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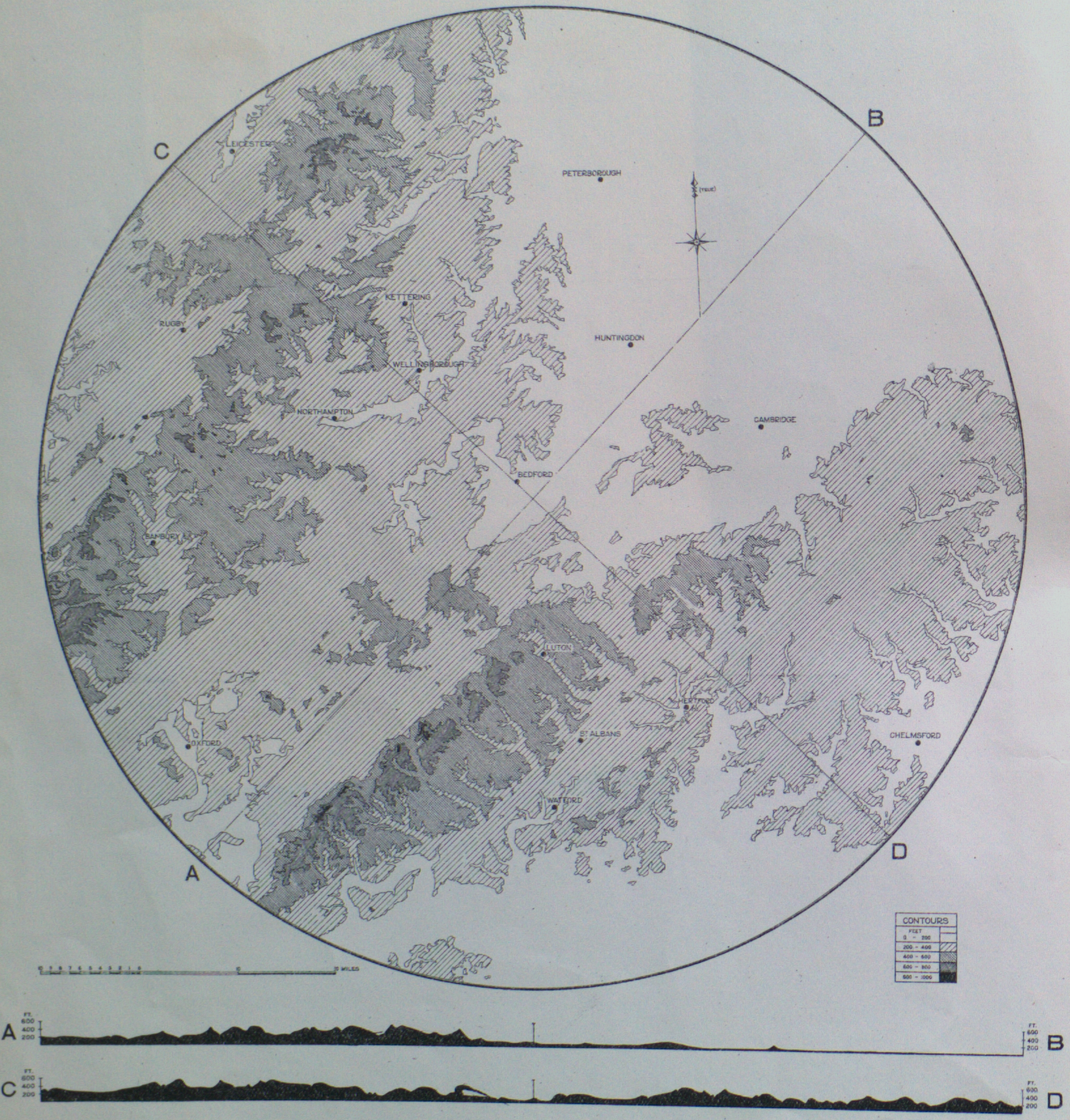

FIG. I.

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AIR MINISTRY

METEOROLOGICAL OFFICE

GEOPHYSICAL MEMOIRS No. 54

(*Fourth Number, Volume VI*)

THE STRUCTURE OF WIND OVER LEVEL COUNTRY

Report on Experiments carried out at the Royal Airship Works, Cardington

By the late M. A. GIBLETT, M.Sc.

(Superintendent of the Airship Division of the Meteorological Office)

and other Members of the Staff of the Office

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PREFACE

The Airship Services Division of the Meteorological Office was established in 1924 to provide the highly specialised meteorological information required in connexion with the construction and navigation of airships. The new Division was placed in charge of the late Mr. M. A. Giblett, who had already exhibited unusual scientific and administrative abilities. When in 1925 the Aeronautical Research Committee asked the Meteorological Office to advise on certain features of the structure of the wind in connexion with airships it was decided to place the work in the hands of the Airship Services Division. Mr. Giblett took up the problems involved with characteristic ability and energy. The various steps of the inquiry are set out in Part I of the *Memoir*, from which it will be clear that the investigation developed into a large undertaking.

During the course of the investigation practically every member of the staff of the Airship Services Division has taken some part in the work. As soon as the specified wind conditions occurred the instruments had to be manned and the observations taken, at whatever time of day. The working up of the records was a large piece of work and had to be undertaken when other more pressing duties permitted. The credit for the accomplishment of this piece of team work must be mainly shared by the whole staff of the Airship Services Division, but nevertheless certain members of the staff took a predominating part in the work.

Mr. Giblett's great interest in, and direction of, the work has already been mentioned. Mr. B. C. V. Oddie was in charge of the installation of the instruments. He devoted the greater part of his time to this work from its inception until he left the Division at the end of 1930. He took a large part also in the reduction of the records and helped Mr. Giblett to draft Part I of the *Memoir.*

In April 1929 Mr. Giblett became anxious to complete the work which had already been in hand for nearly four years; but there were still a large number of records to be worked up and a few more observations to be made. He therefore decided that the wind-structure work should have first priority and he employed almost the whole meteorological staff at Cardington on the investigation and put Mr. C. S. Durst in charge. Preparations for the trial flights of R.100 and R.101, however, soon caused an almost complete cessation of work on the investigation and when Mr. Giblett left on the last voyage of R.101 little more than Part I of the report had been drafted, but he had discussed with Mr. Durst the form and scope of the whole report.

The Airship Services Division has been in charge of Mr. W. C. Kaye since the disaster and he has placed at the disposal of Mr. Durst all the help he required. Mr. A. F. Crossley took over the mathematical problems and the mathematical sections are largely due to him. During the work Mr. Durst formed a theory of the structure of the wind which in many respects is novel and appears to be supported by the observations; this theory is set out in Part III under his name.

The rest of the report, however, is the team work of the Division and no attempt has been made to indicate the parts written by the individual members of the Division. I should like to take this opportunity of expressing my personal thanks to everyone who has taken part in this investigation; to my colleagues on the Wind Structure Sub-Committee of the Aeronautical Research Committee, to the members of the Airship Services Division, and to the staff of the Instruments Division; and I can only hope that the usefulness of the results will prove commensurate with the devotion displayed throughout the investigation.

G. C. SIMPSON,
Director.

Meteorological Office,
London,
November 1, 1931.

THE STRUCTURE OF WIND OVER LEVEL COUNTRY

INTRODUCTION

The research into the structure of the wind which is the subject of the following report was based on the detailed study of a large number of anemograph traces and of many statistical data. It has been necessary to include a large mass of these data, both in the form of diagrams and of tabular matter in the report, with the inevitable consequence that on a first reading difficulty will be experienced in following the line of argument and in clearly seeing the approach to the final conclusions. It has therefore been decided to give in this introductory chapter a short description of the results of the investigation to guide the reader through the great mass of detail of which the report itself consists.

Common experience teaches that the motion of the air in a wind is not a steady flow but consists of gusts and lulls accompanied by small changes in direction. These variations are commonly ascribed to eddies embedded in the general steady flow, and in so far as these eddies are visualised they are supposed to consist of more or less circular disturbances travelling with the wind. When the flow in an eddy coincides with the wind direction the velocity is increased and a gust is experienced; while when the flow in the eddy is against the general wind direction a lull occurs. The work of G. I. Taylor and others indicates that the axes of such eddies are orientated in all directions so that the variations from steady flow are equal in all directions, up and down as well as along and across the general stream of air.

In the present investigation anemographs were used fitted with drums which revolved once in 10 minutes instead of once in twenty-four hours (i.e., at 144 times the normal rate) in order that the velocity trace should be drawn out sufficiently to allow of the structure of the wind between a gust and a lull to be investigated. It was then found that the wind velocity does not change regularly backwards and forwards between gusts and lulls, but that the velocity rises rapidly to a maximum (the gust) then falls off slowly to a minimum (the lull), and superposed on this general change there are many smaller irregular oscillations.

A trace of this nature—called an "ultra-quick run" trace—is shown at the bottom of Plate I. This trace is in two parts, the upper one showing the wind speed and the lower one the wind direction. The numbered arrows are spaced at intervals of 30 seconds. A complete gust and lull is shown between the arrows marked 3 and 7. A rapid rise in velocity from 10 to 20 miles an hour preceded the gust, then the velocity fell relatively slowly to its minimum at 7. Another gust occurred at 12 and its lull about 45 seconds later. For convenience of reference a trace of a typical gust and lull as shown on an "ultra-quick run" trace is reproduced here as Fig. A. The rapid rise in velocity to the gust is shown just before the dotted line, then the velocity falls slowly to the lull five minutes later. Thus the gust and its associated lull extend from the dotted line to the end of the diagram. On this part of the trace, however, will be seen many irregularities. These irregularities are of very short period and the velocity recorder cannot follow them completely; they are, however, much more clearly shown on the direction trace as the wind vane can follow short-period variations much more closely than the relatively slow-moving pressure float.

An inspection of the direction trace shows that the main gust and lull do not affect the direction greatly, in fact the changes in direction produced by the rapid irregularities are as large if not larger than the changes produced by the main gust and lull. It is clear from this that we have to deal with two kinds of disturbance: (*a*) the long-period gust and lull and (*b*) disturbances of a much shorter period. Some light is thrown on the difference between these two types of disturbance by an investigation of the meteorological conditions in which they occur.

It is found that the large type of disturbance—the gust and lull—is most developed when the vertical temperature gradient (lapse-rate) is adiabatic or super-adiabatic, while it disappears almost entirely when temperature inversions form over the surface. On the other hand the smaller disturbances are little affected by the lapse-rate and often persist after the lapse-rate near the surface has changed from super-adiabatic to inversion. If, however, the inversion becomes very pronounced near the ground even the rapid disturbances disappear.

A good example of the effect of the lapse-rate on the two types of disturbance is shown on Plate IV. From the thermograph records at the top of this plate it will be seen that until 17h. the temperature at the high-level thermometer (thick line) was lower than the temperature at the low-level station (thin line) 170 feet lower. After 17h. a very strong inversion set in with the temperature at the upper station 7° F. higher than at the lower station. After 21h. the inversion was greatly reduced but did not entirely disappear. Looking now at the wind traces on this plate it will be seen that until 17 h. the velocity trace shows very marked gusts and lulls as well as small disturbances. The latter are best seen by the thickening of the direction trace. When the inversion was pronounced between 18h. and 20h., both types of disturbance disappeared although there was little change in the wind velocity—at the upper anemometer the wind velocity actually increased at this time. With the decrease in the intensity of the inversion just after 20h. rapid disturbances again make their appearance but there are practically no gusts and lulls, the appearance of the record after 20h. being entirely different from its appearance before 17h.

In Part III C. S. Durst puts forward a theory to explain the two types of disturbance. The short-period disturbances he considers to be eddies or vortices set up in the main air stream by friction on the ground and by obstructions such as trees and buildings. This frictional eddying, when once set up, persists for a long time even with a small surface inversion, but if the inversion becomes very pronounced the eddies are damped out as all other random motion is damped out in the stable air of an inversion. Frictional eddies have their axes in all directions, and therefore the motion of the air which they superpose on the main air stream is equal in all directions; so that the up and down currents are equal to the variations in the horizontal velocity, as described by G. I. Taylor. The measurements made on frictional eddies show that their diameters are of the order up to 50 or 100 feet.

The larger disturbances which give rise to gusts and lulls are, however, according to Durst's theory, of an entirely different nature, and are not just frictional eddies grown to a much larger size. The fact that they only occur when the lapse-rate is either adiabatic or super-adiabatic indicates that they are due to convection currents set up in an unstable atmosphere. If it were possible to arrange a perfectly still unstable atmosphere a regular motion would soon develop within it. The whole atmosphere would arrange itself into vertical compartments like a vast honeycomb, in each cell of which the air would rise in the centre and descend around the sides. The same effect would happen in a modified form if the air were in motion as a whole, and many experiments have been recently made in the laboratory to study the form of such "convection cells" with different types of air motion. It is on the result of such experiments that Durst has based his theory of these larger disturbances which he calls convectional eddies.

The upper portion of Fig. 81, page 60, represents a vertical section through an air current. Three cells are shown and the air motion in each is roughly indicated by arrows. The thick lines indicate the walls of the cells. These walls are, of course, immaterial but they are real in the sense that the air from one cell does not cross the wall into the next cell. The cell travels with the mean velocity of the wind and if this mean velocity is subtracted from the motion of every air particle the motion within the cell is then shown; this has been done in the second compartment of Fig. 81. The motion within the cell is not the same as that described for a stationary cell, for the ascending current is not in the middle but mainly along the rear wall while the descending current is mainly along the forward end of the cell.

The air which descends in the forward part of the cell is moving with the velocity of the upper layers and when it reaches the ground it moves forward at first with this velocity. But its contact with the ground has three effects: (*a*) it causes a drag, this reduces its forward motion, (*b*) it becomes churned up and so full of frictional eddies, and (*c*) it becomes warmed up because by hypothesis the ground is warm. When the air approaches the end of the cell it is relatively warm and therefore rises and travels along the wall of the cell. At a certain height in the atmosphere condensation takes place and cloud appears. At the top of the cell the air moves forward and then downwards to complete the circuit of the cell. A cloud forms over each cell and is thicker in the rear than in the forward end. The air at the ground just in front of a cell wall is moving slowly, is full of friction eddies and is

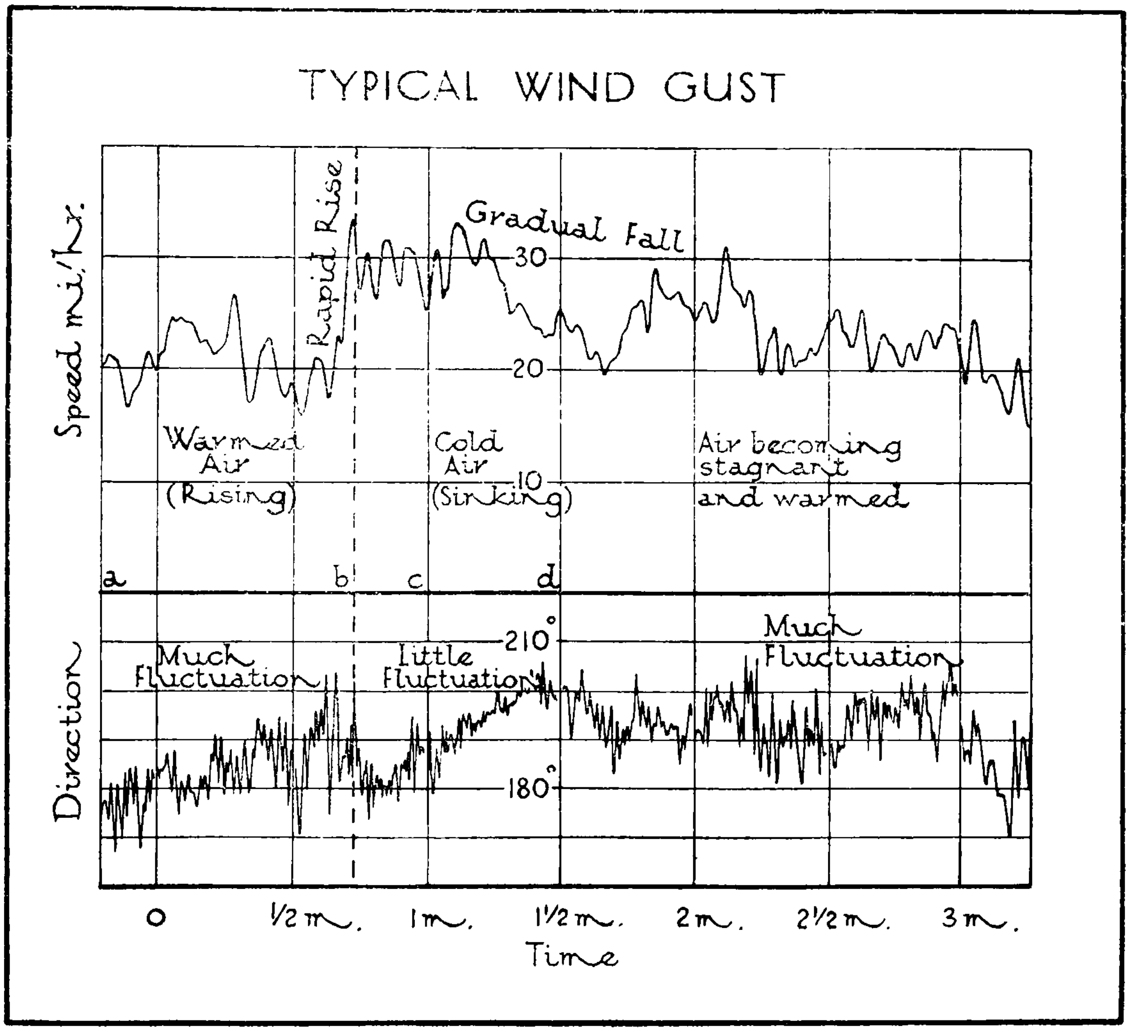

Fig. A.

warm, while behind the cell wall the air at the ground is moving rapidly, has few eddies and is cold. All these characteristics are shown in Fig. A which is taken from an actual record. The air in front (from *a* to *b* of the figure) was moving at only 20 miles an hour, it was warm and the direction trace shows that friction eddies were highly developed. At the dotted line the new air in the next cell appears at the surface. Its velocity is 33 miles an hour, it is relatively cold and the direction trace between *c* and *d*, shows little fluctuation, indicating that friction eddies have not yet formed. From *d* to the end of the diagram the velocity decreases, friction eddies form and the air becomes warmer. The whole process is repeated as the next cell crosses.

If this scheme is correct a gust and its accompanying lull mark the passage of a cell across the station. From measurements made on the wind records the length of a cell of this nature in the direction of the wind is between 3,000 and 8,000 feet, the dimensions varying greatly from cell to cell. Also the height to which the cells extend in the atmosphere is very variable; but in most cases they extend up to and beyond 1,500 feet.

In calm air the ground plan of a convection cell is a more or less regular polygon, but in moving air the plan takes the shape of a horseshoe. The cells are then arranged one behind the other as indicated in the lower compartment of Fig. 81. This diagram, which is in accordance with laboratory experiments, indicates that the cells are longer along the wind than at right angles to it. The observations confirm this conclusion but do not give many data from which to determine the average width; what little information there is indicates that the width varies between 600 and 2,000 feet.

On this theory it is easy to see why convectional eddies disappear as soon as inversions set in. An inversion prevents vertical motion of air and so breaks up the circulation on which the formation of the cells depends.

The conception of two distinct types of eddies—frictional eddies and convectional eddies—is novel and helps to explain many of the details of the structure of the wind revealed in this investigation; but it raises important questions in connexion with the application of the theory of turbulence to the motion of the atmosphere. This problem is touched on in the report and it appears that the analogy between the coefficients of viscosity and turbulence cannot be rigorously upheld within about 1,500 feet of the surface under ordinary daylight conditions, but that usually at night it can be applied down to about 50 feet of the surface.

PART I—HISTORY AND DESCRIPTION OF THE INSTALLATION

§ 1—THE ORIGIN OF THE INVESTIGATION

The origin of the investigations, the results of which form the main part of this report, may be traced to the breakaway of H.M. Airship R.33 from the mooring mast at Pulham, Norfolk, on April 16, 1925. The examination conducted by the Committee of Technical Inquiry into the technical causes of the breakaway served to emphasise what was already beginning to be appreciated, viz., that the rapid fluctuations of the wind in gusts and squalls may give rise to appreciable lateral forces on an airship moored at a tower, as distinct from forces in a purely axial direction, and that due allowance in design and operation must accordingly be made for these large lateral forces.

In the same connection an inquiry was addressed to the Meteorological Office on April 30, 1925, by the Airship Co-ordinating Sub-Committee of the Aeronautical Research Committee for information as to "The changes in wind velocity and direction in gales." This led up to the preparation of a memorandum summarising the knowledge as to wind structure available at the time for use in connection with the problem of airship mooring. This memorandum immediately served to show the need for further full-scale investigational work with anemometers of more open time scale than those in normal use at meteorological observing stations.

The Airship Co-ordinating Sub-Committee and the Committee of Technical Inquiry into the breakaway of R.33 jointly recommended that, as information as to wind structure in relation to airship mooring was scanty, it was essential for future airship development to secure appropriate observations of the rate of change of wind speed and direction and the horizontal extent of eddies. As a result, the Aeronautical Research Committee appointed a Wind Structure Sub-Committee "to review existing information on the subject of variations in the velocity and direction of natural winds, and to decide what experiments should be carried out on this subject in order to obtain sufficient data for calculating stresses likely to arise in aircraft." The members appointed were Professor L. Bairstow, C.B.E., F.R.S., Dr. G. C. Simpson, C.B., F.R.S., and Professor G. I. Taylor, M.A., F.R.S., with Mr. J. L. Naylor as secretary. Lieutenant-Colonel O'Gorman, C.B., D.Sc., also joined as an additional unofficial member. The Committee held its first meeting on February 17, 1926, when Mr. M. A. Giblett, Superintendent, Airship Services Division, Meteorological Office, was also present.

§ 2—THE PROBLEM TO BE INVESTIGATED

The memorandum summarising existing information referred to above was placed before the Wind Structure Sub-Committee at this first meeting.

The need for carrying out further experiments was, however, already fully realised and the steps to be taken were discussed. It was clear at the outset that a network of anemometers working on a very open time scale would be required, and the problem was to decide on the number and distribution of the instruments, on their type, on the site for the experimental work and in whose charge the work should be placed.

As regards the type of instrument, it was natural to employ the Dines pressure-tube anemometer, a standard instrument in the Meteorological Office, provided that it could be adapted for the purpose, and provided that it would be possible to interpret the records when the time scale was opened out to many times the normal. Some examples of records on a time scale some 144 times the normal had recently been obtained with a single instrument at Kew Observatory, Richmond. Both speed and direction ribbons were so resolved into distinct oscillations, but the questions of damping and lag in the case of the speed records and of the reality of all the oscillations in the direction records needed consideration. An alternative proposal had been received from Mr. R. A. Watson Watt, Superintendent, Radio Research Station, Slough, Bucks, with plans for a new type of electrically recording anemometer based on the Thomas ultra-micrometer system, the instruments to be mounted on the wireless masts at the Radio Research Station. For a number of years past the Meteorological Office had, on the initiative of Lieutenant-Colonel E. Gold, D.S.O., F.R.S., Assistant Director, with successive Superintendents of Instruments—Mr. R. Corless, Mr. F. Entwistle and Mr. E. G. Bilham—been investigating the characteristics of the Dines anemometer in matters of detail and approaching a standard design. In February, 1925, certain outstanding but important points were referred to the National Physical Laboratory for experimental examination, and, by the time the Wind Structure Sub-Committee met, enough information was available to enable a provisional decision to be taken to the effect that the Dines pressure-tube anemometer—modified in the light of the results of the experiments then in progress at the National Physical Laboratory to determine the sensitivity of its record of wind speed—would be a suitable instrument for the required observations of wind speed, at any rate in the first instance.

The Baxendell direction recorder was decided on as giving a more open direction scale than the direction recording device fitted to the normal Dines instrument. But it was realised that, whichever direction recorder were employed, some attention would first have to be given to the effect of the inertia of the vane and the rigidly attached portion of the direction recording system. If, after receiving an initial transverse impulse, the vane executed a number of small oscillations not due to wind fluctuations, as appeared to be the case from the Kew sample records, then it would have to be decided whether these would be such as to render the interpretation of the records impossible for the purpose in hand. This point was subsequently investigated by the National Physical Laboratory, at the request of the Meteorological Office, with the result that the Baxendell direction recorder was adopted for the records on the open time scale. In later paragraphs the characteristics of the instruments employed for recording wind speed and direction and the interpretation of the records are dealt with in greater detail.

Further decisions of the Sub-Committee at the meeting on February 17, 1926 were that the observations should be made with a network of four sets of instruments, three sets at the corners of an equilateral triangle having sides of 700 feet (approximately the length of each of the two new rigid airships R.100 and R.101), and a fourth set at the middle point of one side, the orientation of this side being chosen to give the greatest chance of getting a gale blowing along it. This point had been discussed with the Directorate of Airship Development at the Royal Airship Works, Cardington, and the decision was in accordance with the requirements of that Directorate. An electrically controlled time-marking device should be provided for each set of instruments, with a central control. Questions of cost and ease of working led to a decision that the height of the anemometer vanes above ground should be 50 feet, although the mooring tower as at present developed in this country is 200 feet high. It was further decided that the work should be in charge of the Superintendent of the Airship Meteorology (later Airship Services) Division of the Meteorological Office, and that the site for the installation should be one which had been ascertained to be available at the Royal Airship Works, Cardington, Beds., and which had the advantage of being very open and free from the influence of trees. Further consideration of Mr. Watson Watt's proposals was to be deferred until it was seen whether any more detailed information was required beyond that given by the network of Dines instruments. The National Physical Laboratory had reported on Mr. Watson Watt's proposals, and it was clear that the instrument would in all probability be too sensitive for the immediate purpose of the investigations. In any case, it would require considerable development work and would not be of the same ease of operation as the mechanical system adopted. The exposure, too, at the Radio Research Station had been examined and was not at all a good one for the purpose owing to surrounding trees.

Shortly after the meeting at which the preceding decisions were taken, it was decided that the cost of the research should be borne against the Meteorological Office Vote, Research Sub-Head. One complete instrument was then ordered for trial purposes pending the completion of the experiments at the National Physical Laboratory on which the decision to proceed with the Dines and Baxendell instruments would ultimately depend.

§ 3—DESCRIPTION OF THE SITE

The installation at present available (1931) at Cardington for the investigation of wind structure and allied problems has been built up in stages and its complete state will now be described. It consists not only of the special installation recommended by the Wind Structure Sub-Committee, but must be regarded as including certain other instrumental equipment primarily installed to meet the requirements of airships when actually operating at the Cardington base.

Fig. 1 shows the situation of the base which is at the centre of the map, relative to the country for a distance of 50 miles round in each direction. The site of the installation for wind-structure research is in a relatively flat valley running approximately south-west to north-east. The installation lies just to the right of the central point of section CD. The width of the Ouse valley at this point is some 8 to 10 miles and the hills immediately on either side at no point rise above 450 feet above mean sea level (the apparatus being situated on ground at 100 feet above mean sea level). The immediate surroundings are shown in more detail in Fig. 2. The four anemometers of the special installation with vanes 50 feet above ground are marked A, B, C, D. At E is a small auxiliary control hut, without anemometer, the purpose of which is referred to later in the description of the time-marking system (see § 5). The land in the immediate neighbourhood of the anemometers is used for agricultural purposes and is very open in a westerly direction, being broken only by a few trees and hedgerows. Between north-east and north-north-west of the apparatus lie the Royal Airship Works on a low ridge, the distance of the nearest building being about half a mile. At approximately the same distance to the south-east lies a small hamlet. Point F (at the centre of the upper circle) marks the position of the

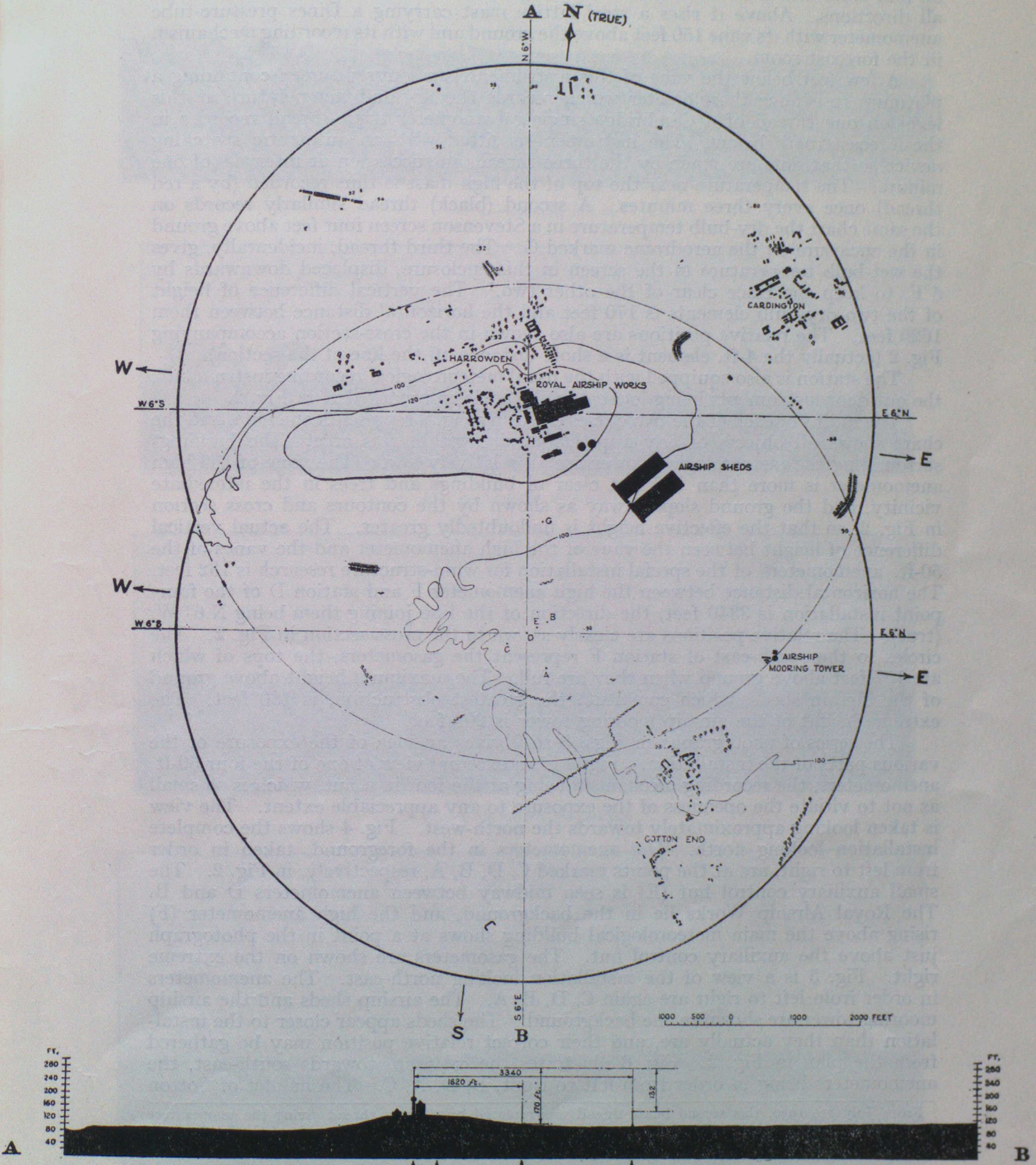

FIG. 2.—MAP SHOWING THE TOPOGRAPHY WITHIN ONE MILE OF THE ROYAL AIRSHIP WORKS.

main meteorological building adjacent to the administrative building of the Royal Airship Works. The meteorological building is in the form of a tower with the forecast room on the uppermost floor. This room has windows completely round all four sides and is sufficiently elevated to give a free view to a distant horizon in all directions. Above it rises a steel lattice mast carrying a Dines pressure-tube anemometer with its vane 150 feet above the ground and with its recording mechanism in the forecast room.

