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A Review of Counting Accelerometer Data on Aircraft Gust Loads

by

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A REVIEW OF COUNTING ACCELEROMETER DATA ON AIRCRAFT GUST LOADS

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SUMMARY

Counting accelerometer data collected over a period of several years on a number of passenger transport aircraft are summarized and the derived gust frequency distributions studied.

The intensity of the turbulence encountered is compared with that observed by research aircraft in storms and clear air.

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* Replaces R.A.E. Tech. Report No. 66234 - A.R.C. 28702.

CONTENTS

1 INTRODUCTION

1.1 For many years, counting accelerometers have been fitted in a number of passenger transport aircraft and a body of operational data covering over 19000 hours or about 5 000 000 miles has been built up.

Since, at the present time, the majority of aircraft carry cloud warning radar and recording on aircraft without such aids has now virtually ceased, this seems a suitable opportunity to summarize the earlier data, some of which have been re-analysed by more up to date methods.

1.2 It should perhaps be emphasized that the data reflect the operational procedures of the aircraft and do not purport to be a study of properties of the atmosphere. For example, many aircraft exhibit a minimum frequency of occurrence of bumps near the nominal cruising altitude. This arises from the fact that in calm conditions, cruising takes place at the nominal height, while when it is rough, the pilot changes altitude in an attempt to avoid the turbulence. Cruising at altitudes other than the nominal cruising height is thus biased towards turbulent conditions. Again, it is apparent from the data that manoeuvre loads contribute to the observed accelerations near the ground. However, the results are presented as typical of passenger transport aircraft operations.

1.3 Differences in the gust frequency distribution with altitude are fairly small and are often influenced by operational procedures; previously these differences have been neglected but an attempt is made here to examine such variation in more detail.

The intensity of turbulence encountered by operational aircraft is compared with that observed by research aircraft in storms and clear air.

2 INSTRUMENTATION

2.1 The data presented here were all obtained from counting accelerometer records from passenger transport aircraft, the instruments being fitted close to the aircraft centre of gravity.

The counting accelerometer[1] is an instrument which records by counters the number of times given levels of normal acceleration are exceeded. These accelerations may be either up or down and a count is made each time the acceleration exceeds a given value and then returns by a given amount towards its mean value. The counters, together with instruments recording aircraft height and speed and the time, are photographed at given intervals of time, usually of a few minutes duration.

3 DATA ANALYSIS

3.1 In order to make comparisons between aircraft, the recorded accelerations are interpreted as gust velocities using a method based on Zbrozek's work[2]. Briefly, a standard gust profile is assumed, ramp shaped with a 100 ft build up to the maximum, and the response of the aircraft calculated assuming that it is rigid and does not pitch, account being taken of the unsteady lift functions.

3.2 The data are divided into different flight conditions and altitude ranges and the results are presented in Tables 6 - 17, which have been extracted from work by Heath-Smith[3,4,5,6,7,8,9] and Judy Aplin[10,11,12]. All gust velocities are expressed in equivalent airspeeds. These tables represent the basic information on which this summary is based.

A list of aircraft types with their characteristics, main cruising conditions and the gust velocity required to produce a normal acceleration of 1g in mean cruising conditions are given in Table 1.

4 DISCUSSION OF RESULTS

4.1 As a first step in classifying the data the numbers of gusts in each altitude band for each flight condition have been summed and the results given in Tables 2 and 3. The "Initial Climb" and "Final Descent" conditions of Tables 6 - 17 are slightly more severe than the remainder of the climb and descent, but not sufficiently so to require different treatment, and, in fact, being a part of the climb and descent have been included as such.

Table 4 has been prepared to examine any change in gust distribution with altitude regardless of flight condition.

4.2 It is customary in studies of this kind to add the numbers of up and down gusts of equal magnitude. It is true that the distributions of up and down gusts are fairly similar in shape and that in any case this is a convenient procedure in fatigue applications but before taking such a step it is worthwhile to look at what differences there are.

The total numbers of gusts of Table 4 are plotted on a logarithmic scale against gust velocity in Fig.1. Below gust velocities of about 30 ft/sec the shapes of the curves are practically identical, the differences in frequency being accounted for by a shift of the origin amounting to about 0.7 ft/sec. With the conversion factors given in Table 1, this corresponds to about 0.02g for most of the flying and is, no doubt, due to some extent to the presence of small manoeuvring loads which influence the results and produce a positive bias, manoeuvres producing positive accelerations being by far the more frequent. However, Anne Burns[14] has shown that there are also other reasons for expecting such a bias.

Above gust velocities of about 30 ft/sec, the ratio of up to down gusts increases; the numbers involved here are smaller and the increased difference is probably due to a few large manoeuvres which are, of course, interpreted in terms of gusts.

4.3 As might be expected, the zero shift is not constant with altitude but is greatest near the ground where most manoeuvring takes place, either in turning on to course after take-off, or in circling when waiting to land. To show this effect more clearly the ratio of the number of up gusts to down gusts is given in the following table and shown plotted in Fig.2.

Ratio of number of up gusts to number of down gusts for gusts greater than 10 ft/sec

Mean altitude ft	Observed ratio	Ratio calculated from empirical formula
820	2.227	2.230
2440	1.892	1.864
4530	1.612	1.624
7940	1.437	1.430
11240	1.270	1.330
15760	1.379	1.251
19230	0.972	1.211
23890	1.039	1.175
34590	1.281	1.125

A useful empirical expression for the ratio is $(h + 7700)/(h + 3000)$ where h is the height in feet.

4.4 As mentioned earlier, for most practical purposes it is convenient to sum the up and down gusts of equal magnitudes and this is done in Tables 2A to 4A. Fig.3 shows the number of gusts per mile greater than 10 ft/sec for cruise and for climb and descent. The values are tabulated overleaf.

ratio of one of the geometrical progressions. The cases in which it proved satisfactory, however, were sufficient to show that the intensity parameter for the light component had a value of about 2.5 ft/sec near the ground falling off to about 1.5 ft/sec at about 10000 ft and then remaining fairly constant.

By assuming this to be exactly the case and then fitting the remaining three parameters by moments, a satisfactory and generally consistent set of distributions was obtained. The resulting fitted values compared with the original data are given in Table 5, and it will be seen that the procedure adopted gives satisfactory agreement. (Since above 29500 ft all the data are from Comet aircraft and the number of gusts greater than $7\frac{1}{2}$ ft/sec for this aircraft and altitude are determined without recourse to extrapolation, this value has been included.) The parameters so determined are as follows:

Altitude band ft	a_1 ft/sec	a_2 ft/sec	A_1 per mile	A_2 per mile
0-1500	5.357	2.418	1.924, -2	1.967, -1
1500-3500	3.922	2.256	3.527, -2	1.363, -1
3500-5500	3.393	2.047	3.722, -2	5.242, -2
5500-9500	3.525	1.706	1.796, -2	1.015, -2
9500-13500	3.982	1.500	7.679, -3	3.347, -3
13500-17500	4.155	1.500	3.457, -3	2.295, -3
17500-21500	4.685	1.500	3.623, -3	3.343, -3
21500-29500	3.871	1.500	2.548, -3	2.256, -3
Over 29500	3.778	1.500	8.045, -4	3.467, -4

These intensity parameters are shown plotted in Fig.4. It seems likely that the rapid rise in the intensity of the severe component near the ground is, in fact, due to a manoeuvring contribution, and this may also be true of the more gradual increase in that of the light component.

5.2 The proportion in which these components are encountered may depend on flight condition. Accordingly, keeping the intensity parameters already determined, values of A_1 and A_2 for climb and descent and for cruise are determined from the data of Tables 2A and 3A and are as follows:

Altitude band ft	Climb and descent		Cruise	
	A_1	A_2	A_1	A_2
0-1500	3.148, -2	3.042, -1	1.209, -2	1.340, -1
1500-3500	4.867, -2	1.615, -1	1.820, -2	1.041, -1
3500-5500	4.091, -2	6.040, -2	2.964, -2	3.602, -2
5500-9500	2.925, -2	1.922, -2	1.293, -2	6.116, -3
9500-13500	1.191, -2	6.716, -3	7.001, -3	2.807, -3
13500-17500	5.058, -3	3.682, -3	3.104, -3	1.989, -3
17500-21500	8.818, -3	3.837, -3	3.081, -3	2.187, -3
21500-29500	2.296, -3	2.084, -3	2.635, -3	2.316, -3
Over 29500	4.727, -4	3.616, -4	8.593, -4	3.441, -4

These are shown plotted in Figs.5 and 6. The two figures are similar in nature and in each both components show a general decrease with increasing altitude above 5000 ft. The severe component also falls off markedly near the ground having a maximum at about 3000 to 5000 ft.

6 THE NATURE OF THE TWO COMPONENTS OF TURBULENCE

6.1 It is often assumed that the severe component of turbulence is associated with strong convective activity in cumulus or cumulo-nimbus cloud and described as "storm" turbulence and the light component referred to as "non storm" turbulence[15].

Do these two components in fact occur on different occasions associated with different meteorological conditions or do they occur in association?

6.2 It has already been noted that aircraft encounter less turbulence in cruise than in climb and descent. If this difference is primarily due to the avoidance of "storm" turbulence the proportions in which the components are encountered in cruise and in climb and descent will differ and will be indicated in the Table in Para. 5.2 by a change in ratio of A_1 to A_2, the value of A_1/A_2 being smaller in cruise. The value of this ratio for the two flight conditions is shown plotted in Fig.7. There is little indication that the severe component is the more easily avoided and for much of the flying the reverse seems to be the case. It is difficult to see why this should be so unless possibly it is caused by autopilot hunting which is sometimes observed on continuous trace records of acceleration[16]. On the whole Fig.7 would suggest that the two components occur in association.

6.3 A number of thunderstorm investigations have been described in which acceleration or gust distributions have been given and these show no evidence of two components being present and are generally well fitted by exponential distributions. The values of the intensity parameter obtained in these investigations are compared below with those of the severe component of the counting accelerometer data.

