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LOW ALTITUDE TURBULENCE MEASUREMENTS OVER LAND AND SEA DURING FLIGHTS IN A CANBERRA AIRCRAFT

by

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SUMMARY

A number of flights have been made at low altitude over a route in the U.K. which included legs flown over land, and over the sea at three and fifteen miles from the coast. Counting accelerometer records have been analysed and the turbulence encountered on the three legs compared. A brief analysis is made of the effect of wind on the turbulence.

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* Replaces R.A.E. Technical Report 69129 - A.R.C. 31 483

CONTENTS

1 INTRODUCTION

A considerable amount of data exists showing the turbulence spectra at low altitude over land, but over the sea the amount of data is more limited. Present day operational roles often require naval aircraft to fly at low altitude over the sea; in the case of land based aircraft this flying takes place mainly close to the coast while carrier based aircraft fly mainly over the open sea. The object of the present trials was to obtain information on turbulence for lifing such aircraft, in particular, to distinguish between flying close to the coast and further out to sea, and to relate turbulence over the sea to the better known turbulence over the land.

The trials consisted of a number of flights made between August 1966 and April 1967, in which a Canberra aircraft was flown over a route in the U.K. which included a land leg and two legs over the sea at distances of three and fifteen miles from the coast. The two sea legs were considered to be representative of flight over coastal waters and the open sea.

The normal accelerations encountered along each leg were recorded on a counting accelerometer mounted near the aircraft cg and the readings were converted to equivalent gust velocities using the discrete gust analysis. Results are presented showing the average gust frequencies over land and sea, and the effect of wind speed on turbulence intensity; the effect of wind direction is also considered for the two legs flown over the sea.

2 DETAILS OF ROUTES

The basic route used on each flight and the order in which the legs were generally flown is shown in Fig.1. It was sometimes necessary to vary the precise starting and finishing points for each leg and also the order in which the legs were flown due to poor visibility over part of the route or air traffic restrictions prevailing at the time of the flight. Nevertheless the general procedure was to fly the first sea leg starting from a point near Skegness and finishing at Newbiggen by the sea, just north of Newcastle, keeping an average distance of three miles off the coast all the way. The second leg was flown over land commencing at a point near Hexham, approximately fifty miles west of Newcastle and, after passing close to Harrogate and Scunthorpe finishing at the coast near Skegness. The first part of the land leg was over the Pennines where the ground rose to a maximum height of about 2200 feet above sea level and ended over the flat terrain of Lincolnshire. On the final sea leg, the aircraft was flown in a northerly direction from a point abeam Skegness keeping an average distance of fifteen miles from the coast. The aim was to cover as much distance as possible on the last leg finishing in the vicinity of Middlesbrough but in fact the length of the run was generally determined by the pilot who decided on the finishing point after estimating the amount of fuel required for the return flight to base.

For reasons mentioned earlier, the distances covered in each leg of each flight were not constant but were of the order of 170 miles for the leg flown three miles out to sea; 180 miles for the land leg and 120 miles for the final sea leg.

3 INSTRUMENTATION, MEASUREMENTS AND FLIGHT TECHNIQUES

The aircraft used in the trials was a standard Canberra B6. A counting accelerometer, consisting of a R.A.E. Observer Unit Type Structures 5 and a modified Accelerometer Type Structures 4, was installed on a platform in the bomb bay (the accelerometer was positioned near the cg of the aircraft) to record the number of normal accelerations experienced during the runs. Details of the aircraft and counting accelerometer are given in Appendix A.

Measurements of drift and ground speed were read by the flight observer from the dials of the Green Satin Doppler equipment at intervals throughout the flight. The signals tended to oscillate with the Dutch roll of the aircraft and the readings taken were a mean value estimated by eye by the observer. The readings were converted to winds using a navigator's Dead Reckoning Computer as the original readings did not justify a more accurate method.

Wind readings from a number of ground meteorological stations located around the route were also obtained. The positions of the reporting stations are included in Fig.1. Hourly readings were obtained from each station with the exception of Kilnsea where the readings were taken every three hours.

The observer unit counters were switched on at the beginning and off at the end of each leg so that the loads caused by the aircraft manoeuvring between legs were not included.

The flights were made at irregular intervals during the period of the trial and no particular weather or wind conditions were favoured. On a few occasions, after flying the first leg over the sea, it was found impossible to start or to complete the land leg due to bad visibility. These partially completed flights are not included in the results.

The aircraft was flown at an average height of 200 feet on the sea legs and approximately the same height above the ground during the land leg. The pilots were instructed to fly normally and not to make an attempt to follow the ground contours too closely. For the first quarter of the trial the aircraft was flown at a speed of 300 knots but, due to a low altitude flight safety restriction put on the aircraft when flying with unmodified ejection seats, the remainder of the flights were made at a speed of 250 knots.

4 DATA AND THEIR ANALYSIS

The data analysed represent the results from twenty eight flights during which measurements were taken on each of the three legs. The total recording time and distance covered on each of the legs were as follows:-

Leg	Duration		Distance
	hr	min	Statute mile
Land	14	50	4591
Sea 3 mile	15	40	4781
Sea 15 mile	10	08	3105

The counting accelerometer installed near the aircraft cg gave information on the number of times each acceleration level had been exceeded during each 2 minute interval of each leg, together with the aircraft's altitude and airspeed at the end of each interval. The all up weight of the aircraft was interpolated from the flight observer's readings of the fuel state taken at intervals during the flight. The overall variation in AUW during the periods of recording throughout the trial was between 41500 and 31500 lb. Using the information obtained from the counting accelerometer, together with aircraft characteristics and appropriate weight, the number of equivalent vertical gusts of various magnitudes encountered during the whole of each leg was obtained using the discrete gust procedure described by Zbrozek[1].

The counting accelerometer recorded the number of occurrences of acceleration which exceeded 9 positive and 9 negative levels. In view of the comparatively light turbulence expected over the sea, especially on the leg flown at fifteen miles from the coast it was decided to increase the number of counting levels at the lower values of acceleration by halving the width of the normal interval between the levels at which counts were made. By this means a better measure of the distribution of gusts occurring at the lower gust speeds was obtained at the expense of not recording the peak values of acceleration which occurred on the few very rough flights encountered.

