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Atmospheric Turbulence Encountered by Hermes Aircraft

By

J.R.Heath-Smith, B.Sc.(Eng.)

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Atmospheric Turbulence encountered by Hermes aircraft

by

J.R. Heath-Smith, B.Sc.(Eng)

SUMMARY

Acceleration records were obtained of the turbulence encountered by B.O.A.C. Hermes aircraft in 417,000 miles of operational flying on routes from London to East and West Africa. It is shown that turbulence decreases with increasing altitude. A result of the pilot's discretion in choice of altitude and course is that the gust frequency encountered during most of the cruise is about one third of the average atmospheric gust frequency. Between 9,500 feet and 14,500 feet gusts were encountered four times as frequently over East and West African sectors as over European sectors.

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1 Introduction

Counting Accelerometers were carried in Hermes IV aircraft of the British Overseas Airways Corporation and acceleration records were obtained in the turbulence encountered in 417,000 miles of normal passenger service between London and Africa.

The records are examined to determine the variation of turbulence with altitude and the difference in turbulence between sectors of the route in the altitude band 9,500 ft to 14,500 ft.

2 Description of equipment and flying

2.1 Instrument and Installation

The Counting Accelerometer[1] responds to the accelerations imposed on it in one direction and records the number of times each of a series of acceleration levels has been exceeded. Successive counters represent levels at intervals of 0.1g and readings are given for a range of 1.2g to 2.9g for upward accelerations and from 0.8g to -0.9g for downward accelerations. These values are nominal and have been corrected in this report except where it is stated otherwise. An altimeter, airspeed indicator and clock are grouped round the counter dial and the whole assembly is photographed at regular intervals of approximately 10 minutes.

The Counting Accelerometer was rigidly attached to the airframe close to the centre of gravity in such an attitude that vertical accelerations were recorded during level flight.

2.2 The flying covered by the records

The records were made between April 1952 and October 1953 on 487 flights covering 417,000 miles of normal passenger service on routes between London and East and West Africa. Details of the main routes are shown in Fig. 1. The distribution of recording time between months of the year is shown in Fig. 2. The instruments were fitted at different times to various aircraft of the fleet.

3 Variation in turbulence with altitude

The records are of average duration 10.4 minutes and contain the counts of acceleration during the interval and the speed, altitude and weight of the aircraft at the end of this interval. Appendix I describes the corrections which are made to these readings and the method[2,3] of translating the accelerations into gust speeds.

Table I is a summary of the counts of acceleration grouped according to speed, altitude and weight. Tables II and III show the distribution of recording intervals according to their content of acceleration increments. (This information is required for subsequent work.)

On the basis of Table I an estimate is given in Table IV of the gust speeds in each altitude band. Fig. 3 shows the gust frequencies and their variation with altitudes. Fig. 4 shows directly the variation with altitude of the frequency of gust speeds greater than 10, 15 and 20 ft/sec E.A.S.; the frequencies of exceeding greater levels are not included as they were not recorded in significant numbers over the whole altitude range. As upward and downward gusts were found in about equal numbers Fig. 3 and 4 are based on the sum of the two, and thus give the frequency of a gust whether it is up or down.

Table V shows the time spent at each altitude on the principal sectors of the routes and it is seen that two bands were used for

cruising centred on about 12,000 ft and 18,000 ft. Examination of the consecutive flight records shows that all flights commenced with a moderate climb at about 500 feet/minute to about 12,000 feet where the cruise commenced. In about two thirds of the flights the aircraft remained at 12,000 feet for the whole cruise but in the remainder of the flights, after 1 hour or more at this altitude the aircraft climbed to about 18,000 feet to complete the cruise. Flight at 18,000 feet occurred most frequently, but not exclusively, over high ground.

The influence of the aircraft operating conditions on the shape of the curves of Fig. 4 is now discussed. As the curves are of similar shape attention will be confined to the 10 ft/sec curve. It is assumed on the basis of previous work[4] that yearly average atmospheric turbulence decreases exponentially with height and therefore may be represented on the logarithmic scale of Fig. 4 by a straight line. The position of this line is determined at low altitudes by the recorded turbulence for the lowest altitude band (sea level to 2,500 feet) because the aircraft flew at these altitudes in all weather conditions and, further, as the aircraft was under ground control there was little possibility of avoiding turbulence by deviating from course. Between 2,500 and 7,500 feet the turbulence was recorded entirely during climb and descent, again in all weather conditions, but as avoidance of turbulence by altering course is considered more possible than at the lowest altitudes, the recorded turbulence is expected to be less severe than the atmospheric average. The bands 7,500 - 12,500 feet and 12,500 - 17,500 feet contain the cruising altitudes of the aircraft and the recorded turbulence will be less severe than average to the extent of the pilot's ability to avoid turbulence by a change of course or altitude.

It was stated previously that the aircraft cruised at 12,000 feet or 18,000 feet and it is possible that the pilot avoided the worst turbulence at 12,000 feet by climbing to 18,000 feet. Thus the recorded turbulence at about 12,000 feet would be less severe than average and at 18,000 feet would be more severe than average.

