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Fatigue Loadings in Flight - Loads in the Tailplane of a Devon

by

Anne Burns, B.A.

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ROYAL AIRCRAFT ESTABLISHMENT

FATIGUE LOADINGS IN FLIGHT - LOADS IN THE TAILPLANE OF A DEVON

by

Anne Burns, B.A.

RAE Ref: Structures E16144/AB

SUMMARY

Data are presented on the number of load cycles of various magnitudes occurring in the tailplane of a Devon in normal ground and flight conditions. The conditions include take-off, landing and taxying on grass and on metalled surfaces, and flight in turbulence. The relative importance of the loads in the different conditions is illustrated by reference to the loads in a typical transit flight.

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1 INTRODUCTION

In March, April and May, 1957, flight tests were made in Devon VP.980 to obtain information on the fatigue loads in the tailplane. This note presents the information obtained. It conforms with a series of notes that describes in terms of numbers of occurrences the spectrum of ground and flight loads in the tailplanes of different aircraft[1,2,3,4].

2 DESCRIPTION OF FLIGHT TESTS

A brief account of the instrumentation and flight tests is given in Appendix 1. Measurements of bending moment at the tailplane root were obtained by means of electric resistance strain gauges and continuous recording equipment. The signals from strain gauges on the front and rear stringers (stations shown in Fig.2) were combined to give a signal which did not vary significantly with chordwise movement of the centre of pressure. Signals from the port and starboard sides were also combined so that symmetric and antisymmetric loads could be recorded at the same time as the separate loads in each side. Records of the variation in load were taken during normal ground and flight conditions; these conditions included taxying, landing and take-off on grass as well as on metalled surfaces, and flight in atmospheric turbulence at speeds of 105, 130 and 145 kts E.A.S., and at heights of from 600 ft to 2,000 ft above ground level.

A type Structures'4 accelerometer, modified to record on the same recorder as the strain gauges, was mounted rigidly on the floor just behind the wing main spar centre section in the region of the centre of gravity. The readings of this accelerometer are, for convenience, referred to throughout the note as "c.g. acceleration". It should be understood, however, that any dynamic effects due to flexibilities of the structure are included. Accelerations were measured during flight in turbulence so that the relation of the tail loads to the c.g. accelerations, and hence to the gust velocities, could be ascertained.

3 PRESENTATION OF RESULTS

Information on the fluctuating loads and accelerations is tabulated in terms of numbers of load and acceleration ranges exceeding various magnitudes (Tables 1 to 5). The method used to obtain these ranges is that of an earlier note[1] adapted to enable the computation to be carried out by DEUCE[5]. Information on the change in mean load when lowering the flaps and undercarriage, and on the ground to air loads is given in Tables 6 and 7. Loads measured in manoeuvres, i.e. in turns at accelerations up to 1·5g and pull-outs up to 1·75g were very small and are not analysed. Maximum loads occurring in take-off, landing and taxying are shown in Table 8. Where absolute values of loads are given, the loads are measured from a datum with the aircraft stationary on the ground, engines idling; in this condition the tail loads are assumed negligible.

In order to assess the relative importance of the loads in the different conditions the occurrences of bending moments at the tailplane starboard root are shown for the component conditions of a typical flight and its associated ground conditions (Fig.3). This flight comprises take-off and climb to 5,000 ft, $\frac{3}{4}$ hour cruise at 5,000 ft 152 kts, and a descent and landing; the total flying time is 80 minutes and the time spent in taxying 10 minutes. Since ground loads differ widely for operation on grass and tarmac both cases are considered. Details of the estimation of the loads is given in Appendix 2.

Fig.4 shows the total loads for the typical flight plotted as a percentage of the estimated ultimate failing load*. To give a comparison

* Design ultimate B.M. x reserve factor = 114,000 lb in. at relevant root section; this value was achieved on static test.

with data on other aircraft, occurrences are shown in terms of numbers per hour rather than numbers per typical flight.

The graphs of Fig.5 have been prepared so that the tail 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 at various airspeeds. The loads have been divided by the appropriate airspeed in an attempt to eliminate, as a first approximation, the effect of airspeed. The gust velocities are derived from the measured c.g. accelerations using alleviation factors which take account of altitude[6].

4 DISCUSSION OF RESULTS

4.1 Loads in typical flight

The tailplane loads are on the whole small especially if the aircraft is operating from metalled surfaces. In a typical flight from a metalled surface the maximum root bending moment associated with a download seldom exceeds 15% of ultimate although bending moments of the order of 12% usually occur at least once when lowering the flaps (Table 6) and once during the landing impact (Table 8). Loads of this order also occur on average once per flight in turbulence. Bending moments associated with uploads are even smaller.

The loads quoted above are due to a combination of mean and fluctuating load. The mean bending moment varies from 0 to 7% of ultimate during take-off and landing and is about 4% for level flight at 150 kts, 2,000 ft, A.U.W. and c.g. position as given in Appendix 1. Thus the load fluctuations in themselves are very small, a value of ±7% occurring only once per flight. The load fluctuation which occurs the same number of times as a gust fluctuation of ±10 ft/sec is only ±4.3% of ultimate at 150 kts.

When operating on grass the magnitude of the load fluctuations during take-off, landing and taxying is about twice that when operating on tarmac (compared on a basis of equal numbers of occurrences). Maximum loads during take-off and landing are of the order of 18% download and 9% upload (Table 8).

4.2 Nature of tail loads

The tail load fluctuations, especially those on the ground, are oscillatory in character (see Fig.6). Two tailplane modes of vibration can be distinguished: a symmetric mode at 20 c.p.s. and an antisymmetric mode at 14 c.p.s. probably associated with fuselage torsion. These two modes can occur simultaneously but the symmetric mode has a more marked effect on the root bending moment. The greater severity of the oscillations when the aircraft is operating on a rough surface, i.e. on grass, suggests that the excitation originates mainly from ground loads acting on the undercarriages. Some buffeting of the tailplane may also arise from the propeller slip stream; this, however, is likely to be only a minor effect as shown by the smallness of the oscillations when the engines are run up on the ground (Tables 1 to 4).