The readings of the Green Satin Doppler equipment, which were used to obtain the aircraft winds, were taken at approximately 10 minute intervals along the route. These were compared with the winds obtained from the ground stations for the appropriate times and places. As might be expected, owing to the greater height above ground, the aircraft measured winds were generally slightly stronger than the winds from the ground stations. The accuracy of the aircraft wind readings are probably not greater than ±5%, owing to the necessity for the flight observer to take a mean reading of drift and ground speed due to the fluctuations of the aircraft. With the considerable distance covered during each leg there was often a noticeable change in the wind speed and direction along the leg but for comparative purposes a mean wind has been chosen for each leg biased slightly towards the higher aircraft wind readings.

5 RESULTS

The numbers of equivalent gusts recorded on each leg of each flight are listed in Table 1. The average number of gusts per mile are also given together with relevant information which includes details on the distance flown and the average wind speed and direction applicable to each leg.

Table 2 shows the total numbers of equivalent gusts encountered for each of the three types of leg, i.e. land, over the sea at three and fifteen miles from the coast. The average number of gusts per mile for the three categories are also given in the table and are shown graphically in Fig.2. The figure indicates that over both the sea legs, up and down gusts exist in approximately equal numbers. Over land, it appeared that more up than down gusts were encountered but it is probable that the accelerations, from which the gusts were deduced, included a contribution from a number of small manoeuvring loads and, being near to the ground, the pilot manoeuvres more readily upwards than downwards.

The most significant point arising from the results is the difference in the number of gust occurrences at all levels between the three leg classifications. The average number of gusts per mile, either up or down, exceeding 10 ft/sec, over land is 1·13 and over the sea it is 0·30 and 0·046 at distances of three and fifteen miles from the coast respectively. The ratios between the number of gusts/mile encountered on the land leg and on each of the sea legs at the same 10 ft/sec gust level are 3·75 and 24·5 respectively.

Heath-Smith[2] from low altitude flights with a Hunter at less than 500 feet, with windy conditions favoured, found that 8·3 times as many gusts of 10 ft/sec or greater were encountered over land as over the sea. The sea leg in this case consisted of a direct out and return flight from the coast to a point approximately thirty-two miles off shore. In the Swifter trials[3], carried out in North Africa, the ratio between the average of all flying over the land at a height of 200 feet and the average of all the flying over the sea at 200 feet for the same gust level of 10 ft/sec gave a figure of 16·6. In this trial again the sea leg started and finished at the coast, the aircraft turning at a point approximately forty miles out to sea. These ratios lie, as might be expected in view of their mixture of coastal and out to sea flying between the two ratios found in the present trial.

By plotting the number of occurrences of up or down gusts/mile exceeding 10 ft/sec against average wind velocity along the leg, an attempt has been made to examine the relationship between turbulence intensity and wind speed for the three types of leg classification. The results from the sea legs have been subdivided according to the wind direction by separating the off-shore from the other winds. The average line formed by the coast in the region where the flying took place was approximately 150/330°. Off-shore winds have been classified as those within the sector 170° to 310°. Winds from a direction within 20° of the mean aircraft track have not been included with the off-shore winds in view of the smallness of their off-shore component.

From Fig.3 it can be seen that, for the leg flown at three miles from the coast, the wind direction has a marked effect on the intensity of turbulence at the higher wind speeds. Off-shore winds produced an increase in turbulence with wind speed but other winds had a much smaller effect on the turbulence intensity.

When flying at fifteen miles from the coast, Fig.4 indicates that the intensity of turbulence does not appear dependent on the wind direction but again there is an increase in intensity at the higher wind speeds.

Fig.5 shows a more positive relationship between turbulence and wind speed when flying over land. This relationship was also found in earlier Canberra trials[4] during low altitude flights over land.

6 CONCLUSIONS

Measurements of atmospheric turbulence have been made during flight at low altitude over land and sea.

Over the land, the number of vertical gusts exceeding 10 ft/sec encountered per mile was 1·13. Over the sea, at three and fifteen miles from the coast, the number of gusts encountered were reduced by factors of 3·75 and 24·5 respectively.

Wind speed appeared to be a significant factor in producing turbulence over the land but over the sea high wind speeds did not always produce an increase in the intensity of turbulence. For the leg flown at three miles from the coast the direction of the wind was an important factor, winds with a significant off-shore component were found to produce significantly more turbulence than other winds at the higher values of wind speeds. Wind direction was not found to be a significant factor on the leg flown at fifteen miles from the coast.

Appendix A

DETAILS OF AIRCRAFT AND INSTRUMENTATION

The characteristics of the Canberra B6 used in the tests are as follows:

Wing span	64 ft	19·51 m
Mean chord	15 ft	4·57 m
Gross wing area	960 ft^2	89·19 m^2
Aspect ratio	4·25	4·25
Slope of lift curve $(\partial C_L/\partial \alpha)$	3·6 per rad.	3·6 per rad.

The aircraft was fitted with an Observer Unit Type Structures 5 and an Accelerometer Type Structures 4 modified so that its range was halved but its sensitivity doubled. Both instruments were mounted on a platform in the bomb bay, the accelerometer positioned within two feet (61 cm) of the aircraft cg.

The accelerometer has an amplitude response ratio which is 90% at 5 Hz, 70% at 7 Hz and falls to 10% at 12 Hz. The fundamental wing frequency of the Canberra used in the trial was approximately 4·5 Hz. In order to record a count at a given level the acceleration must exceed that level and then return a certain distance towards the 1 g level, corresponding to steady flight. The increments of acceleration, in both the positive and negative directions, at which the occurrences were recorded by the counters, and the return distances necessary to complete the counting operation were as follows:-

Acceleration increment g	0·1	0·15	0·2	0·3	0·4	0·5	0·6	0·7	0·8
Return distance g	0·1	0·15	0·15	0·2	0·25	0·3	0·3	0·3	0·3

The counters, together with instruments showing indicated airspeed, pressure altitude and time, were photographed at two minute intervals during the time that the aircraft was flying on the legs. The times when the counters were operating was controlled by the flight observer who also noted the aircraft fuel state at intervals during the flight.

