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Fatigue Loadings in Flight:
Loads in the Wing of a Varsity

By

Anne Burns, B.A.

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Fatigue Loadings in Flight - Loads in the Wing of a Varsity

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Anne Burns, B.A.

SUMMARY

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

A relationship is determined between wing loads and accelerations in turbulence so that the test results can, if required, be related to gust data obtained operationally by means of the counting accelerometer.

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1 Introduction

In June, July and August of 1955, a series of flight tests was made in a Varsity to obtain information on the fatigue loads in the main structure. An account of the loads in the tail unit, fuselage and nose-wheel undercarriage has already been given[1,2]; this note presents the information obtained on the loads in the wings. Although a considerable amount of information on flight loads in wings has already been obtained by means of the counting accelerometer, there is still little information available on ground loads in wings. Particular attention was therefore given in the tests to conditions such as taxying, landing and take-off; and the investigation in flight was restricted to a study of the relationship between acceleration at the c.g.* and loads in the wing.

2 Flight Tests and Method of Analysis

A description of the flight tests and of the method of analysis of the loads in terms of changes of steady load and load ranges has already been given[1]. Appendix I contains further details relevant to the present tests. The main load measurements were bending moments at three stations along the port wing, obtained by means of electric resistance strain gauges; supplementary measurements of bending moment were made at four more stations for some of the flying in turbulence (stations shown in Fig.1). The c.g. acceleration was measured at the fuselage centre line near the main spar of the wing by means of a stepped-trace accelerometer.

The strain gauge signals were calibrated in terms of bending moment by applying known loads to the wings on the ground, and in terms of pull-out loads by subjecting the aircraft to pull-outs at unit incremental acceleration in flight. Results are given mainly in terms of the pull-out loads.

3 Results

Ground to air loads are given in Table I, and the numbers of load ranges occurring in various conditions of flight and on the ground in Tables II to V.

3.1 Loads in Typical Flight

In order to summarise the information, the numbers of load ranges exceeding various magnitudes are shown for the component conditions of a typical flight (Fig.2). The flight, which is intended to represent operational training**, consists of 4 minutes engine running, 5 minutes taxying, a take-off, 33 minutes flight and a landing. Details of the estimation of the loads for the various conditions are given in Appendix II. Fig.2 shows that the load cycles in take-off, landing, ground running of the engines and taxying are much less severe than those in turbulence. It should be noted, however, that the load cycles for the ground conditions occur about a mean load different from that in flight. The most severe ground loads are obtained in landing and occur in the

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* The terms "acceleration at the c.g." and "c.g. acceleration" are used for convenience throughout the note. It must be understood that the acceleration concerned is really the reading of an accelerometer mounted rigidly at the centre line of the aircraft structure so that any dynamic effects due to flexibilities of the structure are included.

** The Varsity is used mainly as a crew trainer.

run-out subsequent to the initial impact when the wing lift is considerably reduced (initial impacts were only moderately heavy, see Table VI).

Fig.3 shows the total load ranges for the typical flight plotted as a percentage of the estimated ultimate load. The load levels are greatest at the wing root and decrease towards the tip.

3.2 Relationship between Wing Loads and c.g. Accelerations

Fig.4 shows the relationship between wing load ranges and c.g. acceleration ranges exceeded the same number of times. The relationship refers to all samples of turbulence analysed (approximately 16 minutes for stations 3, 5 and 6, and 8 minutes for stations 4, 7 and 8) and includes recordings at airspeeds of 130 kt, 145 kt and 170 kt E.A.S. Relationships were also determined for these airspeeds separately, but are not included since no significant variation with speed could be observed.

Fig.4 shows that the relationship between wing loads and c.g. acceleration in turbulence is very similar to that in pull-outs, i.e. there is very nearly a 1 to 1 relationship between wing loads and c.g. accelerations when plotted as multiples of the 1g pull-out loads and acceleration respectively. Departures from this 1 to 1 relationship are very small: for example at the 10 ft/sec gust level (a 10 ft/sec gust is calculated to produce an acceleration of 0.302g at 145 kt E.A.S., 4,000 ft, 33,000 lb A.U.W.) the ratios of wing loads to c.g. accelerations are:-

Position	Ratio of wing load to c.g. acceleration (expressed as multiples of 1g pull-out load and 1g respectively)
Port side - outer wing - station 3	1.07 : 1
" " - mid span - " 4	0.95 : 1
" " - outb'd of engine" 5	0.975 : 1
" " - wing root - " 6	0.95 : 1
Centre line - " 7	1 : 1
Stb'd side- wing root - " 8	0.95 : 1

Examination of the records (see sample record of Fig.8) suggests that the ratio is slightly higher than 1:1 at the most outboard station because the bending moment there contains a vibratory component at about 7 c.p.s. - probably the first flexural overtone - which does not appear in the c.g. acceleration.

4 Conclusions

Information on the load cycles likely to produce fatigue damage in the main structure of a Varsity has been obtained in special flight tests. The results indicate that at all stations along the wing the load cycles in take-off, landing, ground running of the engines and taxying are likely to be much less numerous than the loads in turbulence. It should be noted, however, that the ground load cycles occur about a mean level different from that in flight.

The wing loads and c.g. accelerations exceeded the same number of times show very nearly a 1 to 1 relationship when expressed as multiples of the 1g pull-out loads and acceleration respectively. At the root the loads at the 10 ft/sec gust level are about 5% smaller than indicated by a 1 to 1 relationship, and at the most outboard station about 7% greater.

REFERENCES

No.	Author	Title, etc.
1	A. Burns	Fatigue loadings in flight - loads in the tailplane and fin of a Varsity ARC. 18,418 C.P. 256. January, 1956.
2	E. Wells	Fatigue loadings in flight - loads in the fuselage and nose undercarriage of a Varsity R.A.E. Technical Note Structures 193

APPENDIX I

Details of Flight Tests and Miscellaneous Results not in Main Text

Strain Gauge Installation and Calibration

British Thermostat strain gauges were attached to the wing main spar top and bottom booms at the stations shown in Fig.1, the bridges being arranged to measure bending moment. The signals from the bridges were recorded on a Films and Equipment 12 channel recorder, together with the signal from a type I.T.6-1 accelerometer installed in the fuselage near the c.g. The strain gauge signals were calibrated directly in terms of bending moment by loading the wings with shot bags. They were also calibrated in terms of pull-out loads by subjecting the aircraft to pull-outs at unit incremental accelerations.* The pull-outs were made at sensibly the same air speeds and all-up-weight as those in the turbulence but, since the calibrations did not vary significantly with air speed or all-up-weight, average values were used in the analysis (all-up-weight did not vary much during the tests).

