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Fatigue Loadings in Flight-Loads in the Tailplane of a Comet I

By

Anne Burns, B.A.

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ROYAL AIRCRAFT ESTABLISHMENT

Fatigue loadings in flight - loads in the tailplane of a Comet I

by

Anne Burns, B.A.

SUMMARY

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

LIST OF CONTENTS

LIST OF APPENDICES

LIST OF TABLES

LIST OF ILLUSTRATIONS

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1 Introduction

In June, July and August, 1954, flight tests were made on a Comet IA 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 number of occurrences the spectrum of ground and flight loads in the tailplanes of different aircraft[1,2]. An analysis of the power spectrum of the tail loads is given in a separate report by Jones[3].

2 Description of flight tests

A brief account of the instrumentation and flight tests is given in Appendix I. The main load measurements were bending moments about the tailplane roots; shear loads at the roots were also measured as a check on spanwise load distribution but the results were only analysed for a few cases. Measurements were obtained by means of electric resistance strain gauges and continuous recording equipment. The signals from strain gauge bridges on the front and rear spars were combined electrically in certain proportions to give signals virtually independent of the chordwise position of the centre of pressure. Loads were recorded during flight in turbulence, taxying, take-off, landing, and ground running of the engines. The loads in turbulence were measured in the height band 3,000 to 7,000 ft at two c.g. positions, and at four airspeeds at the lowest of which one-third flap was used. When flying in turbulence, acceleration at the aircraft c.g. was also recorded so that the relationship of the tail loads to the c.g. accelerations, and hence to the gust velocities, could be ascertained. The term "c.g. acceleration" is used for convenience throughout the note but 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.

3 Presentation of Results

Information on the loads and accelerations measured is tabulated in terms of numbers of load and acceleration ranges exceeding various magnitudes (Tables I to III). The method of counting the ranges is described in an earlier note[1]. The term range is defined in the normal manner and is twice the alternating load or acceleration. Changes of load on lowering the flaps and opening the dive brakes are given in Table IV.

In order to summarize the information the numbers of load ranges exceeding various magnitudes are shown for the component conditions of a typical flight (Fig.3). This flight is based on airline usage and consists of 42 seconds of engine running at full power, 10 minutes taxying, a take-off, $2\frac{3}{4}$ hours flight - 70 minutes of which is spent at 35,000 to 40,000 ft, and a landing. Details of the estimation of the loads for the component conditions are given in Appendix II.

The graphs of Fig.5 have been prepared so that the tailplane loads in turbulence can, if required be related to operational data on gust frequencies. The curves show the relationship between tail load and gust velocity ranges that are exceeded the same number of times at various airspeeds and c.g. positions. The loads have been divided by the appropriate airspeed in an attempt to eliminate, as a first approximation, the effect of that quantity. The gust velocities are derived from the measured c.g. accelerations using **standard alleviation factors.**

4 Discussion of Results

(i) Tailplane loads in typical flight

Fig.3 shows the tailplane root bending moment cycles in the component conditions of the typical flight. The occurrences shown are mean values for the port and starboard sides (considered separately, results for the two sides differ little). It is apparent that, for ranges greater than 1×10^5 lb ins, turbulence and landing are the major sources of fatigue loads. Load occurrences in these two conditions are almost equal in number, a bending moment range of 1.64×10^5 lb ins (the calculated bending moment range for a gust velocity range of 20 ft/sec at 220 kts E.A.S.) occurring 8 and 6.8 times respectively in turbulence and landing. For ranges of less than 1×10^5 lb ins taxying and engine running are the major sources of fatigue loads but the fatigue damage at these low load levels is unlikely to be significant. Take-off loads are comparatively unimportant at all levels.

When the tailplane root bending moment ranges are plotted as a percentage of the corresponding ultimate bending moment* the load levels are found to be satisfactorily low (see Fig.4).

(ii) Relationship between tailplane loads and gust velocities

Fig.5 shows the relationship between tailplane load ranges and gust velocity ranges exceeded the same number of times. Except at the lowest speed of 130 kts when one-third flap is used, there tends to be a linear relationship independent of airspeed between tailplane loads (divided by E.A.S.) and gust velocities. This relationship is, however, not independent of c.g. position, the tailplane load for a given gust being about 15% smaller at the c.g. forward position (0.9 ft forward of datum) than at the c.g. aft position (0.746 ft aft of datum). From theoretical considerations4 the increased longitudinal stability at the c.g. forward position might be expected to result in smaller tail loads as was found to be the case in practice.

When flying at 130 kts and one-third flap, the tailplane load (divided by E.A.S.) for a given gust is greater than in the general case perhaps due to tailplane buffeting associated with the use of flaps.

(iii) Spanwise distribution of tailplane load

The ratio of root bending moment to root shear load during flight in turbulence and during landing was some 20%** greater than that calculated, indicating a greater concentration of load outboard in practice than in theory. The concentration of load outboard is probably due to inertia loads arising from oscillations excited by gusts and ground buffeting. These oscillations were neglected in the theoretical estimate of load distribution whereas in practice they have a marked effect on the loading (see typical record of Fig.6).

5 Conclusions

Information on load cycles likely to produce fatigue damage in the tailplane of a Comet IA during operational flying has been obtained in special flight tests. The results show that the ground loads are as important as the loads in turbulence. Most of the ground loads occur during landing but taxying and ground engine running produce more small loads than other ground conditions; the fatigue damage due to these small loads, however, is unlikely to be significant. The loads in take-off are comparatively unimportant at all load levels.

A simple linear relationship is found to exist between tailplane load ranges (divided by E.A.S.) and vertical gust velocity ranges exceeded the

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* The ultimate bending moment is taken to be the root B.M. in the static test at the instant of failure namely 12×10^5 lb ins. Since failure occurred some $3\frac{1}{2}$ ft outboard of the root the true ultimate failing B.M. at the root is really greater than 12×10^5 lb ins.

** Inaccuracies in the measurement of shear loads do not allow precise statements same number of times in turbulence. This relationship is independent of airspeed but varies with c.g. position, a forward movement in c.g. position of 1.65 ft producing a reduction in tail load of about 15%. This reduction in tail load is probably due to the increased longitudinal stability at the forward c.g. position. An exception to the general linear relationship occurs at 130 kts, one-third flap, when the tail load (divided by E.A.S.) for a given gust is greater than in the general case, probably due to tailplane buffeting arising from the use of flaps.

