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THE FALL OF HAIL ALONGSIDE CLOUD

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Introduction.—Hail is occasionally encountered by aircraft when flying in clear air alongside a cumulonimbus cloud, so that if hail is to be avoided in flight these clouds should not be approached within a few miles. For supersonic aircraft considerable stresses arise in making the required turns and it is important for their design and operation to know by how much the clouds should be avoided in order to make sure of missing all hail greater than some specified size. There are few observations on the occurrence of hail alongside cloud and none are known to the writer in which the size of hail has been estimated in these circumstances. It is consequently of some interest to calculate the horizontal displacement of hail from the parent cloud, the object being to find how great the displacement can be in favourable conditions. The displacement is attributed to the effects of wind shear as explained in the next section; the calculations follow (p. 34), and finally there is a general discussion including a comparison with observed values (p. 37).

Vertical shear of wind.—It has become recognized within the last few years that the development and maintenance of an intense thundercloud can take place in the presence of a pronounced increase of wind with height[1]. In these conditions, hail formed in the narrow funnel of strong updraught may, on reaching the upper part of the cloud, be carried sideways into the anvil and afterwards fall down through clear air alongside the main tower of cloud.

The thundercloud is known to maintain its existence on occasions for several hours while drifting with the wind but without being appreciably deformed by the shear except in the anvil itself. The cloud is a thermodynamic structure and the updraughts and downdraughts taking place enable its form to remain on the whole unchanged in spite of the variation of wind with height. Alternatively the cloud may be regarded as repeatedly renewing itself as a nearly vertical tower while drifting along with a speed equal to that of the wind at some intermediate level. If this level is denoted by h_1 and if the wind speed increases with height from the ground up to the top of the cloud, the effect of the shear will be to carry hail and other precipitation away from the cloud at heights greater than h_1 while below this height the precipitation would be carried back towards the cloud. The greatest horizontal displacement of hail from the cloud on the downwind side therefore occurs at approximately the height h_1, but a closer estimate will be given later. The distance travelled by hail horizontally relative to the cloud will be calculated on the basis of these simple assumptions. It will be assumed that the wind increases uniformly from a value V_0 at the surface, h_0, to a value V_2 at a height h_2 near the upper part of the cloud. The wind speed at any intermediate height z is then given by

$$V = V_0 + a\,(z - h_0)$$

where a, the vertical shear, is given by

$$a = \frac{V_2 - V_0}{h_2 - h_0}.$$

Further, if the cloud as a whole is moving with speed V_1 equal to that of the wind at height h_1 then the wind speed relative to the cloud at height z is given by

$$V' = V - V_1 = a\,(z - h_1). \qquad \ldots (1)$$

Some information on vertical shear during falls of hail is given by Beck[2] who states that in two out of 24 encounters with hail of diameter 0·5 inch or larger above 20,000 feet, the wind shear exceeded 40 knots through a layer from 10,000 feet to the level of the encounter; also for encounters between 10,000 and 20,000 feet, four out of six cases in clear air were associated with a shear in excess of 50 knots between 10,000 feet and the level of the encounter. In a storm over south-east England on 9 July 1959 discussed by Ludlam[1] the shear was about 70 knots between the surface and 10 km, above which the wind decreased; on this occasion hail of 2 inch diameter was observed at the ground. A uniform shear of 50 m sec^{-1} (100 kt) between the ground and 12 km will be taken as representing a rather large value, but probably not an extreme one, when hail is present; this gives a value of a equal to $4{\cdot}167 \times 10^{-3}$ sec^{-1}. (The value quoted from Ludlam is equivalent to $3{\cdot}6 \times 10^{-3}$ up to 10 km.)

The height h_1 is usually about 3 km, which with the assumed shear implies that the storm system moves at a speed of 25 knots relative to the wind at the surface, a not unreasonable value. The height at which the hail is released from the updraught, h_2, will be taken as 12 km, again a large but not an extreme value, at least for stones up to about 3 cm diameter.

First stage: hail accelerated away from the cloud.—If a hailstone has a horizontal velocity u relative to the cloud, then the wind has velocity $V' - u$ relative to the hailstone. So long as $V' > u$, the stone is being accelerated away from the cloud and its horizontal motion is determined by equation (2) which relates the drag to the product of the mass of the hailstone and its acceleration,

$$\frac{1}{6}\,\pi\, d^3\, \sigma \frac{du}{dt} = \frac{1}{4}\,\pi\, d^2\, \rho\, C_D\, (V' - u)^2, \qquad V' \geqslant u, \qquad \ldots (2)$$

where d is the diameter and σ the density of the hailstone, ρ the air density and C_D the drag coefficient. A similar equation for vertical motion[3] gives an expression for the terminal velocity,

$$v^2 = \frac{2}{3} \cdot \frac{\sigma}{\rho} \cdot \frac{g}{C_D} d, \qquad \ldots (3)$$

by which equation (2) may be written

$$\frac{\mathrm{d}u}{\mathrm{d}t} = \frac{g}{v^2}(V' - u)^2. \qquad \ldots (4)$$

The terminal velocity will be assumed constant for a given diameter, so that if z is the height reached at time t after falling from the level h_2, then

$$h_2 - z = vt. \qquad \ldots (5)$$

On substituting for V' from equation (1) and for z from equation (5), equation (4) becomes

$$\frac{\mathrm{d}u}{\mathrm{d}t} = \frac{g}{v^2}[a(h_2 - h_1 - vt) - u]^2.$$

Write $\xi = a\,(h_2 - h_1 - vt) - u$

then

$$\frac{\mathrm{d}\xi}{\mathrm{d}t} + \frac{g}{v^2}\xi^2 = -av \qquad \ldots (6)$$

the solution of which is

$$\xi = \frac{av}{k}\tan\,(A - kt), \quad k = \sqrt{\frac{ag}{v}} \qquad \ldots (7)$$

where A is an arbitrary constant. Therefore

$$u = a\,(h_2 - h_1) - avt - \frac{av}{k}\tan\,(A - kt). \qquad \ldots (8)$$

Initially the hailstone is considered to be moving horizontally with the speed of the cloud so that

$$\tan A = (h_2 - h_1)\frac{k}{v}. \qquad \ldots (9)$$

ξ is the horizontal velocity of the air relative to that of the hailstone and equation (6) applies only while $\xi \geqslant 0$. From equation (7), ξ becomes zero at time A/k, a time which (on the assumptions made) is found to vary from about 30 to 50 seconds according to the diameter of the hailstone. The horizontal displacement (x') from the cloud at this time is obtained by integration of equation (8),

$$x' = \int_0^{A/k} u\mathrm{d}t = a\,(h_2 - h_1)\frac{A}{k} - \frac{1}{2}av\frac{A^2}{k^2} + \frac{av}{k^2}\log_e \cos A \qquad \ldots (10)$$

and the corresponding height ζ is given by

$$\zeta = h_2 - \frac{vA}{k}. \qquad \ldots (11)$$

The terminal velocity is calculated from equation (3) for stones of diameter 1, 2, 4, 6 and 8 cm. C_D is about 0·6 for these diameters[4]. σ is taken as 0·9, ρ is for a first approximation given its value at 12 km in the international standard atmosphere, k is given by equation (7) and A by equation (9). The estimated distance fallen in the whole of this stage, vA/k, is found to vary from about $\frac{1}{2}$ km for hail of diameter 1 cm, to 2 km for hail of diameter 8 cm. A second approximation is then obtained by using a value of v appropriate to the mean height $(h_2 - Av/2k)$ obtained from the first approximation. The relevant data and results are given in Table I.

TABLE I—FALL OF HAIL IN FIRST STAGE

Diameter, d cm	1	2	4	6	8
Air density, $\rho \times 10^6$ gm cm^{-3} ..	325	335	350	364	373
Fall-velocity, v cm sec^{-1} ..	1740	2420	3350	4020	4590
Displacement, x' km	1·0	1·1	1·2	1·2	1·2
Final height, ζ km	11·5	11·1	10·6	10·2	9·9

An alternative procedure would have been to assume that the hail starts to fall from rest at height h_2. This reduces the average velocity in the first stage by 5 to 10 per cent according to the diameter of the hail, and it also makes a slight reduction in the depth of this stage. After pursuing the calculations through the second stage, the result is to increase the total horizontal displacement as given in the last line of Table II by 0·1 to 0·2 km, an amount which is hardly significant.