A few feet below the vane of this instrument is a louvred screen containing a platinum resistance thermometer which records the dry-bulb temperature at this level on one thread of a Cambridge single-galvanometer triple-thread recorder in the forecast room below. The instrument is fitted with an automatic switching device so that dots are made by the three threads in succession at intervals of one minute. The temperature near the top of the high mast is thus recorded (by a red thread) once every three minutes. A second (black) thread similarly records on the same chart the dry-bulb temperature in a Stevenson screen four feet above ground in the enclosure on the aerodrome marked G. The third thread, incidentally, gives the wet-bulb temperature in the screen in this enclosure, displaced downwards by 5°F. to keep the trace clear of the other two.[1] The vertical difference of height of the two dry-bulb elements is 170 feet and the horizontal distance between them 1620 feet. The relative positions are also shown in the cross-section accompanying Fig. 2 (actually the 4-ft. element is a short distance off the line of the section).

The station is also equipped with the usual meteorological recording instruments, the out-door instruments being located in the enclosure marked H in Fig. 2.

The radius of each of the two circles enclosing Fig. 2 represents one mile, and the chart shows all objects of any appreciable size within this area. The buildings surrounding the meteorological tower are all relatively low. The vane of the high anemometer is more than 100 feet clear of buildings and trees in the immediate vicinity, and the ground slopes away as shown by the contours and cross section in Fig. 2, so that the effective height is undoubtedly greater. The actual vertical difference of height between the vane of the high anemometer and the vanes of the 50-ft. anemometers of the special installation for wind-structure research is 132 feet. The horizontal distance between the high anemometer F and station D of the four-point installation is 3340 feet, the direction of the line joining them being N.6° W. (true). The relative positions are clearly shown in the cross section in Fig. 2. The circles to the south-east of station F represent the gasometers, the tops of which are 107 feet above ground when they are full. The maximum height above ground of the airship sheds, which constitute the greatest obstruction, is 180 feet. The extreme height of the airship mooring tower is 200 feet.

The series of photographs in Figs. 3 to 9 gives an idea of the exposure of the various parts of the installation. Fig. 3 is an external view of one of the four 50-ft. anemometers, the recording mechanism being at the foot in a hut, which is so small as not to vitiate the openness of the exposure to any appreciable extent. The view is taken looking approximately towards the north-west. Fig. 4 shows the complete installation looking north. The anemometers in the foreground, taken in order from left to right, are at the points marked C, D, B, A, respectively, in Fig. 2. The small auxiliary control hut (E) is seen midway between anemometers D and B. The Royal Airship Works lie in the background, and the high anemometer (F) rising above the main meteorological building shows at a point in the photograph just above the auxiliary control hut. The gasometers are shown on the extreme right. Fig. 5 is a view of the installation looking north-east. The anemometers in order from left to right are again C, D, B, A. The airship sheds and the airship mooring tower are shown in the background. The sheds appear closer to the installation than they actually are, and their correct relative position may be gathered from the plan in Fig. 2. Fig. 6 illustrates the exposure towards south-east, the anemometers being in order from left to right, B, D, A, C. The hamlet of Cotton

[1] From July 17, 1930, this second black thread was replaced by a green thread giving the temperature recorded by a thermometer placed in a louvred screen and hung on the southern side of the lattice work of the tower at a height of 100 ft. above ground level.

GENERAL VIEWS OF THE WIND-STRUCTURE INSTALLATION.

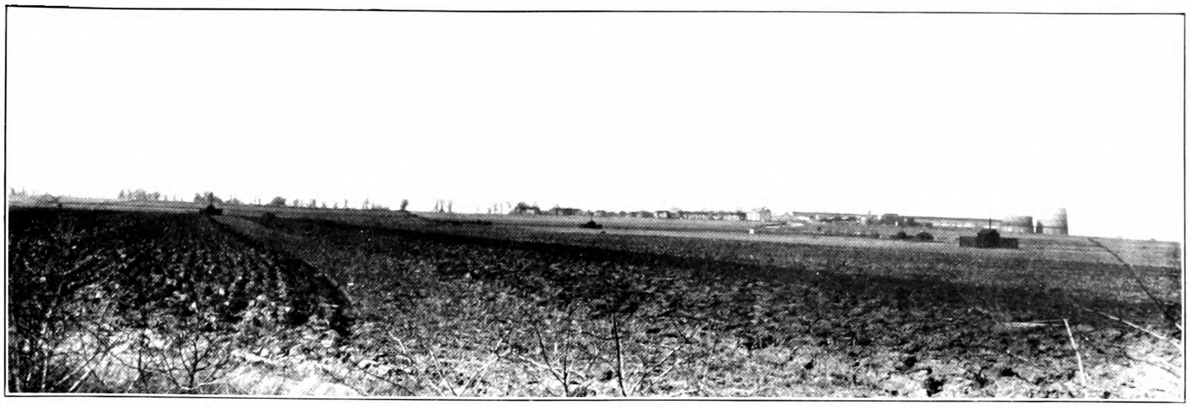

Fig. 4.—Looking north.

Fig. 5.—Looking north-east.

Fig. 6.—Looking south-east.

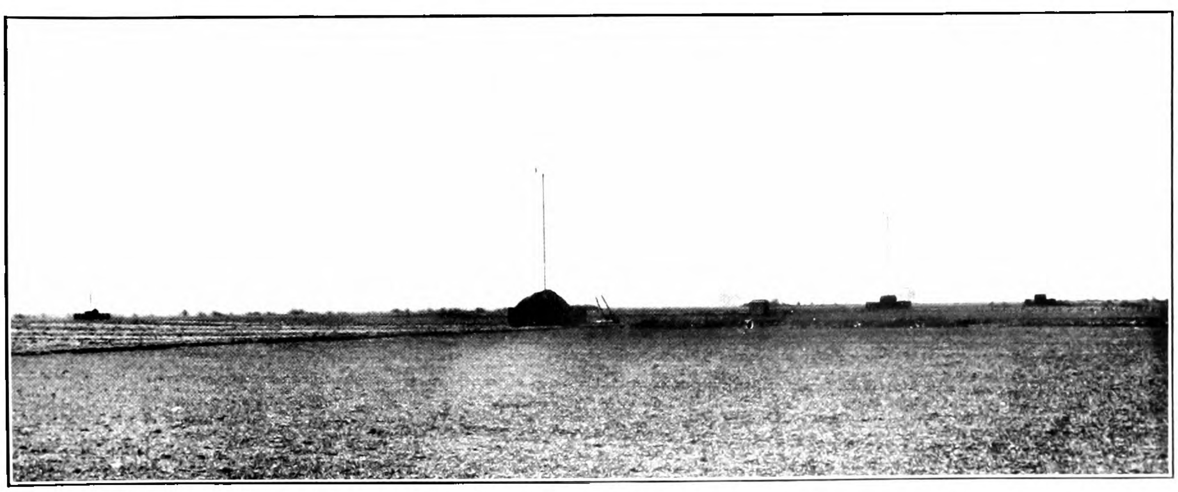

Fig. 7.—Looking south-west.

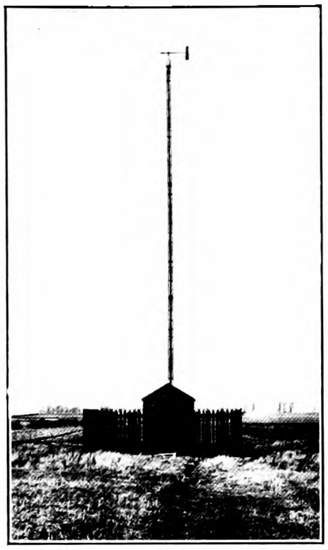

FIG. 3.—FIFTY-FOOT ANEMOMETER MAST AND HUT.

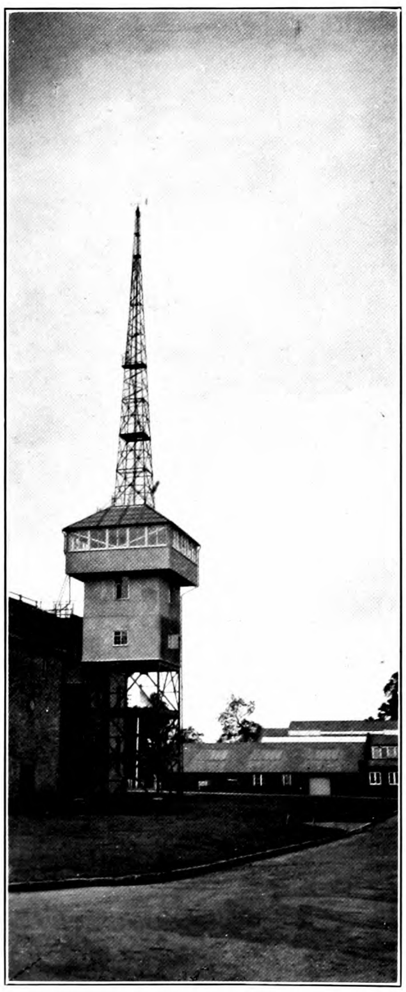

FIG. 8.—METEOROLOGICAL TOWER SHOWING THE HIGH ANEMOMETER.

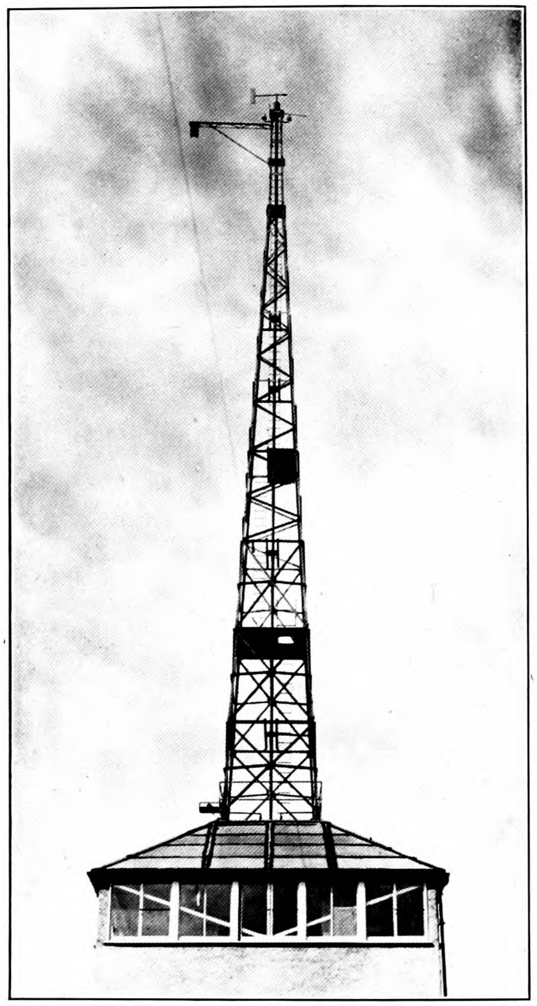

FIG. 9.—LATTICE MAST CARRYING HIGH ANEMOMETER AND THERMOMETER.

End and the low range of hills bounding the valley are included in the picture. The airship mooring tower appears on the extreme left. Fig. 7 was taken looking towards the south-west, the anemometers reading from the left being A, B, D, C. The small rick near anemometer B was removed early in the course of the experiments, but never constituted an obstruction. Figs. 8 and 9 show two aspects of the mast of the high anemometer F rising above the meteorological tower. The uppermost room in the tower is the forecast room in which the recording part of the anemometer and the electrical temperature recorder are situated. In Fig. 9 the screen containing the upper platinum element of the electrical temperature-recording installation may be seen projecting on one side near the top of the mast. (It was not in position when Fig. 8 was taken.)

§ 4—THE INSTALLATION USED

The normal forms of the instruments adopted for use in this research, viz., the Dines pressure-tube wind-speed recorder with standard Meteorological Office pattern vane, the twin-pen Dines direction-recording attachment, and the Baxendell direction recorder, are well known, though there is so far no very adequate published description of the present form of the instruments. They are described in *The Meteorological Observer's Handbook.*[1] The results of the recent research at the National Physical Laboratory (carried out by Mr. L. F. G. Simmons and Mr. F. C. Johansen) are very briefly outlined in the issue for February, 1929 of the *Meteorological Magazine.*[2] The consequent modifications introduced into the standard instrument—viz., the altered arrangement of the suction holes, the provision of the symmetrical shield round the base of the head and, most important of all in the present connection, the substitution of gas piping of one-inch internal diameter in place of half-inch compo piping for the connecting tubes—were incorporated in the instruments in use at Cardington. The symmetrical shield is clearly seen a little below the vane in Fig. 3, as are also the one-inch pressure and suction tubes running down on either side of the central mast which surrounds the light rod which rigidly connects the vane to the direction-recording mechanism in the hut below. The modifications introduced especially for the research work at Cardington consisted mainly of provision for recording on time scales more open than the normal and for the making of time marks on the records at short intervals.

The anemometer equipment at stations A to F (see Fig. 2), as it stood when the installation first reached its complete form, will now be detailed.

Stations C & D. The equipment includes Dines speed recorder and Baxendell direction recorder each with gramophone motors substituted for the normal driving clocks. The charts used with both instruments normally accommodate a record of 24 hours' duration, one inch on the chart representing $1\frac{2}{3}$ hours. In the present case the charts accommodate a record of approximately 10 minutes' duration, the time scale thus being 144 times as open as the normal. Fig. 10 shows a general view of the instruments at these stations. Fig. 11 is a closer view of the recording part of the Dines speed recorder, the special motor (with its case off) being seen below and a little to the left of the drum carrying the chart. The one-inch internal diameter compo tubing connecting the float chamber with the one-inch gas piping running up the mast appears on the right. Fig. 12 is a closer view of the Baxendell direction recorder. The special motor which controls the rate of descent of the pen carriage (on the left) is seen in its case on the right of the drum carrying the chart.

Station A. The recorders are similar to those at stations C and D, but with driving motors such that, as an alternative to the very open-scale 10-minute records, a record lasting about 2 hours, on a time scale about 12 times the normal, can be obtained. The reason for the introduction of this alternative is given elsewhere (§ 7). In the case of the direction recorder, separate motors were supplied for the

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[1] *The Meteorological Observer's Handbook*, 1926, p.104. Published by H.M. Stationery Office.
[2] *Meteor. Mag.*, 64, 1929, p.7.

two speeds. They are shown in Fig. 13. The one on the left of the standard carrying the direction-recorder drum is the gramophone motor for the very open time scale. The other is on the right, and is controlled by a pendulum, the driving power being obtained from a weight hanging from the pen carriage of the recorder. Two clutches were fitted to enable either motor to be connected to the recorder. For the speed recorder, a special clockwork motor with a very powerful spring (Fig. 14) was provided at this station, the two speeds being obtained by a simple change of gear.

Station B. A Dines combined speed and direction recorder, giving a continuous record on the normal time scale, is fitted at this station, with, in addition, provision for taking 10-minute records of speed and direction on the very open time scale similar to those at stations A, C and D. Fig. 15 shows the general arrangement of the apparatus. The left-hand drum on the speed recorder is that on which the normal continuous record of both speed and direction is made, the chart being changed once every 24 hours. The drum for the very open-scale records of wind speed is also mounted on the same float chamber and is seen on the right of the normal drum. The pen which gives the open-scale record is mounted on the same carrier as the speed pen giving the normal record, both pens thus being actuated by the same float. A closer view of the arrangement is shown in Fig. 16. The Baxendell direction recorder with the very open scale is seen in Fig. 15 in front of, and a little below, the speed recorder. It is of the same type as at stations C and D. The drum is connected to an extension of the direction rod which descends from the vane and actuates the Dines normal twin-arm direction recorder. It will be observed that the arrangements at this station are such that during periods when an open-scale record is being taken, the normal record is not broken, a simultaneous record thus being obtained on the two time scales. In both Figs. 15 and 16 may be seen two universal joints inserted at appropriate points in the rod connecting the vane to the direction recorders to allow for any lack of alignment and to reduce friction at the bearings. Such universal joints are fitted as necessary at all the stations A, B, C, D and F.

Station E. See § 5.

Station F. A Dines combined speed and direction recorder gives a continuous record on the normal time scale. In addition there is provision for transferring the open-scale Baxendell direction recorder and the drum and motor of the speed recorder from station A and fitting them to the normal instrument at station F, the ensemble resembling in arrangement the apparatus at station B. During periods when this transfer is made records may be obtained at station F on the normal time scale simultaneously with records on one or other of the open time scales (12 or 144 times the normal).

§ 5—THE TIME-MARKING SYSTEM

Stations A, B, C and D are connected electrically by a four-core underground cable. Field telephones are installed in the four huts in parallel, allowing an operator at any station to communicate with the operators at the other three stations. Station D is normally the control station. An operator must be stationed in or must visit each hut to wind the clocks and to prepare the instruments for recording. The operator at station D can then start any or all of the open-scale recorders at stations A, B, C and D simultaneously by closing a circuit with a tapping key, at which instant electro-magnets remove the brakes from the driving motors. Such an electro-magnet is seen, for example, below the chart drum in Figure 11. The motors having been started the same circuit and tapping key are used at regular intervals, determined by stop watch, to make simultaneous time marks on all the open-scale speed and direction records. In the case of the Baxendell direction recorder an electro-magnet, mounted on the pen-carrier and so descending with it (see Fig. 12), lifts the pen from the paper, thus making a short gap in the trace. On the speed records the time marks are made by an auxiliary pen placed vertically below the recording pen as seen in Fig. 11 (actually the pens were not in adjustment vertically when the photograph was taken). The operation of the control key causes

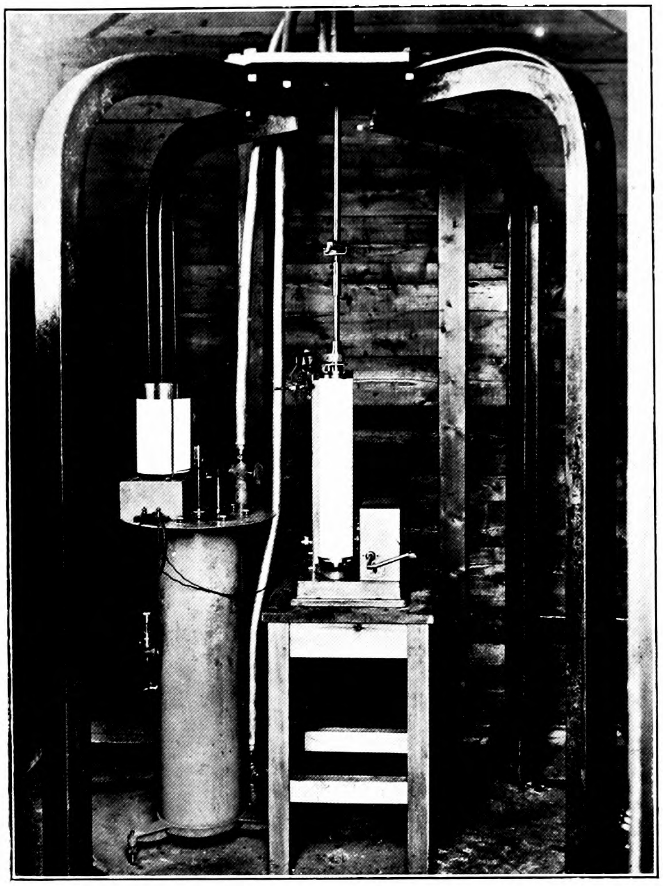


FIG. 10.—INTERIOR OF AN ANEMOMETER HUT.

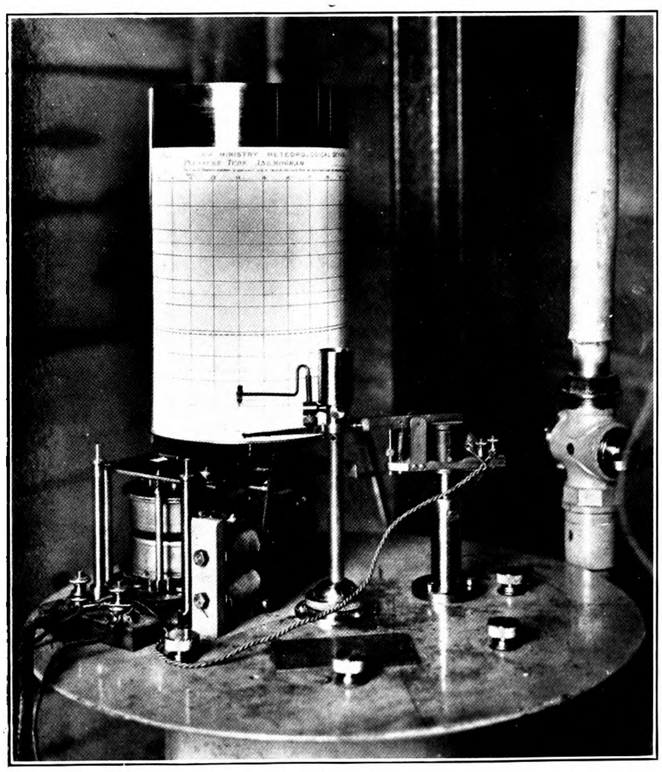


FIG. 11.—RECORDING PART OF THE DINES SPEED RECORDER FOR ULTRA-QUICK RUNS.

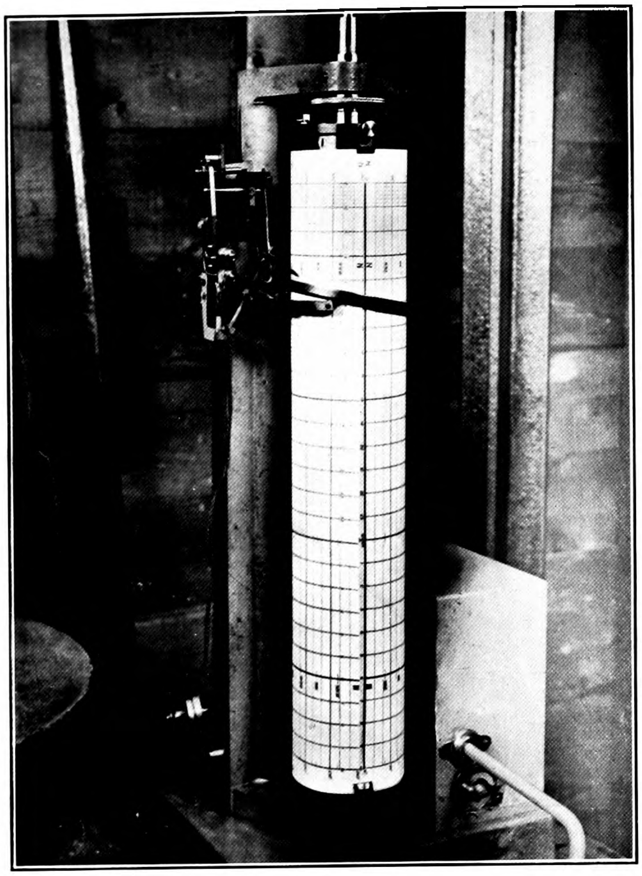


FIG. 12.—RECORDING PART OF THE BAXENDELL DIRECTION RECORDER FOR ULTRA-QUICK RUNS.

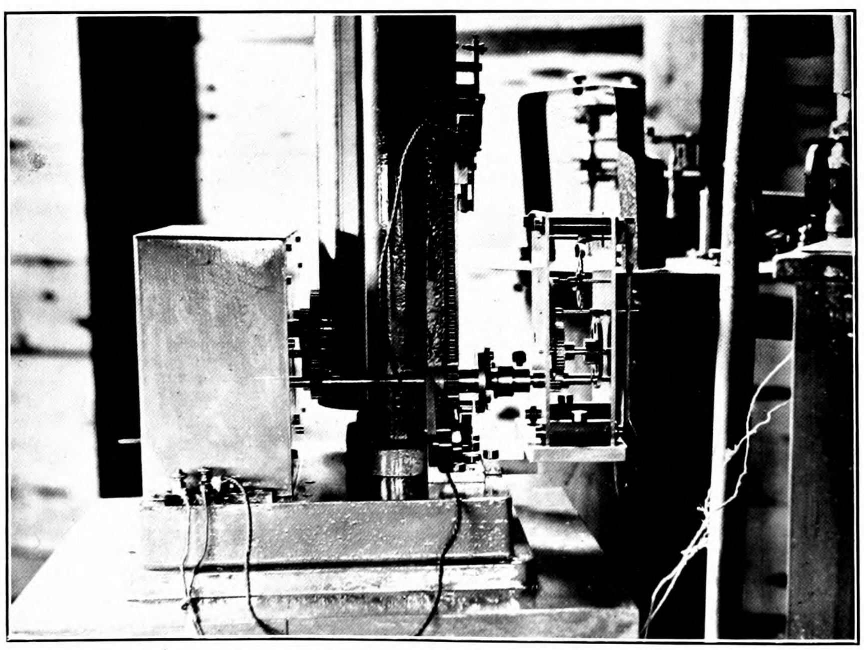


FIG. 13.—MOTORS FOR QUICK AND ULTRA-QUICK RUNS FOR DIRECTION RECORD.

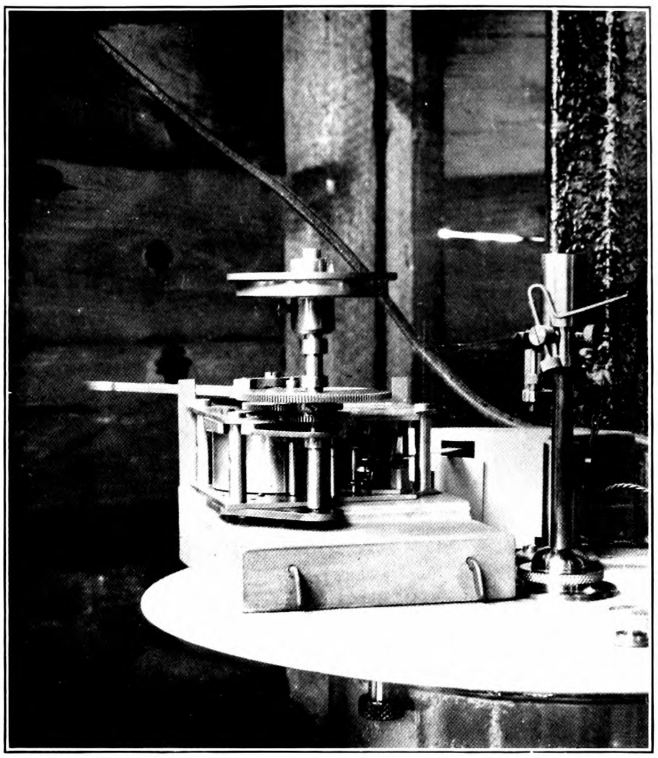


FIG. 14.—MOTORS FOR QUICK AND ULTRA-QUICK RUNS FOR SPEED RECORD.

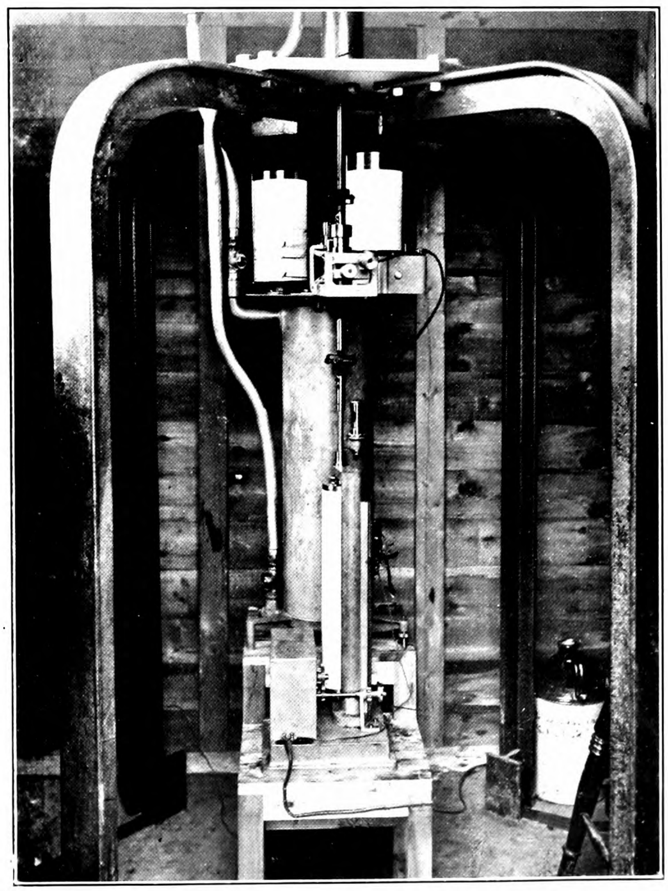


FIG. 15.—NORMAL AND QUICK-RUN ANEMOGRAPH.

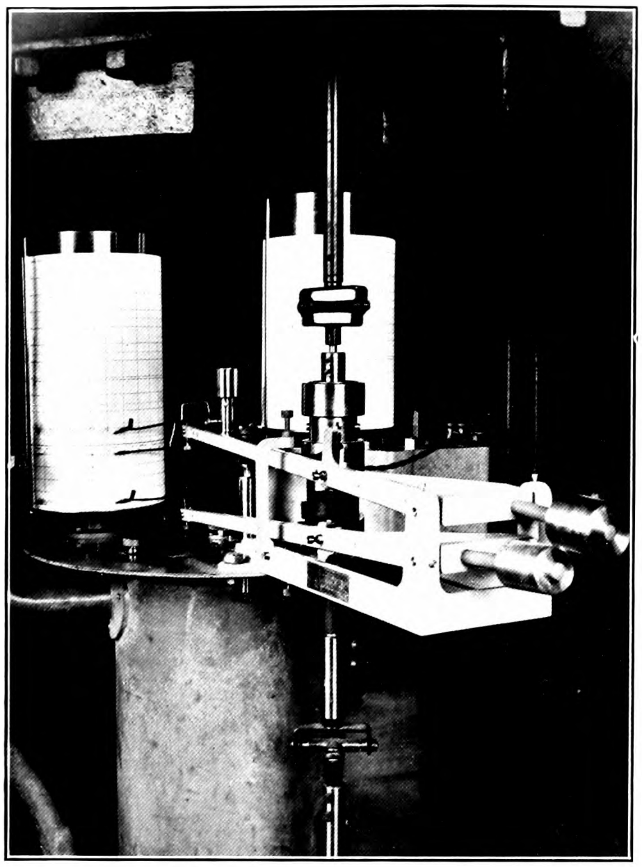


FIG. 16.—DETAILED VIEW OF NORMAL AND QUICK-RUN ANEMOGRAPHS.

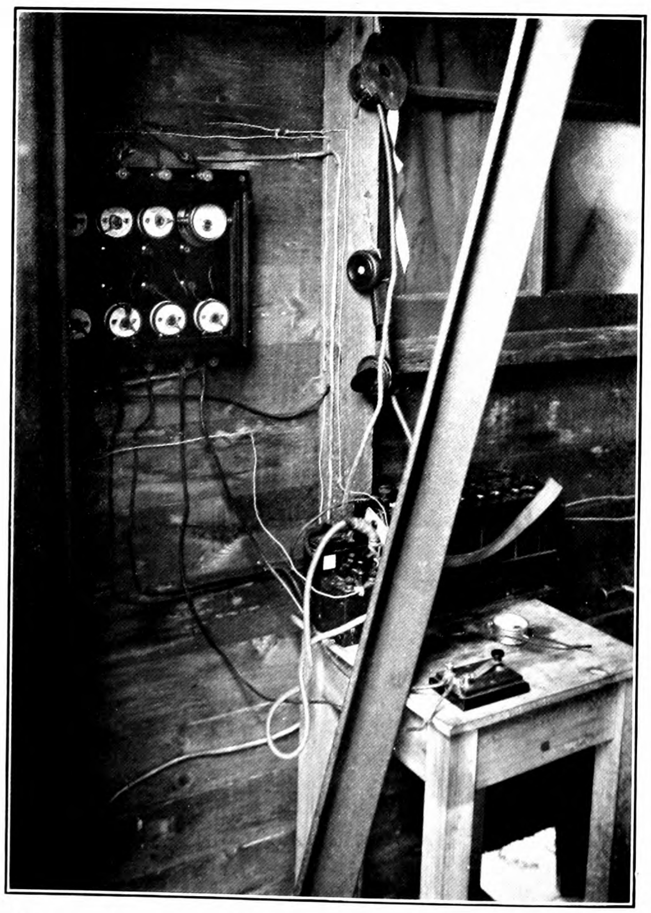


FIG. 17.—CONTROL SWITCHBOARD FOR SYNCHRONISING RECORDS.

this pen to rise about $\frac{1}{8}$ inch. Its trace on the record is therefore a straight line with " kicks " at regular intervals. A similar auxiliary pen is fitted to the normal instrument at station B (though not in position when the photographs in Figs. 15 and 16 were taken). It lies between the speed pen and the upper direction pen and draws a line on the chart in the narrow space between the speed and direction records. The electro-magnet actuating this time-marking pen is in parallel with the electro-magnets operating the time-marking pens on the open-scale recorders, and accordingly automatically marks the part of the normal record corresponding to the open-scale records. The source of power for the starting and time-marking apparatus is a 16-volt accumulator. There is a control switchboard at station D, shown in Fig. 17, to enable the operator to select the recorders which he wishes to use. In the case of 10-minute records on a time scale 144 times normal, time marks are usually made at intervals of 30 seconds. In the case of records of two hours' duration on time scale 12 times normal (not possible at stations B, C and D), time marks are usually made at intervals of five minutes.