Miscellaneous Results not included in Main Text

Comparison of Measured and Calculated Loads

The table below shows calculated and observed loads for various conditions. The observed 10 ft/sec gust loads are half the load range which occurs the same number of times as a gust range of 20 ft/sec.

Condition	Root B.M. Pos.6		B.M. outboard of engine Pos.5		Outer wing B.M. Pos.3	
	Calculated	Observed	Calculated	Observed	Calculated	Observed
	Tons ins	Tons ins	Tons ins	Tons ins	Tons ins	Tons ins
Ground to air load	853	982	707	653	82	51
1g pull-out load	816	855	565	529	78	55
10 ft/sec gust load	195	235	141	149	22	17

Agreement between calculated and observed loads is reasonably good at position 5, but observed values tend to be greater than calculated at position 6 and smaller at position 3. More refined calculations taking account of such items as aileron up-float, propeller lift, etc., might give even better agreement.

Relationship between wing loads and c.g. acceleration in conditions other than turbulence

Fig.5 shows the relationship between wing load ranges and c.g. acceleration ranges exceeded the same number of times in take-offs, landings and in the circuit. Air speeds in the circuit varied from 150 to 85 knots E.A.S. and flap settings from 15° to 47°; nevertheless, the relationship between wing loads and c.g. accelerations is almost identical with that for flight in turbulence at higher air speeds and without flaps. For take-off and landing the relationship is, however,

* The exact value of the acceleration was measured after the flight from the recorded acceleration; a visual-reading accelerometer was provided as a rough guide for the pilot during the pull-out.

significantly different from that in turbulence and in the circuit, the ratio of wing B.M. to c.g. acceleration in take-off and landing being approximately half that in turbulence (for take-off the reduction is slightly less than half probably because the take-off loads include some flight loads). A reduction of as much as three quarters might be expected due to the main undercarriage being further inboard than the C.P. of the gust loading (flexibility effects neglected). Much of the wing loading on the ground is, however, due to flexibility effects as shown by the magnitude of the loads outboard of the undercarriages.

Accelerations and wing loads in landing impacts

The landings were not intentionally heavy and, although some were made by test pilots unused to flying the Varsity, only moderately heavy landings were achieved. Maximum accelerations and wing loads for a few of the initial impacts are given in Table VI.

APPENDIX II

Estimation of load occurrences in typical flight

The numbers of occurrences of wing loads shown in Fig.2 for the landing and take-off are average values of the test results. The numbers of take-offs and landings analysed and the 5% confidence limits for the wing root bending moment are as follows:-

Case	No. of landings or take-offs analysed	No. of occurrences of load range 138 tons in*	
		Mean	5% confidence limits
Take-off	8	6.3	6.3 ± 3.2
Landing	8	12.1	12.1 ± 4.8

* Load range corresponding approximately to a gust range of 5 ft/sec

The estimation of loads for ground running of the engines was made in a similar manner to that already described for tail loads, and is not repeated here since the wing loads proved to be very small.

The taxying loads were estimated by scaling up the number of occurrences in the samples analysed which covered a period of 2 minutes to give the number of occurrences appropriate to 5 minutes. It should be noted that the term 'taxying loads' used in this note does not include the loads in the take-off and landing runs, sometimes classified as taxying loads.

For estimating the loads in turbulence the aircraft was assumed to spend 10 minutes at 130 knots E.A.S., 1,000 ft (an average for the climb and descent) and 23 minutes at 145 knots E.A.S., 2,000 ft.** It was estimated from operational data obtained from a number of different types of aircraft that the average miles travelled to meet a gust of velocity 10 ft/sec or greater (up or down) was 3.2 at 1,000 ft and 7.4 at 2,000 ft. Hence the Varsity in its typical flight would meet 7.9 and 8.9 gusts of 10 ft/sec at 1,000 ft and 2,000 ft respectively, i.e. flying at an all-up-weight of 34,500 lb it would exceed accelerations of 0.26g and 0.29g (above or below 1g) 7.9 and 8.9 times respectively. Using the relative frequency of gusts of different magnitudes obtained operationally to adjust the number of occurrences to a common acceleration level, it is found that an acceleration of 0.3g is exceeded a total of 11.4 times, i.e. an acceleration range of 0.6g is exceeded 5.7 times on the assumption that the numbers of positive and negative gusts are equal.

The estimation of numbers of load ranges by the addition of positive and negative thresholds crossed as carried out above gives a higher answer than that obtained by a direct count of the ranges by the method used for the main analysis of the present note and described earlier[1]. Fig.6 compares the acceleration ranges obtained by the two methods for samples making up 30 minutes of flight in turbulence. A similar result is obtained if wing loads are analysed in the same manner

** Based on average figures for R.A.F. Training Station, Swinderby.

(Fig.7, 6 minutes only). Thus 5.7 acceleration ranges obtained from the sums of positive and negative thresholds crossed are equivalent to only 4.9 load ranges obtained by a direct count. Since it is required to compare load ranges in turbulence with load ranges in take-off and landing obtained by a direct count the figure of 4.9 is used.

The numbers of occurrences of accelerations at other levels were obtained from the relative frequency of gusts of different magnitudes determined in the tests. This relative frequency was compatible with that obtained operationally for other aircraft.

The numbers of occurrences of wing loads in the typical flight were then determined from the numbers of occurrences of accelerations using the relationship of Fig.4.

TABLE I

Ground to air wing loads

A.U.W. 34,600 lb

c.g. 30.45 ft aft of datum

Condition	Port Wing Bending Moment		
	Root (Pos.6)	Outb'd of engine (Pos.5)	Outer wing (Pos.3)
Ground to air - 145 kts, 2,000 ft above ground level, flaps and undercarriage up	982 tons ins	653 tons ins	51 tons ins

TABLE II Bending Moment Cycles at Wing Root (Pos.G)