REFERENCES

No.	Author	Title, etc.
1	A. Burns	Fatigue loadings in flight - loads in the tailplane and fin of a Varsity. C.P.No.256. June 1956
2	A. Burns	Fatigue loadings in flight - loads in the tailplane and fin of a Valiant. R.A.E.Technical Note Structures 218 Feb. 1957
3	D.T. Jones	Power spectrum analysis of gust loads on the Comet wing and tailplane. R.A.E.Report Structures 211 July 1956
4	D. Williams and J. Hanson	Gust loads on tails and wings R & M No.1823. May 1937
5	T.H. Skopinski, W.S. Aiken and W.B. Huston	Calibration of strain gauge installations in aircraft structures for the measurement of flight loads. NACA Technical Note No.2993

APPENDIX I

Flight tests

Instrumentation

British Thermostat strain gauges were attached and waterproofed with Araldite special strain gauge cement at the stations shown in Fig.2. The signals from the gauges were fed into McMichael carrier wave amplifiers and thence to a junction box where signals from front and rear spars were combined in such proportions that the final signals were virtually independent of the chordwise c.g. position. The combined signals were then recorded on a Films and Equipment 12 channel recorder.

The stepped trace from a Type I.T.6-1 accelerometer mounted on the fuselage floor near the aircraft c.g. was recorded on a Hussenot recorder; arrangements were made to synchronise the two recorders.

Calibration

The strain gauge signals were calibrated directly in terms of load during ground calibration tests in which vertical loads were applied to the tailplane through three wooden frames contoured to the tailplane section. By means of these frames concentrated loads could be applied at various chordwise and spanwise positions on the tailplane. The signals from the front and rear spars were first recorded separately and the best multipliers for combining them then determined on the lines of the procedure developed by Skopinski, Aiken and Huston[6].

Test flying

The aircraft was flown throughout the tests at all-up-weights varying between 60,000 lb and 102,000 lb. Turbulence was recorded at weights of 68,000 lb to 81,900 lb, landing at weights of 60,000 lb to 79,000 lb, and take-offs at weights of 72,000 lb to 81,000 lb. During each flight the c.g. was maintained sensibly constant at one of two positions, either 0.746 ft or 0.9 ft forward of the datum (c.g. limits 0.815 ft aft to 0.858 ft forward of datum)*. There was some indication that the tailplane loads were more severe for landings made at the heavier weights. No significant difference in landing loads was observed for the two c.g. positions. One flapless and one heavily braked landing were included in the analysis but the results for these landings did not differ significantly from the results for normal landings (there was considerable scatter in the results for normal landings). Landings and take-offs were made at Farnborough and at Hatfield where the runway was considered to be particularly rough; no significant difference could be observed, however, in the results obtained. For purposes of analysis a landing was defined as a period of 35 seconds starting from the instant of touchdown, and a take-off as a period of 30 seconds ending 10 seconds after the aircraft became airborne.

Turbulence was recorded flying straight and level at altitudes between 5,700 and 7,400 ft above m.s.l. except for one sample at 180 kts, c.g. aft, when the height was 3,400 ft. All the turbulence was found in or below small cumulus cloud. Results given in this note refer to turbulence recorded when the aircraft was being flown by the pilot and not on autopilot. Analysis of records (not included in this note) taken with and without the autopilot, in conditions as nearly identical as possible, showed no significant difference in the relationship between tailplane loads and gust velocities.

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* The forward c.g. position was some 4 in. outside the normal c.g. limits.

APPENDIX II

Estimation of load occurrences in typical flight

Take-off and landing

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. Ten landings were averaged and three take-offs. It was not considered worthwhile to analyse more take-offs since those already analysed indicated the loads to be comparatively unimportant. The 95% confidence intervals for the number of occurrences of load cycles of 1.75×10^5 lb ins range, corresponding approximately to a gust cycle of 20 ft/sec range at 220 kts, are given below:-

Condition	Load	No. of take-offs or landing analysed	Number of load occurrences	
			Average	95% confidence interval
Landing	Port root B.M.	10	5.7	5.7 ±3.9
	Stbd. root B.M.	10	5.2	5.2 ±3.5
Take-off	Port root B.M.	3	1.3	)Too few results
	Stbd. root B.M.	3	1	)for analyses

Ground running of engines and taxying

It was estimated that the engines are run at high revolutions with the aircraft stationary on the ground for a total of 42 seconds per flight made up of 30 seconds engine running prior to take-off and 12 seconds servicing. The difference in the numbers of occurrences of loads with the engines running at normal cruise revs (9,500 r.p.m.), climb revs (9,750 r.p.m.) and take-off revs (10,250 r.p.m.) was not very great (see Fig.7a) and, since details of the times spent at different r.p.m. were not available, it was decided to assume all 42 seconds of engine running occurred at 10,250 r.p.m. It was not necessary to take account of the time spent with the engines idling since flight test results showed the loads to be insignificant.

The loads in taxying were obtained on the assumption that 10 minutes was spent in taxying each flight. Only 2.2 minutes of test flight taxying was analysed since taxying loads were small and it was not considered worthwhile to analyse more. The occurrences for the 2.2 minutes were scaled up to give occurrences for the required 10 minutes.

Loads in turbulence

The flight pattern used for determining the number of gusts of 10 ft/sec or greater encountered in the typical flight was based on operational use of the Comet I by a number of air-lines. Details of the flight conditions and numbers of gusts met are given in the table below:-

/Table

Altitude ft	Time minutes	Airspeed		Miles travelled	No. of gusts met >10 ft/sec
		E.A.S. kts	T.A.S. kts		
0- 2,500	2	201	204	7	2.14
2,500- 7,500	5	250	269	22	2.79
7,500-12,500	4	263	308	20	0.80
12,500-17,500	5	264	330	28	0.35
17,500-22,500	5	254	350	29	0.11^5
22,500-27,500	6	242	360	36	0.05^5
27,500-32,500	10	228	374	62	0.08
32,500-35,000	18	226	394	118	0.15
35,000-40,000	70	247	470	548	0.68
40,000-37,500	5	251	493	41	0.05^5
37,500-32,500	6	253	454	45	0.05
32,500-27,500	5	253	414	35	0.04^5
27,500-22,500	4	252	378	25	0.03
22,500-17,500	4	247	342	23	0.09^5
17,500-12,500	5	243	306	25	0.31
12,500- 7,500	4	234	270	19	0.76^5
7,500- 2,500	5	209	224	18	2.28
2,500- 0	2	152	154	5	1.53
Totals	2 hrs 45 mins			1106 miles	12.32 gusts

The numbers of gusts met shown in the last column have been obtained from the curves of Fig.8 which are based on the gusts met during operational flying on the Comet I and on a number of other aircraft.