Second stage: hail accelerated towards the cloud.—In the second stage the hail falls through air moving horizontally more slowly than the hail itself. Although the hail is still moving away from the cloud, the horizontal drag is now towards the cloud. The sign of the right-hand sides of equations (2) and (4) needs to be reversed to represent these conditions, giving

$$\frac{\mathrm{d}u}{\mathrm{d}t} = -\frac{g}{v^2}(u - V')^2, \quad V' \leqslant u. \qquad \ldots (12)$$

In this stage t will be measured from the time of passing through the level ζ, so that we now write

$$\xi = u - V' = u - a(\zeta - vt - h_1)$$

whence equation (12) becomes

$$\frac{\mathrm{d}\xi}{\mathrm{d}t} + \frac{g}{v^2}\xi^2 = av. \qquad \ldots (13)$$

The solution is

$$\xi = \frac{av}{k} \cdot \frac{Be^{2kt} - 1}{Be^{2kt} + 1}$$

where k is as defined previously (equation (7)) and B is an arbitrary constant. At $t = 0$, $\xi = 0$, hence $B = 1$ and

$$\xi = \frac{av}{k} \tanh kt.$$

Therefore
$$u = a(\zeta - vt - h_1) + \frac{av}{k} \tanh kt \qquad \ldots (14)$$

and the contribution (x'') to the horizontal displacement after time t in this stage is given by integration of equation (14),

$$x'' = a(\zeta - h_1)t - \tfrac{1}{2}avt^2 + \frac{av}{k}\log_e \cosh kt. \qquad \ldots (15)$$

The greatest horizontal displacement from the cloud occurs when the relative velocity u vanishes. At this point t is large enough to make tanh kt practically unity, hence from equation (14)

$$t = \frac{\zeta - h_1}{v} + \frac{1}{k}. \qquad \ldots (16)$$

This shows that the hailstone continues to move away from the cloud for a time $1/k$ after falling through the level h_1, below which the relative wind is towards the cloud. The duration of the part of the fall below h_1 amounts to about 20 to 30 seconds, and it may be shown that in this time the hail falls a distance varying from about 0·2 km to 1 km according to its size. Since h_1 is taken as 3 km, the maximum horizontal displacement from the cloud therefore occurs at a height above the ground varying from nearly 3 km for stones of diameter 1 cm, to 2 km for stones of diameter 8 cm.

The computation of the maximum horizontal displacement in this stage, from equation (15) with t given by equation (16), begins by assuming a fall-velocity appropriate to a height half-way between h_1 and ζ, the height at the end of the first stage. This gives an estimated time of fall from equation (16), and hence a revised fall-distance vt and a revised mean height $(\zeta - vt/2)$, from which point the calculations are re-started with a value of v appropriate to this level. The results are given in Table II. The total displacement x in this table is the sum of the respective displacements x' in the first stage (Table I) and x'' in the second stage.

TABLE II—FALL OF HAIL IN SECOND STAGE

Diameter, d cm	1	2	4	6	8
Air density, $\rho \times 10^6$ gm cm^{-3}	582	599	625	647	667
Fall-velocity, v cm sec^{-1}	1300	1810	2510	3020	3430
Displacement, x'' km	11·5	7·6	4·8	3·6	2·8
Final height, km	2·8	2·6	2·4	2·2	2·0
Total displacement, x km	12·5	8·7	6·0	4·7	4·0

Discussion.—A method has been described for estimating the extent to which hail of various sizes may be displaced laterally from the thundercloud which gives birth to it. Values of the various parameters have been chosen with the object of arriving at figures for a large, but not an extreme, displacement. Comparison with the few observations available show that the results are at least of the right order of magnitude, although no observations are available to the author on the *size* of hail outside cloud. Beck[2], describing a summary of observations made on flights by the United States Air Force, mentions encounters up to 6 miles (10 km) from the parent thunderstorm in the height range 10,000 to 20,000 feet. Also Lehr[5] states without amplification that encounters may occur up to 2 to 3 miles in any direction from the intense radar echo and up to 10 miles (16 km) on the downwind side. Beck's statement regarding hail in clear air is worth quoting at length:

> "Encounters below 10,000 feet exhibited a completely random distribution insofar as the relative location of the aircraft and thunderstorm was concerned. The encounters in clear air alongside the thunderstorm, in rain below the thunderstorm and within the thunderstorm were about equally divided. The fact that more than 90 per cent of these low-level encounters were within two miles or less or were actually within or below the thunderstorm is considered vitally significant to flight operations.

"Encounters in the range 10,000 to 20,000 feet were distributed approximately 60 per cent within the thunderstorm and 40 per cent in the clear air alongside the thunderstorm. The clear-air encounters in this group showed a distribution from 100 feet to six miles from the parent thunderstorm with 82 per cent being under an overhanging cloud from the thunderstorm.

"Encounters in the range above 20,000 feet were distributed approximately 80 per cent within the thunderstorm and 20 per cent in the clear air, with all clear-air cases occurring beneath the anvil or other cloud extending from the parent thunderstorm."

The frequency of encounters with hail is not necessarily the same as the frequency of occurrence of hail, since it is not known how the flights were conducted in the presence of cumulonimbus clouds. Moreover, the "random" distribution mentioned in the first sentence of the quotation presumably implies nothing more than what is stated in the second sentence regarding the equal frequency of encounters below 10,000 feet in clear air, in precipitation, or within the storm itself. The actual distribution of falls of hail would be expected to be biassed towards the direction of the vertical shear.

Several factors which might influence the calculated results have had to be ignored. The air motion in and near the cloud is complicated by the vertical circulation of the cloud itself and by the necessity of preserving hydrodynamic continuity. The hail is assumed to fall without change of size; this is true enough in clear air at temperatures less than 0°C, moreover melting would not usually become appreciable until below 3 km except in low latitudes; if part of the fall takes place through cloud, then growth would occur where the temperature is less than 0°C. The terminal velocity of a hailstone varies with its shape. The fall of hail from 12 to 2 km takes about 5 to 12 minutes, and in this time changes taking place in the cloud may affect the distance between hail and the visual cloud, although distance between hail and core is perhaps less likely to be appreciably modified. The height at which hail is released from the cloud may not be independent of hail size; if the larger hail falls out sooner than the smaller hail, then the larger hail would come down relatively more closely to the cloud than the calculated figures suggest. The variation of wind shear with height is not necessarily uniform; if it is distributed to give a steeper shear in the middle and lower levels than in the upper levels, then the horizontal displacements would be greater than those calculated for a uniform shear, since the fall-velocity is less at lower heights. It is to be noted from equations (10) and (15) that with a uniform shear, the total displacement is proportional to the shear.

In view of the various uncertainties, it is considered that the displacements calculated for a given total shear may be in error by perhaps $\pm$ 2 km. The distances so calculated are in principle measurements from the main updraught or core of the cloud, not from the visual edge of the cloud. Finally, the estimates do not imply the existence of hail of the given diameters in any particular cloud, but state only the distance from cloud at which hail of a specified size is likely to be found when it does occur in the given conditions of shear. It should be noted that any large displacements are necessarily confined to the downwind side of the cloud.

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EXTREME WIND SPEEDS OVER THE UNITED KINGDOM FOR PERIODS ENDING 1959

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Introduction.—This paper is an extension of an earlier investigation by the author[1] and in it account has been taken of anemograph records for an additional five years, 1955–59. The same procedure has been adopted, that is, the statistical theory of extreme values[2] has been applied to the annual maximum mean hourly wind speeds and the annual maximum gust speeds recorded at all anemograph stations in the United Kingdom for which records for ten years or more are available. The number of stations for which data can now be presented is thus increased from 48 to 56. This includes 8 new stations and 35 stations for which the available record has been lengthened by from three to five years.

Results.—Tables I and II set out the results of the new computations for mean hourly wind speeds and for gusts respectively. For each station are given the number of years and period of the record, the speeds likely to be exceeded on the average only once in 10, 20, 50 and 100 years, the highest recorded speed up to December 1959 and the mean annual maximum, the speed likely to be reached or exceeded on the average once in two years. In every case the speeds refer to a height of 10 metres (33 feet) above the ground and have been reduced to that level, as in the previous paper, using the formulae

$$v_{10} = v_h \left(\frac{10}{h}\right)^{0.17} \text{ for mean hourly speeds}$$

$$v_{10} = v_h \left(\frac{10}{h}\right)^{0.085} \text{ for gusts}$$

where h is the "effective height" of the anemograph in metres.

The highest mean hourly speeds at 10 metres likely to be exceeded only once in 50 years are plotted in Figure 1 on a map of the British Isles and tentative isopleths at intervals of 10 m.p.h. have been drawn in. Figure 2 is a similar map showing the distribution of maximum gust speeds on a once in 50 years basis.

Discussion.—It must again be emphasized that Figures 1 and 2 give only a broad picture of the distribution of maximum wind speeds over the United Kingdom and are based on observations from stations which are, generally speaking, on open level sites and which in most cases are below 500 feet above sea level. Since extreme wind speeds are greatly affected by local topography such maps must be used with great caution, as values interpolated from them may need considerable adjustment depending on the actual exposure of any specified location for which estimated extremes are required. This applies particularly to sites on hill tops, in valleys or in heavily built-up areas.