Load Range		Number of Times Load Range is Exceeded																											
tons ins.	± 1g pull-out B.M.	Landing								Take-off								Turbulence						Circuit				Taxying	Engine Ground Running
		No.1	2	3	4	5	6	7	8	No.1	2	3	4	5	6	7	8	130	145	145	145	170	170 kts	No.1	2	3	4	2 mins	
69.2	0.081	39	49	37	30	43	36	32	24.3	35	25.1	16.2	28	22.6	24.3	37	28.5	71	109	161	85	190	153	167	100	115	124	19	
104	0.122	30	28	22	21.5	27.1	15.9	13.8	13.7	21	9.6	8.5	11.8	11.8	16.7	20	11.7	45	68	103	58	138	108	109	63	67	77	4.9	
138	0.162	19.8	18	13	11.7	16.2	6.2	5.2	7.0	12.9	3.3	4.6	4.5	3.4	10.8	6.4	4.5	30	44	70	41	96	77	68	41	40	52	2.0	
173	0.203	11.5	10.8	6.6	6.5	8.2	1.7	0.8	3.8	7.9	1.8	1.8	1.8	1.0	6.8	2.5	1.7	21	29	54	30	71	59	46	29	24	34	1.4	LOADS
208	0.243	7.2	5.9	3.8	3.2	3.6	1.0		0.8	4.7	1.0				3.0	1.0		15	21	42	21	52	45	36	20	13.3	22.5	1.0	
242	0.284	4.6	3.4	1.2	1.4	1.4	1.0			3.4								8.2	14.3	31	16.2	41	32	29	14.8	8.7	16.0		NEGLIGIBLE
277	0.324	1.7	2.4		1.0	1.0	1.0			2.4								5.5	10.2	23.8	12.9	33	23.7	23.5	10.0	7.0	9.5		
311	0.364	1.0	2.0															4.4	8.0	18.6	10.9	26.3	17.5	18.7	5.7	5.9	5.0		
346	0.405																	2.7	6.3	15.5	10.0	22.9	12.2	13.5	4.0	4.4	2.7		
381	0.446																	1.4	5.0	13.4	8.8	18.6	8.6	10.5	2.0	2.5	1.4		
415	0.486																		4.5	10.2	7.0	14.3	6.0	9.5	1.0	2.0	1.0		
450	0.526																		3.4	5.7	4.6	10.0	4.8	6.6	1.0	2.0	1.0		
484	0.567																		1.7	4.0	2.4	7.5	2.8	3.9	1.0	2.0			
519	0.608																		1.0	3.4	2.0	6.5	1.4	3.0		2.0			
554	0.648																		1.0	2.0	1.4	4.7	1.0	2.4		2.0			
588	0.689																		1.0	1.4	1.0	4.0		2.0		1.4			
623	0.729																		1.0	1.0	1.0	3.0		1.4					
657	0.770																		1.0	1.0	1.0	2.4		1.0					
692	0.810																			1.0		2.0		1.0					
727	0.851																					1.4		1.0					
761	0.891																					1.0							
796	0.932																					1.0							
830	0.972																					1.0							

TABLE III - Bending Moment Cycles in Wing Outboard of Engine (Pos.5)

Load Range		Number of Times Load Range is Exceeded																										
		Landing								Take-off								Turbulence						Circuit			Taxying	Engine Ground Running
tons ins	÷1g pull-out B.M.	No.1	2	3	4	5	6	7	8	No.1	2	3	4	5	6	7	8	130	145	145	145	170	170 kts	No.2	3	4	2 mins	
43.3	0.082	48	59	46	44	56	45	43	32	39	29.5	21.2	41	41	33	37	28.1	60	94	131	68	157	141	89	91	100	71	
65.0	0.123	35	44	34	27	44	30	34	18.9	24	15.1	11.3	21.5	16.2	17.5	24.5	11.9	41	61	86	45	117	97	57	52	61	20	LOADS
86.6	0.164	22	30	21.5	15.8	32	19.5	18.8	11.3	7.9	6.7	5.2	11 5	7.6	12.3	15 5	5.4	28	39	63	35	92	72	40	33	41	5.3	
108	0.205	14.7	15.1	11.5	9.5	21.3	10.6	6.3	6.2	4.2	3.4	2.0	5.4	5.0	9.3	6.4	1.0	20.1	27	^9	25.7	66	57	29	21.2	31	1.8	
130	0.246	9.2	7.0	4.8	4.4	12.5	3.8	2.2	2.6	2.5	1.7		1.7	2.4	7.5	0.7		14.5	21	37	19.8	51	40	19.8	13.3	21.5	0.8	NEGLIGIBLE
151	0.287	6.5	3.4	1.4	1.4	5.8	1.4			0.8				2.0	5.8			8.5	16.4	26	17.4	39	29	13.4	9.3	9.5		
173	0.328	4.7	0.8	1.0	1.0	2.2								0.8	2.6			5.9	12.7	19.8	13.3	32	21.9	9.2	6.8	5.5		
195	0.369	2.2													1.0			4.4	9.3	16.9	10.5	23.5	16.0	6.2	4.8	2.8		
216	0.410	1.0													1.0			2.0	7.0	14.3	8.8	18.5	11.7	3.7	3.4	1.4		
238	0.451	1.0																1.0	4.0	11.3	6.9	15.2	8.1	2.4	1.4	1.0		
260	0.492																		3.0	8.2	6.0	11.1	5.4	1.4	1.0			
281	0.533																		3.0	5.0	4.8	8.4	3.2	1.0				
303	0.574																		2.4	4.0	3.4	6.9	2.0	1.0				
325	0.615																		2.0	3.5	1.8	6.0	1.4					
346	0.656																		2.0	2.4	1.0	4.0						
368	0.697																		1.4	2.0	1.0	2.4						
390	0.738																		1.0	1.4	1.0	2.0						
411	0.779																		1.0	1.0	1.0	2.0						
433	0.820																					2.0						
455	0.861																					1.4						
476	0.902																					1.0						
498	0.943																					1.0						

TABLE IV - Bending Moment Cycles in Outer Wing (Pos.3)