The tail loads during flight in turbulence are far less oscillatory in character than are the tail loads on the ground. In flight the loading is mainly symmetrical on the two sides and follows closely the variation in normal acceleration at the c.g., an upload on the tail being associated with a positive acceleration (see Fig.7). Measurements of fluctuating tail loads (not included in note) at 105 kts with and without 20° flap showed no significant differences.

4.3 Relationship between tail loads and gust velocities

Fig.5 shows the relationship between tail root bending moment ranges and vertical gust velocity ranges exceeded the same number of times. The relationship tends to be linear and independent of speed when the tail loads are divided by the equivalent airspeed.

5 CONCLUSIONS

Information on the loads likely to produce fatigue damage in the tail plane of a Devon during normal flying has been obtained in special flight tests. No loads of any severity were measured although small and numerous load fluctuations were found to occur in take-off and landing on metalled surfaces and during flight in turbulence. When operating on grass the magnitude of the ground load fluctuations is about double that when operating on metalled surfaces. Even then, the loads are not severe: the magnitude of the load fluctuation exceeded once per typical flight (defined in Appendix 2) is only ±15% of ultimate. Tail loads in turbulence corresponding to a 10 ft/sec gust are only 4·3% of ultimate when cruising at 150 kts, 2,000 ft.

Mean loads are also small; the root B.M. (download) varies from 0 to 7% ultimate in take-off and landing and has a value of about 4% ultimate when cruising at 150 kts, 2,000 ft (A.U.W. and c.g. as given in Appendix 1).

A simple linear relationship is found to exist between tailplane loads and vertical gust velocities exceeded the same number of times in turbulence. This relationship is approximately independent of airspeed when the tailplane loads are divided by the equivalent airspeed.

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APPENDIX 1

FLIGHT TESTS

INSTRUMENTATION

British Thermostat strain gauges were attached at the stations shown in Fig.2 and water-proofed with Araldite special strain gauge cement. The signals from the gauges were fed into a McMichael carrier wave amplifier and recorded after amplification on a Film and Equipment 12-channel recorder. The stepped signal from a Structures Type 4 accelerometer, mounted rigidly on the floor just rear of the wing main spar centre section near the c.g. position, was also recorded on the Films and Equipment recorder.

CALIBRATION

The strain gauge signals were calibrated on the ground directly in terms of load. Vertical downloads were applied to the tailplane by means of shot bags. The calibration tests indicated that the root bending moment obtained by summing the signals from gauges on the front and rear stringers was virtually independent of the chordwise centre of pressure. Calibrations made before and after the flight tests were in reasonable agreement.

TEST FLYING

The aircraft was flown throughout the tests at an initial all-up-weight of 8,350 lb and c.g. position 0·083 ft forward of datum. Allowance was made for the reduction in all-up-weight due to fuel consumption when deducing gust velocities from the measured accelerations. Initially the aircraft carried 108 gallons of fuel.

Take-offs and landings on metalled surfaces were made at three aerodromes, Farnborough, Thurleigh and Boscombe Down and on grass at White Waltham. Taxying tests were also carried out at the above aerodromes. Approximate average speeds for taxying were "slow" 15 m.p.h., "medium" 22 m.p.h. and "fast" 29 m.p.h. For purposes of analysis a take-off was defined as the period from start of rolling to main undercarriage up, usually about 30 seconds. A landing was defined as a period of 30 seconds starting from the instant of touch-down. The pilot was asked to make normal landings.

Records were taken during flight in turbulence while climbing at 105 kts, cruising at 130 kts and descending at 145 kts I.A.S. Altitudes varied between 600 and 2,000 ft above ground level.

Ground to air measurements were made in two stages in order to minimise strain gauge drift by reducing the time between readings. In the first stage a flight datum was established with the aircraft flying just above the runway at 90 kts, undercarriage and 20° flap down. By using the long runway at Thurleigh the aircraft could be taken off, flown at the above condition and landed straight ahead, allowing ground-air-ground measurements to be taken in quick succession. In the second stage the loads in flight at 2,000 ft, 130 kts, undercarriage and flaps up were determined with reference to the flight datum.

APPENDIX 2

ESTIMATION OF LOAD OCCURRENCES IN TYPICAL FLIGHT

An estimation of ground and flight load fluctuations was made for a typical flight based on short transit flights flown by Devons. The total time of flight was taken to be 80 minutes; this time is not, however, critical since an extension or reduction of time spent cruising affects only the loads due to gusts, most of which occur in the climb and descent rather than during the cruise.

GROUND LOADS

The numbers of occurrences of the tailplane loads for the take-off and landing of the typical flight were obtained by averaging the flight test results. Those for taxying were estimated on the assumption that 10 minutes was spent in taxying per flight, 5 minutes at medium and 5 minutes at slow speeds. Since results were available only for medium speed taxying on grass it was assumed that the ratio of load occurrences in medium and slow taxying was identical for grass and metalled surfaces.

LOADS IN TURBULENCE

The table below shows the number of 10 ft/sec gusts encountered during the various parts of the flight. The last column has been obtained with the aid of Fig.6 which shows the miles flown to meet a gust, up or down, of 10 ft/sec or greater.

Condition	Height ft	Time min	E.A.S. kts	No. of up or down gusts ≥ 10 ft/sec
Take-off and climb	0 to 2,000	6	120	4·52
Climb	2,000 to 4,000	6	120	2.12
Climb	4,000 to 5,000	3	120	0·73
Cruise	5,000	46	152	6·70
Descent	5,000 to 4,000	3	165	1·02
Descent	4,000 to 2,000	6	165	2·93
Descent and landing	2,000 to 0	10	120	7·52
		Total: 80 min		Total: 25·5 gusts

Occurrences of gusts of different magnitudes were obtained from the distribution table of Fig.6. The corresponding tail loads were then obtained from Fig.5 which shows the relationship between tail loads and gusts occurring the same number of times in turbulence. Before using Fig.5, however, a factor had to be introduced to allow for the difference in occurrences of gust ranges obtained by the method of this note and by associating equal up and down gusts together. A value of 0·8 was used at all gust levels although as shown in Fig.7 there is some variation with gust level. The occurrences of tail loads finally obtained are plotted in Fig.3.