These considerations explain why the observed values of Fig. 4 lie above the line suggested for average turbulence conditions. It is concluded that discretion on the part of the pilot is important in reducing the number of gust loads experienced by an aircraft. In the present instance the turbulence experienced by the aircraft is reduced generally by a factor of 3.

4 Turbulence over different regions of the route

Table V shows the time spend at all altitudes during climb, cruise and descent for three geographical regions. These regions are defined in Fig. 1 and are related to the routes flown.

To compare the turbulence over different geographical regions it is necessary to use samples which were obtained under similar flying conditions in a restricted altitude band. Table V shows that the cruising records in the band 9,500 feet to 14,500 feet from fairly representative samples of turbulence in the different regions and a summary of the regional accelerations in this altitude band is given in Table VI. The numbers of gusts exceeding 10 ft/sec and their relative frequencies in different geographical regions are given in Table VII.

The relative frequencies indicate that recorded turbulence is of the same intensity in East and West Africa and is about four times greater than over Europe. This result is not necessarily true of average atmospheric turbulence as the extent to which the pilot avoids turbulence depends on factors in which the geographical regions may differ, such as frequency of the turbulence and associated cloud conditions, congestion of air routes, etc.

5 Conclusions

Examination of gust acceleration records from Hermes aircraft flying between London and East and West Africa lead to the following conclusions.

(i) There is a continuous decrease in the number of gusts with increasing altitude from sea level to 20,000 feet.

(ii) The pilot's discretion in choice of altitude and course with regard to weather conditions results in the turbulence experienced by the aircraft during cruising flight being about one third as frequent as average atmospheric turbulence.

(iii) At moderate cruising altitudes the Hermes aircraft encountered gusts about four times as frequently over East Africa and West Africa as over Europe.

Acknowledgements

Thanks are due to the British Overseas Airways Corporation for their co-operation in installing and servicing the instruments.

REFERENCES

No.	Author	Title etc.
1	J. Taylor	Accelerometer for determining aircraft flight loads. Engineering. 11th and 18th April, 1952
2	-	Air Publication 970, Chapter 203
3	J.K. Zbrozek	Gust Alleviation Factors R & M No. 2812 June, 1950
4	J.R. Heath-Smith	Turbulence encountered by Comet I aircraft Current Paper No. 248, 1956

APPENDIX I

Corrections to acceleration data and calculation of gust speed

Data

The data are consecutive readings of airspeed, altitude and weight at an average interval of 10.4 minutes and the counts of acceleration during each interval. The airspeed is read to the nearest 10 knots, I.A.S., the altitude is read to the nearest 1,000 feet, I.C.A.N., above sea level and the weight is estimated to the nearest 1,000 lb.

Corrections

Those records which may contain the effects of ground loads are discarded with the result that on an average the first and last 5.2 minutes of each flight are excluded from the analysis.

The airspeed associated with the acceleration counts is the average of the initial and final airspeed of the interval, rounded down to 10 knots. The altitude associated with the counts is also the average of the initial and final readings, rounded down, except where the change in altitude was less than 2 nominal units of 1,000 feet during the interval, in which case the final altitude of the interval is used.

The acceleration thresholds are corrected for the instrument error which is given in the footnote to Table I.

Analysis

It is assumed that the normal acceleration at the instrument position is that at the centre of gravity of the aircraft. The recorded accelerations are translated into vertical gust speeds by the following method.

Aircraft weight is divided into 10,000 lb loads centred on 64,500 lb, 74,500 lb and 84,500 lb.

Airspeed bandwidth is 10 knots.

The altitude range is divided into a sea level band up to 2,500 feet and bands of 5,000 feet width centred on 5, 10, 15 and 20,000 feet.

The counts of acceleration are grouped according to the altitude, weight and speed of the aircraft and the gust speed corresponding with each group is found from the formula:

$$U = \frac{\Delta n \; w}{F \, \frac{1}{2} \, \rho_o \, a_o V}.$$

U equivalent vertical gust speed

Δng normal acceleration increment

w wing loading

F gust alleviation factor*

ρ_o air density at sea level (I.C.A.O.)

a_o slope of the lift curve at low speed

V indicated airspeed

By graphical interpolation the counts are referred to gust speeds of $7\frac{1}{2}$, 10, 15, 20 .... ft/sec and a gust distribution is obtained for each altitude band. The mileage flown in each band is calculated and gust spectra are obtained in terms of the average distance between gusts exceeding different magnitudes.

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* The gust is assumed to increase linearly to its maximum value in a horizontal distance of 100 feet. The alleviating factor is calculated as a function of the mass parameter $\mu_g = \frac{2w}{g \rho \bar{c} a_o}$ where ρ is air density and $\bar{c}$ is the mean wing chord. Allowance is made for the effect of wing aspect ratio on the rate of growth of lift. No allowance has been made for the effect of compressibility on the unsteady lift function.

