C. P. No. 676

C. P. No. 676

MINISTRY OF AVIATION

AERONAUTICAL RESEARCH COUNCIL

CURRENT PAPERS

Low Altitude Gust Measurements over Three Routes in the U.K.

By

E. W. Wells

LONDON: HER MAJESTY'S STATIONERY OFFICE

1965

FIVE SHILLINGS NET

U.D.C. No. 551.551:533.6.015.4

C.P. No. 676

October, 1962

LOW ALTITUDE GUST MEASUREMENTS OVER THREE ROUTES IN THE U.K.

by

E. W. Wells

SUMMARY

A number of flights have been made at low altitude over three routes in the U.K. The routes were in Sussex, East Anglia and Wales. Measurements made with a counting accelerometer have been analysed to investigate the effect of variation in terrain and meteorological conditions on the intensity of turbulence. A comparison has also been made between these flights and flights made at low altitude in North Africa.

Replaces R.A.E. Tech.Note No. Structures 320 - A.R.C. 24,504.

LIST OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

1 INTRODUCTION

During the period September 1959 to February 1962 a number of flights were made at low altitude over three routes in the United Kingdom. The object of the experiment was to assess the intensity of turbulence at low altitude and its variation with differences in terrain and meteorological conditions. The flights were made in a Canberra aircraft and the normal acceleration levels exceeded were counted by means of a counting accelerometer near the centre of gravity of the aircraft and converted to equivalent gust velocities by using the discrete gust analysis[1].

2 DETAILS OF ROUTES

The three routes over which the flying took place are shown on Fig.1. The first was in Sussex between Petersfield and Bodiam a distance of 64 miles. This route started over hilly wooded country of the South Downs and later passed over flatter country consisting of a mixture of fields, woods, farms and villages typical of the Sussex Weald.

The second route was in East Anglia between the airfields of Waterbeach and Coningsby. The run was 56 miles in length and passed over flat fen country, which was cultivated in the South and marshy at the Northern end.

The third route was in Wales between Glasbury and Berriew; it was 38 miles in length and lay over open hilly country with peaks rising to approximately 2000 feet above sea level.

A contour of the ground along each route is shown on Fig.2.

3 AIRCRAFT, INSTRUMENTATION AND FLIGHT TECHNIQUE

The aircraft used was a standard Canberra B6. A R.A.E. Compound Counting Accelerometer Mk.4 installed near the aircraft centre of gravity was used to count the normal accelerations levels experienced by the aircraft. Details of the aircraft and accelerometer are given in Appendix 1.

For determining the temperature lapse rate during flight a Meteorological Office Balanced Bridge Thermometer was installed in the aircraft, the element being fitted under the nose. For the early flights the temperature was obtained by reading the Indicator, but on flights made after 1959 the output of the bridge was fed into a Beaudouin A13 recorder and the temperature was continuously recorded.

The flying extended over a period of approximately $2\frac{1}{2}$ years and was part of a larger programme investigating loads due to gusts on aircraft. The flights were made at irregular intervals throughout each year and under varying meteorological conditions. On each flight the route being examined was flown a number of times in each direction, usually a sufficient number to bring the recording time up to approximately 30 minutes. The accelerometer counters were switched on at the start and off at the end of each run so that loads caused by the aircraft turning between runs were not recorded. The aircraft was flown at approximately 200 feet above the ground and an attempt was made to follow the ground contours, hereafter referred to as "contouring".

4 METEOROLOGICAL INFORMATION

Information on the state of the weather for each flight was obtained from the nearest hourly observations made at Gatwick for the Sussex flights, Rhayader for the Welsh flights, and Waterbeach and Coningsby for the flights in East Anglia (positions shown on map, Fig.1). The information supplied by each station was as follows:-

Surface wind speed and direction

Visibility

Cloud type and amount

Screen temperature

Dew point.

A summary of the average meteorological information for the period of each flight is given in Table 1.

An average temperature lapse rate was obtained for each flight over the height band 200 ft to 1000 ft above ground from a thermometer carried externally on the aircraft. Details of the method of measurement are given in Appendix 1.

5 CONVERSION OF ACCELERATION COUNTS TO GUST VELOCITIES

The normal acceleration levels were converted to equivalent gust velocity levels by means of the discrete gust procedure described in Ref.1. The computation was done on a Deuce computer by the method described in Ref.2.

6 RESULTS

In Table 2 are listed details of all the flights showing the number of gusts recorded and the number of gusts per mile. The number of gusts given in Table 2 is the total obtained when the number of occurrences of up and down gusts at equal levels of gust velocity are added together.

Table 3 lists separately the numbers of up gusts and of down gusts recorded during each of the flights.

The average gust spectra for each route are shown on Fig.3. From this Figure it will be seen that the Welsh route produced the largest number of occurrences at the higher levels of gust velocity. This is to some extent due to the inclusion of the loads produced by the pilot "contouring" over the hilly ground along the route.

6.1 Sussex

Fig.4 shows the relationship between occurrences per mile of gusts of 5 ft/sec or greater and wind speed for the Sussex route. There is a correlation between gust intensity and wind speed. The results have also been grouped in ranges of wind speed for four ranges of temperature lapse rate. They are listed in Table 4 and shown plotted on Fig.5. Again the results show correlation between gust intensity and wind speed. The Figure also shows that lapse rate is an important factor and that the difference in the degree of turbulence between the two extreme ranges of lapse rate, one stable and the other unstable, is marked.

Plotting the number of gusts per mile of 5 ft/sec or greater against lapse rate (Fig.6) again shows some correlation, especially for the higher values of wind speed. Grouping the data in ranges of wind speed gives Table 5 and the results are shown plotted on Fig.7. This clearly shows a relationship with lapse rate becoming most marked at the higher wind speeds.

6.2 East Anglia

The number of gusts per mile of 5 ft/sec or greater is plotted against wind speed on Fig.8 and against lapse rate on Fig.9. The results were too few to allow separation of the effects of wind speed and lapse rate. Separation was moreover made impractical by the fact that on the occasions when flights were made, high winds were associated with high lapse rates and low wind speeds with low lapse rates.

6.3 Wales

The results from this route, due to the hilly nature of the terrain, include a considerable effect from loads due to "contouring". Also fewer flights were made over this route making it more difficult to draw conclusions from the results. By comparing the results against wind speed however (Fig.10) there appears to be a significant trend of increasing turbulence with increasing wind speed, but no trend can be observed with lapse rate (Fig.11).

6.4 Comparison between the Sussex and East Anglian Routes

An attempt has been made to examine the variation in the gust spectra due to the difference in the type of terrain. The comparison has been restricted to the Sussex and East Anglian routes, the results from these routes being less affected by "contouring" loads than those from the Welsh route.

The average figure for the number of gusts per mile for six flights over the Sussex route and six over the East Anglian route, when the wind speed and lapse rate were within a limited range, was obtained. Each group of six flights was made on days when the wind was in the range of 11 to 16 kts and the lapse rate 2.0 to 3.1°C/1000 ft. The two sets of results are shown plotted on Fig.12. The flat terrain along the East Anglian route produced fewer gusts than the more hilly and varied terrain of the Sussex route.

6.5 Comparison between U.K. and North Africa

A comparison has been made between the gust spectra measured on the U.K. routes with those measured in North Africa during the 'Swifter' experiment[3].

The results for all the flying on each of the three U.K. routes have been compared with those obtained in North Africa in the most severe conditions, namely, midday flights over the hilly desert leg. An average gust spectrum for the whole year was taken for the North African flying and also an average spectrum for the three summer months of June, July and August, when the turbulence was more severe than in other months. The results are shown plotted on Fig.13.

It will be seen that the average gust intensity even for the three summer months is not significantly higher than the average for all the flying on the Sussex route. The U.K. flights tended to be carried out on days when turbulence was expected although this was not always the case. The flights cover a large range of wind speed and lapse rate and they were made during all months of the year. It is also significant that the largest figure obtained on any flight for the total number of occurrences per mile of gusts of 5 ft/sec or greater was approximately 13 during the North African flying, compared with a figure of 17 obtained during a flight along the Sussex route*.

---

* Comparative gust measurements were made on a B.2 and B.6 Canberra in North Africa to establish that differences were not due to the different marks of Canberra used in North Africa and U.K.

7 CONCLUSIONS

The results from the three routes in the U.K. are as follows:-

(i) Over a varied terrain consisting of a mixture of low hills, woods and farmland, as found in Sussex, both wind speed and temperature lapse rate were found to be significant factors in producing turbulence. The effect of lapse rate increased with increase in wind speed.

(ii) It was not possible to distinguish between the effects of wind speed and temperature lapse rate over the flat terrain of East Anglia due to the limited amount of flying carried out over this route. Unfortunately, high temperature lapse rates occurred when high wind speeds were present and low lapse rates were associated with low wind speeds.

(iii) Over the hilly terrain of Wales, wind speed appeared to be a significant factor in producing turbulence, but the results from this region were affected by the loads caused by following the contours of the hills.

For a given value of wind speed and lapse rate there was found to be significantly more turbulence over the undulating, varied terrain of Sussex than over the flat terrain of East Anglia.

The intensity of turbulence at low altitude over Southern England was comparable with that measured over the hilly desert of North Africa.

LIST OF REFERENCES

No.	Author	Title, etc.
1	Zbrozek, J.K.	Gust alleviation factors. A.R.C. R.&M. 2970. August, 1953.
2	Heath Smith, J.R.	The estimation of atmospheric gust frequencies from counting accelerometer records using the Deuce computer. R.A.E. Tech. Note No. Structures 240, A.R.C. 20,921. October, 1958.
3	Bullen, N.I.	Gusts at low altitude in North Africa. A.R.C. C.P.581. September, 1961.

APPENDIX 1

DETAILS OF AIRCRAFT AND INSTRUMENTATION

1 The aircraft used in the tests was a standard Canberra B.6, having an all-up-weight at take-off of 43,000 lbs. Other aircraft characteristics are:-

Wing span	64 feet
Mean chord	15 feet
Gross wing area	960 sq.ft.
Aspect ratio	4.25
Slope of lift curve	3.6 per radian

The R.A.E. Counting Accelerometer Mk.4 carried on the aircraft records the number of times that the normal acceleration has exceeded the following levels of absolute acceleration:-

Levels > 1.0g level flight condition

1.2 1.3 1.4 1.6 1.8 2.0 2.2 2.4 2.6g

Levels < 1.0g level flight condition

0.9 0.8 0.7 0.6 0.4 0.2 0 -0.2 -0.4 -0.6g

Further details of the characteristics of the accelerometer are given in Ref.2.