The occurrences of tailplane loads were then obtained from the above Table and from the relationship between gust velocity ranges and tail load ranges of Fig.5 (a mean c.g. position at the datum was assumed). In deriving gust ranges from the gusts of the above Table a factor of 0.78 was introduced to allow for the difference in range counts obtained from the geometric mean of equal positive and negative increments and from a direct count. This factor was based on a comparison of c.g. acceleration ranges counted by the two methods (see Fig.9).

TABLE I

Tailplane port root bending moment cycles

Load Range	Number of Times Load Range is Exceeded													
	Take-off	Landing	Taxying	Engine Ground Running 1 min each condition All engines at r.p.m. as for:-			Turbulence							
							c.g. aft				c.g. forward			
lb ins	Mean of 3	Mean of 10	132 secs	Cruise	Climb	Take-off	130 kts 195 secs	180 kts 120 secs	200 kts 202 secs	230 kts 340 secs	130 kts 120 secs	180 kts 120 secs	200 kts 167.5 secs	230 kts 120 secs
0.36×10^5	73	93	79	180	208	219	150	114	127	450	79	119	182	171
0.54×10^5	40	69	24.1	91	110	132	67	58	62	280	32	56	94	91
0.72×10^5	21.7	48	6.4	43	47	57	34	32	34	175	14.8	26.3	55	53
0.90×10^5	10.3	33.7	2.2	16.2	15.2	22.1	21	18.5	25.5	113	7.2	14.5	31	30.5
1.08×10^5	4.7	23.4	0.4	5.2	4.8	9.2	14	10	14.5	74	4.15	8	16.7	19.1
1.26×10^5	2.33	15.5		2.4	1.8	2.4	7.5	4	8	51	2.33	3.75	11.3	12.2
1.44×10^5	0.87	10.5		1.4		1	6	2	4.7	37	1.41	2	6.7	8.1
1.62×10^5		7.1					4	2	3.5	29	1		4.4	6
1.80×10^5		5.15					1.7		2.4	23			4	3.25
1.98×10^5		4.1					1		2	16			2	1.33
2.16×10^5		3.25							2	12			1	1
2.34×10^5		2.3								9				1
2.52×10^5		1.72								5				
2.70×10^5		1.39								3				
2.88×10^5		1.2								1				
3.06×10^5										1				
3.24×10^5										1				
3.42×10^5										1				

TABLE II

Tailplane starboard root bending moment cycles

Load Range	Number of Times Load Range is Exceeded													
	Take-off	Landing	Taxying	Engine Ground Running 1 min each condition All engines running			Turbulence							
							c.g. aft				c.g. forward			
							130 kts	180 kts	200 kts	230 kts	130 kts	180 kts	200 kts	230 kts
lb ins	Mean of 3	Mean of 10	132 secs	10,250 r.p.m.	9,750 r.p.m.	9,250 r.p.m.	195 secs	120 secs	202 secs	340 secs	120 secs	120 secs	167.5 secs	120 secs
0.30×10^5	85	106	155	252	239	216	195	126	190	480	92	152	230	200
0.45×10^5	48	82	41	176	157	133	77	70	99	340	33	76	133	115
0.60×10^5	23.4	60	12.7	108	85	68	44.5	39.5	57	220	14.1	40	76	70
0.75×10^5	13.4	43	6.1	58	28.7	30	26	21.7	38	145	7.9	21	47	47
0.89×10^5	7.8	29.9	3.2	23.5	8.5	14	16	10.7	26.5	105	5	12.5	32	31
1.04×10^5	3.6	21	0.8	10	3.0	6.4	9.5	7.1	16.2	76	2	6.7	21.5	21
1.19×10^5	2.67	13.9		4.6		2	5	4.9	12.5	58	1	2.25	15.9	14.5
1.34×10^5	2.07	10.8		1.2		1	2	3.2	9	44		1	11.4	9.6
1.49×10^5	1.33	8.2				1	1	1.95	6	33			6.5	5.2
1.64×10^5	1.13	6.1				1		1	5	27			3.15	2.75
1.79×10^5	1	4.9							3.7	21			2	2
1.94×10^5		3.9							1.7	16			2	1.33
2.09×10^5		3.3							1	11			2	1
2.24×10^5		2.4								8			1.4	1
2.38×10^5		1.69								6			1	1
2.53×10^5		1.29								4				1
2.68×10^5		1.03								2.5				1
2.83×10^5										2				1
2.98×10^5										1				

TABLE III

C.G. acceleration cycles

Acceleration Range g	Number of Times Acceleration Range is Exceeded in Turbulence							
	c.g. aft				c.g. forward			
	130 kts 195 secs	180 kts 120 secs	200 kts 202 secs	230 kts 340 secs	130 kts 120 secs	180 kts 120 secs	200 kts 167.5 secs	230 kts 120 secs
0.2	32	46.5	50	120	8.3	51	53	46
0.3	20.5	22	30	86	4.7	19.5	31	26
0.4	12.5	10.3	17.5	60	2.7	8.3	19.5	17.7
0.5	7.2	5	10.3	46	1.6	4.1	13.4	13.5
0.6	3.2	2.4	6	32		2.3	8	8.3
0.7	1.5		3.7	24.5		1.4	4	5
0.8			2	17.5		1	2.3	3.3
0.9			1.4	13.5			2.05	2
1			1	10			2	1.4
1.1			1	6.5			1	1
1.2				3.7			1	1
1.3				2.5			1	1
1.4				1.5				1
1.5								1

TABLE IV

Tailplane loads when lowering flaps and opening dive brakes

Condition	E.A.S. Kts	Height ft	Change in tailplane load lb per side*
Lowering flaps to 15°	170	1,600	-2,800
Lowering flaps 15° to 40°	140	1,000	- 100
Lowering flaps 40° to full	120	500	- 900
Opening dive brakes	200	13,000	+2,300
Opening dive brakes	230	1,800	+ 700