A paper by R. F. Jones[17] gives statistical details of accelerations encountered by a Spitfire aircraft traversing cumulus and cumulo-nimbus clouds at different heights.

Plots of the logarithms of the number of accelerations against magnitude of acceleration down to the lowest value of 0.1g often show marked curvature and, in fact, are well fitted by the family of distributions suggested by the author[18]. However, such fitting makes a comparison with the present data difficult. It is found that an exponential distribution can be satisfactorily fitted for accelerations above 0.3g and as this corresponds to a gust velocity of about 8 or 9 ft/sec which is near the lower limit of the counting accelerometer data, this has been considered adequate for purposes of comparison. The intensity parameter is obtained in terms of acceleration and then converted to a gust velocity by Zbrozek's method.

Gust frequency distributions in thunderstorms have also been obtained by Tolefson[19] based on the series of thunderstorm investigations made in Florida and Oklahoma. The gust velocities given were obtained form the accelerations using Pratt and Walker's[20] method. After fitting an exponential to each of the distributions given by Tolefson, a correction has therefore been made to the intensity parameter to obtain the value corresponding to a factor given by Zbrozek's method.

Finally, data given by Wicker[21] for flying in thunderstorms have also been analysed. These were mainly at high altitude and have been combined to give a single value of intensity at 34200 ft. An intensity parameter has been calculated by fitting an exponential distribution to values over 10 ft/sec and the parameter then corrected to the Zbrozek value.

The following Table summarises these results and the values shown are plotted in Fig.8.

Source	Height ft	Intensity parameter ft/sec
Counting accelerometer data from passenger transport aircraft	820	5.36
	2440	3.92
	4530	3.39
	7940	3.53
	11240	3.98
	15760	4.16
	19230	4.68
	23890	3.87
	34590	3.78
R. F. Jones[17]	5000	3.62
	10000	3.41
	15000	3.92
	20000	4.31
	25000	4.90
	30000	5.54
	35000	4.64
	40000	3.90
Tolefson[19] 1941-42	7500	3.99
	12500	5.56
	17500	6.26
	22500	5.66
	27500	5.39
	32000	5.05
1946	6000	4.73
	11000	4.84
	16000	5.25
	21000	5.10
	26000	4.73
1947	5000	5.02
	10000	5.21
	15000	5.61
	20000	5.19
	25000	5.62
Wicker[21]	34200	4.32

The values of intensity parameter from the thunderstorm investigations give reasonably consistent values. Generally speaking, they are about 30% higher than those from the counting accelerometer records but show a similar trend and it is reasonable to suppose that the passenger transport aircraft successfully avoided the most severe turbulence. On the whole, Fig.8 provides fairly convincing evidence that the severe component of the turbulence originates in storms.

6.4 There is little comparable information regarding the light component. However, its intensity above 30000 ft is close to that observed for clear air turbulence.

During the TOPCAT investigation made in Australia, a number of routine flights were made over set tracks and heights to observe clear air turbulence and counting accelerometer records were taken and analysed by Wells[22]. These results give the following numbers of gusts in 8466 miles of flight at a mean height of 36000 ft.

TOPCAT routine flights

Gust velocity v ft/sec	No. of gusts exceeding v
2.5	2313
3.75	937
5.0	409
7.5	74
10.0	14
12.5	1

Fitting an exponential distribution gives a value of 1.42 ft/sec for the intensity parameter in good agreement with that assumed above. It will be noted that the range of gust velocity over which the observations were made is considerably lower than that reached by the passenger transport counting accelerometer records and it is interesting to find that the exponential relationship appears to persist to such low values.

A further piece of information is provided by counting accelerometer data obtained from Comet 2 aircraft operated by the R.A.F. and carrying radar[11]. It is apparent that during cruise, practically all the severe component of turbulence was avoided, and the gust distribution obtained therefore provides a good estimate for the intensity of the light component. The numbers of gusts for 243 000 miles of flight at a mean height of 39400 are as follows:

Gust distribution from Comet 2 cruise

Gust velocity v ft/sec	No. of gusts exceeding v
$7\frac{1}{2}$	255
10	61
15	4

An exponential fit to the above gives a value of the intensity parameter of 1.75 ft/sec.

7 CONCLUSIONS

The gust statistics presented here provide information on the operational experience of passenger transport aircraft over a wide variety of routes up to altitudes of about 35000 ft.

The data are sufficient for the variation in gust frequency distribution with altitude to be examined and the influence of manoeuvring loads on the data near the ground is noted.

In general, the gust frequency distribution consists of two components. The evidence suggests that the severe component originates in cumulus and cumulo-nimbus cloud, and that the light component is associated with it, although at high altitude a contribution to the light component is made by clear air turbulence.

Table 1

Aircraft used in counting accelerometer recording

Aircraft	Operator	Wing area ft^2	Span ft	Slope of lift curve per radian	Mean cruising conditions			
					Weight lb	Height ft	Speed knots E.A.S.	Gust vel. to produce 1g bump ft/sec
Ambassador	B.E.A.	1200	115	4.84	47900	11300	164	31.2
Comet 1	B.O.A.C.	2015	115	5.49*	82100	34950	213	21.6
Freighter (Bristol)	S.A.F.E.	1487	108	4.4	40200	2460	135	31.9
	S.C.A.	1487	108	4.4	38200	1200	134	31.3
Hermes 4	B.O.A.C.	1408	113	4.53	76700	13090	160	44.2
Hermes 4A	Airwork	1408	113	4.70	79700	9410	158	45.4
Strato cruiser	B.O.A.C.	1769	141½	5.1	125500	14150	176	45.8
Superconstellation	Q.A.N.T.A.S.	1650	123	4.93	112500	14990	189	42.2
Viking	B.E.A.	882	89¼	4.58	31000	6870	150	32.6
	C.A.A.	882	89¼	4.58	31100	8810	144	33.7
Viscount	B.E.A. and Aer Lingus	963	94	4.6	51400	21260	186	35.3
	C.A.A.	963	94	4.6	53400	17650	182	37.8

*For mean cruising conditions, corrected for compressibility.

Abbreviations

B.E.A.	British European Airways
B.O.A.C.	British Overseas Aircraft Corporation
S.A.F.E.	Straits Aircraft Freight Express (New Zealand)
S.C.A.	Silver City Airways (English Channel Ferry Service)
Q.A.N.T.A.S.	Queensland and Northern Territories Aircraft Service
C.A.A.	Central African Airways

Table 2

Numbers of gusts observed during climb and descent

Altitude range feet	Mean height feet	Miles flown	Gust velocity ft/sec																	
			Down								Up									
			45	40	35	30	25	20	15	10	10	15	20	25	30	35	40	45	50	55
0-1500	700	48 000		2	2	13	39	132	677	4677	11434	1732	353	96	30	10	6	1		
1500-3500	2490	68 900					25	131	688	5028	9447	1454	279	60	16	4	2	1	1	
3500-5500	4550	91 400				3	16	86	465	3568	5692	855	173	32	7					
5500-9500	7530	236 900		2	3	11	49	174	729	4432	7049	1206	235	43	11	4	2	1		
9500-13500	11560	169 100			1	8	24	71	267	1334	1815	362	88	18	5					
13500-17500	15500	166 100				2	11	39	129	663	789	159	34	8	1					
17500-21500	19270	72 000				3	12	34	94	445	466	135	47	13	3	1	1			
21500-29500	25590	92 900					3	9	35	198	209	32	7	2						
Over 29500	32460	72 400						1	3	26	39	4	1							

Table 3

Numbers of gusts observed during cruise

Altitude range feet	Mean height feet	Miles flown	Gust velocity ft/sec																	
			Down								Up									
			45	40	35	30	25	20	15	10	10	15	20	25	30	35	40	45	50	55
0-1500	890	82 300				4	15	87	623	4041	7985	1192	231	57	16	6	4	4	2	1
1500-3500	2370	54 000				2	6	46	305	2263	4348	582	98	22	6	3				
3500-5500	4480	44 400					1	26	153	1092	1821	288	58	12	4	1				
5500-9500	8130	532 500		2	3	9	36	182	788	4442	5702	1057	236	47	14	6	2	1	1	
9500-13500	11180	1 054 000		1	7	25	82	295	1012	4608	5730	1183	315	81	32	11	4	1		
13500-17500	15820	752 500	2	2	4	14	35	107	338	1558	2274	401	110	33	10	1				
17500-21500	19220	689 900	1	2	8	20	49	148	374	1860	1774	396	122	32	11	5	2			
21500-29500	23300	270 300				2	5	21	106	658	680	110	32	13	3	1				
Over 29500	34950	440 100				1	3	9	39	234	294	64	22	4	2					

Table 4

Numbers of gusts observed during all flying

Altitude range feet	Mean height feet	Miles flown	Gust velocity ft/sec																	
			Down								Up									
			45	40	35	30	25	20	15	10	10	15	20	25	30	35	40	45	50	55
0-1500	820	130 300		2	2	17	54	219	1300	8718	19419	2924	584	153	46	16	10	5	2	1
1500-3500	2440	122 900				2	31	177	993	7291	13795	2036	377	82	22	7	2	1	1	
3500-5500	4530	135 800				3	17	112	618	4660	7513	1143	231	44	11	1				
5500-9500	7940	769 400		4	6	20	85	356	1517	8874	12751	2263	471	90	25	10	4	2	1	
9500-13500	11240	1 223 200		1	8	33	106	366	1279	5942	7545	1545	403	99	37	11	4	1		
13500-17500	15760	918 600	2	2	4	16	46	146	467	2221	3063	560	144	41	11	1				
17500-21500	19230	761 800	1	2	8	23	61	182	468	2305	2240	531	169	45	14	6	3			
21500-29500	23890	363 200				2	8	30	141	856	889	142	39	15	3	1				
Over 29500	34590	512 600				1	3	10	42	260	333	68	23	4	2					
TOTALS			3	11	28	117	411	1598	6825	41127	67548	11212	2441	573	171	53	23	9	4	1

Table 2A

Numbers of gusts observed during climb and descent (up and down combined)