Table 1

GUST OCCURRENCES OVER LAND AND SEA

Flight/ run number	Date	Airspeed kt ias	Duration min	Distance mile	Land or sea	Mean distance off coast mile	Mean wind		Number of vertical gusts greater than v and gusts per mile Gust velocity v ft/s eas (+ up - down)													
							Direction deg.	Speed knot	+17·5	-15·0	-12·5	-10·0	-7·5	-5·0	-3·75	3·75	5·0	7·5	10·0	12·5	15·0	17·5
346·1	4. 8.66	300	29·6	173·6	Sea	3	270	20		4 0·023	10 0·058	44 0·25	165 0·95	606 3·49	1028 5·92	1008 5·81	596 3·43	179 1·03	52 0·30	14 0·081	5 0·029	2 0·011
346·2	"	"	35·3	200·9	Land		270	20	4 0·020	14 0·070	45 0·22	144 0·72	374 1·86	1019 5·07	1452 7·23	1488 7·41	1090 5·43	483 2·40	200 1·00	85 0·42	41 0·20	17 0·085
346·3	"	"	25·4	148·3	Sea	15	270	20				6 0·040	49 0·33	263 1·77	602 4·06	562 3·79	269 1·81	53 0·36	10 0·067			
347·1	10. 8.66	"	26·6	155·8	Sea	3	225	28	8 0·051	19 0·12	40 0·26	104 0·67	256 1·64	668 4·29	934 6·00	929 5·96	671 4·31	291 1·87	115 0·74	48 0·31	21 0·13	9 0·058
347·2	"	"	32·2	183·6	Land		250	30	26 0·14	59 0·32	131 0·71	257 1·40	479 2·61	1009 5·50	1296 7·06	1338 7·29	1048 5·71	577 3·14	282 1·54	142 0·77	75 0·41	26 0·14
347·3	"	"	23·7	137·3	Sea	15	220	28			1 0·007	5 0·036	18 0·13	116 0·84	265 1·93	260 1·89	119 0·87	25 0·18	5 0·036	1 0·007		
348·1	15. 8.66	"	30·4	176·4	Sea	3	010	9					2 0·011	36 0·20	109 0·62	85 0·48	17 0·096					
348·2	"	"	31·2	178·3	Land		030	10		3 0·017	9 0·050	34 0·19	145 0·81	499 2·80	784 4·40	774 4·34	533 2·99	217 1·22	74 0·41	22 0·12	6 0·034	1 0·006
348·3	"	"	25·0	144·4	Sea	15	010	9					1 0·007	18 0·12	57 0·40	48 0·33	15 0·10					
349·1	22. 8.66	"	31·1	179·3	Sea	3	030	16					4 0·022	66 0·37	212 1·18	181 1·01	62 0·35	4 0·022				
349·2	"	"	31·8	182·8	Land		010	15		2 0·011	6 0·033	27 0·15	103 0·56	397 2·17	685 3·75	746 4·08	470 2·57	161 0·88	60 0·33	18 0·098	3 0·016	
349·3	"	"	23·3	134·0	Sea	15	030	16				1 0·007	5 0·037	54 0·40	144 1·07	95 0·71	32 0·24	2 0·015	1 0·007			
350·1	23. 8.66	"	28·5	164·6	Sea	3	010	16				1 0·006	6 0·036	70 0·43	187 1·14	175 1·06	61 0·37	2 0·012				
350·2	"	"	6·5	37·7	Sea	15	360	11						5 0·13	21 0·55	29 0·77	6 0·16					
350·3	"	"	29·6	173·3	Land		355	13			3 0·017	19 0·11	78 0·45	291 1·68	539 3·11	628 3·62	386 2·23	120 0·69	34 0·20	7 0·040	3 0·017	1 0·006
351·1	13. 9.66	"	29·0	167·1	Sea	3	285	26	1 0·006	1 0·006	7 0,042	27 0·16	77 0·46	310 1·85	529 3·17	543 3·25	327 1·96	99 0·59	32 0·19	4 0·024	1 0·006	1 0·006
351·2	"	"	29·3	169·8	Land		300	32	8 0·047	27 0·16	72 0·42	183 1·08	420 2·48	873 5·14	1163 6·85	1251 7·37	998 5·88	541 3·18	265 1·56	108 0·64	52 0·31	26 0·15
351·3	"	"	27·0	156·9	Sea	15	270	25			1 0·006	1 0·006	8 0·051	54 0·34	123 0·78	128 0·82	54 0·34	12 0·077	1 0·006			
352·1	15. 9.66	"	30·1	174	Sea	3	345	32	1 0·006	2 0·011	13 0·078	46 0·26	134 0·77	531 3·05	798 4·59	823 4·73	539 3·10	186 1·07	51 0·29	11 0·063	3 0·017	
352·2	"	"	30·1	173·7	Land		350	30	7 0·040	32 0·19	60 0·35	158 0·91	386 2·22	886 5·10	1230 7·08	1286 7·41	998 5·75	476 2·74	195 1·12	77 0·44	34 0·20	14 0·081
352·3	"	"	11·1	64·3	Sea	15	330	30	1 0·016	1 0·016	2 0·031	10 0·16	53 0·83	181 2·82	326 5·06	334 5·20	202 3·15	52 0·81	9 0·14	3 0·047	1 0·016	

Table 1 (Contd.)

