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THE EXPOSURE OF THE ANEMOMETERS AT ABERDEEN

By G. A. CLARKE

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By G. A. Clarke

Introductory.—In common with the practice at the other observatories of the Meteorological Office the values of wind speed and direction at Aberdeen were obtained originally from the records made by the Robinson-Beckley cup anemograph mounted above the roof of the main observatory tower.

In 1907 a Dines pressure tube anemometer was mounted on the main tower roof about 7 ft. north of the cup anemograph, the height of its vane above this roof being 50 ft.—some 29 ft. higher than the cups of the Robinson-Beckley instrument. This pressure tube anemometer remained on the roof till 1920 when it was dismantled.

In September 1923 a new pressure tube anemometer of standard pattern and height was erected in Ladymill field, about a quarter of a mile due east from the Observatory, in a relatively open position, and the records obtained initially showed that the exposure of this instrument was much better than that of the cup anemograph on the tower. Some five years after its installation however the municipal authorities commenced operations on the north side on a rather large building scheme, which soon began to affect the exposure.

On April 1 1933 the instrument at Ladymill was dismantled, and a new pressure tube anemometer installed on Glebe Hill to the north-west of the Observatory, the only open piece of ground available within reasonable reach of the Observatory. Records obtained at this new site proved to be inferior to those obtained originally at Ladymill, but reasonably comparable with those made by the cup anemograph on the Observatory tower, except in the case of winds coming from 35° to 115°, that is, over the buildings in the High Street of Old Aberdeen.

The Topography of the Neighbourhood.—Fig. 1 is a map which has been drawn by making use of such bench-marks as are available on the six-inch ordnance survey map of the district, and filling in the contour lines smoothly to indicate the general character of the various gradients.

Bordering the seashore on the east is a continuous line of dunes rising on an average about 20 ft. above mean sea level, and along the top of these dunes runs a broad " promenade " road. Within this dune-belt the ground level sinks again in places to about 10 ft. above mean sea level and then rises gradually westward towards the Observatory. The effect of the presence of the dune-belt is strongly evidenced during easterly winds by the increase of horizontal wind velocity at the crest of the dunes and the presence of an upward component on the seaward side as described by Georgii and others(1)*. The landward slope of the dunes is more gentle than the seaward

* The numbers in brackets refer to the bibliography on p. 23.

one, and, with winds not exceeding force 4 on the Beaufort Scale, the air movements on the landward slope are usually more variable and much lighter in force, sometimes nearly stagnant, though a leeward stationary eddy is extremely rare. Beyond the influence of the dune-belt the easterly wind flows up the gentle slope towards Ladymill Field with somewhat diminished speed compared with that experienced on the shore, but with greater steadiness than characterises winds from other directions.

To the west of King's College the ground rises much more rapidly to a ridge running in a general north and south direction, and reaches the 200 ft. contour level at a distance of about 1,500 yds. from the Observatory. A general height of 500 ft. is reached about 5 miles from the Observatory, and culminates there in a north-south line of detached heights from 700 to 900 ft. high. About 600 yds. south-west from the Observatory a spur of high ground reaching heights of 80 to 110 ft. in places is thrown off from the main ridge in an east-south-east direction and terminates rather steeply about 300 yds. from the coastline in a hill 95 ft. high.

Northward from the Observatory the river Don runs through a small gorge, the southern bank of which is about 100 ft. high in one small eminence. On the north bank the ground in this region is generally high.

There is therefore a tendency for winds from the west to flow over the high ground as well as along the river valley, and the convergence of the air streams produces occasionally some interesting effects. A long spell of strong dry winds from the east usually blows large quantities of sand from the beach over the dune-belt and deposits it on the lee side of the dunes. On one occasion such a spell of east wind was followed by a strong westerly wind, and it was observed that the westerly wind was blowing the drifted sand back to the beach in a series of small sandstorms in a rather curious manner. At one period there would be two sandstorms blowing simultaneously, one at the northern end of the dune-belt near the river estuary, the second a little to the north of the end of the spur of high ground already referred to, the separation between the two storms being about 1 mile. These sandstorms lasted for periods of from 5 to 10 minutes and then died down. As they did so they were followed by one similar sandstorm situated about halfway between the previous pair and about due east from the Observatory. When this storm in its turn died away, the two previous storms recommenced almost simultaneously, and this process continued during the afternoon. The sandstorms rendered visible a local and temporary strengthening of the wind which must have been the result of local convergence of air streams.

The Distribution of Built-up Areas in the neighbourhood of the Anemometer.—Fig. 2 showing built-up areas is drawn on the same scale as Fig. 1. A mean height of 30 ft. has been arbitrarily chosen to represent buildings of all types, the object being to show approximately how the heights of these buildings, when superposed upon the ground contours, compare with the height (120 ft:) of the anemometer vane above mean sea level. Built-up areas exceed this height over a large region to the south and west of all the anemometer sites. In the small area comprised within the dotted line AB, north-east of the enclosure, several buildings exist whose tops come to within 10 ft. of the height of the anemometer vane. Groups and lines of trees and bushes which might fairly be regarded as extensions of the built-up areas, are indicated by dots.

Two built-up areas, marked X and Y in the north-east quadrant of the map call for special remark. That marked X is the site of the municipal building scheme, which so seriously affected the exposure at Ladymill, while that at Y shows a later extension commenced about the time of completion of the X area, and continued long after the removal of the anemometer to the Glebe.

Detailed Description of the various Sites.—(a) *Observatory*—The cup anemograph is mounted on the top of a small circular tower rising above the main tower wherein the Observatory is situated. This main tower, called the Cromwell Tower, is almost centrally situated among the various buildings of the College as may be seen by reference to Fig. 2. Details of the immediate surrounds of the anemometer are shown in Fig. 3. The height of the main tower roof above ground is 54 ft., that of the low parapet of the small tower at its south-western corner 64 ft., that of the top of the circular tower 68 ft. and that of the cups themselves 75 ft. In the areas marked B round the main tower, groups of from three to five chimney-stacks rise to a height which brings their tops to about 9 ft. below the level of the cups, while their shortest distances away are about 12 ft. and 15 ft. to the south and north respectively. The telescope domes on the small tower are about 8 ft. below the level of the cups. The heights of the surrounding buildings of the College range between 30 and 50 ft. except in the case of the Crown Tower which lies about 120 ft. due west from the anemograph and whose ornamental summit has a height of approximately 80 ft., i.e., slightly higher than the anemograph cups.

The position of the Robinson anemograph is therefore by no means ideal; its mean clearance above the surrounding buildings may be taken as not more than 20 ft., while the hollow rectangular construction of the College must give rise to extremely turbulent air flow. This is continually in evidence when pilot balloons are released from the top of the main tower, their movements for a substantial part of their first minute being very erratic. In one extreme case a balloon having a velocity of ascent of 500 ft. per minute, when released in a SSE. wind, was swept down 50 ft., in a series of eddies, from the main tower to the ground on the north for a distance of 150 ft. before being carried up with greatly accelerated speed.

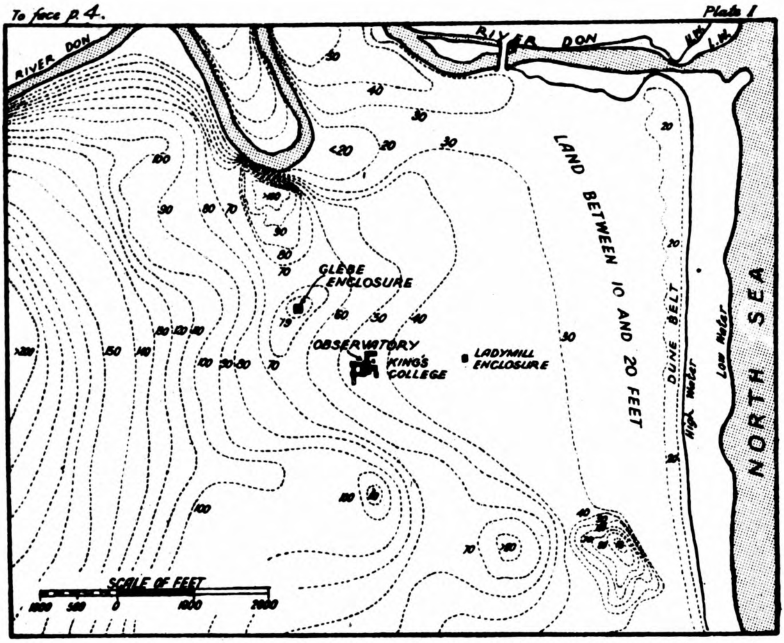


FIG. I. MAP SHOWING APPROXIMATE 10ft. CONTOURS from 30ft. upwards.