TABLE I

Summary of acceleration data from Hermes Aircraft (April 1952 - October 1953)

Altitude above Sea Level I.C.A.N.	Aircraft Weight	Indicated Airspeed	Recording Time	Number of times each level of acceleration was exceeded																	
				Nominal acceleration level (see footnote for correction)																	
(1,000 ft units)	(10,000 lb units)	(10 knot units)	(10.4 min units)	0.0g	0.1g	0.2g	0.3g	0.4g	0.5g	0.6g	0.7g	0.8g	1.2g	1.3g	1.4g	1.5g	1.6g	1.7g	1.8g	1.9g	2.0g	2.1g
00	06	10	2								1	11	19	8	1							
		11	3								1	15	21	8	1							
		12	3									0	14	1								
		13	9							1	6	37	103	31	6	3	1					
		14	7								4	31	73	18								
		15	4								3	15	36	9	3							
		17	1									0	0									
	07	11	2									0	0									
		12	10									3	35	12	2	1						
		13	8								3	6	21	10	1	1						
		14	3							1	2	3	9	2								
		15	4									0	1									
		16	3							2	4	10	24	12	2	1						
		21	1									1	3	2								
	08	16	1									0	0									
			61							4	24	132	359	113	16	6	1					
05	06	12	4								2	1	3	2								
		13	5									0	6	1								
		14	6									0	3	2								
		15	4									2	12	3								
		16	8								2	8	9	5	2							
		17	11							1	1	4	14	5	2	1						
		18	9									4	19	1								
		19	3								2	4	8	3	2	1						
		20	2									0	0									
	07	10	2									0	0									
		11	8						1	1	5	16	20	6	1	1						
		12	17									4	14	2								
		13	33							4	9	32	56	21	1							
		14	36								2	14	29	13	3							
		15	48								5	22	42	12	1	1						
		16	58			1	1	1	1	7	9	19	47	19	5	3						
		17	64							1	2	6	12	1								
		18	43								7	19	44	13	2	1						
		19	18						1	1	2	7	18	5								
		20	10									1	4									
		21	3									2	18	7	1							
		22	1									0	0									
	08	14	71								10	31	27	5								
		15	49								2	19	27	2								
		16	14									0	1	1								
		17	4								1	1	5	1								
			531			1	1	1	3	15	61	216	438	130	20	8						

Table I (Cont'd)

Altitude above Sea Level I.C.A.N.	Aircraft weight	Indicated Airspeed	Recording time	Nominal acceleration level (see footnote for correction)																	
				Nominal acceleration level (see footnote for correction)																	
(1,000 ft units)	(10,000 lb units)	(10 knots units)	(10.4 min units)	0.0g	0.1g	0.2g	0.3g	0.4g	0.5g	0.6g	0.7g	0.8g	1.2g	1.3g	1.4g	1.5g	1.6g	1.7g	1.8g	1.9g	2.0g	2.1g
10	06	12	4							2	20	20	42	20	1	1						
		13	5								1	4	22	7								
		14	4								3	9	11	3	1	1						
		15	8								2	29	16	4	1							
		16	46							1	10	26	33	7	1							
		17	78						1	2	3	20	20	3								
		18	33							1	2	3	15	3								
		19	8									0	0									
		20	2									3	11	4								
		21	3									0	0									
	07	12	8							1	2	11	25	10	2							
		13	9								3	7	9	4								
		14	47								4	12	21	4								
		15	245					1	2	9	36	112	138	47	8	3						
		16	2327						3	18	40	162	252	66	11	5	2					
		17	869					1	1	7	54	173	205	78	18	9	5	3	3	1	1	1
		18	194					1	5	9	32	60	111	37	9	4	1					
		19	51						1	2	6	16	25	9	2							
		20	29							2	7	14	23	7								
		21	12								2	5	9	4								
		22	2									0	0									
	08	13	4									0	0									
		14	107								1	13	8	4	1							
		15	255								8	34	51	12								
		16	1117				2	2	3	10	34	95	124	43	18	4	3	2	1			
		17	184					1	1	1	7	27	46	8	1	1						
		18	12						1	2	4	18	45	23	7	2	1	1				
			5663				2	6	18	67	281	873	1262	407	81	30	12	6	4	1	1	1
15	06	14	1									0	0									
		15	9									0	0									
		16	130								2	15	21	5	2	2						
		17	54						1	1	4	20	15	4								
		18	10									0	1									
		19	5									0	0									
	07	13	8							1	7	28	27	13	2							
		14	66								1	4	3									
		15	571						4	8	19	88	100	29	2							
		16	1933					1	1	4	22	110	169	31	10	1						
		17	390								6	34	21	5	1							
		18	44									2	3									
		19	13									0	0									
		20	5									1	3									
		21	1									0	0									
	08	14	26									1	2									
		15	158				1	1	1	2	5	13	16	5	1	1	1					
		16	571							2	8	37	62	11	4							
		17	71							1	1	3	2									
		18	1									0	0									
			4067				1	2	7	19	75	356	445	103	22	4	1					

TABLE I (Contd)