Load Range		Number of Times Load Range is Exceeded																										
tons ins	÷ 1g pull-out B.M.	Landing								Take-off								Turbulence						Circuit			Taxying	Engine Ground Running
		No.1	2	3	4	5	6	7	8	No.1	2	3	4	5	6	7	8	130	145	145	145	170	170 kts	No.2	3	4	2 mins	
4.29	0.078	103	161	114	70	107	112	91	70	82	68	80	106	102	90	59	101	97	147	226	122	257	231	116	153	168	223	
6.44	0.118	75	118	87	40	73	63	54	33	56	39	42	69	56	44	39	53	65	92	139	78	192	147	74	85	99	84	
8.6	0.157	48	73	55	24.5	51	35	33	14.3	31	22	20	36	23.4	18.6	20	15.4	44	59	91	59	135	104	46	54	59	24	
10.7	0.196	29.5	40	34	11.9	32	15.8	18.5	5.8	17.7	7.2	10.5	18.9	10	8.0	7.3	6.5	30	39	67	3.6	100	76	28	37	39	6.6	
12.9	0.235	20	20.2	20.9	6.2	18.7	5.1	9.5	1.7	11	3.7	5.0	10.5	5.2	3.0	2.3	3.4	21	30	54	3.0	77	58	19.5	23.5	26.5	2.2	LOADS
15.0	0.274	14.2	10.5	11	3.7	12.1	2.4	6.5	1.0	7.2	1.7	1.7	5.3	2.7	1.2		0.7	14.3	21.4	41	24.6	59	42	14.2	17.0	17.8		
17.2	0.314	7.5	6.2	6.2	1.7	5.0	2.0	5.4		4.0	1.0	1.0	2.7	1.4				9.7	16.5	30	20.3	46	30	9.4	13.3	13.3		NEGLIGIBLE
19.3	0.353	4.4	2.2	4.4		2.4	1.4	3.7		1.8	1.0		2.0					7.5	13.9	23.8	16.3	38	24.2	8.9	8.0	8.5		
21.4	0.392	2.8		3.4		1.4		3.0		1.0	1.0		2.0					5.8	11.4	19.2	12.1	31	19.8	5.4	6.0	5.2		
23.6	0.431	0.8		2.4		1.0		2.4		1.0	1.0		1.4					3.7	9.4	15.3	8.8	22.5	15.0	2.3	4.8	4.0		
25.7	0.470			1.4		1.0		1.4		1.0								1.4	6.6	13.5	6.2	18.5	10.7	1.0	3.4	2.2		
27.9	0.510					1.0		1.0		1.0								1.0	5.0	11.9	5.0	16.3	7.8		2.0			
30.0	0.549					1.0												1.0	4.4	7.0	4.4	12.1	5.1		1.4			
32.2	0.588					1.0													2.8	4.5	3.4	9.5	4.0					
34.3	0.627					1.0													2.0	4.0	1.8	7.9	2.8					
36.5	0.666																		2.0	3.4	1.0	6.4	1.4					
38.6	0.706																		1.4	2.4	1.0	5.5	1.0					
40.7	0.745																		1.0	2.0	1.0	4.4	1.0					
42.9	0.784																			1.4	1.0	3.4	1.0					
45.0	0.823																					2.4						
47.2	0.862																					2.0						
49.3	0.902																											

TABLE V - Acceleration Cycles at Aircraft C.G.

Acceleration Range	Number of Times Acceleration Range is Exceeded																		
	Landing				Take-off			Turbulence							Circuit				
g	No.5	6	7		No.5	6		130	145	145	145	170	170 kts		No.1	2	3	4
0.2	65	48	51		19.4	17.5		23	20	49	30	65	65		47	29	17.4	43
0.3	37	22.5	32		10.1	4.9		9.1	14.5	28.3	15.5	39	32		29	14.6	11.8	12.6
0.4	20.8	10.5	15		5.9	1.4		3.6	7.0	16.2	8.4	23.7	16.2		17.9	7.2	7.2	3.8
0.5	9.1	4.4	4.3		3.8				4.4	7.0	5.2	11.7	6.8		9.7	2.0	2.4	1.4
0.6	4.0	0.8	1.5		1.7				2.8	3.0	3.4	5.2	3.0		5.0	1.0		
0.7	2.4				1.0				0.8	1.4	1.2	2.7	1.4		2.7			
0.8	2.0											2.0			1.4			
0.9	1.4											1.4						

TABLE VI - Accelerations and wing bending moments in landing impacts

Maximum c.g. accelerations and wing root B.M!s in initial impact

Landing No.	Max. c.g. acceleration	Max. wing root B.M. ÷ 1g pull-out B.M. Wing root	Outb'd of engine	Outer wing
	g			
9	0.68	0.13	0.17	0.44
10	0.55	0.07	0.06	0.46
3	0.49	0.22	0.17	0.56
5	0.33	0.11	0.19	0.18
7	0.33	0.06	0.06	0.20
6	0.33	0.33	0.11	0.18
11	0.32	0.03	0.04	0.12
12	0.19	0.09	0.09	0.20

Maximum c.g. acceleration cycles and wing B.M. cycles in initial impact

Landing No.	Max. c.g. acceleration range	Max. wing B.M. range ÷ 1g pull-out B.M. Wing root	Outb'd of engine	Outer wing
	g			
9	0.81	0.30	0.31	0.70
10	1.17	0.34	0.27	0.86
3	0.81	0.38	0.33	1.02
5	0.76	0.52	0.58	0.74
7	0.60	0.26	0.29	0.60
6	0.46	0.33	0.32	0.54
11	0.36	0.14	0.23	0.32
12	0.46	0.14	0.15	0.33

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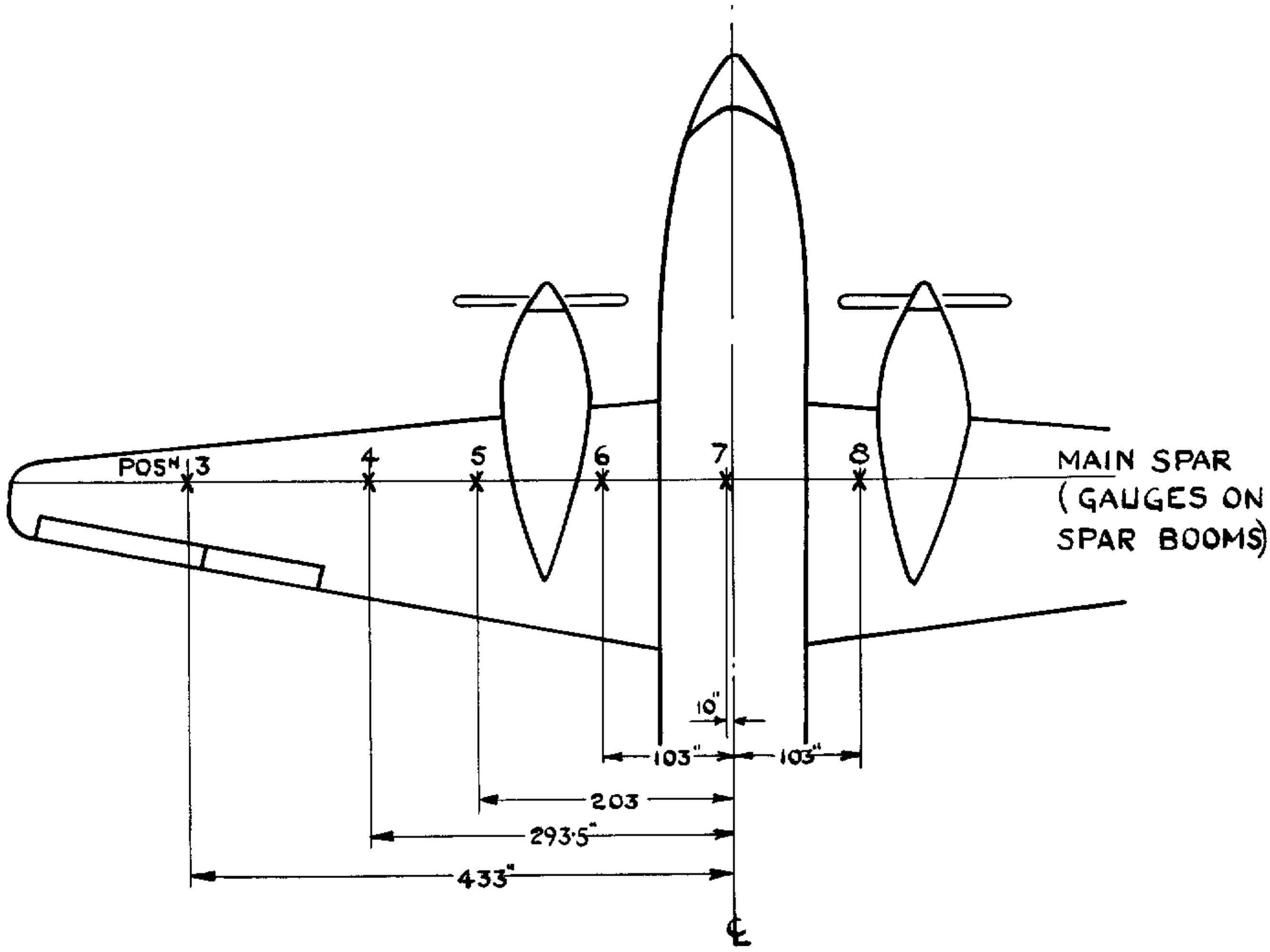