The instrument also contained an airspeed indicator, a clock and, instead of the standard pressure altimeter, a milliammeter connected into the radio altimeter circuit suitably calibrated to indicate the height of the aircraft above ground. Arrangements were made for the acceleration counters to be switched on at the start of a run by an observer in the aircraft. The camera would then commence taking a picture of the counter readings, airspeed, height above ground and time every minute until the end of the run when the observer would switch the counters off. The camera would then take one more picture at the completion of the minute during which the counters were switched off.

Notes on the aircraft fuel state were made by the observer at intervals during the runs.

On flights before 31st May 1960 the lapse rate was obtained by making a run at 1000 ft above ground between two of the 200 ft runs and measuring the outside air temperature by means of a Meteorological Office Balanced Bridge Thermometer at one minute intervals throughout the three runs. By plotting the three sets of readings an average value of lapse rate was obtained and this was scaled to give the average lapse rate over a height band of 1000 ft.

For flights made on and after 31st May 1960 the same three runs were carried out but arrangements were made for the bridge output to be recorded continuously on a Beaudouin A.13 recorder. The lapse rate was obtained by analysing the record in a similar manner, except that the temperature readings were taken at shorter time intervals.

TABLE 1. Details of meteorological information

Flight No.	Date	Route	Mean Time GMT	Height Feet	Speed Knots	Mean values of:- Wind Speed Knots	Wind Direction Degrees	Lapse Rate °C/1000 ft	Visibility N. Miles	Screen Temp. °C	Dew Point °C	Cloud Cover (eights) - Type - Base (1000's ft) Low	Medium	High	Distance Miles	Number of 5 ft/sec Gusts/mile
7	30/9/59	E	1515	200	300	12	120	2·9	12	23	0	Nil	Nil	Nil	145·1	3·02
9	2/10/59	S	1030	"	"	8	180	3·1	8	22	15	1 Cu 2·5	Nil	4 Ci 25	190·9	5·22
10	2/10/59	S	1500	"	"	10	200	1·5	9	22	14	1 Cu 4	3 Ac 14	1 Ci 20	105·5	4·46
11	5/10/59	E	1115	"	"	15	100	2·5	2	21	12	Nil	Nil	Nil	134·5	6·07
12	5/10/59	E	1500	"	"	15	100	3·0	3	20	9	Nil	Nil	Nil	172·0	3·95
13	7/10/59	S	1130	"	400	8	140	2·0	4	22	13	2 Cu 4	Nil	Nil	184·6	5·65
14	7/10/59	E	1530	"	"	3	100	-0·5	5	22	11	Nil	Nil	Nil	101·3	0·11
17	14/10/59	S	1530	"	300	6	180	2·5	8	19	8	1 Sc 5	Nil	Nil	186·2	1·39
18	15/10/59	W	1515	"	"	5	120	2·5	11	16	9	2 Cu 3	Nil	Nil	96·2	2·84
19	16/10/59	S	1500	"	"	15	140	2·0	5	19	11	1 Cu 3·5	Nil	Nil	161·0	6·06
20	19/10/59	W	1145	"	"	18	320	3·0	9	11	7	3 Cu 2 - 5 Sc 3	Nil	Nil	105·4	6·41
21	22/10/59	S	1200	"	"	12	290	3·1	22	15	6	3 Cu 3	Nil	Nil	185·0	7·75
23	23/10/59	E	1200	"	400	14	230	2·2	6	12	8	6 Sc 6	8 Ac 15	Nil	194·1	3·78
24	28/10/59	S	1515	"	300	12	300	3·8	4	9	3	3 Cu 2·5 - 4 Cu 5	3 Ac 10	Nil	190·4	11·20
25	5/11/59	S	1245	"	"	8	300	2·5	3	10	6	3 Cu 2·5 - 5 Sc 4·5	Nil	Nil	56·4	5·82
37	4/12/59	S	1600	"	"	18	300	2·5	13	6	2	3 Cu 2	Nil	7 Cs 22	185·7	9·62
38	8/12/59	S	1100	"	"	11	160	2·5	5	9	6	7 Cb 1	Nil	Nil	187·8	9·24
39	8/12/59	E	1600	"	"	19·5	125	1·9	4	8	5	8 Sc 3	Nil	Nil	141·6	4·36
67	31/5/60	E	1515	"	"	8	090	2·8	32	19	6	1 Cu 4	Nil	6 Ci 25	136·7	5·25
71	9/6/60	S	1500	"	"	16	230	3·1	5	16	15	2 St 1 - 4 Cu 2 - 6 Sc 4	Nil	Nil	176·9	11·99
72	10/6/60	S	1530	"	"	9	290	2·5	22	18	9	3 Cu 3·2 - 4 Sc 5	Nil	Nil	302·9	6·46
73	31/6/60	S	1100	"	"	11	260	3·1	22	17	11	4 Cu 2·5	Nil	Nil	178·6	9·16
81	8/7/60	S	1500	"	"	8	300	3·0	10	17	13	2 Cu 2 - 4 Sc 4	7 Ac 10	Nil	180·7	3·08
82	12/7/60	E	1145	"	"	16	260	2·5	14	19	11	3 Cu 3 - 4 Sc 5	3 Ac 12	Nil	168·2	6·92
91	29/7/60	W	1415	"	"	10	270	2·8	10	14	12	3 Cu 2·5 - 5 Sc 4	Nil	Nil	155·7	6·22
98	20/9/60	W	1045	"	"	12	340	-	10	11	6	2 Cu 2·5 - 5 Sc 4	Nil	Nil	129·3	9·47
100	23/9/60	W	1115	"	"	7	360	3·4	11	13	9	3 Cu 2·5	Nil	5 Cs 20	135·8	3·43
102	5/10/60	S	1430	"	"	11	200	3·1	13	16	13	4 Cu 2	Nil	Nil	187·0	6·90
103	6/10/60	S	1115	"	"	8	140	2·5	9	16	13	7 Cu 2	Nil	Nil	170·1	6·16
107	12/10/60	W	1545	"	"	10	340	3·1	11	9	2	3 Cu 2·5	Nil	Nil	127·7	3·92
111	28/11/60	S	1545	"	"	6	240	2·2	15	5	0	2 St 1·5	Nil	Nil	185·3	2·14
119	31/1/61	W	1145	"	"	10	200	3·5	8	5	3	4 Sc 2·5	8 Ac 10	Nil	66·7	7·09
122	6/2/61	S	1530	"	250	24	260	3·8	38	8	1	2 Cu 2·4	Nil	Nil	186·2	16·99
124	9/2/61	E	1315	"	300	22	295	4·2	22	10	3	3 Cu 2·5	Nil	Nil	132·5	10·43
128	6/3/61	W	1145	"	"	5	090	3·0	15	10	6	Nil	Nil	4 Ci 20	181·6	4·41
130	18/4/61	E	1500	"	"	8	135	3·1	11	16	6	4 Cu 3	Nil	5 Ci 25	117·9	5·20
137	8/5/61	E	1515	"	"	25	280	3·2	22	15	3	6 Cu 4	Nil	Nil	234·0	12·18
140	15/5/61	S	1500	"	"	8	035	2·5	8	12	5	7 Sc 4	Nil	Nil	171·6	5·56
142	16/5/61	S	1445	"	"	15	080	2·5	15	15	6	5 Sc 2·5	Nil	Nil	249·4	9·99
144	6/6/61	S	1500	"	"	2	350	2·8	4	22	13	1 Cb 2·8 - 5 Cu 3	Nil	Nil	186·4	3·62
145	13/6/61	E	1215	"	"	17·5	355	3·4	18	15	7	3 Cu 2·5 - 5 Sc 3	Nil	Nil	185·4	5·05
146	14/6/61	W	1445	"	"	7	140	3·5	11	18	9	2 Cu 2·5 - 6 Sc 4	Nil	Nil	173·8	4·36
147	15/6/61	E	1145	"	"	12	230	2·8	7	20	10	2 Cu 4	Nil	5 Ci 25	222·5	7·14
163	30/8/61	W	1400	"	"	7	320	1·8	12	19	10	4 Cu 3	Nil	Nil	143·9	4·94
176	11/1/62	S	1500	"	"	30	270	2·8	16	8	1	5 Cu 2·5	Nil	3 Ci 25	297·8	14·73
178	12/1/62	S	1630	"	"	24	220	2·0	2	0	-2	Nil	Nil	1 Ci 25	149·8	8·99
181	7/2/62	S	1200	"	"	24	230	2·5	8	9	5	5 Cu 2	Nil	Nil	192·9	13·19
182	13/2/62	S	1200	"	"	20	320	3·0	22	5	-4	3 Cu 2	4 Ac 15	Nil	186·9	12·43