TABLE 1

Tailplane starboard root bending moment cycles

Range lb in.	Number of times B.M. range is exceeded											
	Take-off		Landing		Engine Ground running	Taxying				Turbulence		
	Tarmac mean of 12	Grass mean of 2	Tarmac mean of 12	Grass mean of 2		Tarmac			Grass	105 kts 190 sec	130 kts 300 sec	145 kts 360 sec
						Slow	Medium	Fast	Medium			
3,700	131	264	134	376	1	7	39	115	448	28	131	176
5,500	44	185	47	270			1	10	92	13	53	63
7,400	14	129	17	194					20	5	20	23
9,250	4•5	89	7	128					4	2	9	6
11,100	1•3	56	3•4	83					1	2	7	1
12,950	0•6	36	0•9	55							4	
14,800		23		31							1	
16,650		14		23								
18,500		8		14								
20,350		5		9								
22,200		1		6								
24,050		1		5								
25,900				2								
27,750				1•5								
29,600				0•5								
31,450				0•5								
33,300				0•5								

TABLE 2

Tailplane port root bending moment cycles

Range lb in.	Number of times B.M. range is exceeded					
	Tarmac		Ground running	Turbulence		
	Take-off mean of 12	Landing mean of 12		105 kts 190 sec	130 kts 300 sec	145 kts 360 sec
3,360	145	148	22	43	111	175
5,040	54	57	4	12	59	73
6,720	17·7	23·3		8	28	27
8,400	6	9·3		4	14	10
10,080	2·3	4·3		1	9	3
11,760	0·5	2			4	1
13,440		0·7			3	1
15,120					1	

TABLE 3

Tailplane root symmetric bending moment cycles

Range B.M. per side lb in.	Number of times B.M. range is exceeded					
	Tarmac		Ground running	Turbulence		
	Take off mean of 12	Landing mean of 12		105 kts 190 sec	130 kts 300 sec	145 kts 360 sec
2,800	77	170	2	50	134	197
4,200	33	74		20	75	92
5,600	13·4	32		6	32	46
7,000	5·5	16·4		4	18	19
8,400	1·5	7·5		2	12	7
9,800		4·6		1	7	4
11,200		1·7			4	2
12,600		1			1	
15,400					1	

TABLE 4

Tailplane root antisymmetric bending moment cycles

Range B.M. per side lb in.	Number of times B.M. range is exceeded					
	Tarmac		Ground running	Turbulence		
	Take-off mean of 12	Landing mean of 12		105 kts 190 sec	130 kts 300 sec	145 kts 360 sec
1,040	84	39	27	26	118	183
1,560	23·6	4·9	3	5	22	38
2,080	5·2	0·87	1	1	7	7
2,600	1·83			1	2	4
3,120	0·5				1	3
3,640					1	1
4,160					1	1

TABLE 5

C.G. Acceleration cycles

Range	Number of times acceleration range is exceeded										
	Take-off		Landing		Taxying - 3 minute samples				Turbulence, 2,000 ft		
	Tarmac mean of 12	Grass mean of 2	Tarmac mean of 12	Grass mean of 2	Tarmac			Grass	105 kts 190 sec	130 kts 300 sec	145 kts 360 sec
g					Slow	Medium	Fast	Medium			
0·2	Negligible	36	Negligible	58	66	105	128	309	59	148	209
0·3		25		43	9	10	10	122	33	99	127
0·4		18		29	1	1	1	48	18	67	77
0·5		12		20				20	11	41	48
0·6		9·2		13				8·7	6·6	25	29
0·7		6·5		9·4				4·2	3·8	17	14
0·8		4·7		6				1	1·2	10·5	8·9
0·9		4·2		4·2						5·2	7·5
1·0		2·8		3·1						3·5	4
1·1		1·7		2·2						2·4	1·4
1·2		0·8		1·5						0·8	1
1·3				1							

TABLE 6

Tailplane loads when lowering flaps and undercarriage in circuit

Condition	Change in tailplane root symmetric bending moment*				
	Circuit No.1	Circuit No.2	Circuit No.3	Circuit No.4	Circuit No.5
	lb in.	lb in.	lb in.	lb in.	lb in.
Lowering flap 20° at 120 kt approx.	-3,500 to -11,800	-5,350 to -13,100	-6,000 to -13,900	-4,650 to -11,600	-5,350 to -13,100
Lowering undercarriage	No significant change				
Lowering full flap at 90 kt approx.	-8,600 to -12,000	-11,800 to -13,200	Full flap not used		

* Negative sign denotes down-load

TABLE 7

Change in tailplane root bending moment from ground to air

Condition	Change in tailplane root B.M.†	
	Port root	Stb'd root
	lb in.	lb in.
Ground, engines idling* to straight and level flight 130 kts I.A.S., 2,000 ft above m.s.l.	0 to -4,500	0 to -4,100
Ground, engines idling* to straight and level flight 90 kts I.A.S., 10 ft above runway, 20° flap, undercarriage down.	0 to -7,700	0 to -6,900

* Loads assumed zero for this condition.
† Negative sign denotes down-load.

TABLE 8

Maximum root bending moments in take-off and landing

Flight and record No.	Condition	Maximum root B.M. (starboard)	
		Down-load % ultimate	Up-load % ultimate
3·1986	Take-off - tarmac	8·9	4·6
4·1990	" " "	8·1	3·8
4·1995	" " "	8·9	7·0
4·2004	" " "	11·3	6·5
7·2028	" " "	10·0	3·0
9·2042	" " "	8·7	5·7
10·2045	" " "	9·8	4·9
11·2054	" " "	7·8	3·2
12·2058	" " "	7·6	3·0
13·2072	" " "	8·7	5·1
13·2076	" " "	10·8	5·4
13·2079	" " "	9·2	7·3
	Mean	9·0	5·0
3·1985	Landing - tarmac	10·3	5·1
3·1987	" "	13·5	2·4
4·1991	" "	7·0	5·4
4·2005	" "	11·3	3·5
5·2016	" "	10·3	1·9
7·2027	" "	14·0	2·2
7·2030	" "	11·9	3·0
9·2043	" "	12·5	3·5
10·2051	" "	10·3	4·3
11·2056	" "	12·2	1·9
13·2068	" "	11·9	5·1
19·2158	" "	12·7	1·9
	Mean	11·5	3·3
37·2394	Take-off - grass	18·1	6·2
39·2414	" " "	16·5	5·2
40·2419	" " "	16·8	11·2
	Mean	17·1	7·5
37·2386	Landing - grass	20·0	8·4
39·2413	" "	17·0	12·8
40·2418	" "	Record too faint	9·2
	Mean	18·5	10·1