FIG. I. STRAIN GAUGE POSITIONS IN WING.

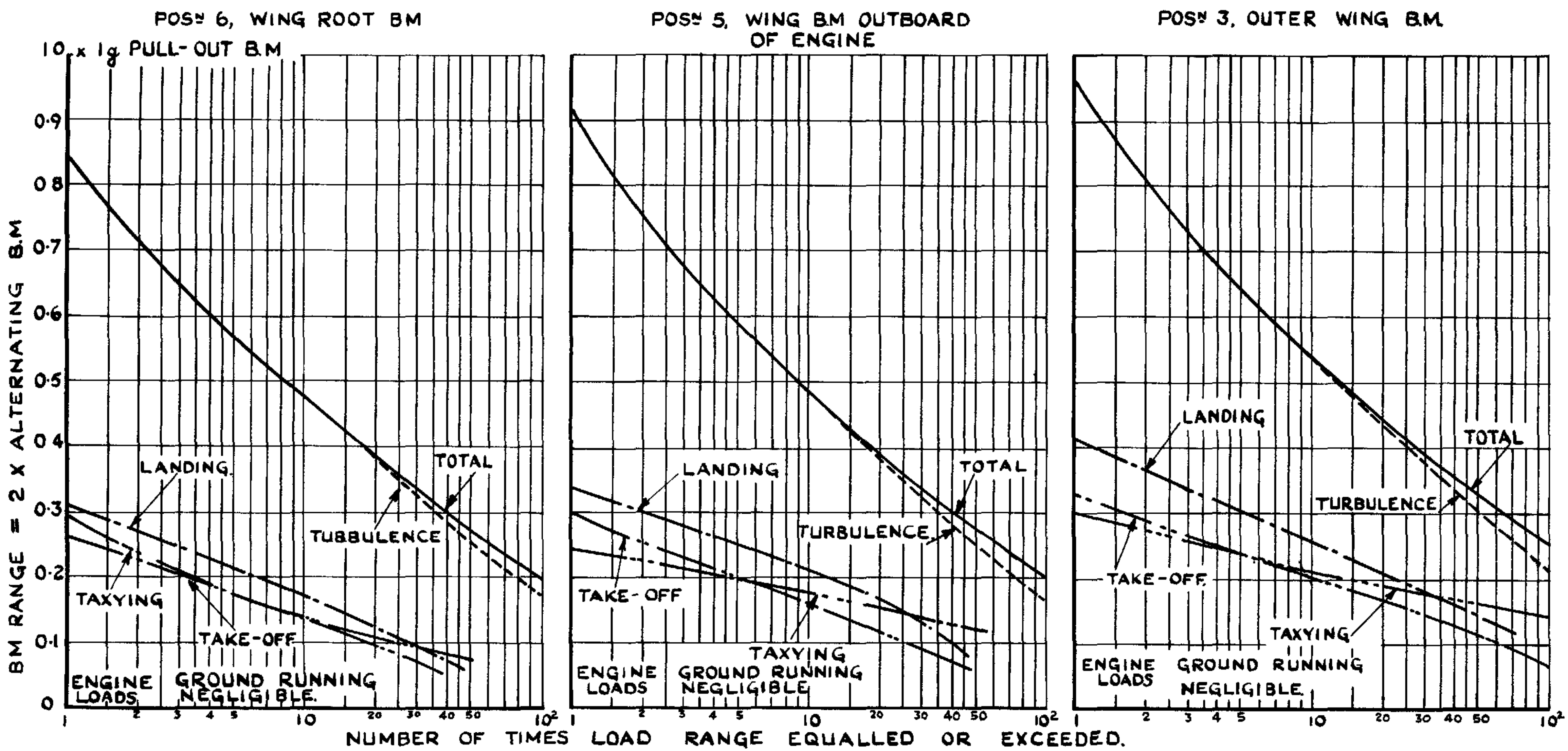
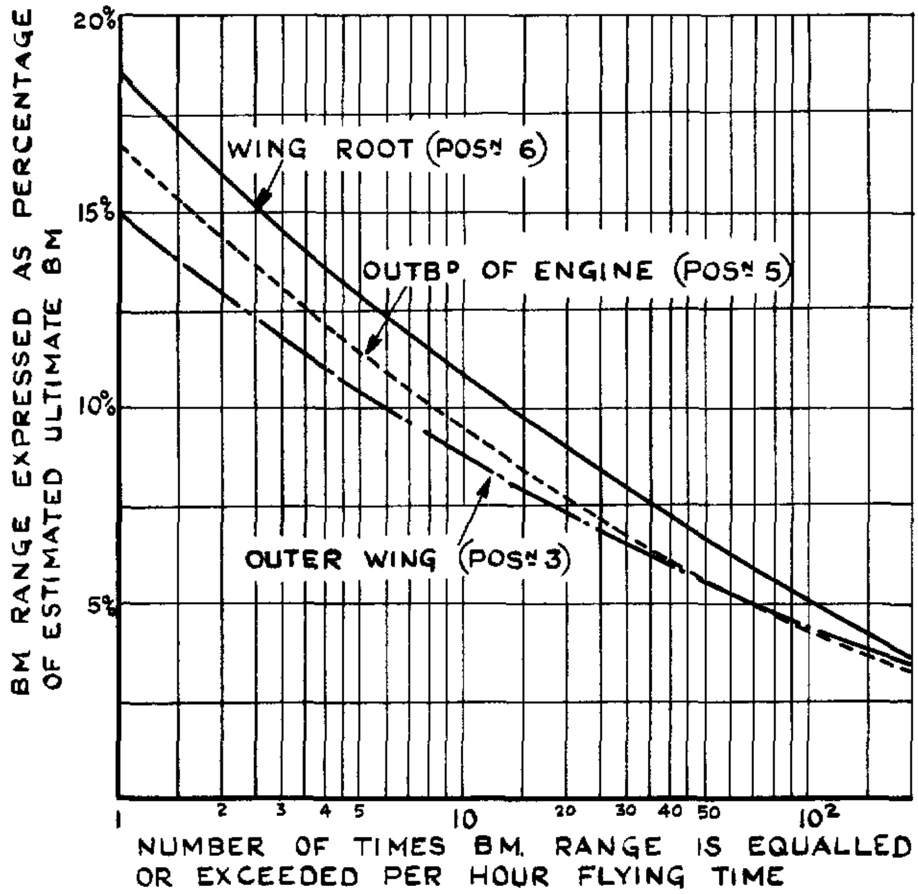