TABLE 2. Flight information and gusts/mile

Flight No.	Date	Route	Mean Time GMT	Height Feet	Speed Knots	Mean values of:- Wind Speed Knots	Wind Direction Degrees	Lapse Rate °C/1000 ft	Distance Miles
7	30/9/59	E	1515	200	300	12	120	2.9	145.1
9	2/10/59	S	1030	"	"	8	180	3.1	190.9
10	2/10/59	S	1500	"	"	10	200	1.5	105.5
11	5/10/59	E	1115	"	"	15	100	2.5	134.5
12	5/10/59	E	1500	"	"	15	100	3.0	172.0
13	7/10/59	S	1130	"	400	8	140	2.0	184.6
14	7/10/59	E	1530	"	"	3	100	-0.5	101.3
17	14/10/59	S	1530	"	300	6	180	2.5	186.2
18	15/10/59	W	1515	"	"	5	120	2.5	96.2
19	16/10/59	S	1500	"	"	15	140	2.0	161.0
20	19/10/59	W	1145	"	"	18	320	3.0	105.4
21	22/10/59	S	1200	"	"	12	290	3.1	185.0
23	23/10/59	E	1200	"	400	14	230	2.2	194.1
24	28/10/59	S	1515	"	300	12	300	3.8	190.4
25	5/11/59	S	1245	"	"	8	300	2.5	56.4
37	4/12/59	S	1600	"	"	18	300	2.5	185.7
38	8/12/59	S	1100	"	"	11	160	2.5	187.8
39	8/12/59	E	1600	"	"	19.5	125	1.9	141.6
67	31/5/60	E	1515	"	"	8	090	2.8	136.7
71	9/6/60	S	1500	"	"	16	230	3.1	176.9
72	10/6/60	S	1530	"	"	9	290	2.5	302.9
73	13/6/60	S	1100	"	"	11	260	3.1	178.6
81	8/7/60	S	1500	"	"	8	300	3.0	180.7
82	12/7/60	E	1145	"	"	16	260	2.5	168.2
91	29/7/60	W	1415	"	"	10	270	2.8	155.7
98	20/9/60	W	1045	"	"	12	340	-	129.3
100	23/9/60	W	1115	"	"	7	360	3.4	135.8
102	5/10/60	S	1430	"	"	11	200	3.1	187.0
103	6/10/60	S	1115	"	"	8	140	2.5	170.1
107	12/10/60	W	1545	"	"	10	340	3.1	127.7
111	28/11/60	S	1545	"	"	6	240	2.2	185.3
119	31/1/61	W	1145	"	"	10	200	3.5	66.7
122	6/2/61	S	1530	"	250	24	260	3.8	186.2
124	9/2/61	E	1315	"	300	22	295	4.2	132.5
128	6/3/61	W	1145	"	"	5	090	3.0	181.6
130	18/4/61	E	1500	"	"	8	135	3.1	117.9
137	8/5/61	E	1515	"	"	25	280	3.2	234.0
140	15/5/61	S	1500	"	"	8	035	2.5	171.6
142	16/5/61	S	1445	"	"	15	080	2.5	249.4
144	6/6/61	S	1500	"	"	2	350	2.8	186.4
145	13/6/61	E	1215	"	"	17.5	355	3.4	185.4
146	14/6/61	W	1445	"	"	7	140	3.5	173.8
147	15/6/61	E	1145	"	"	12	230	2.8	222.5
163	30/8/61	W	1400	"	"	7	320	1.8	143.9
176	11/1/62	S	1500	"	"	30	270	2.8	297.8
178	12/1/62	S	1630	"	"	24	220	2.0	149.8
181	7/2/62	S	1200	"	"	24	230	2.5	192.9
182	13/2/62	S	1200	"	"	20	320	3.0	186.9

Flight No.	Number of Gusts Ft/Sec 5	7.5	10	15	20	25	30	35	40	Gusts/Mile Ft/Sec 5	7.5	10	15	20	25	30	35	40	Gust RMS Ft/Sec
7	438	95	22	1						3.02	0.65	0.15	0.01						1.533
9	997	414	129	7						5.22	2.17	0.68	0.04						3.915
10	471	159	42	2						4.46	1.51	0.40	0.02						3.032
11	816	326	103	6	1					6.07	2.42	0.77	0.04	0.01					3.533
12	680	228	74	6						3.95	1.33	0.43	0.03						2.362
13	1042	447	148	9						5.65	2.42	0.80	0.05						3.919
14	11	1	1	1						0.11	0.01	0.01	0.01						0.317
17	258	52	12							1.39	0.28	0.06							1.372
18	273	170	120	44	12	5	2			2.84	1.17	1.25	0.46	0.12	0.05	0.02			4.410
19	976	415	147	9						6.06	2.58	0.91	0.06						3.533
20	675	471	337	146	55	22	8	3	1	6.41	4.47	3.20	1.39	0.52	0.21	0.08	0.03	0.01	6.213
21	1434	668	289	43	7	3	1			7.75	3.61	1.56	0.23	0.04	0.02	0.01			3.511
23	734	157	26	2						3.78	0.81	0.13	0.01						2.120
24	2133	1202	644	207	39	6	1			11.20	6.31	3.38	1.09	0.20	0.03	0.01			4.513
25	328	128	41	5	1					5.82	2.27	0.73	0.09	0.02					3.338
37	1786	849	370	42	5	2				9.62	4.57	1.99	0.23	0.03	0.01				3.604
38	1735	844	355	38	4					9.24	4.50	1.89	0.20	0.02					3.960
39	618	161	43	3	1	1				4.36	1.14	0.30	0.02	0.01	0.01				1.816
67	718	272	78	8						5.25	1.99	0.57	0.06						3.553
71	2122	1358	910	286	80	31	8	2		11.99	7.68	5.14	1.62	0.45	0.18	0.05	0.01		4.924
72	1958	815	295	33	2					6.46	2.69	0.97	0.11	0.01					3.312
73	1635	865	407	68	9					9.16	4.84	2.28	0.38	0.05					4.299
81	556	147	28	4						3.08	0.81	0.16	0.02						2.717
82	1162	468	166	14	1					6.92	2.78	1.00	0.08	0.01					3.139
91	969	629	431	133	39	5				6.22	4.04	2.77	0.85	0.25	0.03				4.903
98	1225	872	629	257	83	25	5			9.47	6.74	4.86	1.99	0.64	0.19	0.04			6.250
100	465	229	131	42	23	6	1			3.43	1.69	0.97	0.31	0.17	0.04	0.01			3.124
102	1291	573	205	29	3					6.90	3.06	1.10	0.16	0.02					3.919
103	1048	387	116	8	2					6.16	2.27	0.68	0.05	0.01					3.175
107	500	331	215	78	29	5	1			3.92	2.59	1.68	0.61	0.23	0.04	0.01			5.691
111	397	149	51	7						2.14	0.80	0.28	0.04						2.830
119	473	263	147	42	13	2	1			7.09	3.94	2.20	0.63	0.19	0.03	0.02			4.167
122	3165	1987	1172	313	77	21	7	2	1	16.99	10.67	6.29	1.68	0.41	0.11	0.04	0.01	0.01	5.299
124	1382	615	250	38	8	1				10.43	4.64	1.89	0.29	0.06	0.01				3.400
128	801	433	221	38	5	1				4.41	2.38	1.22	0.21	0.03	0.01				4.118
130	613	211	52	4						5.20	1.79	0.44	0.03						3.450
137	2849	1533	739	136	22	3				12.18	6.55	3.16	0.58	0.09	0.01				4.383
140	955	359	105	10	1					5.56	2.09	0.61	0.06	0.01					3.408
142	2491	1122	455	62	14	1				9.99	4.05	1.82	0.25	0.06					3.492
144	674	237	81	8						3.62	1.27	0.43	0.04						2.459
145	936	304	88	3						5.05	1.64	0.47	0.02						2.509
146	758	418	234	48	10	3				4.36	2.40	1.35	0.28	0.06	0.02				3.939
147	1589	648	211	16	2					7.14	2.91	0.95	0.07	0.01					3.577
163	710	439	288	80	18	4	2			4.94	3.05	2.00	0.56	0.13	0.03	0.01			4.487
176	4387	2791	1712	443	99	17	1			14.73	9.37	5.75	1.49	0.33	0.06				5.171
178	1346	638	258	32	3					8.99	4.26	1.72	0.21	0.02					3.921
181	2535	1514	826	169	24	5				13.19	7.85	4.27	0.88	0.12	0.02				4.929
182	2324	1512	937	61	11	1				12.43	8.10	5.00	1.33	0.33	0.06	0.01			5.446

TABLE 3. Summary of estimated gust speeds

Flight No.	Date	Route	Distance Miles	Number of times each gust speed was exceeded. Vertical gust speed in ft/sec E.A.S. (+ up - down)																	
				-40	-35	-30	-25	-20	-15	-10	-7.5	-5	5	7.5	10	15	20	25	30	35	40
7	30/9/59	E	145.1						1	8	33	173	265	62	14						
9	2/10/59	S	190.9						1	41	173	444	553	241	83	6					
10	2/10/59	S	105.5							11	55	192	279	104	31	2					
11	5/10/59	E	134.5						1	39	128	348	468	198	64	5	1				
12	5/10/59	E	172.0						2	22	75	259	421	153	52	4					
13	7/10/59	S	184.6						3	51	169	457	585	278	97	6					
14	7/10/59	E	101.3									2	11	1	1	1					
17	14/10/59	S	186.2							6	20	99	159	32	6						
18	15/10/59	W	96.2					2	16	45	73	126	147	97	75	28	10	5	2		
19	16/10/59	S	161.0						3	56	169	430	546	246	91	6					
20	19/10/59	W	105.4				3	18	57	141	215	319	356	256	196	89	37	19	8	3	1
21	22/10/59	S	185.0					1	15	112	272	611	823	396	177	28	6	3	1		
23	23/10/59	E	194.1							6	51	296	438	106	20	2					
24	28/10/59	S	190.4				1	7	44	229	474	934	1199	728	415	163	32	5	1		
25	5/11/59	S	56.4						1	12	45	148	180	83	29	4	1				
37	4/12/59	S	185.7				1	4	18	143	359	814	972	490	227	24	1	1			
38	8/12/59	S	187.8						16	141	357	787	948	487	214	22	4				
39	8/12/59	E	141.6							12	57	226	392	104	31	3	1	1			
67	31/5/60	E	136.7						3	36	138	361	357	134	42	5					
71	9/6/60	S	176.9		2	4	12	30	131	443	664	1058	1064	694	467	155	50	19	4		
72	10/6/60	S	302.9					1	17	129	375	972	986	440	166	16	1				
73	13/6/60	S	178.6					6	31	178	397	790	845	468	229	37	3				
81	8/7/60	S	180.7						4	17	73	257	299	74	11						
82	12/7/60	E	168.2						4	69	204	535	627	264	97	10	1				
91	29/7/60	W	155.7				3	21	61	184	275	453	516	354	247	72	18	2			
98	20/9/60	W	129.3			3	11	40	126	286	392	574	651	480	343	131	43	14	2		
100	23/9/60	W	135.8				1	13	21	64	114	218	247	115	67	21	10	5	1		
102	5/10/60	S	187.0						12	86	266	615	676	307	119	17	3				
103	6/10/60	S	170.1						3	49	179	505	543	208	67	5	2				
107	12/10/60	W	127.7			1	3	17	38	101	155	233	267	176	114	40	12	2			
111	28/11/60	S	185.3						4	31	82	197	200	67	20	3					
119	31/1/61	W	66.7					5	20	79	130	230	243	133	68	22	8	2	1		
122	6/2/61	S	186.2	1	1	4	11	33	143	555	959	1567	1598	1028	617	170	44	10	3	1	
124	9/2/61	E	132.5				1	2	9	97	275	680	702	340	153	29	6				
128	6/3/61	W	181.6						10	104	208	392	409	225	117	28	5	1			
130	18/4/61	E	117.9						3	35	115	318	295	96	17	1					
137	8/5/61	E	234.0				1	6	47	322	712	1359	1490	821	417	89	16	2			
140	15/5/61	S	171.6						5	51	180	455	500	179	54	4	1				
142	16/5/61	S	249.4				1	7	30	235	553	1223	1268	569	220	32	7				
144	6/6/61	S	186.4						2	38	110	313	361	127	43	6					
145	13/6/61	E	185.4						2	37	141	455	481	163	51	1					
146	14/6/61	W	173.8						16	125	215	392	366	203	109	32	10	3			
147	15/6/61	E	222.5					1	3	87	282	739	850	366	124	13	1				
163	30/8/61	W	143.9					4	34	143	209	341	369	230	145	46	14	4	2		
176	11/1/62	S	297.8			1	7	46	208	852	1382	2193	2194	1409	860	235	53	10			
178	12/1/62	S	149.8					2	13	108	303	666	680	335	150	19	1				
181	7/2/62	S	192.9				2	13	78	386	739	1255	1280	775	440	91	11	3			
182	13/2/62	S	186.9				7	26	107	467	747	1150	1174	765	470	141	35	4	1		