Each instrument in the installation is heavily earth connected, but as a precaution against danger from lightning an extra hut without a mast (station E) is provided as an auxiliary control station. An operator may, from this point, start and time-mark records on any previously prepared instruments at stations A, B, C and D. In this way records can be obtained during thunderstorms without the necessity for an observer being dangerously near the anemometer masts at the actual time of the storm.

Station F is not connected electrically with stations A, B, C and D but when open-scale records are being made at station F, with apparatus transferred from station A, there is provision for time-marking the records, including the making of simultaneous time marks on the normal record at F.

§ 6—THE TYPES OF RECORD OBTAINED

Throughout this report the point at which any record was obtained is indicated by the appropriate letter A, B, C, etc., as marked against the stations in Fig. 2. In the case of temperature, station F refers to the high-level element at this point (see § 3), while station G indicates the element at 4 feet in the enclosure on the aerodrome.

Records of wind on various time scales are designated as follows :—

Normal Run. Record on normal time scale ; 1 inch represents $1\frac{2}{3}$ hour ; chart accommodates record of 24 hours' duration ; taken continuously at stations B and F.

Quick Run. Record on time scale about 12 times as open as the normal ; 1 inch represents about $8\frac{1}{3}$ minutes ; chart accommodates record of about 2 hours' duration ; may be made at station A, or alternatively, by transferring instruments, at station F.

Ultra-Quick Run. Record on time scale about 144 times as open as the normal ; 1 inch represents about 42 seconds ; chart accommodates record of about 10 minutes' duration ; may be taken simultaneously at stations A, B, C, D ; may be taken at station F when instruments are transferred from station A.

Single-Point Run indicates a record obtained at one station only.

Two, Three or Four-Point Run indicates a set of records on similar time scales, taken simultaneously at two, three or four stations.

Dual Run. See § 7.

Fig. 18 shows the lay-out of the four-point installation of 50-ft. anemometers with the directions of lines joining them.

Fig. 19 (Plate I) shows an example of a normal, a quick run and an ultra-quick run taken simultaneously. The normal and ultra-quick runs were taken at station B, these being recorded by the same head and vane. The simultaneous quick run was made at station A. In these, as in all records reproduced in this report, the successive time marks on the speed records have been numbered, and arrows bearing corresponding numbers are placed on the direction records pointing to the time gaps in the traces. In Fig. 19, the numbers placed on the quick-run speed record corres-

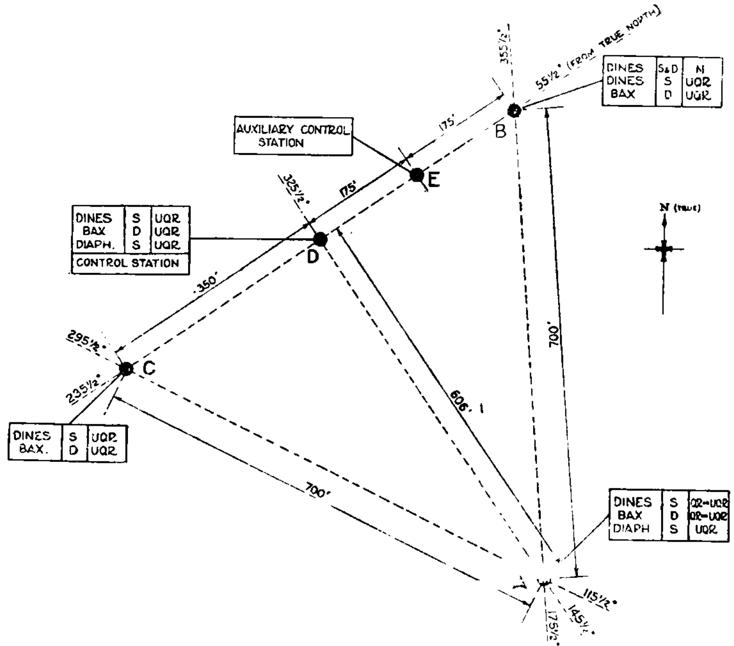


FIG. 18.—DIAGRAM SHOWING THE RELATIVE POSITIONS OF THE FOUR ANEMOMETERS.

pond with those on the quick-run direction record, but not, of course, with the numbers on the ultra-quick run records. It is seen that, while the quick run does not succeed in opening out the trace to show individual oscillations, especially for direction, the ultra-quick run does achieve this.

§ 7—THE CHANGES MADE IN THE INSTALLATION DURING THE INVESTIGATION

The observations required fall broadly into two classes, viz. :

(a) observations of short-period fluctuations in a generally steady or slowly changing wind current.

(b) observations on a time scale more open than normal of the rapid and almost discontinuous transition from one general wind current to another, such as takes place with the passage of a " front," and also observations of the rapid changes which take place in squalls such as may accompany the passage of local showers or thunderstorms.

The research originally planned provided for instruments giving only ultra-quick runs, which are essential for the observations required under (a). It was soon found in practice very difficult to obtain observations of the transient phenomena under (b) on instruments giving records of only ten minutes' duration, although some were successfully made. For this reason provision was made for the taking of quick runs. The duration of the quick-run records being two hours, the chance of catching a " front," the approximate time of arrival of which had been predicted from the synoptic weather charts is materially increased, especially as a matter of two minutes suffices to change the charts if that becomes necessary. Moreover, the time scale provided by the quick runs is sufficiently open for this type of observation.

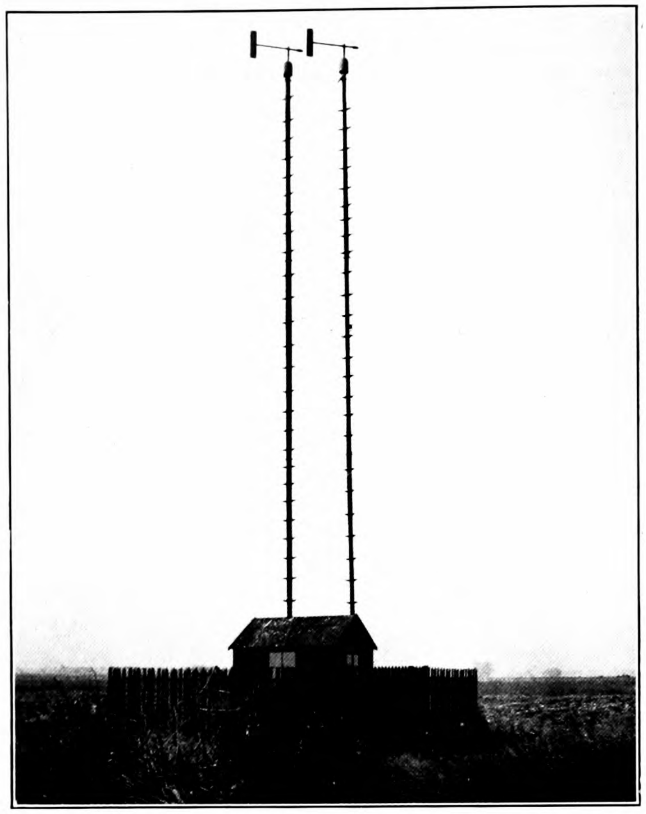
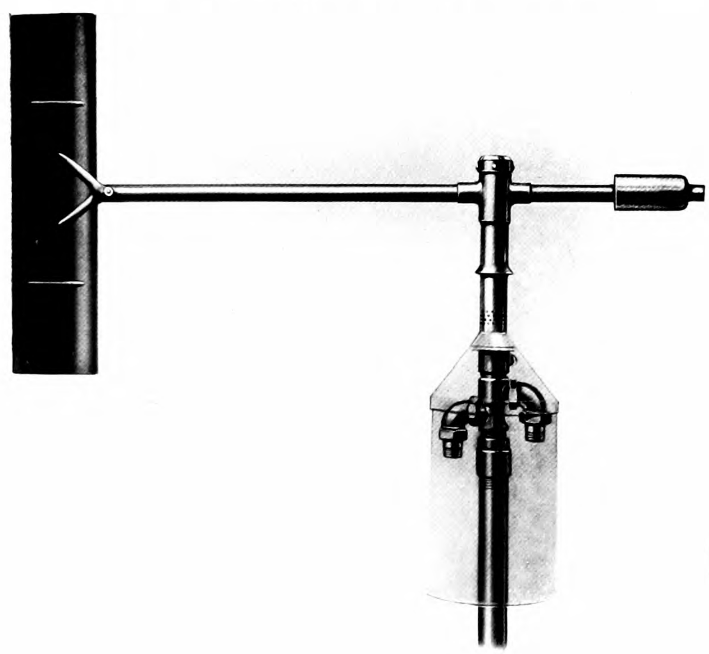


FIG. 20.—TWO ANEMOMETER MASTS SIDE BY SIDE FOR SIMULTANEOUS RECORDING.



[*Block lent by R. W. Munro, Ltd.*]

FIG. 24.—ANEMOMETER HEAD SHOWING SHIELD. THIS PHOTOGRAPH WAS MADE BY TAKING TWO EXPOSURES, ONE WITH THE SHIELD IN PLACE, THE OTHER WITH THE SHIELD REMOVED ; THE RESULT IS TO SHOW THE SHIELD IN OUTLINE WITH BENEATH IT THE DETAILS OF THE SOCKETS OF THE SUCTION AND PRESSURE PIPES.

It was found, however, that it was inconvenient to have to go nearly a mile in order to start the instrument when the passage of a " front " was anticipated. It was, therefore, decided in June, 1928 to transfer the quick-run apparatus from station A to station F. This meant that the apparatus would be in the same room as the meteorological officer who was on duty and was responsible for the working charts, and it could be started by him immediately conditions became interesting. He would be greatly assisted in this, at least during day time, by visual observations of approaching phenomena for which the elevated forecast room with windows all round is peculiarly suited.

This breaking up of the four-point installation provided a suitable opportunity of carrying out comparisons of two similar instruments operating in a natural wind as close to one another as possible, a step which, had it been convenient, would logically have been taken much earlier in the programme. Before attempting to relate the variations of wind at points 700 feet apart it would have been desirable to have made sure that two anemometers close together would give similar records. Although this was assumed at the commencement of the work, it was felt that the point should be tested at the first opportunity. A second 50-ft. mast was accordingly erected at station C, shown on the right in Fig. 20, as close as possible to the original mast consistent with the vanes not fouling. The distance between the centres of the masts is about four feet, and the direction of the line joining them $113\frac{1}{2}°$, the original mast being the more southerly of the two. Transferring instruments from other stations (D or A) to this new point, a series of simultaneous ultra-quick runs with synchronous time-marks has been made, details of which are given in § 11 (b), page 26, and Part IV, § 32 page 66. Such pairs of records made at station C are, for convenience, referred to as " dual runs."

The development of the installation and the various phases of the observing programme are indicated by the following salient dates :—

February 17, 1926.—First meeting of Wind Structure Sub-Committee (at Air Ministry).

July 20, 1926.—Station D available. Commencement of series of single-point ultra-quick runs.

July 27, 1927.—Station B equipped with normal instrument. Continuous record of speed and direction on normal time scale obtained since this date.

September 29, 1927.—Stations A, B, C and D equipped for simultaneous ultra-quick runs with provision for synchronous time marks on all records. Commencement of four-point runs.

November 17, 1927.—Second meeting of Wind Structure Sub-Committee (at Cardington).

February 17, 1928.—Third meeting of Wind Structure Sub-Committee (at Air Ministry).

April 18, 1928.—Station A equipped for quick runs as alternatives to ultra-quick runs. Commencement of series of quick runs to catch " fronts," squalls, etc.

May 17, 1928.—Station F equipped with normal instrument. Continuous records of speed and direction on normal time scale obtained since this date.

June 14, 1928.—Four-point ultra-quick runs suspended to allow of (a) transfer of quick run (and incidentally of ultra-quick run) apparatus from station A to station F, and (b) erection of second 50-ft. mast at station C, adjacent to the existing one, for comparison of two instruments recording in close proximity.

July 22, 1928.—Two masts available at station C. Commencement of comparisons of two instruments side by side.

September 27, 1928.—Quick runs at station A suspended.

October 18, 1928.—Quick-run (and incidentally ultra-quick run) apparatus from station A transferred to station F Commencement of new series of quick runs to catch " fronts," squalls, etc.

January 9, 1929.—Comparisons at station C ceased to allow of successive reduction of height of second mast to 40 ft. and 30 ft., to obtain data on variation of short-period fluctuations with height.

March 21, 1929.—Comparisons at station C with vanes at 50 ft. and 40 ft. respectively commenced.

July 3, 1929.—Fourth meeting of the Wind Structure Sub-Committee (at Burlington House).

June 18, 1930.—Comparisons at station C with vanes at 50 ft. and 30 ft. respectively commenced.

It will be seen from this statement, that during the period October 1927 to June 1928 attention was chiefly devoted to securing four-point ultra-quick runs, while single-point quick runs through " fronts," etc., have been the main object since October 1928.

§ 8—A REVIEW OF POSSIBLE INSTRUMENTAL ERRORS IN THE DIRECTION RECORDS

Before proceeding to the analysis of the observations made, it is necessary to review the possible errors to which they may be subject on account of instrumental characteristics. The present paragraph is devoted to a consideration of the direction records.

(a) *Errors of setting*.—While reasonable care was taken in setting the direction recorders to give as small a zero error as possible, no special steps were taken to secure an accuracy greater than a few degrees, partly because of the difficulty of doing so in the absence of a fine adjustment device and partly because it appeared that the main concern would be an accurate measure of changes of direction and of departures from a mean rather than a precise measure of absolute direction. In certain cases, however, where the latter was desired, the zero error was obtained on each occasion by sighting the vane on a distant object and making a corresponding mark on the chart before taking the record. This would be troublesome as a general practice and was avoided as far as possible.

(b) *Errors due to inertia of moving parts*.—These require very careful consideration. They formed, as mentioned in § 2, the subject of an investigation at the National Physical Laboratory, and the following is based on the report received by the Meteorological Office. A head and vane of the type used at Cardington were mounted in a wind tunnel, and a record obtained of the motion of the vane when released from positions inclined at 40° and 20° respectively to the direction of a steady wind of 40 ft./sec. (27·3 mi./hr.). The results are shown in Figs. 21 and 22. The motion is definitely periodic and was found to be represented by the expression

$$\theta = \theta_0 e^{-\lambda t} \sin\left(\frac{2\pi}{T}t + \varphi\right)$$

where θ is the angular displacement of the vane and t the time.

This is a solution of $I\ddot{\theta} + \alpha\dot{\theta} + K\theta = 0$

Provided θ is restricted to small values (shown by experiment to lie between $\pm 10°$), λ and T may be deduced from the characteristics of the instrument with good agreement with observed values. It is found that

where $\lambda = \dfrac{\alpha}{2I}$ and $T = \dfrac{4\pi I}{\sqrt{\alpha^2 - 4KI}}$ and further $\alpha = \dfrac{Kl}{V}$ and K varies as V^2

Where I is total moment of inertia of system
V is wind speed and
l is the leverage of the forces in the vane.

For the instrument used $I = 0{\cdot}42$ slugs/ft.^{2} $= 13{\cdot}4$ lb./ft.^{2}
$l = 2{\cdot}31$ ft.
K varies as V^2 and for $V = 60$ ft./sec. (or 40·9 mi./hr.)
$K = 31$ lb. ft./radn.

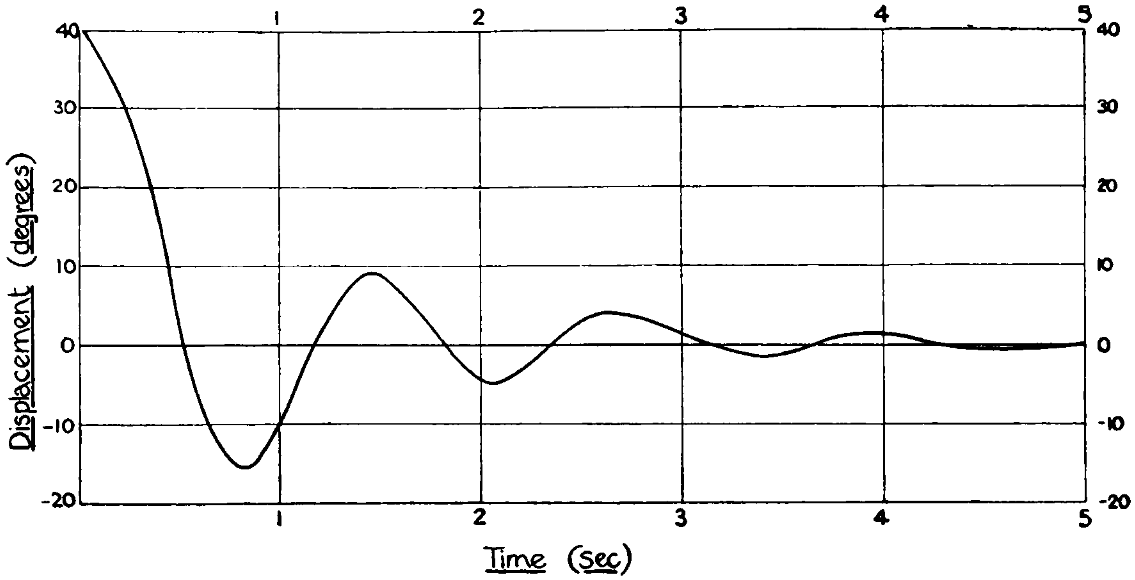


FIG. 21.

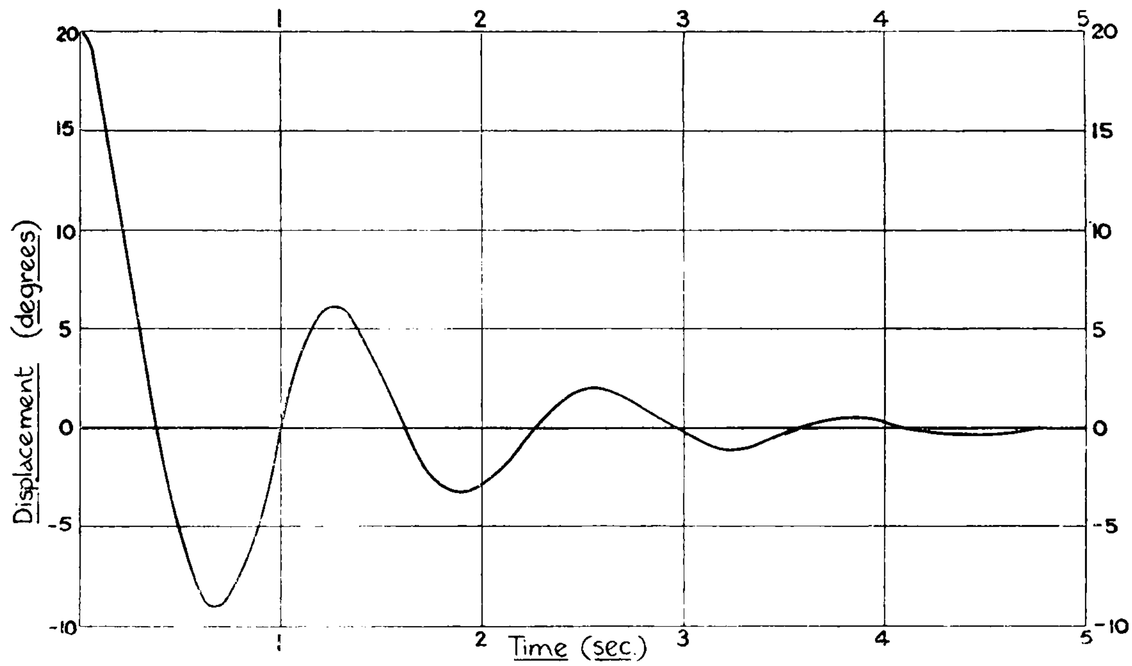


FIG. 22.

DISPLACEMENT-TIME CURVES FOR DINES HEAD.

The calculated and observed values of T, the periodic time, (the observed values having been obtained for initial displacements smaller than 10°) were :—

TABLE I

Wind speed (ft./sec.)	Wind speed (mi./hr.)	T (sec.) Calculated	T (sec.) Observed
20	13·6	2·22	2·30
30	20·5	1·48	1·65
40	27·3	1·11	1·25
50	34·1	0·89	1·05
60	40·9	0·74	0·80
70	47·7	0·63	0·67

Substituting for K and α in the above formula for T we see that T varies inversely as V so that the curves given in Figs. 21 and 22 may be adjusted in this respect for other values of V by an appropriate variation of the time scale. Also λ varies directly as V, so that λT is independent of V, and therefore the ratio in which the amplitude of successive swings is decreased is independent of the wind speed.

The application to one case of a varying wind was dealt with, viz., the case in which the speed is constant and the direction varies according to the law $\psi \sin nt$. The equation of motion is $I\ddot{\theta}+\alpha\dot{\theta}+K\theta=K\psi \sin nt$ and the general solution

$$\theta=\theta_o e^{-\lambda t} \sin\left(\frac{2\pi t}{T}+\varphi\right)+\frac{K\psi}{\sqrt{(K-In^2)^2+\alpha^2n^2}} \sin(nt-\gamma)$$

After the free oscillations are damped out the ratio of the amplitude of the forced oscillations to that of the varying wind direction is $K/\sqrt{(K-In^2)^2+\alpha^2n^2}$ which calculated for $V=60$ ft./sec. (40·9 mi./hr.), for various periodic times given in Table II.

TABLE II

Periodic time (sec.) of wind fluctuations	0·1	0·5	0·8	1·0	5	10	20
Ratio of amplitudes..	0·02	0·81	3·19	1·9	1·02	1·01	1·0

The exaggerated swings in the neighbourhood of resonance are evident from this table.

For the present application the preceding results of the National Physical Laboratory have been amplified by extending Table II to the case of $V=20$ ft./sec. (13·6 mi./hr.), and by considering the question of lag. For $V=20$ ft./sec. we have the following computed values :—

TABLE III

Periodic time (sec.) of wind fluctuations	0·1	0·5	0·8	1·0	3	5	10	20
Ratio of amplitudes..	0·002	0·054	0·153	0·259	1·90	1·22	1·05	1·01

As regards lag it is readily shown that $\tan\gamma=\dfrac{n\alpha}{K-n^2I}$ from which the following has been computed :

TABLE IV

Periodic time (sec.) of wind fluctuations	0·1	0·5	0·8	1·0	2	3	5	10	30
Time lag (sec.) for $V=60$ ft./sec. ..	0·05	0·22	0·13	0·07			0·04	0·04	0·04
Time lag (sec.) for $V=20$ ft./sec. ..	0·05	0·24	0·38	0·47	0·66	0·21	0·15	0·12	0·11

These experimental and calculated results relate to a vane alone, not connected up to the Dines or Baxendell recording device. Allowance has therefore not been made for the moment of inertia of the latter, nor for that of the long connecting rod. But even in the case of station B, where, in addition to the Baxendell drum there is also the helix of the Dines direction recorder, the allowance to be made is only :—

Moment of inertia, Baxendell recorder	0·065 lb./ft.^{2}
„ „ „ direction rod	0·009 lb./ft.^{2}
„ „ „ Dines recorder	0·008 lb./ft.^{2}
	0·082 lb./ft.^{2}

Whereas the value of I for the vane is 13.4 lb./ft^2. Thus the results obtained may be taken as applying to the whole system at any of the stations at Cardington.

Friction has been neglected. It will serve the useful purpose of opposing the tendency of the vane to oscillate with its " free period," but, except in very light winds, the effect of friction on the records is probably quite small and not of practical importance.

§ 9—CONCLUSIONS WITH REGARD TO INSTRUMENTAL ERRORS IN THE DIRECTION RECORDS

The points of importance in connection with the present research appear then to be the following. The vane does not respond to fluctuations whose period is a small fraction of one second. This is borne out by the Cardington records. Exaggerated oscillations may be recorded if the period of the fluctuations lies in the neighbourhood of the " free period " of the vane. This occurs at about 0·8 seconds with a wind of 60 ft./sec. (41 mi./hr.) and at about 2·3 seconds with a wind of 20 ft./sec. (13·6 mi./hr.). For periods of 5 seconds and above the oscillations are reproduced fairly faithfully for wind speeds over 20 ft./sec. (13·6 mi./hr.), and with no important lag. But the vane is not aperiodic, though the " free-period " oscillations are practically damped out in less than 5 seconds for winds of over 20 ft./sec. (13·6 mi./hr.) and, in the case of high wind speeds, in much less than 5 seconds.

Periods in the neighbourhood of the " free period " may be found in the Cardington ultra-quick run direction records and examples are not lacking of what are probably resonance effects, recognised by the exceptional amplitude of the curves and by their smoothness and uniformity. It is unusual to find more than three or four oscillations, as a regular oscillation persisting for more than that number of

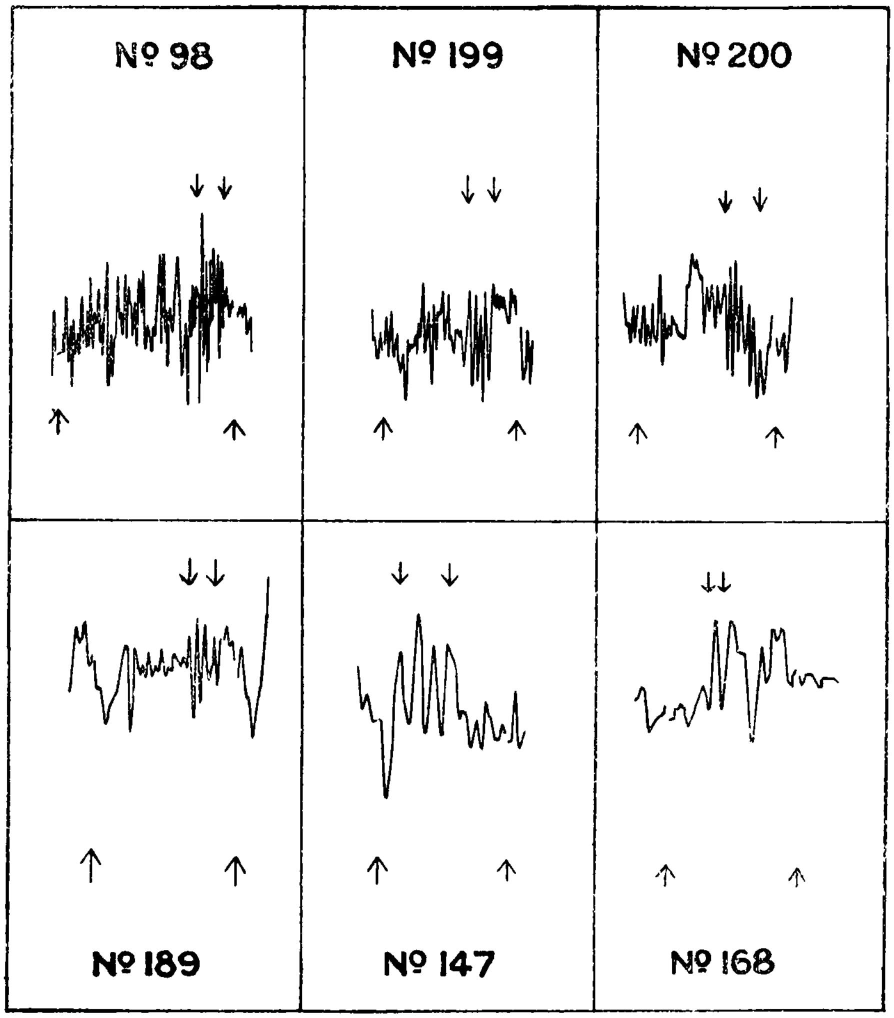


FIG. 23.—SOME EXAMPLES OF DIRECTION RECORDS SHOWING FLUCTUATIONS MAGNIFIED BY RESONANCE.

UPPER ARROWS. SHOW PARTS OF RECORD WHERE OSCILLATIONS ARE CONSIDERED TO BE MAGNIFIED BY RESONANCE.
LOWER ARROWS. SHOW TIME MARK GAPS (AT INTERVALS OF 30 SECONDS).

Note that the periods of resonance are inversely proportional to the wind velocity. The wind velocities on the occasions illustrated above are given in Table V.

periods is not a phenomenon likely to occur often in a natural wind. Table V gives a few examples and shows that the period of oscillation of the vane in such cases is near to the " free period " of the vane at the same speed.

TABLE V

Record ref. no.	No. of oscillations measured	Approx. period (sec.)	Mean wind speed (mi./hr.)	Free period (sec.)
98	4	0·88	37	0·92
199	3	1·33	29	1·19
200	4	1·25	27	1·25
189	2	1·50	17	1·85
147	2	3·5	8·5	3·7
168	1	4·0	8	4·0

The relevant portions of the records are reproduced in Fig. 23.

In view of these considerations, it was natural that serious attention should have been paid to the question of introducing additional damping into the direction-recording system. Several proposals for effecting this were considered at the meeting of the Wind Structure Sub-Committee on November 17, 1927, and certain experiments were actually tried. However, at the meeting on February 17, 1928 it was decided not to proceed with the matter, as satisfactory results from the immediate point of view of the Committee could be obtained from the existing instruments provided the records were first smoothed by taking means over intervals of not less than 5 seconds.

§ 10—A DESCRIPTION OF THE DINES PRESSURE-TUBE ANEMOMETER

Passing now to the speed records, it is necessary first to recall the principle upon which the Dines speed recorder operates. Figs. 24 (facing p. 19) and 25 show respectively a photograph of the head (with vane in position) and a sketch of a cross

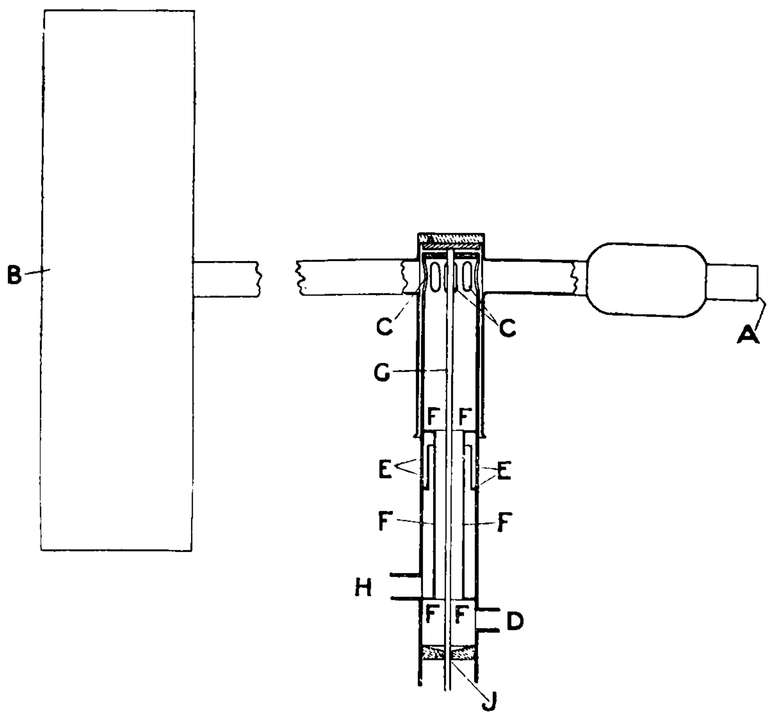


FIG. 25.—ANEMOMETER HEAD (SECTIONAL VIEW).

section of the same. The vane, AB, is carried on a ball bearing, so that it turns very easily. The open tube A is kept facing the wind by the action of the stream-lined fin B. The pressure at the opening is transmitted, through the apertures C, C, into the head, and thence to the recorder via a pipe attached to D. Below the vane, four rows small holes (EE) are bored through the wall of the head into an annular space separated by a partition F from the pressure chamber.