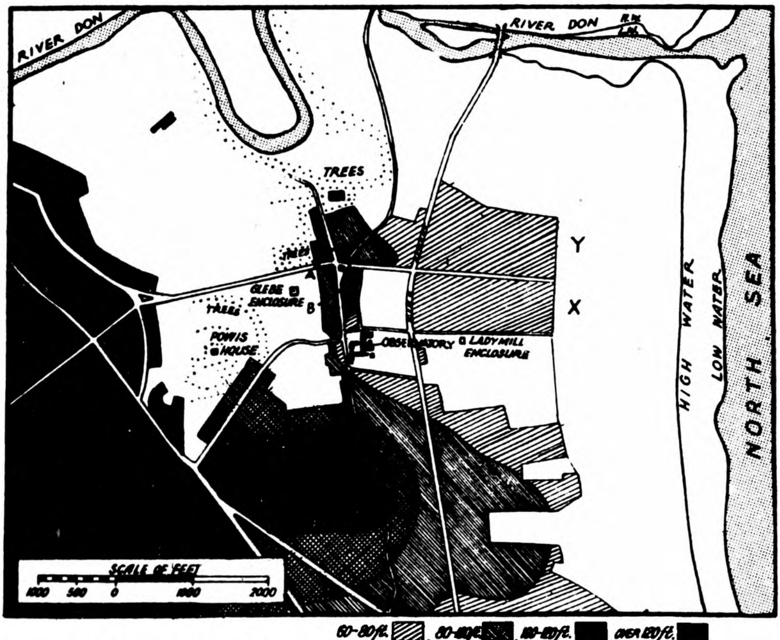


FIG. 2. BUILT-UP AREA SURROUNDING OBSERVATORY

Additional evidence of turbulence was discovered in another manner. As originally designed, the recording of direction in the Robinson anemograph was done by means of a fan-wheel vane travelling by worm-gearing round a stationary toothed circle. With this arrangement the direction trace showed as a comparatively narrow ribbon on the chart. In the course of time the teeth of both worm-gearing and stationary toothed circles became worn away, and the vane ceased to function properly. The fan wheels were removed, and in their place a rod about 2½ ft. long fitted at its outer end with a thin metal plate, somewhat after the pattern of the head of the pressure tube anemometer, was fitted to the instrument. This arrangement was of course more sensitive to changes of wind and direction. In the sector 310° to 360° and more especially in strong winds, the vane frequently turned through the full circle (or " boxed

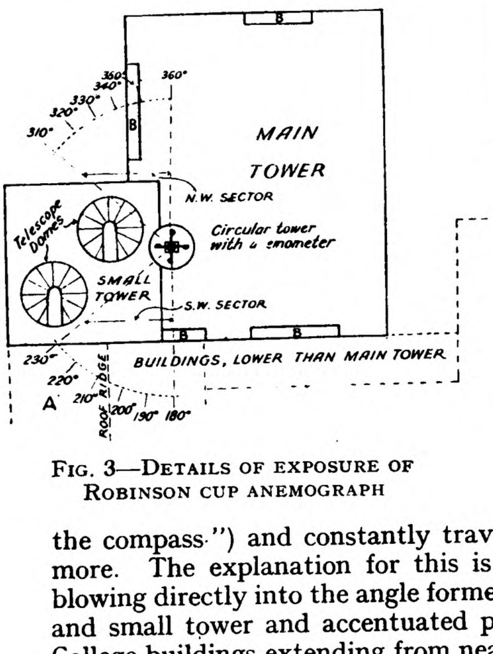


FIG. 3—DETAILS OF EXPOSURE OF ROBINSON CUP ANEMOGRAPH

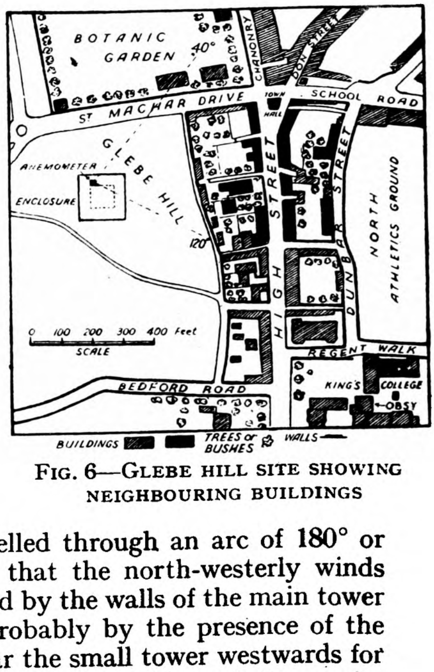


FIG. 6—GLEBE HILL SITE SHOWING NEIGHBOURING BUILDINGS

the compass ") and constantly travelled through an arc of 180° or more. The explanation for this is that the north-westerly winds blowing directly into the angle formed by the walls of the main tower and small tower and accentuated probably by the presence of the College buildings extending from near the small tower westwards for over 100 ft., are forced to escape upwards from this angle in a series of large spiral eddies round a vertical axis. The direction of maximum eddying seems to be 340° where the presence of one large group of chimney-stacks forms an additional obstruction to the free flow of the wind.

In the sector 180° to 230° the vane showed a general oscillation of about 180° with frequent extensions to 270° and occasional complete turns through the full circle; these last were fewer than those experienced in the north-west sector. In the south-west sector winds have crossed an east to west line of the College buildings lying to the southward, and before they reach the anemograph they are partly deflected up the westerly slope of the College Library roof (marked "A" in. Fig. 3), whose ridge is only 23 ft. below the cups. This deflection together with the effect produced by the sheer face of the small tower for an additional 12 ft., must give rise to eddies similar to, though perhaps not so large as, those formed in the north-west sector. In the south-west sector the eddy effect appears to be greatest between 210° and 230°.

(b) *Ladymill*—When the pressure tube anemometer was erected here this site was a very open one. The total height of ground and

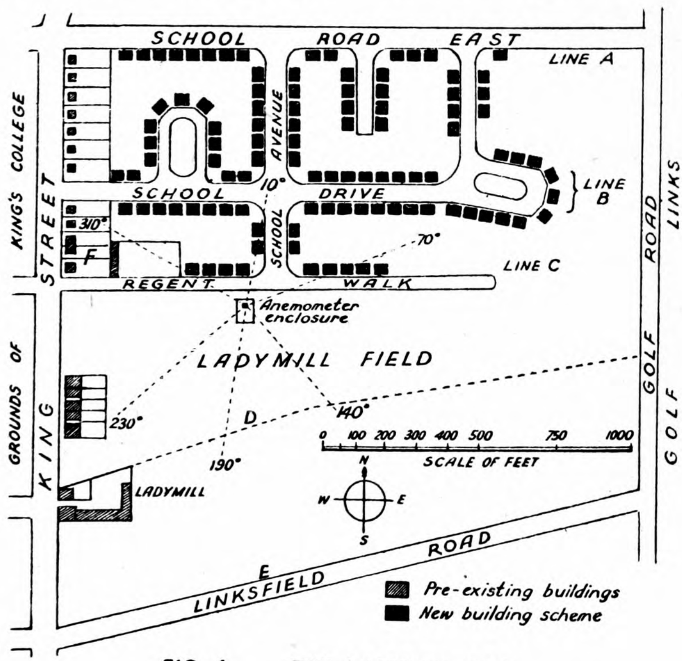


FIG. 4. THE LADYMILL SITE

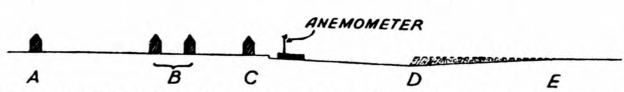


FIG. 5. LADYMILL SITE *from* A *to* E. *Vertical scale twice actual – horizontal scale same as in Fig. 4. Stippled area shows earth ramp progressing northward.*

obstruction to the north was about the same height as that of the roof ridge of the anemometer hut, and did not alter the "effective height" of the anemometer to any marked extent from the standard value of 33 ft. Southwards from the anemometer the open field gradually sloped downwards to the point marked D in Fig. 4, where it was about 12 ft. below the level of the ground to the north of Regent Walk, and from this point D it rose gradually again to the surrounding general level at E.

Simultaneously with the development of the building site to the north of the anemometer the ground between D and E was being used as a rubbish tip by the town authorities in order to bring this ground up to the general level, with the result that, by the time the building scheme was completed, there existed a little to the south of D a slope of 45° whose height varied between 10 and 15 ft. and whose nearest approach to the anemometer was 400 ft. This earth bank lay within the sector 140°–190°, and its possible effect on the exposure is referred to later in this discussion.

A cross section of the ground from A to E after the completion of the buildings on the north and the final approach of the ramp on the south is shown in Fig. 5. The height of the anemometer vane (42 ft. above ground) was approximately only 3 ft. above the roofs of the row of houses immediately to the north of it.

(c) *Glebe Hill*—Fig. 6 shows the present site. The field is an isolated eminence between the general contours of 60 and 70 ft. and the height of its summit is about 80 ft. The slope is steadily upwards from south-east, but westwards, just before the rapid rise in the ground level occurs, there exists a sharp dip to below the 70-foot level and there are trees beyond the dip. Southward the immediate exposure is much better, though, farther away, the main part of the city is situated. To the east the exposure is seriously obstructed by the buildings along the main thoroughfares of Old Aberdeen. At their nearest approach these buildings come to within 350 ft. of the anemometer. The obstruction to the east is fairly continuous and differs considerably in this respect from that existing to the north at Ladymill, where the houses are spaced apart so that some of the air can flow round and between them instead of being compelled entirely to surmount them as is the case at Glebe Hill.

The anemometer vane is 121 ft. above M.S.L. In Fig. 6 the solid black areas show where higher and more massive buildings exist, whose roof ridges are within about 10 ft. of the height of the anemometer vane. (In Fig. 2 this area is very roughly indicated by the dotted line AB). Within the shaded areas tops of the buildings are at least 20 ft. below the vane. After the installation of the anemometer on Glebe Hill it soon became evident that easterly winds were not being recorded satisfactorily, the greatest deficiency being shown in the sector 40° to 110°. This sector is indicated within dotted lines in Fig. 6. and it includes the area of high buildings referred to above.

Tests of the air flow from various directions round Glebe Hill were carried out and are described subsequently in this note.