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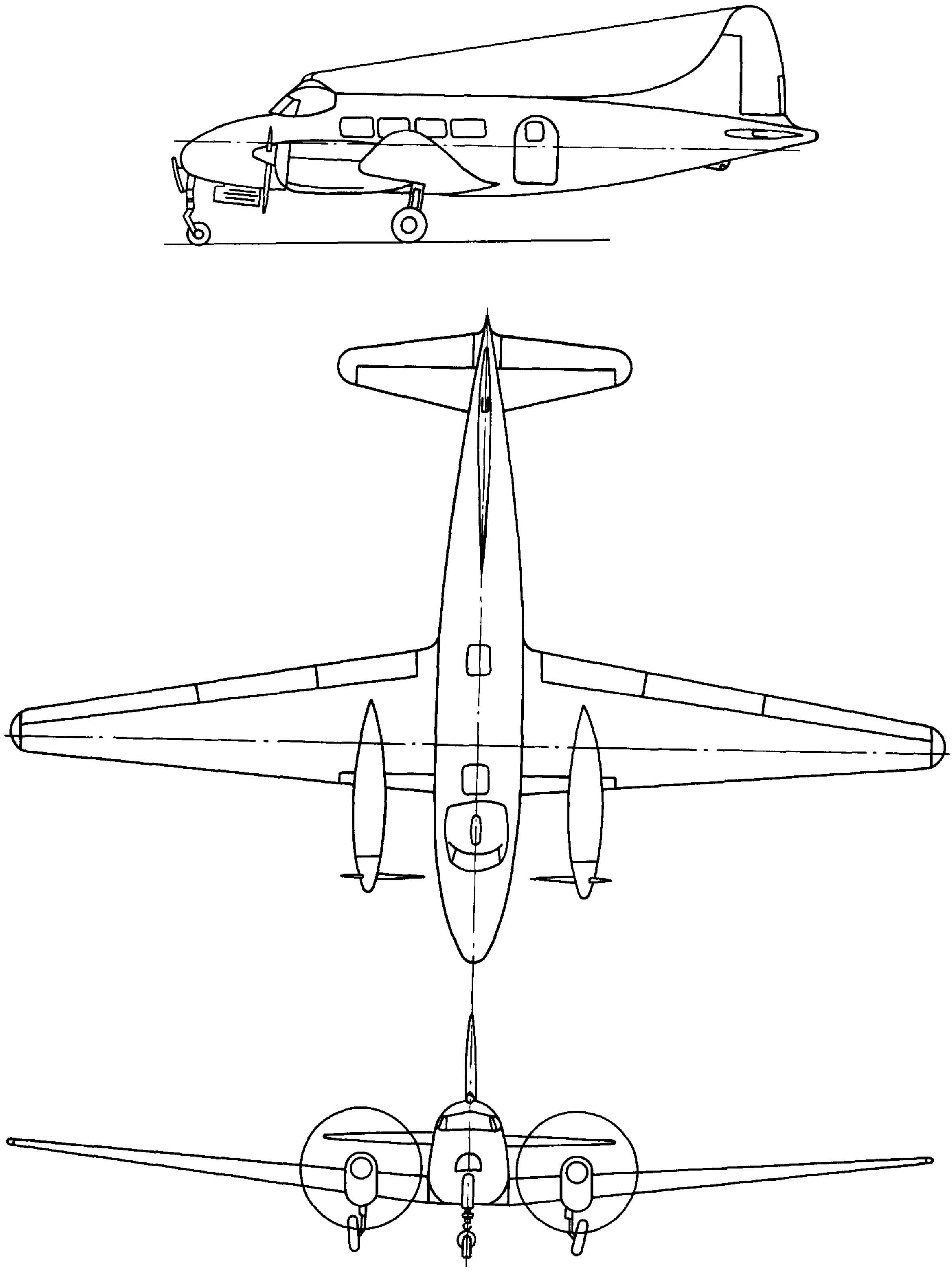


FIG. 1. GENERAL ARRANGEMENT OF DEVON.