An air current past the head reduces the pressure within this space, which is connected to the recorder by a pipe attached at H.

To allow the direction to be recorded a rod G is attached to the vane and rotates with it. It passes through an aperture J at the bottom of the pressure chamber. Leakage at this point is minimised by a seal of vaseline.

The pressure difference produced in the head is transmitted through connecting pipes to the recorder shown in section in Fig. 26 (see also photographs in Figs. 10, 11, 15 and 16). The level of distilled water in the tank A is accurately specified by a water gauge B. There is a copper float in the tank, which carries a vertical phosphor-bronze rod D. This passes through a nearly air-tight collar F in the cover of the tank and carries at the top a brass cup E, and the recording pen.

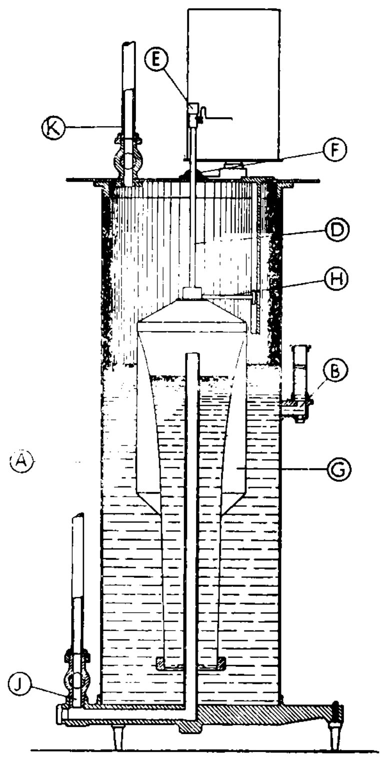


Fig. 26.

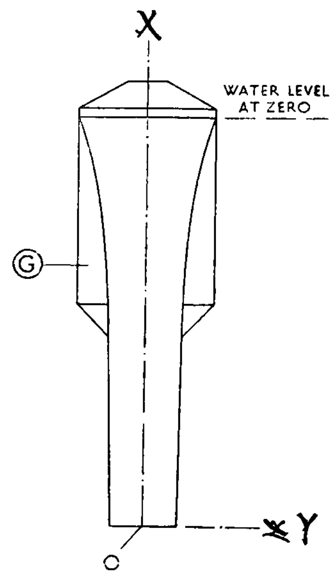


Fig. 27.

Dines recorder (sectional views).

The pressure from the head is applied to the inside of the float through the pipe entering at J, the suction to the outside through the pipe entering at K. Their effects are consequently added, and both tend to raise the float. The float is adjusted by placing a suitable quantity of lead shot in the cup E, so that in the absence of any pressure difference a notch cut on the rod D coincides with the upper edge of the collar F.

The buoyancy of the float is derived from the totally enclosed air space G. Rotation of the float is prevented by the arm H which carries a small roller working in a vertical guide.

The pressure difference produced by the head is expressed by

$$p - p_0 = \tfrac{1}{2}(1+k)\ \rho\ V^2$$

to which the pressure side contributes $\frac{1}{2}\ \rho\ V^2$ k is a non-dimensional constant.

The interior surface of the float is so shaped that equal increments of wind speed V produce equal rises in the float. Its equation referred to the axes OX, OY shown in Fig. 27, is

$$y^4\ (Q+h\ -x)\ =\ QC^4$$

the values of the constants being

$$h\ =\ 18{\cdot}5 \text{ in.},\ \ C\ =\ 3 \text{ in.},\ \ Q\ =\ 0{\cdot}812 \text{ in.}$$

This gives, for a value of k equal to 0·49, and of ρ equal to 1225 gm./m³. a linear scale for speed in which 10 mi./hr. = 0·6 in. The charts employed with the instruments are ruled to this scale.

§ 11—A REVIEW OF POSSIBLE INSTRUMENTAL ERRORS IN THE SPEED RECORDS

The magnitude of the various errors to which the records may be subject will now be examined.

(a) *The value of k*.—The experiments conducted by the National Physical Laboratory, referred to in § 4, revealed the fact that the value of k for the earlier type of head, in which the rows of suction holes were not staggered, and in which the pressure and suction outlets were not enclosed in a symmetrical shield, was by no means independent of the aspect of the head relative to the wind. In the present heads, this effect is removed by the staggering of the suction holes as shown in Fig. 24, and by the provision of a symmetrical shield as shown in the same figure. The form of the upper surface of this shield was the subject of special experiments. One of the forms tried had a hemispherical upper surface and this was at first thought to give a value of k not differing appreciably from that for which the charts were graduated, viz., 0·49. The shields supplied for stations A, B, C, D at Cardington were of this type, but it was subsequently ascertained that the correct value of k for a head with staggered suction holes and this form of shield is 0·39. Values of wind speed as tabulated from charts used at these four stations are accordingly too low and are subject, on this account, to the corrections shown in Table VI. (The correction being $\left(\sqrt{\frac{1{\cdot}49}{1{\cdot}39}} - 1\right) V$).

TABLE VI

Recorded speed (mi./hr.) ..	10	20	30	40	50	60	70	80	90
Correction (+ve) (mi./hr.) ..	0·4	0·7	1·1	1·4	1·8	2·1	2·5	2·8	3·2

For low wind speeds the correction is negligible, and it only amounts to 2·1 mi./hr. at a wind speed of 60 mi./hr.

The standard form of shield ultimately adopted has the conical top shown in Fig. 24. For a specified angle of the cone and distance from the suction holes the shield gives a value of k equal to 0·49 and independent of aspect. It is fitted to the head at station F, which was supplied later than the others, so that for this station the corrections in Table VI do not apply.

(b) *Leakage*.—There are two points at which leakage of air may take place. It may occur on the pressure side at the head of the instrument (at J and near C of Fig. 25). As, however, the distance of the leak from the orifice in the vane is small, the difference of pressure necessary to supply the air lost is very small and its effect on the records is negligible. It tends to make the contribution of the pressure side to the constant term $1+k$ slightly less than unity. The other point at which leakage may occur is on the suction side at the collar F at the top of the float chamber (see Fig. 26). Although the leak here may be smaller than that on the pressure side at the head, its effect may be much more important.

As soon as simultaneous ultra-quick runs became available from stations A, B, C, D it became evident that differences of one or two miles per hour existed between the mean wind at the various stations taken over intervals of the order of ten minutes.

It will be evident from later sections of this report that even for an interval as long as this such means should not be expected always to agree exactly, but on considering the four-point records on different occasions it was clear that systematic differences existed between the records of the various instruments. The recorders at stations A and C appeared to have no appreciable systematic difference, whereas, B appeared to record a little too low by comparison and D rather lower still. Table VII shows the departures of the ten-minute means at A, B and D from those at C on various occasions.

TABLE VII

Record ref. no.	C–A (mi./hr.)	C–B (mi./hr.)	C–D (mi./hr.)	Mean speed at C (mi./hr.)
344	0·9	0·5	2·2	19·3
314	1·3	−0·7	1·7	23·2
361	−0·7	1·4	1·7	40·5
371	−0·7	0·9	1·9	29·1
393	−1·1	1·0	0·6	27·1
400	0·8	2·5	2·2	12·6
401	0·9	2·2	1·9	12·2
402	0·4	1·5	2·3	11·1
427	0·9	0·0	2·8	23·7
Mean	0·3	1·0	1·9	

The dual runs referred to in § 7 provided a better means of comparison. The head, vane and recorder from station D were first transferred to the second mast erected at station C. The difference between the mean speeds shown simultaneously by the two recorders on various occasions, taken over the ten-minute intervals of ultra-quick runs (based on tabulations of means for each five seconds) are shown in the third and sixth columns of Table VIII.

TABLE VIII

Record ref. no.	Mean speed by C (mi./hr.)	C–D (mi./hr.)	Record ref. no.	Mean speed by C (mi./hr.)	C–D (mi./hr.)
489	7·4	1·4	498	12·0	2·6
487	9·7	1·5	499	13·5	2·1
497	11·5	1·9	Trial 30	16·6	2·2
496	16·3	1·7	501	22·1	2·0
495	16·5	1·8	502	22·6	2·1
490	18·0	1·6			
491	24·3	2·4			
492	25·4	2·3			
Mean		1·8	Mean		2·2

The recorders were then interchanged leaving the heads in position. The letters C and D still referring to the same recorders, the sixth column of Table VIII was obtained. It was, therefore, evident that the effect was in the recorders and not due to the heads.

The head, vane and recorder appropriate to station D were then returned and the instruments from station A transferred to station C, the head and vane going on the new mast to which at that time was attached the recorder appropriate to station C, and the recorder from A going on the original mast which still bore its appropriate head. After a number of dual runs the recorders were interchanged bringing them under their appropriate heads. These two series gave the results in Table IX in which the letters refer to the recorders. In this table the ten-minute means were not based on tabulations of five-second means, but were obtained by running a planimeter over the traces. The latter method is much quicker and comparisons on a number of records showed that the two methods gave results in good agreement.

TABLE IX

Record ref. no.	Mean speed by C (mi./hr.)	C–A (mi./hr.)	Record ref. no.	Mean speed by C (mi./hr.)	C–A (mi./hr.)
508	12·3	−0·2	523	4·4	0·0
507	14·8	0·3	517	9·4	−0·7
503	26·5	−0·3	518	10·8	−1·5
510	32·4	−0·6	522	13·6	−1·0
514	37·0	0·3	519	20·2	−0·3
			520	24·1	−0·4
			521	30·5	−1·3
			515	41·0	0·8
Mean		−0·1	Mean		−0·5

The comparisons between the recorders from stations D and A with that at station C by means of dual runs having shown results similar to those deduced from four-point runs, the recorder at station B was not disturbed for dual runs, more especially as it would have entailed a break in the continuous record being made on the normal time scale at that station. The discrepancies having been shown to be due mainly to the recorders and not the heads, it remained to show whether they could be attributed chiefly to leakage at the collar. The following experiments were accordingly carried out on each recorder in turn.

Both pressure and suction taps were turned to the off position, i.e., both the interior of the float and the float chamber were cut off from the anemometer head, but were connected by small orifices to the air within the hut. The float was raised as high as possible and the orifice connecting to the suction side of the float was closed. The float, on being released, naturally fell quickly at first, but in doing so reduced the pressure within the float chamber. This reduction supported the float for some time, but pressure in the float chamber eventually returned to normal owing to the leakage of air into it past the collar. By observing the times taken by the different floats to fall from one selected height to another an estimate of the relative magnitudes of these leaks could be obtained. Table X[1] gives the results of some of these tests.

TABLE X

Recorder	Fall measured on standard chart from (mi./hr.)	to (mi./hr.)	Time for fall (mean of 4 trials) min.	sec.
B	40	0		40
C (50ft.)	40	10	2	21
A	40	10	1	34
D	40	0		12
F	40	10	17	20 (one trial only)

[1] Table X was compiled from data obtained in June 1929. In December 1930 the process was repeated to discover if any important changes in the leakage had occurred owing to the wear on the collar through use. The variations were very slight, except in the case of F, the time of fall from 40 mi./hr. to 10 mi./hr. being reduced to 9 min. 40 sec., showing a slight wear in this case, but the errors so introduced would be negligible. The corresponding figure for the fall from 40 mi./hr. to the zero line for recorder B was 34 sec.

It is evident from a comparison of the times of fall of the floats under the conditions of these tests, with the discrepancies revealed by the dual and four-point runs, that the discrepancies are chiefly due to differences in the amount of leakage at the collars. Further it is evident that the recorders at stations B and D were reading too low by an amount not very dependent on the wind speed, except perhaps at very low values. The amount in the case of station B is approximately one mi./hr. and at station D approximately two mi./hr. on the fairly reasonable assumption that the leakage is negligible in the case of stations A and C. During the observation of the time of fall at station F no sticking of the float rod was observed (though sticking of the rod has been of fairly frequent occurrence there during the making of normal records).

It is noteworthy that in calibrating the recorders it is usual to leave the suction side open to atmospheric pressure and to apply to the pressure side a static pressure p in excess of atmospheric. This pressure is assumed equal to that which would arise from a wind speed of V blowing over a standard anemometer head, where $p=\frac{1}{2}\rho\ (1+k)V^2$. This method evidently cannot reveal the error due to leakage at the collar. It is important to know whether this error affects the gusts and lulls equally on the same record. This point was examined for a selected record by finding the difference in speed recorded by recorders C and D, first for about twenty of the highest crests, and then for about twenty of the lowest troughs. Table XI shows the results for a number of records.

TABLE XI

Record no.	Mean speed (mi./hr.)	Mean C—D Gusts (mi./hr.)	Mean C—D Lulls (mi./hr.)	Diff. (mi./hr.)
489	7·4	1·77	1·25	0·52
498	12·0	2·74	2·65	0·09
496	16·3	1·48	1·79	—0·31
495	16·5	1·61	1·68	—0·07
502	22·6	1·79	2·49	—0·70
492	25·4	2·20	2·23	—0·03
501	22·1	1·69	2·07	—0·38

The figures in this table show fairly conclusively that for very low wind speeds the leakage error affects the gusts more than the lulls. This is really self-evident for the leakage error must be zero at zero wind speed. With moderate or strong wind, however, the lulls are more affected by the leakage than the gusts. The value 0·7 mi./hr. for the excess of error in lulls over that in gusts for record no. 502 may be regarded, probably, as in part accidental and due to the small number of readings used, but it is evident that the value of the error may be 0·5 mi./hr. greater in the lulls than in the gusts. This, however, has been neglected in working up the records, since it is not a serious error and corrections would be almost impossible.

(c) *Inertia of the float.*—It was necessary to consider whether the float of the recorder by reason of its weight was sluggish in following the pressure variations applied to it. Determinations of its natural period of oscillation at various heights were therefore made at the National Physical Laboratory, and the results are given in Table XII. •

TABLE XII

Height of float (cm.)	Corresponding Wind speed (mi./hr.)	Natural period (sec.)
2	13·1	1·06
4	26·2	1·03
6	39·2	0·98
8	52·5	0·92
10	65·6	0·85

The considerations of sub-section (f) make it necessary to take mean values over periods not less than 5 seconds. It is evident that the superposition of oscillations of a period of the order of one second on the record will not affect the accuracy of such means.

An interesting feature of actual records is the complete absence of fluctuations of about this period. This, however, is due to the damping effect of connecting pipes, discussed in sub-section (f).

(d) *Weight of float.*—The weight of the float is adjusted by altering the number of lead shot in the cup E, Fig. 26, at the commencement of each run, so that it is immersed to a standard depth in the water (both sides of the float being subjected to atmospheric pressure). In the case of the relatively short quick and ultra-quick runs no appreciable change of weight is likely to take place. But in the case of a normal run lasting 24 hours, there may in certain circumstances be a change owing to condensation of water on the surface of the upper part of the float. The effect of a change of weight is now considered.

The equation of the inner surface of the float is $y^4\ (Q+h-x)=QC^4$. (See Figs. 26 and 27). C is the radius of the outer cylinder, which consequently meets the inner surface where $x=h$; and when the float is properly adjusted with pressure and suction taps off, the circle in which these surfaces meet lies in the water surface.

Let V be the wind speed

AV the rise of the float due to wind V

σ the water density.

d the depression of the water surface within the float below that outside.

Then height of water surface inside float above origin is $h-AV-d$ where

$$d=\frac{\rho V^2}{2g\sigma}\ (1+k)$$

Area of surface inside float$=\pi C^2\sqrt{\dfrac{Q}{Q+d+AV}}.$

Now let a mass M be placed on the float rod and let δ be the distance which it sinks below the water level in consequence.

Mass of water entering float$=\pi\ C^2\sqrt{\dfrac{Q}{Q+d+AV}}.\ \sigma\ \delta$

Increase in displacement of float $=\pi\ C^2\sigma\delta\left\{1-\sqrt{\dfrac{Q}{Q+d+AV}}\right\}=M$

$$\therefore\ \delta=\frac{M}{\pi\ C^2\sigma}\left\{\frac{1}{1-\sqrt{\dfrac{Q}{Q+d+AV}}}\right\}$$

On the other hand, the water surface has risen slightly owing to the addition of the mass M. If S is the radius of the tank, since the volume displaced by the addition of the mass M is M/σ, the rise of the water surface is $\dfrac{M}{\pi\sigma}\ \dfrac{1}{S^2-C^2}$

the total fall of the float due to the addition of mass M is

$$\frac{M}{\pi\ \sigma\ C^2}\left\{\frac{1}{1-\sqrt{\dfrac{Q}{Q+d+AV}}}\right\}-\frac{M}{\pi\ \sigma\ (S^2-C^2)}\ .$$

Now $h=18{\cdot}5$ in. $Q=0{\cdot}812$ in. $C=3$ in. $S=4$ in.

The table below gives the error due to a weight of 10 grams for various wind speeds.

Speed (mi./hr.) . .	3	6	10	20	40	60	80
Error (mi./hr.) . .	3·7	2·0	1·4	0·9	0·6	0·5	0·5

As already stated the error only arises in 24-hour records, as the quick and ultra-quick recorders are adjusted just before each record is taken. Rapid temperature changes are favourable to the deposition of water on the float; hence the recorder at station B is the more seriously affected. Even here, however, three grams may be regarded as the largest change in the weighting of the float likely to occur in a single day, so that the errors will not exceed one third of the values shown in the foregoing table. It is still, however, evident that readings below about 5 mi./hr. must be treated with caution if the range of temperature during the preceding 24 hours has been at all considerable; but above 10 mi./hr. the effect may usually be neglected.

It is proposed at some future date to cover the water surface in the float chamber with a thin film of medicinal paraffin, which should prevent evaporation and so remove this source of error.

(e) *Air density*.—The charts used with the recorder are graduated for a standard air density of 1225 gm./cu.m. corresponding with a standard temperature of 15·5°C. and a standard pressure of 760 mm. It is, therefore, important to inquire whether any departures from this value may affect the conclusions drawn from the records in this report.

If V is the actual wind speed $p-p_0=\frac{1}{2}\rho V^2(1+k)$ (see § 10).

Now if ρ_0 is the standard air density and v the recorded wind speed

$$p-p_0 = \tfrac{1}{2}\rho_0 v^2(1+k) \text{ so that } \frac{V}{v} = \sqrt{\frac{\rho_0}{\rho}}$$

So that if P, T are the actual and P_0, T_0 the standard pressure and (absolute) temperature of the air $\frac{V}{v} = \sqrt{\frac{P_0 T}{P T_0}}$

It is now possible to find the error due to the change of density for any given conditions of pressure and temperature. The error will be greatest, evidently, when either (1) a high pressure occurs with a low temperature or (2) a low pressure with a high temperature. Special cases were considered for (1), a pressure of 1025 mb. with a temperature of -3°C. It is true that even in this country much lower temperatures are occasionally reached, but not when there is an appreciable wind blowing. In this case, it was found that the recorder read 4 per cent too high. For (2) a pressure of 940 mb. and a temperature of 13°C. were taken, and it was found that the instrument read about 3 per cent low. Neither of these errors has been regarded in working up records, because accuracy in absolute values is of secondary importance provided that instruments operating at the same time are equally affected.

A third case, of more interest in the present work, is that in which two instruments are working simultaneously, but under different density conditions owing to a difference in height and temperature. For two vanes 150 ft. apart, and assuming an inversion of 2°C. per 100 ft. in the intervening space, it is found, however, that the difference between the scales of the two instruments is less than one per cent and as so large an inversion implies a very light wind, the effect is negligible.

Lastly the possibility of a change of scale of the chart during a single record, due to a sudden change of temperature, was considered and it was found that a fall of 7°C. (approximately the largest sudden fall recorded at Cardington) would increase the readings by only about 1½ per cent.

(f) *Effect of connecting pipes*.—A considerable volume of air has to pass through the pressure and suction pipes between head and recorder for every change of wind speed which occurs. The pipes oppose a considerable resistance to the flow of air through them, and it is, therefore, important to know how far records of fluctuating winds are modified by this factor.

Experiments carried out at the National Physical Laboratory showed that an increase in the diameter of the pipes led to greatly improved records. Tables XIII and XIV give some results obtained by applying a variable pressure produced by a piston oscillating in simple harmonic motion, to the pressure side of the recorder through 100 feet of half-inch and one-inch pipe, respectively.

TABLE XIII

100-ft. ½-inch pipe. Mean height of float 8·9 cm.
(equivalent to 85·7 ft./sec. or 58 mi./hr.).

Periodic time (sec.) ..	23·0	18·4	8·0	5·24	3·5	1·32
Indicated pressure range / Applied pressure range	1·0	1·0	0·42	0·22	0·12	0·04

TABLE XIV

100-ft. 1-inch pipe. Mean height of float 9·1 cm.
(equivalent to 87·8 ft./sec. or 60 mi./hr.)

Periodic time (sec.)	4·6	2·3	1·65	1·15
Indicated pressure range / Applied pressure range	1·0	1·0	0·42	0·14

One-inch pipe was adopted, therefore, for the wind-structure installation.

Unfortunately, at lower speeds the accuracy of the instrument is diminished. A further series of experiments, in which the complete recorder was used with 50 feet of 1 in. pipe connecting both pressure and suction sides of the recorder to the head while the head was subject to a wind speed varying approximately in simple harmonic motion, gave the following results.

TABLE XV

Mean speed 31·25 ft./sec. or 21 mi./hr.

Period (sec.)	10	4	2
Indicated speed range / Applied speed range	0·963	0·700	0·465

No data are available for lower winds, but the errors must be somewhat larger than those shown by the table. Fluctuations of periods less than 10 seconds may then be considerably damped at low wind speeds by the action of the connecting pipes. It is not, therefore, possible to trust instantaneous speed values indicated by the recorder, or even means over very short periods, but a careful consideration of actual records in the light of the above tables leads to the conclusion that means over 5-second periods are generally trustworthy.

§ 12—CONCLUSIONS WITH REGARD TO INSTRUMENTAL ERRORS IN THE SPEED RECORDS

The important instrumental corrections shown by the foregoing examination are :—

(a) The heads at A, B, C and D require a correction on account of the form of their shields.

(b) Recorders B and D require a correction for leakage. Table XVI shows the magnitude of these corrections (in mi./hr.), together with the necessary corrections on account of the calibration of the floats.

TABLE XVI

Wind speed (mi./hr.)	A	B	C	D	F
10	+1·2	+1·5	+0·6	+2·6	+1·0
20	+1·1	+1·2	+0·5	+3·4	+0·5
30	+1·2	+1·8	+0·8	+3·2	+0·4
40	+1·3	+2·3	+1·1	+4·1	+0·8
50	+1·6	+3·0	+1·7	+4·2	+0·5
60	+2·1	+3·3	+2·1	+4·7	+0·9
70	+2·7	+3·9	+2·8	+5·3	+1·0

(c) The normal instruments may be a little in error at low wind speeds when subject to large temperature variations. (This applies especially to instrument B.)

(d) The records are " smoothed " by the damping effect of the long connecting pipes, rendering means over periods less than 5 seconds untrustworthy.

PART II—RESULTS: HORIZONTAL FLUCTUATIONS IN WIND IN TIME AND SPACE

§ 13—INTRODUCTION

In this part of the report it is proposed to give an account of the records obtained with the installation described above, and the methods adopted for their analysis, as well as the results obtained from these records. Attention will be concentrated mainly on giving the results of the investigation as far as they concern wind fluctuations from place to place at the same height above ground level.

The discussion of the physical principles underlying the wind fluctuations will be confined to the third part of the paper, while in the fourth part will be given the results of the investigation as far as they concern wind fluctuations at different levels and the variation of wind with height. In the fifth part will be outlined certain theoretical consequences which follow from the data given.

§ 14—DEFINITIONS OF WIND, EDDIES, ETC.

Wind has been defined as the motion of air. This motion of air rarely takes place as a smooth flowing stream past an observer, but as a stream constantly fluctuating both in speed and direction. The fluctuations of the wind stream are due to " *eddies*." In this report the term eddy is not restricted to any definite form of motion, such as circular whirls or waves, or to any size.

If wind is observed over a period of time sufficiently long for a large number of eddies to pass the point of observation (and no general change of conditions is occurring) it will be seen that the fluctuations occur about a mean value of the wind speed and a mean value of the direction. These values are termed the " *mean wind speed* " and the " *mean wind direction* " for that period. The fluctuations of wind due to eddies are thus departures from the mean wind.

If a series of similar eddies were to pass an observer he would find increases and decreases of wind speed and changes of direction at regular intervals, the time interval between such increases or direction changes is defined to be the *period* of the fluctuations.

In the diagram of Fig. 28 let OX be the vector representing the horizontal wind at a given instant at a given station. Then the corresponding fluctuations of speed and direction shown by the records of pressure-tube anemometers, if compounded, would represent the wanderings of the point X over a limited portion of the paper. If the wind were a *steady wind*, the fluctuations of speed and direction on the anemogram would take place about an approximately constant mean, the point X moving about a mean position A, OA being the vector representing the mean wind.

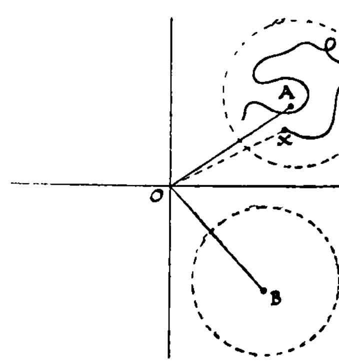


FIG. 28.—VECTOR DIAGRAM SHOWING FLUCTUATIONS IN A STEADY AND SQUALLY WIND.

If the wind were a *squally wind*, however, the fluctuations of speed and direction would no longer take place about a constant mean. In this case, the representative point X leaves one area of the field for another area, staying away for a limited time as in a transient squall, or making a definite departure as in a line squall which marks the sudden change from one wind current to another. In the case of squally winds the representative point may move quickly to a new region, as for example in Fig. 28, and fluctuate about the new mean point B.

The main line of attack on the problem of wind structure in this report is the investigation of the following :—

(a) Fluctuations of wind in steady wind both (i) along the direction of the wind and (ii) across the the direction of the wind.

(b) Fluctuations of wind in a squally wind both (i) along the direction of the wind and (ii) across the direction of the wind.

(c) Fluctuations of wind in sudden changes (such as at the passage of fronts and line squalls) both in speed and direction.

§ 15—THE MATERIAL AVAILABLE FOR DISCUSSION.

The material available for discussion in the present paper is that obtained from the installation described in the first part (§§ 4, 5, pages 15 to 17).

The types of wind record are shown on Fig. 19 (Plate I) and specimens of the temperature records are shown on Figs. 29 to 31 (Plates II to IV), though these latter have had to be modified for the purposes of reproduction. In the originals the traces, being made by a thread recorder, consisted of series of dots at intervals of 3 minutes. For reproduction it has been necessary to join the dots by continuous lines, the temperature at 143 feet being shown by a thicker line to distinguish it from the temperature at 4 feet.

The order of magnitude of the eddies discussed on the wind records was limited, owing to the instrumental characteristics, to those giving fluctuations of a period greater than 5 seconds, the eddies of smaller size than this being damped down on the velocity trace and so having to be ignored (*vide* Part I, § 11f).

It was, therefore, decided that for the ultra-quick runs this period of 5 seconds should be the standard, and in general these records have been discussed by measuring the mean velocity and direction of the wind over periods of this duration, but from these five-second means there have, in some cases, been derived successive means for ten seconds, twenty seconds or other periods which are multiples of five seconds. In dealing with the quick runs it was impossible to measure means for such short periods, and for these a period of one minute was chosen as the standard, while for the normal runs the standard chosen was a period of one hour.

The method of forming these means was as follows :—A celluloid scale was constructed divided into six equal parts such that, when it was laid over the time marks of an ultra-quick run and the appropriate part of the scale chosen to fit these marks, the divisions lay at intervals of 5 seconds from one another. The mean values of the speed trace and the direction trace were then estimated by eye for each period of 5 seconds, and the results were tabulated. Two independent measurements were so made for each record and the results compared, and where they differed by more than a certain amount, were verified. Similar procedure was carried through for the quick runs and normal records, the scale values being appropriately modified.

In Appendices I and II are given the five-second mean values of wind for a number of ultra-quick records, made respectively on the four-point installation, and at a single point. In these appendices are also given notes on the weather during the making of these records.

In dealing with the temperature records, each dot (of the original records) was considered as a determination of the instantaneous temperature (i.e., at intervals of 3 minutes). This is true except when the temperature is changing very rapidly. Since the height of the thermometer at station F was 170 feet above that at station G the difference in temperature between the two under dry adiabatic conditions would be about 0·9°F.

In order that the eddies discussed should be visualised in terms of linear dimensions the following table has been prepared which shows the periods of fluctuations which would be produced on an anemometer by the passage of a repeating pattern carried along by a wind of specified velocity.

TABLE XVII

	Linear scale of repeating pattern in the direction of its travel (feet)											
	10	30	100	500	1000	2000	3000	4000	5000	10000	50000	100000
Velocity of travel mi./hr.	sec.	sec.	sec.	sec.	min. sec.	min. sec.	min. sec.	min. sec.	min. sec.	min.	min.	min.
5	1·4	4·1	13·6	68	2 16	4 32	6 49	9 20	11 20	23	113	226
10	0·7	2·0	6·8	34	1 8	2 16	3 25	4 32	5 41	11	57	113
20	0·3	1·0	3·4	17	34	1 8	1 41	2 16	2 51	6	28	57
30	0·2	0·7	2·3	11	23	46	1 8	1 31	1 54	4	19	38
40	0·2	0·5	1·7	8	17	34	51	1 8	1 25	3	14	28
50	0·1	0·4	1·4	7	14	27	41	55	1 8	2	11	23
60	0·1	0·3	1·1	6	11	23	34	46	57	2	9	19

§ 16—TYPES OF WIND FLUCTUATIONS SHOWN BY NORMAL RUNS

The examination of the normal runs made at 150 feet and 50 feet above ground level showed that the types of trace could be classified broadly in four groups, and three days have been selected for reproduction as illustrative of these. They are shown on Figs. 29, 30 and 31 (Plates II, III, and IV).

Fig. 29 shows the thermogram and normal runs at 50 and 150 feet for April 10–11, 1929, together with a quick run made between 9h. 25m. and 11h. 10m. G.M.T. On this day cumulo-nimbus cloud was present during the morning and afternoon, but disappeared during the evening. The vertical temperature gradient between 143 feet and the surface was about 2°F. (which corresponds to a superadiabatic vertical temperature gradient) up to about 15h. from which time the difference decreased, and after 16h. throughout the night the gradient was slightly less than adiabatic. The wind trace up to 17h. was of a different character from that during the night. During the daylight hours there were pronounced peaks on the speed record at fairly regular intervals of 20 to 40 minutes. At night these pronounced peaks were not present, the trace showing a series of peaks all about of the same magnitude, but following one after the other at intervals of very much less than 20 minutes. The direction trace at night though perhaps as broad as that by day gave a mean direction that was steadier by night than by day. The fluctuations in temperature were great during the day, but small during the night.

Fig. 30 shows the records made on February 12–13, 1929. On this day some cumulo-nimbus cloud was reported at 7h. and 10h., but the predominant cloud was strato-cumulus ; this decreased during the forenoon, and the afternoon and evening observations showed the sky as almost cloudless. The wind trace at 150 feet shows considerable gustiness during the forenoon with occasional decided departures from the mean wind, this effect, however, decreased during the afternoon (though there were considerable excursions of the direction pen until about 15h. 30m.) ; from about 17h. the trace became of a different type both on the speed and direction records, being much more close-knit than before that time. During the night wind fluctuations decreased very decidedly. The temperature record shows superadiabatic conditions until about 15h., adiabatic conditions between 15h. and 20h., after which there was an inversion throughout the hours of darkness.

