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Atmospheric Turbulence Encountered by Super Constellation Aircraft

by

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ROYAL AIRCRAFT ESTABLISHMENT

ATMOSPHERIC TURBULENCE ENCOUNTERED BY SUPER CONSTELLATION AIRCRAFT

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SUMMARY

Counting accelerometer records representing 1 million miles were obtained from Super Constellation aircraft flying between Australia and the U.K. and across the Pacific Ocean and Indian Ocean.

It is shown that, below 10,000 ft the frequency of gusts exceeding 10 ft/sec is less over sea than over land by a factor of at least 2. There is evidence from four geographical regions of a single fluctuation of turbulence during the year, the phase depending to some extent on longitude.

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1 INTRODUCTION

To supplement existing knowledge of atmospheric gusts, counting accelerometers were carried in Super Constellation aircraft flying from Australia to the U.K. and across the Pacific and Indian Oceans. The acceleration records obtained represent 1 million miles and the cruising altitude range is 10,000 ft to 20,000 ft.

This note discusses the variation in gust frequency with altitude, geography and season and comparison is made with previous data.

2 INSTRUMENTATION

Counting accelerometer Mk.4 instruments were installed in two aircraft near the centre of gravity. The accelerometer records the number of times that each of a series of upward and downward accelerations is exceeded. At intervals of time an automatic observer recorded the counts, airspeed, altitude and time. The time interval was 3.5 minutes below about 12,000 ft and 9 minutes above this altitude. To exclude ground accelerations from the records the accelerometer was switched on automatically when the airspeed exceeded 130 knots during take-off and switched off when airspeed was reduced below 105 knots during landing.

3 TEST CONDITIONS

The aircraft carrying the instruments flew normal passenger services mainly between Australia and the U.K. and across the Pacific Ocean and Indian Ocean. The routes are detailed in Fig.1.

The distribution of recording time throughout the year is shown in Fig.3. The distribution is rather uneven owing to variable utilization of the aircraft and periods of instrument unserviceability but records were obtained in all months of the year.

Table 1 gives the time spent at different speeds and heights during climb and descent and during cruise, from which it is seen that most of the cruise was between 10,000 ft and 19,000 ft and tended to be at 11,000 ft or 17,000 ft.

4 ACCELERATION DATA

The total counts of acceleration obtained at each flight condition and in each altitude band are given in Table 2. The counts are subdivided into geographical regions in Table 3 for climb and descent and Table 4 for cruise.

To supplement the acceleration data the date, flight sector, take-off weight and landing weight were recorded for each flight.

5 GUST ANALYSIS

The acceleration data were processed and converted to gust information by a standard method[1]. When interpreting the accelerations recorded during the first interval of a flight the final airspeed and half the final altitude of the interval were assumed to be representative of the whole interval. Similarly for the last interval of a flight the initial speed and half the initial altitude of the interval are assumed. The aircraft characteristics are stated in Table 5 and representative acceleration/gust conversion factors are given in Table 6.

The estimated gust counts from all routes are given in Table 7 and for each geographical region in Table 8 for climb and descent and in Table 9 for cruise.

The counts of gusts exceeding 10 ft/sec during each month of the year are given in Table 10.

6 OVERALL VARIATION OF GUST FREQUENCY WITH ALTITUDE

We will first consider Fig.4 which shows the observed frequency of gusts greater than 10 ft/sec E.A.S. at different altitudes based on the combined data from all routes. The vertical line through each observation shows the 95% confidence limits calculated by the method of Ref.2. The lower straight line is added for comparison and represents a general estimate of atmospheric turbulence[3] which was based on earlier data, comparable in quantity to the present data but from routes differing geographically. The routes from which the present data and the previous data were obtained are shown in Fig.1 and 2 respectively.

The observations show a general decrease in the numbers of gusts with altitude up to 16,000 ft. Above 8,000 ft, i.e. at cruising altitudes, the climb and descent curve and the cruise curve are similar and show the characteristic effects of the pilot's discretion in the choice of cruising altitude with regard to weather conditions[4]. Firstly, the turbulence recorded is always less during cruise than during climb and descent, which indicates that the pilot is able more easily to avoid turbulence during the cruise either by climbing or by a change of course. Secondly, despite evidence[5] of a steady exponential decrease in gust frequency with altitude up to 25,000 ft on widespread routes there is a progressive reduction in the slope of the present curves with altitude which confirms that cruising altitude increases progressively with worsening weather conditions. The difference between the cruise curve and the climb and descent curve (ratio about 1.4) is less marked than that previously found for the Viking (ratio about 2.0) which cruised below 10,000 ft. Possibly this is related to the different cruising altitudes of the aircraft, the incentive to alter cruising height being less frequent at high altitudes than at low altitudes.

To estimate the average atmospheric turbulence during the recording period it is necessary to consider first the observations during climb and descent at altitudes below the cruising range as these records represent the average of all the weather conditions which were encountered.

Starting at low altitude there are four observations below 2,000 ft representing different flight conditions. Point 1 consists of recordings immediately after take-off, point 2 immediately before landing, point 3 all other occasions of climb and descent below 1,500 ft and point 4 the few occasions which are nominally cruise below 1,500 ft but more accurately stand off and landing approach. These four observations were therefore obtained overland mainly below 1,500 ft in all weather and they are in fact in good agreement in view of the assumptions about aircraft speed during take off and landing defined in Section 5.

Points 5, 6 and 7 were obtained during climb and descent between 1,500 ft and 9,500 ft in all weather and represent average atmospheric conditions excluding any sideways avoidance of turbulence by the pilot. These points have equal statistical significance and the straight line drawn through them is the best estimate of average conditions on the routes covered by the present data. The extension of this line intersects the cruise curve at about 16,000 ft which is approximately the mean cruising altitude and corresponds to the least value of recorded gust frequency. Below 16,000 ft the turbulence encountered during cruise was generally less than the average atmospheric conditions and above 16,000 ft conditions were worse than average.

The group of low altitude observations discussed earlier have not been considered in the determination of the line representing average conditions as they are far from representative of conditions at low altitude throughout the routes. Although about two thirds of the present data are from oversea, the low altitude data were recorded mainly overland, where conditions are more severe than oversea[6,7].

By comparison with the previous estimate the suggested average for the present data is very similar in rate of decrease with altitude but is less severe by a factor of 2. This difference may well be accounted for by the difference in routes over which the two sets of data were obtained, in particular, the predominance of overland flying in the previous data and oversea flying in the present data. In this connection it is significant that the present low altitude observations are slightly more severe than the previous estimate.

7 GUST FREQUENCIES IN EACH REGION

The data discussed in the previous section are now divided into arbitrary geographical regions which are defined in Fig.1. Of these 7 regions, 5 contain sufficient data for a useful comparison and will be called Pacific Ocean, Indian Ocean, Australia, Far East and Europe. The variation of gust frequency with altitude is shown separately for each region in Figs.5 to 9.

Pacific Ocean

Over the Pacific Ocean (Fig.5) the turbulence variation with altitude follows the conventional pattern already seen for all routes combined. Turbulence near the ground agrees well with the previous estimate and the line through the three climb and descent points indicates that turbulence over sea is about half the value over land below 5,000 ft.

There are two cruising bands of altitude, in which equal mileages were flown, centred on 12,000 ft and 17,000 ft. The line through the cruise observations is curved due to weather discrimination and is intersected by the climb and descent line at about 17,000 ft. Below this altitude choice of altitude with regard to weather conditions reduced the turbulence experienced during the cruise. The greatest alleviation is a factor of about $1\frac{1}{2}$.

Australia

The recordings from internal routes in Australia are conventional. Observations near the ground and in climb and descent are homogeneous, as all the flying is over land, and they agree well with previous experience. It should be remarked that the turbulence observed at about 2,000 ft is unexpectedly small. Cruising is in two broad altitude bands centred on 11,000 ft and 16,000 ft and choice of altitude with regard to weather conditions has caused a reduction in the turbulence experienced below about 17,000 ft by a factor of 2.

Europe

Only a small amount of data was obtained from the so-called European sectors. The sectors lie over land and sea to an equal extent and consequently the observation near the ground is more severe than the average line based on the two lowest climb and descent points. This line indicates that average conditions were about $1\frac{1}{2}$ times less severe than the previous estimate. There are two cruising bands of altitude centred on 10,000 ft and 17,000 ft and the climb and descent line intersects the cruise curve at about 18,000 ft. Below 18,000 ft, discrimination with regard to weather conditions has resulted in the turbulence recorded being about $1\frac{1}{2}$ times less than average.

Indian Ocean

The value of turbulence recorded near the ground is in fairly good agreement with the previous estimate but as all sectors in this region are over sea the average line based on the three climb and descent points is less severe by a factor of 4. The cruise is in two altitude bands centred on 10,000 ft and 17,000 ft, the upper band containing most of the mileage. The observations made during cruise are unusual in two respects. Firstly, the turbulence during cruise is apparently a maximum at about the mean cruising altitude, not a minimum as is usual. Secondly, the climb and descent line intersects the cruise curve in the region of 14,000 ft (dependent on the drawing of the cruise curve) and the majority of the cruising mileage was recorded above 14,000 ft, that is, during turbulence of more than average severity. These peculiarities lead to the conclusion that cruising altitude was chosen, not with the object of avoiding turbulence, but with another motive, presumably fuel economy, which resulted incidentally in greater than average turbulence being encountered.

Far East

In this region there is a considerable amount of flying over sea with the result that the line through the climb and descent points is more severe than the observation near the ground by a factor of about 3. The value near the ground is in agreement with the previous estimate. Cruising is in two broad altitude bands centred on 11,000 ft and 16,000 ft. The observations made during cruise although giving a cruise curve of conventional shape indicating weather discrimination, show a similar peculiarity to those from the Indian Ocean in that the general level of turbulence during cruise is more severe than is indicated by the climb and descent line.

It is perhaps significant that both the cruise curve and the low altitude observation are well positioned relative to the previous estimate.