* Negative sign denotes a down-load on the tailplane

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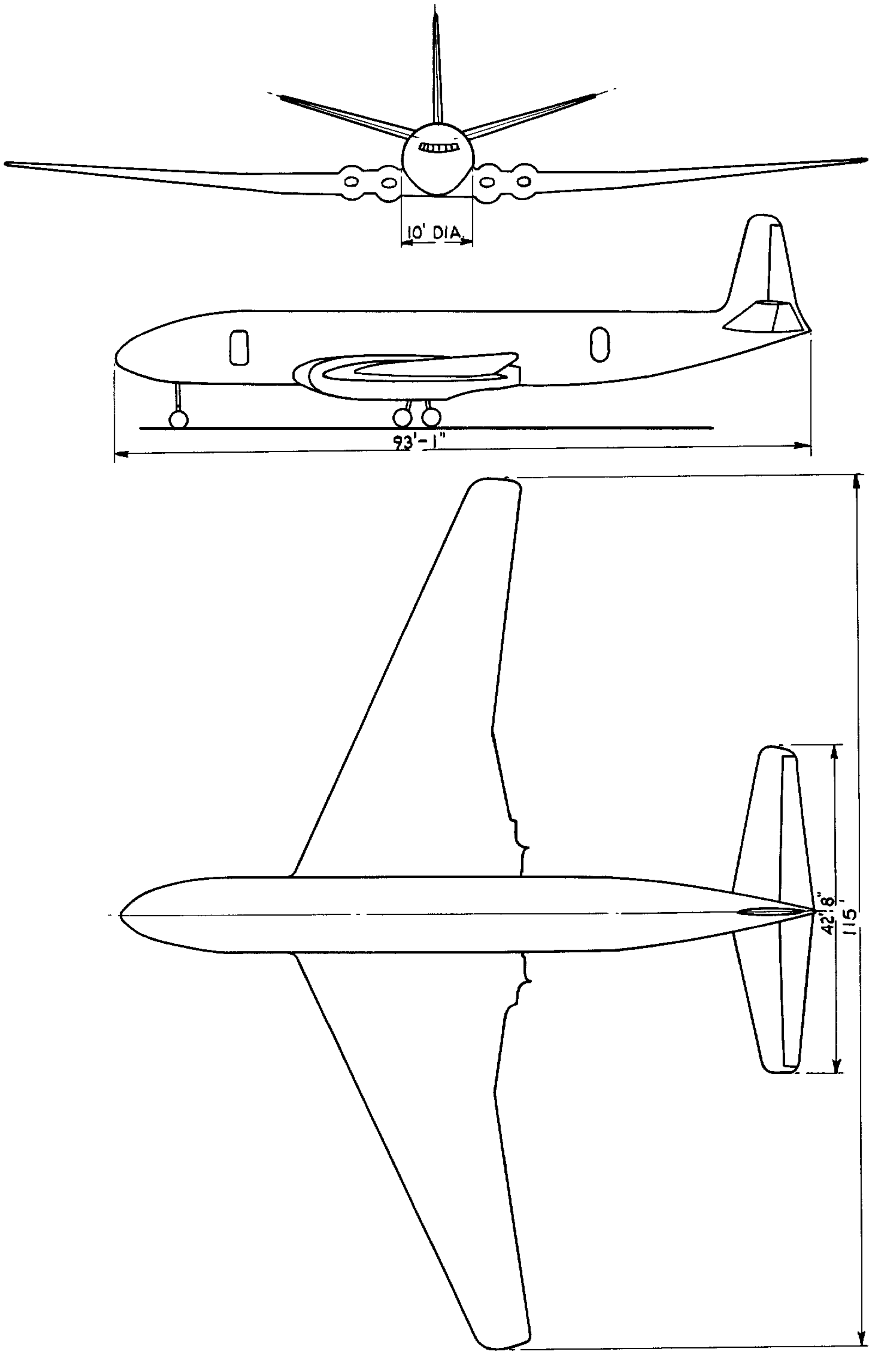
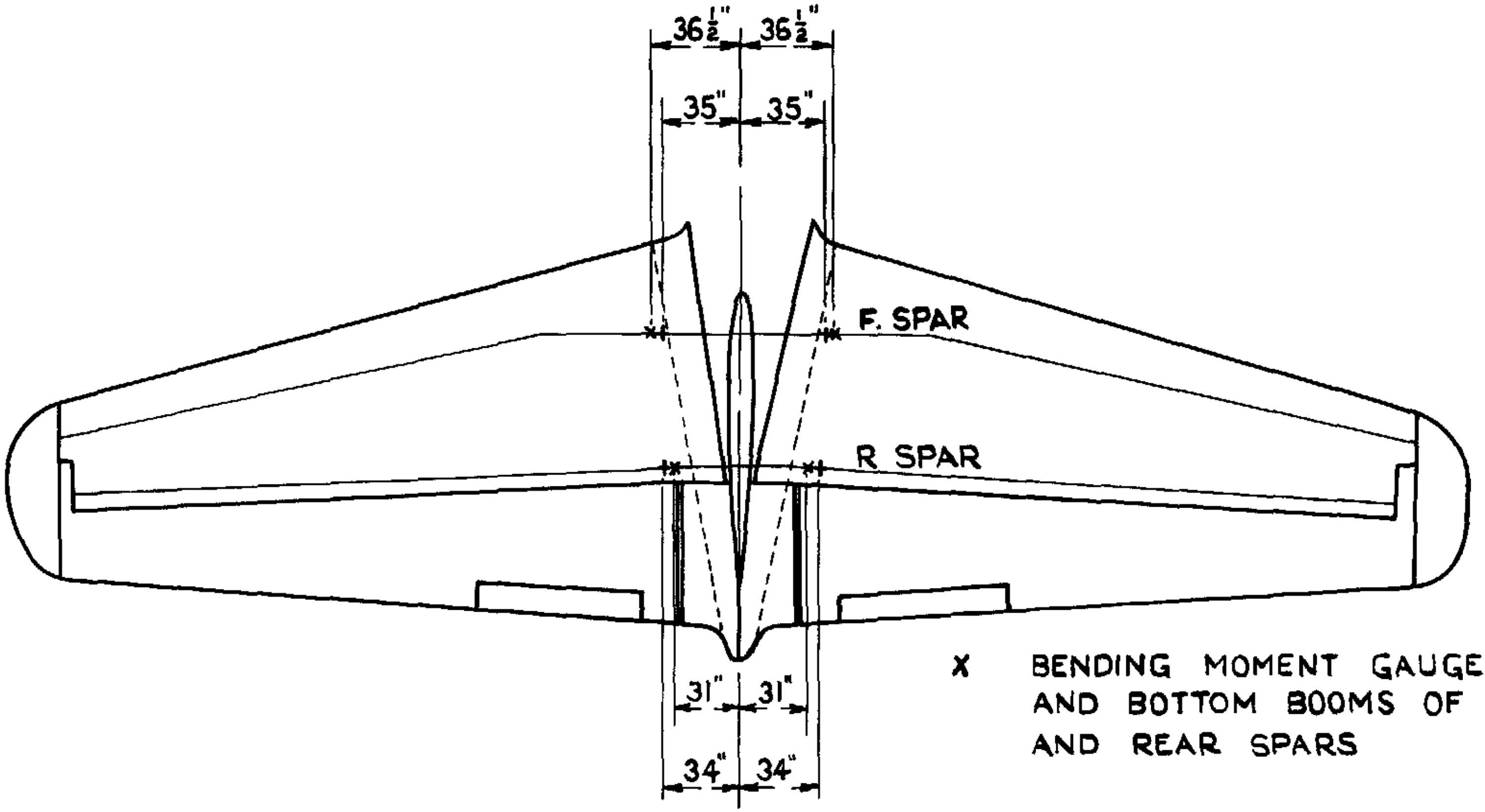


FIG. 1. GENERAL ARRANGEMENT OF COMET I.



x BENDING MOMENT GAUGES ON TOP AND BOTTOM BOOMS OF FRONT AND REAR SPARS

+ SHEAR GAUGES ON FRONT AND REAR FACES OF WEBS OF FRONT AND REAR SPARS

FIG. 2. STRAIN GAUGE STATIONS ON TAILPLANE.

