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Atmospheric Turbulence Encountered over the Atlantic by Stratocruiser Aircraft

by

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ATMOSPHERIC TURBULENCE ENCOUNTERED OVER THE ATLANTIC BY STRATOCRUISER AIRCRAFT

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SUMMARY

Counting Accelerometer records representing 861,000 miles were obtained from Stratocruiser aircraft flying on operational trans-Atlantic routes.

It is shown that the turbulence decreases with increasing altitude and is less than the average of previous analyses, due to the predominance of oversea routes in this data.

Gusts exceeding 10 ft/sec occurred more frequently during the winter months than during the summer over the Atlantic.

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1 INTRODUCTION

To measure the atmospheric gusts encountered over the Atlantic ocean, a Counting Accelerometer[1] was installed in a Stratocruiser aircraft flying on normal passenger service from the United Kingdom to North America and Canada.

In this note the variation in gust frequency with altitude, month, geographical region and gust speed is discussed and comparison is made with previous data.

2 INSTRUMENTATION

Counting Accelerometers[1], Mks. 3 and 4 were installed in the aircraft near the centre of gravity. The accelerometer recorded the number of times that a given series of upward and downward accelerations was exceeded. At intervals of time the automatic observer recorded the counter readings, airspeed, altitude and time.

The time interval of the Mk. 3 instrument was 10.4 minutes, and that of the Mk. 4 was 3.9 minutes below 7,000 ft and 9.2 minutes above this altitude.

In order to exclude take-off, landing and taxying accelerations from the records, the Mk. 3 accelerometer was mechanically locked via an electrical circuit. This was controlled by a manually operated switch in the aircraft cabin.

For the same reason the Mk. 4 accelerometer was switched on automatically when the airspeed exceeded 125 knots I.A.S. during take-off and switched off when the airspeed fell below 110 knots I.A.S. during landing.

3 TEST CONDITIONS

The aircraft carrying the instrument flew on normal passenger services from the United Kingdom across the Atlantic ocean to North America and Canada. A map of the routes flown is shown in Fig. 1. (The discontinuity in the numbering system of the regions on this map is due to the fact that this is part of a larger scheme.)

The distribution of recording time throughout the year is shown in Fig. 2. More flying hours were recorded during the last six months of the year, than during the first six months, as recording began in July 1954 and finished in December 1956.

Tables 1 and 2 give the time spent at different speeds and altitudes during climb and descent, and cruise. From Table 2 it can be seen that most of the cruise was between 6,000 ft and 21,000 ft and tended to be in the region of 10,000 ft or 18,000 ft.

4 ACCELERATION DATA

Tables 3 and 4 give the total acceleration counts recorded in each altitude band during each flight condition, with Mk. 3 and 4 instruments respectively.

The total counts recorded in the four main altitude bands in each geographical region during cruise are given in Tables 5 and 6.

To supplement the information recorded by the automatic observer, a record was kept of the date of each flight, the flight-sector and the take-off and landing weights of the aircraft. This was used when processing the data.

5 GUST ANALYSIS

The acceleration data were processed and converted to gust information by a standard method described in Ref. 2.

From records obtained using the Mk. 3 instrument, the first and last intervals of each flight were used in the analysis for the flight plan only, as it was found that ground accelerations had not always been excluded due to inadequate switching arrangements.

When analysing the accelerations recorded with a Mk.4 instrument, the final airspeed and half the final altitude of the first interval of a flight were assumed to be representative of the whole interval. Similarly the initial speed and half the initial altitude of the interval are assumed for the last interval of a flight.

The aircraft characteristics are stated in Table 7 and representative acceleration/gust velocity conversion factors are given in Table 8.

The estimated gust counts from all routes are given in Table 9 and from cruise in each geographical region in Table 10.

The frequency with which gusts exceeding 10 ft/sec occurred during cruise in the four main altitude bands in each geographical region is given in Table 11. Table 12 shows the frequency of gusts exceeding 10 ft/sec during cruise over the Atlantic in each month of the year.

6 OVERALL VARIATION OF GUST FREQUENCY WITH ALTITUDE

The variation in the frequency of 10 ft/sec gusts with regard to altitude is shown in Fig. 3. These graphs represent the records obtained over all routes.

The vertical line through each point indicates the 95% confidence limits which were calculated by a method given in Ref. 3. The lower straight line, added for comparison, is the general estimate of atmospheric turbulence which was based on earlier data from other routes and aircraft[4].

There is a general decrease in the number of gusts with altitude up to 14,000 ft. Although there is evidence of steady exponential decrease in gust frequency with altitude up to 25,000 ft over widespread routes[5], these curves show progressive reduction in slope which seems to indicate generally that the cruising altitude increases with the severity of the weather conditions.

The best estimate of the average atmospheric turbulence during the recording period is obtained by considering the climb and descent records at altitudes below the cruising range, as these records represent all weather conditions.

The three observations below 2,000 ft are:

Point 1, the recordings obtained immediately after take-off

Point 2, the recordings obtained immediately before landing

Point 3, all other recordings during climb and descent below 1,500 ft.

These observations, therefore, were obtained overland in all weather, and, in view of the assumptions made about aircraft speed during take-off and landing mentioned in Section 5, they agree satisfactorily with the previous general estimate of turbulence. Comparable observations from other data[6], show very similar tendencies.

These low altitude climb and descent points were not used in the estimation of the average atmospheric turbulence, suggested by a straight line on the graph. They are not representative of low altitude conditions over all the routes, being overland recordings, whereas about four fifths of the data were obtained over sea where conditions are less severe[7,8].

Between 2,000 ft and 9,500 ft there are 3 climb and descent points which were obtained in all weather with little sideways avoidance by the pilot, and which represent average atmospheric conditions between these altitudes. A straight line drawn through these points is the best estimate of average conditions encountered on routes covered by the data under consideration. The extension of this line intersects the cruise curve at about 14,000 ft, a point a little above the mean cruising altitude and corresponding approximately to the least value of recorded gust frequency.

By comparison with the previous estimate, the line representing the suggested average for these present data has a greater rate of decrease with altitude and is less severe overall by a factor of about 2.5. This compares quite favourably with other data[6], from records which are two thirds oversea and which give a factor of 2.0. The predominance of overland flying in the data on which the previous estimate was based, probably accounts for the difference in severity. It is significant that the low altitude observations lie very close to both estimates which merge at sea level.

At the higher altitudes, between 16,000 and 19,000 ft, the climb and descent curve shows a sharp increase in the severity of turbulence. The bulk of the records consists of direct crossings of the Atlantic ocean, the aircraft cruising at about 18,000 ft on the eastward crossings to take advantage of the prevailing winds, and at 10,000 ft into the headwind on most of the westward crossings. Possibly the sharp fall in the climb and descent curve is due to the aircraft climbing through a turbulent region in order to reach these tail winds.

No cruise records obtained from altitudes below 6,000 ft have been shown on the graph as they were considered to be more representative of stand-off and landing approach.

The rest of the cruise data below 16,000 ft make up that portion of the curve which lies above the line representing average conditions. This means that, at these altitudes, the aircraft encountered turbulence which was less than average.

At the higher altitudes the cruise curve falls below the extrapolated line indicating that more than average turbulence was experienced.

Unlike the climb and descent curve, the cruise curve does not show a very severe increase in turbulence at its highest altitudes, even though it seems probable from the relative infrequency of flights above 20,000 ft that they were made only during very bad weather. Although more severe by a factor of about 1.7, this cruise curve is in quite good agreement with that of the similar records previously mentioned[6].