8 VARIATION OF GUST FREQUENCY WITH GUST SPEED

Figs.10 and 11 show the variation of gust frequency with gust speed at different altitudes during cruise and during climb and descent. The variation of gust frequency is similar for upgusts and downgusts being approximately exponential at small gust speeds, the slope tending to decrease at higher gust speeds. The upgust and downgust distributions are approximately symmetrical about the zero gust speed datum but in some instances the upgust slope is steeper than the downgust slope which suggests that large upgusts were encountered less frequently than large downgusts relative to the frequency of small gusts. Also, if the low speed ends of the upgust and downgust curves are produced back to meet, the apparent datum varies from 0 to +3 ft/sec. This apparent movement of the datum is generally related to the steepening of the upgust slope relative to the downgust slope but the relation between these variations and the flight condition, weather condition or aerodynamic characteristics of the aeroplane is obscure. It is clear, however, that the climb and descent curves are generally steeper than the cruise curves from which it follows that during cruise large gusts were encountered in greater numbers relative to small gusts than during climb and descent.

Fig.12 shows a regional comparison of the variation of gust frequency with gust speed during cruise in two altitude bands. Relative to the frequency of small gusts, large gusts are most frequent over the Pacific Ocean and Indian Ocean and least over Australia. The distribution over the Far East region which contains land and sea, is intermediate.

9 SEASONAL VARIATION OF GUST FREQUENCY

To investigate seasonal variation of gust frequency the records from each region are grouped in months. From 4 regions there are sufficient data to indicate the seasonal variation. To ensure that the records from each region are comparable and of sufficient quantity to make the comparison significant, cruising records from the altitude range 9,500 ft to 17,500 ft are chosen, representing 80% of the cruise mileage. The variation of 10 ft/sec gust frequency throughout the year is shown in Table 10 and Fig.13 for each region. Observations which contain small gust counts or low mileage are not plotted.

In all regions the variation may be interpreted broadly as a single fluctuation during the year about the mean value. This resembles a previous result[4] from Viking aircraft over Europe which gave some evidence of a single fluctuation during the year. The outstanding difference between the regional variations is the phase of the variation. To determine the phase differences and to illustrate similarity of the curves they have been superimposed in phase on a common mean value in Fig.14. Disregarding fluctuations in the curves the magnitude of the variation is of the same order in all regions and the ratio of maximum to minimum average monthly values is about 4 to 1. The variation of turbulence during the year, above 10,000 ft, is therefore to a large extent independent of surface features.

It is seen that the phase of the variation progresses in the same sense as the longitudes of the regions and it is conceivable that this variation could be caused by an eastward movement of a global distribution of turbulence with a period of one year. It should be noted also that the average latitudes of the routes compared lie within the Tropics.

10 CONCLUSIONS

The frequency of gusts greater than 10 ft/sec decreases with altitude at the same proportionate rate as found previously but is smaller by a factor of 2 due to a preponderance of oversea routes in the present data.

The frequency of 10 ft/sec gusts is generally less over sea sectors than over land sectors. It is estimated that at altitudes less than 10,000 ft the gust frequency is 2 times less over the Pacific Ocean and 4 times less over the Indian Ocean than over land sectors. Over these sea sectors, however, large gusts were encountered more frequently in relation to small gusts than over land sectors.

In all regions during the year there is a single fluctuation of average monthly gust frequency of total amplitude about 4 to 1. Maximum turbulence occurs in the six months centred roughly on June for the Indian Ocean and Far East, November for Australia and January for the Pacific Ocean.

ACKNOWLEDGEMENTS

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TABLE 1

Recording time in minutes at each speed and altitude

I.A.S. knots	Altitude above sea level I.C.A.N. (X 1,000 ft)																				
	Climb and descent																				
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
100	27	6								10											
110	16	11								9		12									
120	150	79	15	7						10	7										
130	250	261	113	19	10		8	4													
140	223	429	252	123	61	7	20	11													
150	104	699	311	508	273	283	248	273	192	186	196	159	195	143	120	124	40	47	17		
160	77	1005	321	908	562	601	517	513	547	608	397	476	415	460	407	369	167	91	59	15	
170	23	254	209	403	182	249	212	207	341	268	338	181	197	169	356	380	269	177	131		8
180	5	78	144	151	114	118	67	122	136	131	188	144	102	81	116	148	116	91	37	10	8
190	2	24	147	150	124	126	115	98	148	67	116	60	132	137	222	179	169	36	45	8	
200	3	27	77	135	141	184	142	170	170	301	222	286	271	420	582	413	260	148	41	7	
210		4	53	110	169	191	211	240	365	376	408	322	208	216	207	93	70	36	31	8	
220		4	17	60	118	193	243	148	203	211	168	128	72	85	46	8		8			
230				10	46	52	35	54	77	86	40	31	12	15	17						
240				5	8	7	24	11	4	12			5		6						
250					8		4		3												
260				3																	
	880	2883	1659	2592	1816	2011	1846	1851	2186	2275	2080	1799	1609	1726	2079	1714	1091	634	361	48	16

TABLE 1 (Contd.)

Recording time in minutes at each speed and altitude

Altitude above sea level I.C.A.N. (X 1,000 ft)																					I.A.S. knots
Cruise																					
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
																						100
																						110
	3													9		7						120
	1	5																				130
	18	2	4	20	6																	140
	23	6	8	29	10	13		7		23	15	18	8		10		18	15	26	9		150
		17	8	7	11	10		12	22	35	56	122	22	75	69	154	295	73	180	51		160
	3	7	7	10	8	14	8	14	36	1010	1126	1231	172	252	340	1234	1024	497	1004	339	19	170
		23	7	6	7	12	18	345	84	1090	4959	3932	463	1321	4339	12602	12487	5720	7357	1728	36	180
		7	15	18		38	12	174	424	3306	3514	6788	1069	3922	8807	15055	19284	6614	8695	1065	18	190
		3	6		9	20		776	801	9396	10094	9467	1023	884	3204	3209	2238	1345	972	265		200
		5	14	6	12	11	49	99	111	985	578	174		58	24	57	36	9				210
				7	4	4	7	9	3	33	13			12		11						220
										9												230
								4														240
																						250
																						260
	48	75	69	103	67	122	94	1440	1481	15886	20354	21732	2757	6533	16793	32329	35382	14273	18234	3457	73	

Total recording time = 224,458 min.

TABLE 2

Accelerations recorded on all routes

Flight condition	Altitude range ft	Recording time min	Statute miles	Number of times each acceleration increment was exceeded (+up -down)													
				-1.20g	-1.00g	-0.80g	-0.60g	-0.40g	-0.30g	-0.20g	0.20g	0.30g	0.40g	0.60g	0.80g	1.00g	1.20g
Initial climb	0-3500	1670	5177					19	44	384	1000	674	52	23			
Final descent	0-2500	1105	2952					5	29	227	684	99	31	3			
	0-1500	1133	3189					11	33	210	536	60	22				
Climb and	1500-3500	4106	13564					14	49	380	1031	141	32	3	2	1	
descent	3500-5500	3827	13951				1	18	61	316	633	95	39	1			
(excluding initial	5500-9500	8158	32001				4	54	126	545	1041	187	64	5	1		
and final	9500-13500	7214	30119				2	11	34	167	326	46	15	2			
intervals)	13500-17500	5518	24229			1	2	12	33	114	153	32	13				
	17500-21500	425	1932					1	3	5	8						
	0-1500	48	136					1	1	10	27	1					
	1500-3500	144	504					3	5	24	46	6	2				
	3500-5500	170	598						6	34	91	10	4	1			
Cruise	5500-9500	3137	13278				2	12	45	179	248	34	9				
	9500-13500	60729	266542		1	3	20	164	357	1578	2303	362	168	10	3		
	13500-17500	91037	418792		2	4	20	122	307	1238	2143	395	118	17	1		
	17500-21500	36037	171717			1	8	79	160	1040	906	131	46	5			
	Totals	224,458	1,005,881														

TABLE 3

Accelerations recorded during climb and descent in each region

Altitude band ft	Region	Recording time min	Statute miles	Number of times each acceleration increment was exceeded (+up -down)									
				-0.6g	-0.4g	-0.3g	-0.2g	0.2g	0.3g	0.4g	0.6g	0.8g	1.0g
0-1,500	Europe	82	226			2	13	55	8				
	Indian Ocean	153	427		1	1	27	89	9	1			
	Far East	342	941			1	40	111	11	1			
	Australia	116	336		4	12	41	95	16	7			
	Pacific Ocean	400	1156		6	17	88	185	16	12			
1,500-3,500	Europe	347	1098			2	24	112	25	8			
	Indian Ocean	622	2086			8	55	138	17	4			
	Far East	1248	4089		1	8	78	254	26	4			
	Australia	475	1617		7	14	98	207	29	7	3	2	1
	Pacific Ocean	1324	4400		4	15	117	274	38	8			
3,500-5,500	Europe	370	1353		4	11	47	93	12	5			
	Indian Ocean	451	1665			9	38	84	10	3			
	Far East	1200	4376		1	7	48	118	18	2			
	Australia	350	1308	1	4	18	75	139	20	6			
	Pacific Ocean	1381	5005		7	15	107	183	31	21	1		
5,500-9,500	Europe	799	3188			2	19	80	12	3			
	Indian Ocean	962	3707		5	6	22	38	6	6			
	Far East	2089	8146	1	8	25	103	176	32	10	1		
	Australia	865	3427	1	12	25	107	240	39	10	2	1	
	Pacific Ocean	3277	12894	2	22	57	252	397	67	27	2		

TABLE 4

Accelerations recorded during cruise in each region

Altitude band ft	Region	Recording time min	Statute miles	Number of times each acceleration increment was exceeded (+up -down)												
				-1.20	-1.00	-0.80	-0.60	-0.40	-0.30	-0.20	0.20	0.30	0.40	0.60	0.80	1.00
9,500-13,500	Europe	606	2763					1	1	11	30	1				
	Indian Ocean	6818	29885				2	7	22	78	110	14	7			
	Far East	7677	33549			1	6	26	75	261	422	68	18	1		
	Australia	6631	29722					11	50	269	422	43	8			
	Pacific Ocean	38997	170623		1	2	12	118	210	960	319	237	135	9	3	
13,500-17,500	Europe	4416	20682					3	18	55	132	18				
	Indian Ocean	15935	73074				7	29	55	219	383	73	36	4	1	
	Far East	27483	125203					39	99	333	628	124	35	3		
	Australia	13315	61580					2	25	153	282	78	5			
	Pacific Ocean	28920	133642			2	7	49	110	477	717	103	42	10		
17,500-21,500	Europe	4715	22711				1	5	13	87	125	16	1			
	Indian Ocean	3391	16055					9	18	23	23	2	1			
	Far East	3940	18495			1	2	9	25	65	138	26	9	3		
	Australia	4975	23489				2	19	49	357	269	47	11			
	Pacific Ocean	974	4836				1	4	8	50	95	14	4	1		

