE LOADS IN STEADY FLIGHT WITH AND WITHOUT AIRBRAKES.

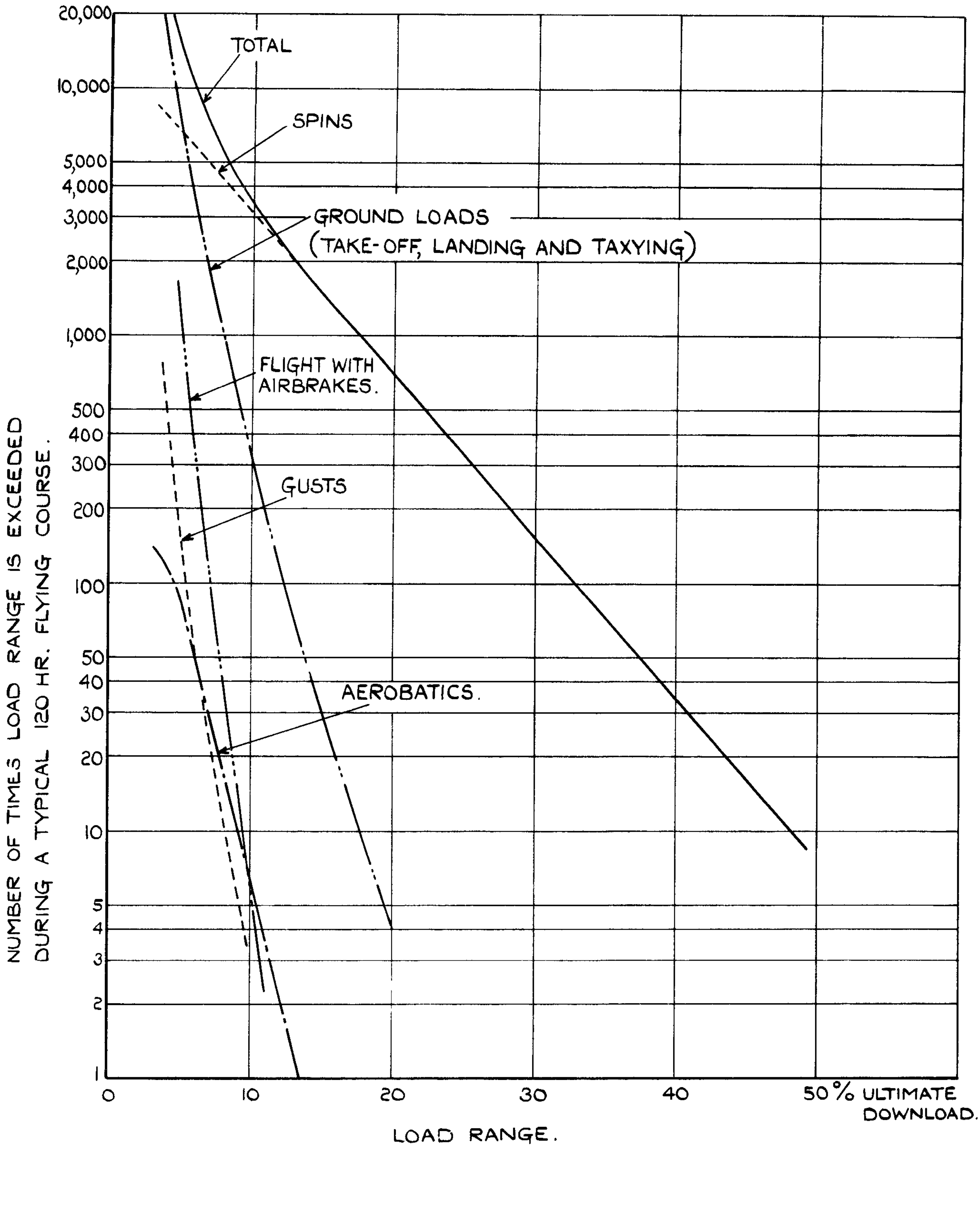

FIG. 5. LOAD OCCURRENCES FOR COMPONENT CONDITIONS OF TYPICAL FLYING COURSE. TAILPLANE ROOT BENDING MOMENT.