The overall ratio between the climb and descent curve and the cruise curve is about 2.0, which agrees exactly with that for the Viking cruising at an altitude of 10,000 ft, but is greater than the 1.4 ratio of the Super-Constellation which cruised at 11,000 or 17,000 ft. It is probable that the gust frequency is less during cruise partly due to the sideways avoidance of turbulence, which is not possible to any great extent during climb and descent, and partly due to the choice of higher cruising altitudes when the weather is bad. This is not meant to imply that on encountering a patch of turbulence the pilot attempts to fly above it. The cruising altitude having been decided at the flight planning stage, the difficulties arising from the density of air traffic over the Atlantic make requests to Air Traffic Control for permission to change altitude unlikely for anything but exceptionally prolonged and severe turbulence.

7 VARIATION OF GUST FREQUENCY WITH ALTITUDE IN EACH REGION

The cruise records from the data discussed in the previous section are now divided into the arbitrary geographical regions shown in Fig. 1. These regions will be called Europe, North America inland, North America coastal, Bermuda and the Atlantic ocean. The Atlantic ocean records comprise the greatest part of the data.

Fig. 4 shows the variation of gust frequency with altitude in all regions, and is discussed below.

Europe

The amount of data obtained from the Europe region was very small and consisted mainly of the short sectors London - Manchester, Prestwick or Shannon. This was, therefore, low altitude cruising overland and it was about 8 times less severe than the previous estimate.

North America, inland

These records, representing flights from Montreal - Chicago, were a very small sample occurring only in the 5,500 - 9,500 ft band. In view of the fact that this flying was entirely overland, very slight turbulence indeed was encountered compared with previous experience.

North America, coastal

In this region, a mixture of oversea and overland flying, the turbulence decreases steadily with altitude up to 15,000 ft and is considerably less severe than average. Above 16,000 ft there is a progressive increase in the frequency of gusts, which from 18,000 - 19,000 ft is more than the previous general estimate. This seems to indicate that these altitudes were used only during very bad weather.

Bermuda

The sectors covered by these records were mainly Bermuda - Gander, New York or Nassau i.e. oversea sectors. This curve shows equal gust frequency in the middle two altitude bands of the cruise with rather more turbulence in the lowest band, 5,500 - 9,500 ft and quite severe turbulence in the highest band, 17,500 - 21,500 ft.

In this region thunderstorms occur frequently and perhaps the increase in gust frequency at the lowest altitude point, and the highest altitude point, on this curve may be attributed to the following facts. By choice the pilot will fly in the region of 18,000 - 20,000 ft, the optimum cruising altitude of the aircraft. This may entail flying through worse than average turbulence due to the thunderstorms, which are building up but which are not yet severe enough to be serious hazards. When a bad storm is in progress, the pilots have found by experience that its effects are often best alleviated by flying through it at a comparatively low altitude rather than by trying to climb above what may be a very extensive storm.

Atlantic ocean

The trans-Atlantic routes on which gust data were recorded were London - New York, Montreal or Gander and Shannon - Goose or Gander.

The eastward crossings of the Atlantic had the advantage of the prevailing winds and jet streams which, if present, occur just below the tropopause in the region of 30,000 ft with strong winds below them. Starting its cruise in this direction at about 13,000 or 14,000 ft the aircraft climbed, as soon as sufficient fuel had been used, to the region of 18,000 ft where it cruised most of the time. This 17,500 - 21,500 ft altitude band is represented by the point of lowest gust frequency on the curve. The line representing the previous estimate of average turbulence also passes through this point, indicating perhaps that the turbulence is slightly more than might be expected from comparing data obtained entirely over the sea with predominantly overland data. This latter fact is significant also when considering the point obtained for the 21,500 - 25,500 ft band. Here the turbulence is considerably more severe than average, no doubt due to weather bad enough to merit the eastward flight having been made at a higher cruising altitude than usual.

On the westward crossings, the cruising altitude was restricted to 10,000 ft by strong head winds. In this direction the pilot frequently takes sideways avoidance of turbulence, which probably accounts for the fact that the frequency of the gusts which the aircraft encountered, is nearly as low in this altitude band as in the two bands above it. The increase in turbulence between the 9,500 - 13,500 ft band and the 5,500 - 9,500 ft band probably indicates that on some occasions the aircraft was forced to fly lower because the head winds were stronger than usual.

The slope of this curve is very similar to that obtained from data collected over the Pacific ocean[6]. between 8,000 ft and 19,000 ft, although the turbulence is less severe by a factor of approximately 1.7 in this Atlantic ocean data.

8 VARIATION OF GUST FREQUENCY WITH GUST SPEED

Figs. 5 and 6 show the variation of gust frequency with gust speed during climb and descent and during cruise. The slopes of the lines obtained from previous data[4] have been shown for comparison. The initial climb and final descent records are incorporated in the low altitude curves of the climb and descent graph.

On both graphs the upgusts and the downgusts show a similar variation in gust frequency, which is approximately exponential at small gust speeds, the slope tending to decrease at higher gust speeds.

The distributions of the upgusts and downgusts are roughly symmetrical about the zero gust speed datum, but if the low speed ends of the curves are produced back to meet the apparent datum varies from -0.5 ft/sec to 2 ft/sec. This apparent movement of the datum is generally related to the slope of the downgust curve relative to that of the upgust curve, though no correlation has yet been found between these variations and the conditions of flight, etc.

The overall tendency shown by both the climb and descent and the cruise curves is for the gust frequency to decrease with altitude; although on both graphs the curves for the 17,500 - 21,500 ft altitude band indicate that gusts of all speeds occurred more frequently than might be expected from this general consideration. The incidence of 20 ft/sec gusts was as high in this altitude band during climb and descent as in the very low bands.

The slopes of the curves for the 9,500 - 13,500 ft altitude band are less steep at the higher gust speed ends than the slopes of the other curves on the climb and descent graph, and this would seem to indicate that at these altitudes the ratio of large gusts to small gusts was higher. It seems probable that the building up of thunderstorms in the Bermuda region, discussed in Section 7, largely accounts for both these deviations from the general trend.

Comparing the slopes of the climb and descent curves with those of the cruise curves, the slopes of the 9,500 - 13,500 ft and 17,500 - 21,500 ft bands are seen to be steeper during cruise for both upgusts and downgusts. This means that fewer large gusts relative to the number of small gusts were encountered while the aircraft was cruising than while it was climbing or descending, in these altitude bands. This is probably connected with the fact that most of the cruise took place in these altitude bands, in the region of 10,000 ft and 18,000 ft.

Both graphs show the slopes of curves to be steeper than those of previous data, no doubt due to the predominance of oversea records in this present data, and the resultant overall decrease in the number of thunderstorms encountered.

9 SEASONAL VARIATION OF GUST FREQUENCY

The cruise records obtained over the Atlantic ocean were divided according to month, to examine the seasonal variation of turbulence. Fig. 7 shows the 10 ft/sec gust frequency throughout the year.

The overall curve approaches a single fluctuation indicating less than the annual mean value of gust frequency in the summer months and more than the mean in the winter months. This agrees quite well with gust measurements taken in other aircraft[6,9].

The April and May observations show the least turbulence and there is a tendency for the gust frequency to increase towards the end of the summer. This may be due to increasing convective activity occurring over the Atlantic at this time of year.

During the winter months the gust frequency is average or higher than average, with a pronounced increase at the February observation which is, however, representative of fewer miles than the observations for other months.

It is known that the prevailing winds across the Atlantic are stronger during the winter, although figures confirming this were not found to be readily available, and it seems probable that there is an accompanying increase in the turbulence.

10 CONCLUSIONS

The frequency of gusts exceeding 10 ft/sec decreases with altitude at a greater rate than that found previously, but is smaller overall by a factor of approximately 2.5 due to the predominance of oversea records in the data.