Altitude above Sea Level I.C.A.N.	Aircraft Weight	Indicated Airspeed	Recording time	Number of times each level of acceleration was exceeded																	
				Nominal acceleration level (see footnote for correction)																	
(1,000 ft units)	(10,000 lb units)	(10 Knots Units)	(10.4 min units)	0.0g	0.1g	0.2g	0.3g	0.4g	0.5g	0.6g	0.7g	0.8g	1.2g	1.3g	1.4g	1.5g	1.6g	1.7g	1.8g	1.9g	2.0g	2.1g
20	06	14	4									0	1									
		15	9									0	3									
		16	71							1	4	6	4	2	1							
		17	11									0	0									
		18	1									0	0									
		21	1									0	0									
	07	14	21									4	2									
		15	238									4	7	1								
		16	379	1	1	1	1	1	5	8	16	36	44	20	6	4						
		17	44								2	3	1									
		18	3									0	0									
		19	1									0	0									
		20	1									0	0									
	08	14	4									0	0									
		15	17									0	4	1								
		16	17									0	0									
		17	2									0	0									
				1	1	1	1	1	5	9	22	53	66	24	7	4						

The necessary corrections for instrument error to the nominal acceleration levels are

1.2g, 1.3g, 1.4g : +0.03g 0.8g, 0.7g 0.6g : -0.03g
1.5g and greater : +0.02g 0.5g and smaller : -0.02g

TABLE II

Distribution of recording intervals according to 0.23g Counts

Number of Acceleration Increments Exceeding 0.23g	Number of intervals (10.4 min) containing a given number of acceleration increments					
	Altitude band (feet)					
	0-2500	2500-7500	7500-12500	12500-17500	17500-22500	0-22500
0	21	409	5313	3887	794	10424
1	5	41	106	70	10	232
2	3	16	67	33	0	238
3	1	10	38	16	4	119
4	5	6	29	14	2	69
5	2	9	11	7	1	56
6	1	4	7	5	1	30
7	1	6	11	2	1	18
8	2	5	11	6	0	21
9	3	2	5	2	0	24
10	2	1	8	7	2	12
11	3	2	5	0	0	20
12	2	6	5	3	1	10
13	0	1	4	2		17
14	1	0	3	1		5
15	0	2	2	0		4
16	2	2	3	1		8
17	2	2	1	2		7
18	1	2	5	0		8
19	0	0	4	1		5
20	0	0	3	1		4
21	2	0	1	1		4
22	1	0	4	0		5
23	1	0	1	2		4
24	1	1	1	0		3
25	0	1	0	0		1
26	0	0	1	0		1
27	0	0	3	0		3
28	0	0	1	0		1
29	0	1	1	1		3
30	1	0	1	0		2
31	0	1	0	0		1
33	2		0	0		2
35	1		2	0		3
38			1	0		1
39			0	0	1	1
40			1	0		1
41			0	1		1
42			1	0		1
43			1	1		2
46			1			1
50			1			1
62			1			1
Totals	66	530	5664	4066	817	11143

TABLE III

Distribution of recording intervals according to acceleration counts

Number of Gusts	Number of intervals (10.4 min) containing a given number of acceleration increments greater than			
	0.23g	0.33g	0.43g	0.52g
0	10424	10793	11020	11087
1	232	136	80	39
2	119	75	18	11
3	69	27	8	5
4	56	30	7	1
5	30	20	2	
6	18	15	2	
7	21	16		
8	24	6	1	
9	12	3	2	
10	20	3	2	
11	10	2	1	
12	17	2		
13	7	3		
14	5	1		
15	4	1		
16	8	2		
17	7	1		
18	8			
19	5			
20	4	1		
21	4			
22	5			
23	4	1		
24	3	1		
25	1			
26	1	1		
27	3	2		
28	1			
29	3			
30	2			
31	1	1		
32				
33	2			
35	3			
38	1			
39	1			
40	1			
41	1			
42	1			
43	2			
46	1			
50	1			
62	1			

TABLE IV

Summary of gust speeds encountered

Altitude Above Sea Level I.C.A.N.	Mean Altitude	Flying distance recorded	Estimated number of times a given gust speed was exceeded Vertical gust speed ft/sec, E.A.S. (+Up, -Down)															
1000 ft units	feet	Stat miles	-45	-40	-35	-30	-25	-20	-15	-10	-7.5	7.5	10	15	20	25	30	35
0-2.5	1,440	1,740						8	52	310	790	1000	560	178	53	15	4	
2.5-7.5	5,550	18,000			2	2	5	35	104	360	720	1200	580	168	40	4	1	
7.5-12.5	11,240	206,500			2	4	14	65	265	1100	2400	2600	1400	370	100	27	7	5
12.5-17.5	13,890	156,000			1	1	5	21	83	400	900	1000	480	150	21	2	1	
17.5-22.5	18,540	35,200	1	1	1	1	2	6	16	53	82	130	69	19	6	1		
	Total	417,440																