Comparison of the values of Wind Velocity as recorded at the three Sites.—After the pressure tube anemometer at Ladymill had been in operation for two years a comparison between the velocities recorded there, and those shown by the cup anemograph on the Observatory roof, indicated that the Ladymill exposure was very much the better in all winds. After the new anemometer at the

Glebe site had been recording for a sufficient time, a similar comparison was made between its recorded values and those from the cup anemograph. These two sets of values showed much closer agreement, and it was therefore clear that the exposure at the Glebe site was definitely inferior to that at Ladymill before the latter site had been adversely affected by the building schemes. In Fig. 7 the values given by the cup anemograph are taken as a standard of reference for the comparisons and are shown by the full circle,

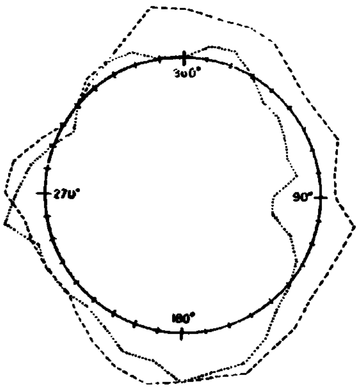


FIG. 7

WIND VELOCITIES AT LADYMILL AND GLEBE HILL AS COMPARED WITH THOSE RECORDED AT THE OBSERVATORY

At Ladymill site- - - - - -

At Glebe Hill site ....

The velocities of winds from the different directions as recorded by the cup anemograph on the Observatory roof are indicated by the full circle.

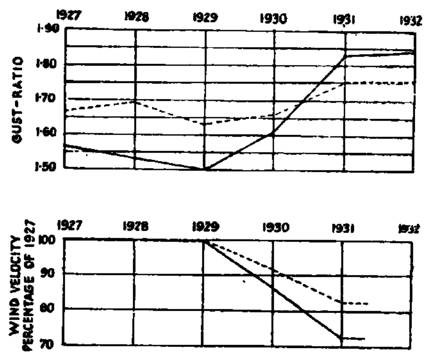


FIG. 8

INCREASE OF GUST RATIO AND DECREASE OF MEAN WIND VELOCITY AT LADYMILL, 1927–33

(The wind velocity is expressed as a percentage of the 1927 value.)

Northern Sectors (310°–80°) ———

Southern Sectors (140°–230°) - - - -

while the comparative values recorded at Ladymill and Glebe Hill are shown by irregular broken lines. From the diagram the following conclusions may be drawn :—

(1) The exposure of the cup anemograph at the Observatory is not satisfactory to the west and south, presumably as a result of its situation at the north-eastern angle of a hollow quadrangular structure.

(2) The exposures towards the north at both the Observatory and Glebe Hill are adversely affected presumably by the irregular topography in that direction and the buildings existing there.

(3) The Glebe Hill exposure is seriously affected in the sector 40° to 110° inclusive. There is abundant evidence that the lines of houses along High Street of Old Aberdeen produce excessive turbulence in the air flow within this sector and that the turbulence reaches well beyond and well above the anemometer vane.

In view of the fact that none of the three sites has a perfect exposure it is not possible, from direct comparison of the velocities recorded at these sites, to estimate the degree of obstruction to the wind from the various directions at each of the sites. But the fact that it was possible to compare the values recorded at Ladymill with those recorded at Glebe Hill through the medium of the cup anemograph values recorded at the Observatory suggested another approach to the problem.

If we assume the gust ratio G/H (i.e., the ratio of the velocity of the highest gust during any hour to the mean velocity for that hour) to be indicative of the degree of turbulence produced by obstacles there ought to exist some relation between this gust ratio and the recorded wind velocity from any specified direction. To test this assumption the gust ratios for each 10° of direction were calculated over a sufficient period at both the Ladymill and the Glebe sites. The anemometer at Ladymill was provided with pressure and suction pipes of only ½-inch diameter while that at the Glebe has 1-inch pipes; the Ladymill gust-ratio values have been increased by 12 per cent. for the purposes of comparison.

In Table I the values of G/H at the two sites for each 10° of azimuth are shown, together with the ratio of the Glebe values to those at Ladymill. All the values of G/H were smoothed by Bloxam's formula $(A + 2B + C)/4$ before entry.

TABLE I.—SMOOTHED VALUES OF G/H (GUST RATIO) AT GLEBE HILL AND LADYMILL

Wind direction, degrees from N.	B (at Glebe Hill)	A (at Ladymill)	$\frac{B}{A}$	Wind direction, degrees from N.	B (at Glebe Hill)	A (at Ladymill)	$\frac{B}{A}$
°				°			
10	2·23	1·80	1·24	190	2·07	1·93	1·08
20	2·19	1·79	1·22	200	2·15	1·91	1·13
30	2·17	1·68	1·29	210	2·16	1·90	1·14
40	2·16	1·59	1·36	220	2·16	1·96	1·10
50	2·11	1·59	1·33	230	2·13	2·06	1·03
60	2·09	1·59	1·31	240	2·11	2·11	1·00
70	2·11	1·62	1·30	250	2·13	2·12	1·01
80	2·07	1·63	1·27	260	2·11	2·11	1·00
90	2·08	1·61	1·30	270	2·12	2·05	1·03
100	2·09	1·57	1·33	280	2·05	2·03	1·01
110	2·05	1·56	1·32	290	2·00	2·00	1·00
120	2·00	1·58	1·27	300	1·95	1·97	0·99
130	1·96	1·60	1·22	310	1·99	2·01	0·99
140	1·96	1·64	1·19	320	2·02	2·04	0·99
150	1·95	1·74	1·12	330	2·04	2·00	1·02
160	1·92	1·80	1·07	340	2·07	1·94	1·07
170	1·94	1·85	1·05	350	2·12	1·89	1·12
180	1·99	1·89	1·05	360	2·19	1·82	1·20

In Table II there are given for the same directions the percentage ratios of the recorded velocities at the two sites, using the cup anemograph velocities as the medium of comparison, the percentages having been smoothed in a similar manner. In the fourth column of Table II is given the ratio of the Ladymill values to the corresponding velocities at the Glebe.

TABLE II.—SMOOTHED VALUES OF 100 × SPEED BY PRESSURE TUBE ANEMOMETER/SPEED BY CUP ANEMOGRAPH AT LADYMILL AND GLEBE HILL

Wind direction, degrees from N.	A (at Ladymill)	B (at Glebe Hill)	A/B	Wind direction, degrees from N.	A (at Ladymill)	B (at Glebe Hill)	A/B
°				°			
10	132	105	1·26	190	136	122	1·11
20	131	104	1·26	200	131	114	1·15
30	127	98	1·29	210	124	108	1·15
40	120	93	1·29	220	115	105	1·10
50	115	89	1·29	230	110	107	1·03
60	116	84	1·38	240	110	109	1·01
70	117	81	1·44	250	112	115	0·97
80	114	79	1·44	260	117	121	0·97
90	115	73	1·58	270	123	115	1·07
100	121	74	1·64	280	121	106	1·14
110	122	85	1·44	290	113	99	1·14
120	119	94	1·27	300	102	96	1·06
130	120	98	1·23	310	102	99	1·03
140	124	103	1·20	320	107	105	1·02
150	129	113	1·14	330	113	111	1·02
160	134	123	1·09	340	122	111	1·10
170	135	128	1·06	350	133	106	1·25
180	135	128	1·06	360	135	104	1·30

Now if the ratio B/A of Table I be compared directly with the ratio A/B of Table II for each direction it will be seen, as shown in Table III, that the differences between the two ratios are, except in certain small sectors, very slight indeed, not exceeding 4 per cent. The excepted sectors are :—

(1) The eastward exposure at Glebe Hill, the sector 40° to 110° already referred to.

(2) The sector 280° to 300° to the west of Glebe Hill.

(3) The sector 350° to 360°, to the north of Glebe Hill.

In the case of (2) there lies near at hand a sharp dip in the land, beyond which the ground again rises fairly steeply. In (3) as the map, Fig. 1, shows, the contours are also irregular and steep at no great distance from the anemometer.

If these three exceptions due to abnormal and close obstructions be disregarded meantime it may be accepted that, at Aberdeen, the value of the gust-ratio G/H and that of the recorded velocity are related to each other in approximately inverse linear proportion. This means that, except in the specified sectors, the highest gusts at the two sites are approximately equal, a matter which will be dealt with again later.

TABLE III.—GUST RATIOS AND VELOCITIES AT LADYMILL (A) AND GLEBE (B)

Wind direction, degrees from N.	Gust-ratios $\frac{B}{A}$	Velocity ratios $\frac{A}{B}$	Per-centage difference	Wind direction, degrees from N.	Gust-ratios $\frac{B}{A}$	Velocity ratios $\frac{A}{B}$	Per-centage difference
°				°			
10	1·24	1·26	2	190	1·08	1·11	3
20	1·22	1·26	4	200	1·13	1·15	2
30	1·29	1·29	0	210	1·14	1·15	1
*40	1·36	1·29	7	220	1·10	1·10	0
*50	1·33	1·29	4	230	1·03	1·03	0
*60	1·31	1·38	7	240	1·00	1·01	1
*70	1·30	1·44	14	250	1·01	0·97	4
*80	1·27	1·44	17	260	1·00	0·97	3
*90	1·30	1·58	28	270	1·03	1·07	4
*100	1·33	1·64	31	*280	1·01	1·14	13
*110	1·32	1·44	12	*290	1·00	1·14	14
120	1·27	1·27	0	*300	0·99	1·06	7
130	1·22	1·23	1	310	0·99	1·03	4
140	1·19	1·20	1	320	0·99	1·02	3
150	1·12	1·14	2	330	1·02	1·02	0
160	1·07	1·09	2	340	1·07	1·10	3
170	1·05	1·06	1	*350	1·12	1·25	13
180	1·05	1·06	1	*360	1·20	1·30	10

* Affected Sectors.