No general result is apparent from the comparison of oversea, coastal and overland records, but in the lower altitude bands more gusts exceeding 10 ft/sec were encountered in the coastal than in the oversea regions, and over the European routes which are mainly overland, the gust frequency was considerably less than might be expected even from such a small sample.

On the trans-Atlantic routes the turbulence was sensibly constant at all but the lowest and highest altitude bands, where it was considerably less than the previous average and considerably more than the previous average respectively.

When compared with data obtained from over the Pacific ocean, the turbulence over the Atlantic proved to be about 1.7 times less severe.

In most altitude bands large downgusts occurred slightly more frequently than large upgusts relative to the frequency of small gusts.

The seasonal variation in the frequency of gusts over the Atlantic approaches a single fluctuation with the lowest frequencies occurring during the summer months. The recorded turbulence appears to be at its minimum during May and at its maximum during February.

ACKNOWLEDGEMENTS

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Table 1

Estimated time in minutes spent at each speed and altitude during climb and descent

Indicated airspeed in knots	Altitude above sea level (I.C.A.N.) in 1000s of feet: 00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
100	23																									100
110	21	4																								110
120	93	74	3																							120
130	169	103	46	35	7	5		15																		130
140	191	187	134	48	41	4																				140
150	143	215	128	69	65	25		7	9					10				10								150
160	96	298	248	237	273	155	179	128	132	158	126	133	91	91	178	136	120	70	31	42	10	31	10			160
170	99	529	370	615	482	407	446	397	489	373	356	413	428	269	414	501	440	282	229	83	52	42	21		10	170
180	37	183	163	279	239	278	337	288	312	350	166	203	238	241	217	298	188	277	218	94	52	10				180
190	32	78	40	172	236	266	156	225	169	197	65	156	159	124	138	158	276	201	146	52	10	21				190
200	16	67	85	101	112	148	359	293	287	385	158	186	194	227	203	140	148	102	52	21						200
210	9	63	49	52	78	165	302	437	284	174	153	183	213	177	77	59	50	26	10							210
220		56	46	55	80	127	135	126	122	200	69	110	71	82	31	31										220
230	3	31	21	5		10	21	63		17	21	21	21		10											230
240																										240
250					5																					250
Total	932	1,888	1,333	1,668	1,618	1,590	1,935	1,979	1,804	1,854	1,114	1,405	1,415	1,221	1,268	1,323	1,222	968	686	292	124	104	31	-	10	

Total climb and descent: 27,784 mins.

Table 2

Estimated time in minutes spent at each speed and altitude during cruise

		Altitude above sea level (I.C.A.N.) in 1000s of feet																										
		00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
Indicated airspeed in knots	120	3	4	5	4	4	8				10																	120
	130	12	70	20	4	24	7	5																				130
	140	11	140	79	42	12	7	18	16			9											18					140
	150	3	44	71	75	55	49	73	29	20		38	21	9	47	45	18	10	47	9	110	96	104			42		150
	160	4	40	88	47	119	83	203	67	151	51	239	263	192	1,281	531	592	387	1,744	1,267	2,619	797	2,190	247	183	62	10	160
	170		68	98	106	129	105	268	477	1,152	417	5,093	2,075	2,401	5,514	4,955	5,144	2,846	7,016	8,419	12,644	3,801	4,157	674	962	302	10	170
	180		31	84	119	130	106	2,358	963	5,910	2,480	19,286	3,004	4,163	3,984	4,978	3,284	2,885	3,277	5,359	4,107	1,895	510	21	21	83		180
	190		70	91	113	271	167	1,407	821	3,813	1,264	5,190	1,239	1,421	1,081	1,006	382	497	546	447	312	175	10			10		190
	200		42	326	124	186	185	968	718	1,793	567	821	212	282	31	41	21	103	21	94	42	10				10		200
	210		38	23	72	42	51	137	120	29	31	60	20			10												210
	220			25	14		21	10	10	10	9	10	10					10		10								220
Total		33	547	910	720	972	789	5,447	3,221	12,878	4,829	30,746	6,844	8,468	11,938	11,566	9,441	6,738	12,651	15,605	19,834	6,774	7,380	942	1,166	509	20	

Total cruise: 180,968 mins.

Table 3

Summary of acceleration data from a Counting Accelerometer Mk.3 in a Stratocruiser aircraft

Flight condition	Altitude band feet	Recorded time mins	Statute miles	Number of times each acceleration increment was exceeded (+ up, – down)										
				-0.72g	-0.62g	-0.52g	-0.43g	-0.33g	-0.23g	+0.23g	+0.33g	+0.43g	+0.52g	+0.62g
Climb and descent	0 – 1,500	41	132					2	7	23	6	1		
	1,500 – 3,500	946	3,274				1	8	114	379	65	7		
	3,500 – 5,500	1,788	6,732					17	190	355	63	7		
	5,500 – 9,500	3,733	15,366	1	1	2	10	22	210	387	64	9	1	
	9,500 – 13,500	2,849	12,403			3	6	14	81	87	21	10	1	
	13,500 – 17,500	2,641	11,775				3	6	25	31	4	1		
	17,500 – 25,500	1,248	5,719	1	4	6	15	31	123	133	58	37	9	1
	Totals	13,246	55,401	2	5	11	35	100	750	1.395	281	72	11	1
Cruise	0 – 1,500	104	365						1	3	2	1		
	1,500 – 3,500	551	2,042						14	36	3			
	3,500 – 5,500	634	2,446				6	18	107	152	37	9	3	
	5,500 – 9,500	12,458	50,104				1	16	203	282	60	7	1	
	9,500 – 13,500	32,681	133,674		1	1	7	25	224	351	75	11	5	1
	13,500 – 17,500	23,766	102,093				4	13	97	157	26	5		
	17,500 – 21,500	33,356	149,453		3	5	20	47	395	426	89	20	2	
	21,500 – 25,500	2,381	11,101					1	37	36	3			
	Totals	105,931	451,278		4	6	38	120	1,078	1,127	295	53	11	1

Table 4

Summary of acceleration data from a Counting Accelerometer Mk.4 in a Stratocruiser aircraft

Flight condition	Altitude band feet	Recorded time mins	Statute miles	Number of times each acceleration increment was exceeded (+ up, – down)											
				–0.67g	–0.53g	–0.40g	–0.27g	–0.20g	–0.13g	+0.13g	+0.20g	+0.27g	+0.40g	+0.53g	+0.67g
Initial climb	0– 1,500	664	2,192				17	88	440	707	170	31	2		
	1,500– 3,500	209	676			4	22	74	290	446	149	40	4		
	3,500– 5,500	42	160				1	4	40	52	11	1			
	5,500– 9,500	17	69				1	6	22	41	11	4			
Final descent	0– 1,500	576	1,552			1	25	80	525	762	248	79	3	1	
	1,500– 3,500	25	89					2	28	46	45	16			
Climb and descent	0– 1,500	101	265				1	4	70	96	27	6			
	1,500– 3,500	922	3,096			1	26	94	404	724	217	66	6		
	3,500– 5,500	1,244	4,570			6	35	112	414	551	179	52	5		
	5,500– 9,500	3,776	15,169			9	36	122	505	707	224	79	10		
	9,500–13,500	2,307	9,637			2	18	60	256	308	90	29	5		
	13,500–17,500	2,140	9,242				4	12	132	129	18	6			
	Totals	10,490	41,979			18	120	404	1,781	2,515	755	238	26		
Cruise	0– 1,500	477	1,460	1	1	3	25	97	429	734	235	66	5	1	
	1,500– 3,500	1,078	3,788			2	24	95	406	738	231	75	1		
	3,500– 5,500	1,127	4,346		1	5	28	83	334	419	147	51	5	1	
	5,500– 9,500	13,920	54,865		5	31	193	495	1,748	1,956	679	295	53	5	1
	9,500–13,500	25,310	101,658			11	79	268	1,359	1,534	380	115	9		
	13,500–17,500	16,631	69,463	1	4	18	68	171	757	715	195	79	11	3	
	17,500–21,500	16,237	70,662	1	3	18	56	171	702	672	188	64	11	2	
	21,500–25,500	255	1,169							1					
	Totals	75,035	307,411	3	14	88	473	1,380	5,735	6,769	2,055	745	95	12	1