TABLE V

Relative time spent at all altitudes in different regions

Altitude 1000 ft Units	GEOGRAPHICAL REGION												
	1				2				3				All
	Climb	Cruise	Descent	All	Climb	Cruise	Descent	All	Climb	Cruise	Descent	All	
00	0	4	2	6	0	0	1	1	0	0	0	0	7
01	1	10	8	19	0	0	1	1	0	0	2	2	22
02	0	8	17	25	0	0	5	5	0	0	5	5	35
03	4	0	34	38	1	0	11	12	1	0	4	5	55
04	14	3	37	54	12	0	20	32	0	0	6	6	92
05	21	0	25	46	22	7	23	52	0	0	5	5	103
06	11	1	33	45	21	4	37	62	2	0	8	10	117
07	29	2	43	74	31	8	36	75	3	4	4	11	160
08	27	18	46	91	37	25	40	102	4	4	5	13	206
09	31	30	35	96	49	51	61	161	3	7	3	13	270
10	28	146	35	209	53	102	50	205	3	25	4	32	446
11	29	750	25	804	38	734	28	800	2	125	4	131	1735
12	18	886	22	926	29	1679	18	1726	2	246	1	249	2901
13	9	1024	13	1046	18	923	15	956	1	121	1	123	2125
14	8	524	11	543	13	243	9	265	1	28	0	29	837
15	7	47	12	66	7	70	6	83	0	28	1	29	178
16	9	207	4	220	11	88	16	115	0	10	0	10	345
17	6	127	4	137	2	132	0	134	0	8	0	8	279
18	4	379	2	385	1	64	1	66	1	24	0	25	476
19	2	195	2	199	0	24	1	25	0	1	0	1	225
20	1	57	0	58	1	4	0	5	0	1	0	1	64
21	0	16	0	16	0	1	0	1	0	0	0	0	17
22	0	3	0	3	0	2	0	2	0	0	0	0	5
	259	4437	410	5106	346	4161	379	4886	23	632	53	708	10700

Time in 10.4 minute units

TABLE VI

Summary of accelerations recorded between 9500 and 14,500 feet in different regions

Geographical region	Aircraft Weight	Indicated Airspeed	Recording time	Number of times each level of acceleration was exceeded — Nominal acceleration level (see footnote for correction)												
	10,000 lb units	10 knot units	10.4 min units	0.3g	0.4g	0.5g	0.6g	0.7g	0.8g	1.2g	1.3g	1.4g	1.5g	1.6g	1.7g	1.8g
1	06	16	2						0	0						
		17	11						0	0						
		18	2						0	0						
		19	1						0	0						
	07	12	1						0	0						
		13	4					1	5	4	3	1				
		14	15					1	3	2						
		15	188				2	9	36	25	12	1				
		16	1327					2	23	18	3					
		17	450					7	28	22	2	1				
		18	53						0	0						
		19	8						0	0						
		20	1						0	0						
	08	14	11						0	0						
		15	143	1	1	1	2	3	5	6	3	1	1	1		
		16	944						18	25	3	1	1			
		17	163						3	4	1	1	1			
		18	3						0	0						
			3327	1	1	1	4	23	121	106	27	6	3	1		
2	06	14	1					3	9	10	2					
		15	6						0	0						
		16	73				1	9	26	25	8	2	1			
		17	68			1	2	4	26	22	3					
		18	12						0	0						
	07	12	1						0	0						
		13	1				1	6	23	18	10	1				
		14	5					1	4	7	1					
		15	207			3	7	23	85	97	36	6	2			
		16	2066		1	1	11	45	202	260	64	17	5	2		
		17	470		1	1	4	27	89	98	33	11	5	3	2	2
		18	30			1	5	14	25	40	14	1				
		19	5					2	11	18	6					
	08	14	11						1	3						
		15	134					7	20	32	10					
		16	535	2	2	2	11	36	87	107	39	17	3	3	2	1
		17	45				1	2	6	9	2					
		18	1						0	0						
			3671	2	4	9	43	179	614	746	228	55	16	8	4	3
3	06	15	1						0	0						
		16	21						0	4						
		17	15						0	2						
		18	2						0	0						
	07	15	23						1	0						
		16	233			1	1	3	16	80	15	1				
		17	103						0	9	3					
		18	9						0	2						
	08	14	1						0	0						
		15	25						5	2	1					
		16	106						2	11						
		17	6		1	1	1	1	4	16	3					
			545		1	2	2	4	28	126	22	1				

The necessary corrections for instrument error to the nominal acceleration levels are

1.2g, 1.3g, 1.4g : +0.03g 0.8g, 0.7g, 0.6g : -0.03g

1.5g and greater : +0.02g 0.5g and smaller : -0.02g

TABLE VII

Comparison of 10 ft/sec gust frequency in different geographical regions

Flight sector	Number of Flights	Geographical region	Flight distance recorded 9500 ft to 14500 ft Stat.miles	Number of gusts exceeding 10 ft/sec	Average miles per gust
London-Rome Rome-Cairo London-Tripoli Rome-Tripoli	84 87 8 4	1. Europe	128,200	285	450
Cairo-Khartoum Khartoum-Entebbe	89 89	2.East Africa	141,200	1466	96
Tripoli-Kano Kano-Lagos Lagos-Acra	15 13 6	3.West Africa	21,100	174	121
Entebbe-Nairobi Dar-es-Salaam-Entebbe Nairobi-Lusaka	59 5 18	4.South Africa	small mileage recorded in this region		