Flight/ run number	Date	Airspeed kt ias	Duration min	Distance mile	Land or sea	Mean distance off coast mile	Mean wind		Number of vertical gusts greater than v and gusts per mile. Gust velocity v ft/s eas (+ up - down)													
							Direction deg.	Speed knot	-17·5	-15·0	-12·5	-10·0	-7·5	-5·0	-3·75	3·75	5·0	7·5	10·0	12·5	15·0	17·5
355·1	2.11.66	250	36·8	176·9	Sea	3	090	16			2 0·011	5 0·028	33 0·19	159 0·90	365 2·06	412 2·33	200 1·13	42 0·24	6 0·035			
355·2	"	"	36·7	179·1	Land		020	15	1 0·005	4 0·022	17 0·095	45 0·25	146 0·82	462 2·58	703 3·93	661 3·69	470 2·62	180 1·01	62 0·35	23 0·13	7 0·039	2 0·011
355·3	"	"	24·1	118·5	Sea	15	100	11				2 0·017	11 0·093	82 0·69	202 1·70	226 1·91	107 0·90	14 0·12	2 0·017			
356·1	3.11.66	"	31·7	161·4	Sea	3	340	6				2 0·012	13 0·081	65 0·40	177 1·10	167 1·04	56 0·35	13 0·081	3 0·018			
356·2	"	"	32·1	162·6	Land		360	5				2 0·012	8 0·049	18 0·11	36 0·22	41 0·25	12 0·074	2 0·012				
356·3	"	"	25·7	128·0	Sea	15	270	3					6 0·046	62 0·49	163 1·27	137 1·07	45 0·35	5 0·039				
357·1	9.11.66	"	42·7	213·5	Sea	3	290	13			2 0·009	11 0·051	54 0·25	238 1·11	497 2·32	424 1·98	195 0·91	38 0·18	13 0·061	3 0·014		
357·2	"	"	35·7	178·0	Land		295	16		2 0·011	5 0·028	15 0·084	66 0·37	295 1·66	555 3·12	539 3·03	307 1·73	83 0·47	18 0·10	7 0·039	2 0·11	2 0·11
357·3	"	"	13·9	69·1	Sea	15	280	9					4 0·058	50 0·73	134 1·94	131 1·89	43 0·62	3 0·044				
358·1	14.11.66	"	33·7	164·3	Sea	3	230	22	1 0·006	3 0·018	15 0·090	53 0·32	183 1·11	578 3·52	968 5·90	881 5·36	496 3·02	169 1·03	53 0·32	17 0·10	4 0·024	
358·2	"	"	35·7	179·8	Land		280	20		1 0·006	11 0·061	51 0·28	158 0·88	602 3·35	952 5·29	956 5·32	588 3·27	163 0·91	35 0·19	8 0·044	3 0·017	1 0·006
358·3	"	"	24·9	121·6	Sea	15	270	20				2 0·016	44 0·36	270 2·22	516 4·24	491 4·04	264 2·17	51 0·42	9 0·074			
359·1	18.11.66	"	37·3	181·2	Sea	3	040	27				3 0·016	39 0·22	211 1·16	490 2·71	459 2·54	198 1·09	40 0·22	6 0·033	1 0·006		
359·2	"	"	8·0	39·1	Land		030	20			1 0·03	12 0·31	42 1·07	137 3·51	205 5·25	208 5·34	142 3·63	38 0·97	12 0·31	2 0·05		
359·3	"	"	40·5	197·6	Sea	15	030	26			1 0·005	2 0·010	25 0·13	212 1·07	465 2·35	494 2·50	237 1·20	45 0·23	5 0·025	1 0·005		
360·1	22.11.66	"	36·2	176·7	Sea	3	060	22			1 0·006	9 0·051	50 0·28	290 1·64	622 3·52	601 3·40	272 1·54	59 0·33	12 0·068	1 0·006		
360·2	"	"	29·6	144·3	Land		036	18			2 0·014	13 0·089	54 0·37	286 1·98	503 3·49	437 3·03	248 1·72	63 0·44	17 0·12	7 0·049	2 0·014	
360·3	"	"	26·9	132·5	Sea	15	060	23			4 0·030	10 0·076	63 0·48	267 2·02	509 3·84	564 4·26	308 2·32	83 0·63	17 0·13	3 0·023		
361·1	23.11.66	"	32·2	157·8	Sea	3	070	5					2 0·013	20 0·13	81 0·51	56 0·36	18 0·11	4 0·025	1 0·006			
361·2	"	"	37·2	189·1	Land		350	10					1 0·005	6 0·032	24 0·13	22 0·12	9 0·048	1 0·005				
361·3	"	"	14·8	72·5	Sea	15	060	8						11 0·15	52 0·73	41 0·57	9 0·12					

Table 1 (Contd.)

Flight/ run number	Date	Airspeed kt ias	Duration min	Distance mile	Land or sea	Mean distance off coast mile	Mean wind Direction deg.	Mean wind Speed knot	Number of vertical gusts greater than v and gusts per mile. Gust velocity v ft/s eas (+ up - down): -17·5	-15·0	-12·5	-10·0	-7·5	-5·0	-3·75	3·75	5·0	7·5	10·0	12·5	15·0	17·5
363·1	6.12.66	250	35·1	171·3	Sea	3	280	12			2 0·012	11 0·064	41 0·24	193 1·13	378 2·21	308 1·80	155 0·90	34 0·20	7 0·041	1 0·006		
363·2	"	"	36·2	180·2	Land		295	10	1 0·006	2 0·011	5 0·028	28 0·16	94 0·52	388 2·15	657 3·64	628 3·49	365 2·03	107 0·59	32 0·18	10 0·056	3 0·017	
363·3	"	"	15·6	76·8	Sea	15	300	12					2 0·026	22 0·29	88 1·15	61 0·79	18 0·23	1 0·013				
364·1	7.12.66	"	33·8	164·7	Sea	3	260	11					9 0·055	43 0·26	133 0·80	124 0·75	46 0·30	11 0·067	2 0·012			
364·2	"	"	20·2	98·5	Land		290	8				4 0·041	20 0·20	125 1·26	229 2·33	246 2·50	126 1·28	31 0·32	7 0·071	2 0·020		
364·3	"	"	25·4	122·2	Sea	15	260	10						12 0·098	46 0·38	39 0·32	4 0·033					
366·1	16.12.66	"	34·2	166·3	Sea	3	260	13				4 0·024	24 0·14	102 0·62	225 1·35	224 1·35	102 0·61	20 0·12	4 0·024			
366·2	"	"	27·5	135·4	Land		280	15	1 0·007	2 0·015	9 0·066	30 0·22	93 0·69	352 2·60	536 3·96	546 4·03	370 2·73	105 0·77	26 0·19	4 0·030	1 0·007	
366·3	"	"	21·1	101·4	Sea	15	270	13					1 0·010	16 0·16	58 0·57	49 0·48	17 0·17	1 0·010				
367·1	20.12.66	"	37·8	184·1	Sea	3	320	18				6 0·033	43 0·23	219 1·19	526 2·86	436 2·37	159 0·86	33 0·18	3 0·016			
367·2	"	"	34·0	167·4	Land		280	15			3 0·018	16 0·095	65 0·39	304 1·81	547 3·27	519 3·10	319 1·90	82 0·49	17 0·10	5 0·030	2 0·012	
367·3	"	"	38·4	186·5	Sea	15	295	20					13 0·070	142 0·76	339 1·82	317 1·70	101 0·54	6 0·032	2 0·011			
370·1	26. 1.67	"	35·5	172·8	Sea	3	270	18	1 0·006	4 0·023	7 0·041	18 0·10	64 0·37	229 1·32	480 2·78	402 2·33	204 1·18	50 0·29	18 0·10	9 0·052	5 0·029	3 0·017
370·2	"	"	34·7	177·0	Land		285	24	13 0·073	21 0·12	51 0·29	113 0·64	236 1·34	671 3·79	922 5·21	859 4·85	595 3·36	282 1·59	127 0·72	62 0·35	27 0·15	14 0·079
370·3	"	"	24·7	122·4	Sea	15	260	21						5 0·041	30 0·25	31 0·25	10 0·082					
372·1	8. 2.67	"	10·0	48·0	Sea	15	320	20					9 0·19	37 0·77	90 1·87	79 1·64	30 0·62	6 0·12				
372·2	"	"	37·7	182·9	Sea	3	315	17				2 0·011	17 0·093	93 0·51	255 1·40	242 1·32	88 0·48	13 0·071	1 0·005			
372·3	"	"	29·1	142·8	Land		295	15		1 0·007	5 0·035	18 0·13	72 0·50	321 2·25	513 3·59	497 3·48	340 2·38	105 0·74	27 0·19	7 0·049	3 0·021	
373·1	14. 2.67	"	36·3	179·5	Land		105	18	1 0·006	5 0·028	14 0·078	50 0·28	155 0·86	575 3·21	941 5·24	841 4·68	524 2·92	160 0·89	50 0·28	18 0·10	7 0·039	3 0·017
373·2	"	"	20·2	98·4	Sea	3	135	24				3 0·031	27 0·28	174 1·77	291 2·96	331 3·36	176 1·79	38 0·39	11 0·11	4 0·041		
373·3	"	"	22·2	111·1	Sea	15	110	26				3 0·027	33 0·30	164 1·48	327 2·94	360 3·24	183 1·65	33 0·30	5 0·045	1 0·009		