Table 5

Accelerations recorded with a Mk.3 Counting Accelerometer during cruise in each region

Altitude band feet	Geographical region	Recorded time mins	Statute miles	Number of times each acceleration increment was exceeded (+ up, − down)									
				−0.62g	−0.52g	−0.43g	−0.33g	−0.23g	+0.23g	+0.33g	+0.43g	+0.52g	+0.62g
5,500– 9,500	Europe	2,173	8,981					12	23	5			
	Atlantic ocean	7,062	28,041			1	11	128	173	41	7	1	
	N. America coast	1,851	7,657				4	70	72	9			
	Bermuda	977	3,818				1	8	7	2			
	N. America inland	301	1,226					1	7	3			
9,500–13,500	Europe	592	2,575					3	14	1	1		
	Atlantic ocean	28,284	115,058			2	14	172	261	46	5	2	1
	N. America coast	2,922	12,386			4	9	38	64	18	5	3	
	Bermuda	582	2,398					0	0				
	N. America inland	114	482					0	0				
13,500–17,500	Atlantic ocean	20,812	89,128			2	6	79	130	20	2		
	N. America coast	1,882	8,241					5	13				
	Bermuda	998	4,407			2	7	13	14	6	3		
17,500–21,500	Atlantic ocean	25,841	115,633	2	3	10	22	209	246	43	10	2	
	N. America coast	3,317	14,952			2	9	73	67	10	2		
	Bermuda	3,848	17,242	1	2	8	16	111	114	36	8		
	N. America inland	270	1,297					1	0				

Table 6

Accelerations recorded with a Mk.4 Counting Accelerometer during cruise in each region

Altitude band feet	Geographical region	Recorded time mins	Statute miles	Number of times each acceleration increment was exceeded (+ up, - down)											
				-0.67g	-0.53g	-0.40g	-0.27g	-0.20g	-0.13g	+0.13g	+0.20g	+0.27g	+0.40g	+0.53g	+0.67g
5,500- 9,500	Europe	2,319	9,445		1	5	38	111	391	255	69	26	1		
	Atlantic ocean	7,814	30,061		1	9	65	172	735	869	257	100	8	1	
	N. America coast	2,804	11,453		1	13	78	186	536	727	312	159	42	4	1
	Bermuda	541	2,159		2	2	9	20	57	67	18	6	2		
	N. America inland	367	1,469			2	3	7	28	37	13	4			
9,500-13,500	Europe	1,478	6,000			1	2	6	43	58	9	5	1		
	Atlantic ocean	18,566	73,665			7	54	179	896	942	231	67	4		
	N. America coast	4,421	18,495			3	20	73	365	460	121	36	3		
	Bermuda	396	1,651				2	6	24	28	12	5	1		
	N. America inland	292	1,166				1	3	27	41	7	2			
13,500-17,500	Europe	203	875					1	5	6	2				
	Atlantic ocean	12,224	50,880	1	4	16	62	155	653	606	170	71	10	3	
	N. America coast	2,894	12,269			2	6	12	80	92	19	7	1		
	Bermuda	1,016	4,226						5	4	3				
	N. America inland	281	1,159					3	14	7	1	1			
17,500-21,500	Europe	313	1,339						4	2					
	Atlantic ocean	12,552	54,627	1	1	9	27	97	476	427	111	31	5	2	
	N. America coast	2,157	9,349		1	6	18	41	102	102	38	13	4		
	Bermuda	1,114	4,952		1	3	11	32	120	142	39	20	2		
	N. America inland	88	375						1	0					

Table 7

Aircraft characteristics assumed

Wing area	1769 sq ft
Mean chord	12.6 ft
Aspect ratio	11.2

Slope of the lift curve constant at 5.10/radian

Table 8

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)											
	110	120	130	140	110	120	130	140	110	120	130	140
100	79.78	87.06	81.89	98.97	75.78	82.71	87.40	94.14	72.17	78.76	85.30	89.74
120	66.49	72.55	76.58	82.48	63.15	68.93	72.83	78.45	60.14	65.53	71.08	74.79
140	56.99	62.19	65.64	70.70	54.13	59.08	62.43	67.24	51.55	56.26	60.93	64.10
160	49.87	54.41	57.43	61.86	47.36	51.70	54.63	58.84	45.10	49.22	53.31	56.09
180	44.32	48.37	51.05	54.99	42.10	45.95	48.56	52.30	40.09	43.75	47.39	49.86
200	39.89	43.53	45.95	49.49	37.89	41.36	43.70	47.07	36.08	39.38	42.65	44.87
220	36.26	39.57	41.77	44.99	34.44	37.60	39.73	42.79	32.80	35.80	38.77	40.79
240	33.24	36.27	38.29	41.24	31.57	34.46	36.42	39.22	30.07	32.82	35.54	37.39

Table 9

Gusts encountered on all routes

Flight condition	Altitude band feet	Recorded time mins	Statute miles	Number of times each gust speed was exceeded Vertical gust speed in ft/sec E.A.S. (+ up, - down)										
				-30	-25	-20	-15	-10	+10	+15	+20	+25	+30	+35
Initial climb	0- 1,500	664	2,192			1	16	136	245	30	4	1		
	1,500- 3,500	209	676		1	7	23	112	201	46	8	2		
	3,500- 5,500	42	160					2	6					
	5,500- 9,500	17	69					5	10	2				
Final descent	0- 1,500	576	1,552		1	8	29	197	411	110	21	2	1	1
	1,500- 3,500	25	89					4	8					
Climb and descent	0- 1,500	142	397				4	33	71	18	3			
	1,500- 3,500	1,868	6,370			3	27	255	780	126	21	1		
	3,500- 5,500	3,032	11,302		1	11	65	401	740	138	22	1		
	5,500- 9,500	7,509	30,535		1	12	57	362	686	124	18	2		
	9,500-13,500	5,156	22,040		2	8	33	158	194	45	15	2		
	13,500-17,500	4,781	21,017			3	9	42	60	8	1			
	17,500-25,500	1,248	5,719	2	5	13	32	144	145	58	24	4		
Cruise	0- 1,500	581	1,825	1	2	6	35	145	314	74	13	5		
	1,500- 3,500	1,629	5,830			3	19	124	311	30	1			
	3,500- 5,500	1,761	6,792			8	34	187	313	67	14	3		
	5,500- 9,500	26,378	104,969		3	26	128	742	981	251	57	11	3	1
	9,500-13,500	57,991	235,332		1	15	84	574	806	148	22	4	1	
	13,500-17,500	40,397	171,556	2	5	18	65	306	437	80	15	4	1	
	17,500-21,500	49,593	220,115	3	9	36	97	725	734	136	32	2		
	21,500-25,500	2,636	12,270				3	83	70	5				
	Totals	206,235	860,807											