The Effects of the successive changes in the Exposure at Ladymill.—The houses erected under the new building scheme have each about 40 ft. frontage, 30 ft. depth from front to rear, and roofs of a pyramidal form whose tops are between 30 and 35 ft. above the ground level. The houses are separated from each other by intervals of 15 ft. and wide gaps occur at the street corners. The wind is therefore not constrained entirely to surmount the roofs of the houses, it can in considerable measure find its way between the houses, as the anemometer records amply demonstrate. In the summer of 1928 the building scheme was initiated by the commencement of work on the houses along the line A (see Fig. 4). Work progressed slowly southward as far as line B which was completed by July 1930. The final group of houses—those in line C—commenced at the eastward extremity of the line about the same time as line B was completed, and by November 1930 the westward end of line C which included the houses immediately north of the anemometer and very close thereto was well advanced.

The distances of these lines of houses from the anemometer were as follows :—

Line A .. 820 ft.
Line B .. 400 ft. on north side and 320 ft. on south side of the street.
Line C .. 95 ft.

The erection of line A did not have any noticeable effect on the velocities recorded by the anemometer. It was not until the month of July 1930, when line B was being completed that a diminution in the velocities recorded at Ladymill became evident. In November 1930, with the erection of buildings in line C, this effect became intensified.

It is unfortunate that, simultaneously with the building progress at Ladymill, a new wing was being added to the University buildings, embracing the sector 5° to 45°. Its roof was considerably lower than that of the Observatory tower, but its effect upon the recording of wind velocities within that sector by the cup anemograph is not amenable to estimation, and therefore a comparison of the corresponding winds within that sector as recorded by the two anemometers at the Observatory and Ladymill is subject to some uncertainty. This building was completed in 1929, but in view of the differences shown in other northerly sectors, its effect does not seem to have been serious.

An analysis of the velocities recorded at Ladymill as compared with those at the Observatory showed that, following the completion of line B in July 1930, a loss of velocity of from 10 to 15 per cent. occurred there within the northern sector 300° to 70°, and that in November 1930, when the houses of line C nearest to the anemometer were erected, this loss had increased to between 25 and 30 per cent. Simultaneously, in the southern sector 140° to 230°, a loss of velocity of between 5 and 10 per cent. had occurred in July and had increased to between 15 and 20 per cent. in November. After this month no further loss occurred.

These results may now be compared with the changes that took place in the G/H ratio during the same period. In order to obtain a more detailed presentation of the course of events, the northern exposure has been divided into separate sectors which have been chosen with some reference to the successive phases of the building scheme. The G/H values during the periods detailed below are the actual G/H ratios from the anemometer records, and have not been increased by the 12 per cent. as was done in the previous section.

Epoch	Sectors			
	310°–330°	340°–10°	20°–50°	60°–80°
1927 year	1·70	1·65	1·50	1·45
1928 year	1·70	1·55	1·40	1·45
1929 year	1·70	1·60	1·35	1·35
Mean of above 3 years ..	1·70	1·60	1·42	1·42
1930, January–June ..	1·80	1·60	1·50	1·35
1930, July–October.. ..	1·80	1·60	} 1·60	1·35
1930, November–December	1·80	1·95		
1931 year	2·00	1·95	1·80	1·55
1932 year	1·95	2·00	1·85	1·55
Mean of above 2 years ..	1·97	1·97	1·83	1·55

It is clear that during the year 1928—the date of commencement of building—and during 1929, the effect upon the exposure must have been very slight, even if present at all. During these two years, as already stated, the line of houses A was completed, and its absence of effect on the G/H ratio agrees with its absence of effect on the recorded velocities. Early in 1930 a slight increase is shown in the gust ratio in the sector 310°–330° in which sector the building of line B began, but another slight increase is shown in July in sector 20°–50°, while in November a sharper rise is shown in sector 340°—10° immediately to the north of the anemometer when line C was under construction. With the gradual completion of the whole of the buildings, i.e., by the end of 1930 the gust ratio had increased definitely over all sectors but especially between 340° and 50°. Throughout the two succeeding years the ratio remained constant at the higher value.

In discussing the decrease of velocity in the northern sectors reference was made to a simultaneous decrease of velocity in the southern sectors possibly due in some measure to the gradual approach of the ramp from the southward. To decide the probably real cause of the diminished velocities the changes in the gust ratio over the same period in the southerly sectors have been examined. The sectors chosen were 140° to 180° and 190° to 230° because the ramp referred to was confined to the former sector. The results of the examination are set out below :—

Epoch	Sectors	
	140°–180°	190°–230°
1927 year	1·60	1·74
1928 year	1·64	1·73
1929 year	1·59	1·67
Mean of above three years..	1·61	1·71
1930, January–June ..	1·60	1·70
1931 year	1·72	1·79
1932 year	1·69	1·82
Mean of above two years ..	1·71	1·81

It is evident that the increase in gust ratio occurred in both sectors to practically the same degree, and its cause together with that of the decrease in wind velocity was not the encroachment of the ramp but the growth of the buildings to the north of the anemometer.

Taking for the comparison the mean values of G/H and of wind velocity for the combined northern sectors and for the combined southern sectors respectively, the course of the changes over the period under review is shown diagrammatically in Fig. 8 (on p. 8), from which it will be seen that the changes occurring in the southern sectors correspond to those in the northern sectors.

Tests of the Exposure of the Anemometer on the Glebe Hill site.—Acting upon a suggestion made by Mr. E. Gold a series of tests of the flow of air from various directions towards the anemometer on Glebe Hill was carried out during the spring of 1935 on lines resembling those followed at the Lizard by M. J. Thomas (2). The primary object of the tests was to discover whether increasing the height of the anemometer mast would raise the vane out of the region of excessive turbulence produced by the groups of houses to the east of the instrument. At the Lizard this object was achieved satisfactorily by an increase of the height of the mast to 75 ft. above the ground in place of the previous height of 40 ft.

The tests at Aberdeen were made principally by releasing " zero-lift " balloons from various points indicated in Fig. 9 round the anemometer site, and carefully recording their subsequent movements. In addition some other observations were made by the use of tethered balloons of zero lift or of very slight lift.

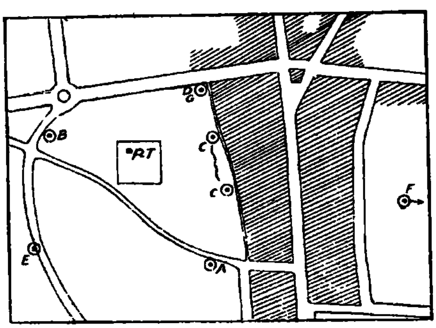


FIG. 9—POINTS WHENCE BALLOONS WERE DESPATCHED DURING TESTS (built-up areas shaded).

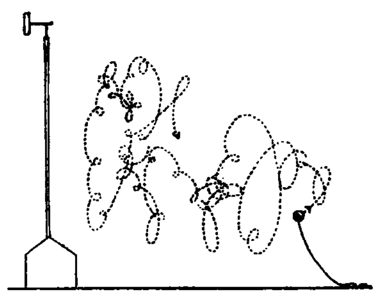


FIG. 10—MOVEMENTS OF TETHERED BALLOON IN ESE. WIND, MARCH 14, 1935.

Test No. 1—March 14 at 15h. Wind from 110° to 130°, 9 m.p.h. (4 m/sec.) ; weather cloudy with stratocumulus layer.

A pilot balloon having a very small lift was tethered by a long string of lint thread within the enclosure close to the anemometer mast, and its movements shown in Fig. 10 bear considerable resemblance to the succession of downward spiral eddies experienced at the Lizard. Another balloon having just over zero lift, was attached by lint thread about 32 ft. long to a point as near the anemometer head as practicable. The position of the balloon varied from about 6 ft. below to 14 ft. above the point of support which represents a variation in the angle of pitch for the wind of over 30°.

Test No. 2—March 15 at 15h. Wind 130°, 16 m.p.h. (7m/sec.) ; weather cloudy but some cumulus cloud present below and increasing.