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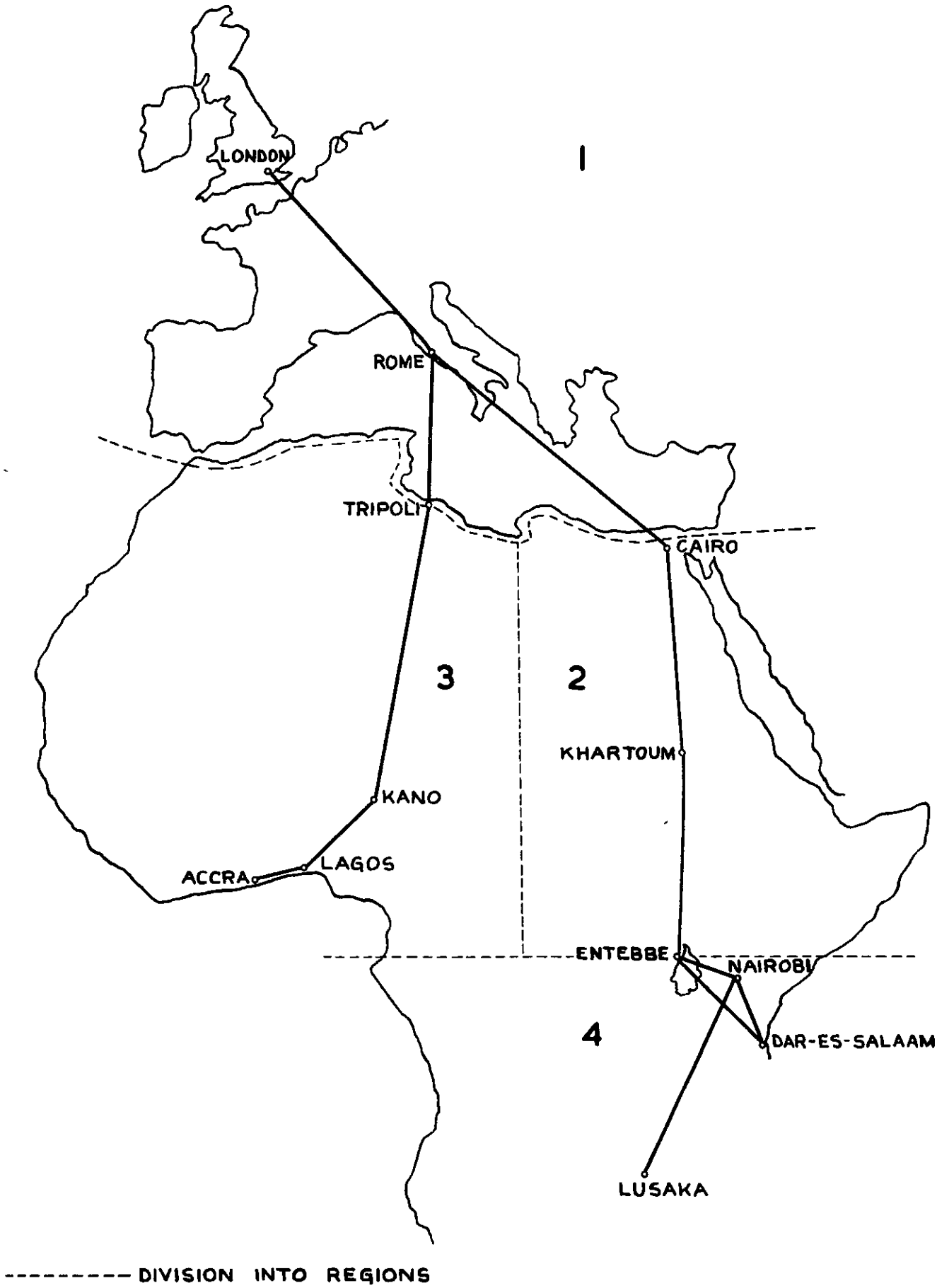


FIG. I. MAP OF THE ROUTES FLOWN.