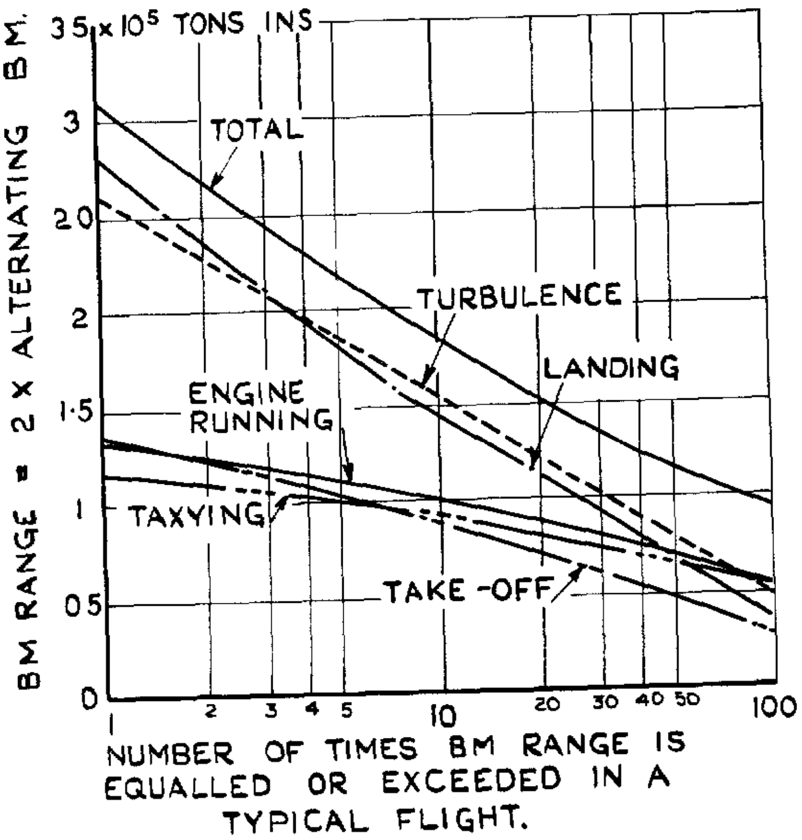


FIG. 3. TAILPLANE LOADS IN COMPONENT CONDITIONS OF TYPICAL FLIGHT.
(INCLUDING ASSOCIATED GROUND CONDITIONS)
FLYING TIME = 2¾ HOURS

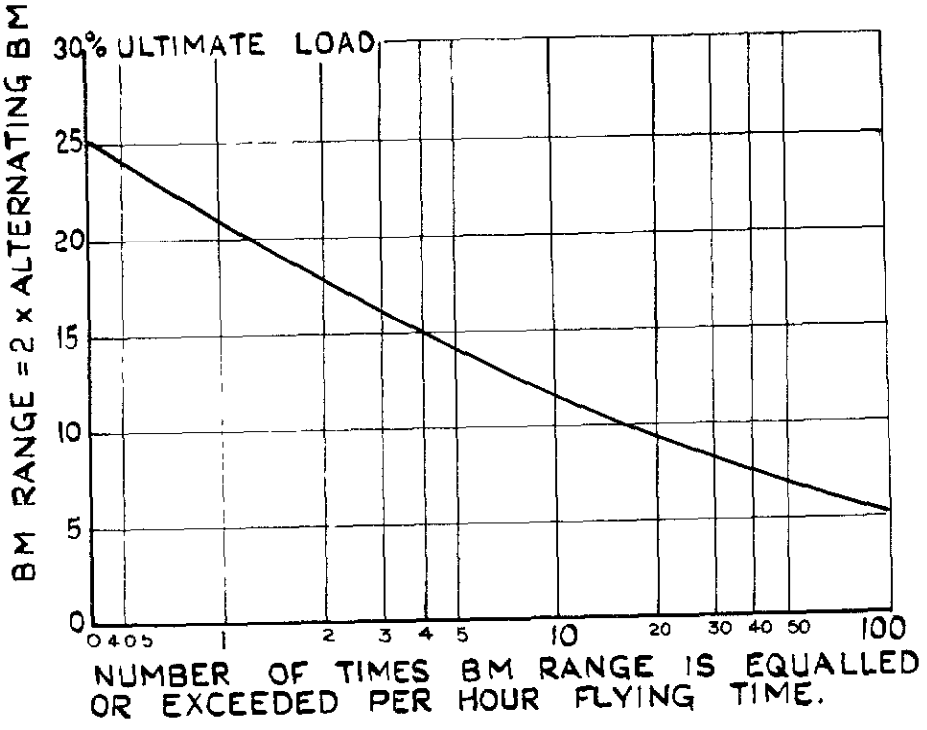


FIG. 4. RATE OF OCCURRENCE OF TOTAL LOAD RANGES IN TYPICAL FLIGHT.