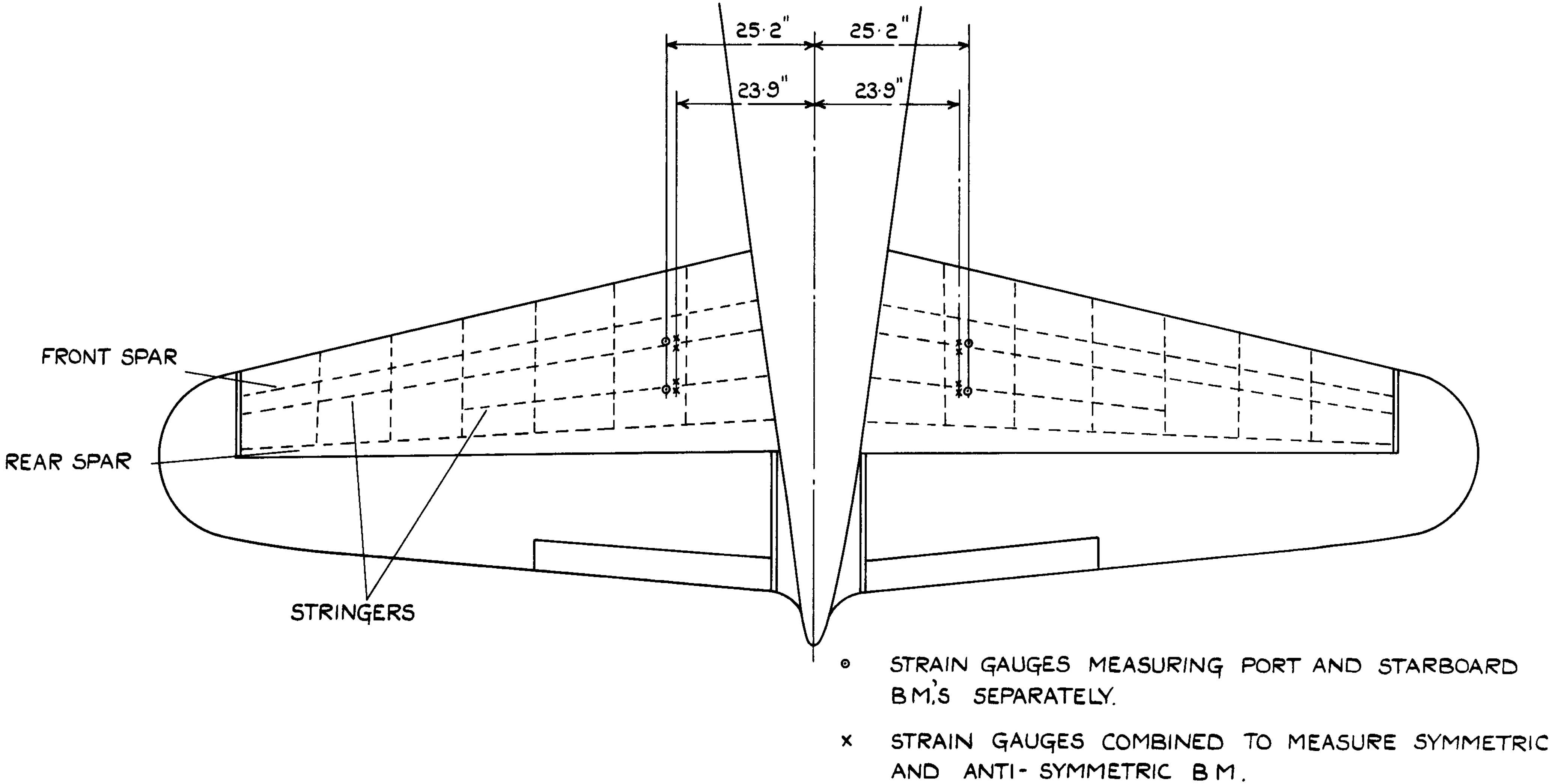
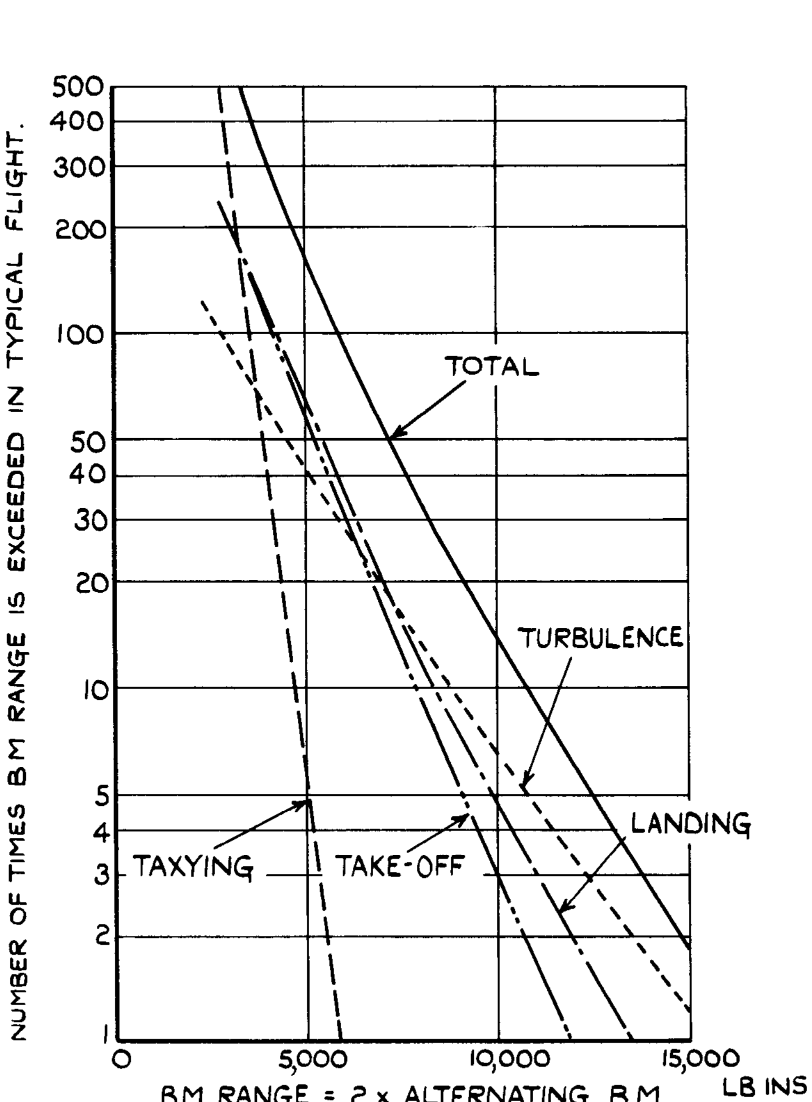
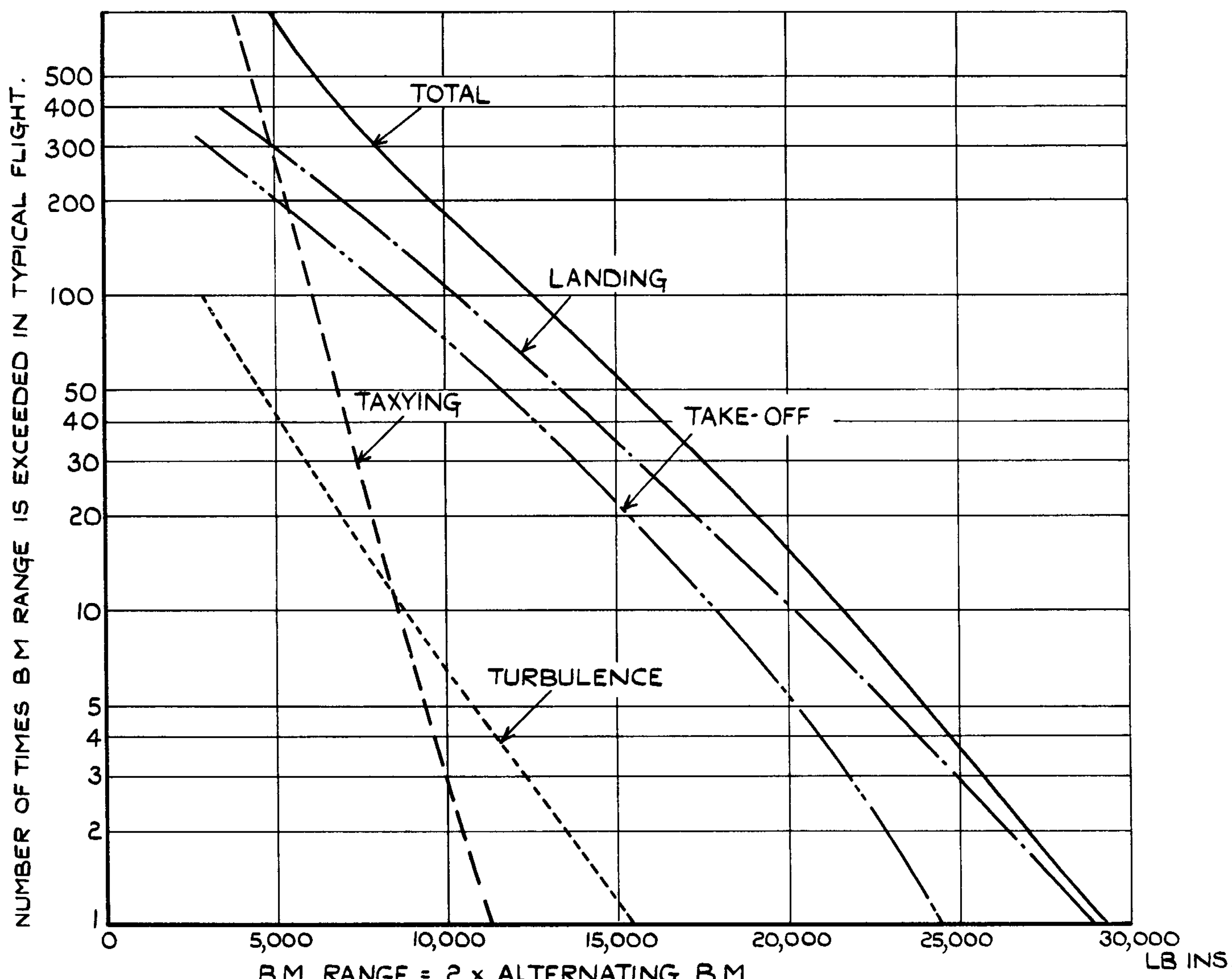