Table 1 (Contd.)

Flight/ run number	Date	Airspeed kt ias	Duration min	Distance mile	Land or sea	Mean distance off coast mile	Mean wind		Number of vertical gusts greater than v and gusts per mile Gust velocity v ft/s eas (+ up - down)													
							Direction deg.	Speed knot	-17·5	-15·0	-12·5	-10·0	-7·5	-5·0	-3·75	3·75	5·0	7·5	10·0	12·5	15·0	17·5
374·1	22. 2.67	250	32·5	158·5	Sea	3	235	15					6 0·038	41 0·26	148 0·93	137 0·86	44 0·28	9 0·057	1 0·006			
374·2	"	"	38·1	185·8	Land		230	12		1 0·005	6 0·032	21 0·11	74 0·40	287 1·54	551 2·96	594 3·20	282 1·52	78 0·42	23 0·12	7 0·038	5 0·027	2 0·011
374·3	"	"	20·3	98·7	Sea	15	230	18						2 0·020	14 0·14	16 0·16	7 0·071	1 0·010	1 0·010	1 0·010		
376·1	16.3.67	"	44·8	216·1	Sea	3	320	23	1 0·005	1 0·005	3 0·014	11 0·051	42 0·19	168 0·78	476 2·21	456 2·11	164 0·76	40 0·18	9 0·041	3 0·014		
376·2	"	"	45·6	226·5	Land		300	25	2 0·009	13 0·058	46 0·20	141 0·62	369 1·63	933 4·12	1277 5·64	1291 5·71	1008 4·46	513 2·27	223 0·98	98 0·43	42 0·19	20 0·088
376·3	"	"	10·2	50·0	Sea	15	315	16						7 0·14	24 0·48	24 0·48	8 0·16					
377·1	17. 3.67	"	37·4	182·9	Sea	3	280	32	26 0·14	52 0·28	104 0·57	201 1·10	385 2·11	821 4·49	1120 6·13	1054 5·77	744 4·07	392 2·14	207 1·13	112 0·61	59 0·32	30 0·16
377·2	"	"	35·3	175·3	Land		280	35	70 0·40	125 0·71	233 1·33	442 2·52	728 4·15	1358 7·74	1644 9·37	1558 8·88	1338 7·63	872 4·97	519 2·96	218 1·24	146 0·83	85 0·48
377·3	"	"	23·1	113·5	Sea	15	280	30			2 0·018	5 0·044	27 0·24	154 1·36	304 2·68	311 2·74	166 1·46	28 0·25	5 0·044	1 0·009		
379·1	21.3.67	250	36·9	180·1	Sea	3	250	24	3 0·017	6 0·033	28 0·16	80 0·44	224 1·25	590 3·27	839 4·65	808 4·48	566 3·14	239 1·33	99 0·55	34 0·19	12 0·067	5 0·028
379·2	"	"	20·5	101·3	Land		275	25	13 0·13	27 0·27	57 0·56	134 1·32	276 2·72	601 5·93	730 7·20	695 6·86	570 5·63	328 3·24	162 1·60	78 0·77	34 0·34	15 0·15
379·3	"	"	20·0	97·6	Sea	15	245	25		1 0·010	3 0·031	9 0·092	20 0·20	82 0·84	147 1·51	167 1·71	88 0·90	30 0·31	11 0·11	4 0·041	1 0·010	1 0·010
381·1	20. 4.67	"	33·9	164·9	Sea	3	260	24		4 0·024	10 0·061	37 0·22	112 0·68	368 2·23	610 3·70	555 3·37	331 2·01	110 0·67	31 0·19	9 0·055	2 0·012	
381·2	"	"	33·8	167·9	Land		280	28	14 0·083	29 0·17	66 0·39	180 1·07	399 2·38	919 5·47	1107 6·60	1117 6·65	915 5·45	420 2·50	243 1·45	112 0·67	49 0·29	21 0·13
381·3	"	"	22·5	109·3	Sea	15	250	23					7 0·065	60 0·55	144 1·32	115 1·06	53 0·48	6 0·055	1 0·009			
382·1	21. 4.67	"	36·1	180·5	Sea	3	320	20			1 0·006	11 0·061	56 0·31	235 1·30	477 2·64	408 2·26	197 1·09	47 0·26	10 0·055	2 0·011	1 0·006	
382·2	"	"	40·0	197·9	Land		330	21	3 0·015	8 0·040	38 0·19	113 0·57	290 1·47	828 4·20	1104 5·60	1115 5·65	873 4·43	420 2·13	154 0·78	47 0·24	17 0·086	10 0·051
382·3	"	"	17·0	83·1	Sea	15	315	25				2 0·024	17 0·20	110 1·32	225 2·69	208 2·50	91 1·09	13 0·16				
384·1	28.4 67	"	27·9	134·7	Sea	3	275	6					3 0·022	15 0·11	49 0·36	57 0·42	24 0·18	4 0·030				
384·2	"	"	24·6	120·9	Land		320	11	1 0·008	5 0·041	12 0·10	39 0·32	81 0·67	259 2·14	366 3·03	343 2·84	237 1·96	94 0·78	43 0·36	19 0·16	13 0·11	8 0·066
384·3	"	"	24·9	121·5	Sea	15	300	4							4 0·033	3 0·025						