TABLE 5

Aircraft characteristics assumed

Wing area 1650 ft^2

Mean chord 13.41 ft

Aspect ratio 9.17

Slope of the lift chord constant at 4.93/radian

TABLE 6

Representative values of acceleration/gust speed

Conversion factors

Gust speed/acceleration in ft/sec/g									
Indicated airspeed knots	Sea level			10,000 ft			20,000 ft		
	Aircraft weight (X 1,000 lb)								
	90	110	130	90	110	130	90	110	130
100	73.39	87.35	100.63	69.68	83.06	95.75	66.31	79.15	91.36
120	61.16	72.79	83.86	58.06	69.21	79.79	55.26	65.96	76.13
140	52.42	62.40	71.88	49.77	59.33	68.39	47.36	56.54	65.25
160	45.87	54.60	62.90	43.55	51.91	59.84	41.44	49.47	57.10
180	40.77	48.53	55.91	38.71	46.14	53.19	36.84	43.97	50.75
200	36.69	43.68	50.32	34.84	41.53	47.87	33.15	39.57	45.68
220	33.36	39.71	45.74	31.67	37.75	43.52	30.14	35.98	41.52
240	30.58	36.40	41.93	29.03	34.61	39.90	27.63	32.98	38.06
260	28.22	33.60	38.70	26.80	31.94	36.83	25.50	30.44	35.14

TABLE 7

Gusts encountered on all routes

Flight condition	Mean altitude ft	Altitude range ft	Recording time min	Statute miles	Number of times each gust speed was exceeded. Vertical gust speed in ft/sec, E.A.S. (+up -down)																	
					-50	-45	-40	-35	-30	-25	-20	-15	-10	10	15	20	25	30	35	40	45	50	55
Initial climb	1,500	0-3,500	1670	5177					5	17	31	122	728	1444	158	33	19	5					
Final descent	500	0-2,500	1105	2952					2	4	15	67	390	1143	224	59	23	11	4	2			
Climb and	1,000	0-1,500	1133	3189					1	3	15	63	288	889	146	36	8	2					
descent	2,600	1,500-3,500	4106	13564						4	11	62	383	1172	169	37	12	3	2	2	1	1	
(excluding	4,500	3,500-5,500	3827	13951						4	16	54	298	582	98	29	10	1					
initial and	7,600	5,500-9,500	8158	32001			1	1	4	14	35	115	427	780	142	33	15	5	2	1			
final intervals)	11,500	9,500-13,500	7214	30119					1	6	11	28	122	249	33	9	2						
	15,000	13,500-17,500	5518	24229					1	2	6	21	84	110	21	4	1						
	18,100	17,500-21,500	425	1932						1	1	3	5	11	1								
Cruise	1,000	0-1,500	48	136						1	1	3	16	54	8								
	2,500	1,500-3,500	144	504							2	5	20	40	5	1							
	4,400	3,500-5,500	170	598									20	49	11	2	1						
	8,300	5,500-9,500	3137	13278					2	4	7	29	139	170	24	6	1						
	11,200	9,500-13,500	60729	266542			1	3	11	38	117	278	1261	1634	277	92	24	5	1				
	16,100	13,500-17,500	91037	418792		2	2	4	12	29	78	223	897	1459	244	78	26	7	1				
	18,700	17,500-21,500	36037	171717			1	2	6	14	47	133	598	565	100	33	10	3					
		Totals	224,458	1,005,881																			

TABLE 8

Gust counts during climb and descent in each region

Altitude band ft	Region	Recording time min	Statute miles	Number of times each gust speed was exceeded. Vertical gust speed in ft/sec E.A.S. (+up -down)																
				-45	-40	-35	-30	-25	-20	-15	-10	10	15	20	25	30	35	40	45	50	55
0-1,500	Europe	82	226						2	4	19	93	18	2							
	Indian Ocean	153	427				1	1	1	5	42	152	27	3	1						
	Far East	342	941						1	10	69	219	38	7	1	1					
	Australia	116	336					1	5	15	47	112	25	11	3						
	Pacific Ocean	400	1156					1	7	25	108	287	37	11	2						
1,500-3,500	Europe	347	1098							3	23	135	36	9	3						
	Indian Ocean	622	2086							8	48	124	17	4	1						
	Far East	1242	4089					1	3	15	82	353	42	7	1						
	Australia	475	1617					1	3	15	72	144	21	6	4	3	2	2	1	1	
	Pacific Ocean	1324	4400					1	3	24	128	337	50	10	4						
3,500-5,500	Europe	370	1353					1	4	13	43	86	14	4	1						
	Indian Ocean	451	1665							3	29	56	4	2	1						
	Far East	1200	4376							6	41	103	14	1							
	Australia	350	1308					1	5	17	61	144	23	7	4	1					
	Pacific Ocean	1381	5035					1	5	13	97	174	35	12	5						
5,500-9,500	Europe	799	3188							2	9	49	7								
	Indian Ocean	962	3707				2	3	4	9	22	32	9	5	5	2					
	Far East	2089	8146		1	1	1	2	6	21	91	117	21	5	2	2	1	1			
	Australia	365	3427					3	9	22	71	194	39	8	3	1	1				
	Pacific Ocean	3277	12894					4	14	50	206	316	56	14	5						

TABLE 9

Gust counts during cruise in each region

Altitude band ft	Region	Recording time min	Statute miles	Number of times each gust speed was exceeded. Vertical gust speed in ft/sec E.A.S. (+up -down)															
				-50	-45	-40	-35	-30	-25	-20	-15	-10	10	15	20	25	30	35	40
9,500-13,500	Europe	606	2763							1	1	9	31	1					
	Indian Ocean	6818	29885							5	15	61	71	11	4				
	Far East	7677	33549				1	5	7	18	54	215	332	44	10	3			
	Australia	6631	25722							5	26	181	281	24	5				
	Pacific Ocean	38937	170623			1	3	5	25	87	177	739	917	188	75	22	5	1	
13,500-17,500	Europe	4416	20582							1	6	36	63	2					
	Indian Ocean	15935	73074					4	11	22	46	170	283	65	24	7	2	1	
	Far East	27483	125203		2	2	2	4	7	23	69	243	406	75	20	5	1		
	Australia	13315	61580						1	2	16	103	219	20	3				
	Pacific Ocean	28920	133642				2	4	11	33	81	340	458	74	29	14	3		
17,500-21,500	Europe	4715	22711						1	3	8	46	60	5	1				
	Indian Ocean	3391	16055							6	16	20	17	2	1				
	Far East	3940	18495			1	1	2	3	7	18	50	92	17	8	5	2		
	Australia	4975	23489					2	5	17	44	226	217	37	10	2			
	Pacific Ocean	974	4336						1	2	6	19	38	7	2	1			

TABLE 10

Frequency of gusts exceeding 10 ft/sec in each month and region during cruise (9,500-17,500 ft)

Region		Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec
Indian Ocean	Miles	1581	6563	19554	12099	11168	1914	14609	4062	10297	4730	10062	6320
	Gust counts	0	63	88	41	7	134	93	68	46	4	33	5
	Miles/count	-	104.2	222.2	295.0	1595.0	14.3	157.0	59.7	223.8	1183.0	304.9	1264.0
Far East	Miles	2596	4192	15959	3140	9552	7019	20836	16430	23173	14849	31770	9206
	Gust counts	0	52	167	35	176	9	232	94	182	54	70	54
	Miles/count	-	80.6	95.6	36.9	54.2	780.0	89.8	175.3	127.3	274.9	453.8	170.5
Australia	Miles	2619	4607	11743	7248	5742	3879	11053	8522	9774	4995	15491	5628
	Gust counts	3	16	53	8	4	32	43	13	153	81	212	156
	Miles/count	873.0	287.9	221.5	906.0	1436.0	121.2	257.0	655.5	63.9	61.7	73.1	31.1
Pacific Ocean	Miles	4576	29474	29715	41512	19933	0	15295	29391	51071	25621	38472	19205
	Gust counts	7	380	212	413	97	0	49	198	432	132	356	205
	Miles/count	653.7	77.6	140.2	100.5	205.4	-	312.1	148.4	118.2	194.1	108.1	93.7

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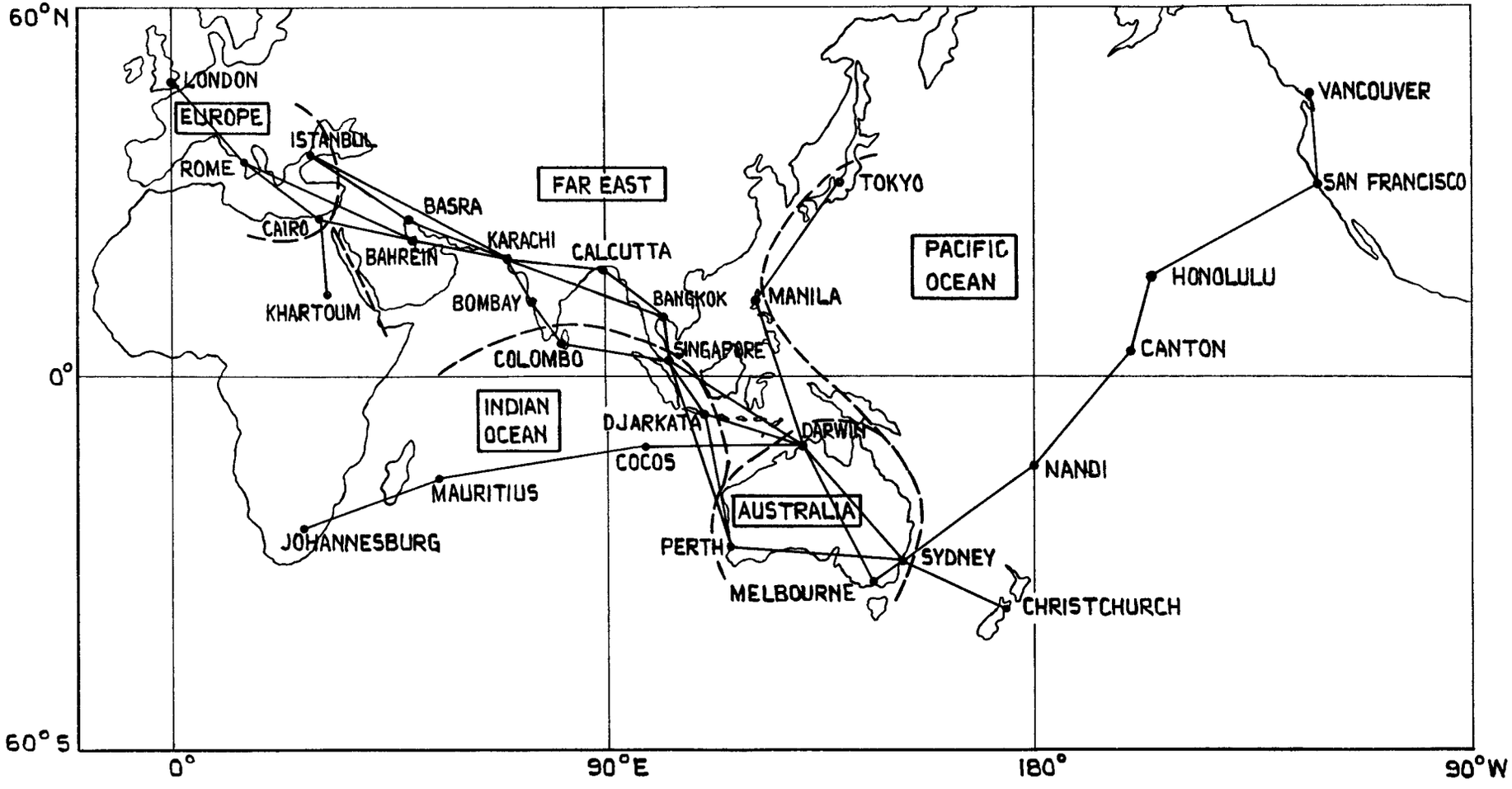