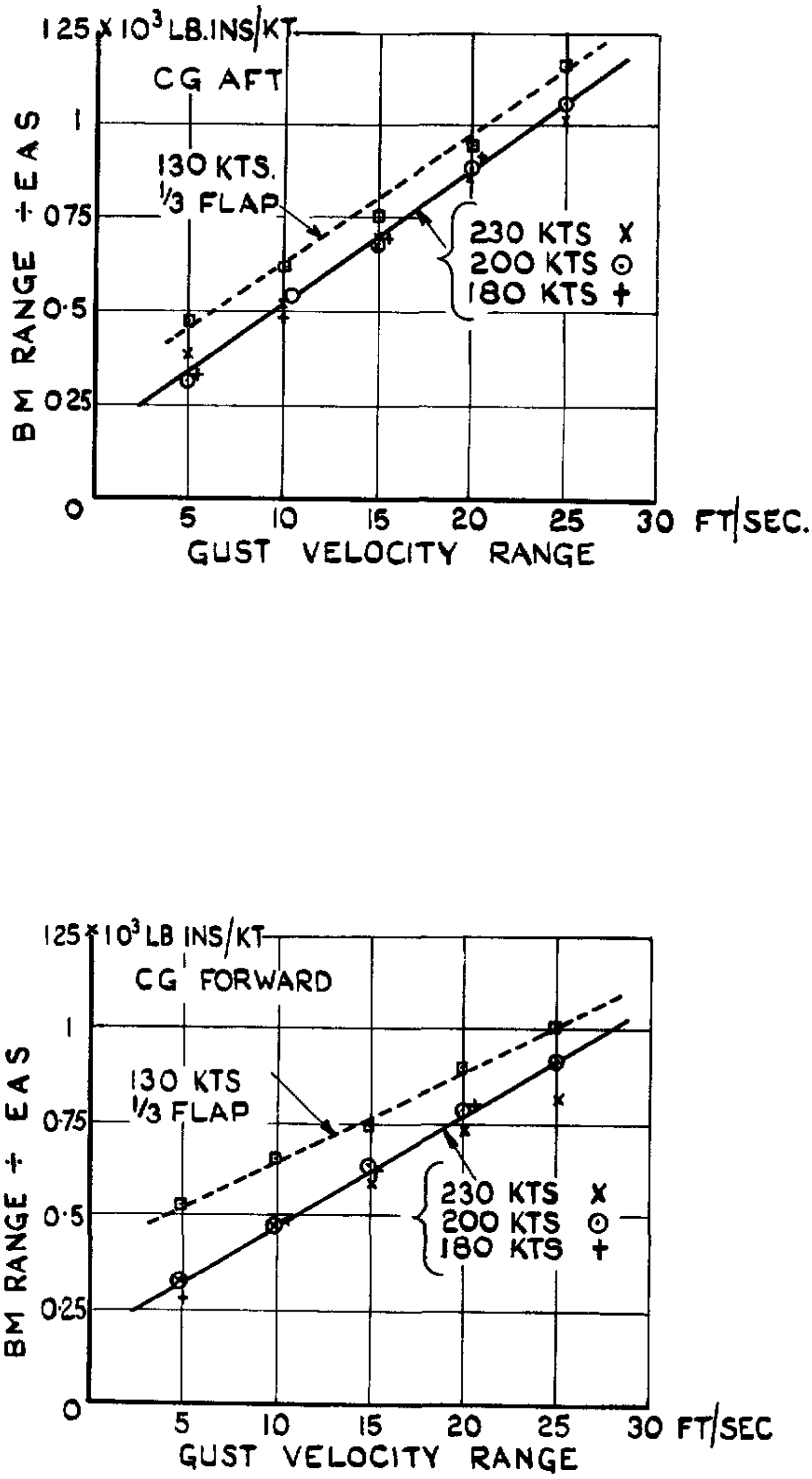


FIG. 5. RELATIONSHIP BETWEEN TAILPLANE LOAD RANGES AND GUST VELOCITY RANGES EXCEEDED THE SAME NUMBER OF TIMES.