FIG. 2. POSITION OF STRAIN GAUGES ON TAILPLANE OF DEVON.



(a) OPERATING ON TARMAC.



(b) OPERATING ON GRASS.

FIG. 3 (a & b) TAILPLANE STARBOARD ROOT BENDING MOMENTS IN COMPONENT CONDITIONS OF TYPICAL FLIGHT.
(FLYING TIME = 80 MINS)

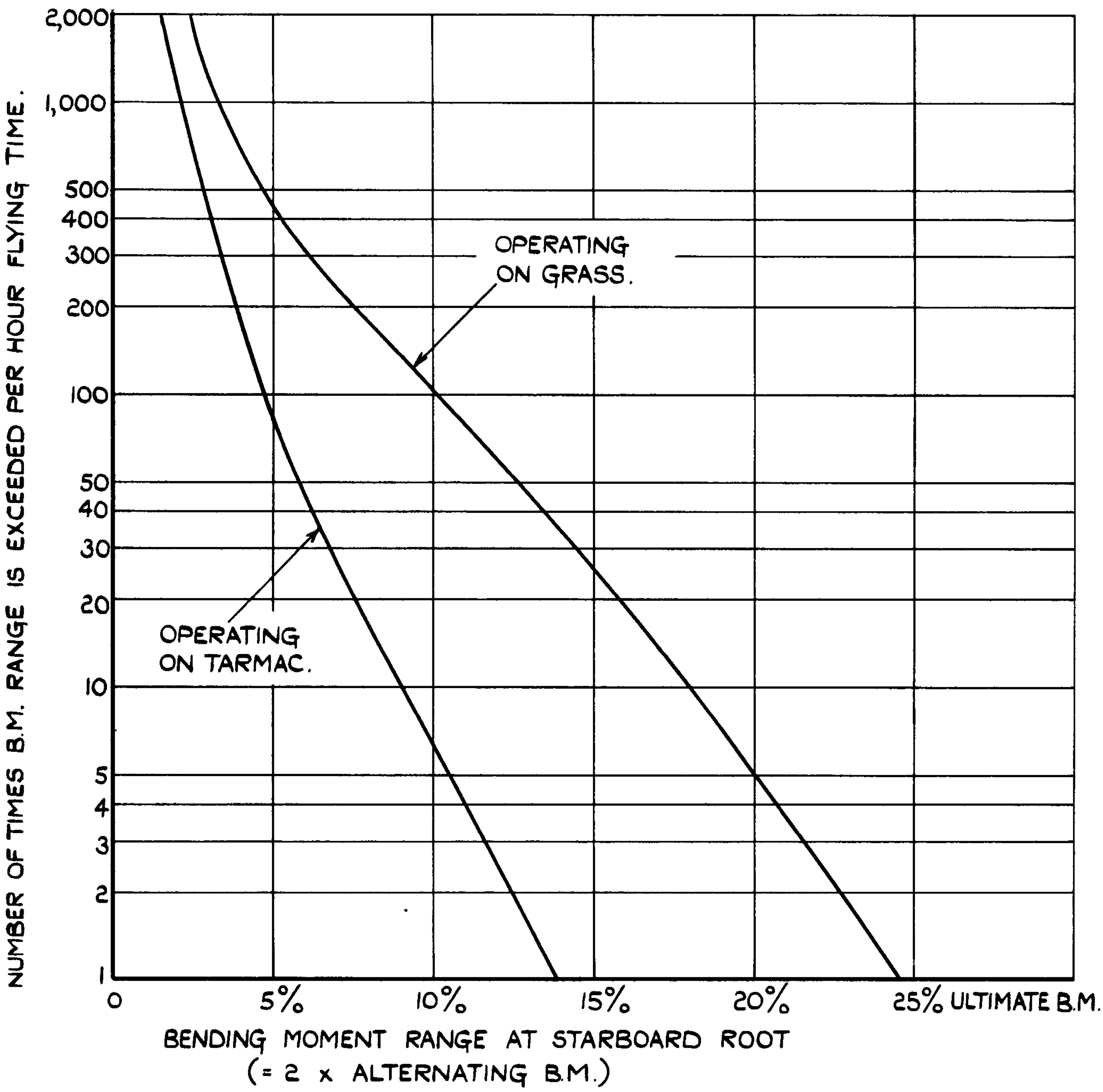


FIG. 4. RATE OF OCCURRENCE OF LOAD RANGES (BASED ON TOTAL LOADS FOR TYPICAL FLIGHT)