Fig. 31 shows the records made on April 6–7, 1929. The day was practically cloudless throughout. The wind traces show wide fluctuations during the daylight hours, and up to about 17h. 30m. Between that hour and 20h. the fluctuations died out though the wind velocity at 150 feet did not decrease. Soon after 20h. fluctuations increased very decidedly, but they were of a very different type to those recorded during daylight.

The temperature record shows variations in the vertical temperature gradient, which correspond in time to these changes of type in the wind. Up to 16h. superadiabatic conditions prevailed, while at about 17h. 15m. an inversion formed and increased till shortly after 20h. from which time it decreased to about 21h. From 21h. until the record broke at 1h. 30m. there was an inversion of from one to two degrees in 170 feet.

The four types of trace illustrated above were found to be constantly occurring in the normal-run records, associated in a very definite way with the vertical temperature gradients, and with the cloud type. It is fair to assume these four types of trace are due to four types of eddies and accordingly a classification of the characteristics associated with these eddies may be made as under :

Eddies of Type I.—(e.g., April 10, 1929, 10h. to 15h., Fig. 29, Plate II). On the occasions when cumulo-nimbus cloud was present and convection was taking place in the upper layers of the troposphere,[1] the high gusts were spaced out at comparatively wide intervals, but the whole trace was irregular both in direction and velocity. From this type the fluctuations varied by gradations to those due to a second main type.

Eddies of Type II.—(e.g., February 12, 1929, 15h. to 17h., Fig. 30, Plate III). With this type instability was predominantly taking place in the lower layer of the troposphere.[1] The major fluctuations in speed and direction were still considerable, but were more rapid. The vertical temperature gradient was generally approximately adiabatic, and the cloud type was often strato-cumulus. These fluctuations again graduated down to those due to a third main type of eddies.

Eddies of Type III.—(e.g., April 6–7, 1929, 21h. to 3h., Fig. 31, Plate IV). With this type the vertical temperature gradient near the ground was less than adiabatic and might show an inversion. The trace on the anemograms was broad both in velocity and direction, but the fluctuations appeared to be very rapid, more so than with either of the two previous types.

Eddies of Type IV.—(e.g., April 6, 1929, 18h. 30m. to 20h., Fig. 31, Plate IV). With this type the fluctuations almost entirely disappeared from the anemograms, and the thermograms showed a decided inversion of temperature below the top of the 150-foot mast.

The transition from type to type generally takes about an hour or so to be effected except in the case of the transition from type III to type IV or vice versa, which may occur quite abruptly.

These types may be associated with wind characteristics which would be described by the aviator as very bumpy in the case of type I, bumpy in that of type II ; but with the last two types the aviator would not experience bumps.

§ 17—THE EXAMINATION OF THE STRUCTURE OF EDDIES OF TYPE I

On the occasion of April 10–11, 1929 (which is illustrated in Fig. 29, Plate II) quick runs were made from 9h. 25m. to 17h. 1m. from which one-minute means of direction and velocity were measured. The results are plotted in Fig. 32 together with the records of temperature at 143 feet and at the surface, vertical temperature gradient, temperature changes at the two heights, sunshine and rainfall. The most outstanding features of this figure are :—

(a) Strong gusts occurred just after a maximum of temperature had been reached, and were followed by a decrease in absolute humidity.

(b) Strong gusts were associated with a wind from a more veered direction than lulls.

(c) Rain was associated with falling temperature.

(d) Breaks in the sunshine record were associated with high wind speed.

[1] The troposphere may be roughly divided into two portions, that up to a height of some 1500 to 2000 feet, and that between 2000 feet and the base of the stratosphere. In the former of these the diurnal variation of temperature is appreciable, the heating of the ground being, in general, communicated upwards by convection in which ascending air expands along the dry adiabatic, clouds of the diurnal variation type seldom forming in that region. In the latter region the diurnal variation of temperature is, in general inappreciable. Clouds of the diurnal variation type (large cumulus and cumulo-nimbus) do, however, appear in it, and it would seem that diurnal convection in this region is mainly produced by ascending air which expands along the wet adiabatic.

Together with these it was noticeable that the periods of high or falling wind velocity were associated with a decrease in the fluctuations of the wind vane, as shown by the original direction records, as well as a diminution of the extent of speed fluctuations (*vide* Fig. 29, Plate II). These decreases extended for two or three minutes and do not seem to be related to any instrumental effect.

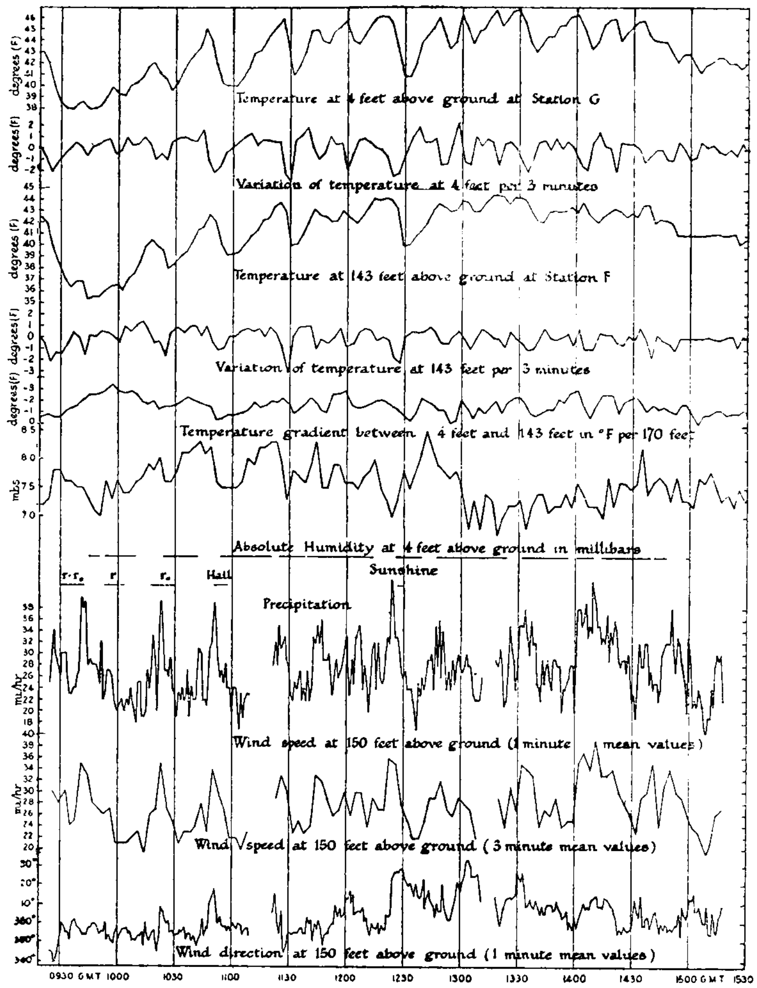


FIG. 32.—APRIL 10, 1929. THIS DIAGRAM SHOWS IN DETAIL THE BEHAVIOUR OF THE AUTOGRAPHIC INSTRUMENTS ON A GUSTY DAY AND ILLUSTRATES THE ASSOCIATION OF FLUCTUATIONS OF WIND WITH THE OTHER ELEMENTS.

There appeared, moreover, to be a definite form taken by the velocity record during the high gusts. The increase in wind was abrupt, the decrease more slow.

§ 18—THE EXAMINATION OF THE STRUCTURE OF EDDIES OF TYPE II

In the case of eddies of type II the time scale of fluctuations of wind (and other elements) was very much smaller than in the case of type I. An example of this type is shown by the quick run made on February 12, 1929, illustrated in Fig. 30 (Plate III). It is noticeable that this trace is not so gusty as that of April 10–11, 1929, even allowing for the fact that the mean wind has not so high a velocity. There is visible, however, the same characteristic of the gusts, namely, a rapid increase and a more gradual decrease in wind speed. The intervals between these gusts is seen to be of the order of 5 to 7 minutes so that the distance of wind run between consecutive occasions of high speed is of the order of 8000 feet.

In order to investigate eddies of these types still further, certain records made by ultra-quick clocks have been examined in detail, these records being, in general, those made synchronously at the four 50-foot anemometers described previously.

The 5-second mean values of wind speed and direction are given in Appendix I.

Four of these sets of records have been chosen for reproduction (Figs. **33**, **34**, **35** and **36**, Plates V to VIII.) Records 351 and 360 (Figs. **34** and **36**) have been selected as representing the type in which super-adiabatic conditions were prevailing (type I), (though no example of a four-point run is available in which these conditions were pronounced), and records 314 and 371 (Figs. **33** and **35**) as representing the eddies associated with the adiabatic state (type II).

In each case of the records 314, 351, 360 and 371, simultaneous records have been made at all of the four anemometers of the wind-structure installation. Fig. **37** shows the plan of this installation with arrows indicating the direction of the mean wind during these four ultra-quick runs.

Record 371 was directly along the line of the anemometers C, D and B, 314 and 351 were slightly off the line AB, but in opposite directions, while 360 was slightly off the line CA.

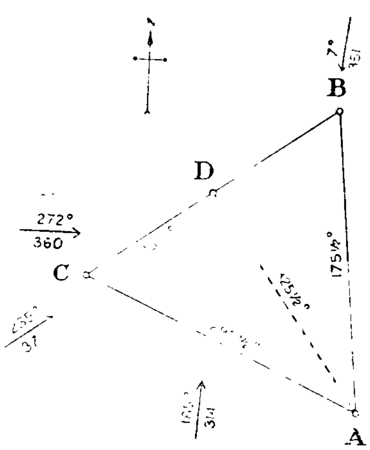


FIG. 37.—SKETCH DIAGRAM SHOWING LAY-OUT OF ANEMOMETERS AND DIRECTIONS OF FOUR SELECTED 4-POINT ULTRA-QUICK RUNS. THE FIGURES BENEATH THE ARROWS SHOW THE REFERENCE NUMBERS OF THE ULTRA-QUICK RUNS, THE FIGURES ABOVE THE MEAN DIRECTIONS OF THE WIND DURING THOSE RUNS.

(a) *Computation of the mean value of wind over horizontal areas.*—As an indication of the air speeds which would be operating on the area represented by the four stations A, B, C and D diagrams are shown (Figs. 38, 39 and 40).

Figs. 38a, b and c give data in regard to the 5-second mean values of wind speed. In each case, the thick curve shows the mean of the simultaneous wind

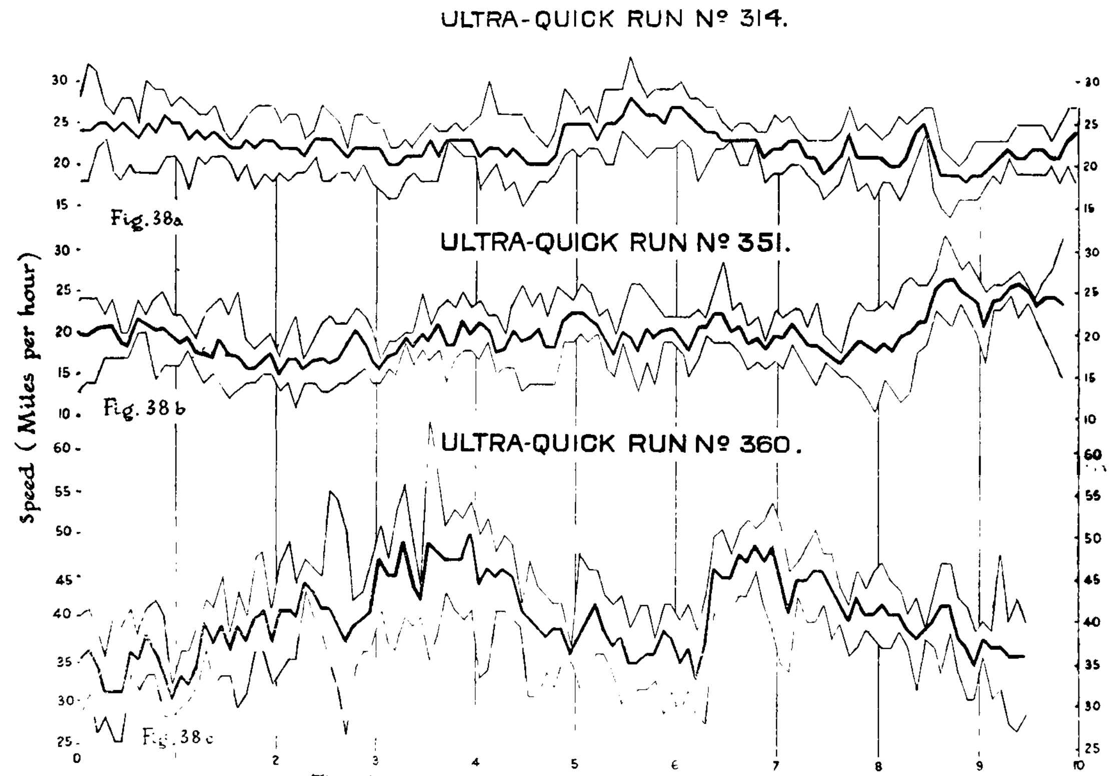


FIG. 38 THE CURVES ABOVE INDICATE THE AIR SPEEDS WHICH WOULD BE OPERATING SIMULTANEOUSLY ON THE AREA REPRESENTED BY THE FOUR INSTRUMENTS A, B, C AND D, THE UPPER GROUP OF CURVES REFERRING TO RECORD NO. 314, THE MIDDLE TO RECORD NO. 351, AND THE LOWER TO RECORD NO. 361. IN EACH CASE, THE THICK CURVE GIVES THE MEAN SPEED OF THE FOUR INSTRUMENTS OVER 5-SECOND INTERVALS, THE CURVE BELOW THIS GIVES THE MINIMUM 5-SECOND MEAN SPEEDS RECORDED BY ANY OF THE FOUR INSTRUMENTS, AND THE CURVE ABOVE THIS IS THE MAXIMUM 5-SECOND MEAN SPEED RECORDED BY ANY OF THE FOUR INSTRUMENTS.

speeds at the four stations at each 5 seconds of time. The upper thin curve gives the mean wind speed experienced at that one of the four stations that had the highest mean wind speed during the appropriate 5 seconds of time, the lower thin curve the corresponding lowest mean wind speed.

In Fig. 39a similar data are given in regard to record 371, but this is further amplified by two broken curves which show, in a similar way, the maximum gust and the minimum lull.

Record 371 is that made when the wind was blowing along the line of the stations C, D and B. In Fig. 39b similar data to Fig. 39a are given, but for these three stations only, simultaneous values of wind speed again being shown.

In Fig. 39c, however, the data shown are similar to Fig. 39b, but in this case a time lag has been introduced so that the values used are not simultaneous, but are such that the same air mass is over each anemometer. Thus Figs. 38 and 39a show the extent to which the area comprised in the triangle ABC is subjected to differing wind speeds at the same time. Fig. 39b shows the extent to which the line CDB is subjected to differing wind speeds at the same time. Fig. 39c shows the extent to which a body floating with the velocity of the mean wind would be subjected to differing wind speeds.

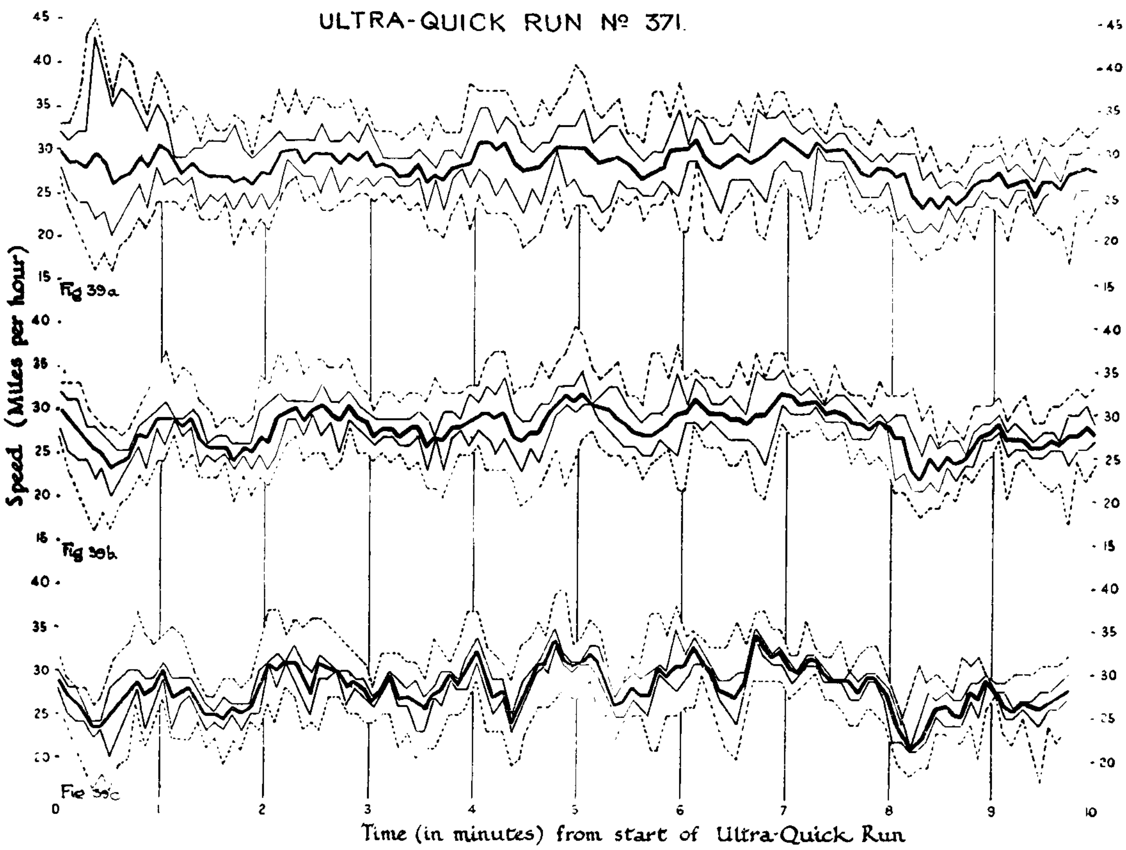


FIG. 39a SHOWS SIMILAR CURVES FOR RECORD NO. 371 AS ARE SHOWN IN FIG. 38, BUT TWO FURTHER CURVES ARE ADDED GIVING THE MAXIMUM AND MINIMUM INSTANTANEOUS SPEEDS RECORDED.

FIG. 39b SHOWS SIMILAR CURVES TO THOSE IN FIG. 39a, BUT FOR INSTRUMENTS B, C AND D ONLY. (THESE INSTRUMENTS WERE ON THE LINE OF THE WIND).

FIG. 39c SHOWS SIMILAR CURVES TO THOSE IN FIG. 39b, BUT A TIME LAG HAS BEEN INTRODUCED TO THE RECORDS FOR INSTRUMENTS D AND B PROPORTIONAL TO THE MEAN WIND SPEED OF THE WHOLE RECORD.

So far we have been dealing with speed alone. The wind, however, is constantly varying from the mean wind direction. To get an idea of the magnitudes of the changes across the direction of the mean wind it is necessary to resolve the 5-second values of wind into the component velocities across the mean wind direction. This has been done, and in Fig. 40 curves are shown for these cross-wind components for records 360 and 371, the components in this case being treated in a manner similar to that in which the velocities had been treated in forming the curves of Figs. 38 and 39. The mean values of the components for the four instruments over the same 5 seconds are shown by more heavy curves in Figs. 40a and b with which are compared the extreme components for the four instruments over the same 5 seconds. These curves have been drawn for both records. The figures for record 371 have been elaborated still further by giving similar curves for the three instruments B, C and D, both simultaneously (in Fig. 40c) and with a lag in D and B instruments appropriate to the wind speed.

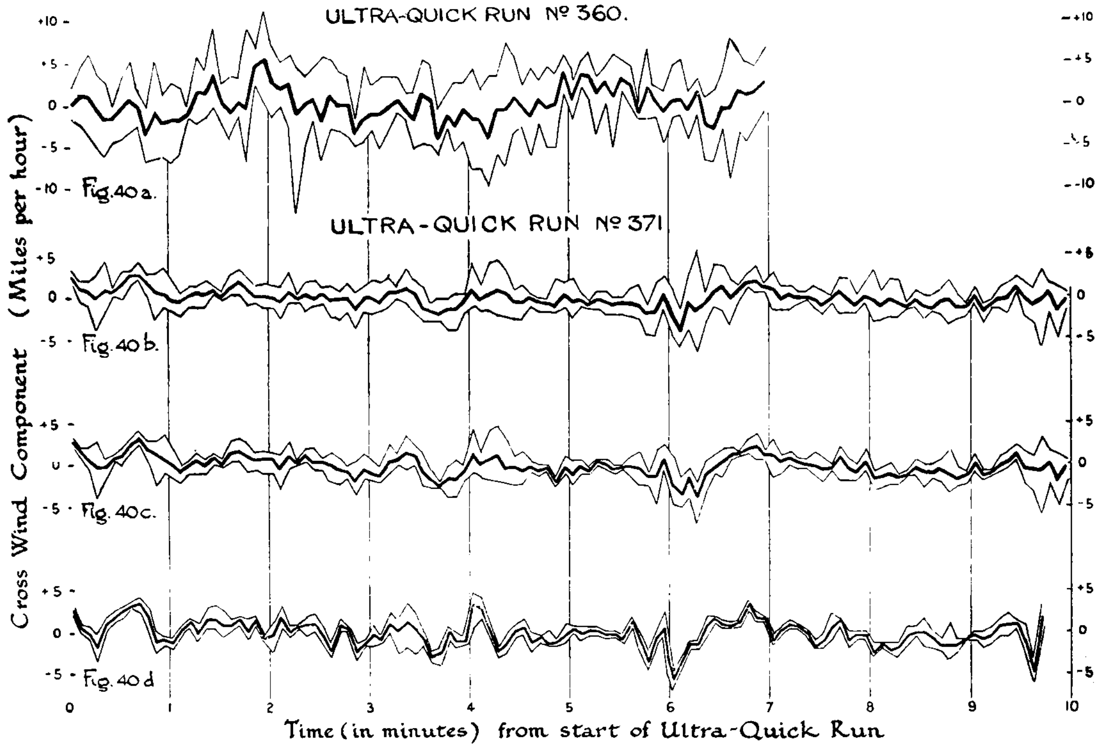


FIG. 40.—THE CURVES IN FIGS. 40a AND 40b INDICATE THE CROSS WIND COMPONENTS OF AIR SPEED WHICH WOULD BE OPERATING ON THE AREA REPRESENTED BY THE FOUR INSTRUMENTS A, B, C AND D IN A SIMILAR MANNER TO THOSE SHOWN IN FIGS. 38c AND 39a.

THE CURVES IN FIGS. 40c AND 40d INDICATE THE CROSS WIND COMPONENTS OF AIR SPEED WHICH WOULD BE OPERATING ON THE LINE REPRESENTED BY THE THREE INSTRUMENTS B, C AND D IN A SIMILAR MANNER TO THOSE SHOWN IN FIGS. 39b AND 39c.

IN FIG. 40c THE VALUES USED ARE SIMULTANEOUS, IN FIG. 40d THE TIME LAG HAS BEEN INTRODUCED TO THE RECORDS FOR INSTRUMENTS D AND B PROPORTIONAL TO THE MEAN WIND SPEED OF THE WHOLE RECORD.

(b) *The type of change of wind speed in a gust.*—In Fig. 36 (Plate VIII) at the point marked a in speed record 360A there is a sudden increase of speed. This increase is followed by a gradual decrease to the point marked b. Such a feature is of common occurrence and may be seen more or less pronounced on many of the records of the ultra-quick runs, such as record 351 (Fig. 34, Plate VI), and to a less degree in records 314 and 371 (Figs. 33 and 35, Plates V and VII).

A similar feature has been already noticed on the quick runs of April 10 and February 12, 1929 (Figs. 29 and 30, Plates II and III).

This characteristic of greater frequency of high acceleration values and smaller retardation values was submitted to a statistical examination as follows:—Differences in mean speeds over 5 seconds were formed from the 5-second mean values of speeds given in Appendix I, and percentage frequency diagrams for these differences are exhibited in Fig. 41. The values were then grouped into those occasions on which the wind was above 28 miles per hour, 18 to 24 miles per hour and 11 and 12 miles per hour. The percentage frequency curves for these groups are shown in Fig. 42.

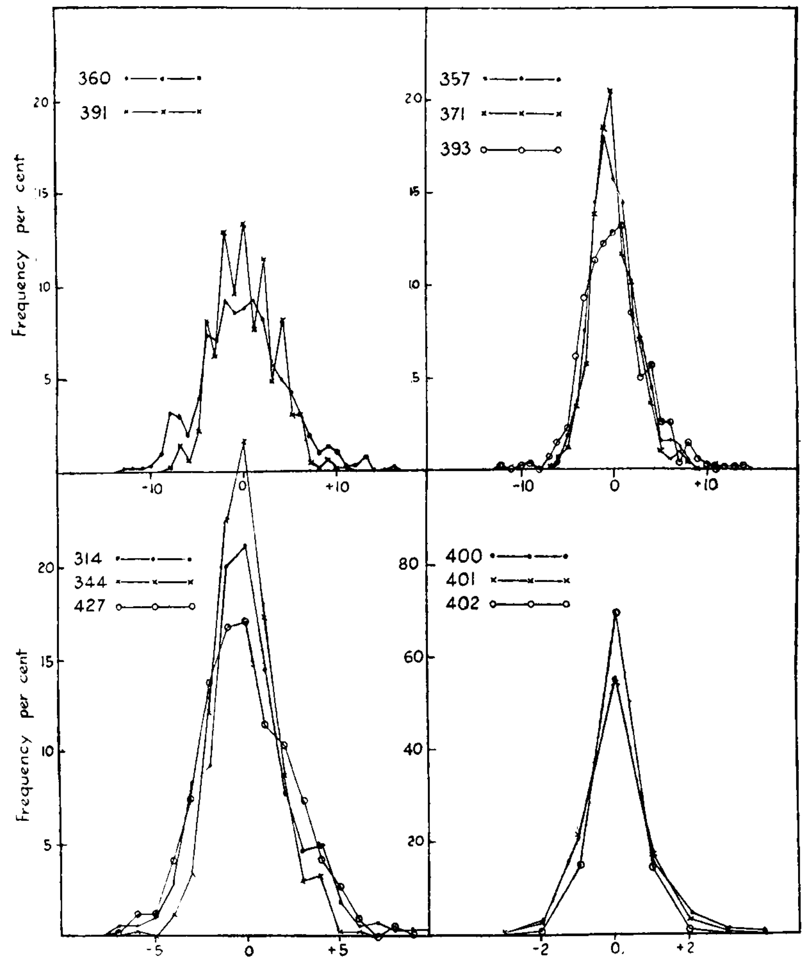


FIG. 41.—THIS DIAGRAM SHOWS THE FREQUENCIES OF ACCELERATION OF WIND OVER INTERVALS OF 5 SECONDS FOR CERTAIN RECORDS. THE ORDINATES ARE GIVEN IN PERCENTAGE FREQUENCY, THE ABSCISSÆ IN THE UNIT MILES PER HOUR PER 5 SECONDS.

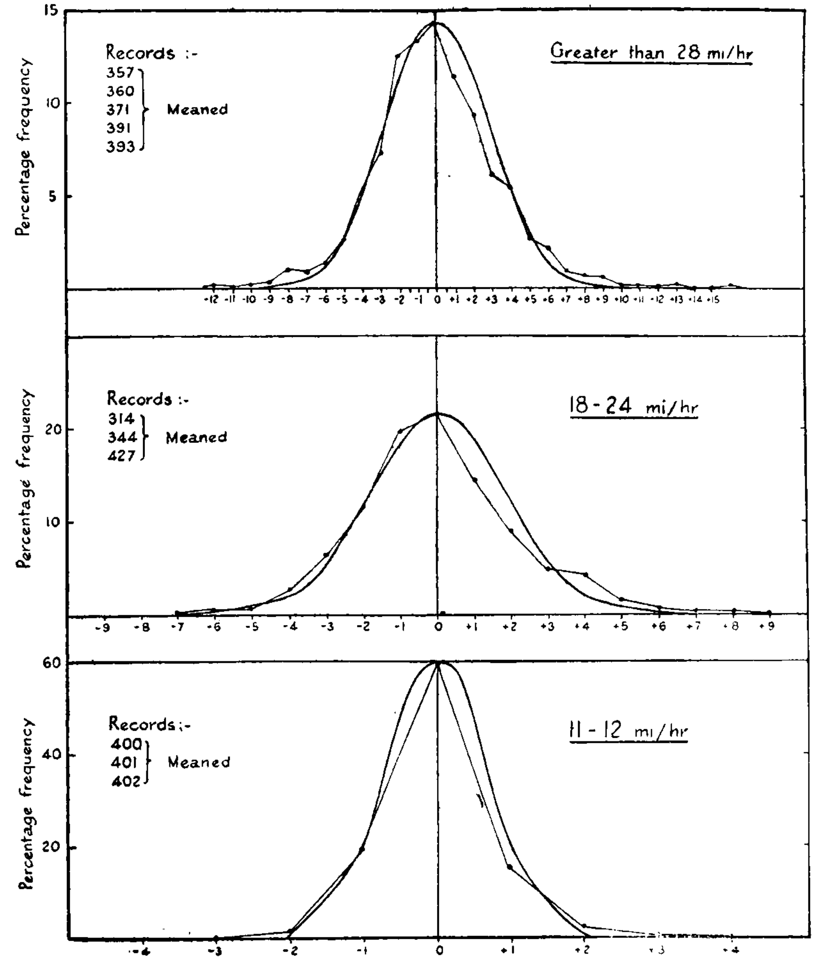


FIG. 42.—THIS DIAGRAM SHOWS THE FREQUENCIES OF ACCELERATION OF WIND OVER INTERVALS OF 5 SECONDS, THE DATA USED BEING THE SAME AS THOSE SHOWN IN FIG. 41, BUT COMBINATIONS WERE MADE OF THE CASES IN WHICH THE MEAN WIND OF THE RECORD WAS OVER 28 MI/HR., 18 TO 24 MI/HR. AND 11 TO 12 MI/HR. FOR COMPARISON FREQUENCY CURVES ARE ALSO DRAWN TO PASS THROUGH THE PEAK OF THE CURVE OBTAINED FROM THE DATA. THE ORDINATES ARE GIVEN IN PERCENTAGE FREQUENCY, THE ABSCISSÆ IN THE UNIT MILES PER HOUR PER 5 SECONDS.

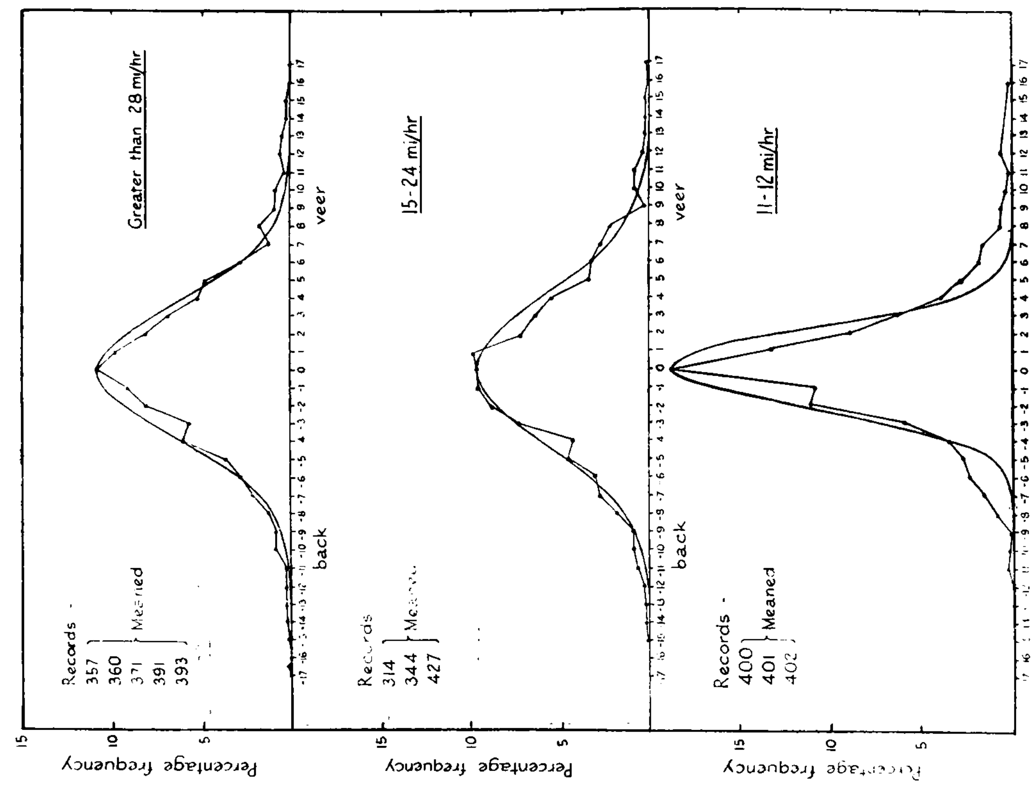


FIG. 44.—THIS DIAGRAM SHOWS SIMILAR INFORMATION TO FIG. 42, BUT FOR FREQUENCIES OF VEERING AND BACKING OF THE WIND IN DEGREES PER 5 SECONDS.