FIG. I. ROUTES FLOWN DURING TESTS.

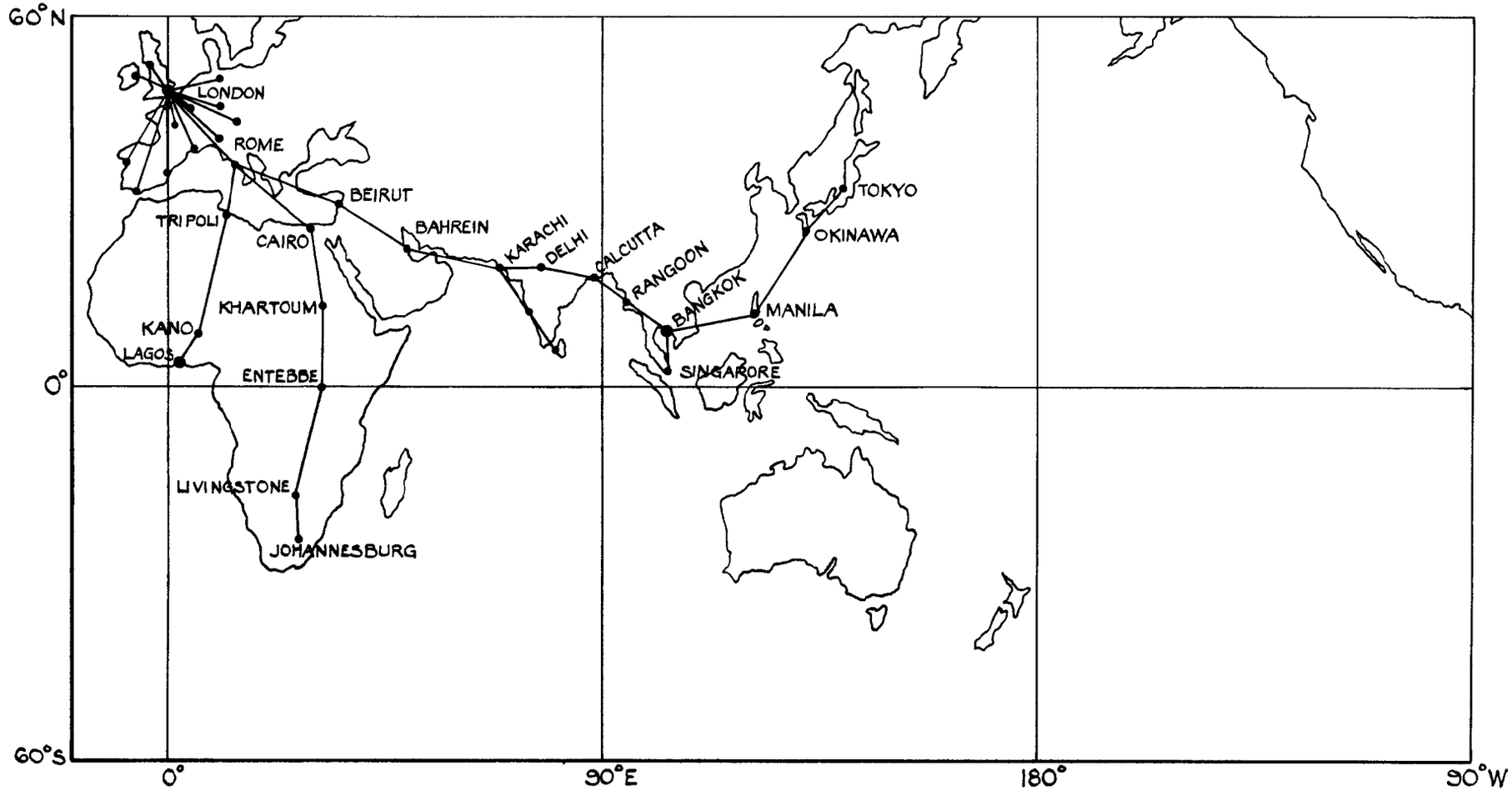


FIG. 2. ROUTES PREVIOUSLY RECORDED.

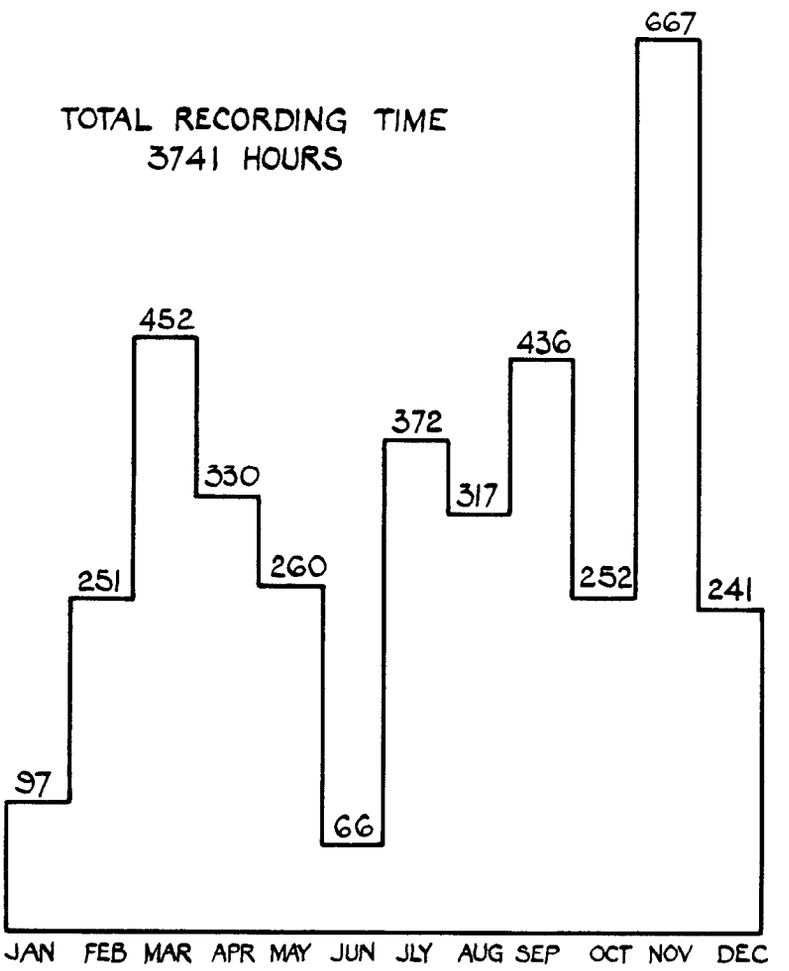


FIG. 3. MONTHLY DISTRIBUTION OF RECORDING TIME.