Altitude range feet	Mean height feet	Miles flown	Gust velocity ft/sec									
			10	15	20	25	30	35	40	45	50	55
0-1500	700	48 000	16111	2409	485	135	43	12	8	1		
1500-3500	2490	68 900	14475	2142	410	85	16	4	2	1	1	
3500-5500	4550	91 400	9260	1320	259	48	10					
5500-9500	7530	236 900	11481	1935	409	92	22	7	4	1		
9500-13500	11560	169 100	3149	629	159	42	13	1				
13500-17500	15500	166 100	1452	288	73	19	3					
17500-21500	19270	72 000	911	229	81	25	6	1	1			
21500-29500	25590	92 900	407	67	16	5						
Over 29500	32460		65	7	2							

Table 3A

Numbers of gusts observed during cruise (up and down combined)

Altitude range feet	Mean height feet	Miles flown	Gust velocity ft/sec									
			10	15	20	25	30	35	40	45	50	55
0-1500	890	82 300	12026	1815	318	72	20	6	4	4	2	1
1500-3500	2370	54 000	6611	887	144	28	8	3				
3500-5500	4480	44 400	2913	441	84	13	4	1				
5500-9500	8130	532 500	10144	1845	418	83	23	9	4	1	1	
9500-13500	11180	1 054 000	10338	2195	610	163	57	18	5	1		
13500-17500	15820	752 500	3832	739	217	68	24	5	2	2		
17500-21500	19220	689 900	3634	770	270	81	31	13	4	1		
21500-29500	23300	270 300	1338	216	53	18	5	1				
Over 29500	34950	440 100	528	103	31	7	3					

Table 4A

Numbers of gusts observed during all flying (up and down combined)

Altitude range feet	Mean height feet	Miles flown	Gust velocity ft/sec									
			10	15	20	25	30	35	40	45	50	55
0-1500	820	130 300	28137	4224	803	207	63	18	12	5	2	1
1500-3500	2440	122 900	21086	3029	554	113	24	7	2	1	1	
3500-5500	4530	135 800	12173	1761	343	61	14	1				
5500-9500	7940	769 400	21625	3780	827	175	45	16	8	2	1	
9500-13500	11240	1 223 200	13487	2824	769	205	70	19	5	1		
13500-17500	15760	918 600	5284	1027	290	87	27	5	2	2		
17500-21500	19230	761 800	4545	999	351	106	37	14	5	1		
21500-29500	23890	363 200	1745	283	69	23	5	1				
Over 29500	34590	512 600	593	110	33	7	3					

Table 5

Gust frequency distributions for each altitude band

Altitude band ft	Gust velocity v ft/sec	Number of gusts greater than v from		Total number of gusts greater than v	
		Severe component	Light component	Calculated	Observed
0 to 1500	10	2506.6	25630.4	28137.0	28137
	15	985.7	3241.2	4226.9	4224
	20	387.6	409.9	797.5	803
	25	152.4	51.8	204.2	207
	30	59.9	6.6	66.5	63
	35	23.6	0.8	24.4	18
	40	9.3	0.1	9.4	12
	45	3.6	-	3.6	5
	50	1.4	-	1.4	2
	55	0.6	-	0.6	1
1500 to 3500	10	4335.2	16750.8	21086.0	21086
	15	1211.6	1826.0	3037.6	3029
	20	338.6	199.1	537.7	554
	25	94.6	21.7	116.3	113
	30	26.4	2.4	28.8	24
	35	7.4	0.3	7.7	7
	40	2.1	-	2.1	2
	45	0.6	-	0.6	1
	50	0.2	-	0.2	1
3500 to 5500	10	5054.2	7118.8	12173.0	12173
	15	1157.9	618.9	1776.8	1761
	20	265.3	53.8	319.1	343
	25	60.8	4.7	65.5	61
	30	13.9	0.4	14.3	14
	35	3.2	-	3.2	1
5500 to 9500	10	13815.0	7810.0	21625.0	21625
	15	3345.1	416.7	3761.8	3780
	20	810.0	22.2	832.2	827
	25	196.1	1.2	197.3	175
	30	47.5	0.1	47.6	45
	35	11.5	-	11.5	16
	40	2.8	-	2.8	8
	45	0.7	-	0.7	2
	50	0.2	-	0.2	1

(Contd.)

Table 5 (Contd.)

Altitude band ft	Gust velocity v ft/sec	Number of gusts greater than v from		Total number of gusts greater than v	
		Severe component	Light component	Calculated	Observed
9500 to 13500	10	9392.8	4094.2	13487.0	13487
	15	2675.7	146.1	2821.8	2824
	20	762.2	5.2	767.4	769
	25	217.1	0.2	217.3	205
	30	61.9	-	61.9	70
	35	17.6	-	17.6	19
	40	5.0	-	5.0	5
	45	1.4	-	1.4	1
13500 to 17500	10	3175.9	2108.1	5284.0	5284
	15	953.2	75.2	1028.4	1027
	20	286.1	2.7	288.8	290
	25	85.9	0.1	86.0	87
	30	25.8	-	25.8	27
	35	7.7	-	7.7	5
	40	2.3	-	2.3	2
	45	0.7	-	0.7	2
17500 to 21500	10	2760.1	1784.9	4545.0	4545
	15	949.3	63.7	1013.0	999
	20	326.5	2.3	328.8	351
	25	112.3	0.1	112.4	106
	30	38.6	-	38.6	37
	35	13.3	-	13.3	14
	40	4.6	-	4.6	5
	45	1.6	-	1.6	1
21500 to 29500	10	925.5	819.5	1745.0	1745
	15	254.3	29.2	283.5	283
	20	69.9	1.0	70.9	69
	25	19.2	-	19.2	23
	30	5.3	-	5.3	5
	35	1.4	-	1.4	1
Above 29500	$7\frac{1}{2}$	799.4	940.6	1740.0	1740
	10	412.4	177.7	590.1	593
	15	109.8	6.3	116.1	110
	20	29.2	0.2	29.4	33
	25	7.8	-	7.8	7
	30	2.1	-	2.1	3

Table 6

Ambassador - Gust frequency distributions

Flight condition	Altitude band feet	Mean altitude feet	Recorded time minutes	Statute miles	Number of times each gust speed was exceeded Vertical gust speed in ft/sec E.A.S.											
					Down					Up						
					30	25	20	15	10	10	15	20	25	30	35	40
Climb and descent (excluding initial climb and final descent intervals)	0-1500	1000	59	160				2	14	16	3	1				
	1500-3500	2600	2011	5953		2	9	24	160	310	66	17	6	1		
	3500-5500	4500	4914	15820			2	26	310	580	53	17	1			
	5500-9500	7200	7794	26780			4	27	220	370	57	9	1			
	9500-13500	11300	3403	12299	1	3	8	27	98	120	32	7	2	1		
	13500-17500	14900	988	3679	1	2	4	15	72	92	37	10	1			
	17500-21500	18800	48	184					0	0						
	21500-25500	23500	24	110					0	0						
TOTALS			19241	64985	2	7	27	121	874	1488	248	61	11	2		
Cruise	0-1500	500	262	697			1	19	190	200	50	15	6	2	1	
	1500-3500	2700	809	2668		1	3	22	130	230	45	7	1			
	3500-5500	4400	1273	4434			1	5	55	80	19	3				
	5500-9500	7700	13362	48709		3	13	41	170	260	47	9	3	2	1	1
	9500-13500	11600	11554	43326		1	3	9	41	56	7					
	13500-17500	15300	8995	34600			2	10	53	84	15	3				
	17500-21500	18800	797	3147					0	0						
TOTALS			37052	137 581		5	23	106	639	910	183	37	10	4	2	1

Table 7

Comet 1 - Gust frequency distributions

Flight condition	Altitude band feet	Mean altitude feet	Recorded time minutes	Statute miles	Number of times each gust speed was exceeded Vertical gust speed in ft/sec E.A.S.											
					Down							Up				
					40	35	30	25	20	15	10	10	15	20	25	30
Climb and descent (excluding initial climb and final descent intervals)	0-1500	1000	83	238								9	1			
	1500-3500	2600	458	1497				4	6	14	54	135	24	4	1	
	3500-5500	4600	1164	4130					1	14	140	292	59	16	6	3
	5500-9500	7600	5016	20723	1	2	2	7	20	95	556	980	193	39	5	1
	9500-13500	11300	4351	20863			1	1	3	14	115	197	19	3		
	13500-17500	15700	4333	22737				1	4	12	61	95	13	2		
	17500-21500	19600	5121	28401				1	5	14	76	109	29	7	2	
	21500-25500	23600	6363	37063				1	2	4	22	33	4	1		
	25500-29500	27600	7754	47329						2	27	27	4	1		
	29500-33500	31300	7753	50199						2	18	28	4	1		
	33500-37500	34800	2902	20699					1	1	8	11				
	37500-41500	38400	197	1538							0	0				
TOTALS			45495	255 417	1	2	3	15	42	172	1077	1916	350	74	14	4
Cruise	0-1500	900	432	1134					9	83	353	549	125	25	6	1
	1500-3500	2100	159	521						1	32	37				
	3500-5500	5000	55	204						2	23	59	11	3	1	
	5500-9500	6000	18	77												
	9500-13500	-	-	-												
	13500-17500	15100	171	876								5	1			
	17500-21500	19200	54	272								2	1			
	21500-25500	22600	45	243												
	25500-29500	28600	451	3036							5	11	3			
	29500-33500	32200	17114	121 442			1	1	1	8	49	57	9	3	2	1
	33500-37500	35400	35157	260 273				2	8	29	169	208	52	18	2	1
	37500-41500	38600	7502	57985						2	16	29	3	1		
	41500-45500	42800	56	436												
TOTALS			61214	446 499			1	3	18	125	647	957	204	50	11	3