Table 10

Gusts encountered during cruise in each region

Altitude band feet	Region	Recorded time mins	Statute miles	Number of times each gust speed was exceeded Vertical gust speed in ft/sec E.A.S. (+ up, - down)										
				-30	-25	-20	-15	-10	+10	+15	+20	+25	+30	+35
5,500- 9,500	Europe	4,492	18,426			2	11	86	75	15	3			
	Atlantic ocean	14,876	58,102			7	57	354	480	104	16	3	1	
	N. America coast	4,655	19,110		2	12	51	268	383	124	38	7	2	1
	Bermuda	1,518	5,977		1	2	8	31	28	7				
	N. America inland	668	2,695				2	5	15	1				
9,500–13,500	Europe	2,070	8,575				1	8	18	4	1			
	Atlantic ocean	46,850	188,723			9	63	456	612	102	13	2	1	
	N. America coast	7,343	30,881			4	17	89	145	32	9	1		
	Bermuda	978	4,049				1	5	11	3	1			
	N. America inland	406	1,648					3	1					
13,500–17,500	Europe	203	875					0	1					
	Atlantic ocean	33,036	140,008	2	5	16	54	277	379	71	11	4	1	
	N. America coast	4,776	20,510				3	15	34	2				
	Bermuda	2,014	8,633			2	7	15	19	6	3			
	N. America inland	281	1,159					4	1	1				
17,500–21,500	Europe	313	1,339					0	0					
	Atlantic ocean	38,393	170,260	2	4	17	43	352	396	63	15	2		
	N. America coast	5,474	24,301		1	8	25	173	150	24	6			
	Bermuda	4,962	22,194	1	4	11	29	197	188	49	11			
	N. America inland	358	1,672					1	0					

Table 11

Frequency of gusts exceeding 10 f.p.s. in each region during cruise 5,500 - 25,500 ft

Altitude band feet	Region	Statute miles	Gust counts	Miles/ count
5,500 - 9,500	Europe	18,426	161	114.4
	Atlantic ocean	58,102	834	69.7
	N. America coastal	19,110	651	29.4
	Bermuda	5,977	59	101.3
	N. America inland	2,695	20	134.8
9,500 - 13,500	Europe	8,575	26	329.8
	Atlantic ocean	188,723	1068	176.7
	N. America coastal	30,881	234	132.0
	Bermuda	4,049	16	253.1
	N. America inland	1,648	4	-
13,500 - 17,500	Europe	875	1	-
	Atlantic ocean	140,008	656	213.4
	N. America coastal	20,510	49	418.6
	Bermuda	8,633	34	253.9
	N. America inland	1,159	5	-
17,500 - 21,500	Europe	1,339	0	-
	Atlantic ocean	170,260	748	227.6
	N. America coastal	24,301	323	75.2
	Bermuda	22,194	385	57.6
	N. America inland	1,672	1	-
21,500 - 25,500	Atlantic ocean	12,270	153	80.2

Table 12

Frequency of gusts exceeding 10 f.p.s. in each month during cruise 5,500 - 25,500 ft over the Atlantic

Month	Statute miles	Gust counts	Miles/count
January	45,552	275	165.6
February	11,379	272	41.8
March	43,187	374	115.5
April	40,071	133	301.3
May	44,990	107	420.5
June	27,771	114	243.6
July	41,659	144	289.3
August	81,347	562	144.7
September	62,023	365	169.9
October	58,680	224	262.0
November	45,737	382	119.7
December	54,697	349	156.7

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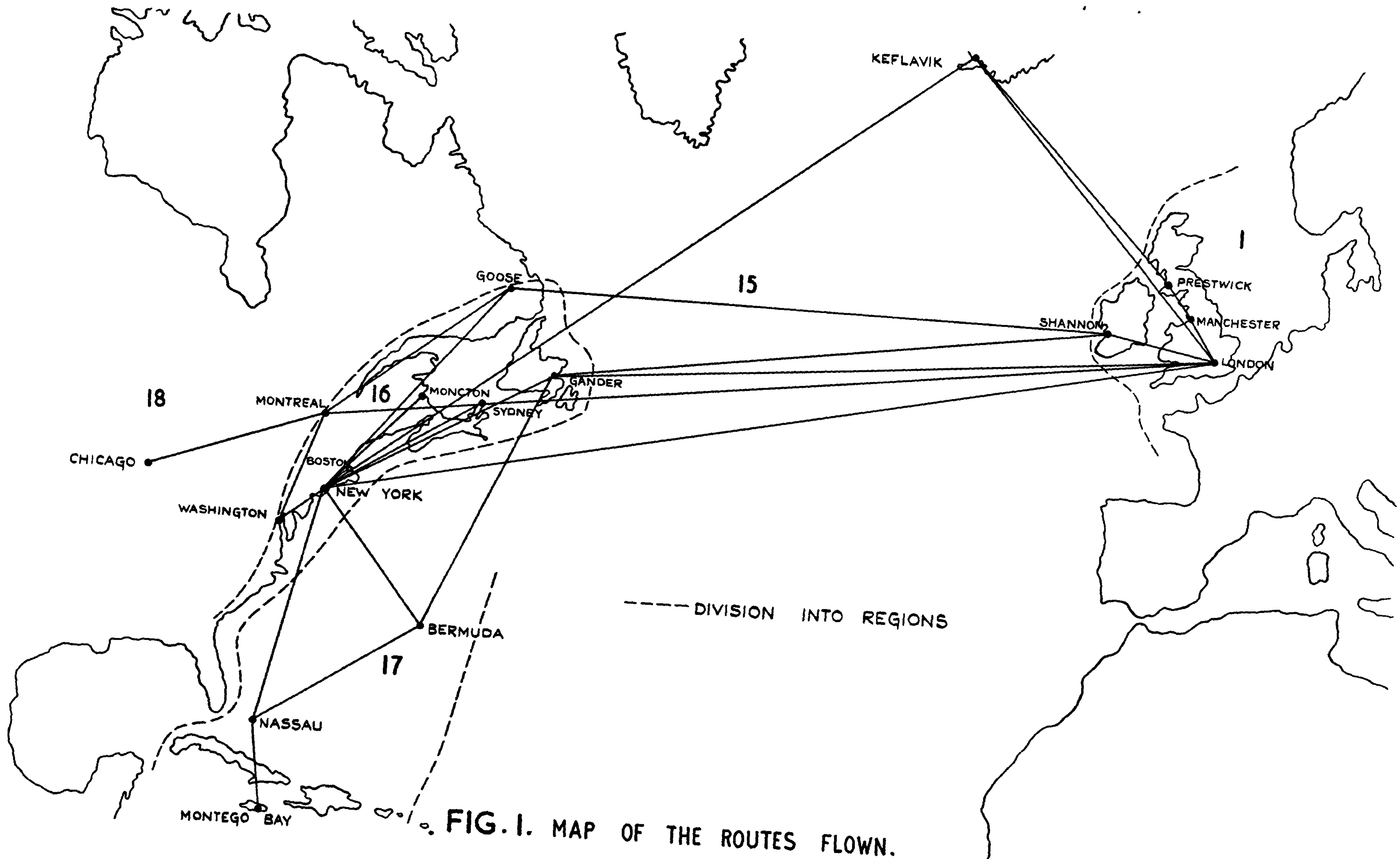

FIG. I. MAP OF THE ROUTES FLOWN.