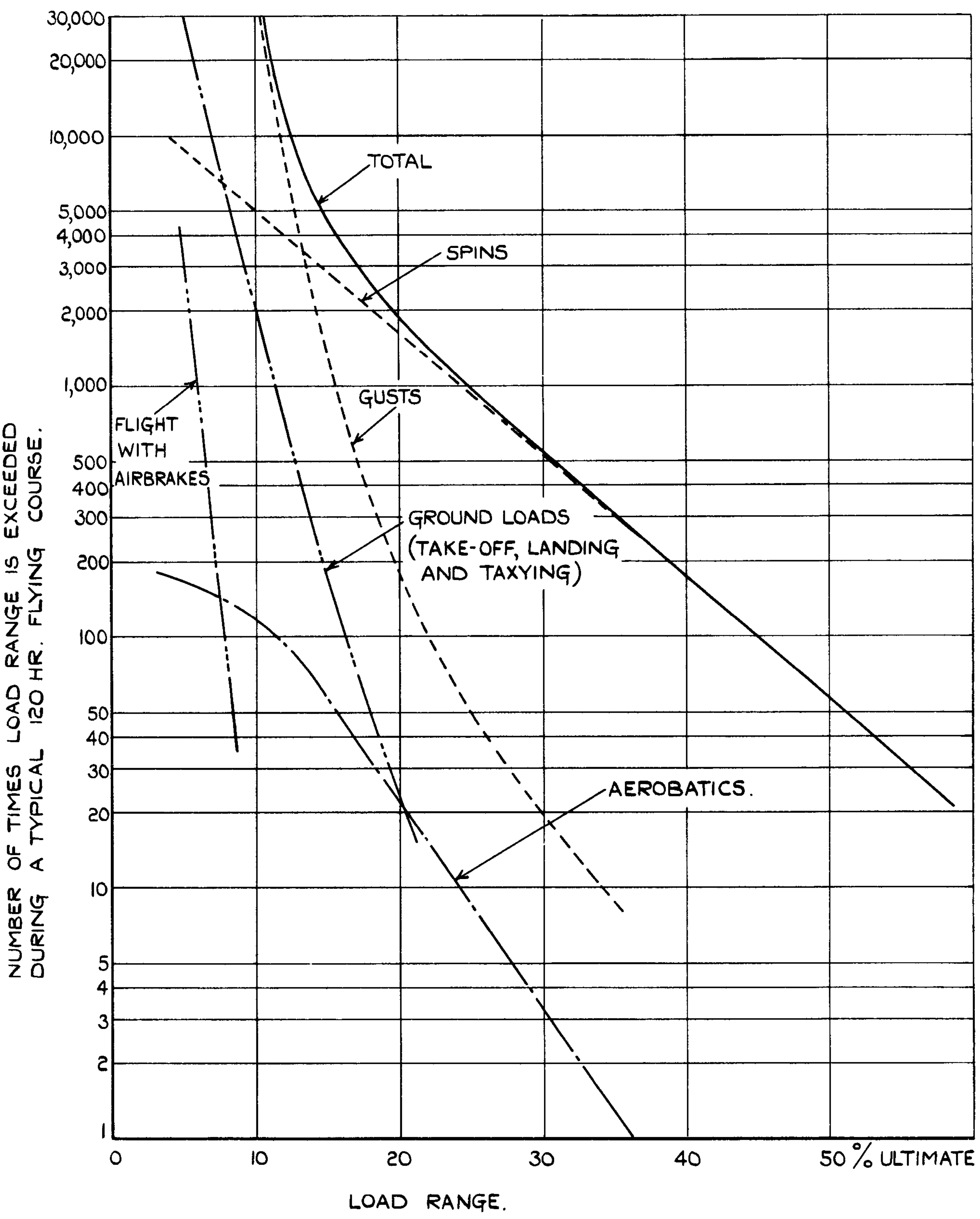

FIG. 6. LOAD OCCURRENCES FOR COMPONENT CONDITIONS OF TYPICAL FLYING COURSE. FIN ROOT BENDING MOMENT.