Table 8

Bristol Freighter (S.C.A.) - Gust frequency distributions

Flight condition	Altitude band feet	Mean altitude feet	Recorded time minutes	Statute miles	Number of times each gust speed was exceeded Vertical gust speed in ft/sec E.A.S.												
					Down						Up						
					35	30	25	20	15	10	10	15	20	25	30	35	40
Initial climb	0-1500	400	2994	7577				2	40	359	1033	122	21	3	1		
Climb and descent	0-1500	600	2256	5262		1	2	3	11	125	254	29	3				
	1500-3500	2200	259	696						7	17	1					
	3500-5500	4400	45	123						3	5						
TOTALS			2560	6081		1	2	3	11	135	276	30	3				
Cruise	0-1500	800	15201	39276				5	68	644	1391	171	27	6	2		
	1500-3500	2100	3683	9991				3	18	186	492	51	3	1			
	3500-5500	4200	623	1732						1	4						
	5500-9500	6000	119	323						1	5	1					
TOTALS			19631	51322				8	86	832	1892	223	30	7	2		

Table 9

Bristol Freighter (S.C.A.) - Gust frequency distributions

Flight condition	Altitude band feet	Mean altitude feet	Recorded time minutes	Statute miles	Number of times each gust speed was exceeded. Vertical gust speed in ft/sec E.A.S.														
					Down							Up							
					40	35	30	25	20	15	10	10	15	20	25	30	35	40	45
Initial climb	0-1500	500	2389	5991	1	1	2	3	23	118	758	2095	307	56	12	1			
	1500-3500	2200	376	968					1	10	79	192	33	5					
TOTALS			2765	6959	1	1	2	3	24	128	837	2287	340	61	12	1			
Climb and descent	0-1500	800	1945	4877	1	1	2	4	15	76	455	1636	237	50	13	5	3	2	1
	1500-3500	2300	1224	3346				1	10	41	258	647	104	17	5	2			
	3500-5500	4400	594	1651					4	16	62	96	15	3					
	5500-10500	7000	228	611					1	3	11	4							
TOTALS			3991	10485	1	1	2	5	30	136	786	2383	356	70	18	7	3	2	1
Cruise	0-1500	1000	13145	34839			2	7	27	172	1505	3560	371	52	9	2			
	1500-3500	2400	8031	21803			1	2	18	121	707	1859	220	43	11	4	2		
	3500-5500	4300	4086	11105					3	45	307	553	71	16	5	3	1		
	5500-9500	6800	2512	6881			1	2	9	23	101	90	30	3					
	9500-13500	10600	67	185							2	1							
TOTALS			27841	74813			4	11	57	361	2622	6063	692	114	25	9	3		

Table 10

Hermes 4A (Airwork) - Gust frequency distributions

Flight condition	Altitude band feet	Mean Altitude feet	Recorded time minutes	Statute miles	Number of times each gust speed was exceeded. Vertical gust speed in ft/sec E.A.S.																
					Down							Up									
					40	35	30	25	20	15	10	10	15	20	25	30	35	40	45	50	55
Climb and descent (excluding initial climb and final descent)	0–1500	1000	100	246					3	18	186	234	32	6	3	2	1	1			
	1500–3500	2690	1733	5086				2	17	117	832	1177	184	31	3	1					
	3500–5500	4510	3550	11273				1	11	68	452	597	107	24	5	1					
	5500–9500	7100	9269	31639			2	4	14	55	356	559	100	20	4	1	1				
	9500–13500	10450	915	3200						1	33	27	3	1	1						
TOTALS			15567	51462			2	7	45	259	1859	2594	426	82	16	5	2	1			
Cruise	0–1500	870	110	306			1	3	24	67	167	434	136	41	14	5	4	4	4	2	1
	1500–3500	2270	150	445				1	6	46	436	347	62	14	3						
	3500–5500	4830	292	981					2	8	90	123	9	2							
	5500–9500	8680	69309	241473	1	2	5	19	84	319	1653	1857	412	106	22	8	3				
	9500–13500	10290	56746	199937		1	7	23	90	300	1172	1154	308	100	24	12	4	3	1		
TOTALS			126607	443142	1	3	13	46	206	740	3518	3915	927	263	63	25	11	7	5	2	1

Table 11

Hermes 4 (B.O.A.C.) - Gust frequency distributions

Flight condition	Altitude band feet	Mean altitude feet	Recorded time minutes	Statute miles	Number of times each gust speed was exceeded. Vertical gust speed in ft/sec E.A.S.															
					Down								Up							
					45	40	35	30	25	20	15	10	10	15	20	25	30	35	40	45
Climb and	0-1500	900	135	336							2	13	184	60	20	5	1			
descent	1500-3500	2300	866	2470					1	6	20	77	275	59	22	5	3	1		
(excluding	3500-5500	5000	1899	5876				1	3	12	42	136	208	59	14	3	1			
initial	5500-9500	8700	6332	22038					2	21	78	286	560	164	46	4	1	1	1	1
climb and	9500-13500	12000	4890	18040				2	5	19	70	224	318	104	27	6	2			
final	13500-17500	16000	1414	5556					1	1	4	16	19	3	1					
descent)	17500-21500	18600	173	733								-	-							
TOTALS			15709	55049				3	12	59	216	752	1564	449	130	23	8	2	1	1
Cruise	0-1500	900	145	364						4	32	239	199	62	19	6	2			
	1500-3500	2100	96	271						2	5	18	59	25	4					
	3500-5500	4700	102	348								4	7							
	5500-9500	8400	1612	5864		1	1	1	2	18	32	64	136	42	11	3				
	9500-13500	12000	70933	263625			3	5	13	48	200	802	1100	274	68	18	8	4	1	
	13500-17500	15000	17494	66706						7	30	213	190	34	6					
	17500-21500	18500	8498	34186	1	1	1	1	3	7	17	57	70	23	6	1				
	21500-25500	22000	63	249								-	-							
TOTALS			98945	371613	1	2	5	7	18	86	306	1397	1761	460	114	28	10	4	1	

Table 12

Stratocruiser - Gust frequency distributions

Flight condition	Altitude band feet	Mean altitude feet	Recorded time minutes	Statute miles	Number of times each gust speed was exceeded Vertical gust speed in ft/sec E.A.S. (+Up, -Down)										
					Down					Up					
					30	25	20	15	10	10	15	20	25	30	35
Initial climb	0-1500	1000	664	2192			1	16	136	245	30	4	1		
	1500-3500	2100	209	676		1	7	23	112	201	46	8	2		
	3500-5500	4800	42	160					2	6					
	5500-9500	7200	17	69					5	10	2				
TOTALS			932	3097		1	8	39	255	462	78	12	3		
Final descent	0-1500	500	576	1552		1	8	29	197	411	110	21	2	1	1
	1500-3500	2200	25	89					4	8					
TOTALS			601	1641		1	8	29	201	419	110	21	2	1	1
Climb and descent	0-1500	1000	142	397				4	33	71	18	3			
	1500-3500	2700	1868	6370			3	27	255	780	126	21	1		
	3500-5500	4500	3032	11302		1	11	65	401	740	138	22	1		
	5500-9500	7500	7509	30535		1	12	57	362	686	124	18	2		
	9500-13500	11500	5156	22040		2	8	33	158	194	45	15	2		
	13500-17500	15400	4781	21017			3	9	42	60	8	1			
	17500-21500	18800	1248	5719	2	5	13	32	144	145	58	24	4		
TOTALS			23736	97380	2	9	50	227	1395	2676	517	104	10		
Cruise	0-1500	1000	581	1825	1	2	6	35	145	314	74	13	5		
	1500-3500	2400	1629	5830			3	19	124	311	30	1			
	3500-5500	4400	1761	6792			8	34	187	313	67	14	3		
	5500-9500	7600	26378	104969		3	26	128	742	981	251	57	11	3	1
	9500-13500	11000	57991	235332		1	15	84	574	806	148	22	4	1	
	13500-17500	15500	40397	171556	2	5	18	65	306	437	80	15	4	1	
	17500-21500	19100	49593	220115	3	9	36	97	725	734	136	32	2		
	21500-25500	22900	2636	12270				3	83	70	5				
TOTALS			180966	758689	6	20	112	465	2886	3966	791	154	29	5	1

Table 13

Super-constellation - Gust frequency distributions

Flight condition	Altitude band feet	Mean altitude feet	Recorded time minutes	Statute miles	Number of times each gust speed was exceeded. Vertical gust speed in ft/sec E.A.S. — Down 45	Down 40	Down 35	Down 30	Down 25	Down 20	Down 15	Down 10	Up 10	Up 15	Up 20	Up 25	Up 30	Up 35	Up 40	Up 45	Up 50
Initial climb	0-1500	1500	1541	4768				5	17	31	119	693	1377	151	33	19	5				
	1500-3500	2000	129	409							3	35	67	7							
TOTALS			1670	5177				5	17	31	122	728	1444	158	33	19	5				
Final descent	0-1500	500	1095	2925				2	4	15	67	388	1135	223	58	22	11	4	2		
	1500-3500	2000	10	27								2	8	1	1	1					
TOTALS			1105	2952				2	4	15	67	390	1143	224	59	23	11	4	2		
Climb and descent (excluding initial climb and final descent intervals)	0-1500	1000	1133	3189				1	3	15	63	288	889	146	36	8	2				
	1500-3500	2600	4106	13564					4	11	62	383	1172	169	37	12	3	2	2	1	1
	3500-5500	4500	3827	13951					4	16	54	298	582	98	29	10	1				
	5500-9500	7600	8158	32001		1	1	4	14	35	115	427	780	142	33	15	5	2	1		
	9500-13500	11500	7214	30119				1	6	11	28	122	249	33	9	2					
	13500-17500	15500	5518	24229				1	2	6	21	84	110	21	4	1					
	17500-21500	18100	425	1932					1	1	3	5	11	1							
TOTALS			30381	118985		1	1	7	34	95	346	1607	3793	610	148	48	11	4	3	1	1
Cruise	0-1500	1000	48	136					1	1	3	16	54	8							
	1500-3500	2500	144	504						2	5	20	40	5	1						
	3500-5500	4400	170	598								20	49	11	2	1					
	5500-9500	8300	3137	13278				2	4	7	29	139	170	24	6	1					
	9500-13500	11200	60729	266542		1	3	11	38	117	278	1261	1634	277	92	24	5	1			
	13500-17500	16100	91037	418792	2	2	4	12	29	78	223	897	1459	244	78	26	7	1			
	17500-21500	18700	36037	171717		1	2	6	14	47	133	598	565	100	33	10	3				
TOTALS			191302	871567	2	4	9	31	86	252	671	2951	3971	669	212	62	15	2			