Table 2

GUSTS ENCOUNTERED DURING ALL FLYING OVER LAND AND SEA

Leg	Recorded time min	Distance statute mile	Number of vertical gusts greater than v and gusts per mile Gust velocity v ft/s eas (+ up - down)													
			-17·5	-15·0	-12·5	-10·0	-7·5	-5·0	-3·75	3·75	5·0	7·5	10·0	12·5	15·0	17·5
Land	890·4	4590·8	165 0·036	383 0·083	907 0·20	2289 0·50	5412 1·18	14701 3·20	21251 4·63	21224 4·62	15161 3·30	6702 1·46	2907 0·63	1193 0·26	575 0·13	266 0·058
Sea 3 miles	939·7	4780·8	42 0·009	96 0·020	245 0·051	689 0·14	2071 0·43	7139 1·49	13004 2·72	12286 2·57	6706 1·40	2166 0·45	747 0·16	273 0·057	113 0·024	50 0·010
Sea 15 miles	608·2	3104·8	1 0·0003	2 0·0006	14 0·0045	58 0·019	416 0·13	2458 0·79	5419 1·75	5320 1·71	2486 0·80	470 0·15	84 0·027	15 0·0048	2 0·0006	1 0·0003

REFERENCES

No.	Author	Title, etc.
1	J. K. Zbrozek	Gust alleviation factors. A.R.C. R & M 2970 (1953)
2	J. R. Heath-Smith	Atmospheric turbulence encountered by a Hunter aircraft at low altitude. R.A.E. Technical Note 245 (1958)
3	N. I. Bullen	A review of information on the frequency of gusts at low altitude. A.R.C. C.P. 873 (1965)
4	E. W. Wells	Low altitude gust measurements over three routes in the U.K. A.R.C. C.P. 676 (1962)

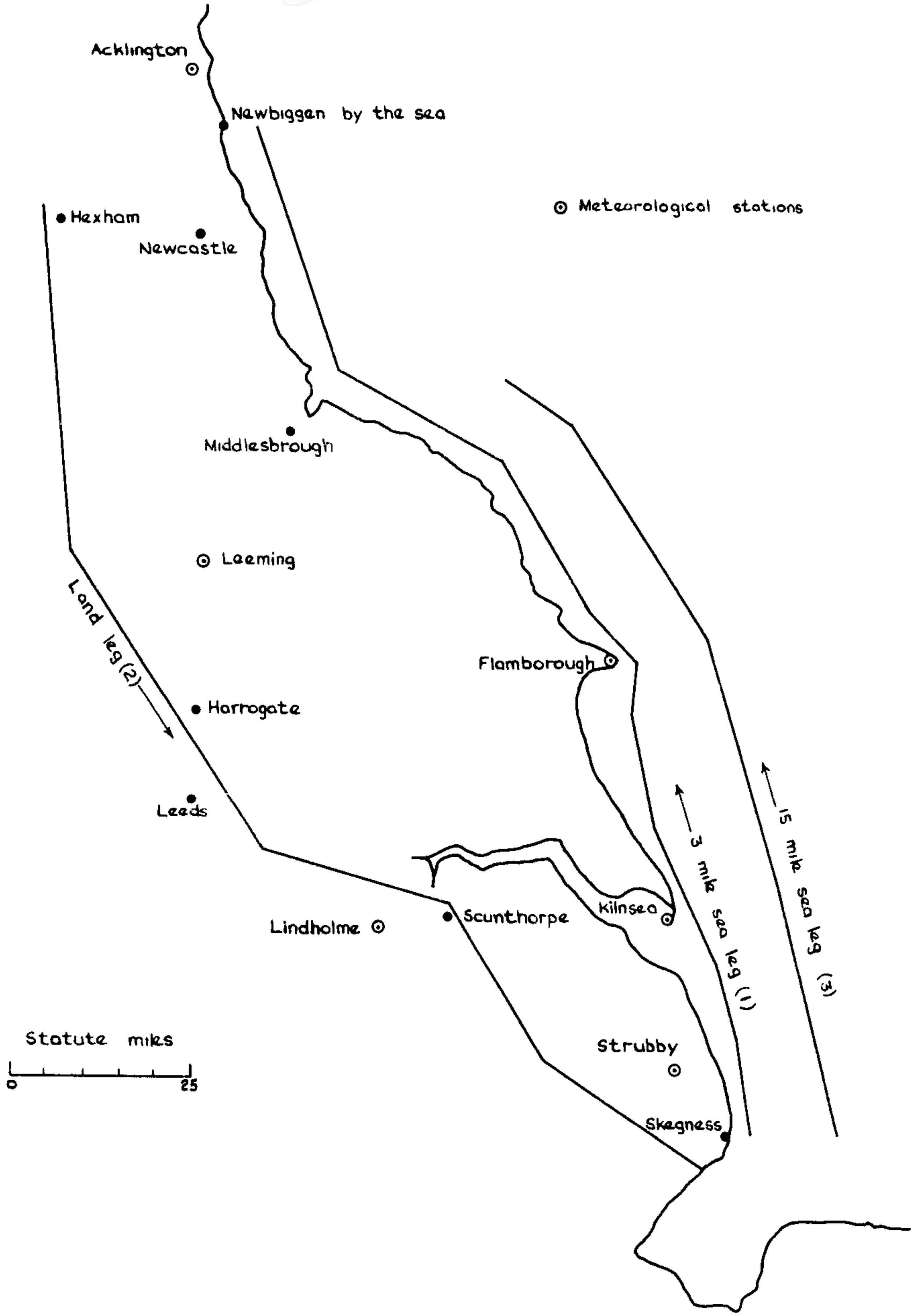

Fig. 1 Route and positions of meteorological stations along the coast of N.E. England