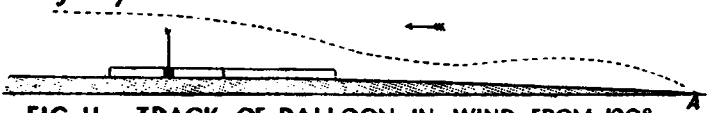


FIG. 11 – TRACK OF BALLOON IN WIND FROM 130°

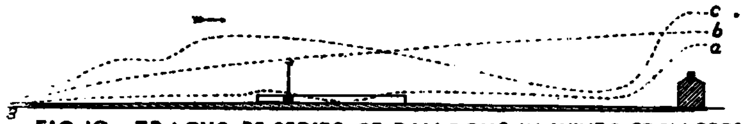


FIG. 12 – TRACKS OF SERIES OF BALLOONS IN WINDS FROM 280°

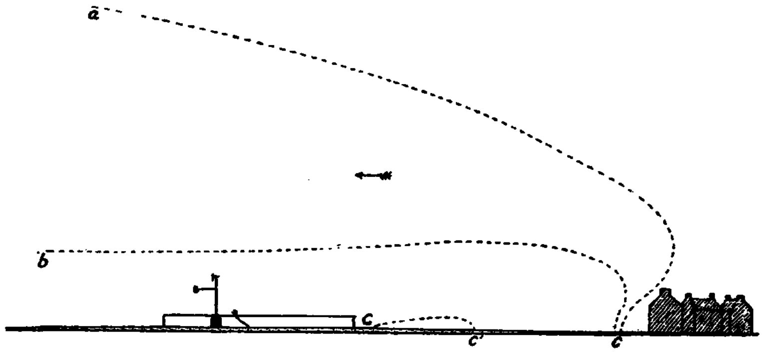


FIG. 13 – TRACKS OF SERIES OF BALLOONS IN WINDS FROM 70°–110°

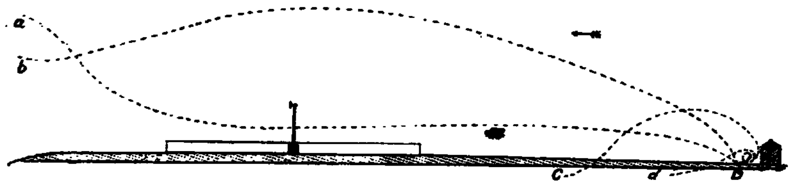


FIG. 14 – TRACKS OF SERIES OF BALLOONS IN WIND FROM 40° *(average)*

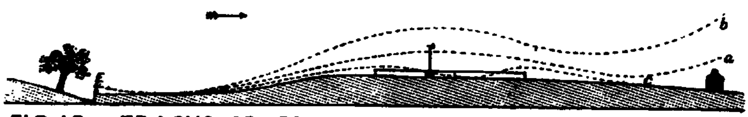


FIG. 16 – TRACKS OF SERIES OF BALLOONS FROM 225°

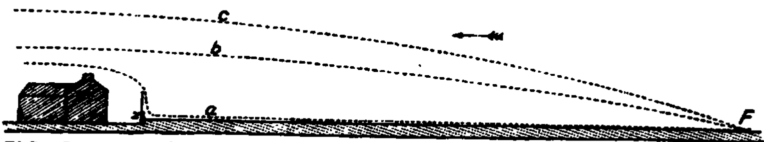


FIG. 19 – TRACKS OF SERIES OF BALLOONS IN WINDS FROM 90°–110°
(Section 1. Starting point to first line of houses)

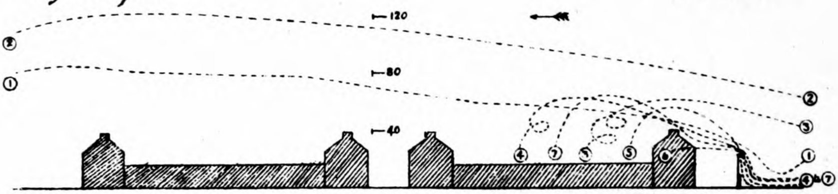


FIG. 20 – TRACKS OF BALLOONS IN WINDS FROM 90°–110°

Section 2a. Crossing buildings during rain. Heights in feet are shown thus: ⊢— 40

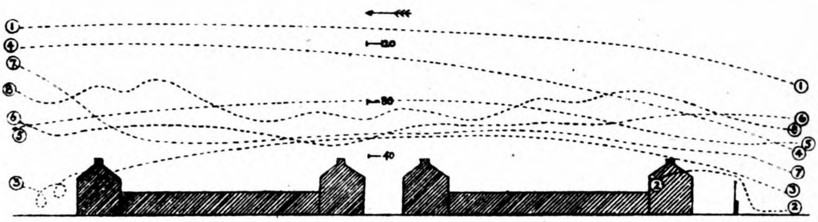


FIG. 21 – TRACKS OF BALLOONS IN WINDS FROM 90°–110°

Section 2b. Crossing buildings, no rain. Heights in feet are shown thus: ⊢— 40

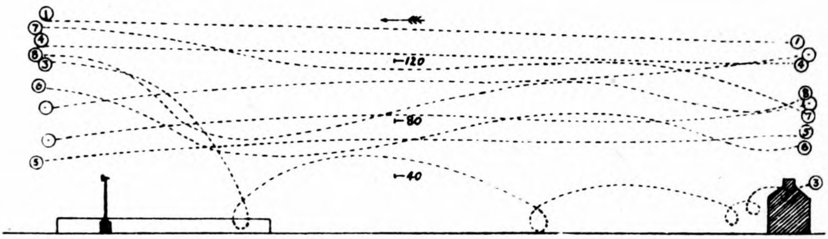


FIG. 22 – TRACKS OF BALLOONS IN WINDS FROM 90°–110°

Section 3. Between buildings and anemometer. Heights in feet are shown thus: ⊢— 40

(NOTE: THE TWO UNNUMBERED BALLOON TRACKS ARE Nos. 1 & 2 OF APRIL 16.)

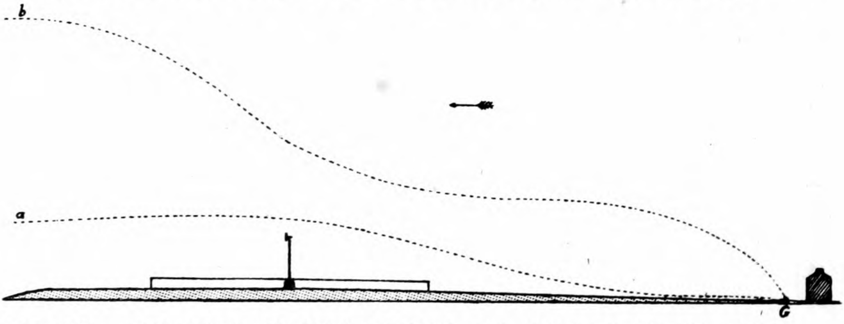


FIG. 23 – TRACKS OF BALLOONS IN WINDS FROM 40°

A zero-lift balloon was released from point A 160 yds. distant from the anemometer. The balloon track, drawn to correct scale in Fig. 11 was smooth throughout, and passed about 10 or 15 ft. above the head of the anemometer.

Test No. 3—March 26 at 11h. Wind 280°, 29–33 m.p.h. (13–15 m/sec.) ; weather fair but rather squally ; sky one-quarter covered with small cumulus.

Seven zero-lift balloons were released, at intervals of approxi mately one minute from point B. All but one passed between the limits *a* and *b* shown in Fig. 12, i.e., between ground level and the head of the anemometer. The one exception pursued the course shown at *c*, passing 20 or 25 ft. above the vane. As the balloons passed over the houses to eastward they were swept violently upwards and crossed the house-tops at heights of from 30 to 60 ft. above them.

Test No. 4—March 29 at 10h. Wind 70°–110°, 4 m.p.h. (2 m/sec.) ; weather cloudy after rain up to 7h., air becoming dry ; cumulonimbus cloud dispersing rapidly, giving place to widespread sheets of altocumulus.

In view of the lightness of the wind the balloons were given a small negative lift in order to ensure that such upward movement as they might show would be due to real air movement. Seven were despatched from the line between the points marked C in Fig. 10. An eighth balloon having a very small lift was tethered within the enclosure. The courses of five balloons despatched from C lay between the limits *a* and *b* in Fig. 13. The general characteristics of their movement were a very slow eddying rise in the lee of the houses, a marked tendency to be drawn eastward until a height above the house roofs of between 20 and 60 ft. had been reached, then a slow ascending course in the easterly wind stream, followed in three cases by a descent and much more rapid velocity as the balloon passed over the top of the anemometer. This passage was made by three balloons at a height above the vane of from 20 to 60 ft , but by two others at upwards of 200 ft. Another balloon, after rising slowly, passed over a wall at about 15 ft. and fell into a garden well to the eastward of its point of release.

Two other balloons were released at a point C about halfway between the eastward houses and the anemometer. These balloons showed only a slow drift. The tethered balloon in the enclosure drifted slowly about, occasionally being lifted a few feet upwards in an eddy and then descending again. It was evident therefore that a comparatively stagnant layer of air lay between the enclosure and the houses and had a depth of from 10 to 15 ft.

After these experiments two balloons were coupled together with a short thread (together they had a zero net lift), and were tethered to the mast at about 12 ft. below the vane, so that they drifted in the air-stream about 10 ft. to the westward of the mast, and their behaviour was observed for about 10 minutes. At times the two balloons circulated round each other rapidly, at others they remained fairly steady. They showed a vertical pitch through an angle of about 20°. Their movements in azimuth were erratic. Very seldom did the directions of vane and tethering thread coincide, divergences of from 15° to 30° were the usual condition and once a difference of nearly 90° occurred. Occasionally as the vane veered in direction the balloons backed, and vice versa. Small-scale turbulence was therefore much in evidence at a height of 25 ft. and upwards from the ground.

Test No. 5—April 8 at 11h. Wind 35°–45°, 21 m.p.h. (9 m/sec); weather cloudy, occasional slight rain, somewhat squally at times; cloud, largely convectional cumulus, cumulonimbus and stratocumulus.

Six zero-lift balloons were released from point D at the north-east corner of the Glebe near the point of convergence of several streets. The air would have to flow partly over the neighbouring houses and partly through the converging streets. It was therefore not surprising that the tracks shown by the individual balloons differed very widely in both vertical and horizontal planes. Four pursued erratic courses between the limits shown by *a* and *b* in Fig. 14, passing more or less over the enclosure, while two were drawn into a feeble leeward eddy somewhat spiral in character along the side of the houses and took courses *c* and *d*. The wide divergence of the six balloon tracks in the horizontal plane is shown in Fig. 15. The further course of the four balloons which passed over the enclosure was interesting.