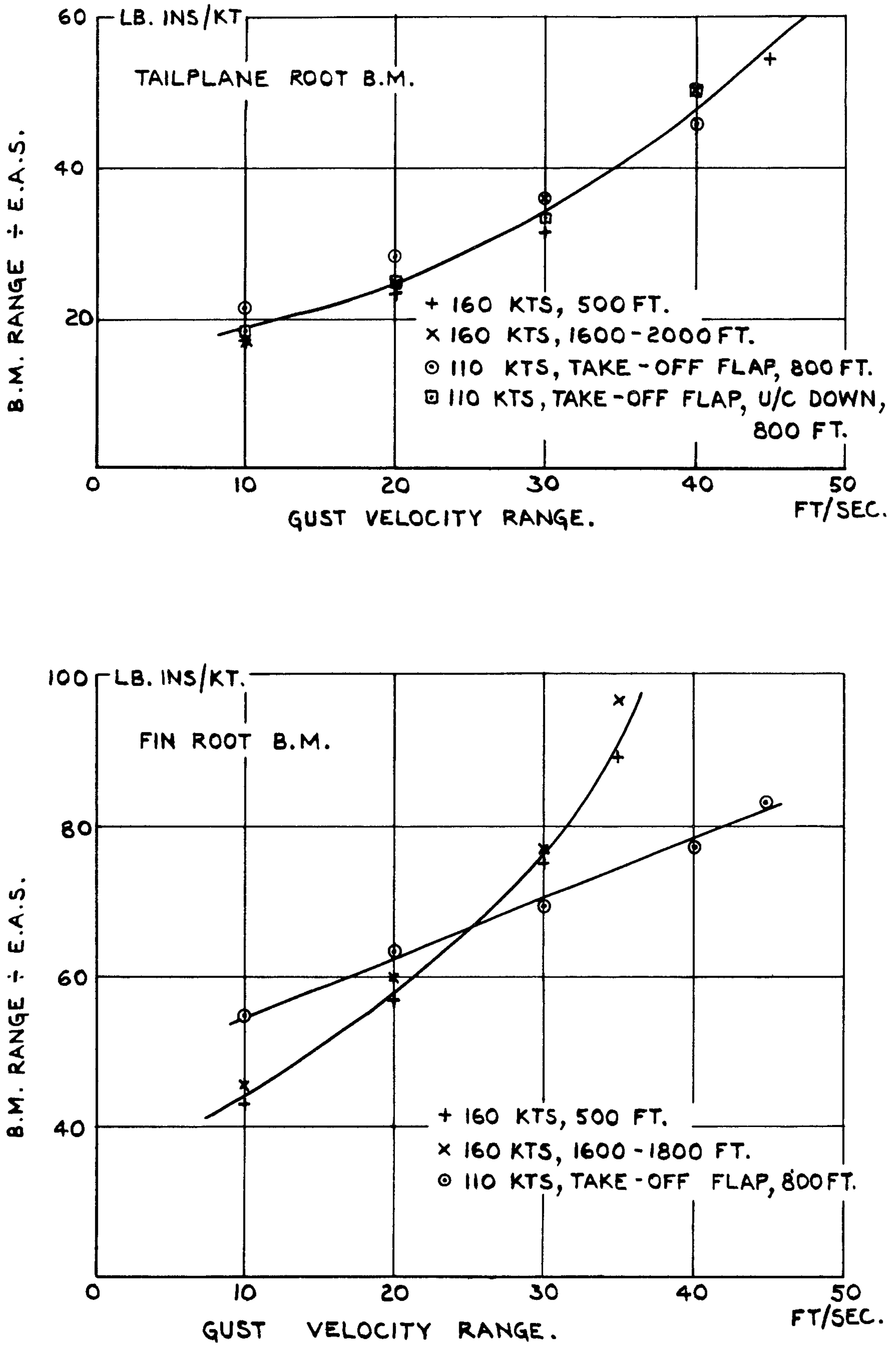

FIG. 7 RELATIONSHIP BETWEEN LOAD RANGES IN THE TAIL UNIT & VERTICAL GUST VELOCITIES EXCEEDED THE SAME NUMBER OF TIMES.