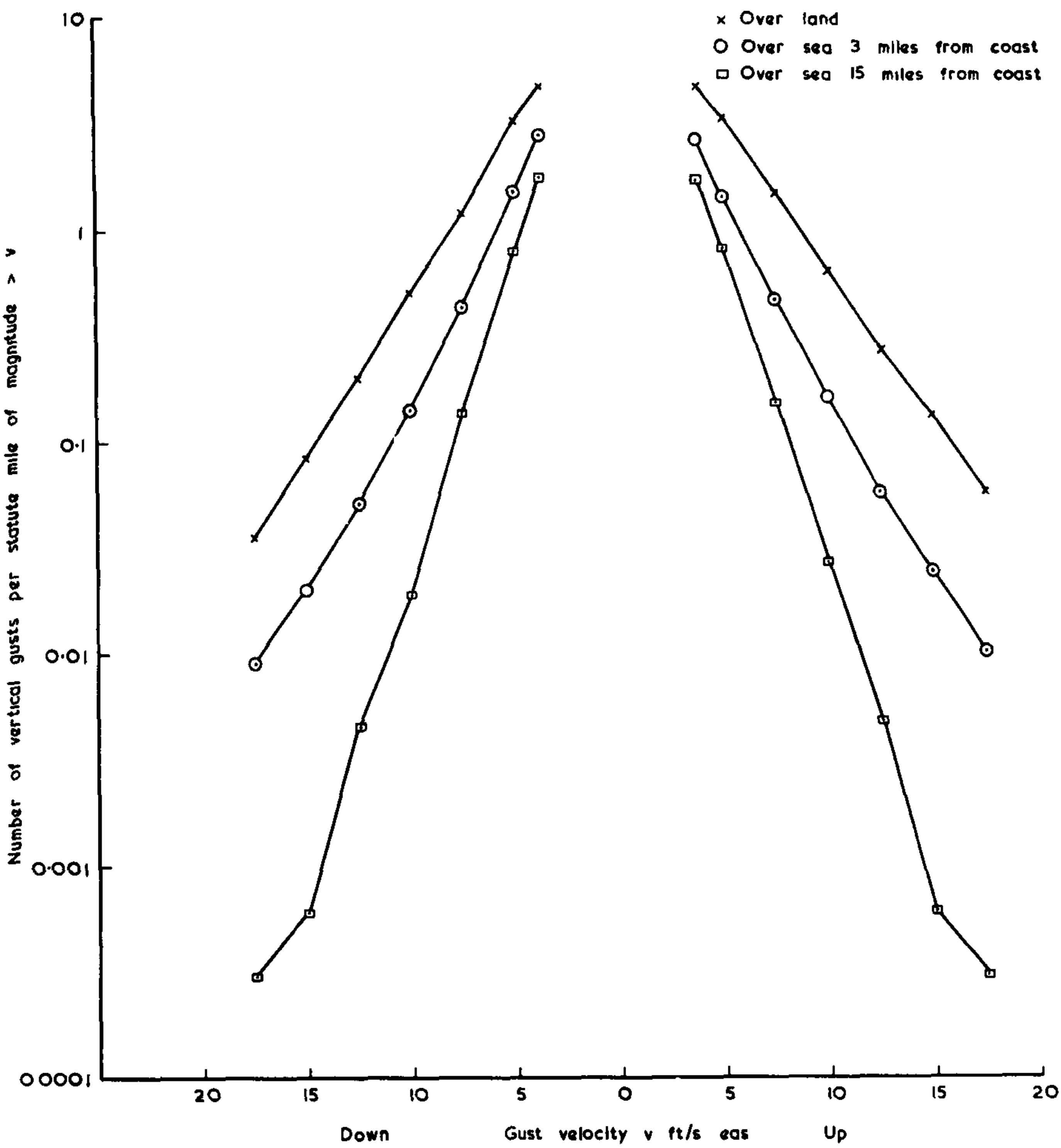

Fig. 2 Mean gust spectra for all flights over each leg

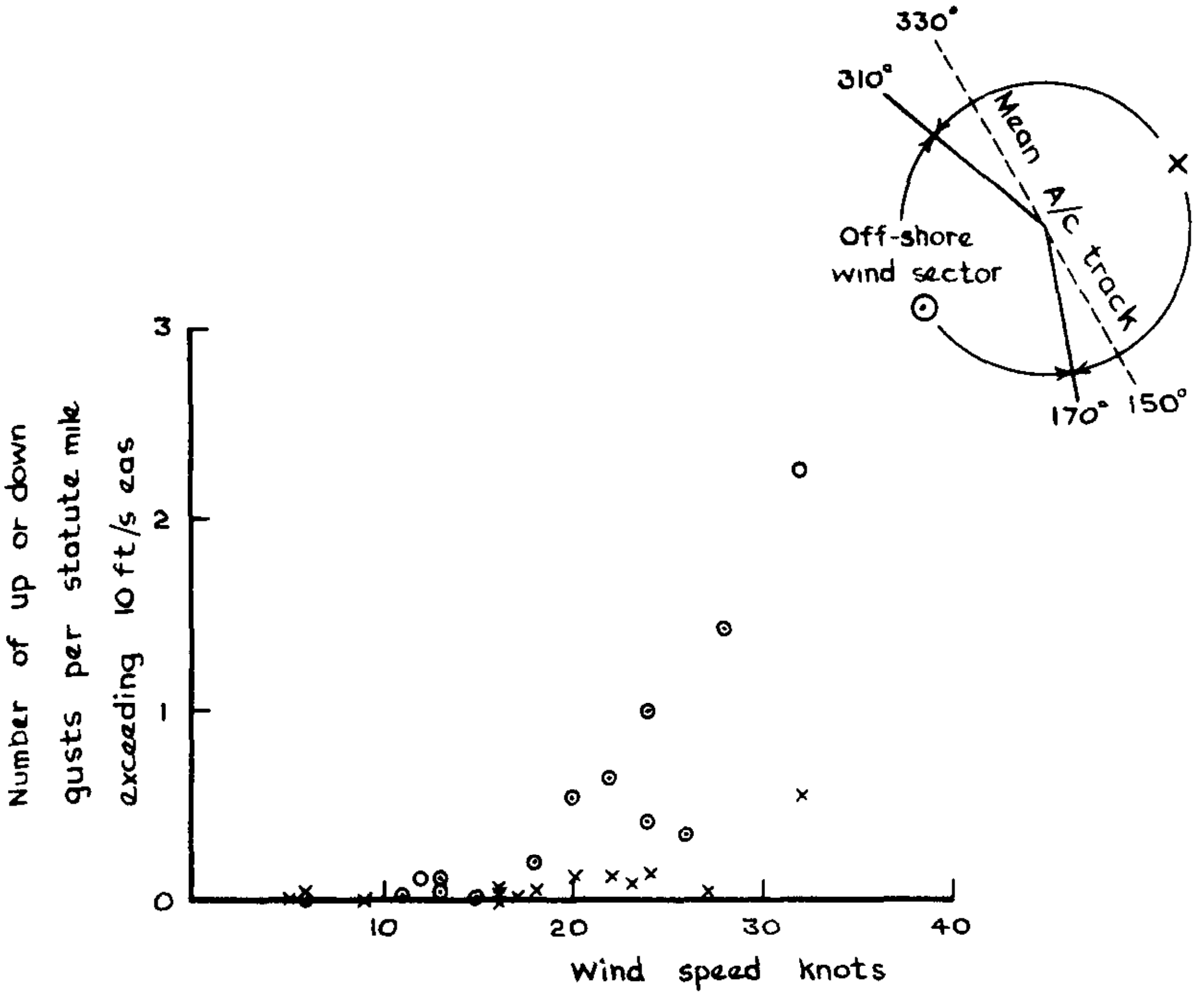

Fig. 3 Relation between wind speed and gust frequency over the sea at 3 miles from the coast