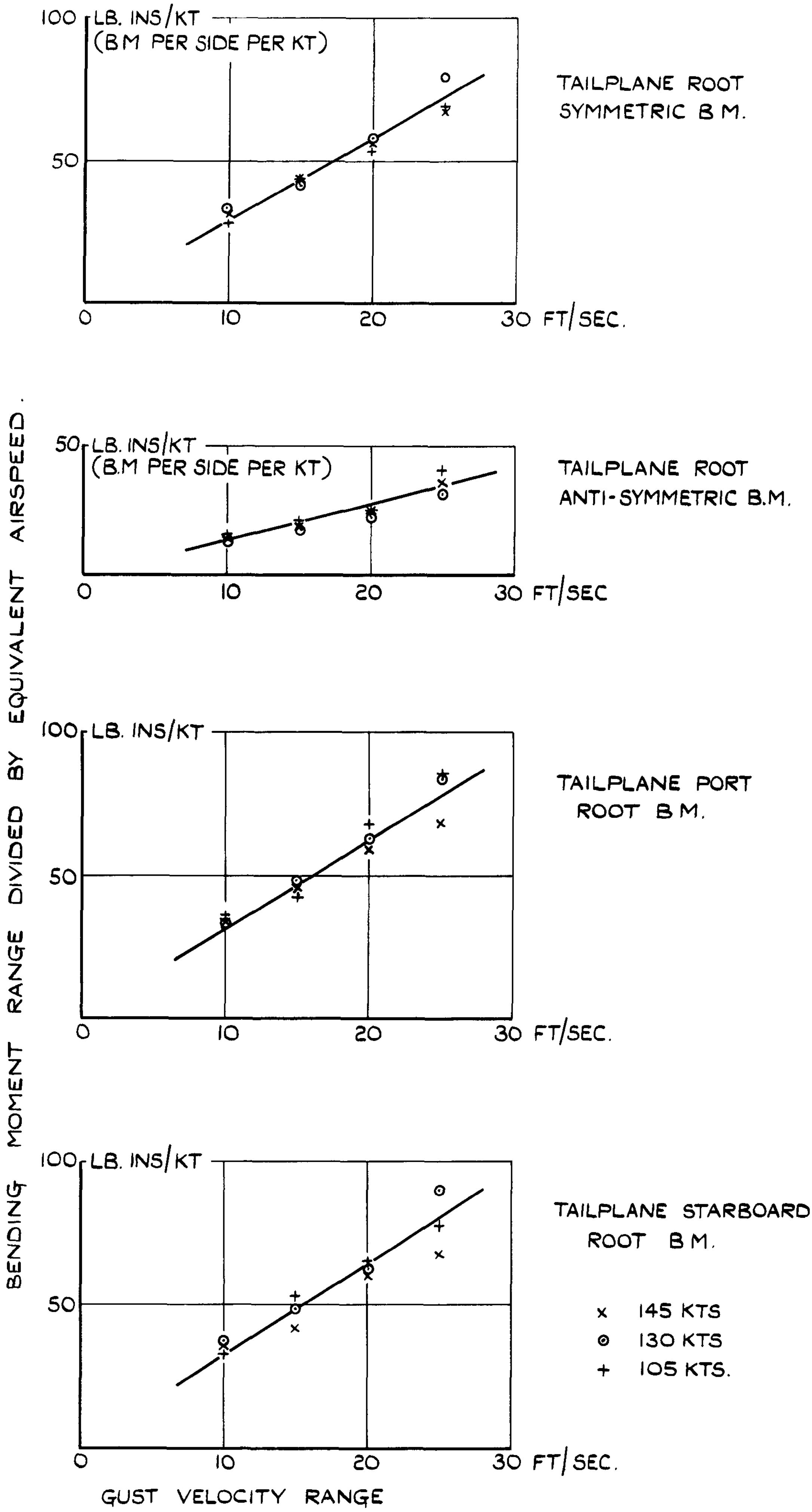
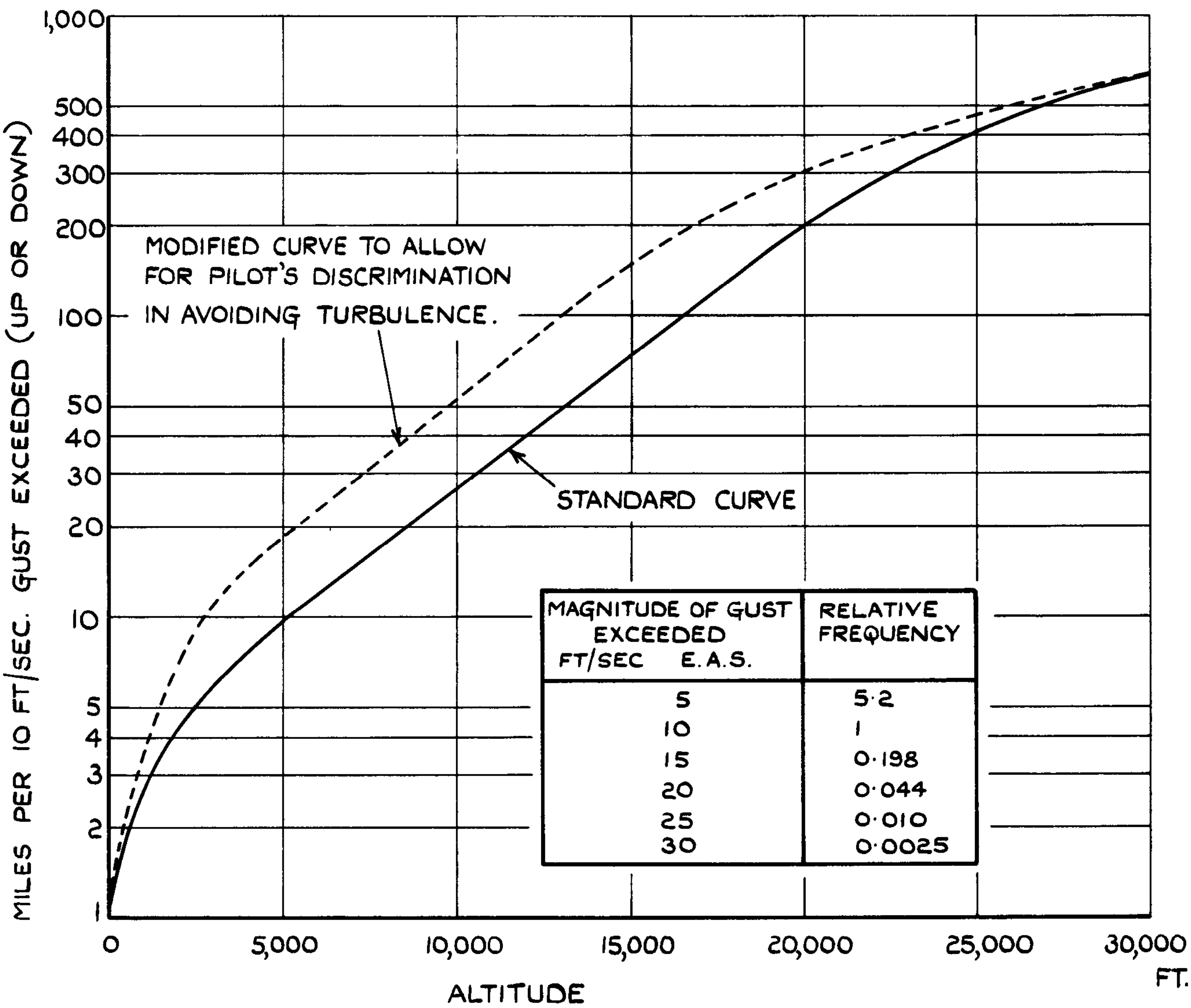