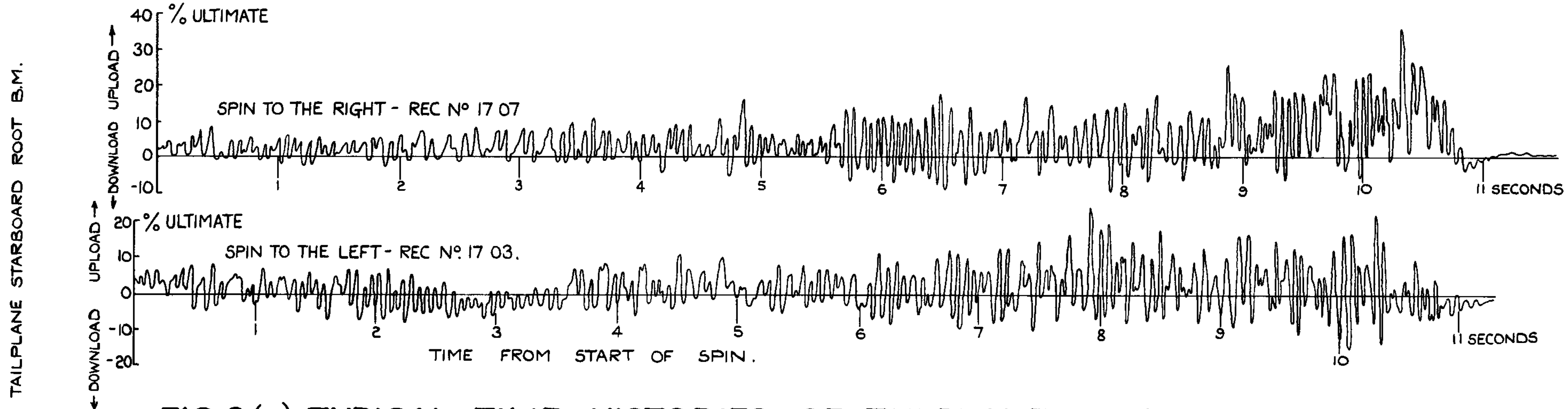

FIG. 8(a) TYPICAL TIME HISTORIES OF TAILPLANE ROOT BENDING MOMENTS DURING SPINS.

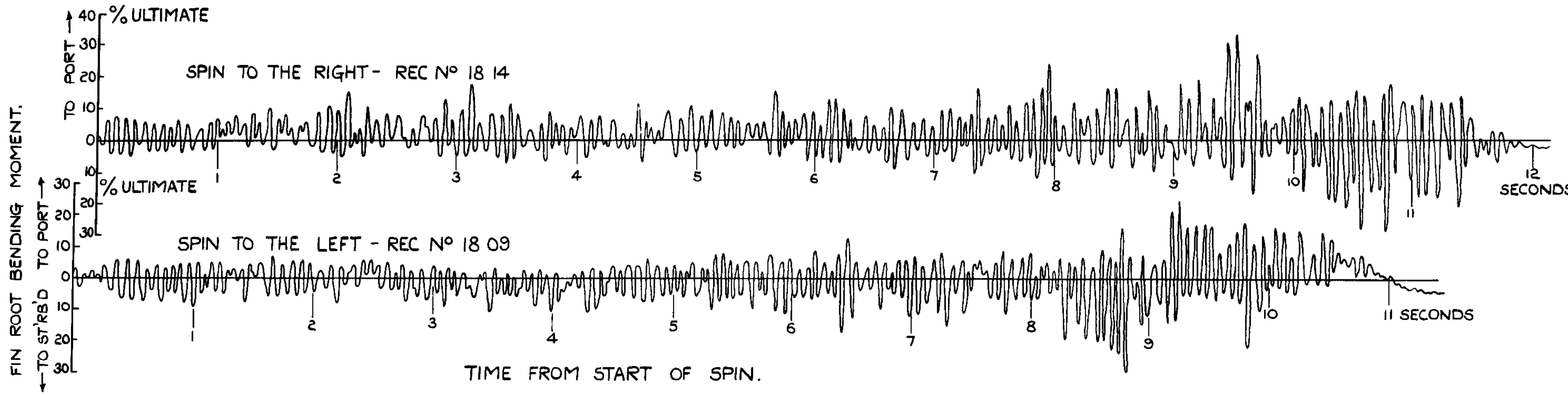

FIG. 8(b) TYPICAL TIME HISTORIES OF FIN ROOT BENDING MOMENTS DURING SPINS.

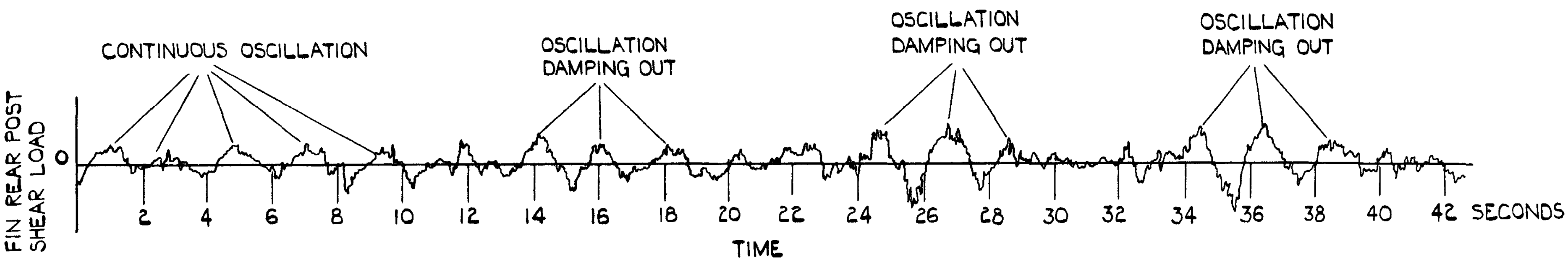

FIG. 9. TYPICAL TIME HISTORY OF FIN LOAD IN TURBULENCE SHOWING OSCILLATION AT 1 CYCLE EVERY 2 SECONDS.