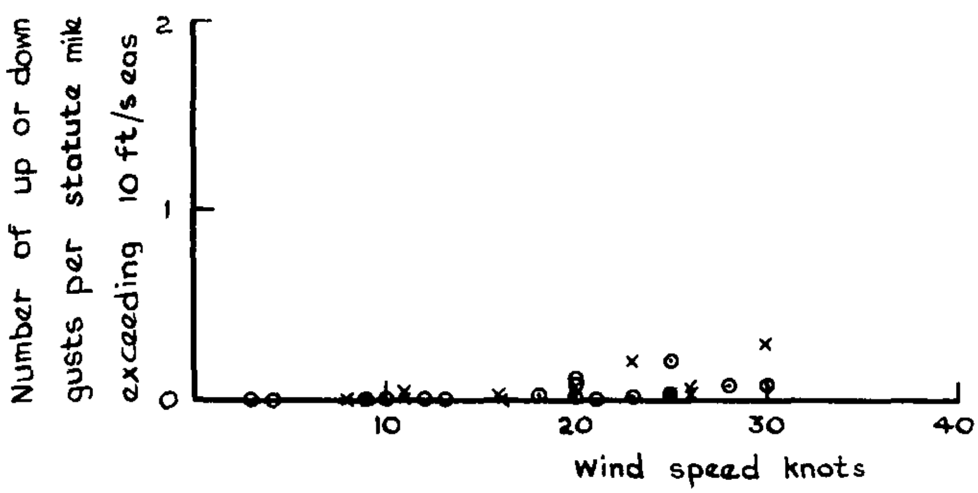

Fig 4 Relation between wind speed and gust frequency over the sea at 15 miles from the coast

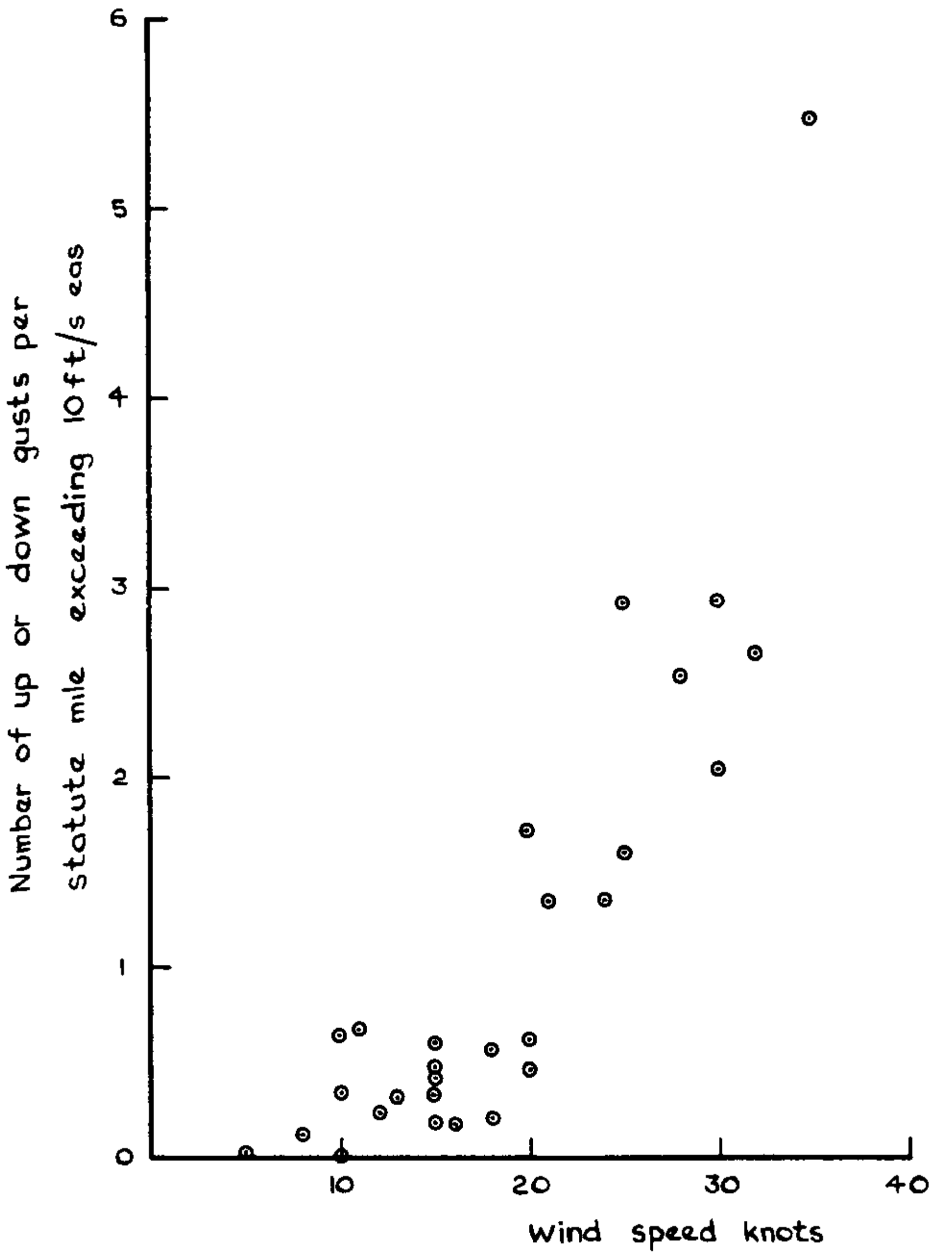

Fig. 5 Relation between wind speed and gust frequency over land

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Wells, E.W.

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