Table 14

Viking (B.E.A.) - Gust frequency distributions

Flight condition	Altitude band feet	Mean altitude feet	Recorded time minutes	Statute miles	Number of times each gust speed was exceeded Vertical gust speed in ft/sec E.A.S.									
					Down					Up				
					30	25	20	15	10	10	15	20	25	30
Climb and descent (excluding initial climb and final descent intervals)	0-1500	600	200	506				5	82	126	26	2		
	1500-3500	2400	2059	5640		1	7	51	367	642	93	18	3	1
	3500-5500	4500	2867	8860		2	7	40	259	392	46	11		
	5500-9500	6800	2605	8460				12	108	162	23	2	1	
TOTALS			7731	23466		3	14	108	816	1322	188	33	4	1
Cruise	0-1500	900	620	1740			2	37	250	450	57	5	1	
	1500-3500	2500	2709	8020	1	2	5	45	360	520	55	9	2	1
	3500-5500	4700	4400	13700		1	4	22	198	235	29	6		
	5500-9500	7500	19478	62800		2	14	70	448	408	59	14	2	
	9500-13500	10100	2373	7790			1	8	72	88	9	2		
TOTALS			29580	94050	1	6	26	182	1328	1701	209	36	5	1

Table 15

Viking (C.A.A.) - Gust frequency distributions

Flight condition	Altitude band feet	Mean altitude feet	Recorded time minutes	Statute miles	Number of times each gust speed was exceeded. Vertical gust speed in ft/sec E.A.S. Down					Up								
					30	25	20	15	10	10	15	20	25	30	35	40	45	50
Climb and descent (excluding initial climb and final descent intervals)	0-1500	1000	10	22		1	2	5	19	24	3							
	1500-3500	2400	48	143			1	2	7	3								
	3500-5500	4700	403	1180			2	13	89	145	29	1						
	5500-9500	7500	4408	13641		2	13	108	850	1281	149	21	5	1				
	9500-13500	10600	816	2636		1	1	12	109	149	15	1						
	13500-17500	14500	19	68					-	-								
TOTALS			5704	17690		4	19	140	1074	1602	196	23	5	1				
Cruise	0-1500	1000	29	77			1	5	24	28	8	3	1	1				
	1500-3500	2800	144	426			1	6	33	32	7	3	1					
	3500-5500	4800	442	1262			6	23	107	216	44	6						
	5500-9500	7900	13603	42750			7	133	1053	1701	174	25	4	1	1	1	1	1
	9500-13500	10700	7315	23498	2	5	18	112	546	705	115	22	9	6	2			
	13500-17500	14000	115	384					11	7	2							
TOTALS			21648	68297	2	5	33	279	1774	2689	350	59	15	8	3	1	1	1

Table 16

Viscount (B.E.A. and Aer Lingus) - Gust frequency distributions

Flight condition	Altitude band feet	Mean altitude feet	Recorded time minutes	Statute miles	Number of times each gust speed was exceeded. Vertical gust speed in ft/sec E.A.S.													
					Down							Up						
					40	35	30	25	20	15	10	10	15	20	25	30	35	40
Initial climb	0-1500	1000	694	2459					1	11	112	182	19	2				
	1500-3500	2200	3080	10075				2	19	134	1153	1703	229	39	4	1		
	3500-5500	4200	49	159						2	25	29	3					
TOTALS			3823	12693				2	20	147	1290	1914	251	41	4	1		
Final descent	0-1500	700	1385	3885				1	5	54	524	1000	139	22	5	1	1	1
	1500-3500	2200	394	1217						6	86	179	15	2	1			
	3500-5500	4300	21	74							-	2	1					
TOTALS			1800	5176				1	5	60	610	1181	155	24	6	1	1	1
Climb and descent	0-1500	1000	411	1119				3	8	24	171	327	49	11	2			
	1500-3500	2600	2883	8851				7	31	124	841	1461	244	52	15	4	1	
	3500-5500	4600	4308	14868			1	3	13	63	651	1012	126	18	2	1		
	5500-9500	7500	12325	44951			3	18	47	126	866	1222	197	39	4	2		
	9500-13500	11700	13291	51352		1	2	3	14	55	552	452	88	18	1			
	13500-17500	15500	18935	79479				1	12	42	270	309	51	11	5			
	17500-21500	19200	7385	32843			1	4	11	35	191	175	38	13	6	2		
	21500-25500	22900	1654	7873				2	6	17	93	97	14	4	1			
	25500-29500	26900	74	356					1	12	56	52	10	1	1			
TOTALS			61324	242 272		1	7	41	143	493	3[illegible]69	5107	817	167	37	9	1	
Cruise	0-1500	900	676	1686				2	7	95	462	733	116	29	3	1	1	
	1500-3500	2400	954	3510					3	17	251	403	70	12	3	1	1	
	3500-5500	4300	825	2933					1	6	46	116	14	3	1	1		
	5500-9500	7600	1122	4614				1	3	8	51	44	8	2				
	9500-13500	11400	2515	11023					1	12	59	151	34	6	1			
	13500-17500	16000	7216	37023				1	2	5	41	31	8	3	1			
	17500-21500	19900	46558	229 686		4	8	19	48	101	504	303	99	37	14	7	4	2
	21500-25500	23000	45307	230 482			1	4	18	89	492	516	93	27	9	3	1	
	25500-29500	26500	4078	20615			1	1	3	14	75	80	9	5	4			
TOTALS			109 859	541 784		4	10	28	86	347	1831	2577	451	124	36	13	7	2

Table 17

Viscount (C.A.A.) - Gust frequency distributions

Flight condition	Altitude band feet	Mean altitude feet	Recorded time minutes	Statute miles	Number of times each gust speed was exceeded Vertical gust speed in ft/sec E.A.S.													
					Down						Up							
					35	30	25	20	15	10	10	15	20	25	30	35	40	45
Initial climb	0-1500	1000	34	103					4	30	83	12	2	1				
	1500-3500	2800	493	1501				3	22	236	342	33	4	1				
	3500-5500	4000	226	691		1	2	3	9	126	187	18	1					
TOTALS			753	2295		1	2	6	35	392	612	63	7	2				
Final descent	0-1500	700	51	140					4	70	84	12	2					
	1500-3500	2500	26	71					1	24	22							
	3500-5500	4600	232	658				1	19	261	289	45	10	2				
	5500-9500	6300	48	150					2	36	42	5						
TOTALS			357	1019				1	26	391	437	62	12	2				
Climb and descent	0-1500	1000	14	37					5	24	19	3						
	1500-3500	2600	83	242						24	33	4						
	3500-5500	4700	212	632					8	87	105	13	1					
	5500-9500	7800	1648	5300			1	7	51	371	393	50	8	2				
	9500-13500	11900	2189	7953		1	3	7	27	123	109	23	7	4	2			
	13500-17500	15200	2384	9354			4	9	26	118	104	26	5	1	1			
	17500-21500	18700	522	2172			1	4	10	29	26	9	3	1	1	1	1	
	21500-25500	22600	43	182						-	-							
TOTALS			7095	25872		1	9	27	127	776	789	128	24	8	4	1	1	
Cruise	0-1500	800	13	35					7	46	73	14	2					
	1500-3500	2200	17	46						16	18	12	1					
	3500-5500	4700	96	276				1	8	54	66	13	3	1				
	5500-9500	7200	207	790				1	5	40	50	9	3	1				
	9500-13500	12000	658	2791			1	2	9	39	35	11	3	1				
	13500-17500	16000	4971	22571					5	37	61	17	5	2	2			
	17500-21500	18800	6623	30741	1	2	4	10	26	96	100	37	14	5	1	1		
	21500-25500	22800	672	3315						3	3							
	25500-29500	26900	11	58						-	-							
TOTALS			13268	60623	1	2	5	14	60	331	406	113	31	10	3	1		