TABLE I—MAXIMUM MEAN HOURLY WIND SPEEDS (M.P.H.) AT 33 FEET ABOVE THE GROUND

Station	No. of years of record	Period of record used	Speeds likely to be exceeded only once in stated number of years: 10	20	50	100	Highest on record	Mean annual maximum
			miles per hour					
Lerwick	29	1931–59	67	70	75	78	73	58·0
Kirkwall	14	1930–43	58	61	65	69	59	50·1
Stornoway	23	1937–59	69	74	79	84	73	58·4
Aberdeen	15	1933–47	44	47	52	55	44	35·5
Balmakewan	21	1915–35	45	48	53	56	51	36·8
Bell Rock	28	1930–55, 58–59	56	59	63	66	60	49·2
Leuchars	11	1949–59	48	51	55	57	46	41·7
Edinburgh	43	1915–33, 36–59	56	58	62	65	59	49·3
Tiree	33	1927–59	64	69	75	80	66	52·7
Paisley	46	1914–59	42	45	48	50	46	36·2
Renfrew	14	1946–59	50	54	59	62	51	41·2
Prestwick	16	1944–59	51	54	58	61	49	43·8
Eskdalemuir	36	1914–45, 56–59	54	57	61	64	56	46·3
Point of Ayre	24	1936–59	58	61	66	69	63	49·2
Durham	22	1938–59	48	51	54	57	50	39·6
South Shields	26	1934–59	55	58	64	69	61	44·0
Catterick	10	1933–42	51	56	62	67	49	38·8
Spurn Head	32	1922–46, 48–50, 54, 56–58	56	58	62	64	59	49·9
Cranwell	28	1928–42, 44, 47–48, 50–59	45	49	53	56	49	38·0
Gorleston	39	1913–31, 34–39, 41–46, 48, 51–57	50	53	57	59	55	44·0
Mildenhall	22	1938–59	47	50	55	59	56	37·2
Felixstowe	22	1931–35, 37–38, 44–52, 54–59	45	48	51	53	45	39·0
Dunstable	14	1944–48, 51–59	46	49	54	57	48	37·4
Cardington	28	1932–59	45	48	53	56	50	36·9
Stevenage	10	1950–59	40	43	46	50	39	34·0
Shoeburyness	34	1926–59	47	50	54	57	51	40·4
Leicester	10	1938–40, 43–45, 47–50	45	50	56	61	42	33·0
Birmingham	36	1924–59	37	40	43	45	38	31·2
London (Kingsway)	11	1944–54	37	40	43	46	34	29·7
Hampton	10	1950–59	33	35	38	40	31	27·9
Croydon	27	1928–39, 44–58	41	43	46	49	45	34·7
Kew Observatory	29	1931–59	33	35	37	38	34	29·0
Dover	26	1924–39, 48–50, 53–59	44	46	48	50	46	39·3
Lympne	27	1923–29, 31–43, 45–51	48	50	54	56	52	42·0
Manston	12	1943–54	46	48	51	54	45	39·6
Thorney Island	17	1943–59	43	46	49	52	45	36·2
Calshot	24	1920, 22–41, 50–52	51	54	58	61	50	43·0
South Farnborough	15	1945–59	46	50	56	60	49	35·5
Abingdon	13	1944–45, 49–59	38	41	44	46	38	32·7
Larkhill	29	1931–59	45	48	50	53	46	40·1
Boscombe Down	27	1933–59	48	51	56	59	49	40·1
Sellafield	10	1950–59	50	53	57	60	50	42·0
Fleetwood	32	1924–43, 46–57	61	65	69	72	62	52·6
Southport	45	1913–54, 57–59	59	63	67	71	65	50·8
Liverpool (Speke)	11	1948–50, 52–59	47	49	52	54	47	42·3
Bidston Observatory	30	1929–44, 46–59	56	59	63	67	62	47·4
Manchester Airport	15	1942–50, 54–59	50	55	59	62	54	42·5
Sealand	19	1928–41, 43–47	49	52	56	59	53	41·4
Holyhead	19	1933–51	61	64	69	73	64	51·7
Aberporth	15	1945–59	56	60	64	68	56	46·6
St. Ann's Head	14	1935–46, 48–49	69	75	83	89	70	54·9
Plymouth	35	1921–43, 47–48, 50–59	53	56	60	63	58	45·7
Scilly	33	1927–59	62	65	70	74	63	52·9
Lizard	22	1935–42, 45–47, 49–59	62	65	69	72	67	54·7
Pendennis Castle	20	1929–38, 41–50	65	68	72	75	67	58·2
Aldergrove	30	1928–46, 49–59	47	50	54	56	49	39·9

TABLE II—MAXIMUM GUST SPEEDS (M.P.H.) AT 33 FEET ABOVE THE GROUND

Station	No. of years of record	Period of record used	Speeds likely to be exceeded only once in stated number of years: 10	20	50	100	Highest on record	Mean annual maximum
			miles per hour					
Lerwick	29	1931–59	98	103	109	114	103	87·2
Kirkwall	14	1930–43	92	97	102	106	100	82·3
Stornoway	23	1937–59	106	113	123	130	110	88·2
Aberdeen	15	1933–47	78	83	89	93	83	67·8
Balmakewan	21	1915–35	76	82	89	94	87	62·8
Bell Rock	28	1930–55, 58–59	89	94	101	106	91	76·6
Leuchars	11	1949–59	82	87	95	100	82	68·0
Edinburgh	43	1915–33, 36–59	87	91	97	101	89	77·0
Tiree	33	1927–59	100	107	117	124	110	81·6
Paisley	46	1914–59	87	93	100	105	105	74·7
Renfrew	14	1946–59	94	101	110	117	97	76·2
Prestwick	16	1944–59	86	91	97	101	89	75·1
Eskdalemuir	36	1914–45, 56–59	87	92	98	103	91	74·7
Point of Ayre	24	1936–59	87	91	97	102	90	75·5
Durham	22	1938–59	89	94	100	105	95	77·4
South Shields	26	1934–59	83	88	95	101	86	69·3
Catterick	10	1933–42	86	92	99	105	88	71·1
Spurn Head	32	1922–46, 48–50, 54, 56–58	85	90	96	101	91	73·1
Cranwell	29	1928–44, 47–48, 50–59	85	92	101	109	108	67·2
Gorleston	39	1914–31, 34–39, 41–48, 51–57	77	81	86	90	82	66·6
Mildenhall	22	1938–59	86	93	101	107	94	70·4
Felixstowe	22	1931–35, 37–38, 44–52, 54–59	80	86	93	98	85	66·5
Dunstable	14	1944–48, 51–59	79	86	95	102	82	62·1
Cardington	28	1932–59	77	82	90	95	83	63·6
Stevenage	10	1950–59	75	80	87	91	73	63·2
Shoeburyness	34	1926–59	74	78	84	88	79	63·8
Leicester	10	1938–40, 43–45, 47–50	83	91	101	108	84	65·2
Birmingham	36	1924–59	74	79	86	90	79	62·7
London (Kingsway)	11	1944–54	79	86	95	102	77	61·3
Hampton	10	1950–59	69	74	80	84	69	58·4
Croydon	27	1928–39, 44–58	74	78	84	88	77	64·0
Kew Observatory	29	1931–59	70	73	78	81	71	61·6
Dover	26	1924–39, 48–50, 53–59	79	84	92	97	87	65·2
Lympne	27	1923–29, 31–43, 45–51	80	84	89	93	84	69·8
Manston	12	1943–54	78	82	87	91	80	68·1
Thorney Island	17	1943–59	78	82	87	91	81	68·0
Calshot	24	1920, 22–41, 50–52	80	85	92	98	86	67·2
South Farnborough	15	1945–59	75	79	84	87	79	65·6
Abingdon	13	1944–45, 49–59	74	80	87	92	77	60·8
Larkhill	29	1931–59	79	82	87	90	80	70·8
Boscombe Down	27	1933–59	80	85	92	97	86	66·2
Sellafield	10	1950–59	85	90	97	102	87	73·0
Fleetwood	32	1924–43, 46–57	88	93	100	106	91	76·0
Southport	45	1913–54, 57–59	89	94	101	106	93	76·5
Liverpool (Speke)	11	1948–50, 52–59	84	90	96	101	84	71·8
Bidston Observatory	30	1929–44, 46–59	93	98	105	110	100	81·2
Manchester Airport	15	1942–50, 54–59	85	90	97	102	90	73·5
Sealand	18	1928–41, 44–47	82	87	93	97	86	70·7
Holyhead	19	1933–51	94	100	107	113	107	79·1
Aberporth	15	1945–59	91	97	104	110	92	76·5
St. Ann's Head	13	1935–45, 48–49	105	112	122	128	>107	88·3
Plymouth	35	1921–43, 47–48, 50–59	80	85	92	97	91	67·4
Scilly	33	1927–59	96	102	109	114	107	83·3
Lizard	22	1935–42, 45–47, 49–59	92	96	100	103	94	83·7
Pendennis Castle	20	1929–38, 41–50	100	106	114	120	102	85·2
Aldergrove	30	1928–46, 49–59	82	87	93	97	87	71·3