FIG. 5. RELATION BETWEEN TAIL ROOT B.M. RANGES AND VERTICAL GUST VELOCITY RANGES EXCEEDED THE SAME NUMBER OF TIMES.



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. 6. DATA USED IN CALCULATION OF GUST LOADS EXPERIENCED DURING TYPICAL FLIGHT.

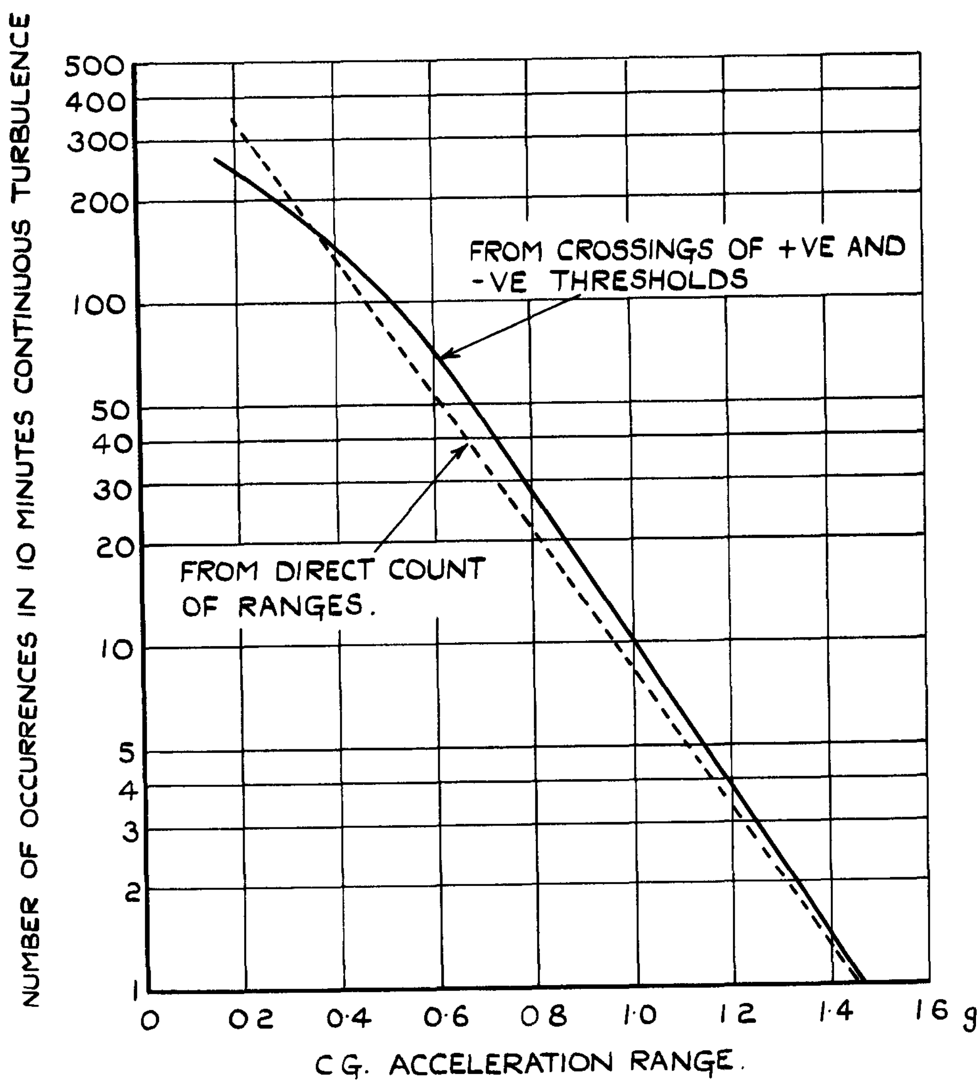


FIG.7. COMPARISON OF COUNTS OF C.G. ACCELERATION RANGES OBTAINED BY DIFFERENT METHODS.

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