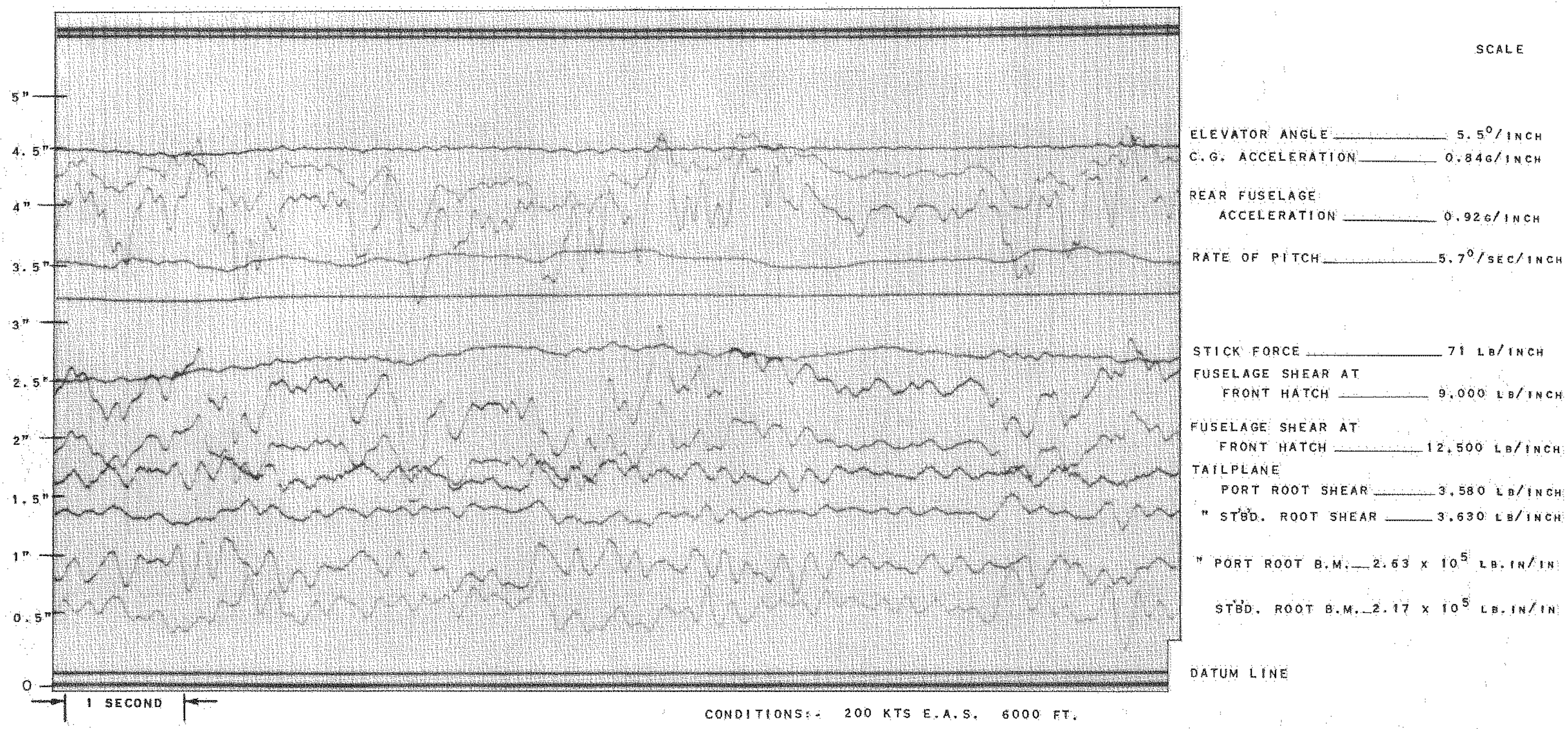
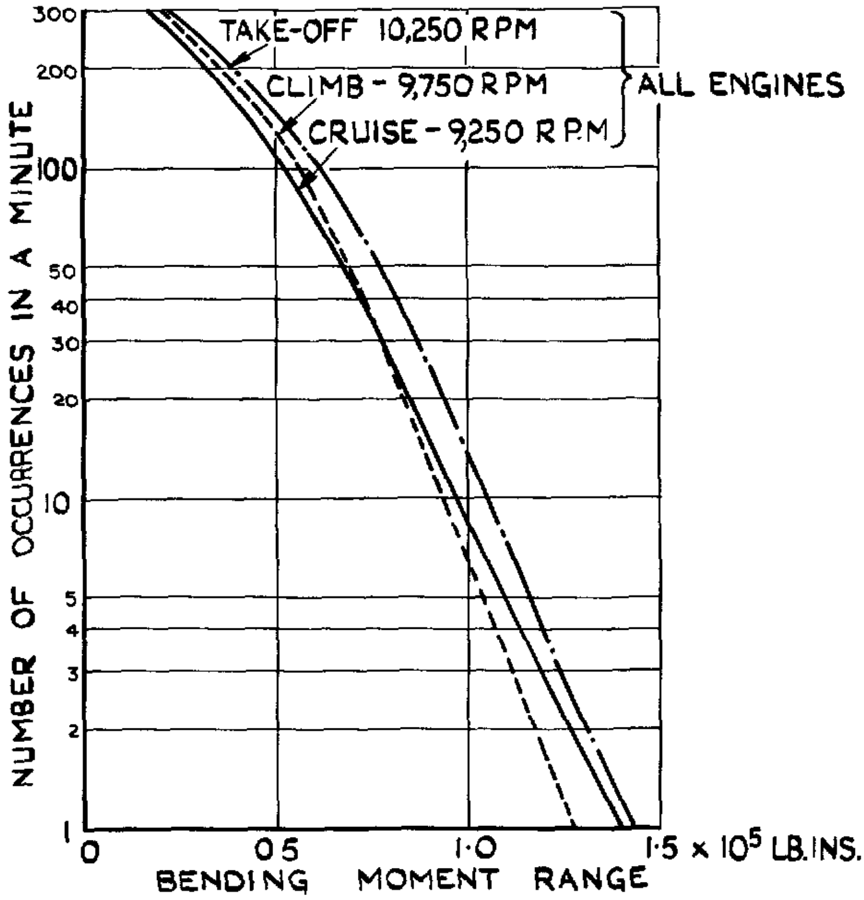
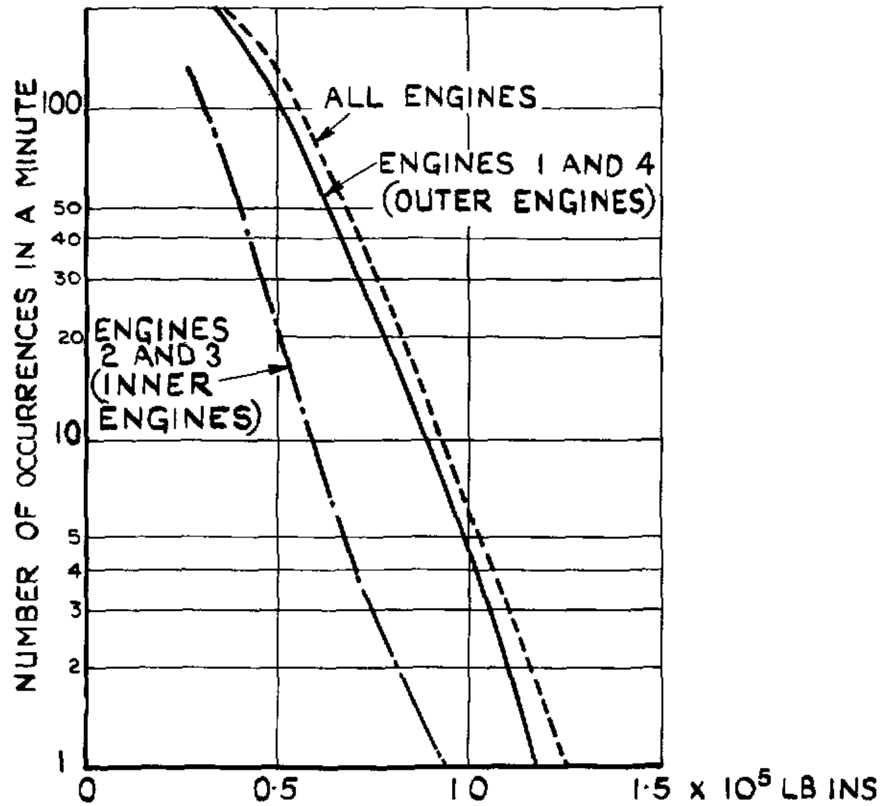