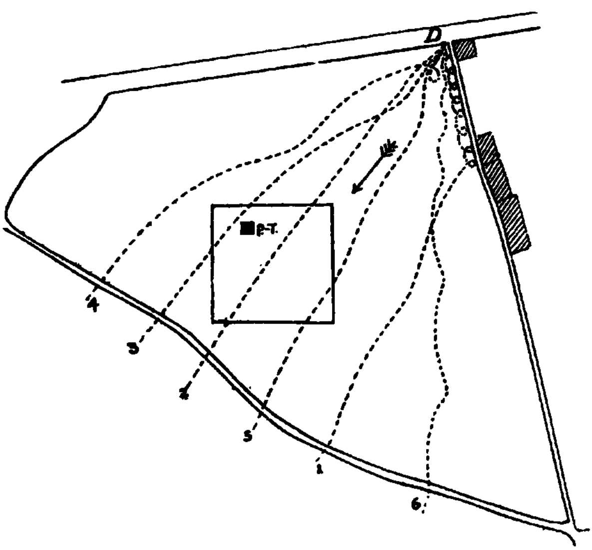


FIG. 15—TRACKS IN THE HORIZONTAL PLANE OF BALLOONS IN WIND FROM 40° (AVERAGE). P.-T. is the anemometer and the numerals attached to the various tracks indicate the order of despatch of the balloons.

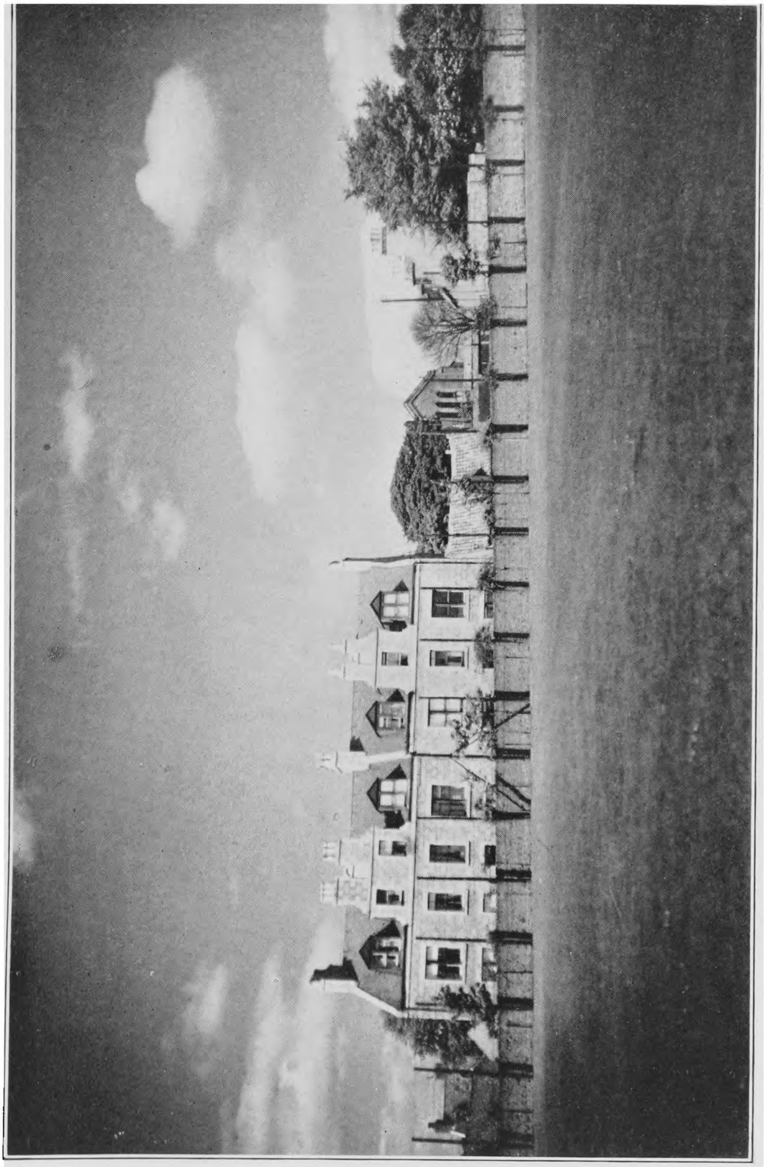


FIG. 17—VIEW OF EAST FRONT OF BUILDINGS AREA (seen from near balloon-despatching point F)

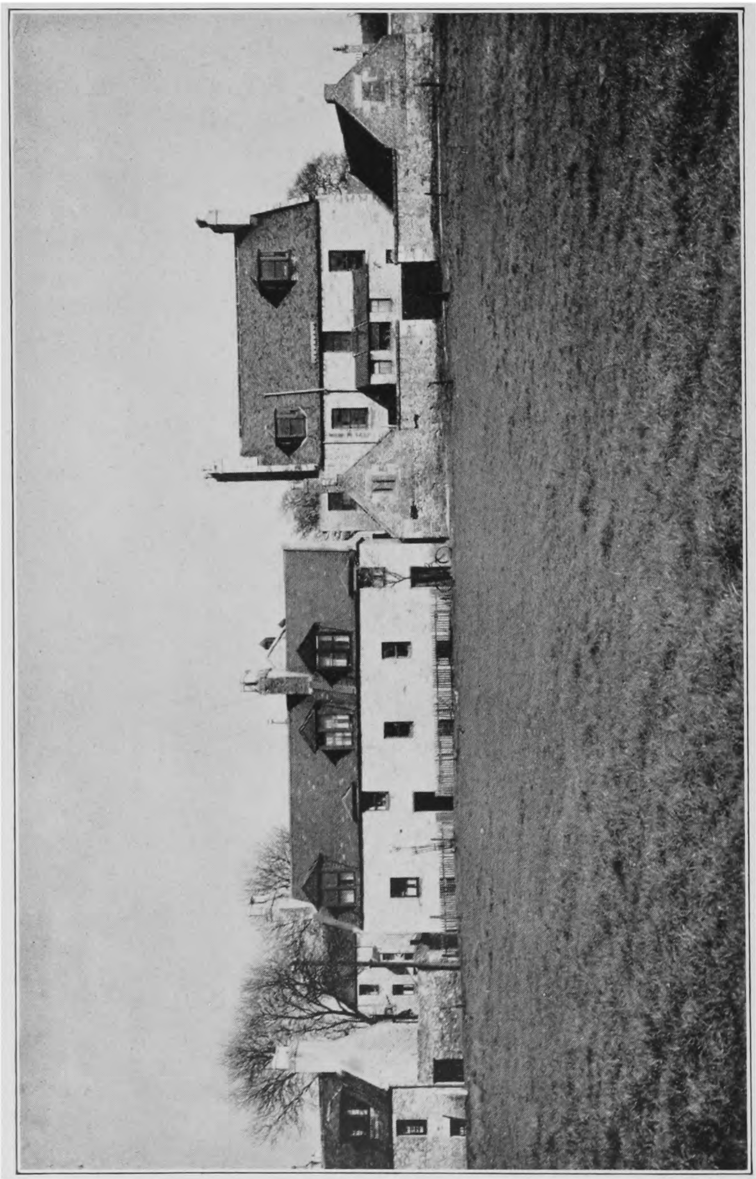


FIG. 18—VIEW OF WEST FRONT OF BUILDINGS AREA (seen from anemometer enclosure)

One became entangled in the trees on the slope of the rising ground to the south-westward and the other three rose rapidly above this rising ground to heights estimated up to as much as 500 ft. Reference to Fig. 1 will at once suggest that the strong vertical component in the motion of the air in this region was the combined result of the fairly steep slope itself and the deflection and consequent forced convergence of the air flow produced by the eastward-extending spur of high ground. To these influences there may also have been added the effect of convection which was demonstrably present that day in the form of cumulonimbus cloud.

Test No. 6—April 10 at 15h. Wind 225°, 21 m.p.h. (9 m/sec.) ; weather cloudy after rain ; some cumulus and stratocumulus below widespread sheet of altostratus.

A series of five zero-lift balloons was released at intervals from point E in Figs. 10 and 16. With one exception the paths lay between the limits *a* and *b* in Fig. 16, i.e., within 10 ft. below and 20 ft. above the head of the anemometer. The fifth balloon travelled almost on the ground all the way up the slope to the enclosure, crossed the fence into the enclosure, where it descended, then rose again over the other fence and came to ground at *c* in the north-east. The other balloons rose up sharply above the houses to the east and north-east of the anemometer to heights estimated to be about 40 ft.

Test No. 7—April 16 at 11h. Wind 100°–110°, 18 m.p.h. (8 m/sec.) ; weather overcast with continuous light rain. April 17 at 15h. Wind 90°, 22 m.p.h. (10 m/sec.) ; weather cloudy after continuous light rain.

The weather conditions on both days were such as to preclude the possibility of convection exercising any effect on the movement of the balloons. Such paths as they travelled may therefore be accepted as due entirely to the turbulence produced by the obstructions over which they travelled. The distribution of the obstructions eastward of the anemometer has been fully described earlier in this paper and illustrated in Fig. 6, and photographs of the actual buildings over which the balloons travelled are shown in Figs. 17 and 18. Of these Fig. 17 gives the eastward-facing buildings towards which the balloons travelled, and which in most cases they surmounted, while Fig. 18 shows the westward side, the nearest to the anemometer.

The balloons were on both days released from a point F the direction of which is shown in Fig. 9, but whose distance to the eastward is greater than can be included in that diagram. The point was roughly 160 yds. east of the wall in front of the houses shown in Fig. 17 and about a quarter of a mile from the anemometer. No comprehensive diagram to scale can therefore usefully be drawn on one chart, but, instead, the paths of the balloons at separate sections of their tracks are given. Fig. 19 (Plate II) gives, correct to scale, a sectional view from the starting point F to the eastward face of the obstruction.