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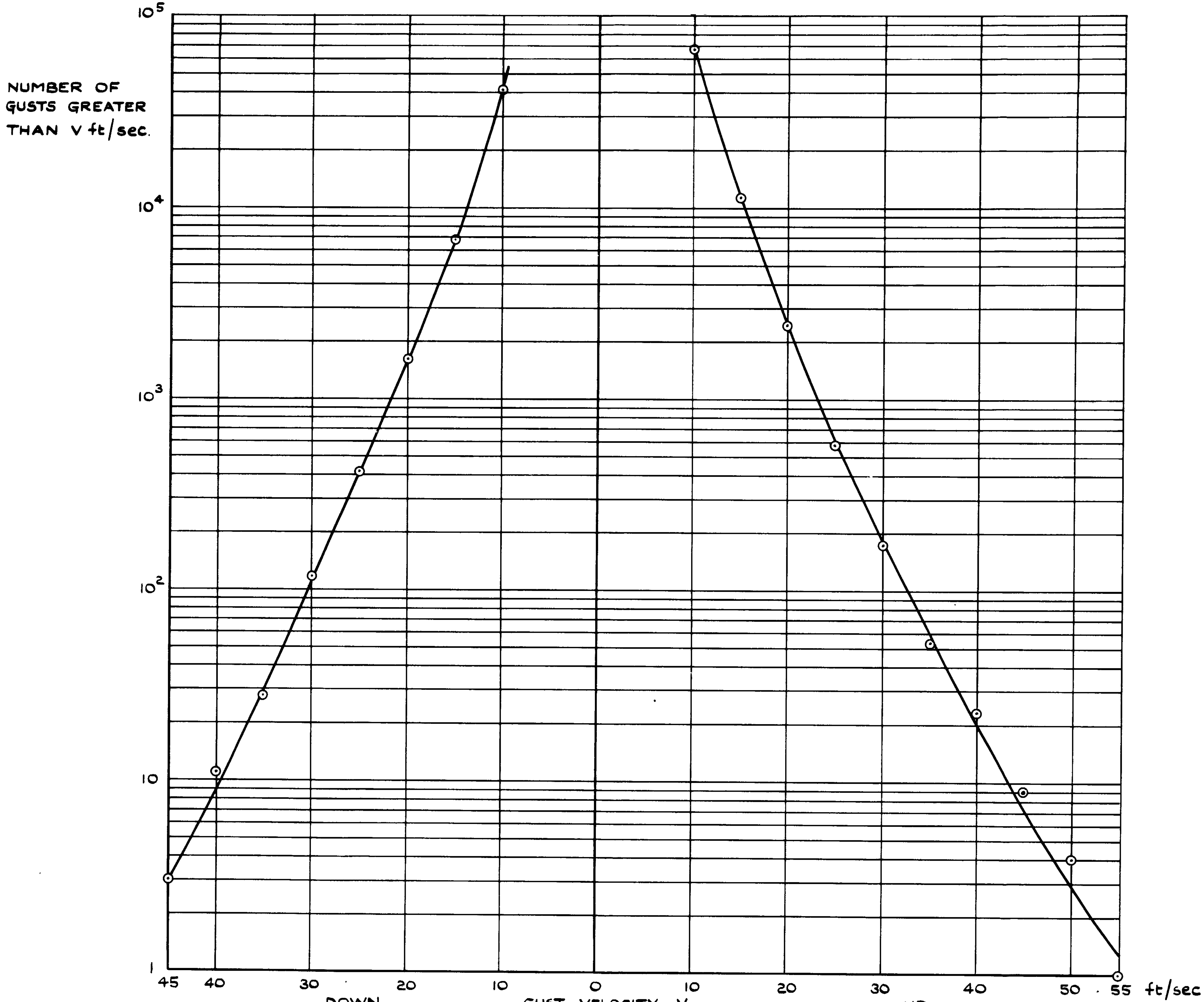