FIG. 2. WING LOADS IN COMPONENT CONDITIONS OF TYPICAL FLIGHT INCLUDING ASSOCIATED GROUND CONDITIONS (FLYING TIME = 33 MINUTES).



NOTE:- THE ULTIMATE B.M. IS ESTIMATED FOR EACH SECTION STRAIN GAUGED ON THE ASSUMPTION THAT THE MAXIMUM BOOM FIBRE STRESS EQUALS THE ALLOWABLE COMPRESSIVE STRESS.

FIG. 3. RATE OF OCCURRENCE OF WING LOAD RANGES.
(TOTAL LOAD RANGES FOR TYPICAL FLIGHT SCALED UP FROM 33 MIN. TO 1 HOUR)

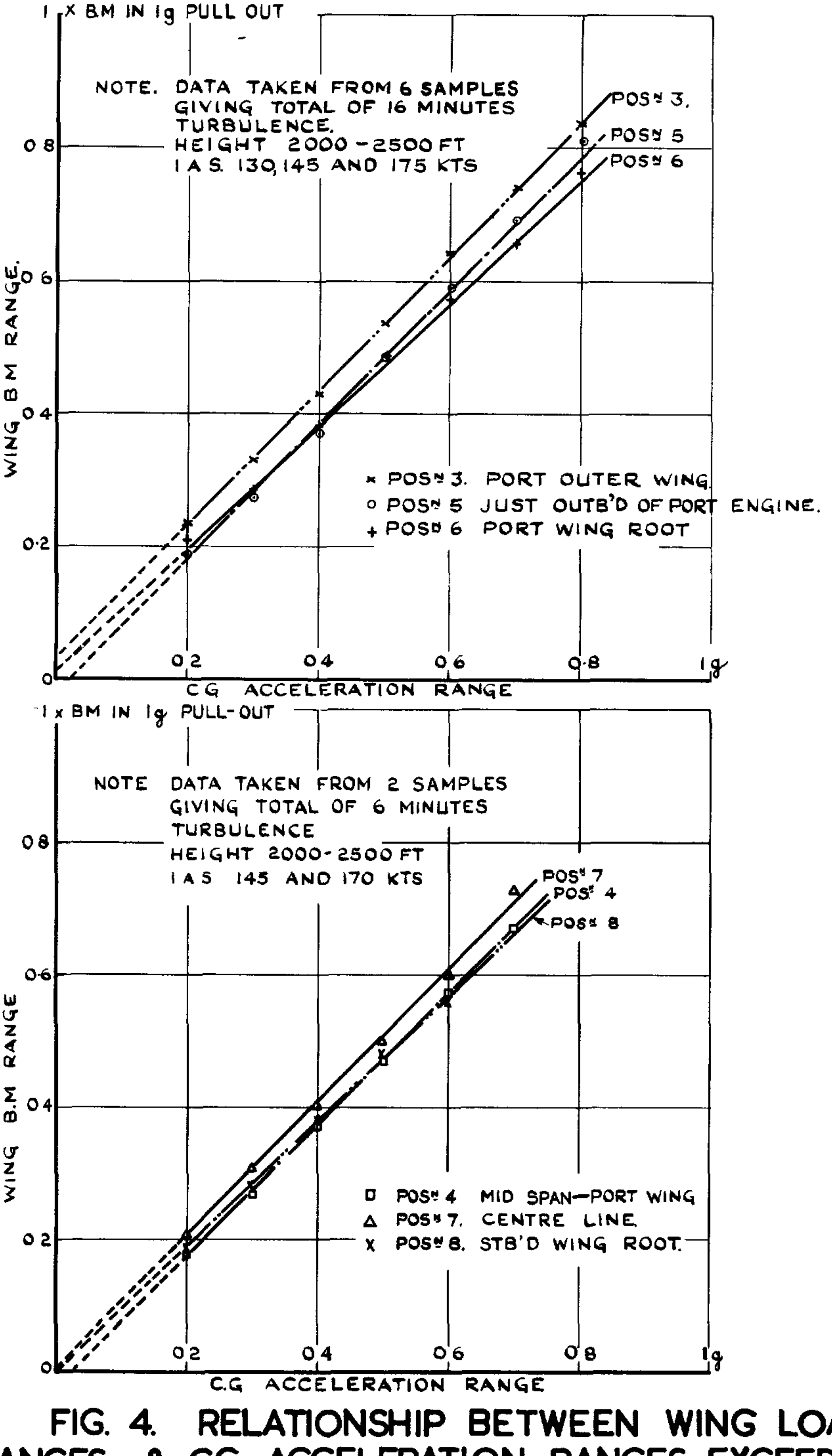
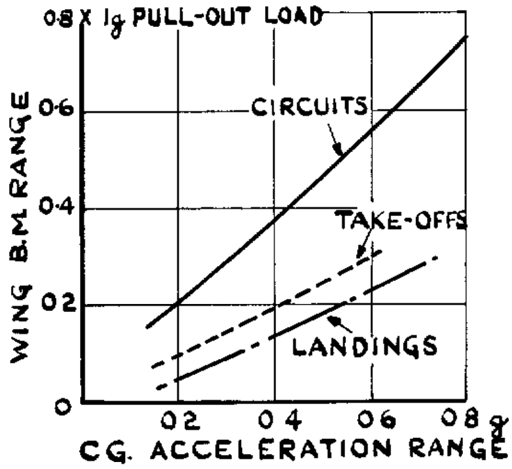
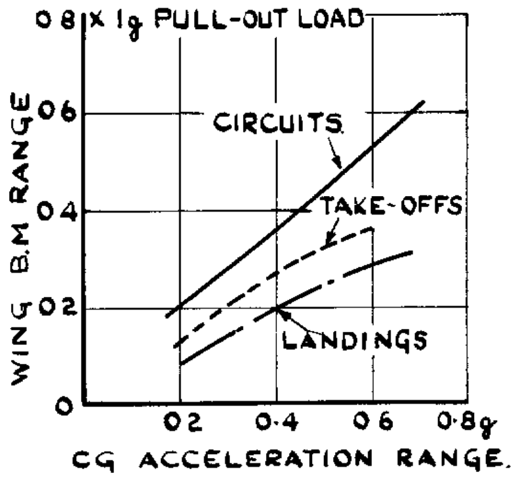