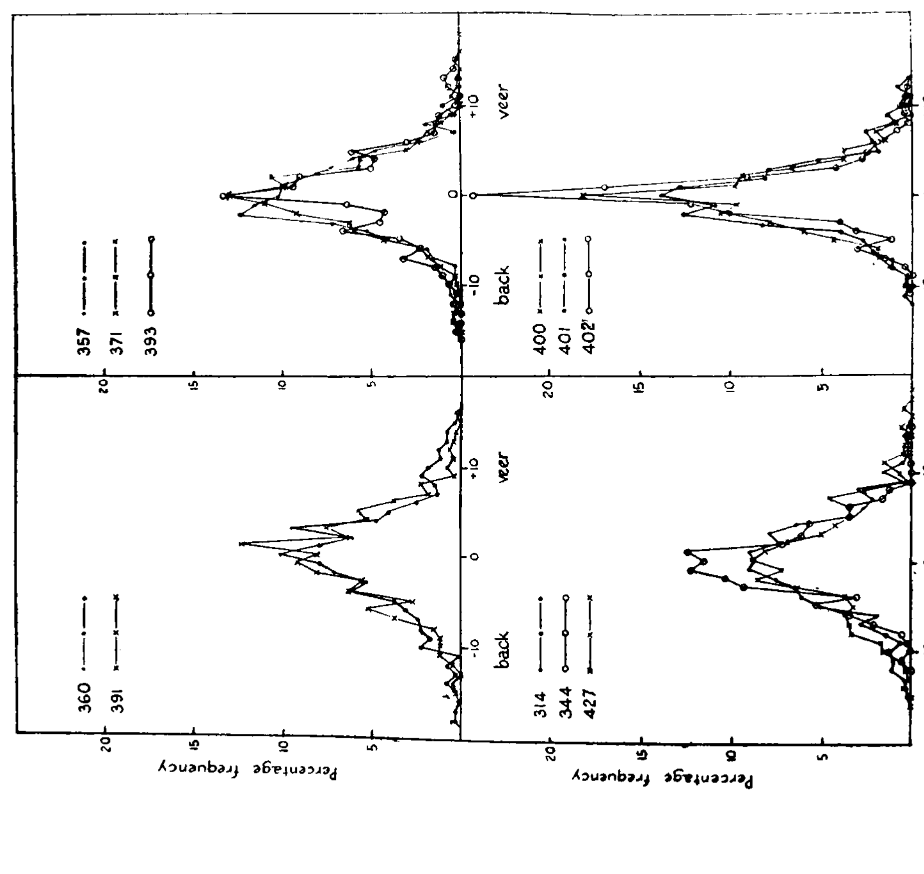


FIG. 43.—THIS DIAGRAM SHOWS SIMILAR INFORMATION TO FIG. 41, BUT FOR FREQUENCIES OF VEERING AND BACKING OF THE WIND IN DEGREES PER 5 SECONDS.

To face page 42.

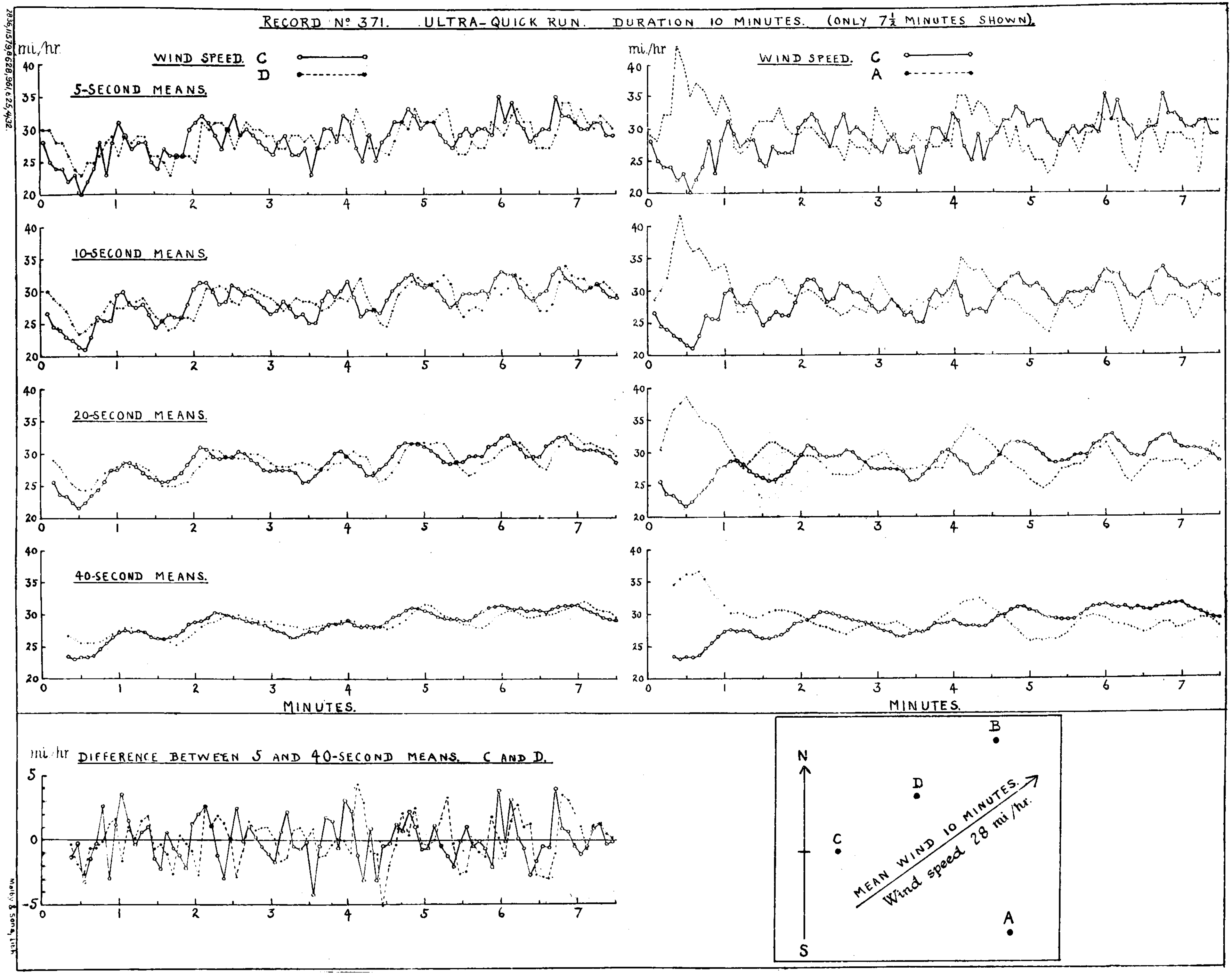


Fig. 45. Curves showing the wind speeds at different stations meaned over 5 seconds, 10 seconds, 20 seconds and 40 seconds together with curves showing the difference between speeds meaned over 5 and 40 seconds.

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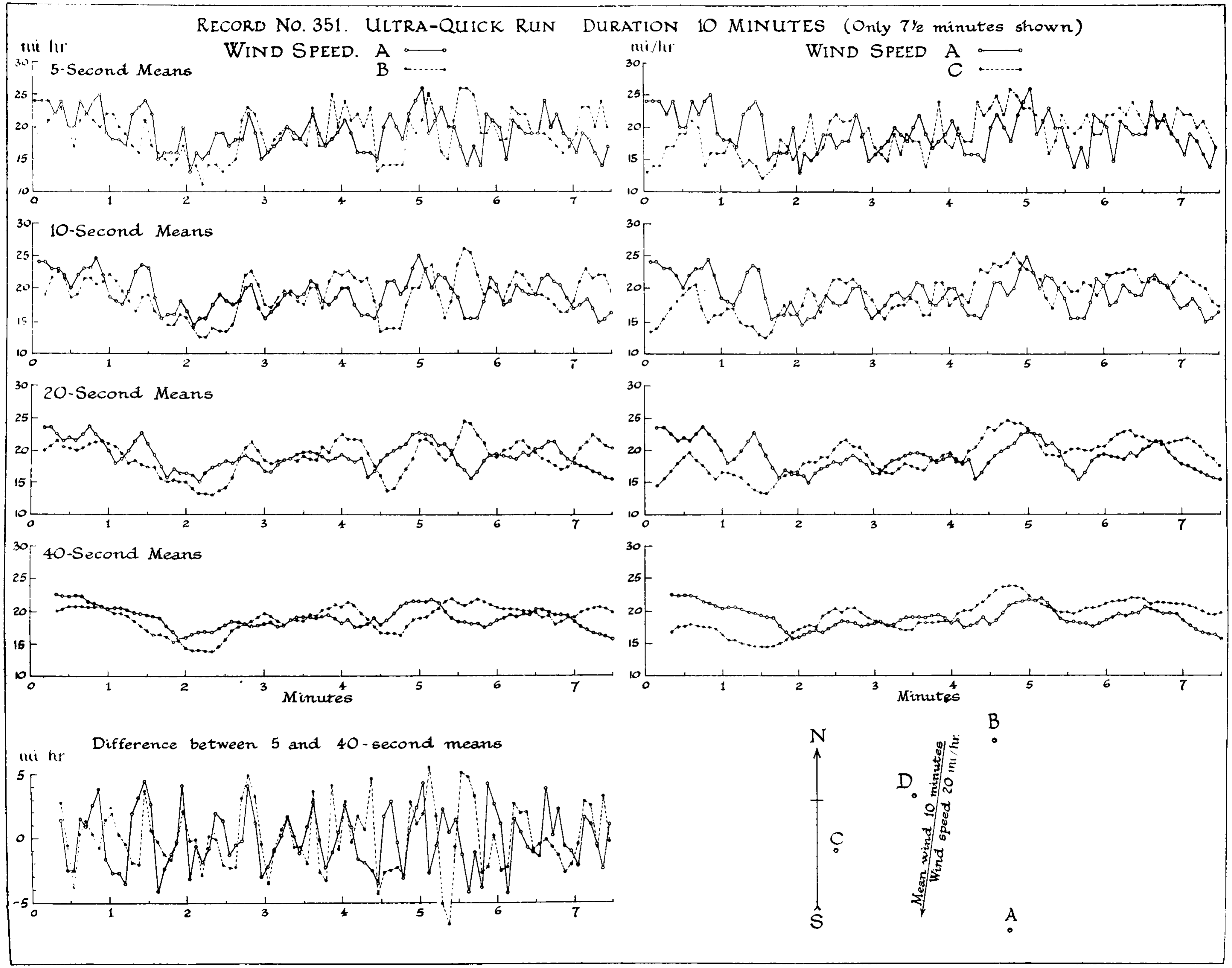

Fig. 46. Curves showing the wind speeds at different stations meaned over 5 seconds, 10 seconds, 20 seconds and 40 seconds together with curves showing the difference between speeds meaned over 5 and 40 seconds.

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For comparisons with these frequency curves, curves of error were calculated based on the formula $y = \frac{h}{\sqrt{\pi}} e^{-h^2x^2}$ where $\frac{h}{\sqrt{\pi}}$ is the maximum frequency. In Fig. 42, $\frac{h}{\sqrt{\pi}}$ is given the value of the observed frequency for zero acceleration. These curves show by contrast that the frequency curves derived from the data are skew shaped. Comparing the frequencies of retardation (on the left-hand side of the diagram) with the frequencies of acceleration (on the right-hand side) it is seen that low retardations are more frequent that low accelerations, while rapid retardations are less frequent than rapid accelerations. There does not appear to be any instrumental error which is likely to give such a result.

In Figs. 43 and 44 the frequencies of swing of the wind vane (in five seconds) are shown in a similar manner to the changes in velocity shown in Figs. 41 and 42. There is not in this case a corresponding skew shape of the curves of frequency.

(c) *The tracing of gusts from station to station.*—The comparison of the simultaneous records at the different anemometers does not reveal an identical wind pattern travelling over the anemometers even in those cases where the wind was blowing almost directly from one anemometer to another. In particular, it is exceedingly difficult, if not impossible in most cases, to follow pronounced gusts on successive anemometers.

An attempt has been made to do so for certain gusts in the case of record 371. The general conclusion reached was that an individual wind gust is a most ephemeral phenomenon even over a stretch of 350 feet, though, as will be seen in the subsection below, a group of gusts moves with approximately the mean wind speed.

The attempt to trace wind gusts between two anemometers 700 feet apart was even more hopeless though it was attempted in several other cases, notably in the case of record 351, in order to see if gusts were of a more persistent type in that case.

(d) *The comparison of wind speeds averaged over various intervals.*—In Fig. 45 are given curves of the wind averaged over five seconds, ten seconds, twenty seconds and forty seconds for record 371 (the originals of which are reproduced in Fig. 35, Plate VII) as well as a curve showing the difference between that averaged over five seconds and forty seconds.

In Fig. 46 are given corresponding curves for record 351 (the originals of which are reproduced in Fig. 34, Plate VI).

Examining first the left-hand portion of Fig. 45, there are given curves for station C and station D (which was directly down wind to it). These curves show that, as the fluctuations of shorter period are removed by successive smoothing, the curves for the two stations become very similar, if allowance is made for the fact that the mean wind at 50 feet took on this occasion about 8½ seconds to travel from C to D. In the lower left-hand portion of Fig. 45 are shown the residual curves, when the 40-second means are removed from the 5-second means. These curves then show how far the fluctuations due to the smaller eddies are reproduced at successive anemometers. It is seen that, though there is a certain amount of similarity in the two curves, when allowance has been made for the time taken for the wind to travel from C to D, the similarity is considerably less than is found in the case of the longer-period mean curves.

On the right-hand side of Fig. 45 are shown the curves for wind speed at two stations, C and A, which did not lie along the line of the wind. It is seen that during the first 5½ minutes there appears to be a decided similarity between the curves for C and those for A, when inverted. After the 5½-minute mark this inverse agreement gives place to an indication of direct agreement. This is a somewhat surprising result and will be referred to again later (page 46).

In contrast to Fig. 45, Fig. 46 shows how small a variation in direction of the wind off the line joining two anemometers may give very dissimilar traces.

(e) *Vector diagrams of wind departures from the mean.*—It is one of the generalisations of G. I. Taylor[1] that in a " steady " wind the fluctuations of direction bear such a relation to those of speed that the movement of the point X of Fig. 28 (page 33) is mostly within a *circle* centre A, or if three dimensions are being considered within a sphere centre A.

There are not available in the present observations records of the vertical velocities, but from the mean values of wind for 5 seconds, 10 seconds, etc., it is possible to verify how far this generalisation is justified in the horizontal plane. This has been done by counting the number of occasions on which the point X (of Fig. 28) lay in different parts of the horizontal field on certain occasions. The results are exhibited in Fig. 47 for two such occasions.

In Fig. 47a are shown the 5-second means which are seen to be definitely elongated in the direction of the wind. In Fig. 47b are shown values similarly plotted of the 5-second means minus the 80-second means, which are embraced by a circle, while in Fig. 47c are shown the 80-second means similarly drawn. These latter show on both occasions a very pronounced elongation.

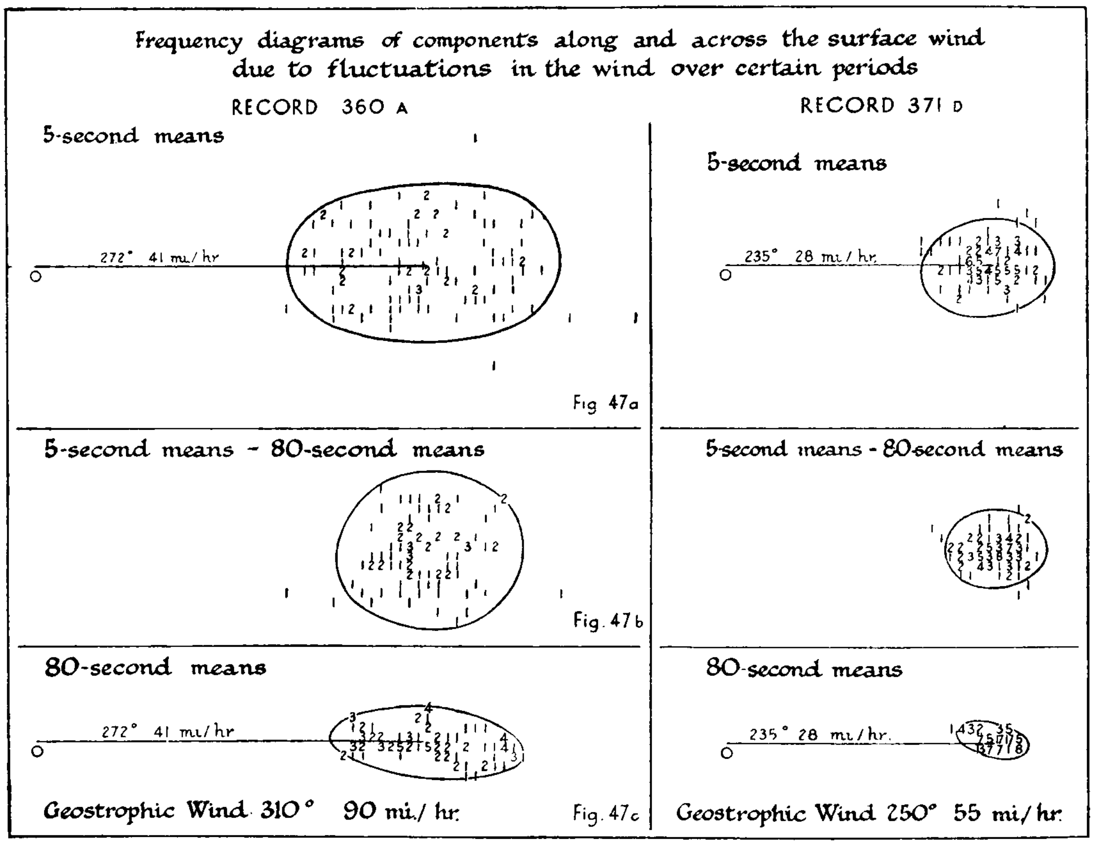


FIG. 47.—THE METHOD OF FORMATION OF THESE DIAGRAMS IS AS FOLLOWS :—THE 5-SECOND MEAN VALUES OF WIND SPEED AND DIRECTION WERE RESOLVED INTO COMPONENTS OF WIND SPEED ALONG AND AT RIGHT ANGLES TO THE WIND DIRECTION MEANED OVER THE WHOLE TEN MINUTES. A COUNT WAS THEN MADE OF THE FREQUENCY WITH WHICH THESE COMPONENTS LAY IN DIFFERENT PORTIONS OF THE FIELD OF CO-ORDINATES. THE RESULT OF THE COUNT IS SHOWN BY FIGURES IN THE TWO UPPER DIAGRAMS. THE ORIGIN OF CO-ORDINATES IS INDICATED BY THE POINT O. SUCCESSIVE 80-SECOND MEANS WERE THEN MADE AND WERE SIMILARLY TREATED IN THE TWO LOWER DIAGRAMS. THE DIFFERENCES BETWEEN THE 5-SECOND COMPONENTS AND THE 80-SECOND COMPONENTS WERE SIMILARLY TREATED AND ARE SHOWN IN THE MIDDLE PORTION OF THE DIAGRAM.

The inference to be drawn from this figure is that the eddies which produce the fluctuations of longer periods are not heterogeneous, but that there is a type

[1] Taylor, G. I. Observations and speculations on the nature of turbulent motion. *Adv. Com. Aeron. R. & M.* (new series) No. 345. 1917.

of eddy which predominates. The eddies which produce the fluctuations of short periods are, however, distributed at random and so their wind fluctuations obey Taylor's law.

(f) *The results of the application of correlation to certain records of ultra-quick runs.*—Correlation has been applied to a number of the four-point ultra-quick records and a table showing all the correlation coefficients obtained is given in Appendix III.

The process adopted in these numerical calculations is as follows :—

Let V_0, V_1, V_2, V_3, V_4, etc. and W_0, W_1, W_2, W_3, W_4, etc. be two series of mean values for 5 seconds, or any other period, at two anemometers, each V being synchronous with the corresponding W. Then by correlating V_0 with W_0, V_1 with W_1, etc., there is obtained the coefficient for the time interval t=o ; by correlating V_0 with W_1, V_1 with W_2, etc., the coefficient for the interval t=5 seconds and so on. In the tables these coefficients have been entered in the columns headed "time interval in seconds." Before, however, discussing the results obtained from this work it is necessary to form a clear idea of the meaning of these coefficients as applied to the present problem, and the results which would be expected.

In Fig. 48a conventionalized circular eddies are supposed to be travelling with the speed of the wind V over the anemometers marked A, B, C and D. First let us consider one point (say station B) only. As the wind system travels over this point, the recorded wind will rise and fall in some such curve as is shown in Fig. 48b. With the type of eddies shown in Fig. 48a the time interval between successive maxima on the curve of wind speed will be equal to the mean wind speed divided by twice the diameter of the eddies. Such wind curves are shown in Figs. 45 and 46, and in these figures it will be seen that there are more or less regular rises and falls, which appear perhaps best in curves of 20-second means.

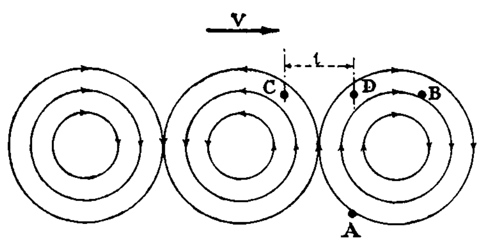


Fig. 48 a

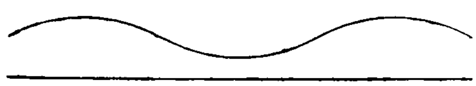


Fig. 48 b

If a series of mean values were correlated with itself but with different "time intervals," the correlation coefficient with time interval zero would be unity but with other time intervals would be less than unity. If, however, there was a tendency for the rises and falls to occur at more or less regular intervals the correlation coefficient would decrease to some negative value as the time interval increased and would then rise again to some positive maximum, in fact it would follow a curve of decay and from the time intervals between successive maxima it would be possible to obtain a measurement of the size of the preponderating eddies. If the eddies were quite random and heterogeneous there would be no negative correlation.

Next let us consider what is to be expected if series of means from two neighbouring anemometers are correlated with varying time intervals. If the mean wind is blowing from one of these anemometers to another (as from C to D in Fig. 48a), the correlation coefficient will attain a maximum with a certain value of the time interval which will be dependent on the mean wind speed and the distance apart of the anemometers. If the eddies continue unchanged in their passage between C and D the value of the maximum correlation coefficient will be unity : but if they are modified in their passage the value of the maximum coefficient will be less than unity and its size gives a criterion of the amount of modification which has taken place. If the mean wind is not blowing from one of the anemometers to another (as in the case of C and A of Fig. 48a), then the sign of the maximum correlation coefficient can give an indication whether the two anemometers are in the same stream of eddies or neighbouring streams.

As an example of the correlation of a speed curve with itself for different time intervals may be given record 391, item 3 of Appendix III. In this case the correlation coefficient decreases to a negative maximum of —·42 at time interval 50 seconds. From this it is to be inferred that there was a pattern which tended to repeat itself in about 100 seconds and as the mean wind was 34 miles per hour in this case the size of the repeating pattern was of the order of 5,000 feet.

An illustration of the correlations made between records at two anemometers is given in Fig. 49, in which are plotted certain values from the table given in Appendix III for record 371. In the upper portion of the diagram are given the curves of correlation coefficients for different time intervals for stations C and D, C and B, and C and A. In the first of these pairs the stations were 350 feet apart on the line of the mean wind when the records were being made and in the second pair the stations were 700 feet apart on the same line. Near the maxima, dotted lines have been drawn following the general trend of the curve ; they show the true maxima to be ·82 and ·60 at time intervals of 8 seconds and 16 seconds respectively for the curves C D and C B. The time taken by the mean wind to travel from C to D was 8½ seconds and from C to B 17 seconds, so that the time intervals of maximum correlation coefficients agree well with the supposition that there was a wind pattern travelling with a velocity only very slightly greater than the mean wind at the height of the anemometers.

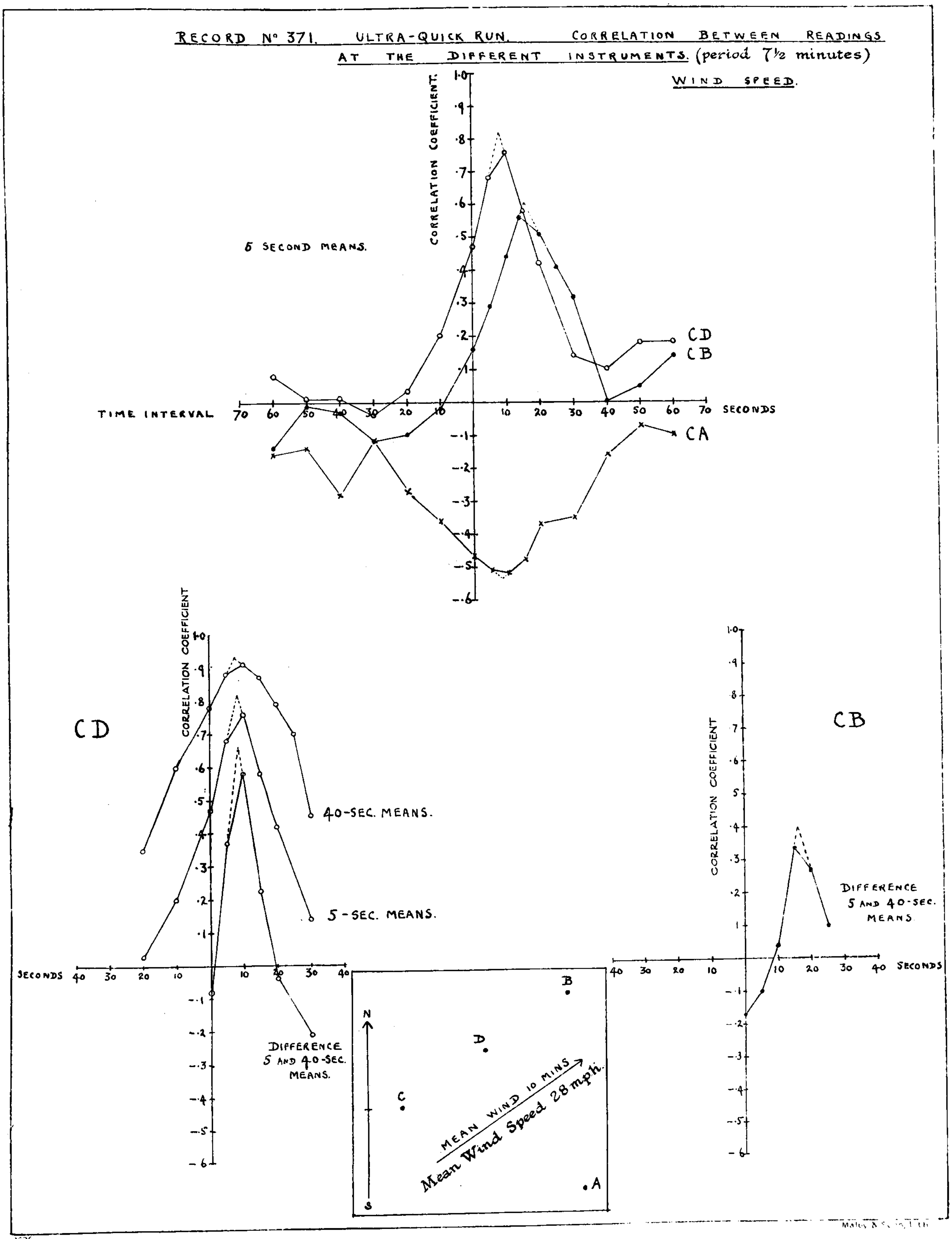
In the lower left-hand section of Fig. 49 there are shown curves of correlation coefficients for various time intervals for the stations C and D. The upper curve shows the coefficients for 40-second means, the middle curve for 5-second means and the lower curve for the difference between 5-second and 40-second means. (The actual curves of wind speed are given in Fig. 45.) This diagram shows that the maximum correlation coefficient for the long-period fluctuations (40-second means) is considerably greater than that for the short-period fluctuation (5-second minus 40-second means), from which it may be deduced that the larger-scale eddies persist for longer than the small-scale eddies.

The curve in Fig. 49 marked CA shows a significant negative correlation (−0·52 at the time interval of 10 seconds). In the calculation of these correlation coefficients only 90 of the 5-second means were used, i.e. 7½ minutes of the record only. Reference to Appendix III record 371, items 8 and 9 shows that though the correlation of 40-second means for A and D gave a significant negative correlation for the first 6 minutes of the record (−0·58), the last 4 minutes gave a very decided positive correlation (+0·71). Item 15, moreover, shows that short-period fluctuations are not reproduced across wind.

To explain this result it is necessary to consider the types of eddy which might be expected, and to see which type could produce such a result. For simplicity the eddies will be pictured as spinning masses of air, and two general cases will be considered : (a) the type which has its axis vertical, such as for example a dust devil, (b) the type which has its axis horizontal and may be pictured as a rolling and skidding cartwheel.

If a succession of the first type of eddy passed the points marked A and D in Fig. 48a, there would arise negative correlation between stations A and D, which would change to positive, if the whole line of eddies was shifted laterally across the wind. There would then be a succession of alternating positive and negative correlation coefficients obtained by taking different synchronous portions of the two wind traces. The diameters of these eddies would be of the order of 600 feet, the distance apart of stations D and A, and so these eddies would pass any point in about 15 seconds, and would be revealed on the anemometer traces by fluctuations of about that period. The negative correlation is shown by item 15 of record 371 in Appendix III not to occur in fluctuations of that period, but in fluctuations of a very much longer period, hence the type of eddy with a vertical axis must be rejected.

To get negative correlation between stations A and D from eddies of the cartwheel type, it is necessary to suppose that there are parallel lines of such rolling and skidding eddies, any two contiguous lines being displaced by exactly half a diameter. If then the breadth of the eddy (or cartwheel) is supposed to be something greater than 600 feet and the whole train of eddies has a slight lateral as well as forward motion, the correlation coefficients obtained from anemograms made at stations 600 feet apart in the cross-wind direction will sometimes be positive


RECORD No 371. ULTRA-QUICK RUN. CORRELATION BETWEEN READINGS AT THE DIFFERENT INSTRUMENTS. (period 7½ minutes)
WIND SPEED.
CORRELATION COEFFICIENT.
5 SECOND MEANS.
TIME INTERVAL
SECONDS
CD
CB
CA
CD
CORRELATION COEFFICIENT
40-SEC. MEANS.
5-SEC. MEANS.
DIFFERENCE 5 AND 40-SEC. MEANS.
N
S
A
B
C
D
MEAN WIND 10 MINS
Mean Wind Speed 28 mph.
CB
CORRELATION COEFFICIENT
DIFFERENCE 5 AND 40-SEC. MEANS.
SECONDS

2636

Fig. 49

and sometimes negative as different synchronous portions of the anemograms are used. Moreover, the down-wind extent of such eddies may be far greater than 600 feet, depending only on the vertical diameter of the eddy.

The conclusion to be drawn from these coefficients is then that, on the day when record 371 was made, the predominant larger eddies were of the " cartwheel " type and were of the order of 3000 to 4000 feet in the down-wind direction, and of the order of 600 feet in the cross-wind direction.