TABLE 4. Sussex - effect of wind speed on turbulence

Range of Wind Knots	Mean Wind in Range Knots	Miles	5 Ft/Sec Gusts	5 Ft/Sec Gusts/Mile
Lapse Rate Range 2.0 - 2.4°C/1000 ft				
6 - 10	7	369.9	1439	3.92
11 - 15	15	161	976	6.06
21 - 25	24	149.8	1346	8.99
Lapse Rate Range 2.5 - 2.9°C/1000 ft				
0 - 5	2	186.4	674	3.62
6 - 10	7.8	887.2	4547	5.11
11 - 15	12.3	615.8	5861	9.52
16 - 20	18	185.7	1786	9.62
21 - 25	24	192.9	2335	13.19
26 - 30	30	297.8	4387	14.73
Lapse Rate Range 3.0 - 3.4°C/1000 ft				
6 - 10	8	371.6	1553	4.18
11 - 15	11.3	550.6	4360	7.92
16 - 20	18	363.8	4446	12.23
Lapse Rate Range 3.5 - 3.9°C/1000 ft				
11 - 15	12	190.4	2133	11.20
21 - 25	24	186.2	3165	16.99

TABLE 5. Sussex - effect of lapse rate on turbulence

Range of Lapse Rate °C/1000 ft	Mean Lapse Rate in Range °C/1000 ft	Miles	5 Ft/Sec Gusts	Gusts/Mile
Wind Range 5 - 8 Knots				
2.0 - 2.4	2.1	369.9	1439	3.89
2.5 - 2.8	2.5	584.3	2589	4.43
2.9 - 3.2	3.05	371.6	1553	4.18
Wind Range 9 - 12 Knots				
1.5 - 2.0	1.5	105.5	471	4.46
2.1 - 2.5	2.5	490.7	3693	7.53
3.1 - 3.5	3.1	550.6	4360	7.92
3.6 - 4.0	3.8	190.4	2133	11.20
Wind Range 21 - 24 Knots				
2.0 - 2.4	2.0	149.8	1346	8.99
2.5 - 2.9	2.5	192.9	2535	13.19
3.5 - 3.9	3.8	186.2	3165	16.99

FIG. 1. MAP OF LOW LEVEL ROUTES AND METEOROLOGICAL STATIONS.

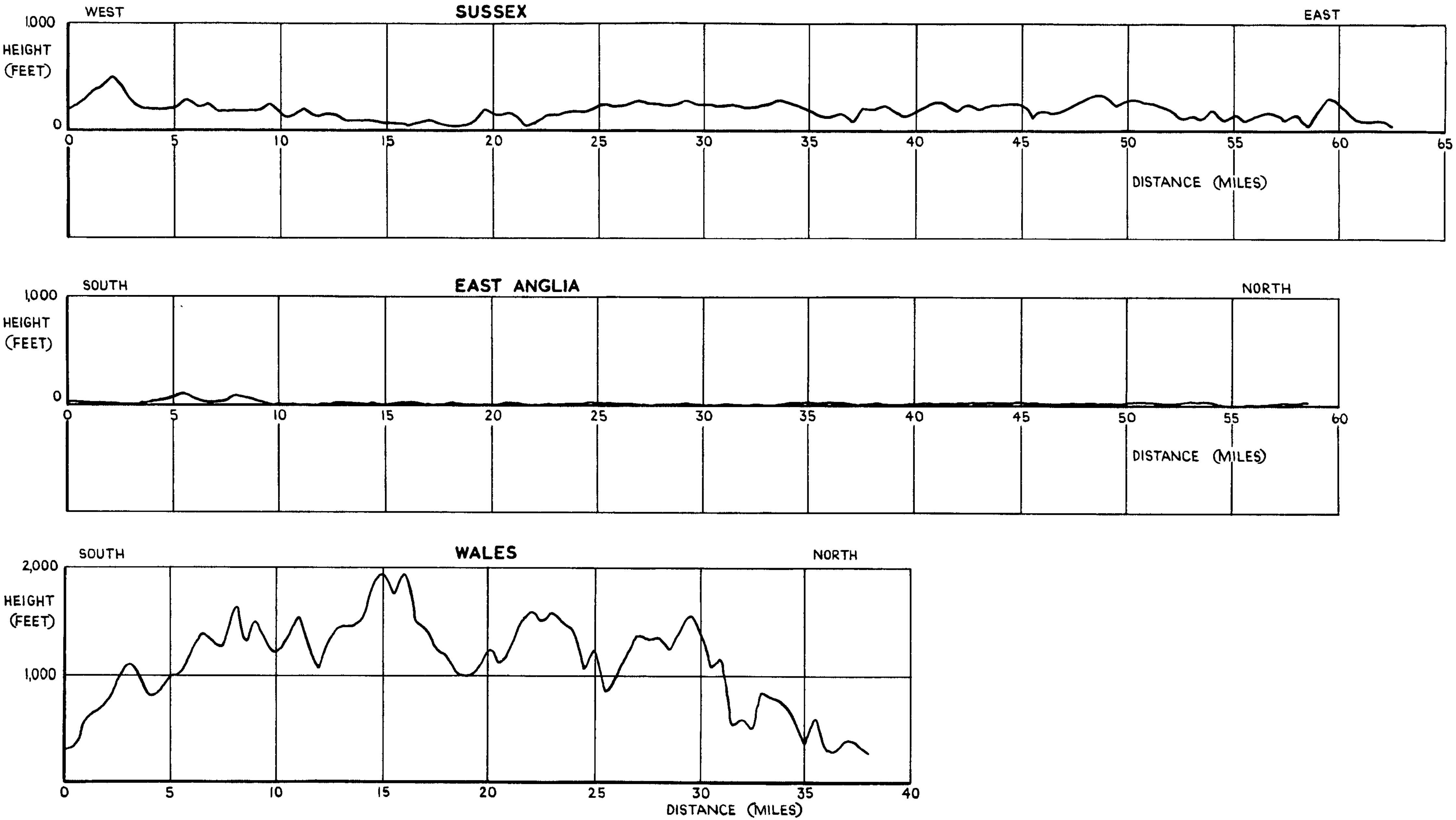

FIG. 2. CONTOUR OF GROUND ALONG THE ROUTES.

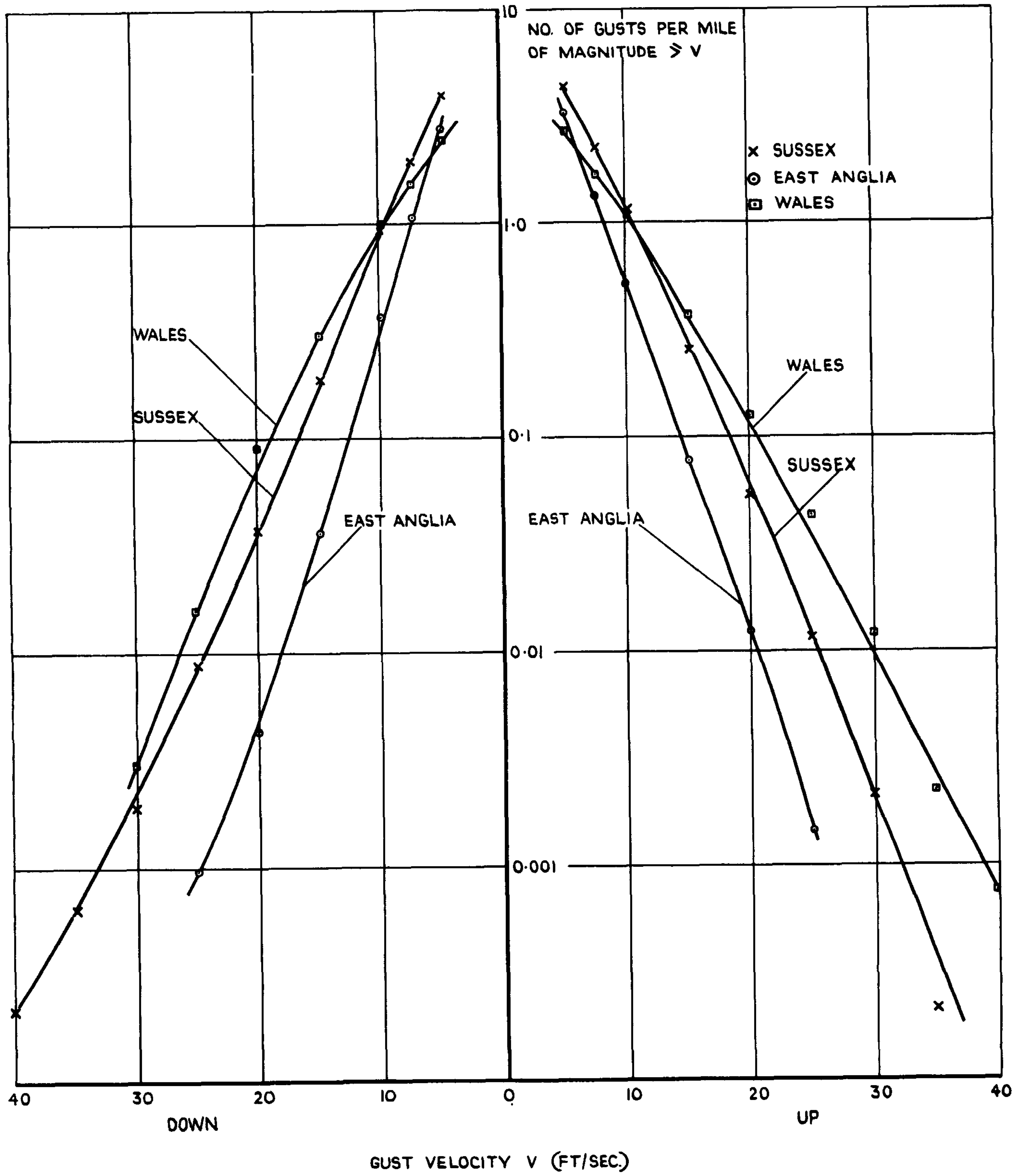

FIG. 3. GUST SPECTRA FOR THE THREE ROUTES-ALL FLIGHTS.