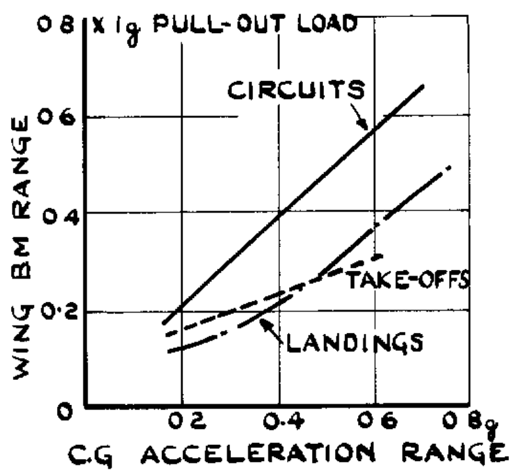
FIG. 4. RELATIONSHIP BETWEEN WING LOAD RANGES & C.G. ACCELERATION RANGES EXCEEDED THE SAME NUMBER OF TIMES IN TURBULENCE.



WING ROOT B.M.
POSN 6



WING BM OUTBOARD
OF ENGINE POSN 5



OUTER WING BM
POSN 3.

FIG. 5. RELATIONSHIP BETWEEN WING LOAD RANGES AND C.G. ACCELERATION RANGES EXCEEDED THE SAME NUMBER OF TIMES IN VARIOUS CONDITIONS.

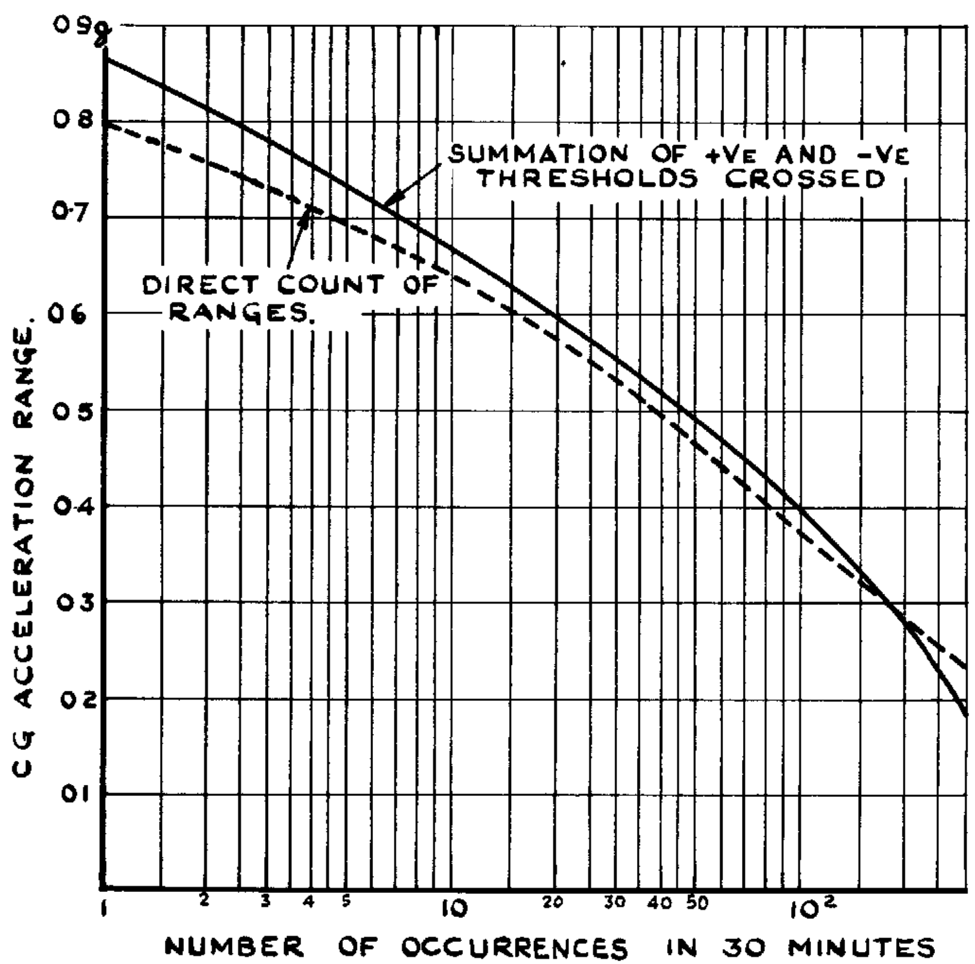


FIG. 6. COMPARISON OF ACCELERATION CYCLES OBTAINED BY DIFFERENT METHODS.