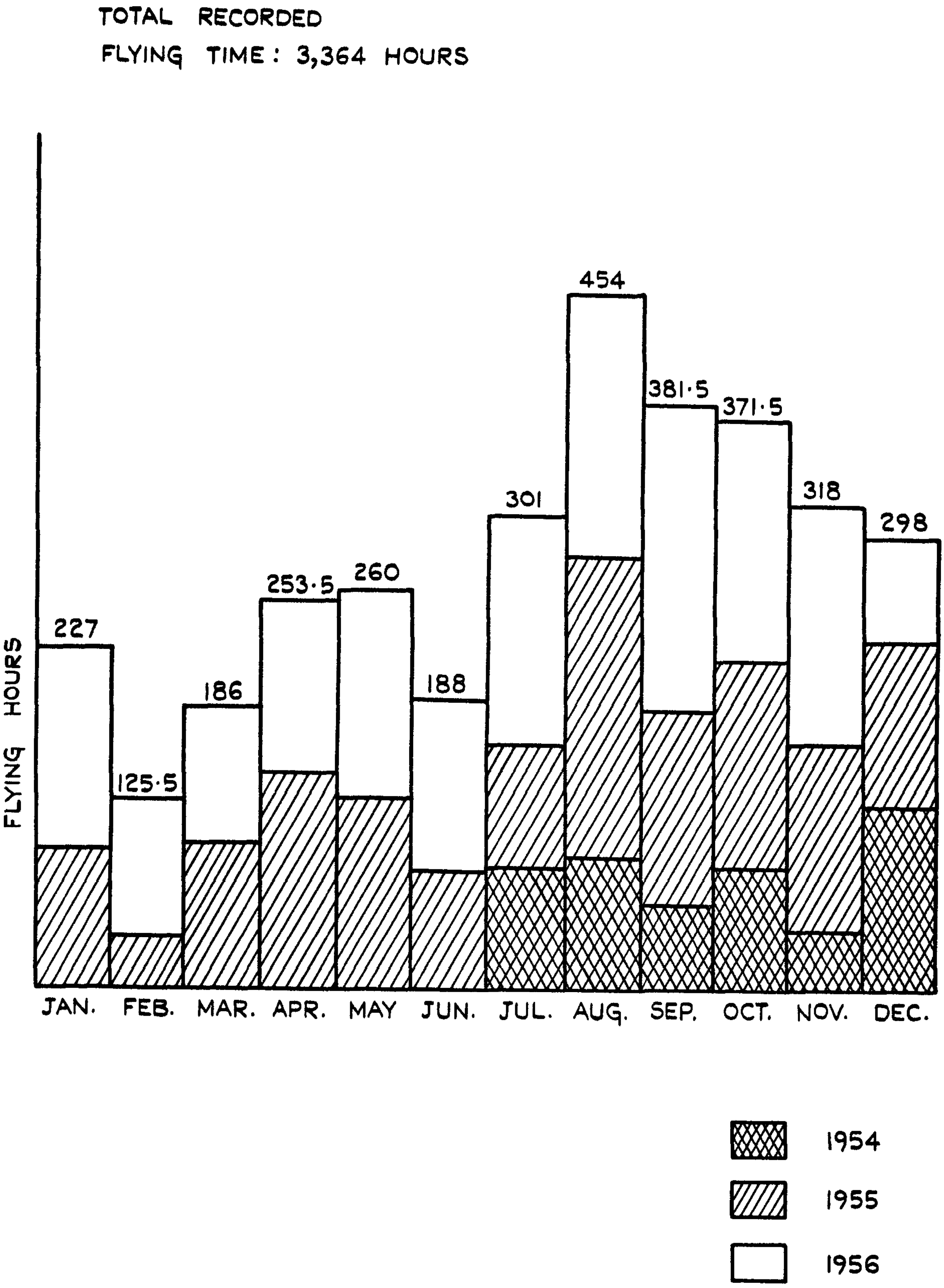

FIG. 2. MONTHLY DISTRIBUTION OF RECORDED FLYING TIME.

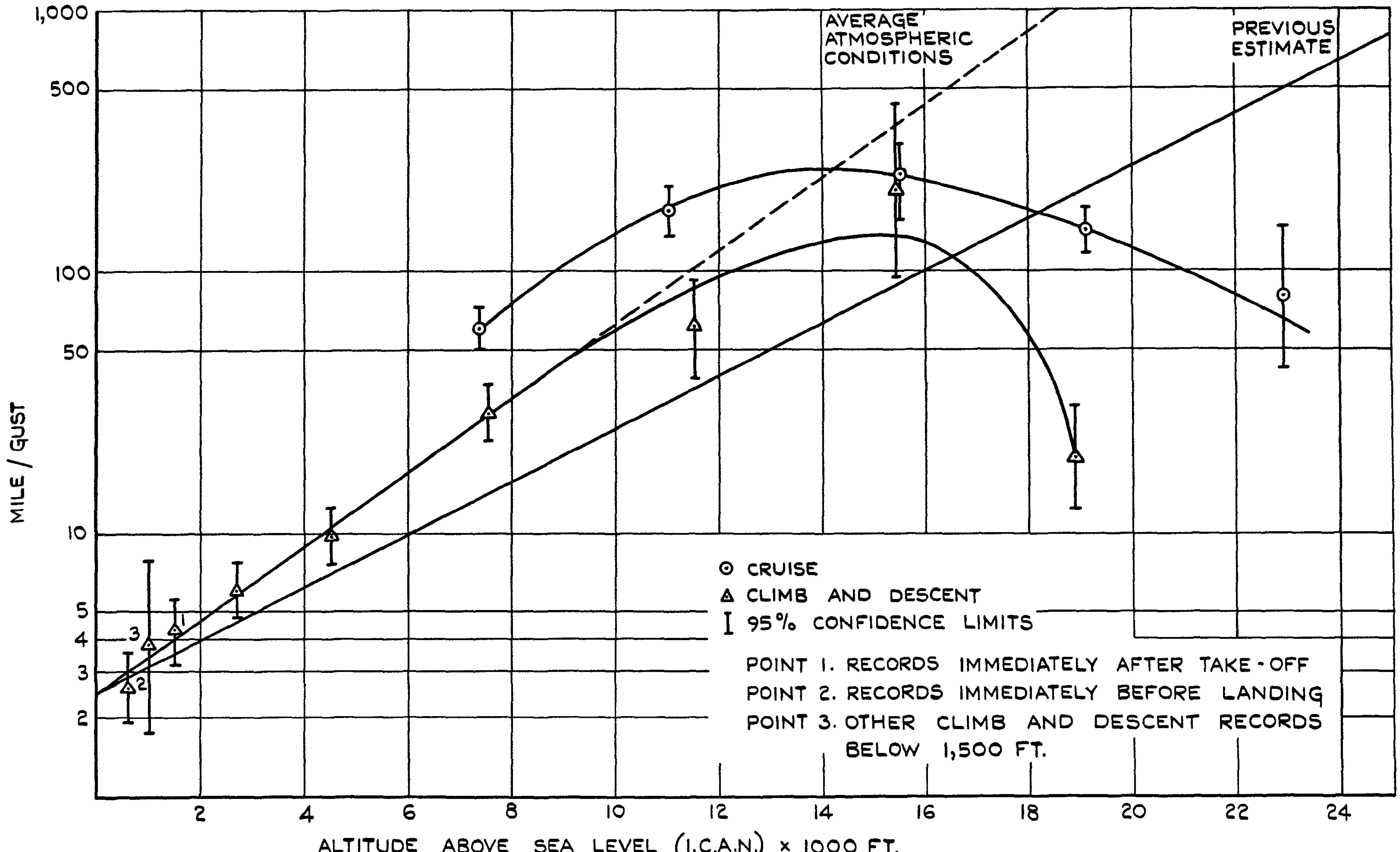

FIG. 3. VARIATION OF 10 FT./SEC. GUST FREQUENCY WITH ALTITUDE.