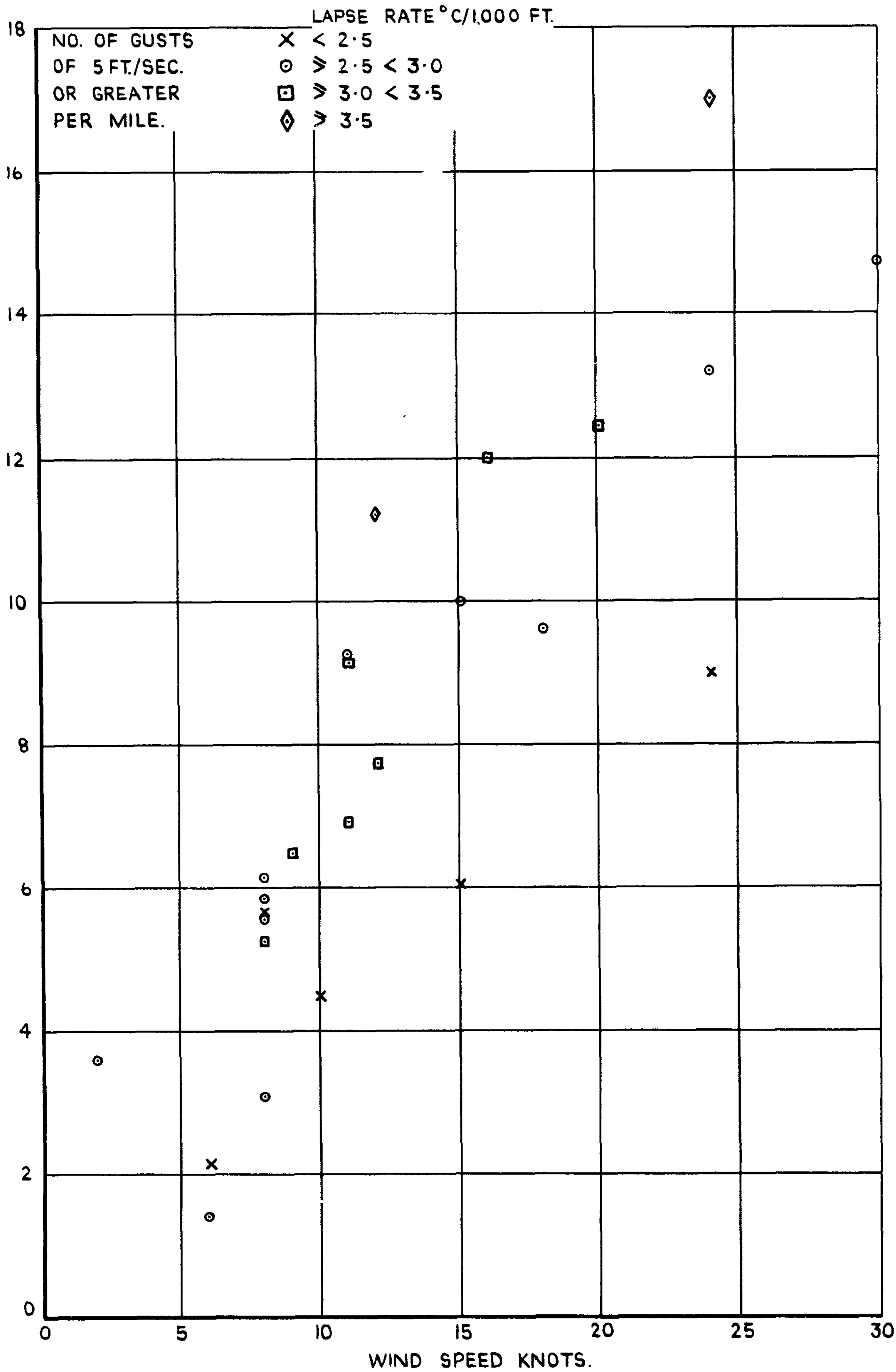

FIG. 4. SUSSEX-EFFECT OF WIND SPEED ON TURBULENCE.

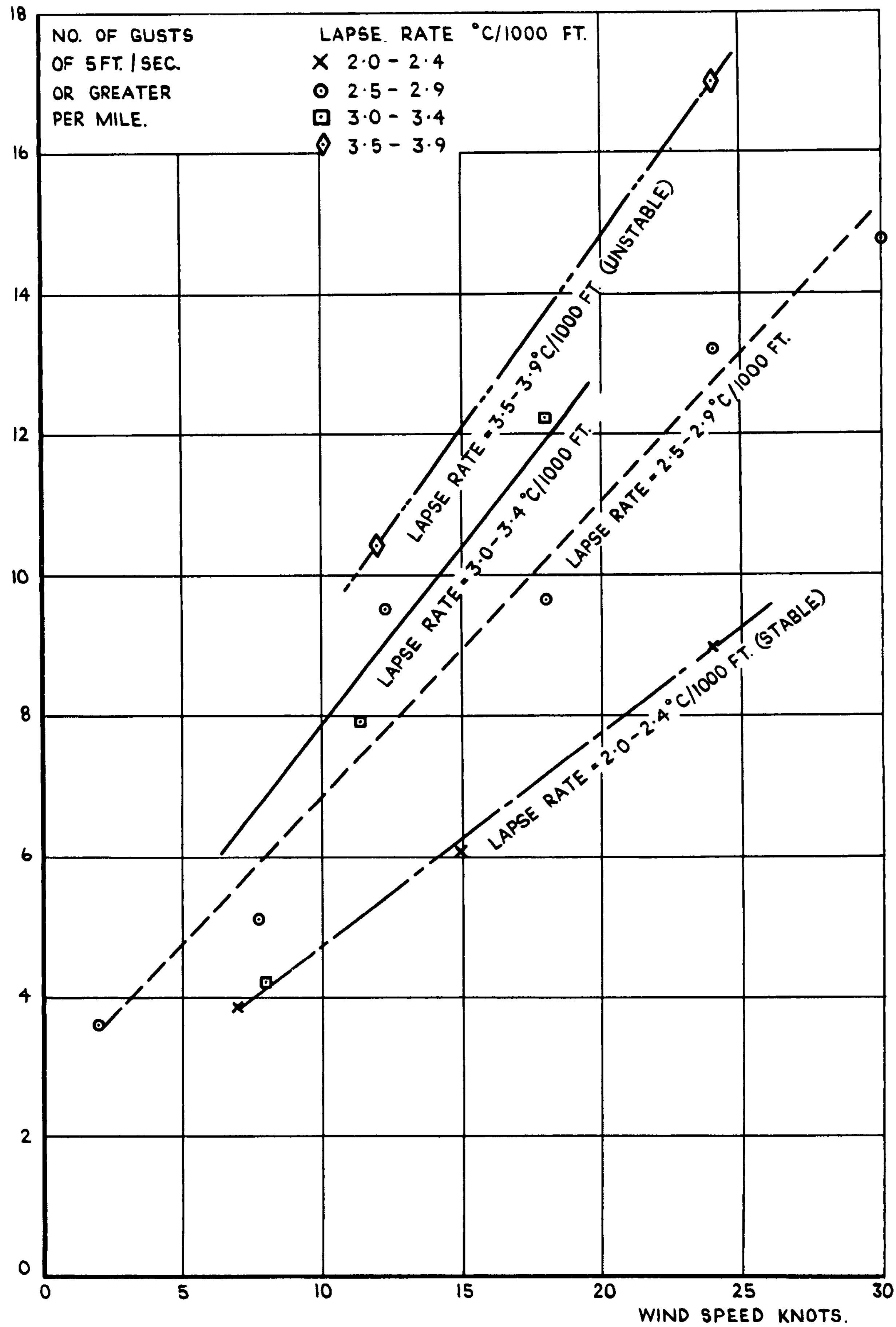

FIG. 5. SUSSEX-EFFECT OF WIND SPEED ON TURBULENCE FOR FOUR RANGES OF LAPSE RATE (GROUPED DATA.)