FIG. 1 TOTAL NUMBERS OF GUSTS OBSERVED DURING ALL FLYING

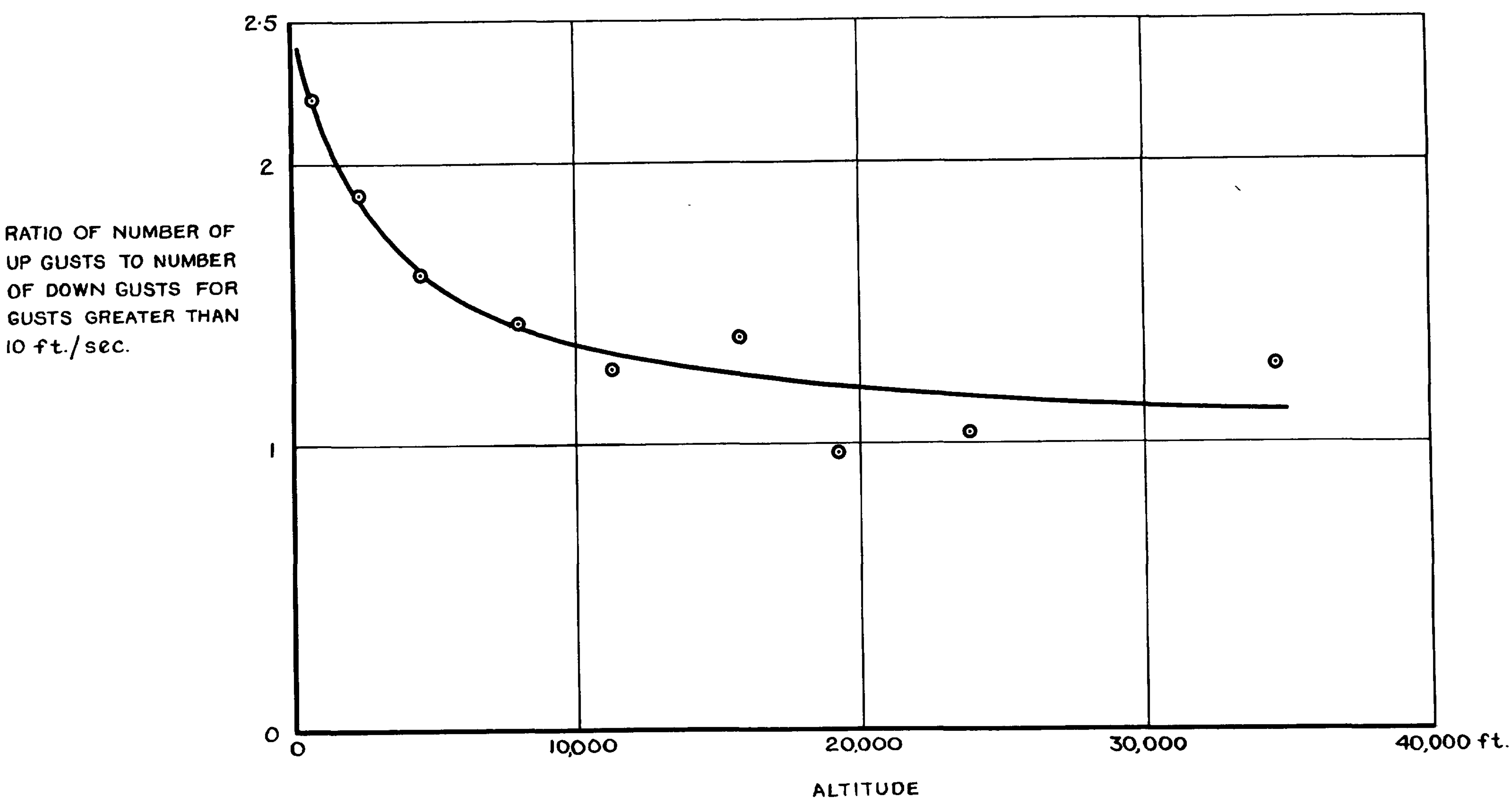

FIG. 2 VARIATION WITH ALTITUDE OF RATIO OF NUMBER OF UP GUSTS TO NUMBER OF DOWN GUSTS

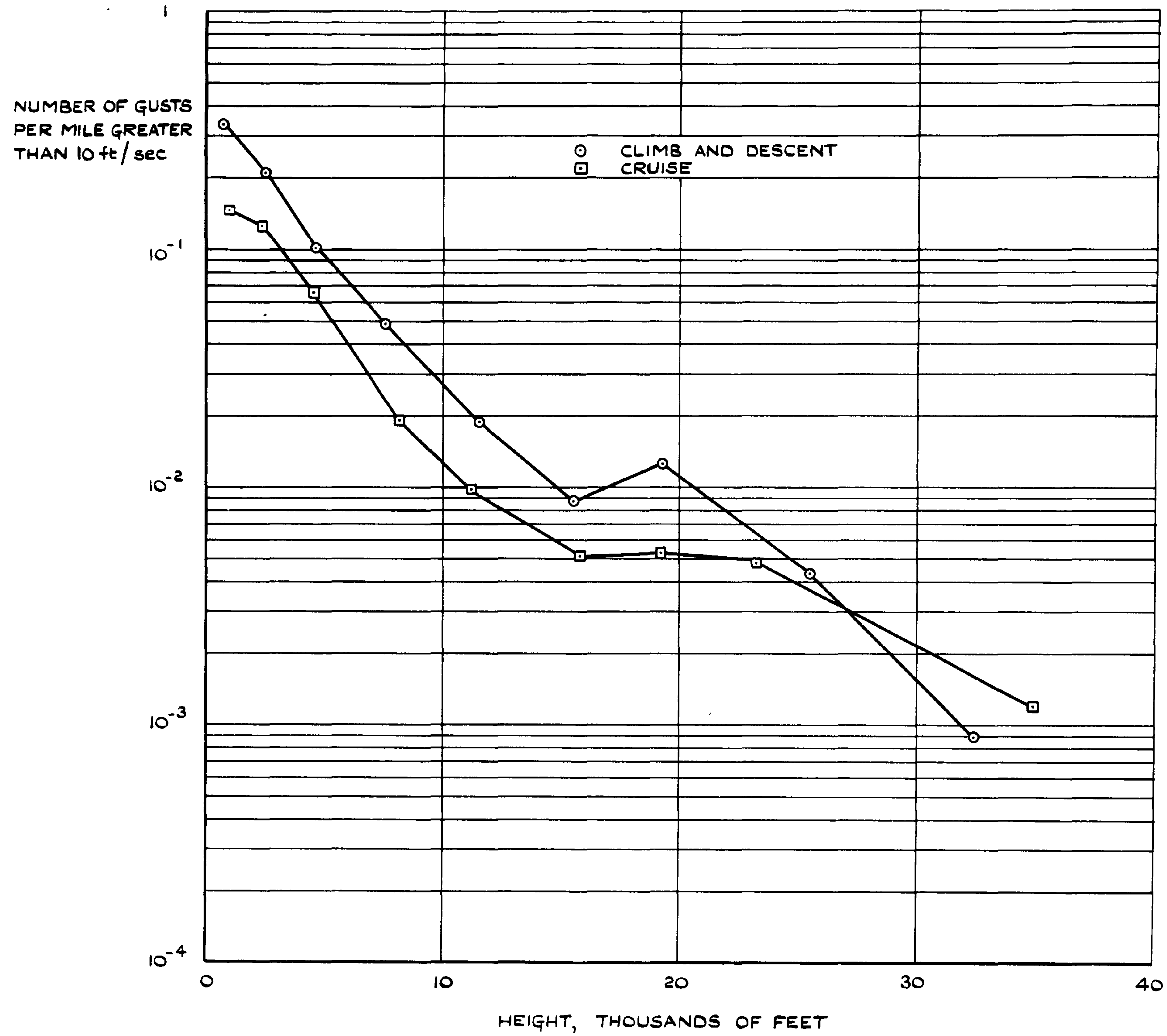

FIG. 3 NUMBER OF GUSTS PER MILE GREATER THAN 10 ft /sec. IN CLIMB AND DESCENT, AND CRUISE

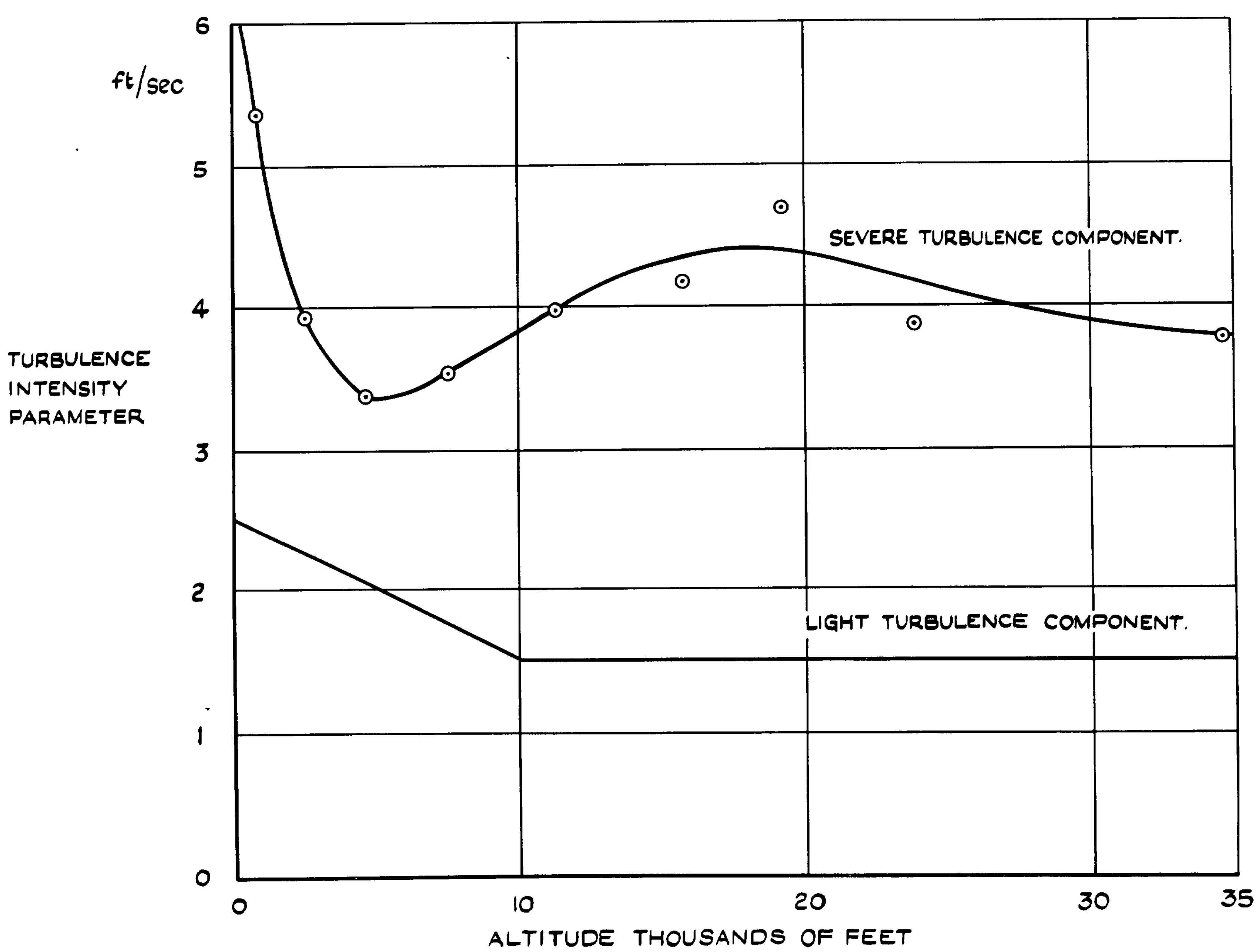

FIG. 4 VARIATION OF TURBULENCE INTENSITY WITH ALTITUDE.