It would, however, seem from the examination of other quick and ultra-quick runs that in this particular case the sizes of these eddies were smaller than the average, which is estimated to be often of the order of 8000 feet in the direction along the wind.

(g) *Small-scale eddies shown by fluctuations of the wind vanes.*—If the records are examined, it will be seen that the wind vane has a tendency to oscillate very decidedly at certain times, and at others to remain very much more steady. For instance, on record 371A & D (Fig 35, Plate VII), and on record 360A (Fig. 36, Plate VIII) between the points marked c and d there is considerably more fluctuation on the direction records than between the points marked d and e. A comparison of these points with the speed records shows that the period of oscillation corresponds to a lull in the wind while the subsequent period of little oscillation corresponds to an increased velocity. The same feature may be recognised on almost every record and it was noticed before its physical significance, which will be pointed out later (Part III, § 26), was known.

As a rough measure of the amount of oscillation of the vane, the sum of all the movements of the vane in each 5 seconds was measured for some of the records. The means of eight of these values were obtained giving means over intervals of 40 seconds. Treating these mean values of oscillation in the same way as mean values of wind velocity and direction had been previously treated, that is, correlating the values from the different instruments at the same time and at intervals, the results for the oscillations were found to be very similar to those for velocity and direction (*vide* Appendix III, record 371, items 19 to 24).

Correlation was then made between the speed at one instrument and oscillation of the vane at the same instrument (items 26 and 29). The coefficient of correlation for station C was $-\cdot 57$ for synchronous observations and $-\cdot 80$ when the interval between the observation of speed and that of oscillation was 20 seconds. This indicated that the decrease of oscillation occurred some 20 seconds after the increase of speed. Correlation was also made between the speed at one instrument and the oscillation of the vane at another (items 27 and 28). These coefficients were also of significant size, which makes the likelihood small that these oscillations of the vane were due to instrumental effects rather than inherent in the wind. Since the speed recorder of the Dines instrument, as has been pointed out in Part I, is highly damped for fluctuations of less than about 5 seconds, while the direction vane is by no means so highly damped, it is probable that the presence of small-scale turbulence will be indicated on the latter, but not on the former. If this is so, it would appear that during lulls in the wind and the initial stages of a gust there is greater small-scale turbulence than after the establishment of the higher wind speed.

§ 19—CHARACTERISTICS OF WINDS WHEN THERE IS A SURFACE INVERSION

It has been pointed out in § 16 page 35 that there is a marked difference in the type of wind record when the temperature records show a superadiabatic or adiabatic vertical temperature gradient near the surface, and when they show an isothermal layer or an inversion near the surface. This contrast has been attributed to the presence of eddies of different types. The eddies which predominate in the latter case have been classified as eddies of types III and IV. It is now proposed to discuss these eddies in detail.

(a) *The examination of eddies of type III.*—In Fig. 50 (Plate IX) are shown two records of ultra-quick runs made on the 150-foot anemometer during the night of October 8–9, 1929. The mean wind speed during the making of these two records was not dissimilar, and the air masses, in which they were made, were of similar origin. Record 547 (the upper pair of anemograms), however, was made while the sky was overcast. Before record 548 (the lower pair) was made the sky had entirely cleared, and an inversion of just over 1°F. was recorded between the high and low thermometers. The contrast in the type of eddying is striking, for the earlier record shows three well marked instances indicated by A, B and C on the record, in which there was the sudden increase of wind speed and gradual decrease which has been associated with eddies of types I and II ; record 548 does not show these characteristics, though the fluctuations of the period 10 to 15 seconds are greater.

The contrast of eddies in these two records is shown by Fig. 51 (with which may be compared Fig. 47). This figure shows the variations of wind in the form of vector diagrams. The five-second means give a greater elongation down wind before the inversion formed, than afterwards. When 40-second means are formed the variations are very much greater in the record before the inversion formed than after it had formed, while for the short-period fluctuations between 5 seconds and 40 seconds they are very similar in the two cases.

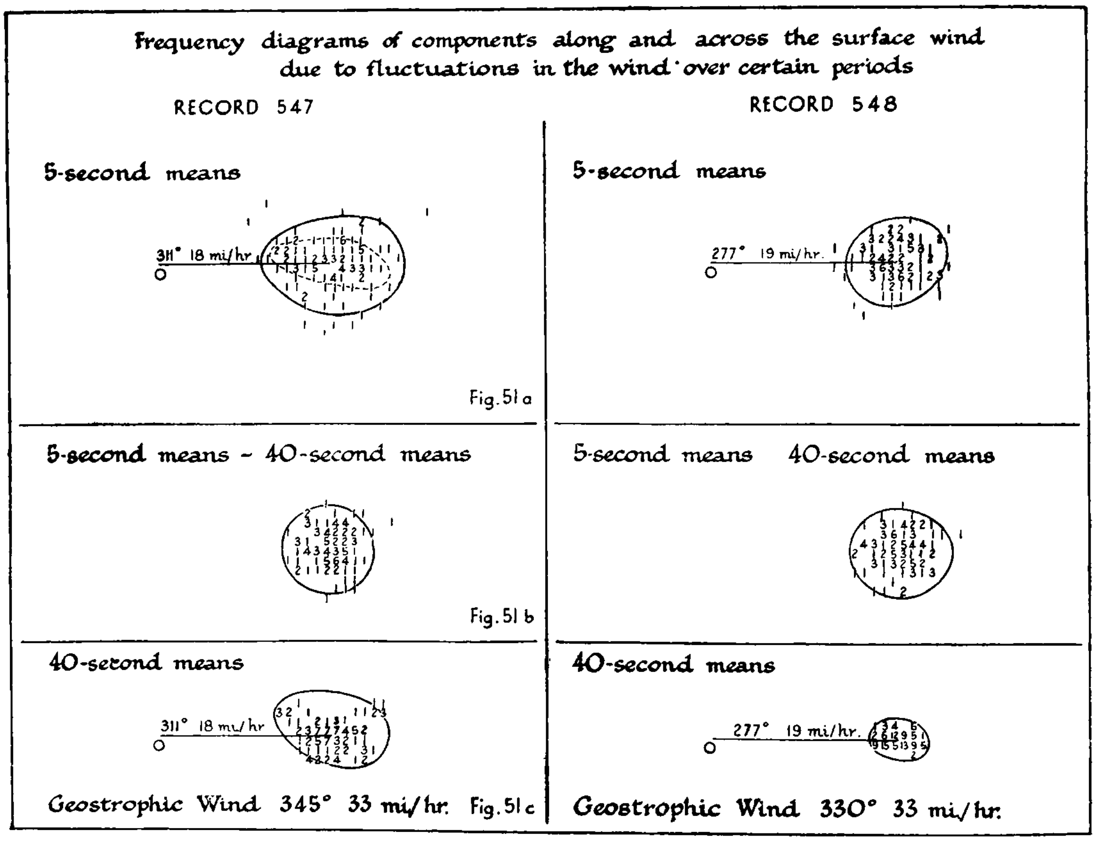


FIG. 51. THE METHOD OF FORMATION OF THESE DIAGRAMS IS SIMILAR TO THAT EMPLOYED FOR FIG. 47. IT THROWS UP INTO CONTRAST THE ELONGATION OF EDDIES BEFORE THE ESTABLISHMENT OF AN INVERSION WITH THE MORE UNIFORM EDDIES AFTER THE INVERSION IS ESTABLISHED.

The change-over in type referred to above is well illustrated also by Fig. 52 (Plate X) which was made during the early stages of the formation of an inversion on September 26, 1929. The contrast between the large amplitude of the wind fluctuations before the seventeenth time mark at 16h. 51m. with the small amplitude after is striking. On this day the inversion began at about 16h. 30m.

Other examples of this type of eddying are given in Figs. 53 and 54 (Plates X and XI).

Fig. 53 shows evidence of very considerable eddying at the 150-foot level, though the inversion between the 143-foot thermometer and the 4-foot one was 2°F., and the sky was clear. A similar type of fluctuation was shown on the 50-foot anemometer. It is to be noted that the wind was blowing from a direction of 155°, and thus was not passing over the airship sheds before reaching the high anemometer.

Fig. 54 shows evidence of eddying of a similar nature, at the 150-foot level, but the sky was overcast and the inversion was only ½°. When the wind blows over the largest obstacle in the neighbourhood, namely the airship sheds, the position of which is shown in Fig. 2 (page 13), it is possible to see very distinctly the effect of such an obstacle on the eddying. During the period when the wind backed to 135° in this record the eddying became very much more violent as is shown on both the speed and direction records. The two ends of the airship sheds lie in the directions 100° and 125° from the high anemometer (station F), and this effect of eddying is due to the wind wake of these sheds, since the same effect is not shown on the low anemometer.

The wind wake of the sheds may be seen on the normal records of the high anemometer, an example being given in Fig. 55 (Plate XI). The interesting feature of this record is the contrast between the period before 17h. 30m. and after that hour. During the superadiabatic conditions up to that hour the small-scale eddying was not abnormal, but after that hour when the inversion had formed the small-scale eddying became excessive, though during the period from 13h. onwards the wind was blowing from the shed to the high anemometer. (This will be referred to later in Part III, § 28.)

The amplitudes of the wind fluctuations which occur with inversions may be quite small as is shown in Fig. 56 (Plate XII), and may die out until the anemogram becomes a straight line, an example of which is shown in Fig. 31 (Plate IV).

An ultra-quick run made during the formation of an inversion is shown in Fig. 57 (Plate XII), and in this case there seems to be a certain tendency for the velocity record to show small regular oscillations which may, perhaps, be due to wave motion established in the interface between the warm air above and the cold air below.

§ 20—THE RELATION OF MEAN VARIATION OF WIND AND MEAN EDDY SPEED TO WIND SPEED AT 50 FEET ABOVE GROUND LEVEL

In Fig. 58 let OX_r and OX_{r+1} represent two consecutive 5-second mean values of wind in direction and speed and let OA represent the mean value of wind taken over the ten-minute record. The change in wind during the 5 seconds is represented by the vector X_rX_{r+1}. The " mean variation " of wind is defined to be $\frac{\Sigma|X_rX_{r+1}|}{n}$, (i.e., the mean of the moduli of vector differences of consecutive 5-second mean values of wind).

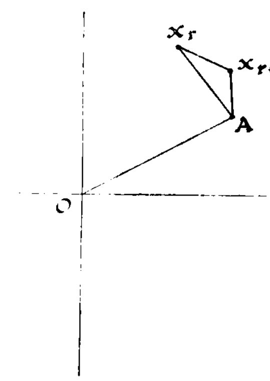


FIG. 58.

The " mean variation " of wind has been computed for certain records of ultra-quick runs and the results have been plotted against the mean wind speed in Fig. 59 ; a striking linear relationship is shown. It is to be noticed that these records were all made during daylight hours so that this relationship does not necessarily hold under conditions associated with inversions.

The " mean eddy speed " is defined to be $\frac{\Sigma|AX_r|}{n}$ (i.e., the mean of the moduli of vector differences of the 5-second mean value of wind and the mean wind). The " mean eddy speed " has been computed for the same records and is also plotted against the mean wind speed in Fig. 60. This also shows an increase with wind speed, but the agreement is not so close as in the case of the mean variation of wind.

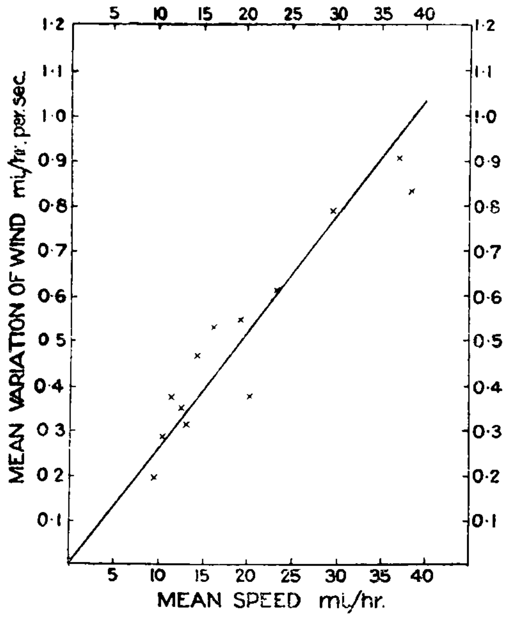


FIG. 59.—RELATIONSHIP BETWEEN MEAN VARIATION OF WIND AND MEAN WIND SPEED.

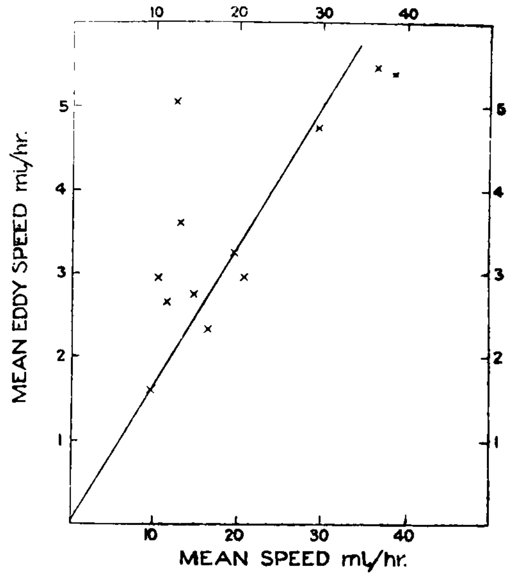


FIG. 60.—RELATION BETWEEN MEAN EDDY SPEED AND MEAN WIND SPEED.

§ 21—EDDY ENERGY AND EDDY PRESSURE

Let U,V be the mean vector co-ordinates of air motion taken over a certain period (T) and u_1, v_1, the departures from the mean values of the air motion averaged over a fraction of that period (t seconds say) so that

$$TU = t\,\Sigma\,(U+u_1)$$
$$TV = t\,\Sigma\,(V+v_1)$$

Now the energy per t seconds due to the wind given by the components $U + u_1 \quad , V + v_1$ is $\frac{1}{2}\,\rho\,t\,[(U+u_1)^2+(V+v_1)^2]$

TABLE XVIII

Record	Date	G.M.T.	Geostrophic wind		Mean wind		
			Direction	Speed	Direction	Speed	Energy
	1927	h. m.		mi./hr.		mi./hr.	ergs.
265D	July 5	17 57			195°	15	270
270D	July 5	19 00			200°	15	270
274D	July 5	19 49			220°	12	170
344A	Nov. 2	14 53	245°	33	233°	19	430
	1928						
357A	Jan. 4	15 05	270°	70	226°	28	940
357B	Jan. 4	15 05	270°	70	226°	28	940
357D	Jan. 4	15 05	270°	70	226°	28	940
360A	Jan. 6	12 32	310°	90	272°	41	2000
371A	Jan. 24	11 02	250°	55	235°	28	940
371B	Jan. 24	11 02	250°	55	235°	28	940
371C	Jan. 24	11 02	250°	55	235°	28	940
371D	Jan. 24	11 02	250°	55	235°	28	940
391A	Feb. 11	11 16	295°	85	249°	34	1380
393A	Feb. 17	12 00	300°	50	275°	27	870
401A	Feb. 21	14 54	200°	30	175°	11	140
427A	Mar. 21	10 22	125°	40	110°	23	630

where ρ is the density of the air, and the total energy per T seconds due to all values of wind averaged over t seconds is

$$\tfrac{1}{2}\rho\, t\, \Sigma\, [(U+u_n)^2 + (V+v_n)^2]$$

$$\text{or} \quad \tfrac{1}{2}\rho\, T\, (U^2+V^2) + \tfrac{1}{2}\rho\, t\, \Sigma\, (u_n{}^2+v_n{}^2)$$

since $\Sigma\, Uu_n = \Sigma\, Vv_n = 0.$

$\frac{1}{2}\rho\, T\, (U^2 + V^2)$ is the energy of the mean wind. Hence $\frac{1}{2}\rho\, t\Sigma\, (u_n{}^2 + v_n{}^2)$ is the difference in energy between the wind including its eddies of a period longer than t seconds, and its mean value, that is the expression $\frac{1}{2}\rho\frac{t}{T}\, \Sigma\, (u_n{}^2 + v_n{}^2)$ gives the eddy energy of eddies having periods between t seconds and T seconds.

By taking means for different values of t and subtracting the one from the other a species of energy spectrum of the wind may be constructed.

In certain cases this has been done for ultra-quick runs and the results are given below, the energy being computed along the mean wind direction and across it.

On the analogy of the dynamical theory of gases there will be an " eddy pressure" in turbulent wind which will be given by the formula

$$p_e = \tfrac{1}{3}\, \rho\, \frac{t}{T}\, \Sigma\, (u_n^2 + v_n^2 + w_n^2)$$

where p_e is the eddy pressure due to eddies having periods between t and T seconds.

The analogy does not hold in one respect, since in the theory of gases the molecules are assumed to bounce back off the walls of the containing vessel without loss of energy. Such resistance cannot be assumed for the separate elements in the eddy case, but the average velocity of the elements approaching a boundary is equal to the average velocity of those moving away from it, although in practice the velocity actually vanishes at the boundary itself.

If it be assumed that the total eddy energy is $1\frac{1}{2}$ times the horizontal eddy energy, it is seen from Table XVIII that the eddy pressure in a natural wind ranges up to an order of 7×10^{-2} mb.

TABLE XVIII

Eddy energy 5 sec.—160 sec. in C.G.S. units.					Cloud
Component down wind	Component cross wind	Total Horizontal	Down wind / Cross wind	Total horizontal / Mean wind	Type and amount
7·9	3·1	11·0	2·5	·041	A.St.6 ; Cu.Nb.1
6·1	2·5	8·6	2·4	·032	A.St.6 ; Cu. tr.
5·0	1·3	6·3	3·8	·037	A.St.4 ; Cu. tr.
5·0	1·8	6·8	2·8	·016	St.Cu.8 ; A.Cu.1
11·2	4·6	15·8	2·4	·017	
9·5	2·6	12·1	3·6	·013	Nb.5 ; St.Cu.5
9·8	2·8	12·6	3·5	·013	
52·0	16·3	68·3	3·2	·034	Fr.Cu.3 ; A.Cu.1 ; Cu.1
12·6	3·7	16·3	3·4	·017	
9·8	3·8	13·6	2·6	·015	A.St.2 ; A.Cu.5 ; Cu.2
8·5	3·6	12·1	2·4	·013	
7·3	3·5	10·8	2·1	·011	
19·1	6·7	25·8	2·8	·019	St.Cu.4 ; Nb.4
13·4	8·7	22·1	1·5	·025	Cu ; Cu.Nb ; St.Cu.8
1·9	0·6	2·5	3·2	·018	Nil.
8·1	5·4	13·5	1·5	·021	A.St.7 ; St.Cu.3

TABLE XIX—EDDY ENERGY (IN C.G.S. UNITS)

Record no.	Date	G.M.T.	Height (Feet)	Wind component	Eddy Periods (sec.)					
					5 to 10	10 to 20	20 to 40	40 to 80	80 to 160	5 to 600
	1928	h. m.								
371A	Jan. 24	11 2	50	Down wind	2·0	2·0	3·0	4·0	1·6	14·4
				Cross wind	1·2	0·8	0·7	0·7	0·2	4·0
371B	Jan. 24	11 2	50	Down wind	1·9	2·0	2·4	1·9	1·4	10·7
				Cross wind	1·1	1·1	0·7	0·5	0·4	4·2
371C	Jan. 24	11 2	50	Down wind	1·6	1·4	1·9	1·9	1·7	10·3
				Cross wind	1·2	1·0	0·7	0·4	0·2	3·7
371D	Jan. 24	11 2	50	Down wind	1·2	1·6	1·7	1·3	1·4	8·4
				Cross wind	1·3	1·0	0·6	0·4	0·2	3·7
360A	Jan. 6	12 32	50	Down wind	8·8	4·9	7·2	12·8	18·2	61·2
				Cross wind	3·0	4·4	3·6	3·4	2·0	16·0
	1929									
547F	Oct. 8	22 12	150	Down wind	1·7	1·8	2·5	3·0		12·9
				Cross wind	2·3	1·7	1·3	1·0		8·0
548F	Oct. 9	3 39	150	Down wind	1·2	1·3	0·9	0·7		7·0
				Cross wind	1·4	1·3	1·3	0·4		4·5
	1930									
579C	Oct. 16	22 22	50	Down wind	1·0	0·7	0·6	0·6		3·6
				Cross wind	0·4	0·4	0·2	0·1		1·3
579C	Oct. 16	22 22	30	Down wind	1·0	0·7	0·8	0·8		4·1
				Cross wind	0·5	0·2	0·1	0·1		1·0

From these tables the following facts emerge :—

(i) The eddy energy over a ten-minute sample of wind varies considerably from place to place across the wind stream, and even to some extent along the line of the wind stream, as is shown by the contrast between amount of eddy energy calculated from record 371A and from records 371B, C and D. The cross-wind component of eddy energy, however, does not vary as much as the down-wind component.

(ii) The amount of eddy energy varies considerably under different conditions and does not bear a marked relationship to the wind speed.

Table XIX shows the eddy " spectrum " for certain records.

(iii) In the case of records 547F and 548F which were made at night, respectively before and after the formation of an inversion (*vide* § 19a and Fig. 50, Plate IX) the falling off of the eddy energy after the formation of the inversion is pronounced for the larger eddies, but not for the smaller eddies.

(iv) In the case of records 579C which were made at heights of 50 feet and 30 feet, and which are referred to later in the report (§ 32), there is a slight indication that the eddy energy due to the large eddies decreased with height.

§ 22—VARIATIONS OF WIND DURING SQUALLS

Information has been given so far as to the nature of fluctuations that occur in steady flowing air and under moderately squally conditions. It remains to discuss the cases which have been recorded of sudden changes of wind speed and direction when these changes were of the permanent or semi-permanent type, i.e., the type of cases in which the wind after oscillating about a mean wind vector OA in Fig. 28 changes in such a way as to oscillate about a new mean wind vector OB. Such changes are associated with thundery conditions or with definite discontinuities in the atmosphere (fronts) which travel with a more or less ordered mode of progression across the earth's surface and may be followed by means of synoptic charts.

In Appendix IV is given a list of some examples of these phenomena during which quick-run records were obtained, together with the amounts of greatest change in speed and direction of the wind that occurred in one minute, two minutes and three minutes.

Some of the more pronounced changes are illustrated by the reproduction of the actual quick-run records in Figs. 61 to 75 (Plates XIII to XVI), and in Fig. 76 are given vector diagrams which show the wind speed and direction measured over consecutive minutes during the changes. In these diagrams the minute values are numbered in sequence and on each of the reproductions of the records is indicated the period for which the corresponding vector diagram has been drawn.

It has not been possible to obtain quick-run records of all the fronts and squalls which have passed over Cardington during the period over which the investigation extends and some very pronounced ones have not been recorded. It may, however, be considered that the front of November 12, 1929 was the sharpest that occurred and the thunderstorm of July 20, 1929 gave the most rapid speed change.

The district of Cardington is not so subject to sharp fronts of the line-squall type as are regions to north and west. The changes of wind shown in Figs. 61 to 75 are probably less pronounced than might be obtained in other districts.

It is not proposed to discuss here the physical processes which give rise to wind changes in fronts and thunderstorms, but below are given briefly the main points which are outstanding in the records reproduced.

Fronts.

November 19, 1928 (Figs. 61, Plate XIII and 76a). Slight intermittent rain occurred with this front, but not of measurable quantity. Pressure began to rise at 18h. 40m. G.M.T. (before the veer of wind). Temperature fell 1½°F. just after the veer of wind and humidity fell from 83% to 77% during the veer. Cloud at 18h. G.M.T. was stratus 8 tenths and alto-stratus with an overcast sky, the height of low cloud being estimated as 1,500 feet. It is noticeable that there is considerably greater gustiness in the wind after the passage of the front than before. There is a squall gust shown during the passage of the front though not a very pronounced one. This gust occurs at about the middle of the veer of wind.

November 23, 1928 (Figs. 62, Plate XIII and 76b). This record shows the final veer of a very diffuse front during a gale. The veer had been in progress for 5 or 6 hours with a fall of pressure. Pressure steadied up about 15h. G.M.T. and began to rise about 15h. 40m. G.M.T. Temperature after tending to rise between 15h. and 15h. 30m. G.M.T. then fell steadily. The rainfall was very small.

June 6, 1929 (Figs. 63, Plate XIII and 76c). Slight rain began at 18h. 37m. G.M.T. and became heavy at 18h. 39m. G.M.T. ceasing at 18h. 47m. G.M.T. At about 18h. 42m. G.M.T. pressure began to rise sharply, at the same time temperature fell sharply about 3°F. in five minutes and humidity rose from 80% to 90%. This shows an example of a fairly sharp front, but with moderate winds only, and a pronounced decrease in wind speed after the passage. It is noticeable that rainfall did not begin to occur till the wind veer was half completed and did not become heavy till the veer was finished.

August 4, 1929 (Figs. 64, Plate XIV and 76d). The observers' notes are as follows :—

11h. 45m. G.M.T. clear squall line of nimbus stretching north to south horizons ; first observed nimbus 3000 feet ; 12h. 10m. G.M.T. nimbus commenced passing over station and took roughly half-an-hour, followed by blue sky and strato-cumulus (high) then cumulus ; 12h. 15m. G.M.T. slight shower ; temperature dropped 4½°F. (69° to 64½°) ; 12h. 17m. G.M.T. sharp shower for a few seconds. Pressure rose ½ mb.

This record shows a front of somewhat similar characteristics to the previous one except that the wind speed increased after the passage of the front. It will be noticed, however, that this increase in speed occurred quite definitely after the veer was completed. Again rain did not begin till late in the veer and the sharpest shower was after the veer was over.

October 24, 1929 (Figs. 65, Plate XIV and 76e). Rain began at 15h. 3m. G.M.T and immediately became heavy, but became moderate at about 15h. 8m. G.M.T. and continued for some hours. Pressure rose sharply at about 15h. 2m. G.M.T. and temperature at the same time began a very sharp fall, the thermometer at 143 feet showing a fall of 10°F in 9 minutes. This is an example of a sharp veer of wind followed by a fall in speed. As in the two preceding cases the rain occurred after the veer was well advanced. There was, however, a very marked gust which occurred before the veer began.

November 10, 1929 (Figs. 66, Plate XIV and 76f). Rain began at 6h. 51m. G.M.T. A bank of nimbus appeared from about north-west at 8h. 22m. G.M.T., and reached the station at 8h. 26m. G.M.T. stretching from north-east to south-west ; it was accompanied by hail. Heavy rain fell after the passage of the front, and precipitation continued till 10h. 30m. G.M.T. Pressure rose sharply at about 8h. 25m. G.M.T. and temperature at 143 feet fell suddenly 2½°F. between 8h. 24m. and 8h. 27m. G.M.T. This record shows a rather remarkable break in the veer just as the nimbus cloud was passing over the station. Associated with this break in the veer there occur rather high gusts on the speed record. The character of the trace suggests that this break is due to the striking of the station by a small tornado with a vertical axis, the type of whirl, which when very developed produces the phenomenon of the waterspout. In Fig. 76f are shown the vectors for one-minute intervals and in addition vectors for 20-second intervals during the passage of this whirl (these are numbered consecutively 8b, 8c, 9a, 9b, 9c, 10a, 10b, and are connected by a broken line). From the values of these 20-second measurements the mean values for one-minute intervals were calculated and, by subtraction from the 20-second values, departures were obtained which show the wind speeds due to the whirl. These have been plotted in Fig. 77 where they are shown by arrows. Dotted lines have been added to indicate the approximate lines of flow of the air. The mean velocity of the main stream of the wind was about 30 feet per second. The indications are that this whirl was of the order of 2,000 feet in diameter rotating in a clockwise direction.

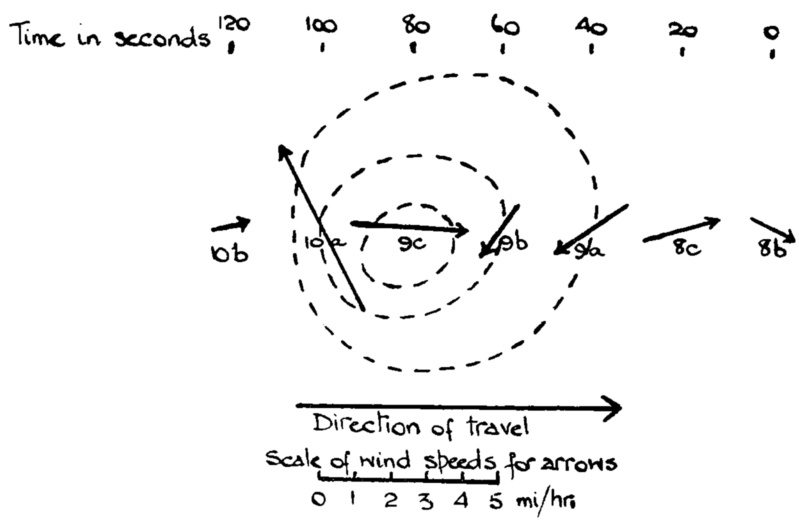


FIG. 77.—DIAGRAM SHOWING WINDS IN A WHIRL ACCOMPANYING A FRONT.

November 12–13, 1929 (Figs. 67, Plate XIV and 76g). Rainfall which had been light since 22h. 30m. G.M.T. became moderate at 0h. 52m. G.M.T. and heavy at 1h. 10m. G.M.T. moderating again at about 1h. 15m. G.M.T. At 1h. 10m. G.M.T. pressure rose suddenly 1½ mb. At 1h. 12m. G.M.T. temperature at 143 feet fell 9° F. in 3 minutes (continuing to fall, but not so rapidly afterwards). The front shown on this record is of historical interest as being the most intense front ridden out by H.M. Airship R.101 at the mooring tower. The record is not perfect, unfortunately, and consequently the mean directions for one-minute intervals that were measured are not rigorously accurate. It has been possible to obtain them sufficiently closely to be able to draw Fig. 76g. with a fair approximation of the truth. From this it is seen that the speeds of the vector changes were 35 and 30 miles per hour in consecutive minutes.

VECTOR DIAGRAMS SHOWING WIND CHANGES DURING THE PASSAGE OF CERTAIN FRONTS AND SQUALLS

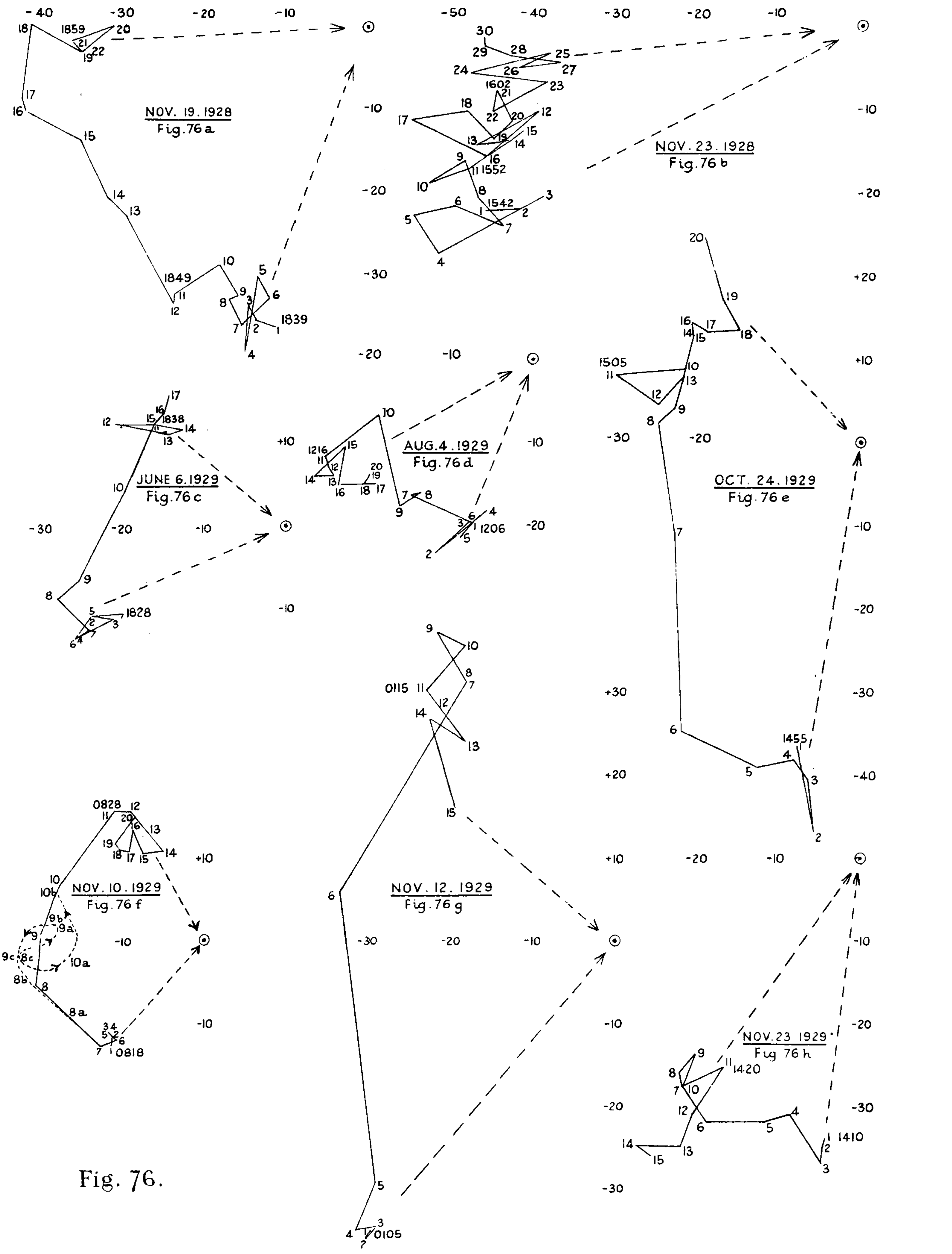


Fig. 76.