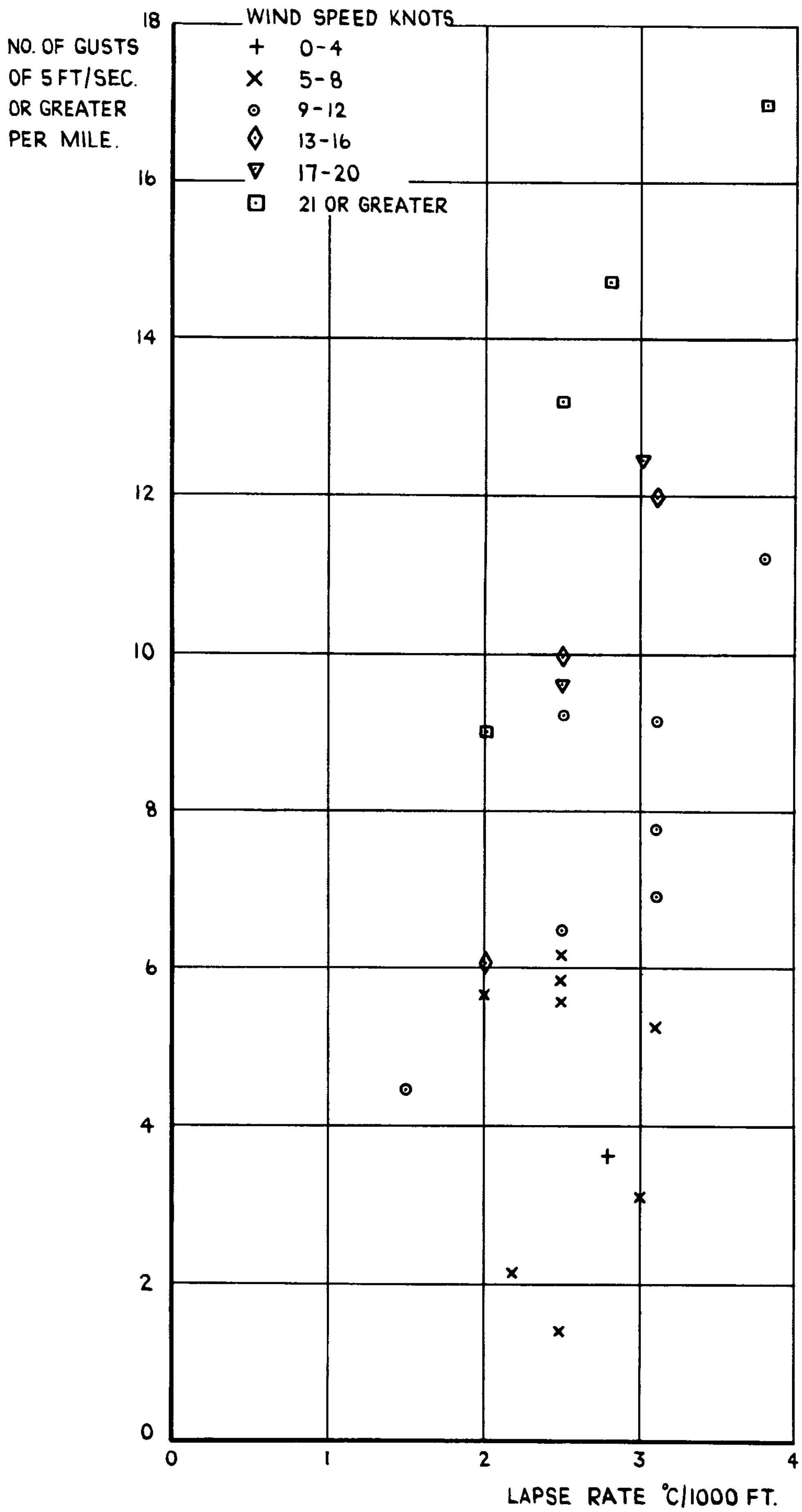

FIG. 6. SUSSEX-EFFECT OF LAPSE RATE ON TURBULENCE

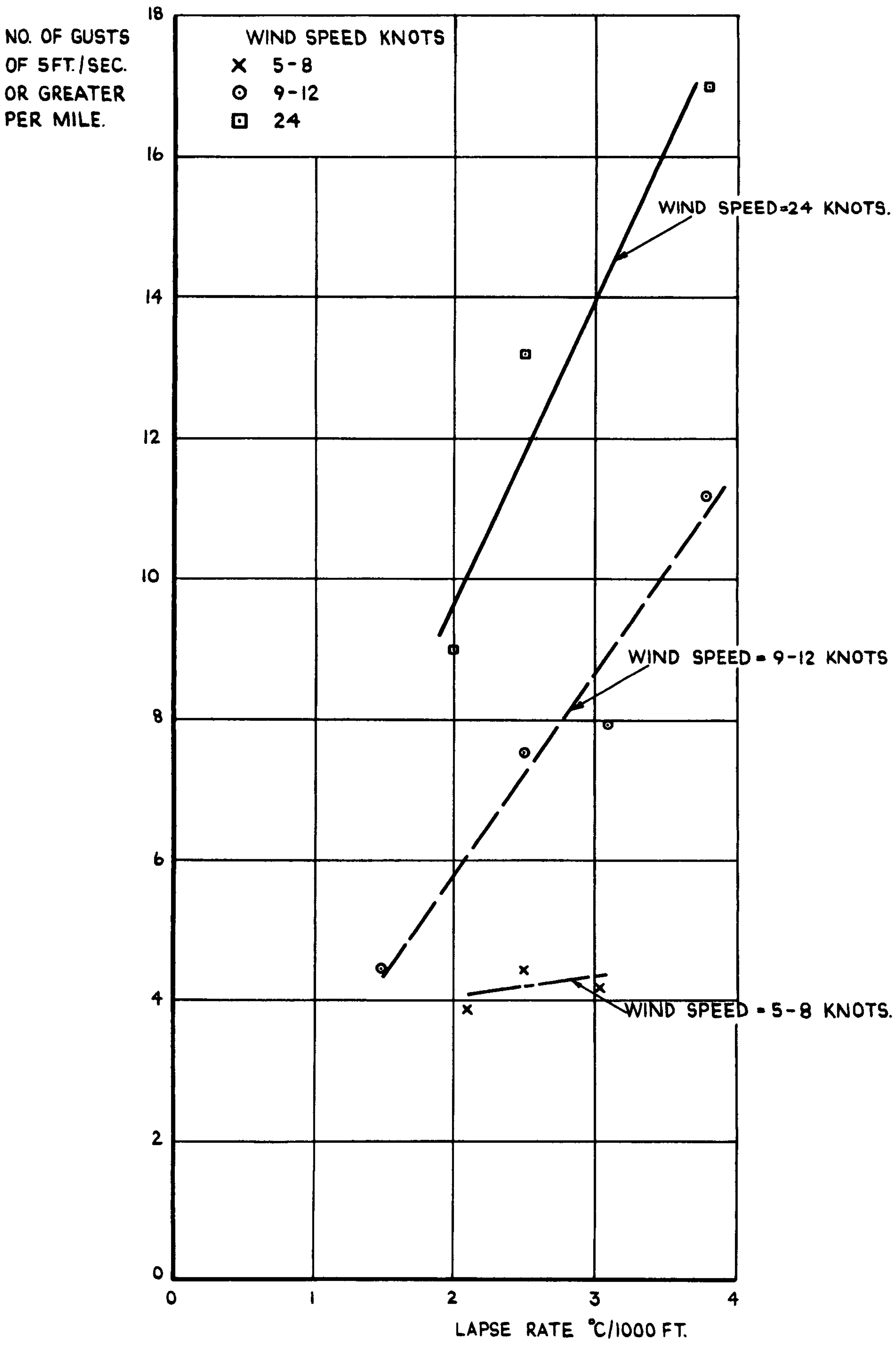

FIG. 7. SUSSEX-EFFECT OF LAPSE RATE ON TURBULENCE FOR THREE RANGES OF WIND SPEED (GROUPED DATA.)

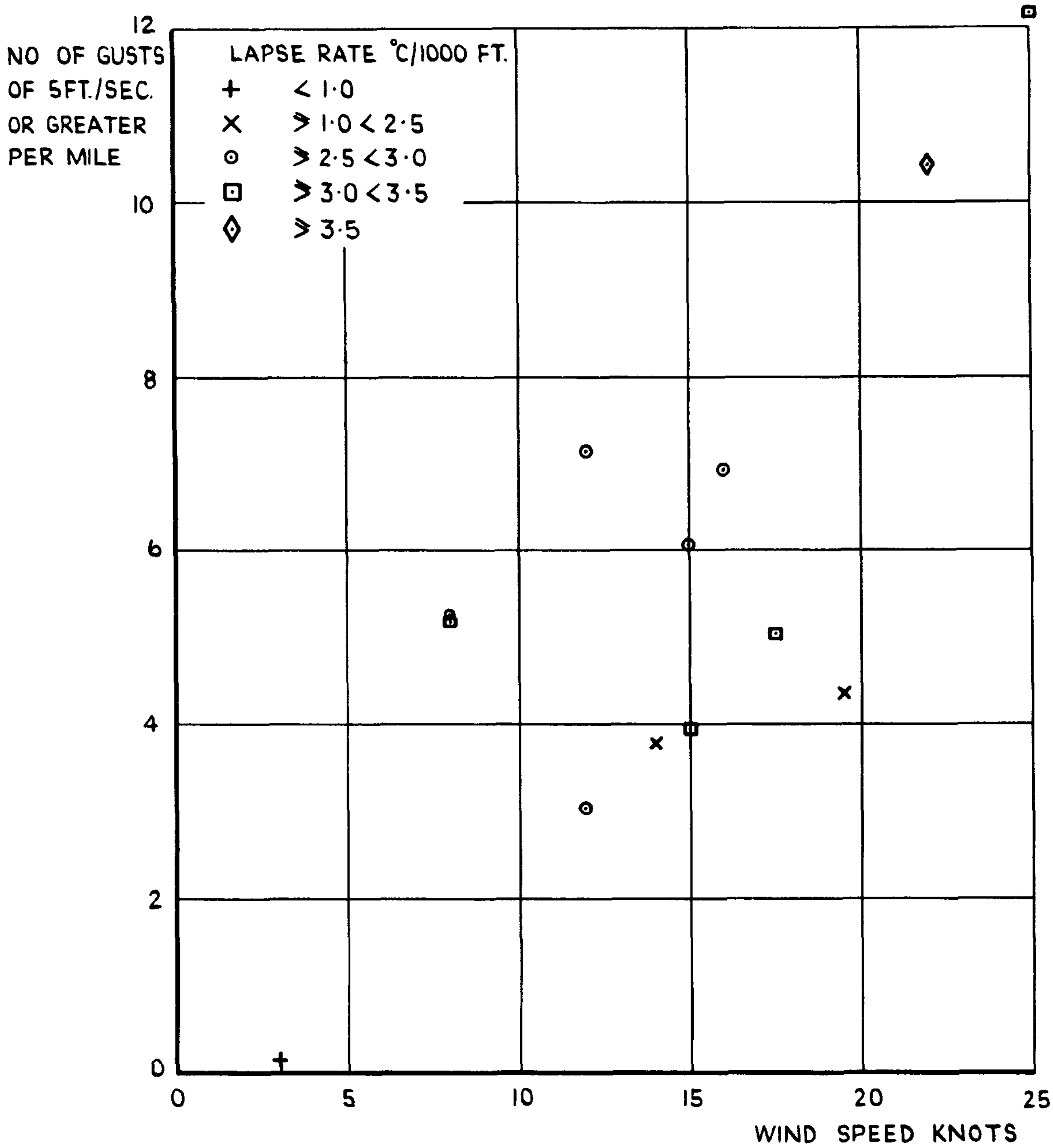

FIG. 8. EAST ANGLIA-EFFECT OF WIND SPEED ON TURBULENCE.