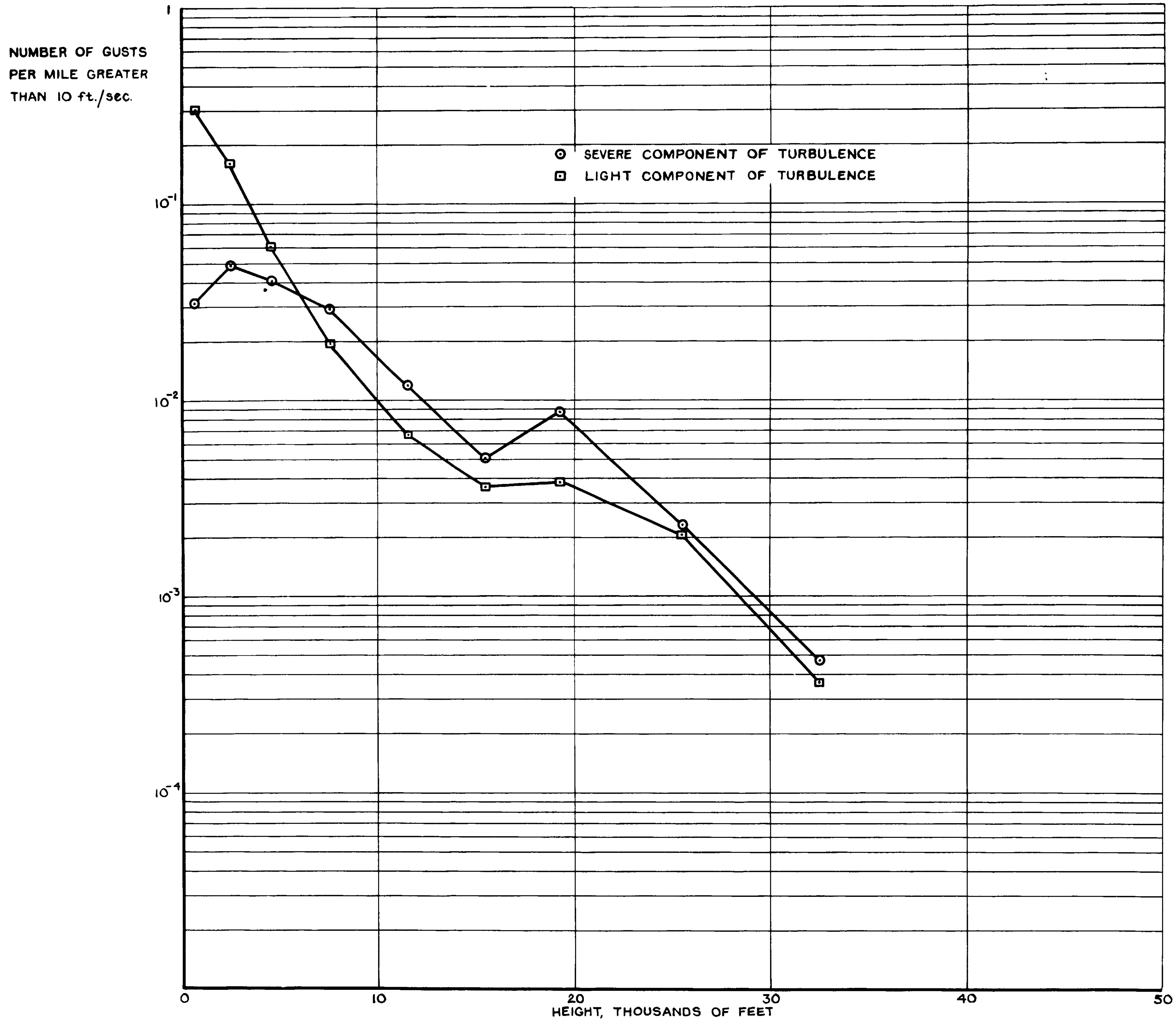

FIG. 5 NUMBERS OF GUSTS PER MILE FROM EACH COMPONENT OF TURBULENCE DURING CLIMB & DESCENT

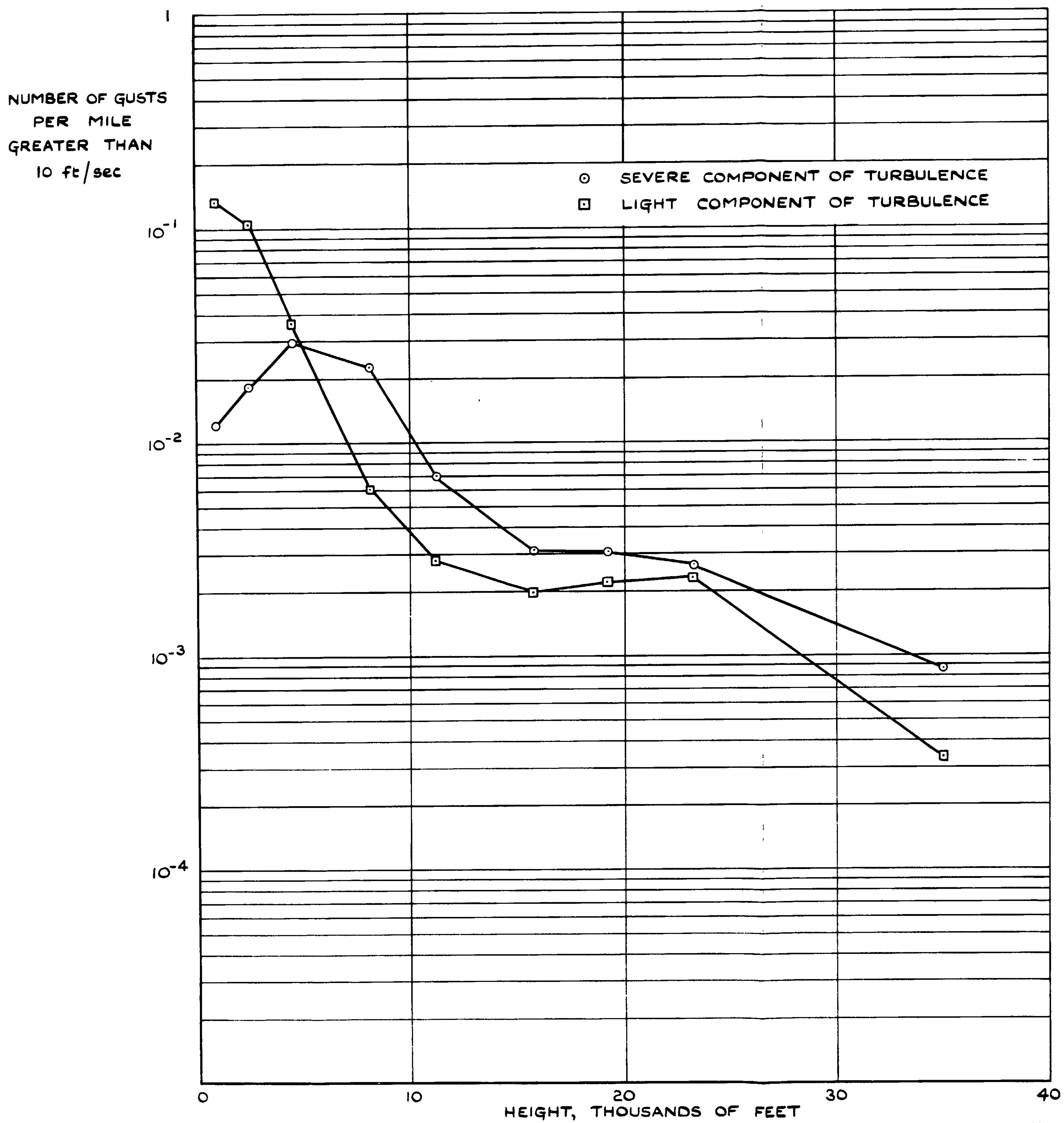

FIG.6 NUMBERS OF GUSTS PER MILE FROM EACH COMPONENT OF TURBULENCE DURING CRUISE

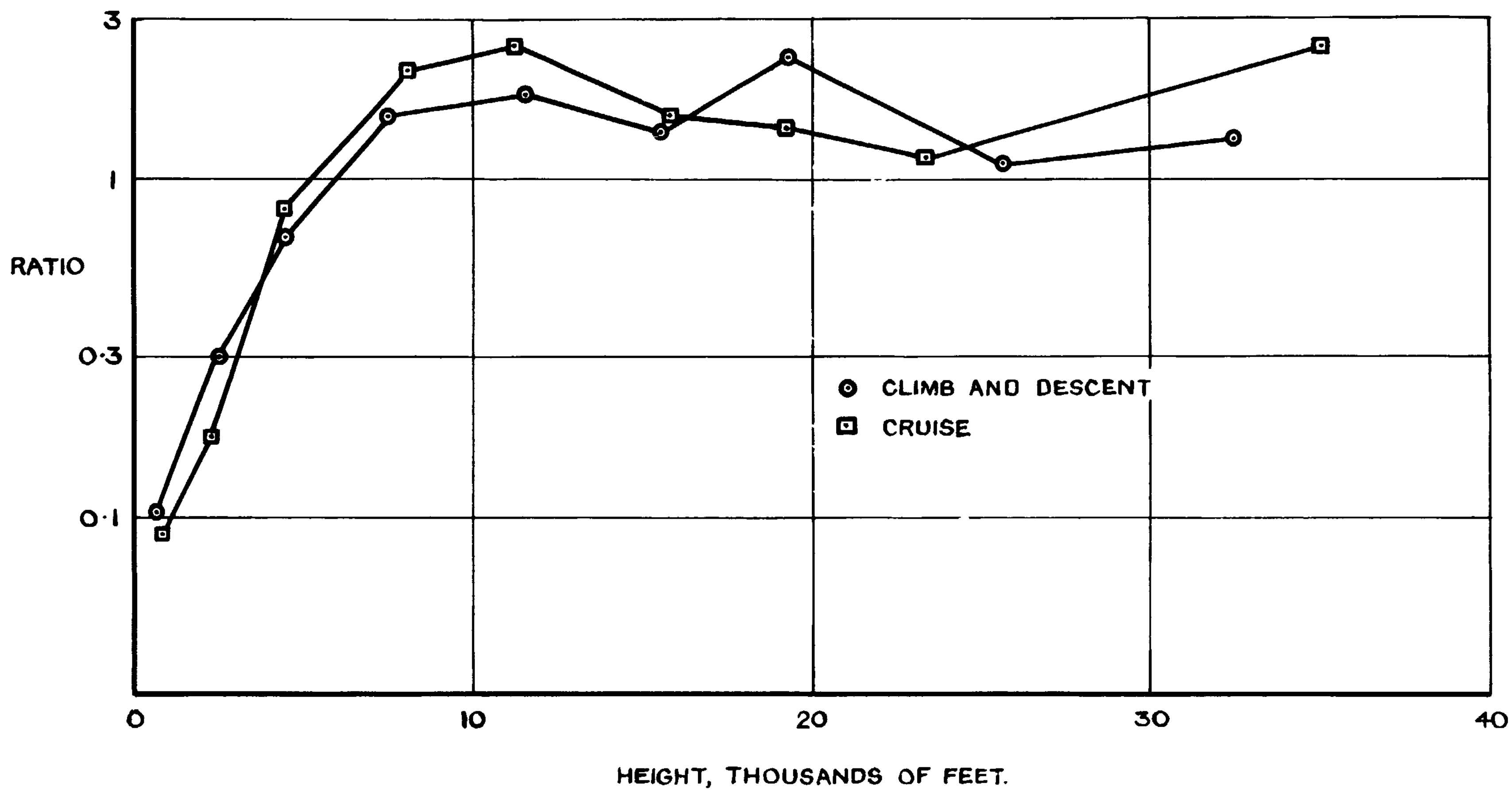

FIG. 7 RATIO OF THE NUMBER OF GUSTS GREATER THAN 10 ft./sec. FROM THE SEVERE TURBULENCE COMPONENT TO THE NUMBER FROM THE LIGHT COMPONENT

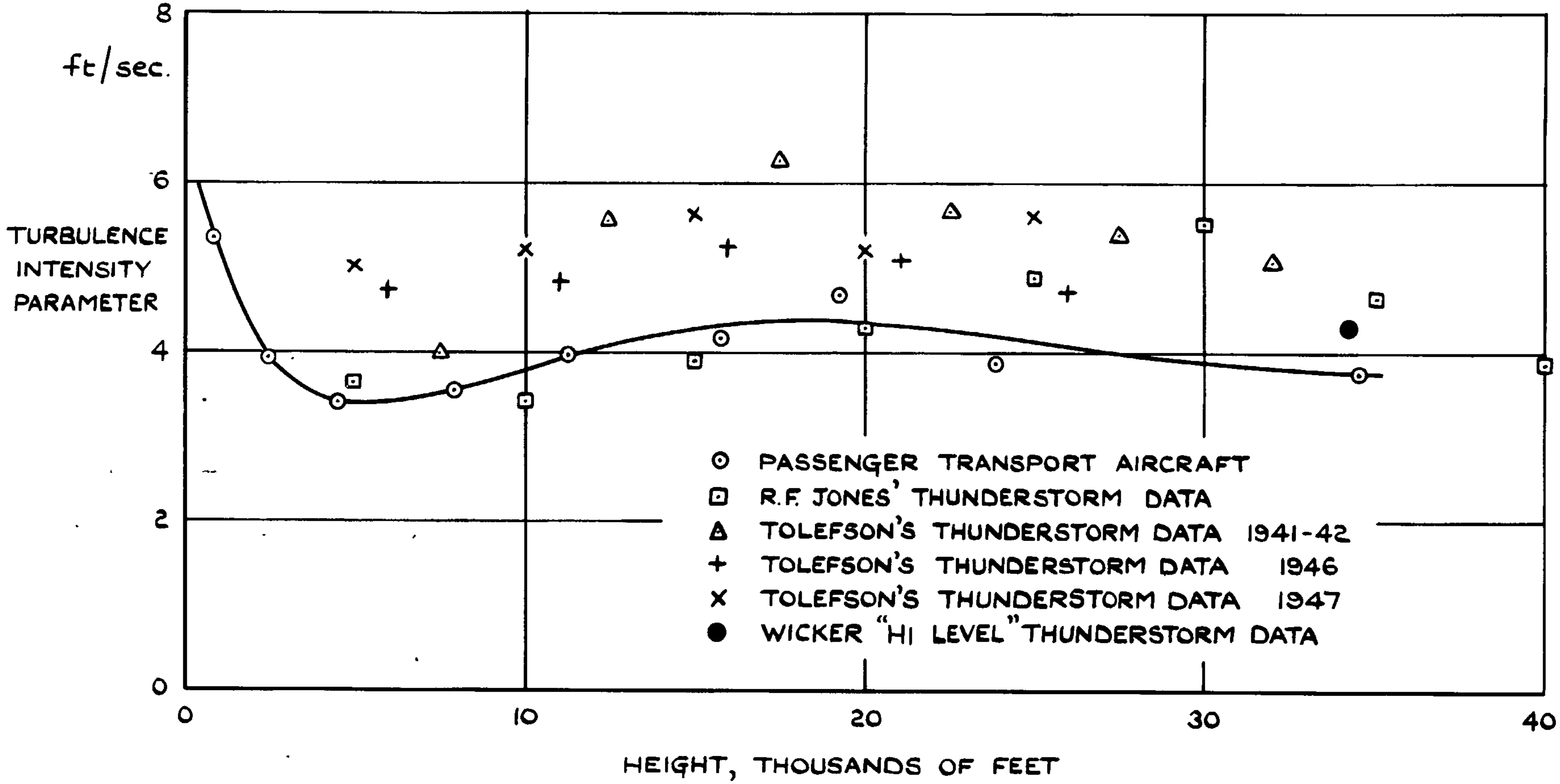

FIG. 8 INTENSITIES OF STORM TURBULENCE

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