It has been possible roughly to group the paths of the fifteen balloons sent off on the two days into three main divisions with mean paths as at *a*, *b* and *c* in the figure. Of the seven balloons despatched on the 16th when light rain was falling four chose path *a*, climbing almost vertically over the wire netting at x, two chose path *b* and only one path *c*. Next day, with no rain falling the numbers were two, four and two respectively for the eight balloons released on that day. Combining these results the numbers become six, six and three respectively. Thus twelve balloons crossed the initial obstruction within 20 ft. of its summit while in the remaining three cases the clearance was approximately double this distance, i.e., 40 ft.

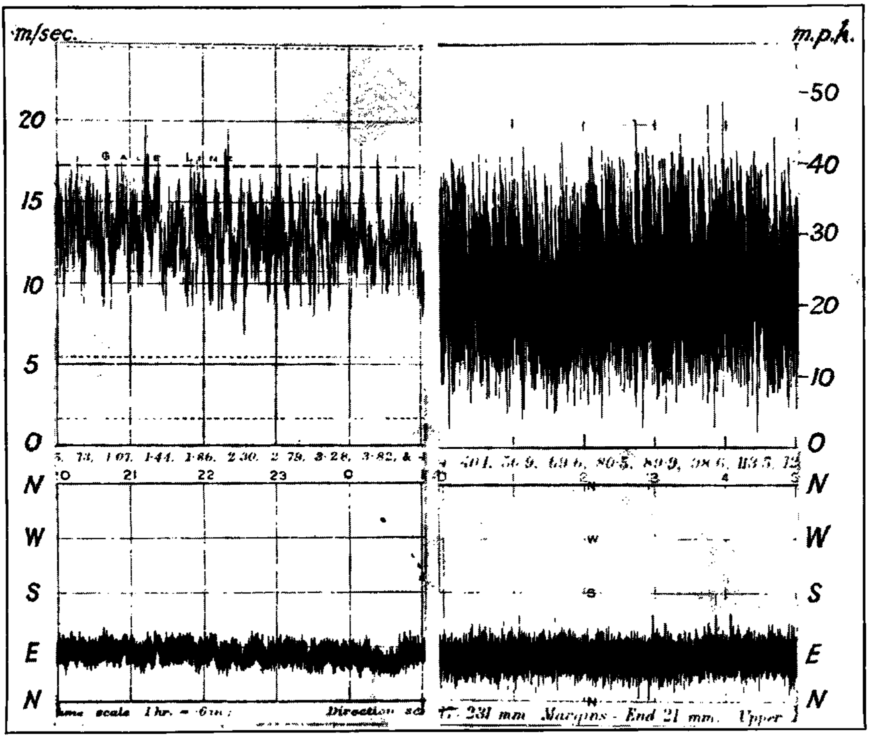
After crossing the initial obstruction the further courses of the balloons were so erratic that they are shown individually in Figs. 20 to 22 (Plate III). Fig. 20 indicates how, on the 16th, four of the balloons were brought down into the maze of buildings (shown only conventionally in the figure) behind the eastward house. One balloon passed round this house and was lost to view, while the remaining two pursued fairly level courses 40 to 80 ft. above the roof-tops. Rain was falling on this day, and the weight of the rain collected by the balloons in their flight may have been a predisposing factor in determining the paths of those which came down within the buildings but it was not the sole cause, for it was observed that the balloons numbered 3 and 4 were drawn down definitely and fairly sharply in spiral eddies.

The experience on the next day—the 17th—when no rain was falling is shown in Fig. 21. One balloon passed between houses, but the remaining seven passed across the whole of the buildings; those whose paths lay within about 40 ft. of the roofs showing marked undulation or irregularity while those which passed at higher levels had relatively smoother paths. The movements of the balloons after crossing the last obstruction are shown in Fig. 22 and refer with two exceptions (unnumbered) to the experience on the 17th. From the tracks shown in this figure it may be inferred that in easterly winds the group of buildings gives rise to very marked eddies in the wind, up to a height of at least 80 ft., and that a relatively smooth flow is not found until a height of about 120 ft. is reached.

The speeds of the balloons were comparatively low (considering the wind velocity) while they were travelling near the ground and approaching the eastward building, but they all swept very rapidly upwards over its roof and thenceforward their speeds remained high well beyond the westerly border of buildings. Considerable variations—sometimes abrupt—in azimuth were observed in their paths after the balloons had crossed the eastward houses.

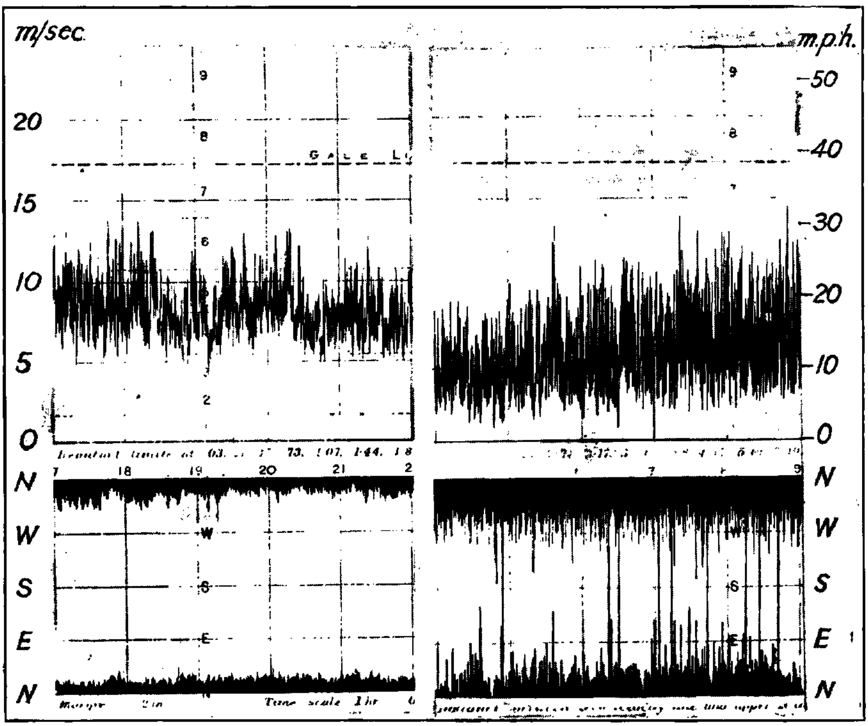
Test No. 8—April 18 at 10h. Wind 40°, 13 m.p.h. (6 m/sec.); weather cloudy with cumulonimbus and stratocumulus cloud.

This test was practically a repetition of that made on April 8, though the wind on the earlier date was rather stronger. Ten balloons with zero lift were despatched at short intervals and their



(a) (b)

FIG. 24—RECORDS OF EASTERLY WINDS AS OBTAINED (a) AT LADYMILL AND (b) AT GLEBE HILL



(a) (b)

FIG. 25—RECORDS OF NORTHERLY WINDS AT LADYMILL (a) BEFORE THE INITIATION OF THE BUILDING SCHEME AND (b) AFTER ITS COMPLETION

paths, except in one case, fell between the boundaries *a* and *b* in Fig. 23 (Plate III). The chief difference between the balloon tracks of the 8th and 18th was that on the 18th all but one converged into a fairly narrow channel just before reaching the anemometer. The speed of the balloons increased sensibly as they neared and passed over the anemometer.

From an examination of the results of the whole series of tests the following conclusions may be drawn.

(1) The proximity of buildings to the anemometer, and the presence of irregularities in the surface of the ground give rise to large scale eddies having horizontal axes, and thereby produce a large amount of vertical movement in the air. Particularly is this the case in winds from between 40° and 110°.

(2) This vertical movement extends to heights above the ground of approximately 60 ft. in winds from SE. and SW., 70 to 80 ft. in winds between N. and NE. increasing to at least 120 ft. in winds from E. Occasionally vertical movement exceeds these limits even in weather conditions unfavourable to thermal convection.

General Discussion.—One of the most striking features of the wind records obtained from the anemometer at Glebe Hill was their difference from those obtained at Ladymill in easterly winds, as shown in Fig. 24. Whereas the excursions made by the velocity pen at Ladymill exhibit the normal character, those at the Glebe are much more violent and much more frequent. The direction ribbon is also considerably widened at the Glebe thus indicating a considerable increase in the general turbulence of the air, but the widening of the direction ribbon is much less conspicuous than is that of the velocity ribbon. It is suggested that the reason for the difference may be found in the violent vertical eddies (i.e., eddies round horizontal axes) produced by the unbroken wall of obstructions to the east of the anemometer. The very irregular paths of the balloons in the tests demonstrated that these vertical eddies were often of large diameter, while the visible fluctuations in the velocities of the balloons would explain the rapid alternations of gust and lull shown by the records.

If the turbulence in easterly winds is predominantly in the vertical plane, it follows that, in addition to the diminution of actual wind speed there will be a further diminution in the recorded wind speed, due to the fact that the anemometer vane, which is free to move in the horizontal plane, is incapable of a similar movement in the vertical plane. The presence of these vertical eddies and the different behaviour of the anemometer vane to the yaw and to the pitch of the wind may therefore account for the lack of agreement in the relation between gust ratio and recorded velocity for easterly winds, which was referred to on p. 10.

A variation of quite a different character was shown by the records of northerly winds at Ladymill before and after the erection of the houses to the north of the anemometer, as shown in Fig. 25.

Here the velocity trace, though definitely more gusty after the completion of the buildings than before, is less affected than the direction trace. The general breadth of this latter was approximately 50° before the building began, but after the completion thereof it increased to 90°, with very frequent oscillations through 135° and occasional traverses through the whole 360°, thus "boxing the compass", as did the vane at the Lizard (2) and also the vane of the cup anemograph at Aberdeen in certain winds. It is therefore obvious that the disturbance created by the buildings at Ladymill took the form partly of vertical eddies over the roofs of houses, and partly also of large scale eddies in the horizontal plane, which latter type of eddy would produce the type of direction record shown in Fig. 25 (*b*). Reference to Fig. 4 will demonstrate how the wind could filter between the houses and more especially through the street whose centre lay approximately at azimuth 10° from the anemometer. It is worthy of remark that, during the examination of wind velocities recorded before and after the erection of the buildings, the smallest decrease of velocity was registered in winds from 10°.