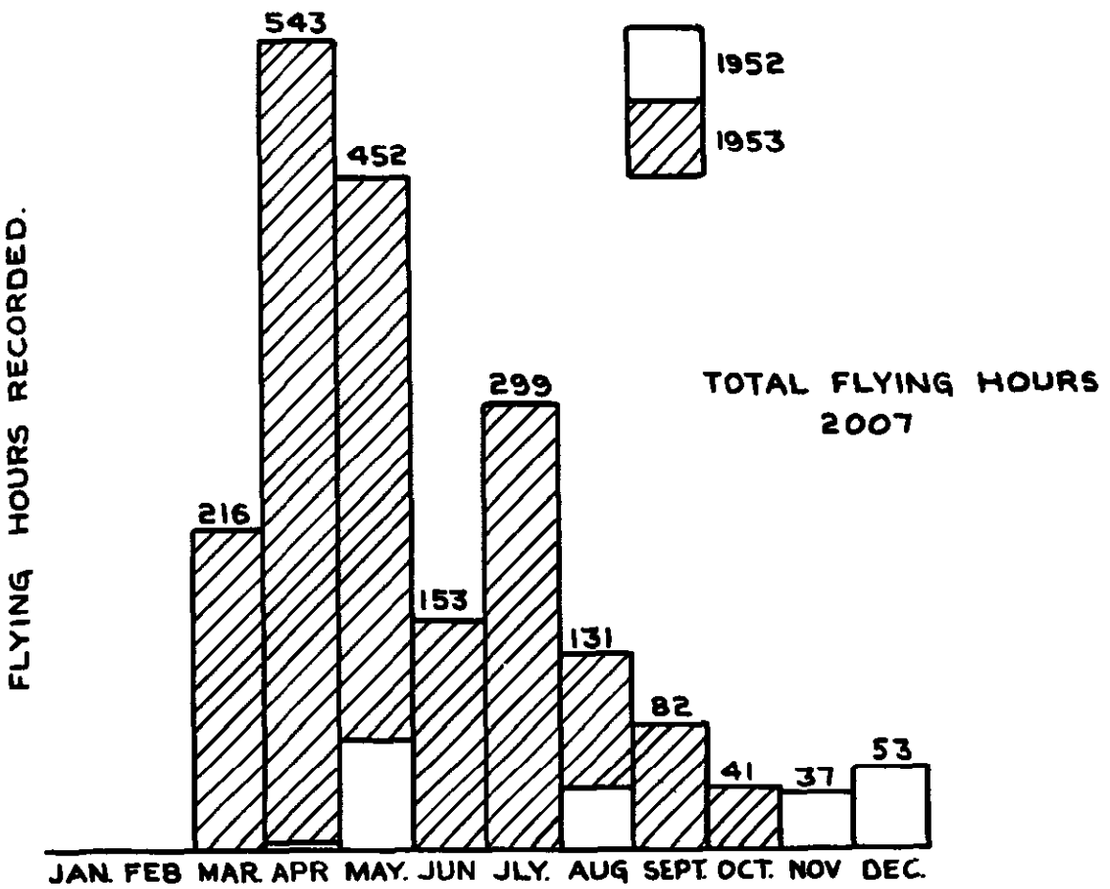
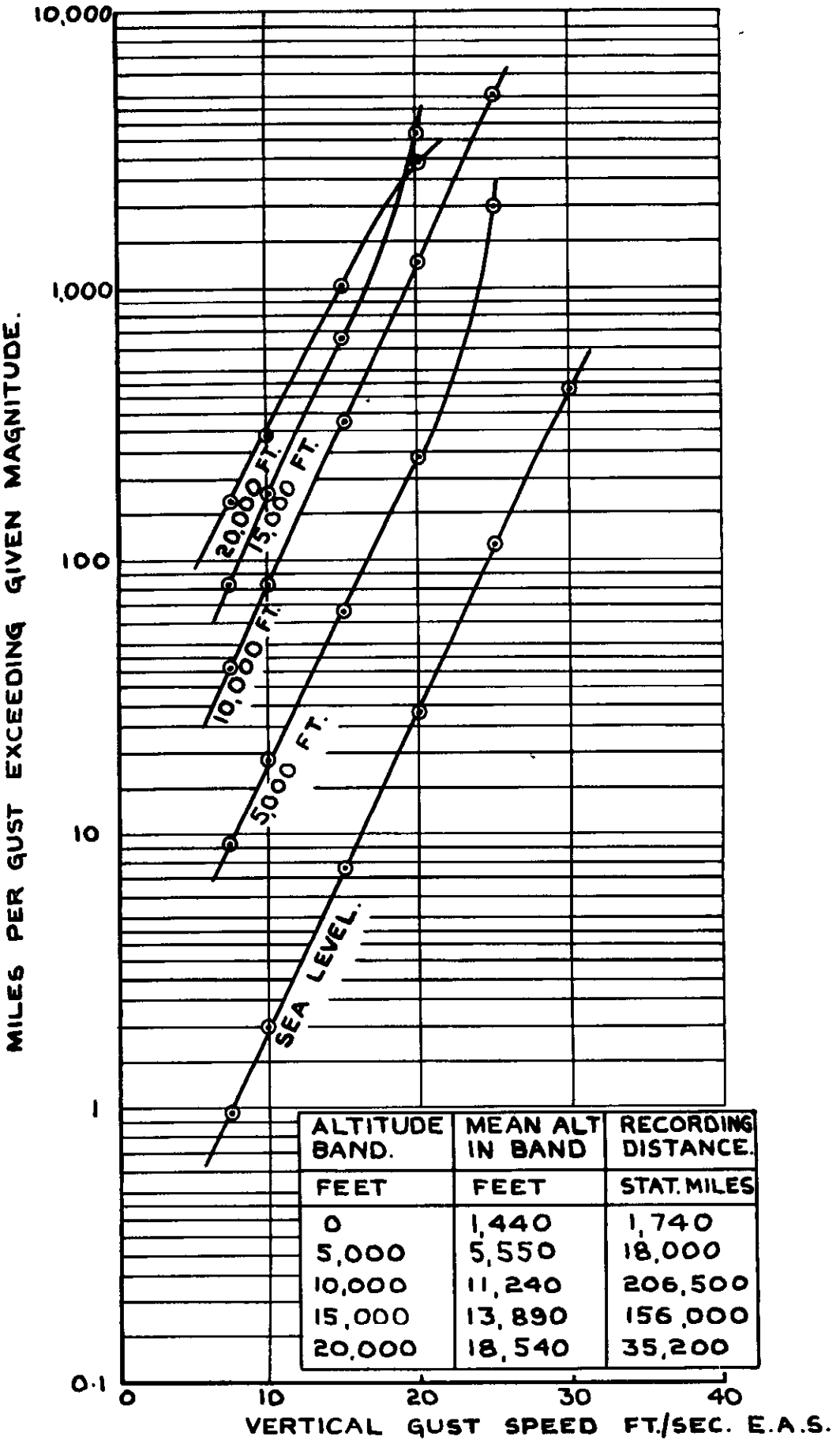


FIG. 2. DISTRIBUTION OF RECORDING TIME IN THE YEAR.