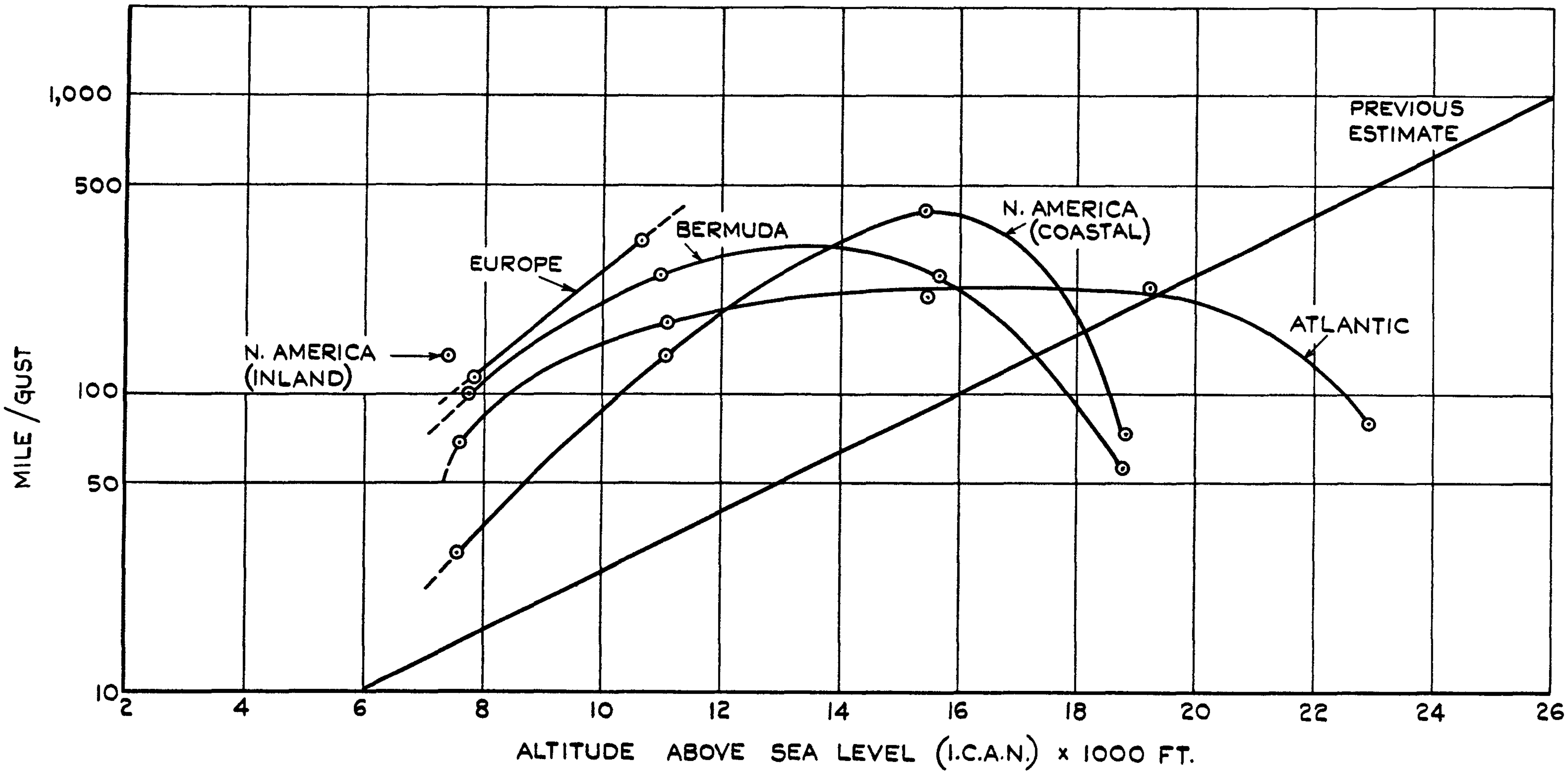

FIG. 4. VARIATION OF 10 FT. / SEC. GUST FREQUENCY WITH ALTITUDE DURING CRUISE IN EACH REGION.

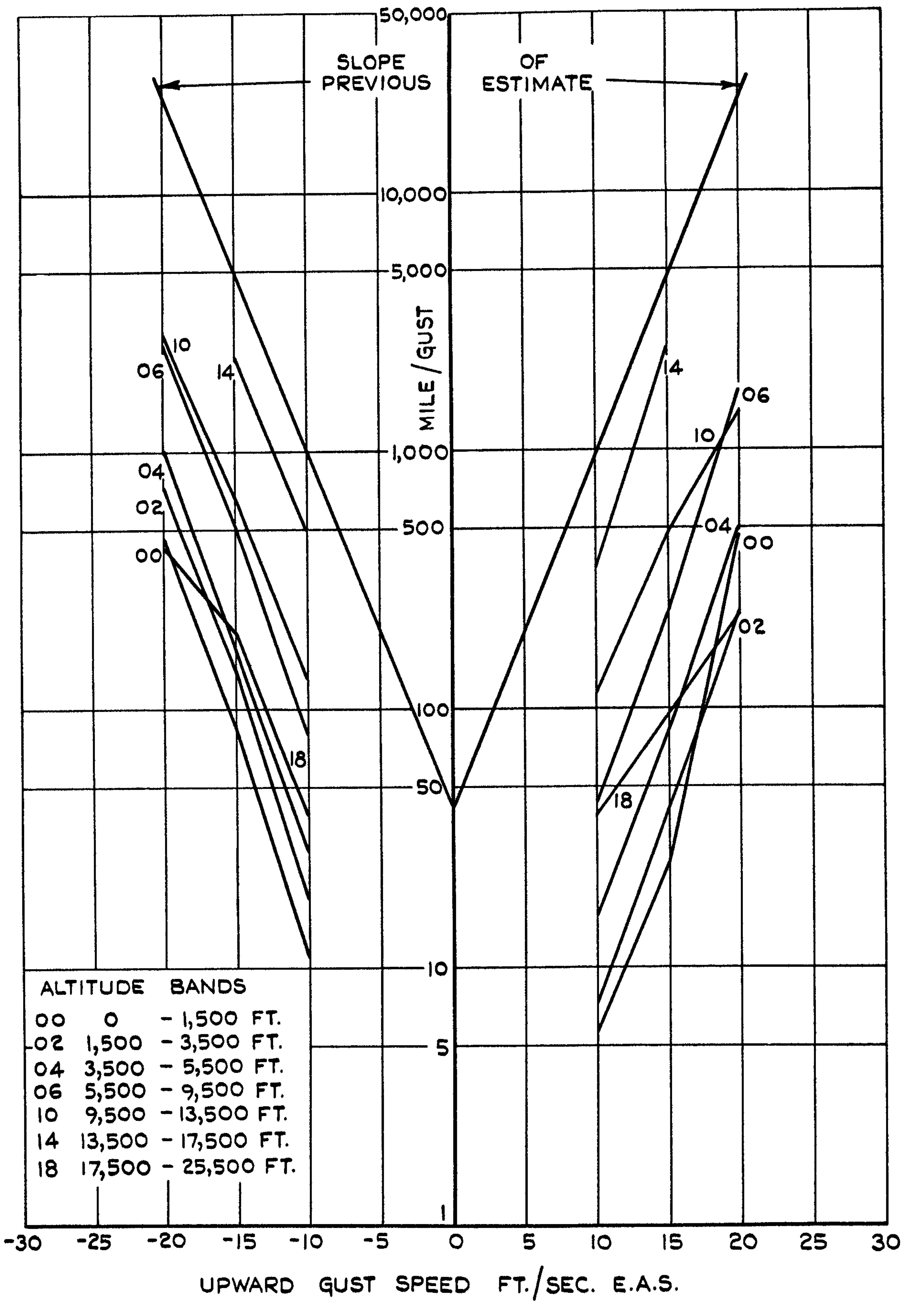

FIG.5. VARIATION OF GUST FREQUENCY WITH GUST SPEED DURING CLIMB AND DESCENT.