FIG.10. FIN UNDER LOAD DURING CALIBRATION TEST

FREQUENCY OF OTHER GUSTS RELATIVE TO 10 FT./SEC. GUST.

MAGNITUDE OF GUST EXCEEDED FT./SEC. E.A.S.	RELATIVE FREQUENCY
5	5·2
10	1
15	0·198
20	0·044
25	0·010
30	0·0025

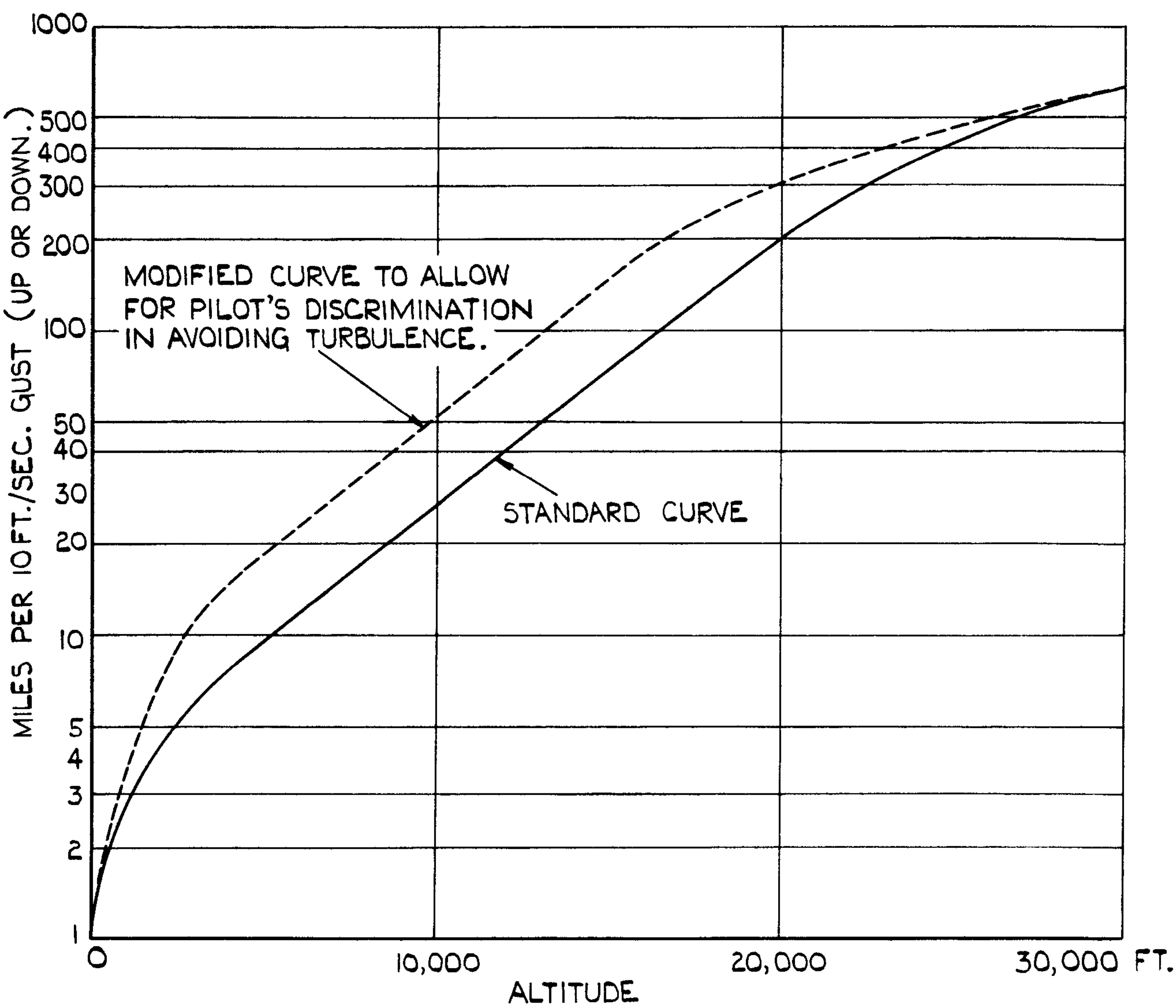

FIG. 11. DATA USED IN CALCULATION OF GUST LOADS EXPERIENCED DURING TYPICAL FLYING COURSE.