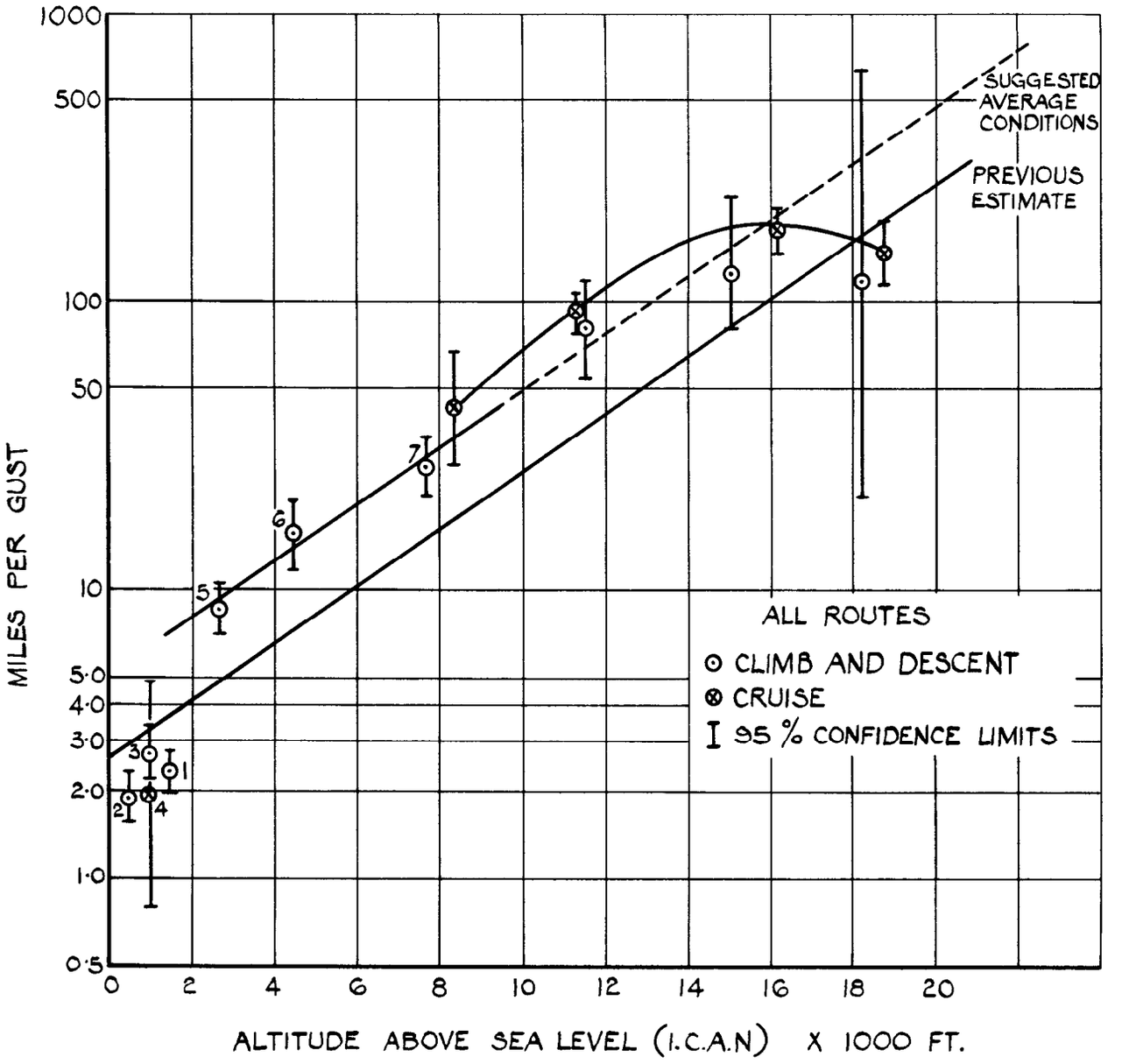


FIG. 4. VARIATION OF 10 FT./SEC. GUST FREQUENCY WITH ALTITUDE.

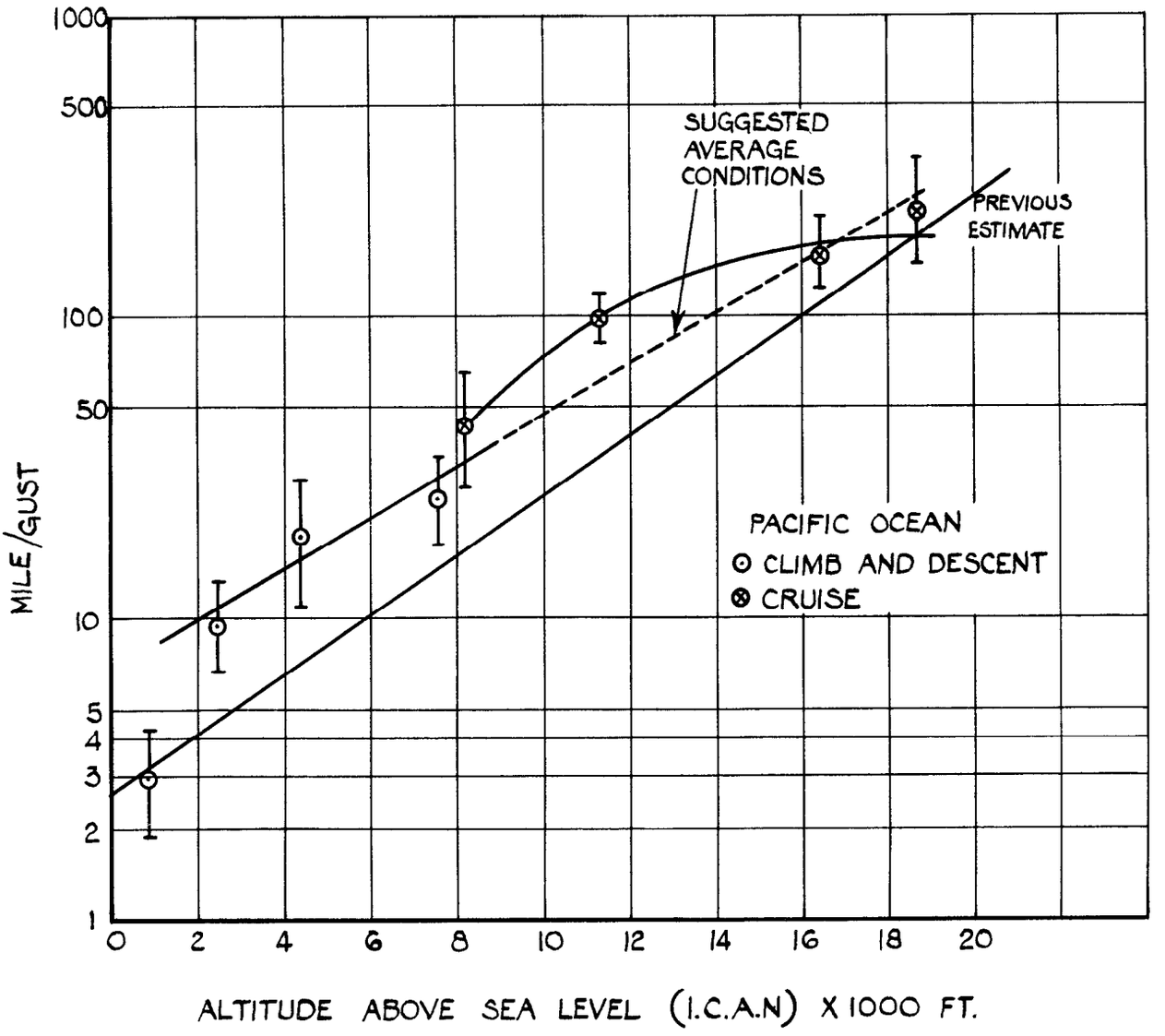


FIG.5. VARIATION OF 10 FT./SEC. GUST FREQUENCY WITH ALTITUDE OVER PACIFIC OCEAN.

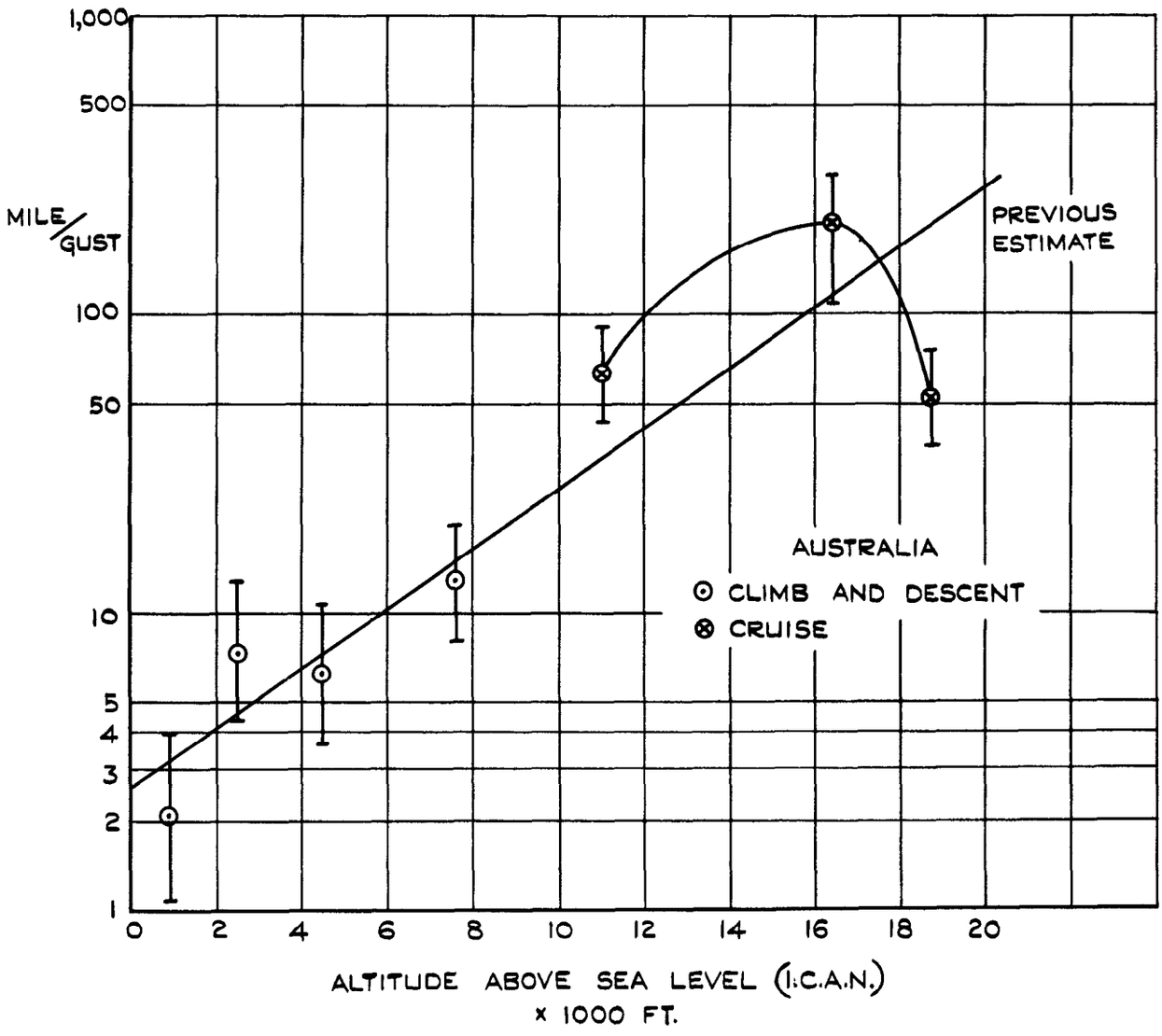


FIG. 6. VARIATION OF 10 FT/SEC GUST FREQUENCY WITH ALTITUDE OVER AUSTRALIA.