ALTITUDE BAND.	MEAN ALT IN BAND	RECORDING DISTANCE.
FEET	FEET	STAT. MILES
0	1,440	1,740
5,000	5,550	18,000
10,000	11,240	206,500
15,000	13,890	156,000
20,000	18,540	35,200

FIG. 3. GUST SPEED FREQUENCIES AT DIFFERENT ALTITUDES.

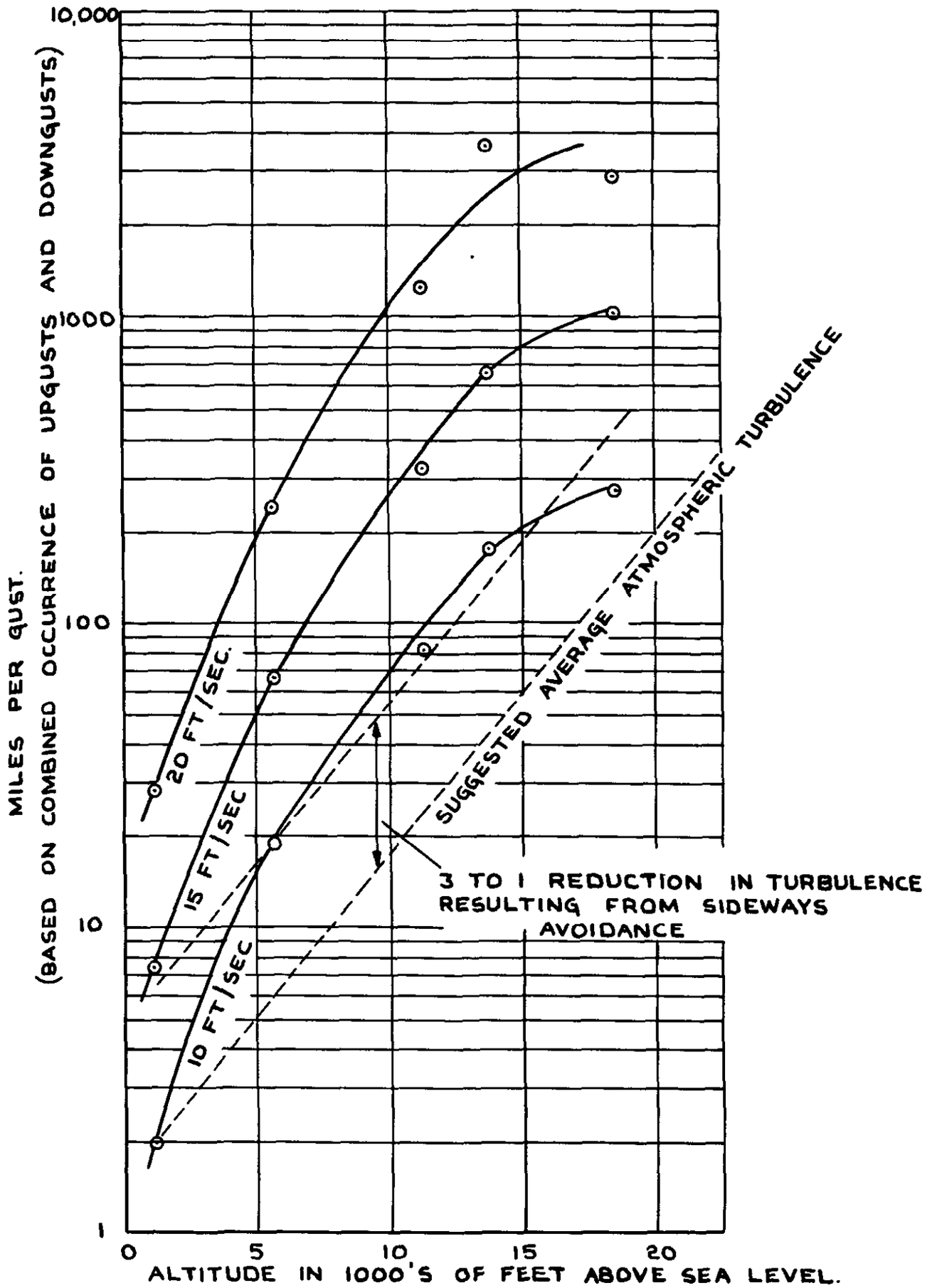


FIG. 4. VARIATION OF TURBULENCE WITH ALTITUDE IN TERMS OF GUSTS EXCEEDING 10, 15 AND 20 FT./SEC. E.A.S.

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