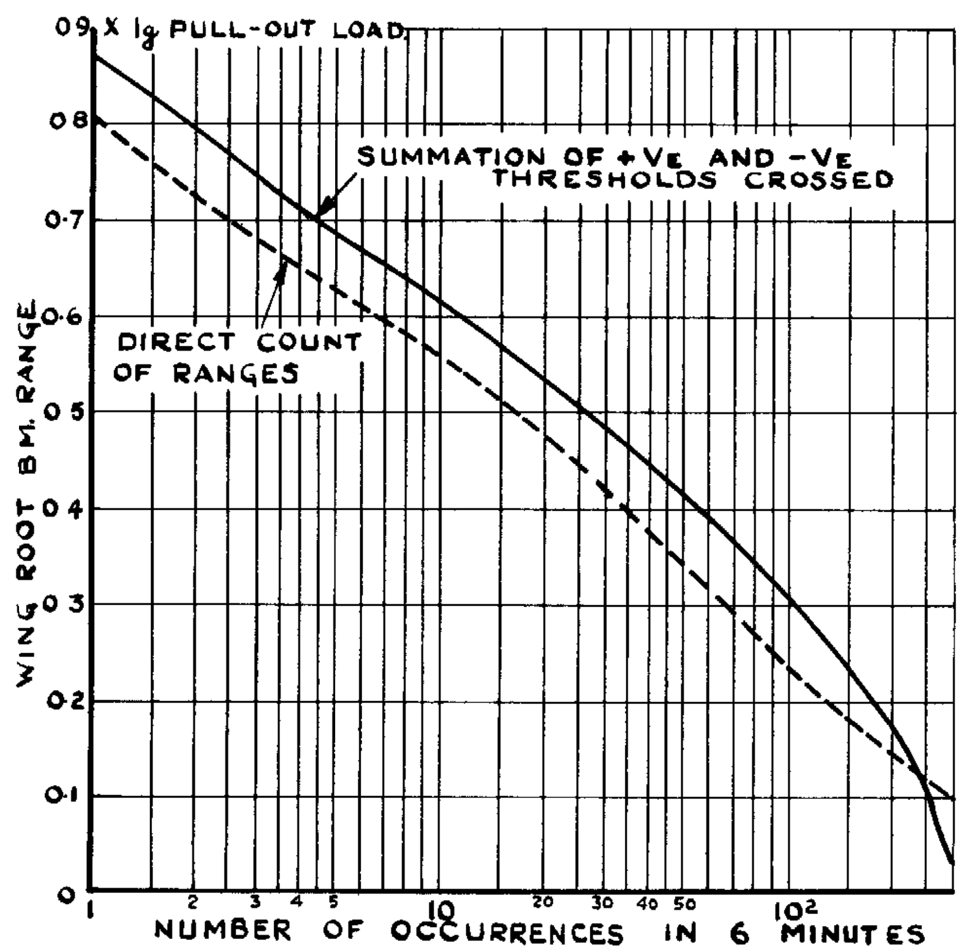
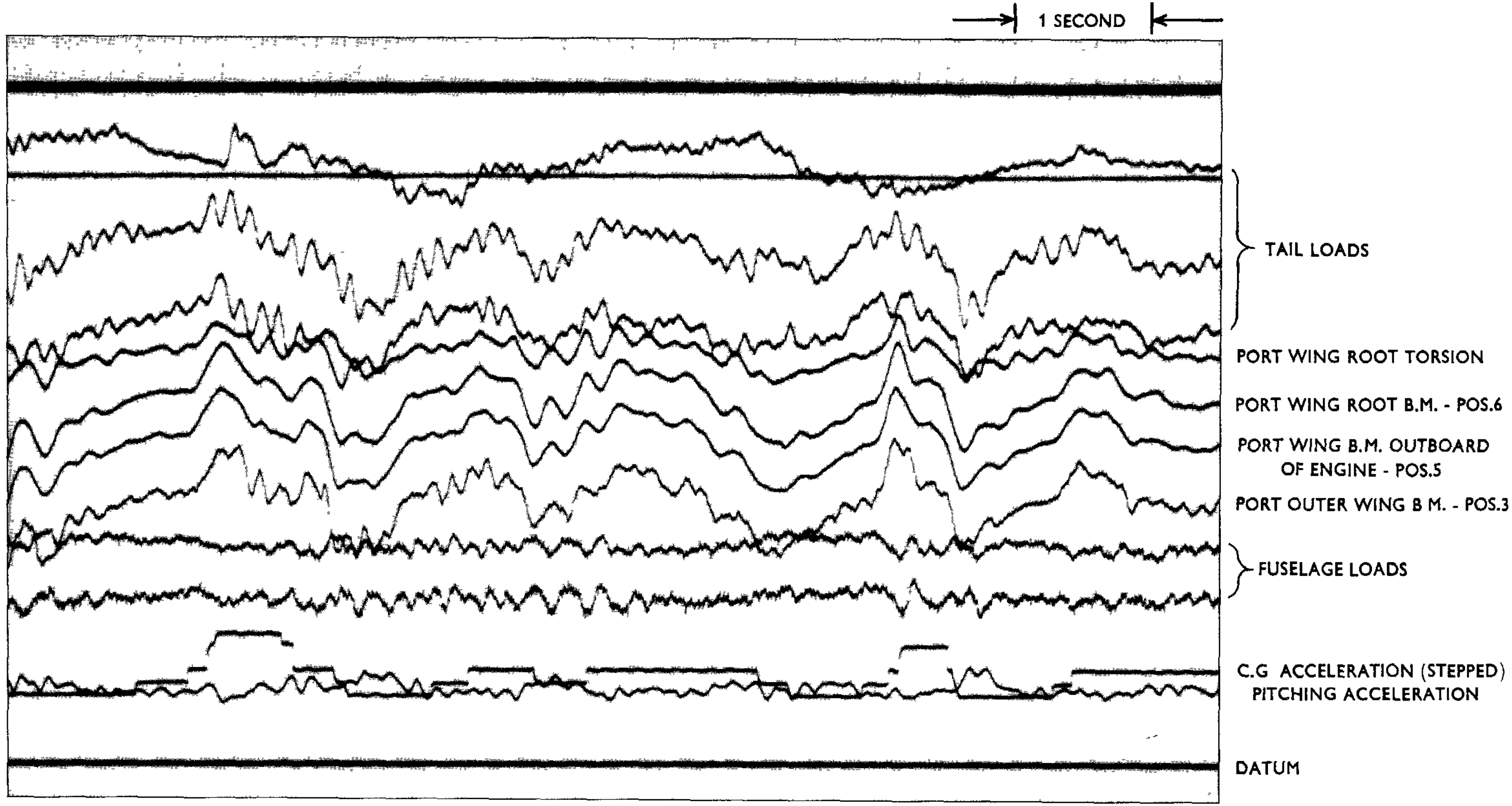


FIG. 7. COMPARISON OF WING LOAD CYCLES OBTAINED BY DIFFERENT METHODS.



CONDITIONS - 170 knots E.A.S. 4,000 ft. A U.W. 34,500 lb

FIG.8. TYPICAL RECORD OF LOADS IN TURBULENCE

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