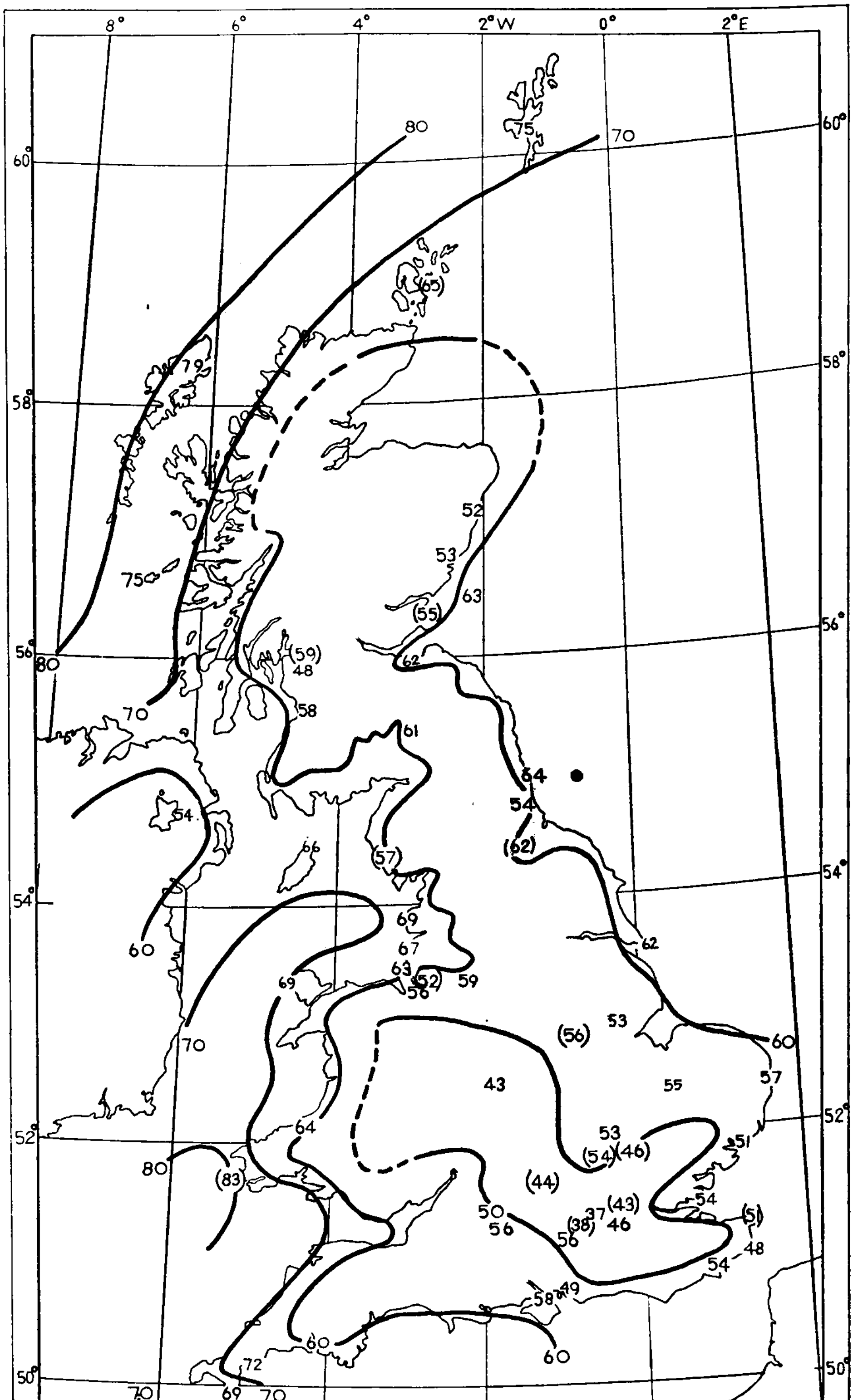

FIGURE 1—HIGHEST MEAN HOURLY WIND SPEED (M.P.H.) AT 33 FEET LIKELY TO BE EXCEEDED ONLY ONCE IN 50 YEARS

Values based on less than 15 years of record are bracketed.

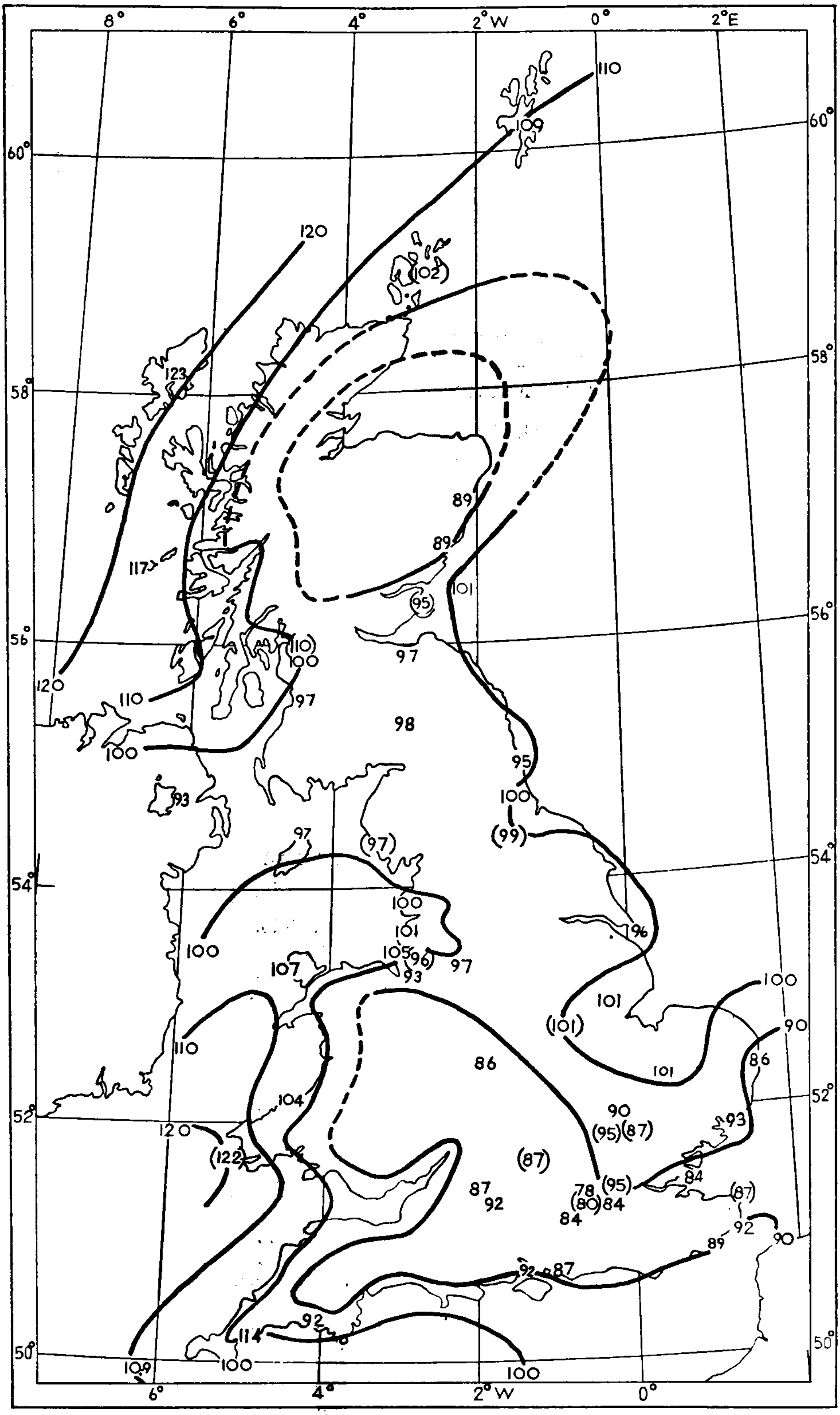

FIGURE 2—HIGHEST GUST SPEED (M.P.H.) AT 33 FEET LIKELY TO BE EXCEEDED ONLY ONCE IN 50 YEARS

Values based on less than 15 years of record are bracketed.