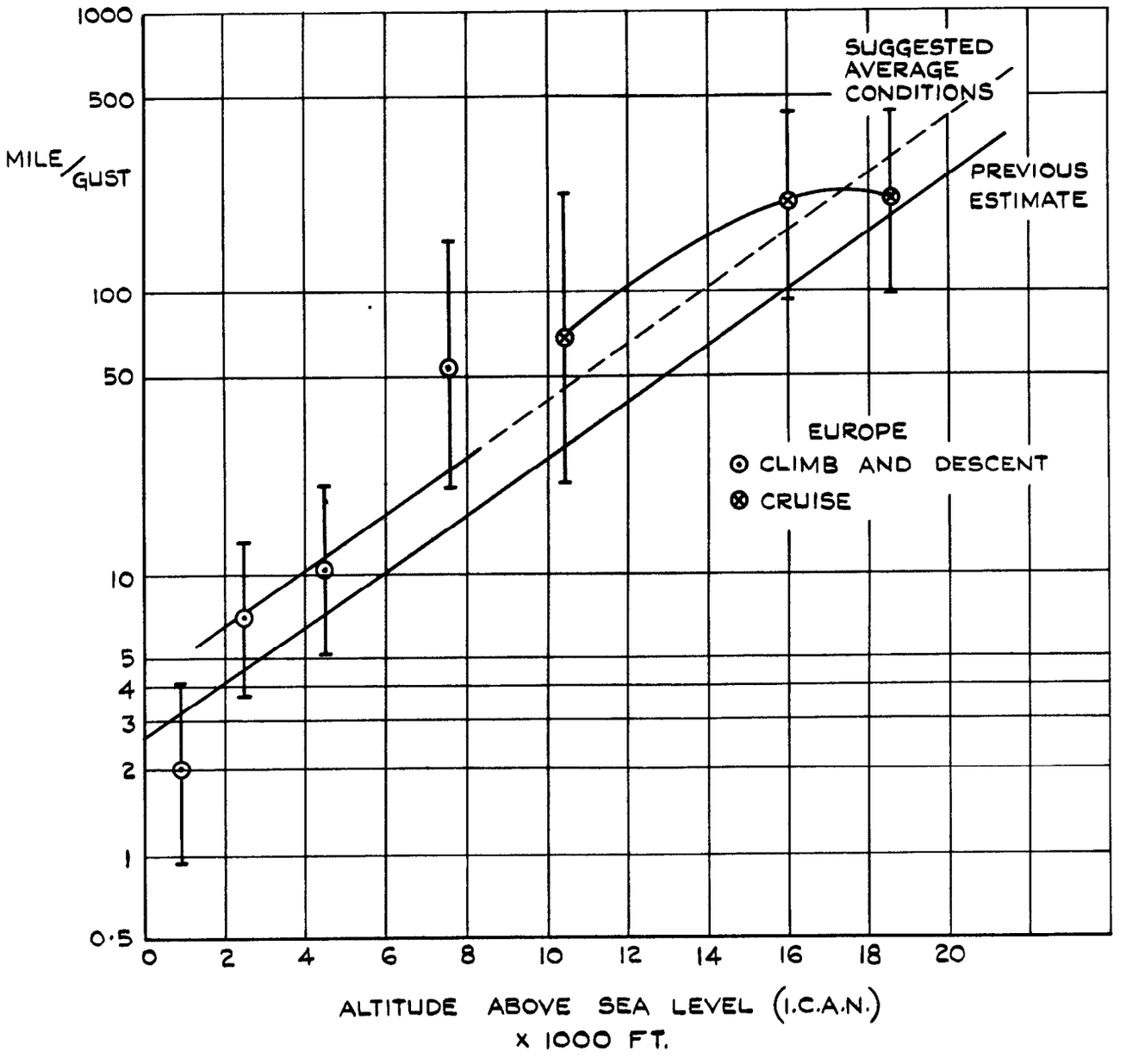


FIG. 7. VARIATION OF 10 FT/SEC GUST FREQUENCY WITH ALTITUDE OVER EUROPE.

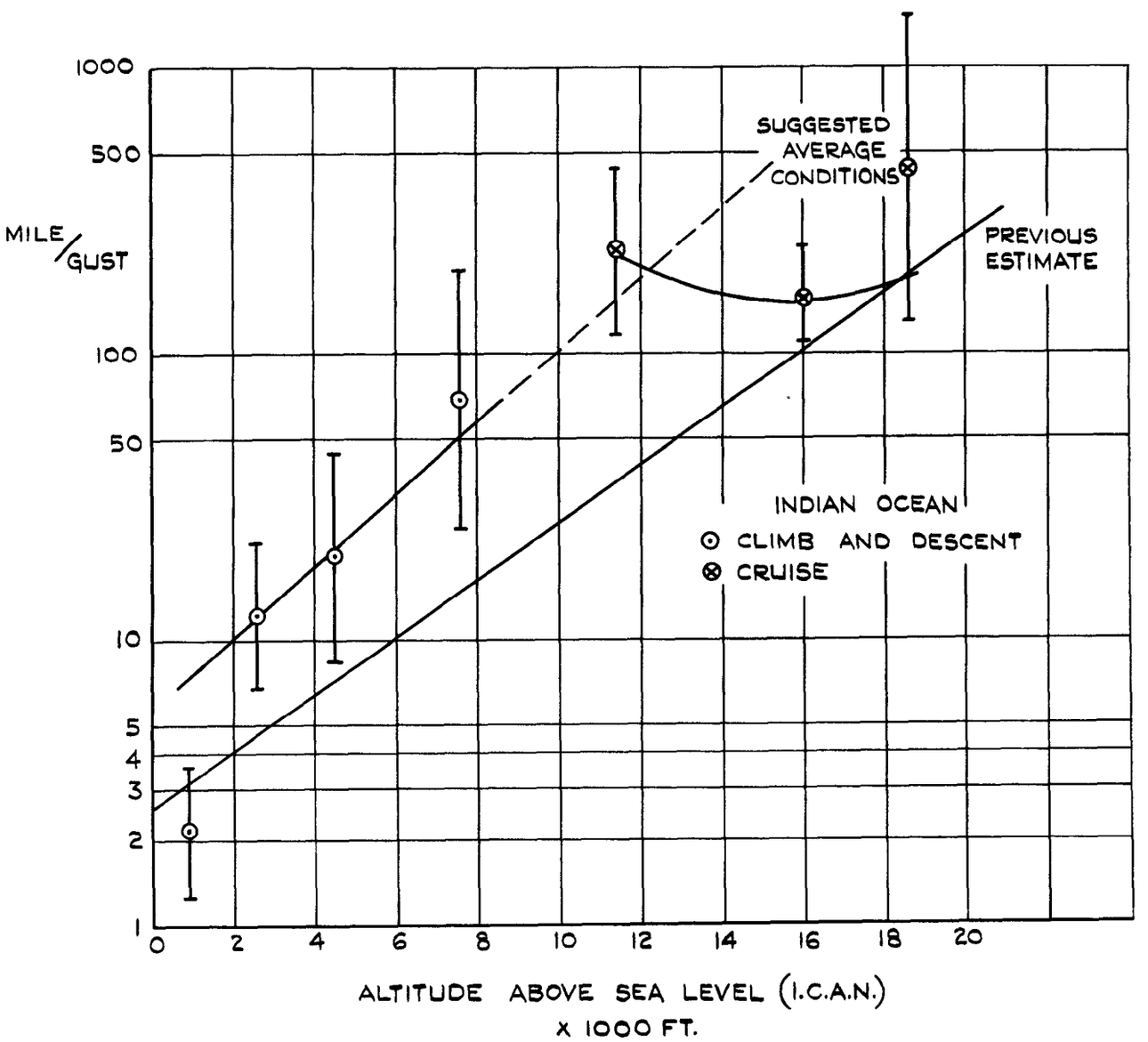


FIG. 8. VARIATION OF 10 FT/SEC GUST FREQUENCY WITH ALTITUDE OVER INDIAN OCEAN.

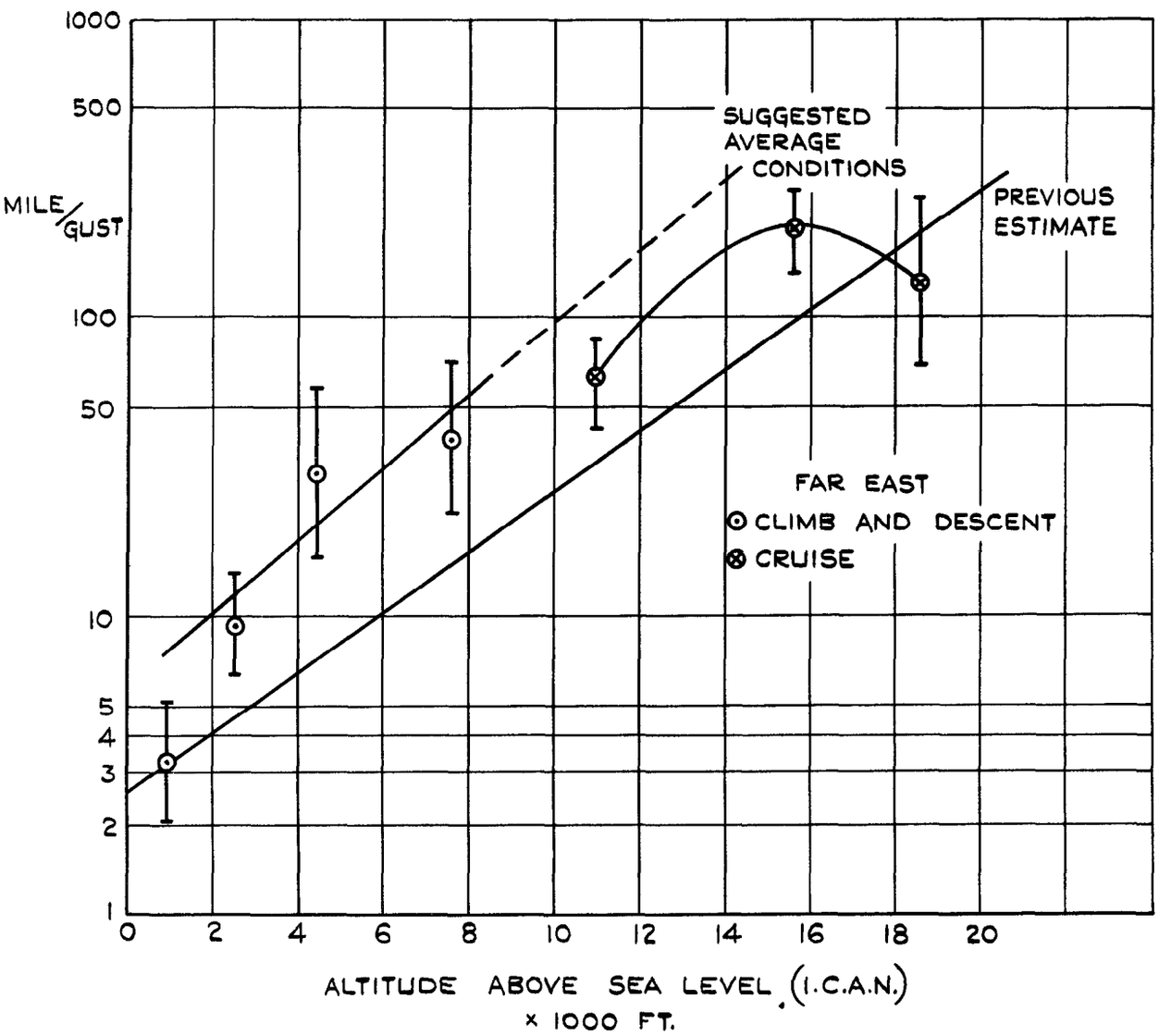


FIG. 9. VARIATION OF 10 FT/SEC GUST FREQUENCY WITH ALTITUDE OVER FAR EAST.