The mean gust-ratio value for the northerly sectors 310°–80° was 1·54 before the erection of the buildings, and had risen to 1·83 afterwards. On the assumption of a linear relationship between the gust ratio and the recorded velocity this would indicate a decrease in velocity of about 16 per cent. Actually the decrease found from the comparison of velocities was greater than this by about 10 per cent. Similarly in the southern sectors 140°–230° the corresponding gust-ratio values of 1·66 and 1·76 indicate a decrease of 6 per cent. whereas the actual decrease was here also about 10 per cent. greater. The reason suggested for these discrepancies is again the very considerable vertical component that must have existed in the motion of the air and to which the vane of the anemometer could not adjust itself. In the northerly sectors the lines of houses must have given rise to eddies round horizontal axes as was the case at the Glebe in easterly winds, while winds from the southerly sectors must have surged upwards over these buildings in somewhat the same manner as did the zero-lift balloons when they approached an obstruction or rising ground (see the various figures referring to the tests).

Georgii (1) has quoted a value of $0 \cdot 3H$ as the height of influence on the flow of the air of an isolated obstacle of height H, and a value up to $4H$ for the height of influence in the case of an infinitely extended obstacle at right angles to the wind. In view of the practically unbroken line of buildings stretching along the High Street of Old Aberdeen this obstruction to the easterly winds at the Glebe may be conveniently regarded as an "infinitely extended obstacle". Assuming this to be so, and taking a mean value of 30 ft. as the height of the houses, trees, etc., along the street, the height of influence might reach up to 120 ft. The tests carried out with zero-lift balloons in such winds gave approximately this value as the height to which the disturbed conditions reached (Test No. 7).

It has not been found possible to form any dependable estimate of the horizontal distance to which the influence of the obstructions extends. The nature of the contours to the westward of the Glebe introduces marked complications into the subsequent movements of the balloons, as the tests showed, but it appeared that turbulence was still present at a distance of at least 700 ft. west of the High Street houses.

With regard to the conditions during the building at Ladymill it appeared, from the fact that no decrease in wind speed was recorded, that the turbulence caused by the line of houses 800 ft. away from the anemometer had died out within that distance. Some slight effects were felt from the lines 300 to 400 ft. distant, though owing to the very irregular manner in which the building proceeded in these lines no emphasis can be laid on this last distance.

Subsequently to the installation of the anemometer at Glebe Hill, a second building scheme was undertaken by the local authorities in the area marked Y in Fig. 2. In order to discover whether these additional buildings produced any modification of the gust ratio recorded at the Glebe, this value was investigated over the years 1933 to 1936, during which period the building scheme was brought to completion. Group Y embraces the sector 50° to 80° and the earlier group X embraces the sector 90° to 110° as seen from the anemometer. The ratio of the value of G/H in sector Y to that in sector X in each of the four years above mentioned showed no appreciable change and it may therefore safely be assumed that the growth of group Y did not further affect adversely the already unsatisfactory exposure of the anemometer in these sectors.

In this investigation considerable use has been made of the gust-ratio value G/H, and the comparative constancy of G as contrasted with H has been commented upon. Table IV includes the values of G (the mean of the highest gust in each month) and H (the mean of the monthly maxima of hourly wind speed) at a number of stations in the British Isles for the period 1933–7. It is at once evident from the table that G varies much less widely than H, even omitting the best exposed stations such as Butt of Lewis and Lerwick, and the worst exposed, e.g., South Kensington and Kew. The

TALLE IV.—MEAN OF MONTHLY MAXIMA OF GUSTS AND MEAN HOURLY SPEEDS 1933–7 (M.P.H.)

	G	H		G	H		G	H
Lerwick	67	44	*Gorleston(4)	52	34	*Manchester(4)	57	35
Kirkwall	63	37	*Felixstowe(4)	51	31	Southport	56	36
*Butt of Lewis(3) ..	69	46	Cardington	55	34	Liverpool	62	35
*Aberdeen(2)	50	25	Shoeburyness	52	36	Holyhead	61	39
Bell Rock	61	45	South Kensington ..	47	20	Sealand..	53	32
Edinburgh	51	31	Kew	49	25	Plymouth	52	37
Tiree	57	38	Croydon	51	30	*The Lizard(3) ..	66	44
*Abbotsinch(4)	56	31	Dover	51	33	Pendennis Castle ..	64	44
Eskdalemuir	58	34	Lympne	55	32	*Dunfanaghy (4) ..	61	39
*Point of Ayre(2) ..	57	39	Calshot	53	35	Aldergrove	52	27
South Shields	54	34	Boscombe Down ..	51	30	Quilty	51	34
Catterick	53	28	Larkhill	52	31	Valentia	61	35
Spurn Head	57	40	Fleetwood	54	37	Scilly	63	43
Cranwell	51	28						

* The means refer to the 5 years 1933–7 except at those stations marked with an asterisk in which cases the number of years used is given in brackets after the station name.

geographical variation of G is shown on the map (Fig. 26). On the west coasts and at Bell Rock, the anemometer with the most open exposure on the east coast, G exceeds 60 m.p.h. ; 55 m.p.h. is also exceeded by a few of the better situated inland stations, and only where the site is sheltered as at Aberdeen does G fall below 52 m.p.h.

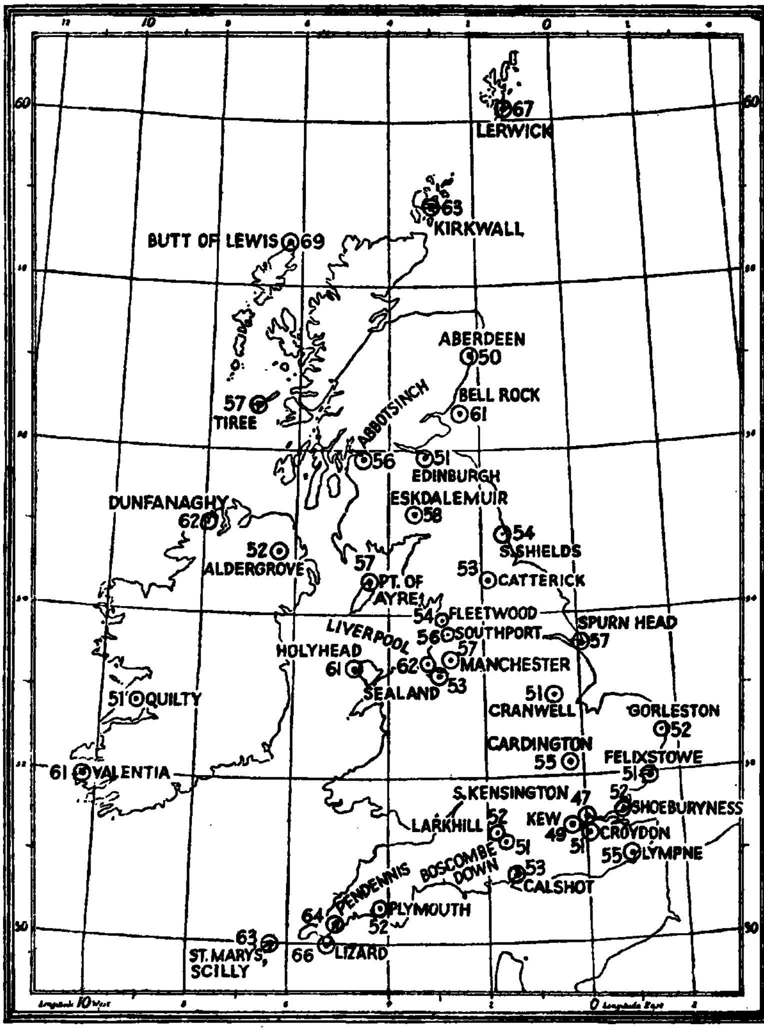


FIG. 26—MEAN OF HIGHEST GUST (M.P.H.) IN EACH MONTH 1933–7

This suggests that, although the mean speed at any station is considerably reduced by nearby buildings, etc., and varies widely with the height of the anemometer above the ground, the highest gusts, and therefore probably all gusts, are affected to a smaller degree. If the gusts are less affected than the hourly speeds by the differences in exposure it is possible to use the fact in tabulating wind records, since the exposure is usually different in different directions. Mean values of the gust ratio can be obtained for, say each 20° of azimuth, and these divided into a standard ratio of 1·4, to give a series of 18 factors. If the speed measured directly from the anemogram be now multiplied by the appropriate factor the product will be the mean speed corrected for exposure. The value of 1·4 for the gust ratio adopted as standard is based on Goldie's analysis of the Bell Rock records (3).

It is also possible to correlate the value of G/H with the Hellmann logarithmic formula for the variation of wind speed with height. Taking a basic G/H value of 1·4 as applicable to the standard height of 33 ft., then the mean G/H value of 2·05 at Aberdeen would give a mean equivalent height of about 1 ft. to the vane of the Aberdeen anemometer, a value 32 ft. below the standard value. Since the buildings and trees in the surrounding town have an average height of at least 30 ft., and since the bulk of the town region stretching between south and west from the anemometer has a height exceeding the height of the vane (see Fig. 2) this value of 1 ft. for the equivalent height may be a not unreasonable estimate.

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