When Figures 1 and 2 are compared with the corresponding maps of the author's earlier paper[1] (Figures 2 and 3 respectively) it will be noted that most of the changes are relatively minor ones, perhaps the most noteworthy difference being an increase in expected maximum speeds by a few miles per hour in the north and west of Scotland. For the 35 stations for which the new values may be compared with the old values the frequency distributions of the speed differences for mean hourly and gust speeds on a once in 50 years basis are given in Table III.

TABLE III—FREQUENCY DISTRIBUTIONS OF CHANGES (NEW MINUS OLD) IN MAXIMUM SPEEDS ON A ONCE IN 50 YEARS BASIS RESULTING FROM THE ADDITION OF THREE TO FIVE YEARS' ADDITIONAL RECORDS (35 STATIONS)

Differences* *m.p.h.*	Max. mean hourly speeds *No. of stations*	Maximum gust speeds *No. of stations*	Differences *m.p.h.*	Max. mean hourly speeds *No. of stations*	Maximum gust speeds *No. of stations*
+8		1	−1	12	7
+7			−2	4	10
+6		1	−3		
+5			−4	1	
+4		1	−5		2
+3	1	1	−6	1	1
+2	5		−7		
+1	3	4	−8		1
0	8	6			

* Differences = new values minus old values.

TABLE IV—RATIO OF MAXIMUM GUST SPEED (g) TO MAXIMUM MEAN HOURLY SPEED (v), ON ONCE IN 50 YEARS BASIS, FOR 56 STATIONS, AT 33 FEET ABOVE THE GROUND

Station	g/v	Station	g/v
Lerwick	1·45	London (Kingsway)	2·21
Kirkwall	1·57	Hampton	2·11
Stornoway	1·56	Croydon	1·83
Aberdeen	1·71	Kew Observatory	2·11
Balmakewan	1·68	Dover	1·92
Bell Rock	1·60	Lympne	1·65
Leuchars	1·73	Manston	1·71
Edinburgh	1·56	Thorney Island	1·78
Tiree	1·56	Calshot	1·59
Paisley	2·08	South Farnborough	1·50
Renfrew	1·86	Abingdon	1·98
Prestwick	1·67	Larkhill	1·74
Eskdalemuir	1·61	Boscombe Down	1·64
Point of Ayre	1·47	Sellafield	1·70
Durham	1·85	Fleetwood	1·45
South Shields	1·48	Southport	1·51
Catterick	1·60	Liverpool (Speke)	1·85
Spurn Head	1·55	Bidston	1·67
Cranwell	1·91	Manchester Airport	1·64
Gorleston	1·51	Sealand	1·66
Mildenhall	1·84	Holyhead	1·55
Felixstowe	1·82	Aberporth	1·63
Dunstable	1·76	St. Ann's Head	1·47
Cardington	1·70	Plymouth	1·53
Stevenage	1·89	Scilly	1·56
Shoeburyness	1·56	Lizard	1·45
Leicester	1·80	Pendennis Castle	1·58
Birmingham	2·00	Aldergrove	1·72

[To face p. 44

PLATE I—VIEW OF METEOROLOGICAL OFFICE LIBRARY FROM ENTRANCE

(see p. 47)

PLATE II—LIBRARY LOAN AND ISSUE COUNTER

(see p. 47)

Crown Copyright

PLATE III—MAIN LIBRARY

(see p. 47)

To face p. 45]

PLATE IV—STOCK ROOM IN "THE TOWER"

(see p. 47)

Nearly all the changes are of 2 m.p.h. or less. The majority of the differences greater than 2 m.p.h. occurred at stations with short records (15 years only) or at stations in the west and north-west where some exceptional gusts have occurred in the last few years.

The ratios of the maximum gust speeds to the maximum mean hourly speeds are of some interest and these are set out in Table IV, using once in 50 years estimates.

These "gust factors" range from 1·45 to 2·21 with an average value of 1·70. The lowest values are found where the anemographs are on well exposed sites, usually near the sea, and the highest ones in cities and well built-up areas. There are, however, a number of stations such as Kew Observatory, Durham, Mildenhall, Stevenage, Leicester, Hampton, Croydon and Liverpool (Speke) where the "gust factor" is 1·80 or higher although the exposures were reasonably open, and this may be at least partly due to the fact that the anemographs at these stations were mounted on fairly large buildings.

Davenport[3] has made use of the values of u and $1/a$ in the expression for the reduced variate,

$$y = a\,(x - u)$$

where a is the scale factor, x the maximum wind speed and u the mode of the extreme value data, to estimate corresponding values referring to the gradient wind speed, after making allowances for the influence of surface roughness. Therefore it may be useful to list the values of u and $1/a$ which have been obtained in this study and they are given in Table V, for maximum mean hourly speeds and for maximum gusts. These parameters may also be used to calculate the maximum speeds for return periods other than those listed in Tables I and II from

$$x = u + \frac{1}{a} \cdot y$$

where $$y = -\log_e\,(-\log_e p)$$

and the return period T is equal to $1/(1-p)$ years.

Values of y corresponding to various values of T are as follows:

T years	y	T years	y
2	0·37	60	4·09
5	1·50	70	4·24
10	2·25	80	4·38
20	2·97	90	4·49
25	3·20	100	4·60
30	3·38	120	4·82
40	3·68	150	5·01
50	3·90	200	5·30
		500	6·21

It should be mentioned that the values of u given in Table V have not been reduced to the standard height of 33 feet, as have the values in Tables I and II. The effective height allotted to each anemograph has therefore been included in Table V.

The British Standard Code of Practice on wind loading[4] is undergoing revision, but the current code still requires the highest maximum mean wind

TABLE V—VALUES OF u AND $1/a$ FOR MAXIMUM MEAN HOURLY SPEEDS AND MAXIMUM GUST SPEEDS AT 56 STATIONS

Station	Effective height	Maximum mean hourly speeds u	Maximum mean hourly speeds $\frac{1}{a}$	Maximum gusts u	Maximum gusts $\frac{1}{a}$
	feet	*m.p.h.*		*m.p.h.*	
Lerwick	39	56·8	5·06	84·6	6·69
Kirkwall	35	48·3	4·54	79·7	5·88
Stornoway	36	55·7	6·33	83·3	10·30
Aberdeen	32	32·9	4·69	64·4	6·17
Balmakewan	20	31·6	4·38	57·1	7·51
Bell Rock	124	59·2	5·14	81·4	7·98
Leuchars	35	40·2	3·81	64·5	7·88
Edinburgh	23	44·2	3·62	71·6	5·63
Tiree	42	51·2	6·97	77·6	10·68
Paisley	31	33·9	3·35	70·3	7·44
Renfrew	35	39·0	5·15	71·4	10·06
Prestwick	35	42·0	4·33	72·2	6·43
Eskdalemuir	35	44·4	4·40	71·3	7·00
Point of Ayre	35	47·1	4·88	72·5	6·48
Durham	33	39·6	3·70	73·8	6·71
South Shields	44	42·9	6·28	66·7	7·96
Catterick	33	35·4	6·80	67·0	8·33
Spurn Head	34	48·3	3·48	69·5	6·86
Cranwell	47	37·9	4·56	63·5	10·51
Gorleston	34	42·2	3·73	63·5	5·86
Mildenhall	60	38·1	5·95	69·1	9·52
Felixstowe	65	41·6	4·02	66·1	8·27
Dunstable	33	35·0	4·80	57·2	9·70
Cardington	135	43·6	6·17	67·3	8·62
Stevenage	33	32·2	3·66	59·8	6·84
Shoeburyness	89	45·2	4·97	65·3	6·72
Leicester	33	29·6	6·81	60·1	10·41
Birmingham	73	33·6	4·02	63·1	7·32
London (Kingsway)	40	27·5	3·70	57·7	10·26
Hampton	100	31·9	3·57	60·7	6·93
Croydon	70	37·3	3·96	64·9	6·20
Kew Observatory	50	29·9	2·39	61·2	4·91
Dover	60	42·0	2·84	64·1	8·25
Lympne	48	42·7	3·72	68·5	5·97
Manston	46	39·9	3·70	66·8	5·68
Thorney Island	42	35·6	4·04	66·5	5·68
Calshot	42	42·3	4·55	64·2	7·65
South Farnborough	35	32·8	5·98	63·0	5·40
Abingdon	40	32·2	3·28	57·9	7·73
Larkhill	36	39·0	3·08	68·7	4·77
Boscombe Down	33	37·6	4·59	62·1	7·74
Sellafield	35	40·2	4·46	69·9	7·07
Fleetwood	31	49·5	4·77	71·7	7·14
Southport	33	48·1	4·95	72·6	7·27
Liverpool (Speke)	65	45·8	3·32	72·3	7·56
Bidston	39	46·2	4·85	78·5	7·16
Manchester Airport	40	41·4	5·01	70·8	7·56
Sealand	42	40·8	4·41	68·6	6·60
Holyhead	35	49·4	5·28	75·1	8·39
Aberporth	41	45·8	5·35	73·7	8·40
St. Ann's Head	70	57·8	9·51	88·1	10·34
Plymouth	65	48·7	4·73	67·2	7·66
Scilly	57	55·0	5·65	82·9	8·02
Lizard	60	58·2	4·65	85·4	5·09
Pendennis Castle	42	58·2	4·30	82·2	8·65
Aldergrove	42	39·3	4·20	69·3	6·53

speed over a period of one minute to be specified. The records from standard anemographs have too close a time scale for means to be measured over such a short period and, in the absence of any other evidence, it is recommended that the results obtained by Durst[5] from his statistical analysis of the "ultra-quick runs" made at Cardington, should be used. These indicate that the probable value of the maximum wind speed averaged over one minute is about 1·24 times the maximum mean hourly wind speed. Corresponding factors for mean values over other short periods, based on Durst's Table VIII, are as follows:

Period	10 min	1 min	30 sec	20 sec	10 sec	5 sec
Factor	1·06	1·24	1·33	1·36	1·43	1·47

As Durst has emphasized, these values strictly refer only to sites where the wind is unobstructed and the topography is flat, although they can also be reasonably applied to sites where the countryside is undulating and slopes are not too steep. There is a need for similar data which would be applicable to the more common case where the site is obstructed by buildings or trees, that is, to built-up areas. To meet this requirement a series of open-scale recordings in moderate and strong winds are needed from a typical site in a city such as London.

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551.5:026:06

NEW ACCOMMODATION FOR THE METEOROLOGICAL OFFICE LIBRARY

By R. F. ZOBEL, O.B.E.

The Meteorological Office Library has now been transferred from its former home at Harrow to the new Meteorological Office Headquarters at Bracknell, Berkshire. This library is, of course, primarily intended to provide the books, papers and data, in addition to those available at outstations, required for study and research by the Office staff. But it is more than that, as it constitutes a national library of meteorology and allied subjects. The reference facilities provided are available to the general public and documents may be lent to approved institutions and individuals.

The accommodation at Harrow to which the Library was moved at the end of World War II suffered from a number of defects. The new accommodation at Bracknell was specifically designed to house this major British special library and it is now in keeping with that status. It comprises two main parts, that housing the open shelves of the Library, and the stock rooms to which borrowers are not normally admitted.

The Library itself is a large, pleasant room containing the main collection of documents for lending. The bookcases and much of the panelling are faced in polished chestnut, relieved here and there by the darker tones of Australian walnut. The impression of quiet elegance as one enters from the Main Hall (Plate I) is undoubtedly pleasing and conducive to study. The lending counter

(Plate II), specially designed for convenience in handling loans and returned documents, is on the left and the "author catalogue" is contained in an array of card cabinets built into the wall on the right.

Ample space has been provided in good lighting conditions at the ends of the bookcases and elsewhere for quiet study and browsing amongst the documents (Plate III). This space includes a separate room in which hand-operated calculating machines, for example, may be used without annoyance to other library users. Under-floor heating has been used with the object of providing a reasonably uniform circulation of air around the bookcases.

The stock rooms consist of a six-storey steel structure built within the hollow brick and masonry tower at the far end of the main library. These rooms are the repository of much of the older and less frequently used material and they are air-conditioned. Plate IV shows part of the interior of one of the stock rooms.

The work of the Library has been described previously in this Magazine[1], but after a lapse of 14 years some recapitulation may not be out of place. Its aim is still largely the same—"to be of the utmost assistance to all members of the Meteorological Office, by acting not only as a repository of books, but also as an information bureau". The first requirement in meeting this objective is a steady flow of new literature. This is achieved mainly by the exchange, mostly of an international character, of Meteorological Office publications with those of other institutions. Nearly 400 such exchange arrangements are in being at the present time. However, not all documents of value to the Library are published by institutions with whom we have exchange arrangements, so that such deficiencies are made good by purchase. The second requirement, equally essential, is that the system of cataloguing shall be such that an inquirer can speedily find any document he wants, or can be given lists of references to papers on the subject in which he is interested. The cataloguing system adopted is very complete. The "author catalogue", already referred to, is an alphabetically arranged card index. There is a separate card under each author's name for every book, paper, etc., he has written, whether it appeared as a separate publication, or was one of a number of articles in a journal. Cards are duplicated or triplicated in the event that a document had two or three joint authors. This index also contains cards in relation to series issues of the various publishing bodies. The "author catalogue" therefore shows all the papers by a given author held in the Library, what institution was responsible for publication and where to find it on the shelves. The number of cards in the index is now about 120,000.

In addition, all books and papers are entered in at least one "subject catalogue", or permanent bibliography of meteorological and allied literature. Entries are made in chronological order under Universal Decimal Classification headings. Thus an inquirer asking what literature is available in the Library on the subject of, say, noctilucent clouds, would be referred to the entry 551.593.653 in the permanent bibliography, where he would find the author and title of every paper held on the subject. Special geographically arranged catalogues are also maintained for some of the more important subjects, i.e. climatology, synoptic climatology and upper air conditions.

Abstracts are not, at present, prepared in the Library, but short descriptive notes are added to many of the entries in the monthly bibliography which is a classified list of accessions to the Library in the particular month and which has a wide circulation.

There is only one full-time translator on the staff, engaged wholly on translating from the Russian. But translating is also done by a number of volunteers and paid linguists, whilst a number of translations are bought or exchanged, so that members of the staff may request the translation of papers in almost any language with the reasonable expectation that it will be done. This service cannot, of course, be provided for other than Office staff, but translations already held can be loaned in the same way as the original text.

But not all available literature is in normal printed form. There is therefore a room set aside for viewing microfilm, microcards and films. There is also a good collection of lantern and colour slides and of photographs in the Library for illustrating lectures or articles. All visual aids are available for loan to members of the staff and some may be hired by non-members for bona fide purposes.

So if you have a problem in which you think the literature or other facilities of the Library can be of assistance, do not hesitate to ask. It is the purpose of the Library not only to collect meteorological papers and information, but also to ensure that the greatest amount of information may be obtained from them.

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551 ·5:51

MATHEMATICS AND METEOROLOGY

By E. KNIGHTING, B.Sc.

The journals of applied mathematics and meteorology have always contained papers written about meteorology and using mathematics; in the nineteenth century Helmholtz, Kelvin and Bjerknes spring to mind. And yet meteorology was not in the main a quantitative science and there was no coherent mathematical theory. Of course, special branches employed quantitative reasoning, such as turbulence theory which in the two decades following World War I was expressed in the form of differential equations. Nevertheless, the meteorological journals of twenty years ago were mainly descriptive. In the last two decades meteorology has emerged as a quantitative science in nearly all its aspects, and this is reflected in the journals where it is now almost impossible to pick up a current number which does not contain articles which are formidably mathematical in content. The scope of the mathematics is wide, ranging through matrix theory, tensor analysis, differential equations, etc. Additionally, the use of electronic computers has become commonplace in meteorological research and a knowledge of computational methods, not only in the solution of differential equations but also in statistics and many other branches, has become part of the meteorologist's equipment. This emergence as a quantitative science has made it necessary for meteorologists to note books which are not primarily of meteorological interest; in the case of the two books under review,* they are primarily of mathematical interest, the first being a text on differential equations and the second on computational methods. Both of these subjects are currently of great interest to meteorologists.

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* *Differential equations for engineers and scientists,* by C. G. Lambe and C. J. Tranter. 8¾ in. × 5½ in., pp. xii + 372, *illus.,* English Universities Press Ltd., London, 1961. Price: 30*s.*

An introduction to computational methods, by K. A. Redish. 10 in. × 7½ in., pp. xii + 211, *illus.,* English Universities Press Ltd., London, 1961. Price: 30*s.*

Differential equations abound in the literature of meteorology and it would scarcely be possible to read much of the modern work without a considerable background knowledge of the subject. Certain books acquire a "classical" reputation and among general texts on differential equations Piaggio's book has this reputation. Any book which seeks to cover much the same field must invite comparison. Moreover, the field covered by such books must have a common content, for there is a body of knowledge common to most of the physical sciences which essentially expresses the balance between forces and accelerations and therefore gives rise to second order differential equations. It is no accident, then, that books on differential equations written for engineers and scientists should be largely concerned with second order equations, whether ordinary or partial. The first two chapters of Lambe and Tranter's text probably have less physical content than the remainder because they deal with preliminary ideas and first order equations. The third and fourth chapters deal with linear differential equations with constant coefficients and the methods of integration are the classical ones stemming from Euler with the particular integrals obtained by inversion of the linear differential operator. The first parts of each of these chapters are, of course, simply mathematical and provided with plenty of exercises. The later parts are much more physical in content and deal with the sort of problems which give rise to these second order equations, such as vibrations of elastic springs, electric circuits and a good explanatory section on servomechanisms. These sections are more extended than the corresponding examples on physical systems in Piaggio, which are confined to the end-of-chapter exercises. The meteorological applications of these chapters will probably be mostly in instrument theory.