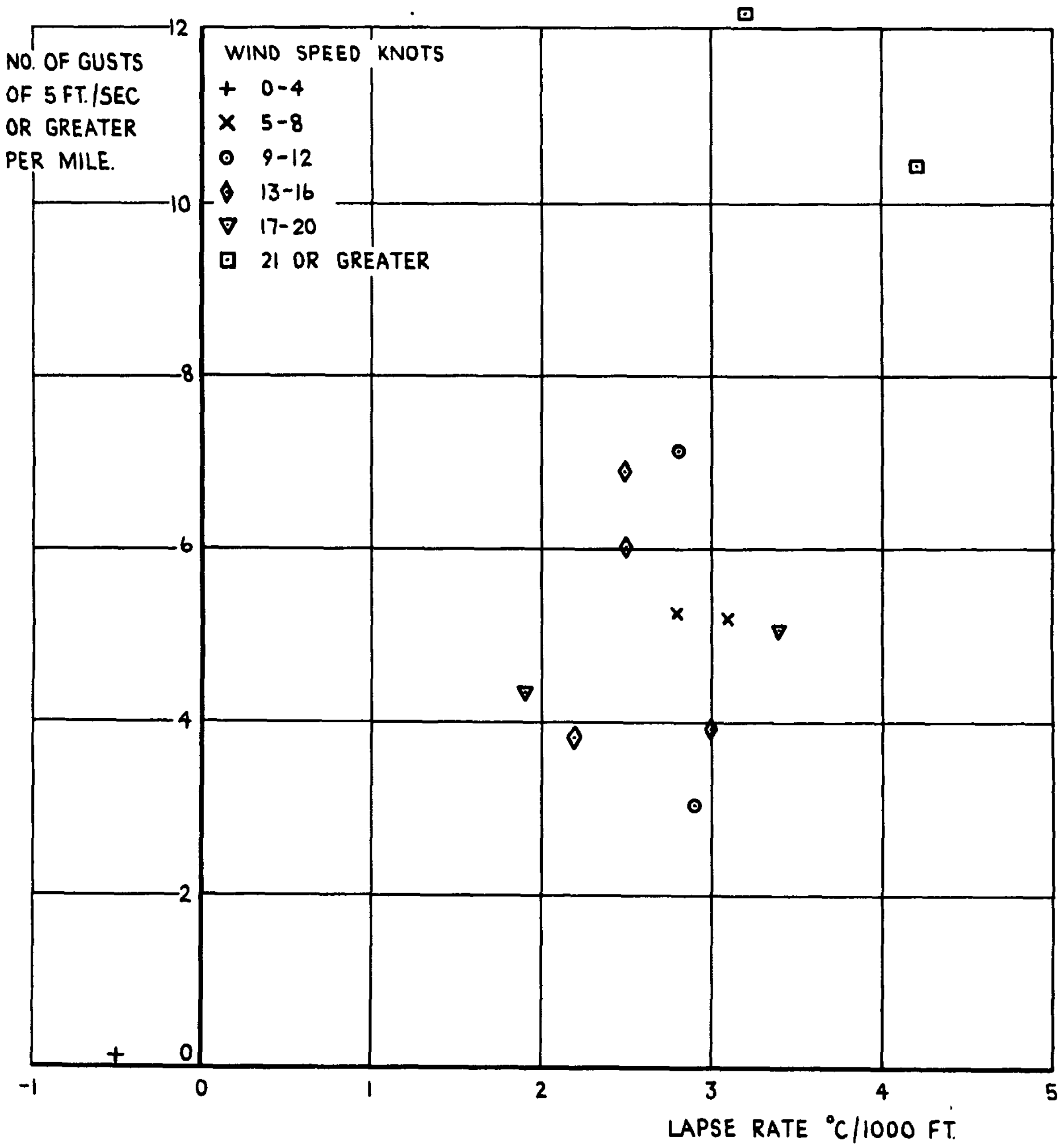

FIG. 9. EAST ANGLIA-EFFECT OF LAPSE RATE ON TURBULENCE.

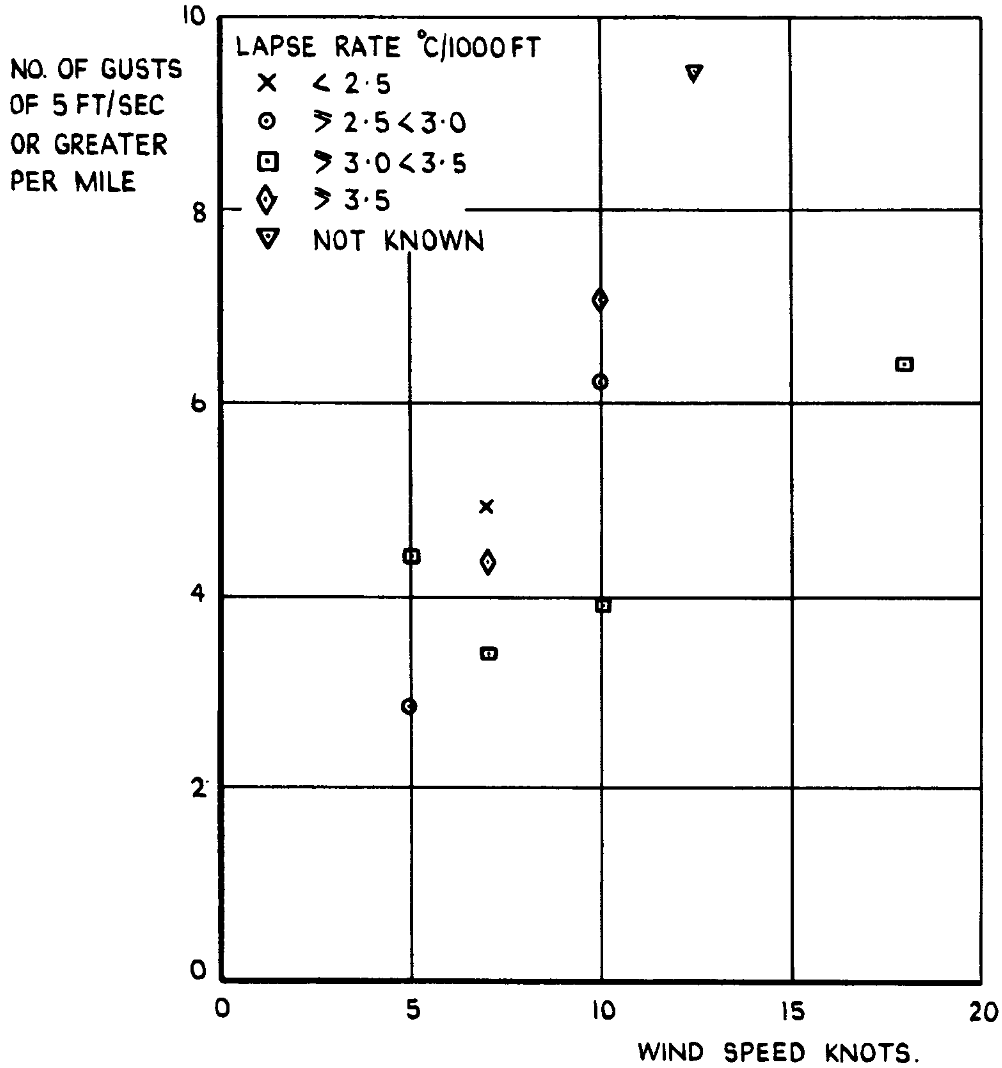

FIG. 10. WALES - EFFECT OF WIND SPEED ON TURBULENCE.

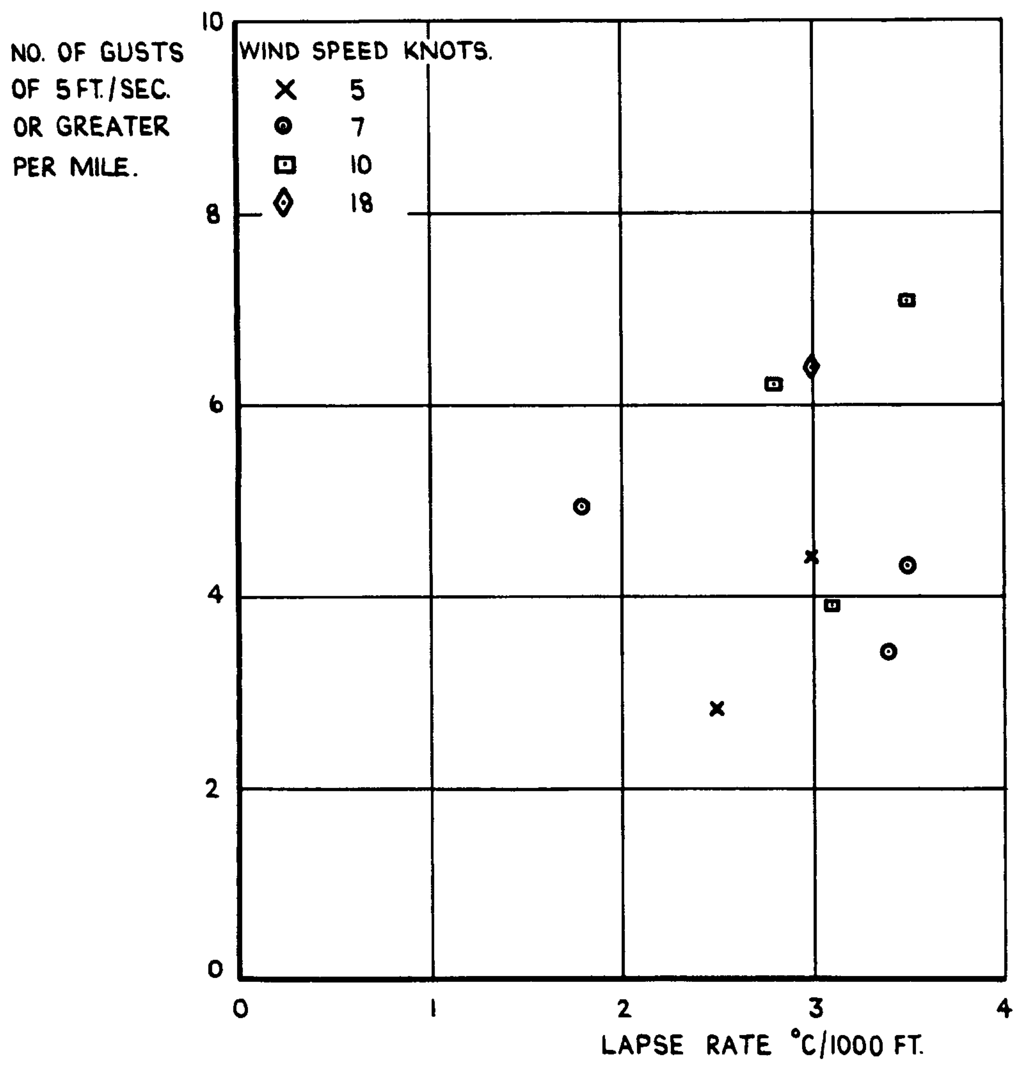

FIG. 11. WALES-EFFECT OF LAPSE RATE ON TURBULENCE.