FIG.6. TYPICAL RECORD OF LOADS IN TURBULENCE

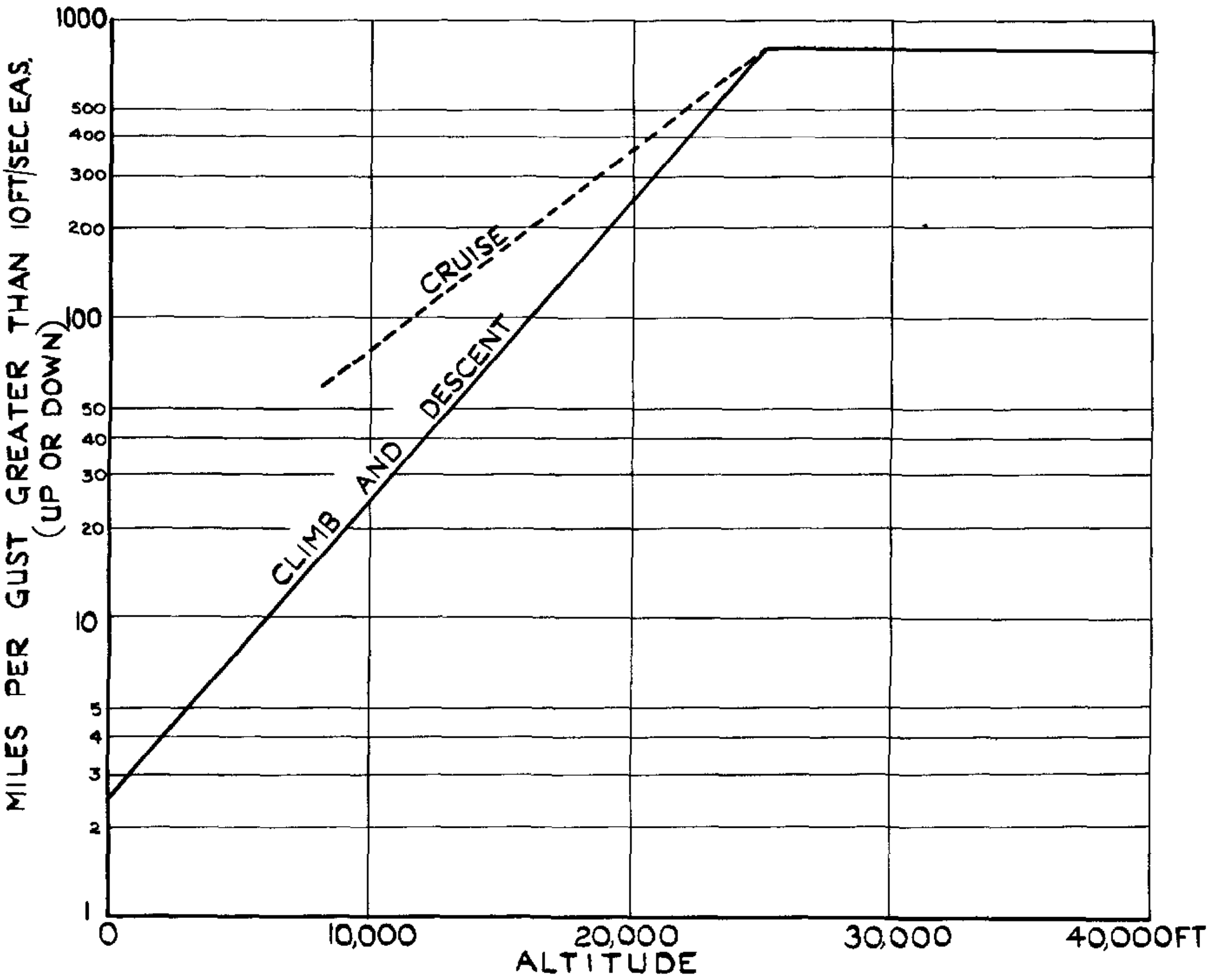


(a) LOADS FOR ENGINES RUNNING AT VARIOUS R.P.M.



(b) LOADS FOR VARIOUS ENGINE COMBINATIONS RUNNING AT CLIMB R.P.M.

FIG. 7 (a&b) TAILPLANE LOADS DURING ENGINE GROUND RUNNING.



GUST MAGNITUDE EXCEEDED FT/SEC. E.A S	FREQUENCY RELATIVE TO 10FT/SEC GUST
5	5 2
10	1
15	0 2
20	0 044
25	0 0097
30	0 0025

RELATIVE FREQUENCY
OF GUSTS OF DIFFERENT
MAGNITUDES

FIG. 8. DATA USED IN CALCULATION OF TURBULENCE LOADS IN TYPICAL FLIGHT.

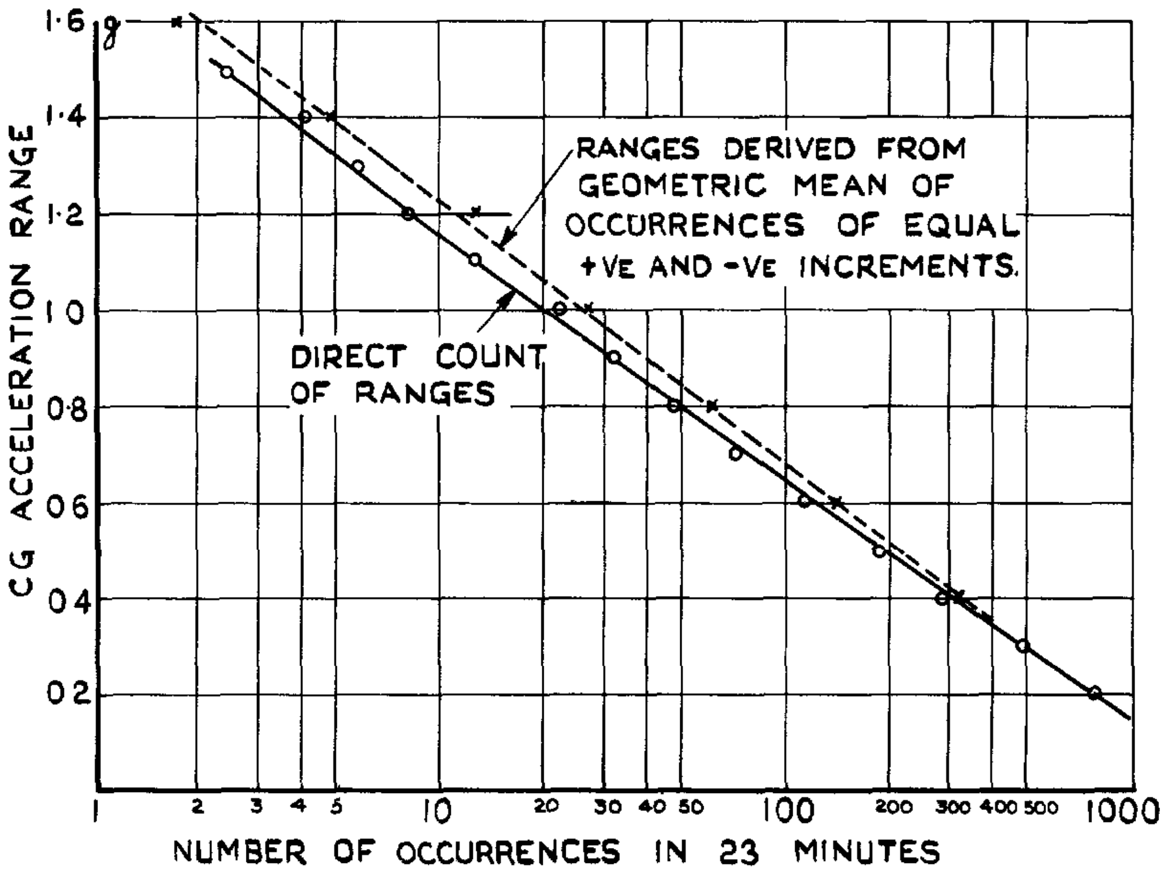


FIG. 9. COMPARISON OF ACCELERATION RANGES. OBTAINED BY DIFFERENT METHODS

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