When the second order differential equations do not have constant coefficients the operator methods of solution are rarely practical and recourse is usually made to solutions in series. The systematic use of such methods is due to Frobenius and Fuchs (*c.* 1870), although series solutions had been used much earlier. Many of the well known functions in mathematics are definable by series (e.g. $\cos x = 1 - x^2/2! + x^4/4! \ldots$) and this important chapter is well presented and includes a sketch of the hypergeometric function. It is difficult to assess where such knowledge will be required, but as examples the confluent hypergeometric function arises in considering the statistics of winds and the hypergeometric function in the vertical transfer of energy in the atmosphere. Not having included a chapter on miscellaneous methods of solving such equations, for example by the method of variation of parameters, the authors have inserted in this chapter almost irrelevantly, the Wronskian theorem. It must be exceedingly difficult to collate the material for a text on differential equations and both this text and Piaggio's have information which belongs to no particular part of the development scattered about in odd places.

Lambe and Tranter devote a complete chapter to some special functions and in it they treat Legendre, Bessel and various Jacobi polynomials as well as those of Hermite and Laguerre—a much more complete treatment than that of Piaggio, whose information is mainly scattered in examples. The meteorological necessity for such information is too varied to more than indicate Legendre functions in representing a field over the earth's surface (although one will want more than is given here to follow the development) while Bessel functions, like elliptic integrals, are ubiquitous and both occur in the statistics of winds.

Čebyčev* polynomials are also now creeping into various statistical and representational problems, to say nothing of computational mathematics. This is a very good chapter and an excellent introduction to the more specialized texts. It is also the basis for the text in the following chapter dealing with partial differential equations.

Meteorology naturally gives rise to partial differential equations since one of the central sets of equations is the Navier-Stokes set, expressing the dynamics of fluid motion. The chapter given here deals only with second order linear partial differential equations arising from physical problems. One may regret the omission of first order partial differential equations, which are basic for thermodynamical considerations, but selection of material must be judicious and the large number of worked physical examples is valuable; the way in which special functions arise in the solution of Laplace's equation and its generalizations is made clear.

The use of integral transforms in solving differential equations is one of the most powerful methods developed over the last sixty years and is the subject of a vast literature. In meteorology the method has been used with increasing frequency in recent years, the Fourier transform in problems concerning gravity waves, the Laplace transform in problems of micrometeorology and the Bessel transform in some considerations of the optimum distribution of observing stations. Dr. Tranter is a well known expert in this field and as expected the chapter is clear and concise. One notes, however, that there is no mention of treating two point boundary problems by use of the Laplace transform. Would it be too revolutionary to sweep away the differential operator methods given earlier and replace them by a consistent use of the Laplace transform? One notes also with regret that the authors decided against including the use of Laplace transforms in the solution of partial differential equations, because the list of transforms would be excessively long: Carslaw and Jaeger (*Operational methods in applied mathematics*) used a quite short list, in solving numerous problems.

The formal methods of solving differential equations, expressing the answer in some closed form or as a series of identifiable functions, can really only be applied to simple equations; the equations that one wishes to solve in practice are rarely simple. Moreover, the formal solution itself may in practice be very difficult to evaluate numerically, or may indeed be in an unsuitable form for computation. In many cases the only practical way of solving the differential equation, or indeed any equation, may be by direct numerical methods. This has, of course, long been recognized and one of the earliest examples in meteorology is that of computing corrections to ballistic range tables due to the departures of wind and temperature from some standard state. The current uses of numerical methods in meteorology are too numerous to mention, but it is well known that the equations predicting the pressure distribution are solved numerically and that no other way is possible. Mr. Redish's book deals, among other subjects, with the numerical solution of differential equations as does the book of Drs. Lambe and Tranter. It should be said at once that the treatment given by Lambe and Tranter is adequate as an introduction and rounds off their text apart from a valuable chapter on non-linear equations.

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*[Often written Tchebychev, or other variants, in mathematical texts. *Ed.*]

The problems of numerical integration of differential equations are more complicated when one deals with partial differential equations. Ordinary differential equations, say of the second order, may have boundary conditions all given at the same point or some given at one point and some at another. If all the boundary values are given at one point the problem is a "marching problem" and reduces to constructing the solution near the boundary point for say four or five neighbouring points in order to get a start and then using these values to extrapolate a new value; the extrapolated value is then corrected by using the differential equation itself. This is precisely the process used in the meteorological ballistic problem. A variety of methods have been constructed for each of these processes, the crux lying in constructing an extrapolated value which requires little correction. Redish deals with a selection of these methods and illustrates them numerically. The author and publishers are to be congratulated upon the page size adopted for this book, which allows the numerical computations to be beautifully displayed without any crowding together.

If the boundary values are given at two different points then one has a "jury" problem, that is the solution must satisfy conditions at a set of points. One way of solving the problem is to guess another boundary condition at the first point and see how well the solution computed using this guess fits the boundary value at the second point, followed by a refined guess at the boundary condition; a meteorological application of this method lies in estimating the wavelength and amplitude of gravity waves. Perhaps the most obvious way is simply to make the differential equation in difference form and solve the simultaneous equations which arise and Redish deals well, if briefly, with this method of solution, which replaces the problem by that of selecting the best method of solving sets of linear equations.

It is the chapter on functions of two variables that will most interest meteorologists, who are likely to meet partial differential equations of the second order. Here the treatment is limited to elliptic equations and the method of solution to that of relaxation. This is, of course, a most effective method if the computations are to be carried out by hand and the number of equations is small. If the number of equations is large, that is the number of grid points at which the solution is to be obtained is large, then the work is prohibitive, even for experienced computers and to solve a pair of simultaneous equations may take months. The impact of the electronic computer on such computations is enormous. The methods used for the solution of partial differential equations are more elementary and would be time-wasting if used by hand; for example, a Liebmann-type process is far preferable to a relaxation process and perhaps one could complain that the author does not deal with such methods.

The first part of the book deals with the standard formulae of finite differences, interpolation, differentiation and integration. They are very clear, but do not present any new material. The author is careful in his warnings but does not draw attention to the dangers of using experimental information, for example in forming a derivative. One might have expected some discussion of smoothing of experimental data in a practical text, especially if aimed at the "occasional" computer. Additionally, there are chapters on simultaneous and non-linear equations, and a final chapter on miscellaneous methods.

One wonders what the ultimate impact of electronic computers will be on textbooks of mathematics. Even now one can solve a second order differential equation numerically without knowing anything about the methodology of either differential equations or computing. Standard programmes exist for the solution of sets of first order differential equations which automatically suit the interval to the accuracy required; they also exist for many other processes such as solving sets of simultaneous equations or obtaining eigenvalues and eigenvectors. In the future, mathematical functions may no longer be tabulated in book form except in the description of the best method to use for computing over a given interval. Facilities for using electronic computers will undoubtedly spread to everyone at university level. Perhaps then the flow of new books will shrink as has that of books on geometry.

Both books are well produced. That of Drs. Lambe and Tranter is a serious rival to that of Piaggio, having a more physical outlook although it is less of a mathematicians' book and one would miss the useful results given in the latter's miscellaneous examples. One would also miss the references and perhaps the authors could be persuaded to add a bibliography to the next edition. It is not apparent from the text that books by Ince, Kamke, Von Mises, Courant-Hilbert, Bateman, to mention but a few, exist. I found Mr. Redish's book to be rather in the nature of lecture notes with a few irritating obscurities, for example on p. 174 "the nature of the equation may vary from point to point" and not "will vary". The printer has not been consistent in his symbols for partial derivatives. Nevertheless, it is a good, practical and useful book.

REVIEW

Das Klima der Vorzeit, by M. Schwarzbach, $9\frac{1}{2}$ in. $\times 6\frac{1}{2}$ in., pp. xi + 275, *illus.*, Ferdinand Enke Verlag, Hasenbergsteige 3, Stuttgart, 1961 (2nd edition). Price: geheftet *DM* 53·50, ganzleinen *DM* 57.