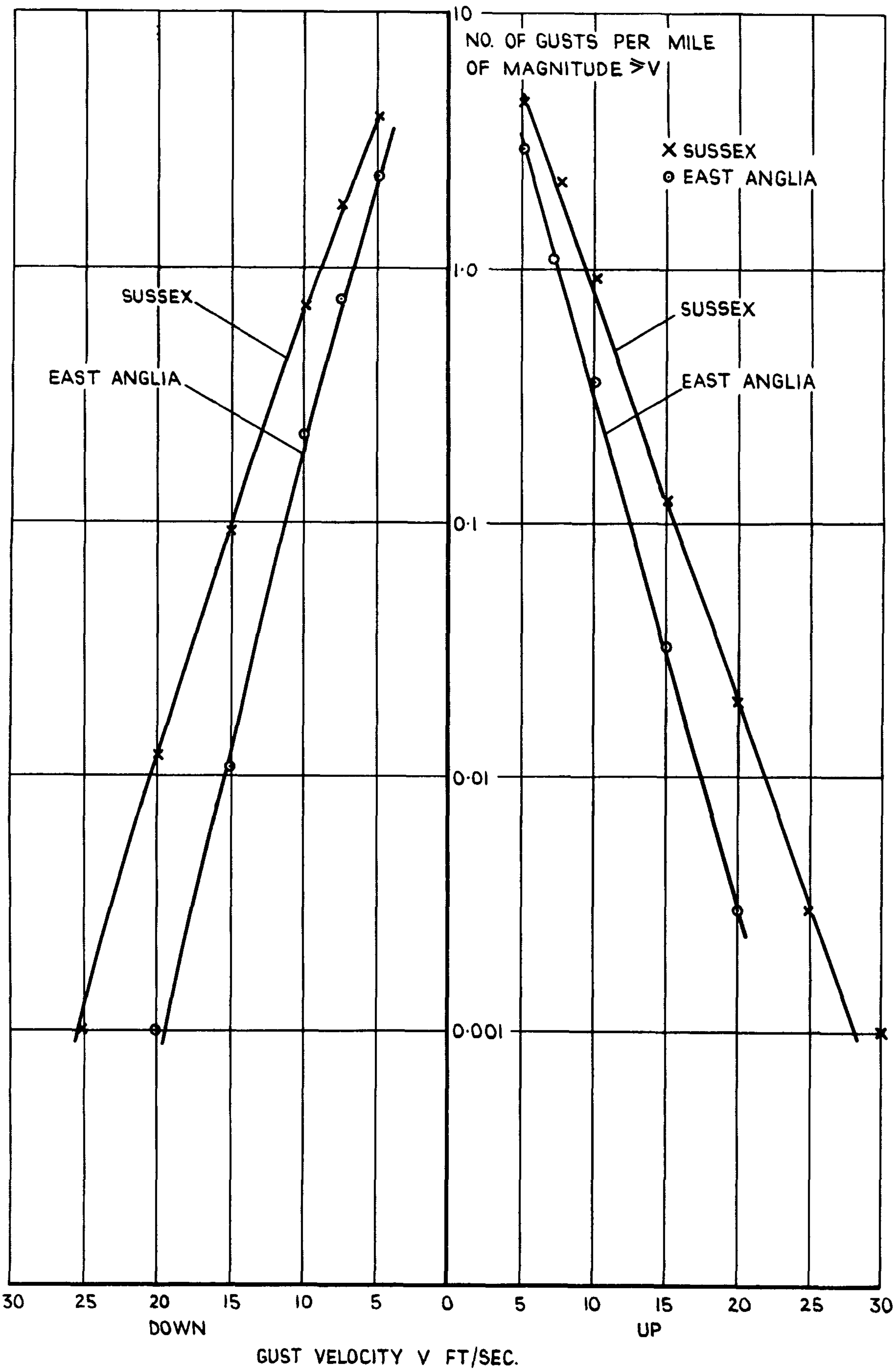

FIG. 12. COMPARISON BETWEEN THE SUSSEX AND EAST ANGLIAN ROUTES FOR FLIGHTS MADE IN SIMILAR METEOROLOGICAL CONDITIONS.

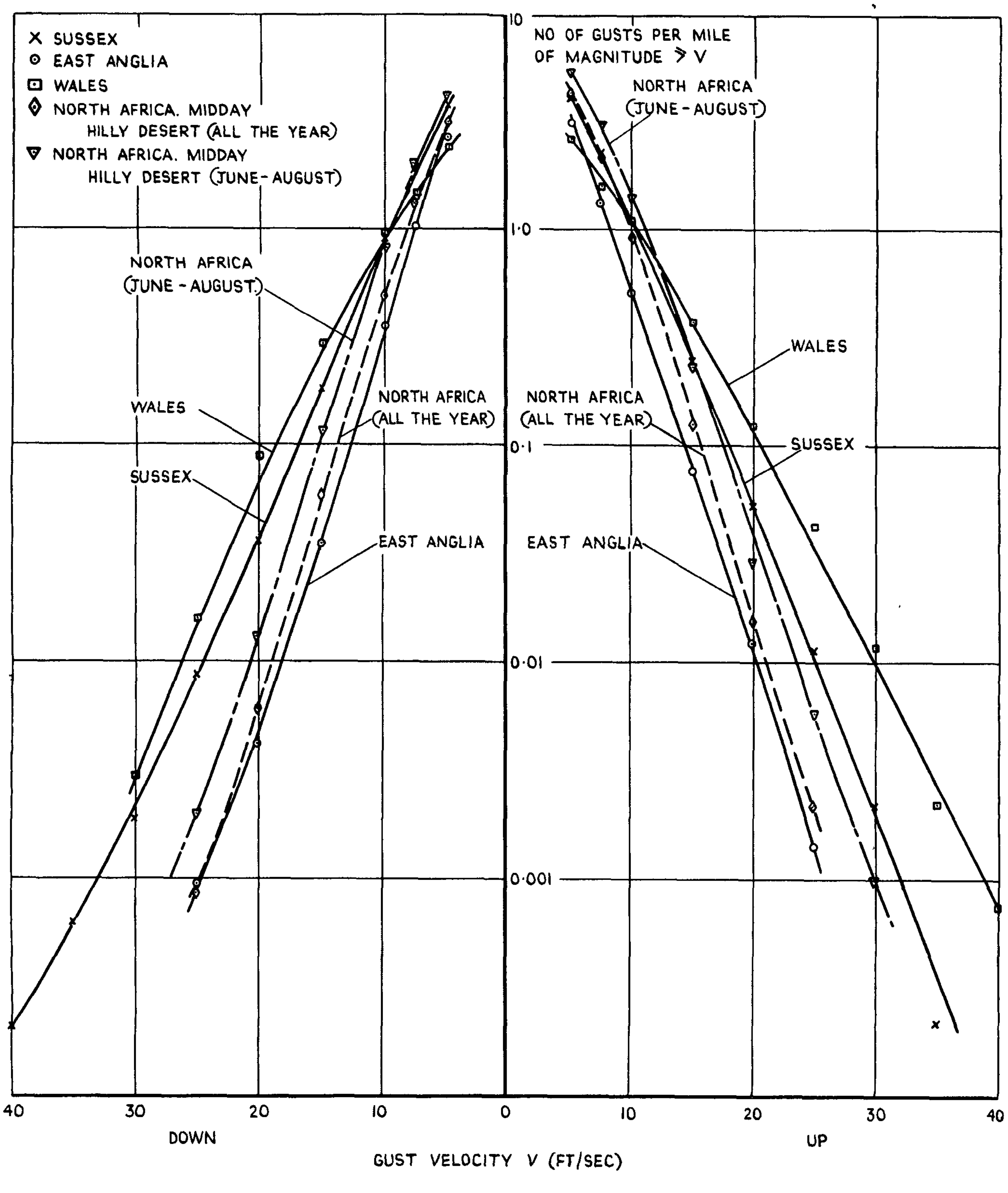

FIG. 13. COMPARISON BETWEEN GUST SPECTRA OBTAINED IN U.K. AND NORTH AFRICA.

A.R.C. C.P. No. 676

551.551:
533.6.015.4

LOW ALTITUDE GUST MEASUREMENTS OVER THREE ROUTES IN THE U.K.
Wells, E.W. October 1962.

A number of flights have been made at low altitude over three routes in the U.K. The routes were in Sussex, East Anglia and Wales. Measurements made with a counting accelerometer have been analysed to investigate the effect of variation in terrain and meteorological conditions on the intensity of turbulence. A comparison has also been made between these flights and flights made at low altitude in North Africa.

A.R.C. C.P. No. 676

551.551:
533.6.015.4

LOW ALTITUDE GUST MEASUREMENTS OVER THREE ROUTES IN THE U.K.
Wells, E.W. October 1962.

A number of flights have been made at low altitude over three routes in the U.K. The routes were in Sussex, East Anglia and Wales. Measurements made with a counting accelerometer have been analysed to investigate the effect of variation in terrain and meteorological conditions on the intensity of turbulence. A comparison has also been made between these flights and flights made at low altitude in North Africa.

A.R.C. C.P. No. 676

551.551:
533.6.015.4

LOW ALTITUDE GUST MEASUREMENTS OVER THREE ROUTES IN THE U.K.
Wells, E.W. October 1962.

A number of flights have been made at low altitude over three routes in the U.K. The routes were in Sussex, East Anglia and Wales. Measurements made with a counting accelerometer have been analysed to investigate the effect of variation in terrain and meteorological conditions on the intensity of turbulence. A comparison has also been made between these flights and flights made at low altitude in North Africa.

C.P. No. 676

Published by
HER MAJESTY'S STATIONERY OFFICE
To be purchased from
York House, Kingsway, London, W.C.2
423 Oxford Street, London, W.1
13A Castle Street, Edinburgh 2
109 St. Mary Street, Cardiff
39 King Street, Manchester 2
50 Fairfax Street, Bristol 1
35 Smallbrook, Ringway, Birmingham 5
80 Chichester Street, Belfast 1
or through any bookseller

C.P. No. 676

K.Ltd.

S.O. Code No. 23-9013-76.