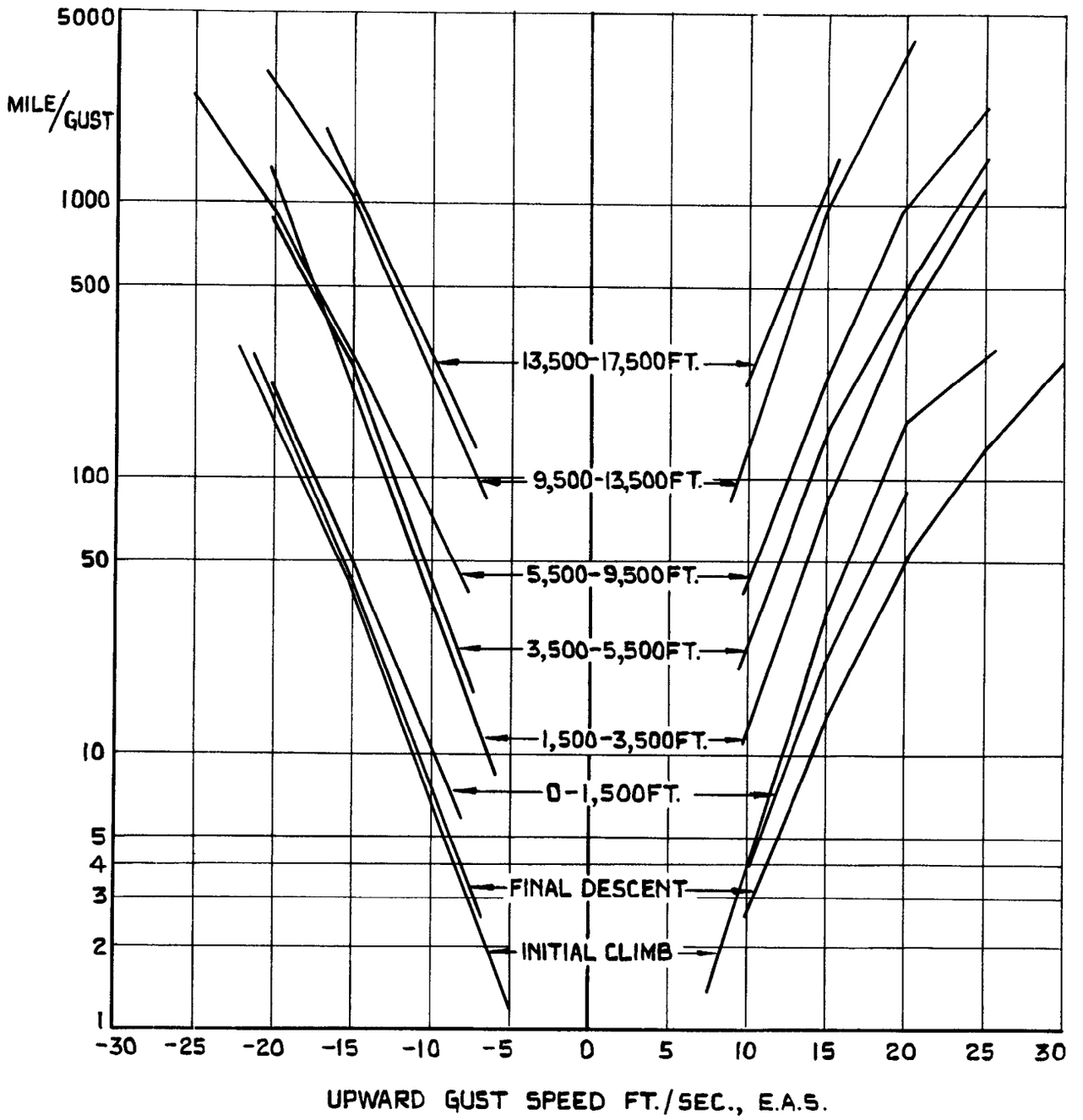


FIG. 10 VARIATION OF GUST FREQUENCY WITH GUST SPEED DURING CLIMB AND DESCENT.

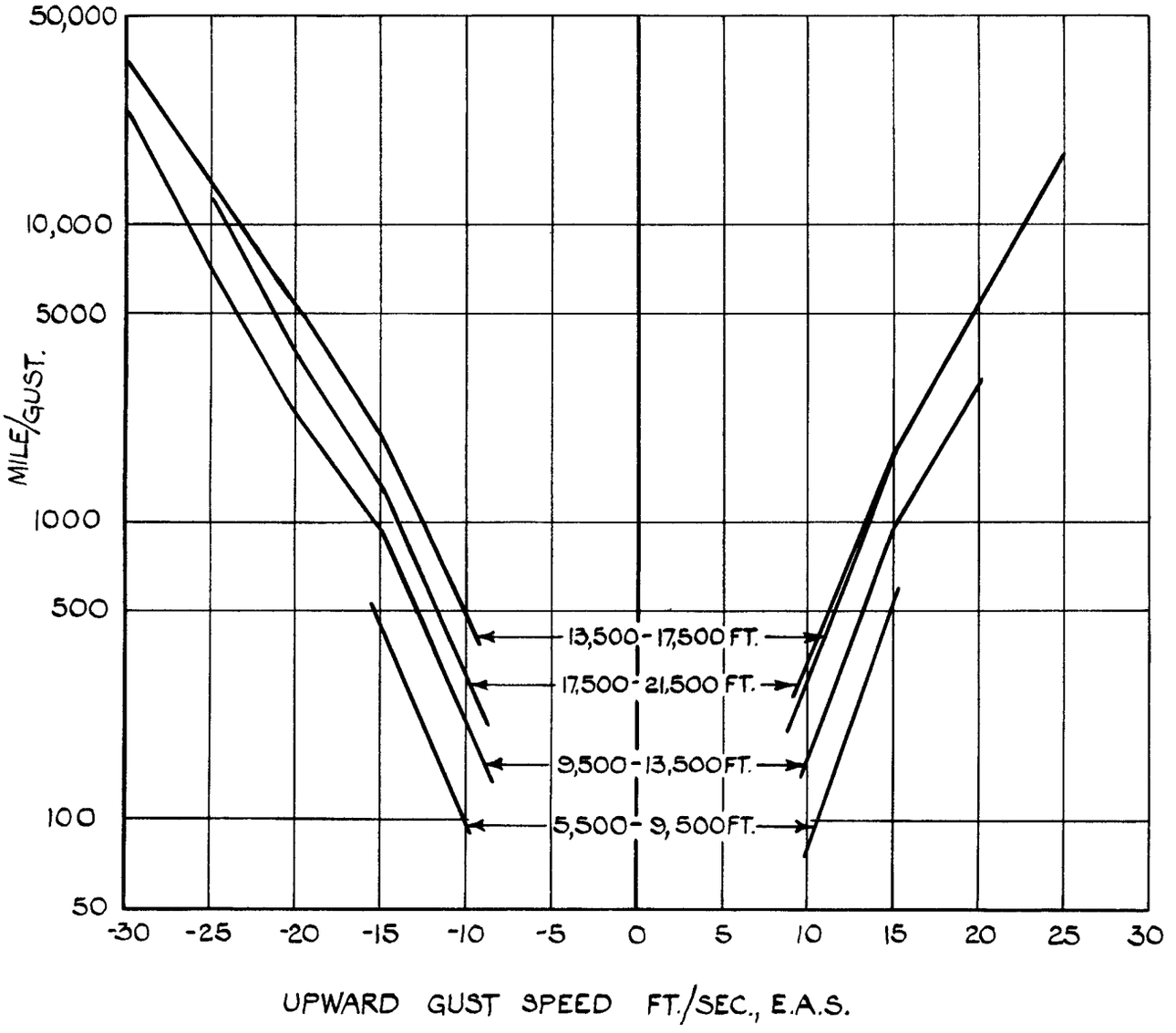


FIG.11. VARIATION OF GUST FREQUENCY WITH GUST SPEED DURING CRUISE.