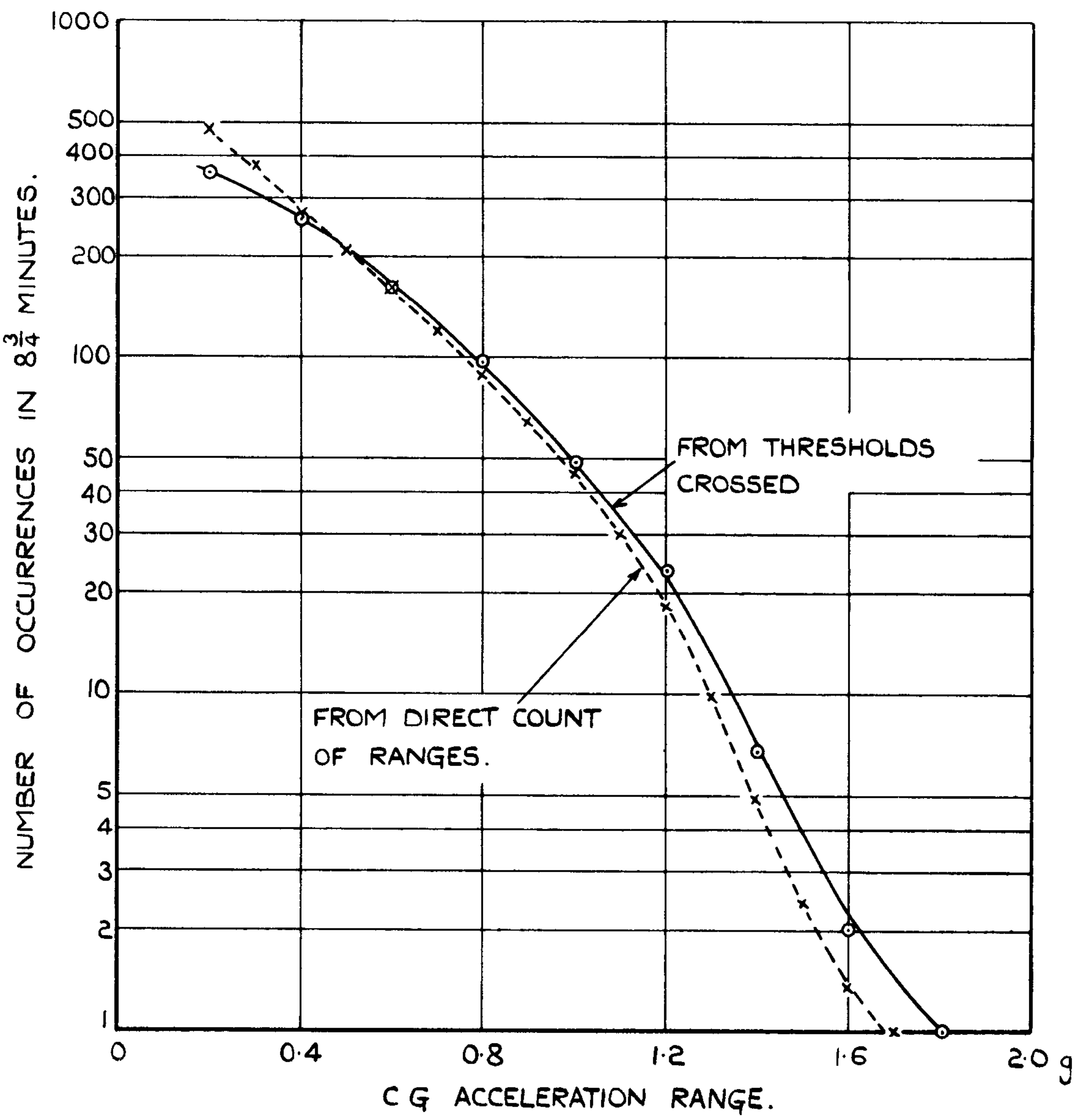

FIG.12. COMPARISON OF ACCELERATION CYCLES OBTAINED BY DIFFERENT METHODS.

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