This book is an admirable guide to palaeoclimatology, handy in size, full of data presented wherever possible in figures (temperatures, rainfall, etc.) of direct significance to meteorology, illustrated by 134 aptly chosen pictures, maps and diagrams, succinctly written (in places in note form), yet with room for many a wise caution about sources of error and misinterpretation and more than a few shafts of humour. Though a second edition, it contains so much that is new that possessors of the 1950 edition will want the new one. The need for rewriting so soon of what had quickly become a standard work arises largely from the burgeoning of the subject brought about by the development of so many new tools—the O^{18}/O^{16} method of determining palaeotemperatures, C^{14} dating, palaeomagnetism studies and the sampling of cores taken from the ocean bed. It is still true, however, as the author says, that "no really satisfying explanation of climatic history can yet be given; though the theoretical hypotheses are interesting, and their numbers continue to mount, the main interest must still be focussed on the facts—or what geology counts as facts—that is to say the traces left by past climates".

The work starts with a few pages indicating the history of knowledge and ideas about palaeoclimatology from 1686, when from the finding of fossil tortoises in England Robert Hooke deduced the former existence of a warm climate and the possibility that the Earth's axis had shifted. The second chapter is on present-day climate and its relevance to palaeoclimatology. Here, in eight pages including several world maps, nothing more than a sketch of the basic framework of world weather and ocean currents is attempted and extra space might, with advantage, have been given to introducing such elements as the role of the upper westerlies with their ridges and troughs and the variations of thermal stability and instability. Successive chapters are devoted to characteristic traces left by warm climates, cold climates, dry climates and wet climates, evidences of former average pressure and wind distribution, of regular seasonal changes and of climatic oscillations of various period lengths in the geological and more recent past. The middle section of the book (from p. 93 to 193) gives the known facts of climate and its distribution in successive geological epochs from the pre-Cambrian to the Quaternary, including a few pages on the post-glacial or Holocene. The final chapters survey the numerous, and often conflicting, theories with shrewd notes pro and con in each case, mustering a remarkable breadth of knowledge and a critical insight which does not fail to detect the fanciful and the far-fetched even in fields remote from the author's own (geology). Two pages at the end are devoted to an attempted synthesis which accepts as a probability that some variations of the radiation from the sun do occur and allows many secondary (terrestrial) influences affecting the receipt and redistribution of solar energy, especially through the relief and extent of land and sea; moreover, the author believes that the climatic history of epochs before the Tertiary cannot be explained without the assumption of shifting poles and drifting continents.

On a thorough reading the reviewer learnt a lot and found little to criticize and few misprints—perhaps the only confusing misprint is on p. 70 where the prevailing winds at the foot and top of Mt. Erebus have got interchanged. On p. 8 the extreme high temperature at Death Valley should be 56° not 50°C.

From the evidence presented, it appears that the meteorologist must take stock not only of warm and cold epochs in the Earth's history, but of some which were generally moist and others which were generally dry, of times of only low relief and others of high relief, of epochs when both poles were in an oceanic environment (maps pp. 113 and 135) and possibly of shorter epochs (geologically speaking) when both poles were on land. By now one is amazed at the extraordinary lengths to which Brooks was driven (pp. 201–2) to explain the Permo-Carboniferous glaciation without resort to changes in the positions of the poles. The traces of this glaciation are all in low latitudes today, and Brooks's explanation was based on very high plateau levels, combined with a geography that diverted the equatorial ocean currents towards the (warm) poles. The theory seems in any case at variance with the observed role of extensive high plateaux (for example, Tibet, Bolivia) in low latitudes today as raised heating surfaces. From this point it is reassuring to come to the much broader range of evidence in favour of polar wandering, etc. One notes (with Schwarzbach) the most obvious virtue of Ewing and Donn's ice-age theory in stressing the importance of the peculiar Arctic geography of the Quaternary with the pole in an almost enclosed sea.

Meteorological theories of climatic variations on shorter time-scales from the separate Quaternary ice ages and interglacials downwards are presented. These give an impression of a chartless maze until one comes to the radiation curves calculated by Milankovitch, and others since, on the basis of astronomical variables. But one is reminded that here too the firmest evidence (C^{14} dating) both before and since the last ice age does not clearly confirm the theory. "No one enjoys more peace of mind than he who has no opinion"—as one might translate a remark quoted by the author at this point!

The book is well indexed and has a 21-page bibliography which includes full titles—a valuable guide to further studies of the geological, botanical and other evidence and its interpretation. The work will be found very valuable by theoreticians who know nothing of the facts of past climates and by geologists and others working in the field who wish to know more of the picture so far built up.

H. H. LAMB

HONOUR

The following award was announced in the New Year Honours List, 1962:

B.E.M.

H. F. Clifton, Boatswain, Ocean Weather Ship *Weather Reporter.*

OBITUARIES

Charles Sumner Durst, O.B.E., B.A.—The news of the sudden death of Mr. C. S. Durst on Christmas Day, 1961, was a great shock to his many friends. Born in 1888, Durst graduated in mathematics at Pembroke College, Cambridge, in 1910. During the next nine years he served as a surveyor in the Malay States and, during the First World War, in the Royal Engineers in Gallipoli, Palestine and the Western Desert. In 1919 Durst joined the Meteorological Office and so started a career as a research worker which was to be distinguished by a steady output of original work, up to the time of his death. His field of interest was extraordinarily wide, ranging from aerial navigation to the efflux of gas in mines; it is described in more detail in the notice of his retirement from the Office in the issue of this Magazine for November 1957. During his service in the Meteorological Office his work earned him many marks of public recognition, the Buchan Prize of the Royal Meteorological Society in 1937, the award of the O.B.E. in 1946, a Groves Memorial Prize in 1949 and the Bronze Medal of the Institute of Navigation in both 1950 and 1956. Perhaps just as important as these prizes was the affection and respect he inspired in his colleagues. In 1953 Durst retired from his post as Assistant Director in the Office but remained on the staff for a further four years to continue his research work. In 1957 his official connexion with the Office came to an end. At an age at which most men are content to rest on their laurels Durst then started a career as an independent meteorological consultant which continued up to the time of his death.

During his lifetime Durst earned our respect for his wisdom, his wide range of knowledge and for his ever active mind. Combined with this respect was a deep affection for a man who was always ready to use his talents to help others.

In 1921 Mr. Durst married Miss Mary Helen Blakiston. To his widow and to their son and daughter goes the sympathy of his colleagues.

A. C. BEST

Mr. William Shannon.—It is with deep regret that we learn of the death on 5 January 1961 of Mr. W. Shannon, Senior Scientific Assistant, at the age of fifty-one. He joined the Office in October 1938 as a Technical Assistant, Grade III, and his first three and a half years were spent in the Forecast Division at Headquarters. From 1941 he served at numerous aviation outstations, mainly in the north of England and in Scotland. He also undertook tours of duty in Germany and Gan Island. At the time of his death he was serving at Turnhouse. He is survived by a widow and three sons to whom the sympathy of all who knew him is extended.

Mr. Michael John Samways.—It is with deep regret that we learn of the death on 22 December 1961, as a result of a car accident, of Mr. M. J. Samways, Scientific Assistant, at the age of twenty-four. He joined the Office in October 1954, and all his service was spent at aviation outstations, including a tour of duty in Germany. At the time of his death he was serving at Upavon. He is survived by a widow and two children to whom the sympathy of all who knew him is extended.

Mr. Christopher James Oxley.—It is with deep regret that we record the death on 21 December 1961, as a result of a car accident, of Mr. C. J. Oxley, Scientific Assistant, at the age of twenty-one. He joined the Office in October 1959 and, apart from a short spell at Headquarters in the Observations and Communications Division, his service was spent at an aviation outstation, Scampton, where he was stationed at the time of his death. The sympathy of all who knew him is extended to his parents.

HONORARY DEGREE

We note with pleasure the award of the degree of D.Sc. *honoris causa* by the University of British Columbia to Mr. P. D. McTaggart-Cowan, M.B.E., Director of the Meteorological Service of Canada.

BOOK RECEIVED

Annual Meteorological Tables 1958, Falkland Islands and Dependencies Meteorological Service. 13 in. × 8½ in., pp. iii + 167, Falkland Islands Dependencies Survey, Stanley, 1960. Price: £1.

METEOROLOGICAL OFFICE NEWS

Following a meeting of the Meteorological Research Committee at Bracknell on 21 November 1961, Professor H. Bondi gave a lecture on "Special Relativity". This was the first lecture to be given in the new lecture theatre, which was filled to capacity by members of the staff from headquarters and outstations.

CORRIGENDA

The key to Figure 4 on page 8 of the January 1962 *Meteorological Magazine* is incorrect. It should read:

o————o initial radiosonde ascent
x--------x actual ascent 24 hours later
●——● predicted ascent 24 hours later