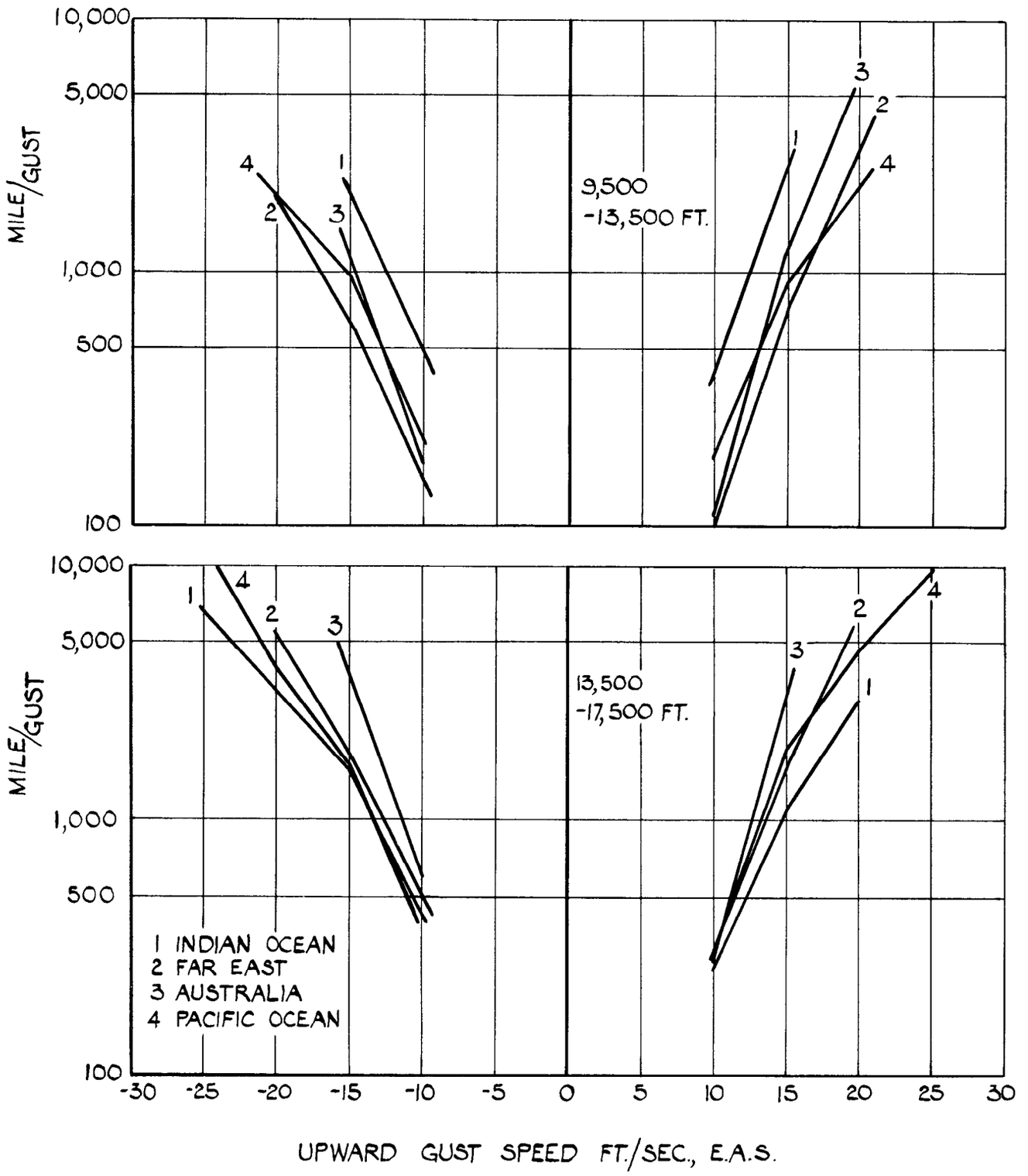


FIG. 12. VARIATION OF GUST FREQUENCY WITH GUST SPEED DURING CRUISE IN EACH REGION.

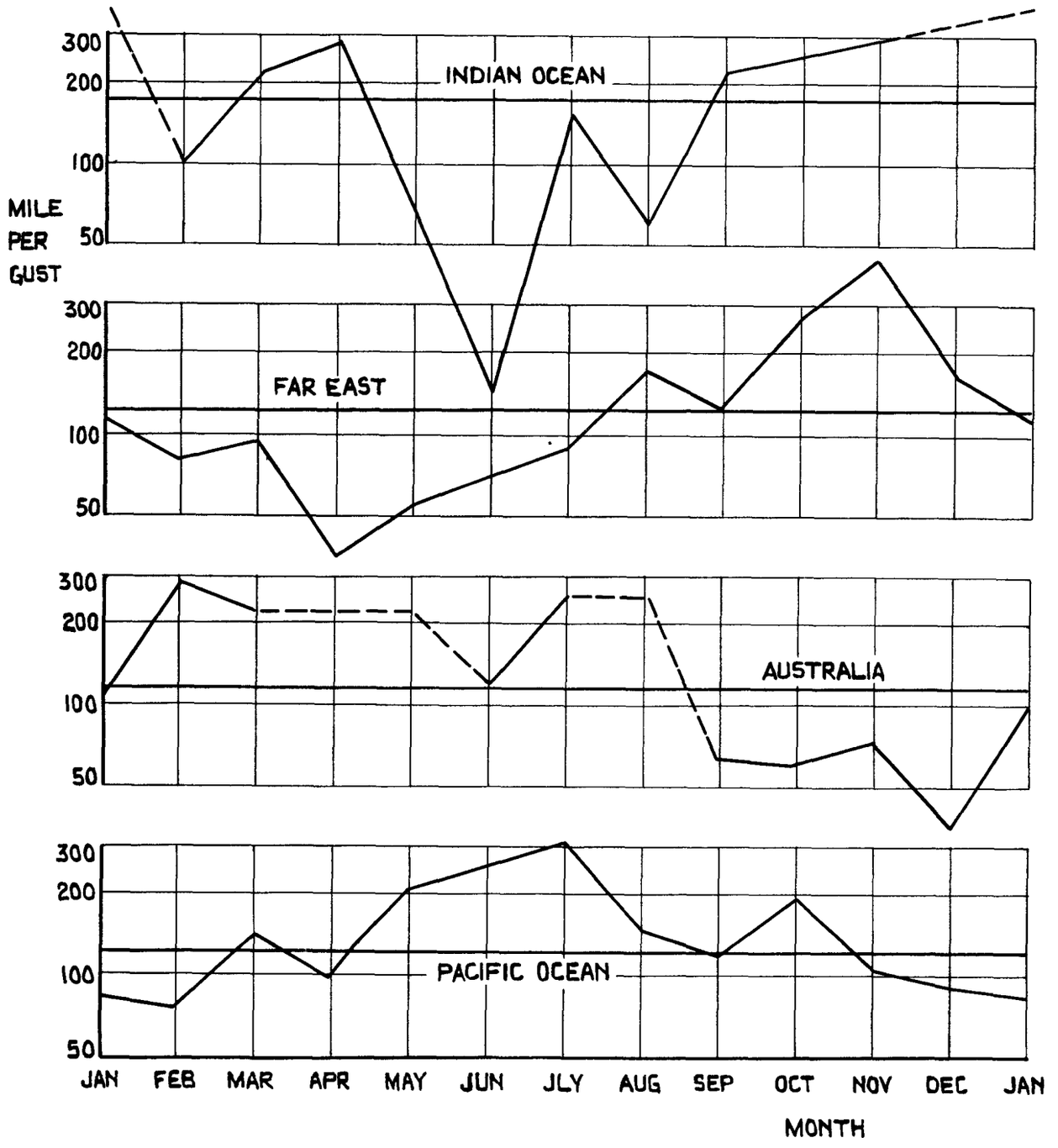
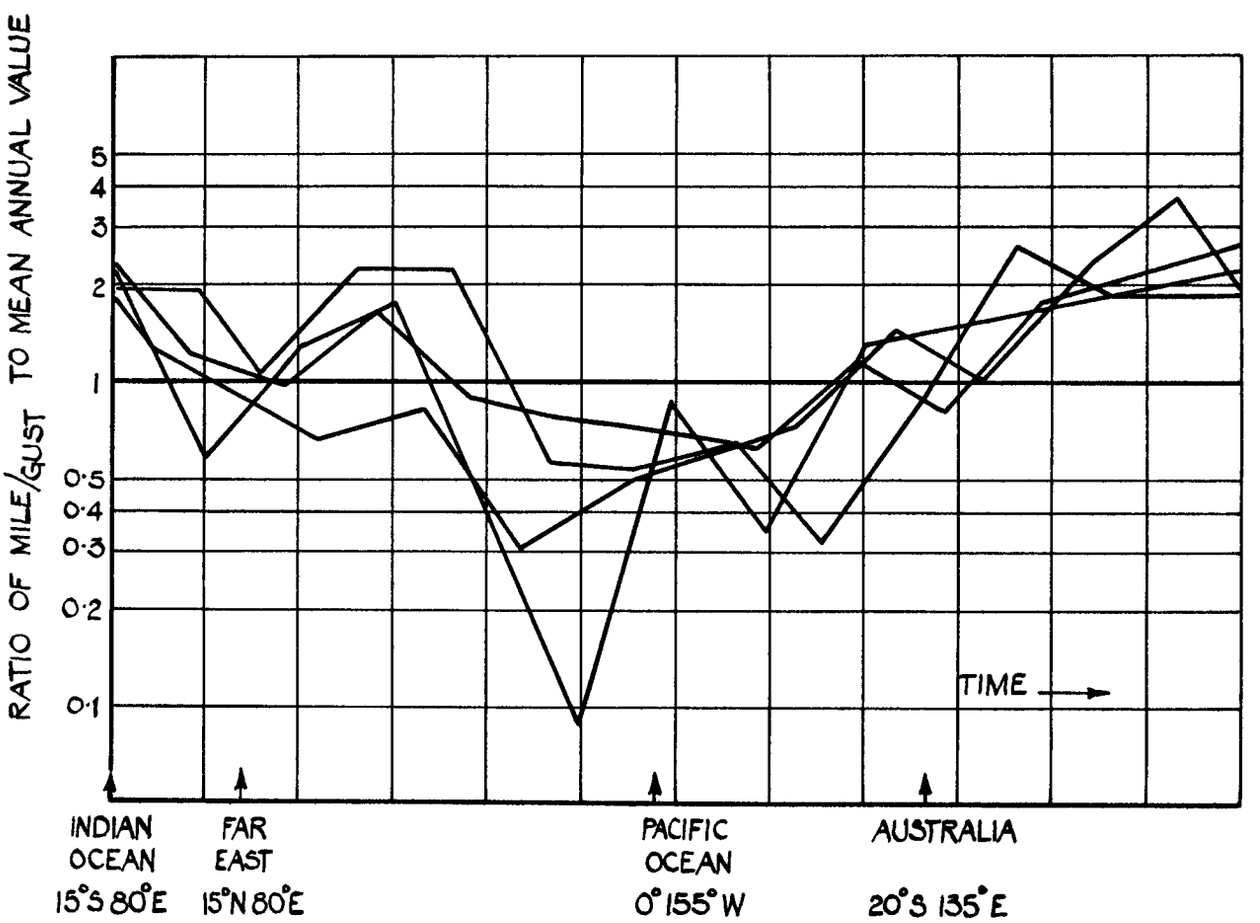


FIG. 13 ANNUAL CYCLE OF GUST FREQUENCY IN EACH REGION RECORDED DURING CRUISE BETWEEN 9,500 AND 17,500 FT.



POSITION OF JANUARY FOR EACH REGION.

FIG. 14. COMPARISON OF ANNUAL CYCLE OF GUST FREQUENCY FOR EACH REGION.

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