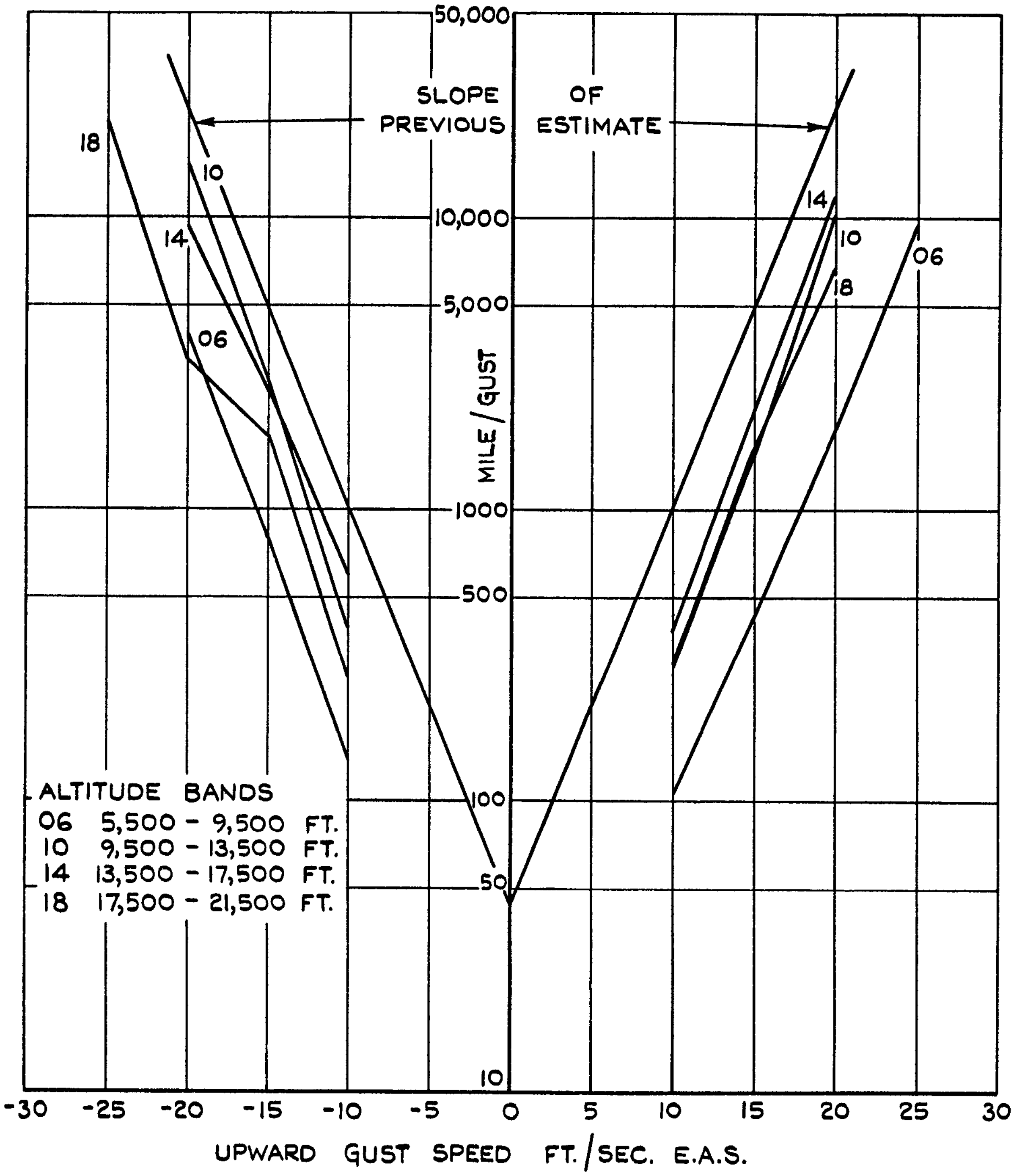

FIG. 6. VARIATION OF GUST FREQUENCY WITH GUST SPEED DURING CRUISE.

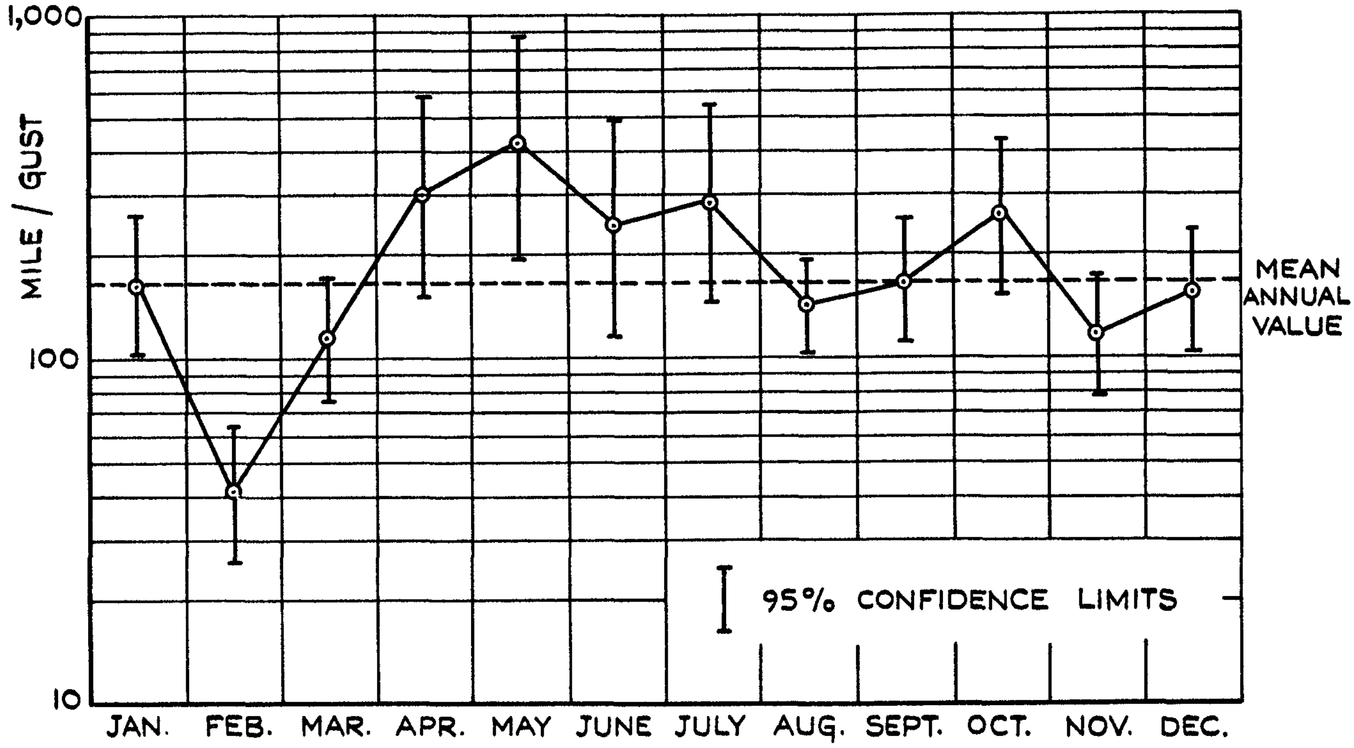

FIG. 7. MONTHLY VARIATION IN FREQUENCY OF GUSTS EXCEEDING 10 FT./SEC. OVER THE ATLANTIC.

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ATMOSPHERIC TURBULENCE ENCOUNTERED OVER THE ATLANTIC BY STRATOCRUISER AIRCRAFT. Aplin Judy E. August 1960.

Counting accelerometer records representing 861,000 miles were obtained from Stratocruiser aircraft flying on operational trans-Atlantic routes.

It is shown that the turbulence decreases with increasing altitude and is less than the average of previous analyses, due to the predominance of oversea routes in this data.

Gusts exceeding 10 ft/sec occurred more frequently during the winter months than during the summer over the Atlantic.

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