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VECTOR DIAGRAMS SHOWING WIND CHANGES DURING THE PASSAGE OF CERTAIN FRONTS AND SQUALLS

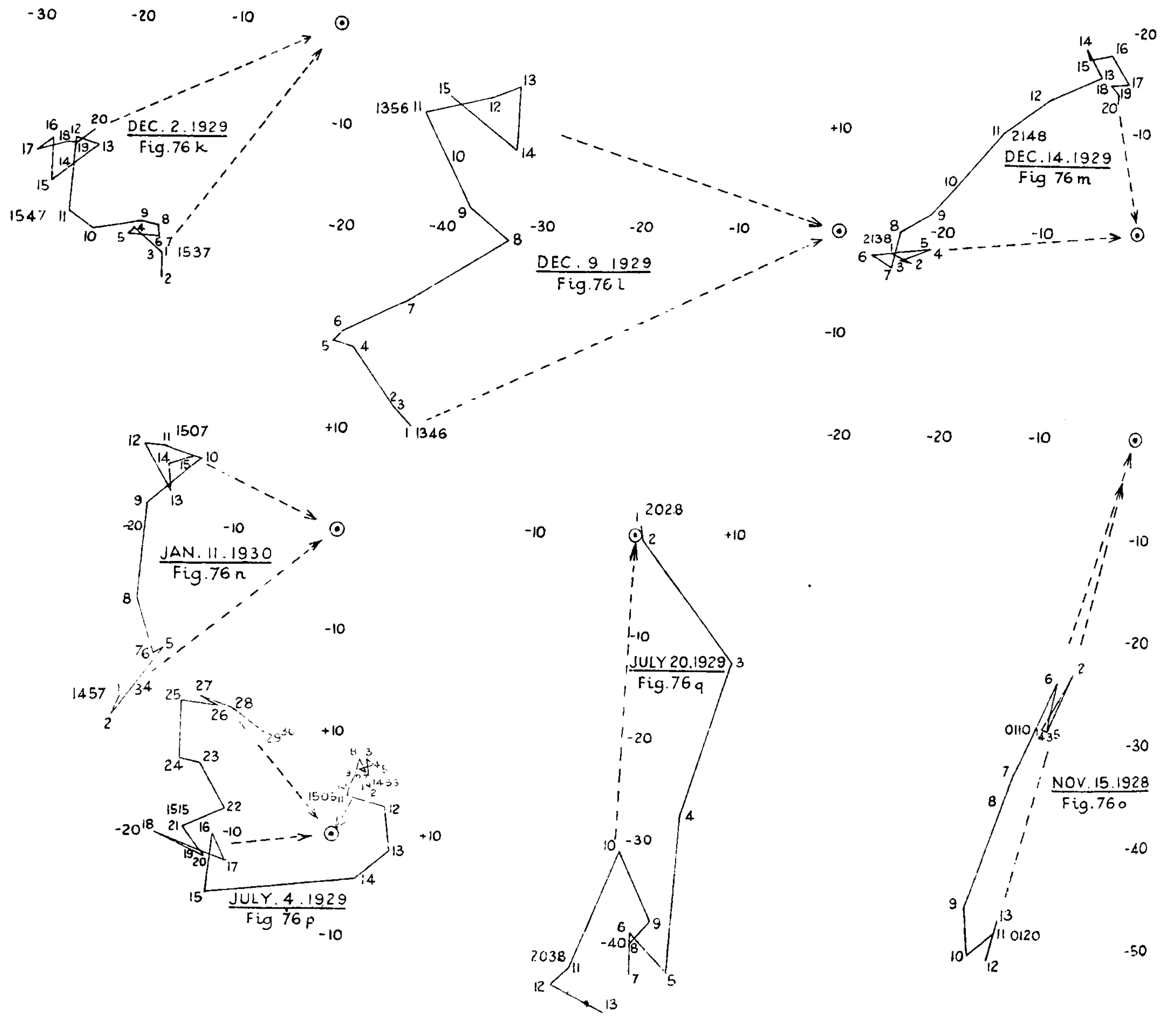

Fig. 76

P4464 11573 528 361 525 4/32

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Misc. Points from G.M. 54. — on eddies etc.

p 36. Strong gusts associated with a wind from a more veered direction than lulls.

p 37 Characteristically — a rapid rise followed by a slower fall.
int. between gusts 5-7 min
∴ ~~wind~~ distance ground-run between consecutive occ of high speed of order 8000 ft.
60 mph = 88 ft/sec = 5280 ft/min.

38. N. diff. to "label" trace a gust. (Crossover only 350 ft.
Group of gusts move with the mean wind speed.

54. With special cases i.e. extreme thr. rapid changes can occur
Speeds of vector change 35, 30 m/h. in consecutive minutes.

55. Particular case involved (Nov. 23 1929)
veer of 25°. 35 to 45+ in < 1 minute.

November 23, 1929 (Figs. 68, Plate XV and 76h). Intermittent rain had occurred since 12h. 22m. G.M.T. At 14h. 14m. G.M.T. heavy rain accompanied the squall. Pressure rose sharply at about the same time, and between 14h. 13m. G.M.T. and 14h. 16m. G.M.T. temperature at 143 feet fell 6°F. The veer during the making of this record was not sharp ; there was, however, a fairly sharp increase of wind speed which occurred after the veer was completed and which was followed by a squall gust which reached 54 miles per hour.

December 2, 1929 (Figs. 69, Plate XV and 76k). Rain which had been slight for some hours before increased to moderate rain at about 15h. 40m. G.M.T., and then decreased again to slight intensity. No sharp features are recorded on the autographic records, but with the occurrence of the front, temperature which had been rising steadily began to fall steadily. This record is reproduced because it shows rather strikingly a feature which has been seen on several records of fronts (which are not reproduced). During the actual veer of the wind the oscillation of the wind vane decreases very definitely.

December 9, 1929 (Figs. 70, Plate XV and 76l). Rain was falling from 9h. 45m. G.M.T. to about 13h. 5m. G.M.T. and pressure was decreasing up to the same hour. From then to about 13h. 55m. pressure rose slightly, but at about 13h. 55m. there was a sharper rise. Temperature had been tending to rise up to 13h. 10m. when it began to fall unsteadily. At 13h. 57m. there was a sharp drop of about 2°F.

This record gives the final veer in a direction change which had been going on for some hours. The wind was strong just prior to the veer and decreased as the front passed over.

December 14, 1929 (Figs. 71, Plate XV and 76m). Moderate rain occurred with this front beginning almost simultaneously with the veer of the wind, and continuing till 22h. G.M.T., after which slight rain continued for some hours. Pressure rose suddenly at about 21h. 50m. G.M.T. Temperature at 143 feet began to fall at 21h 30m. G.M.T., and between 21h. 48m. and 21h. 51m. G.M.T., fell sharply 3½°. Humidity rose steadily between 21h. 35m. and 22h. G.M.T. This record shows a fairly sharp veer, but with a decrease of wind speed.

January 11, 1930 (Figs. 72, Plate XV and 76n). At 14h. 40m. G.M.T., a squall cloud with centre north-west was seen approaching the station, at 14h. 56m. G.M.T. and at 15h. 5m. G.M.T. light rain was reported, and at 15h. 27m. G.M.T. light sleet increasing to moderate sleet which turned to snow at 15h. 32m. G.M.T. Snow ceased at 16h. 25m. G.M.T. Pressure rose, but not very sharply, between 15h. and 15h. 10m. G.M.T. At 15h. 4m. G.M.T. temperature (at 143 feet) which had been falling slowly fell 3½°F. in 6 minutes. Humidity rose from 65% at 14h. 50m. G.M.T. to 87% at 15h. 10m. G.M.T. and continued to rise to 97% at 16h. G.M.T.

This record shows a fairly sharp veer, but with a decrease of wind speed.

The records shown above are chiefly those made during the passage of fronts between a preceding warmer air mass and a following colder air mass, i.e., cold fronts or cold occluded fronts. Such fronts are usually the sharpest and so best lend themselves to the detailed investigation of a quick-run record. One feature that appears to stand out is that the frontal showers, the sudden rise of pressure and the fall of temperature occur (with such fronts) after the veer of wind has begun, and in some instances after the veer is finished.

The speed of wind change in these fronts is best seen from the examination of Fig. 76. It is not usually rapid in the Cardington district, and the only two cases where it was at all rapid were those of October 24 and November 13, 1929.

Squalls.

November 15, 1928 (Figs. 73, Plate XV and 76o). No large changes were recorded on the autographic instruments except a rather sharp fall of 1½ mb. in pressure. Intermittent rain occurred during the night. This record is included because it shows the type of wind change which may occur at night in what appears to be a uniform current of air.

July 4 1929 (Figs. 74, Plate XVI and 76p). A fall in temperature of 2°F. occurred with the passage of this storm. The notes made by the observer are as follows :—

" 14h. 20m. G.M.T. cloudy, mainly Cu. Nb. some Nb. NW. and SW. at 1500 feet with a strip of A.St. on horizon SW. to NW. beyond a layer of Nb. 14h. 40m. G.M.T. onwards intermittent t more frequent at 14h. 52m. G.M.T. to SW. t 15h. 18m. G.M.T. and 15h. 20m. G.M.T. ENE. approx. 14h. 42m. G.M.T. jp E'S. and W'N. 14h. 52m. G.M.T cloud from 225° 14h. 54m. G.M.T. R 205° to 225°. 14h. 57m. G.M.T. l SW. 14h. 59m. G.M.T. l SW. and rain spreading northwards. 15h. 1m. G.M.T. R on station. 15h. 2m. G.M.T. l. 15h. 7m. G.M.T. Nb. and St. clearing 240–280° (still R on station). 15h. 10m. G.M.T. edge of low Nb. passing over station. 15h. 13m. G.M.T. r ceased over station. 15h. 33m. G.M.T. Cu. Nb. cloud from 237° 15h. 45m. G.M.T. some strips of blue sky W. Centre of storm passed to S. of station."

This record shows the details of wind changes during the passage of a thunderstorm over the station in which the wind swung almost through a complete circle. The gusts, however, did not exceed 28 mi./hr. and the wind changes were not very great.

July 20, 1929 (Figs. 75, Plate XVI and 76q). Prior to this storm there had been an inversion of about 2°F. in 170 feet, during the storm temperature at 143 feet fell 14°F., and there were superadiabatic conditions for about 20 minutes after the fall. The observer's notes are as follows :—

" First thunder heard 18h. 49m. G.M.T. to S. Cu. Nb. 2/10, St. Cu. and Cu. 5/10, Ci. St. 2/10. Very hazy sky. Thunder and lightning at 20h. 15m. G.M.T. to S. and SSE. Cu. Nb., Ci. St. Black sky to S. 20h. 30m. G.M.T. heavy TL SW.–SE. Cu. Nb. 8/10, Ci. St. to N. 2/10. 20h. 33m. rain and squall. Sky black with low Nb., broken pieces at about 400 or 500 feet. 20h. 46m. G.M.T. heavy TLR over station At 20h 33m. G.M.T. the barograph jumped up 2mb. but fell ½mb. almost at once. Heavy rain ceased about 20h. 55m. G.M.T. but slight rain continued. Moderate rain started about 21h. 20m. G.M.T. Temperature at the time of the squall dropped 10° F (from 77½° to 67½°). Rain measured 8·9mm."

This record shows the greatest wind changes which have been recorded at Cardington during a thunderstorm. In less than 3 minutes the wind had increased from almost calm to over 40 mi./hr., and to very nearly 50 mi./hr. in gusts. After this sudden increase of wind speed, the speed fluctuated between 40 and 50 mi./hr. for about 7 minutes and then gradually decreased. The form of this wind trace is thus similar to, but on a very much larger scale than, the type of trace that has been noticed as being characteristic of the fluctuations produced by eddies of type I (*vide* § 17).

§ 23—RECAPITULATION

Summarising the results that have been found in the present investigation into the horizontal changes in wind, it may be said that there is a comparatively sharp difference in the type of air motion when the vertical temperature gradient is adiabatic or superadiabatic and when it is less than adiabatic.

During adiabatic and superadiabatic conditions the following are the main characteristics.

(i) In wind there are major eddies composed of alternating masses of fast and slow-moving air, while embedded in these air masses there is a large number of small-scale eddies.

(ii) These air masses are considerably longer in the direction of the wind than they are broad.

(iii) The mean motion of these air masses is equal to the mean motion of the wind.

(iv) The changes of velocity in wind from air mass to air mass are characterised by abrupt increases and comparatively gradual decreases.

(v) Before, during, and for a short period after one of these abrupt increases, small-scale eddying is greater than during the gradual decrease.

These facts have been found in eddies, which are on the scale of 4000 feet long by 600 feet wide (these measurements are probably below the average). There is another group of major eddies which appears in wind under certain conditions and which ranges up to a dimension in the direction of the wind of the order of 10 or even 20 miles. The wind gusts in these eddies show two important points of similarity with the eddies on the 4000-feet scale namely :—

(i) The changes in velocity in the wind from air mass to air mass are characterised by abrupt increases and comparatively gradual decreases.

(ii) Small-scale eddying decreases shortly after an increase of wind velocity. The other features of the group of larger eddies are :—

(iii) Strong gusts occur just after a maximum of temperature has been reached, and are followed by a decrease of absolute humidity.

(iv) Strong gusts are associated with a wind from a more veered direction than lulls.[1]

(v) Rain is associated with falling temperature.

(vi) Cloud masses are associated with the strong gusts.

Temperature changes which may occur in the eddies on the 4000-feet scale would be so small and rapid that they could not be detected with the thermographs available, and as will be seen later there is certain evidence that cloud masses are associated in a similar way with the eddies on the 4000-feet scale.

It is considered that the eddies on these two scales may be considered, as a working hypothesis, to be of similar physical formation, and if so, the relationship between temperature and wind justifies the assumption that the wind gusts are primarily due to thermal instability.

During the occurrence of surface inversions the following are the characteristics of eddies :—

(i) There are no pronounced major eddies.

(ii) The eddies are not predominantly elongated in the direction of the wind.

(iii) The eddies are probably due largely to surface obstacles.

(iv) The presence of an obstacle causes, on some occasions, more eddying if there is a surface inversion than if there is not.

(v) In some circumstances the presence of a large inversion may damp out the eddying until there is the phenomenon of a smooth flowing wind. The velocity of such a wind has been observed to be as high as 11 or 12 miles per hour at the height of 150 feet above the surface.

Certain results are set out with regard to the relation of wind variation and eddy speed to the mean wind speed.

The eddy energy of the wind is calculated in certain cases.

Certain examples of the changes of wind in squalls are given.

In the case of a line squall which can be characterised as sharp, but not probably exceptionally so, the greatest vector change of wind between consecutive one-minute mean values of the wind was 35 miles per hour.

In the case of a thunderstorm of not abnormal intensity the greatest vector change between consecutive one-minute mean values of the wind was 17 miles per hour.

PART III—A THEORY OF EDDIES

By C. S. Durst, B.A.

§ 24—THE CLASSIFICATION OF EDDIES

Eddies in wind may be classified as follows :—

(a) *Convectional eddies* due to local convection caused by vertical temperature differences.

[1] To see if some such association could be found between the wind direction and sudden increases in speed on the ultra-quick records, two series of measurements were made of certain of the direction records on occasions of pronounced increases. These two series (which combined contained 125 occasions of sudden increases) agreed in showing a decided, though small, veer of the wind 5 seconds after the sudden increase; so that the faster-moving air was moving from a more veered direction also in the case of the eddies on the 4000-feet scale.

The study of convectional processes in a fluid has become intensified during the last few years, largely owing to the experimental work of Bénard[1] and its mathematical exposition by Rayleigh,[2] which were first brought to the notice of meteorologists by Low and Brunt.[3] More recently still the experimental work has been carried further by Terada[4] and the mathematical study has been generalised by Jeffreys.[5]

The general result of these investigations is that in a still, unstable, viscous, fluid (or one moving with uniform velocity throughout its depth) there is a mode of convection such that upflowing convective currents take place in a regular pattern with downflowing currents surrounding them, the whole presenting an appearance of cellular structure, which in some cases, at any rate, devolves into regular hexagons. Fig. 78 shows an example of the cellular structure described by Low and Brunt. It is obtained by the convection due to cooling by evaporation at the surface of a dish of amyl acetate. The form of the cells is revealed by aluminium particles suspended in the solution. The depth of the fluid was 0·2 inches over most of the dish, but near the right-hand edge it was deeper, and this is shown by the increased size of the cells. If, however, the fluid is in motion and the velocity is a function of height in the fluid without change of direction the convective currents take place in lines along the direction of motion of the fluid and the appearance is that of infinite strips of upflow and downflow moving side by side. In each case, the horizontal dimensions of the cell or strip are a function of the depth of the unstable layer of the fluid, being $2\sqrt{2}h$ for square cells and $2h$ for strips where h is the height of the instability layer[6].

Fig. 79 shows an example of the strip structure. In this case, motion was imparted to the fluid by a fan blowing air on to its surface in the direction indicated by the arrow. Where the sides of the dish and two large corrugations in the bottom constrained the fluid to flow parallel to the sides long strips have been formed. The depth of the fluid was 0·25 inches.

A further case arises in which the fluid is in motion but the direction of motion varies with height. This case does not appear to submit itself to mathematical analysis, but at first sight it would seem that it would probably tend to an elongated cellular form. The discussion of an experiment which revealed the pattern of this type of convection will be given later (§ 27).

(b) *Wave eddies.*—If two currents of air moving with different velocities are in contact waves will be generated in the surface of discontinuity and a regular motion will be imparted to the air in the neighbourhood of the discontinuity.

(c) *Frictional eddies.*—When a mass of air flows over an obstruction breaking waves will be formed in the sheering surfaces from which rotating eddies will arise. Or, in the case of two air masses of different characteristics frictional eddies may arise as a limiting case of wave eddies. Frictional eddies will be easily set up in a fluid that is in unstable equilibrium, but will be resisted by fluid that is in stable equilibrium.

(d) *Splashing eddies.*—If an air mass strikes an obstacle it will be broken up into smaller, irregularly moving masses. Such an effect will take place when a wind gust strikes a tree or house, or when a downward-moving air gust strikes the ground.

§ 25—PHYSICAL CONSIDERATIONS WITH REGARD TO THE SHAPES AND SIZES OF EDDIES

Certain physical considerations may be stated with regard to shapes and sizes of eddies which may be expected.

(a) In the layer of the atmosphere between the surface of the ground and a height of 1500 feet in which there is usually an increase of wind speed and a change

[1] Bénard, C., *Ann. Chim. Phys., Paris*, **23**, 1901.
[2] Rayleigh, Lord, *Phil. Mag., London*, **32**, 1916, pp. 529–46.
[3] Low, A. R. and Brunt, D., *Nature, London*, **115**, 1925, pp. 299–301.
[4] Terada, T., *Tokyo Rep. Aeron. Res. Inst.*, **3**, 1928, No. 1.
[5] Jeffreys, H., *Proc. R. Soc.*, A, **118**, 1928.
[6] Brunt, D., *Meteor. Mag.*, February, 1925, pp. 1–5.

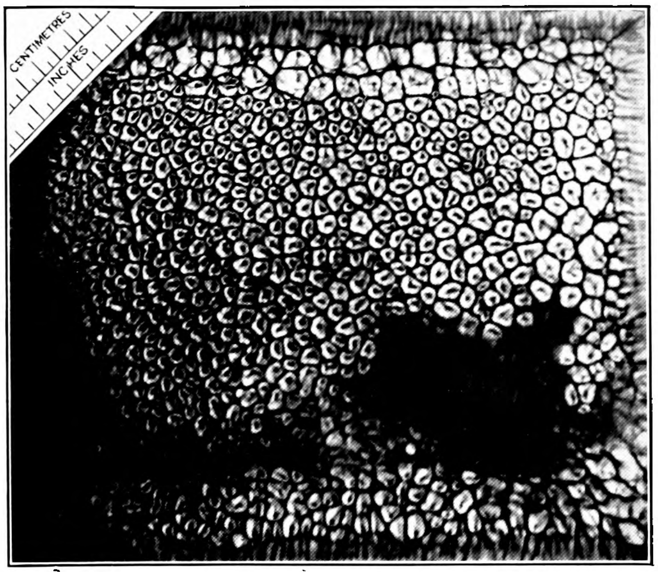


FIG. 78.—THIS PHOTOGRAPH SHOWS THE PATTERN OF A CONVECTIVE FLUID AT REST. IT IS FORMED OF AMYL ACETATE WITH ALUMINIUM PARTICLES IN SUSPENSION, THE DEPTH BEING 0·2 INCHES.

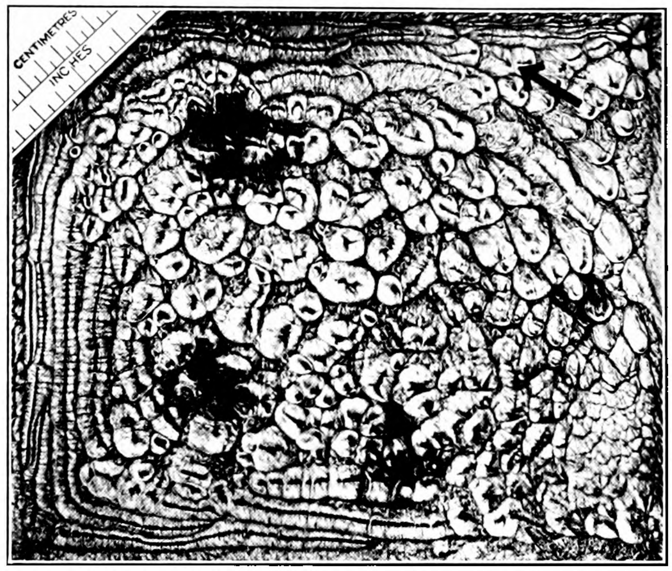


FIG. 79.—THIS PHOTOGRAPH SHOWS THE PATTERN OF A CONVECTIVE FLUID IN MOTION, THE SURFACE BEING BLOWN BY A STREAM OF AIR IN THE DIRECTION OF THE ARROW. WHERE CHANGE OF VELOCITY WITH HEIGHT IS OCCURRING (ALONG THE EDGE) THE CONVECTION TAKES PLACE IN LONG STRIPS. THE DEPTH OF THE FLUID IS 0·25 INCHES.

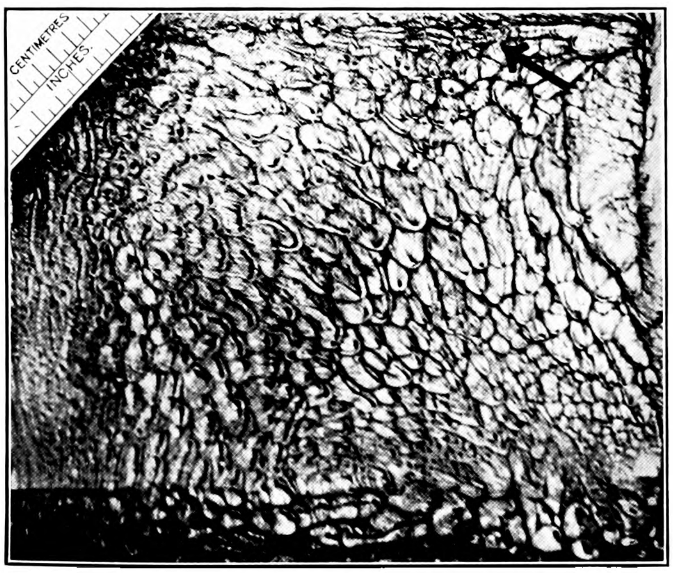


FIG. 82.—THIS PHOTOGRAPH SHOWS THE PATTERN OF A CONVECTIVE FLUID IN MOTION, THE SURFACE BEING BLOWN BY A STREAM OF AIR IN THE DIRECTION OF THE ARROW, AND THE LOWER LAYERS BEING CONSTRAINED TO MOVE ACROSS THE DISH BY A CORRUGATED PLATE LAID ON THE BOTTOM. THE DEPTH OF THE FLUID IS 0·2 INCHES.

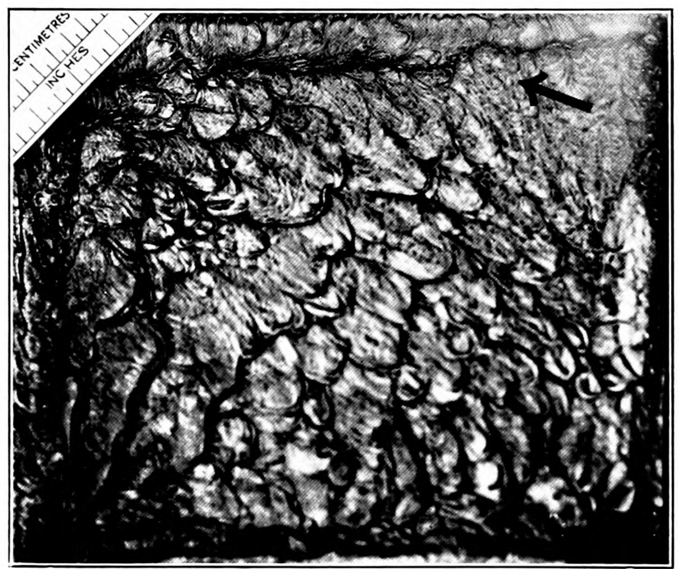


FIG. 83.—THIS PHOTOGRAPH SHOWS THE PATTERN OF A CONVECTIVE FLUID IN MOTION, THE SURFACE BEING BLOWN BY A STREAM OF AIR IN THE DIRECTION OF THE ARROW, AND THE LOWER LAYERS BEING CONSTRAINED TO MOVE ACROSS THE DISH BY A CORRUGATED PLATE LAID ON THE BOTTOM. THE DEPTH OF THE FLUID IS 0·45 INCHES.

[The scale of the photographs is shown by measures in the corners of centimetres divided into halves and inches divided into quarters]

in the wind direction, the slipping of layer on layer may engender friction eddies with a tendency to be of the " rolling type," i.e., eddies with horizontal axes, but the shearing of different layers will have a definite tendency to the breaking up of any rolling eddies that exceed a very small size, and indeed in an investigation made by Schmidt[1] there was no sign of rolling eddies apparent.

Friction eddies will, however, be generated by obstacles such as houses and trees, which obstruct the air flow and eddies so generated will be of a size comparable with those objects. It is indeed well known that differences in the type of land over which air has recently travelled is shown by different widths of an anemometer trace due to the different sizes of eddies set up by the obstacles. Goldie[2] has shown that in a wind blowing off the sea the eddies revealed on an anemometer trace were of the same periodicity as the waves of the sea. Thus the sizes of purely frictional eddies in the neighbourhood of the ground may be expected to be of the order of 50 feet with probably an increase in frequency with decrease in size down to at least 10 feet.

(b) As has been pointed out earlier in this paper the troposphere may be roughly divided into the part in which diurnal convection takes place along the dry adiabatic, which is limited to a height of the order of 1500 to 2000 feet, and the part into which diurnal convection can only extend if there is a condensation of water vapour.

As a first classification of convection currents we may take those which form owing to dry instability in the lower layer and those which form owing to wet instability in the upper layer.

In the former case the distance across wind between convective currents will be less than 4000 feet, since the width of the convective strips on the theory of convection mentioned above is twice the height of the instability layer ; in the latter case the distance across wind between convective currents can be up to 90,000 feet (18 miles) when the convective layer extends up to the tropopause.

When instability occurs in the upper layer and is made visible by the appearance of large cumulus or cumulo-nimbus cloud, the depth of the convectional layer is usually considerable as compared with the lower layer, and the mean wind of the upper layer will change with height only slowly, hence there is a probability of the mode of convection of cumulus and cumulo-nimbus cloud being roughly cellular and this is seen to be the type when such clouds are scattered about the sky.

On the other hand, in the lower layer any ordered pattern of convective currents will tend to be of the strip type owing to the variation of the mean wind current with height. Throughout most of their height such convective currents will be invisible, but on occasions the tops of the rising strips may be seen as fracto-cumulus cloud. Such a condition occurred on May 28–29, 1929 when careful observations were made at the Royal Airship Works, Cardington, to ascertain whether this strip formation could be observed. The result of the observations is contained in the following note :—

CLOUD FORMS ON MAY 28, 1929

"The early morning of May 28 was characterised by a layer of stratus cloud covering the whole sky. At 9h. 45m. G.M.T. the stratus cloud broke and blue sky appeared in places. At the same time there was a change in the wind trace of the anemometer to a type connected with more vigorous convection.

About midday fracto-cumulus clouds were apparent, which were definitely travelling along their own length. At 13h. 28m. G.M.T. some cumulus appeared on the north-eastern horizon and passed the station at 13h. 49m. G.M.T. At 13h. 30m. G.M.T. some cumulo-nimbus appeared and when passing the station was observed to be travelling lengthwise ; the sky then cleared. At about 18h. when the sun was getting low fracto-cumulus was seen becoming more dense, and was definitely moving along its own length. The sky clouded over during the night and was again overcast with stratus between 7h. and 8h. G.M.T. on the morning of the 29th. At 9h. G.M.T. a streakiness appeared in the stratus which was seen to be parallel to the wind direction.

The explanation of these clouds would seem to be that during the whole period a cool north-easterly wind was blowing over warm land (no inversion formed during the nights). Convection was taking place up to the height of the stratus cloud and this convection was occurring in strips

[1] Schmidt, W., Die Struktur des Windes, *Wien, SitzBer. Ak. Wiss.*, IIa, **138**, 1929, pp. 85–116.
[2] Goldie, A. H. R., *London, Q. J. R. Meteor. Soc.*, **51**, 1925, p. 357.

During the night radiation was taking place from the upper surface of the water particles condensed by the convection, and thus a cloud sheet was formed. During the early mornings the radiation from the sun was absorbed by the cloud surface and so water was evaporated, thinning the cloud until it vanished along the lines of the descending current. The evaporation gradually ate away the heads of the convective current until during the afternoon the sky cleared. When, however, the sun was setting evaporation was no longer taking place and the streaks of convection once more reappeared."

The anemograms and thermogram for May 28–29, 1929 are given in Fig. 80 (Plate XVII).

It is to be noted that the dimensions of the two types of convection will vary the one from the other, that in which the seat of convection is in the upper layer being considerably greater in the cross-wind direction at any rate than that in which the seat of convection is in the lower layer.

§ 26—THE PICTURE OF THERMAL EDDIES

Based on the facts stated at the end of Part II (§ 23) an attempt has been made to picture diagrammatically the structure of the convectional eddies. This picture is shown in Fig. 81. It is supposed that in the wind there are discontinuities, which

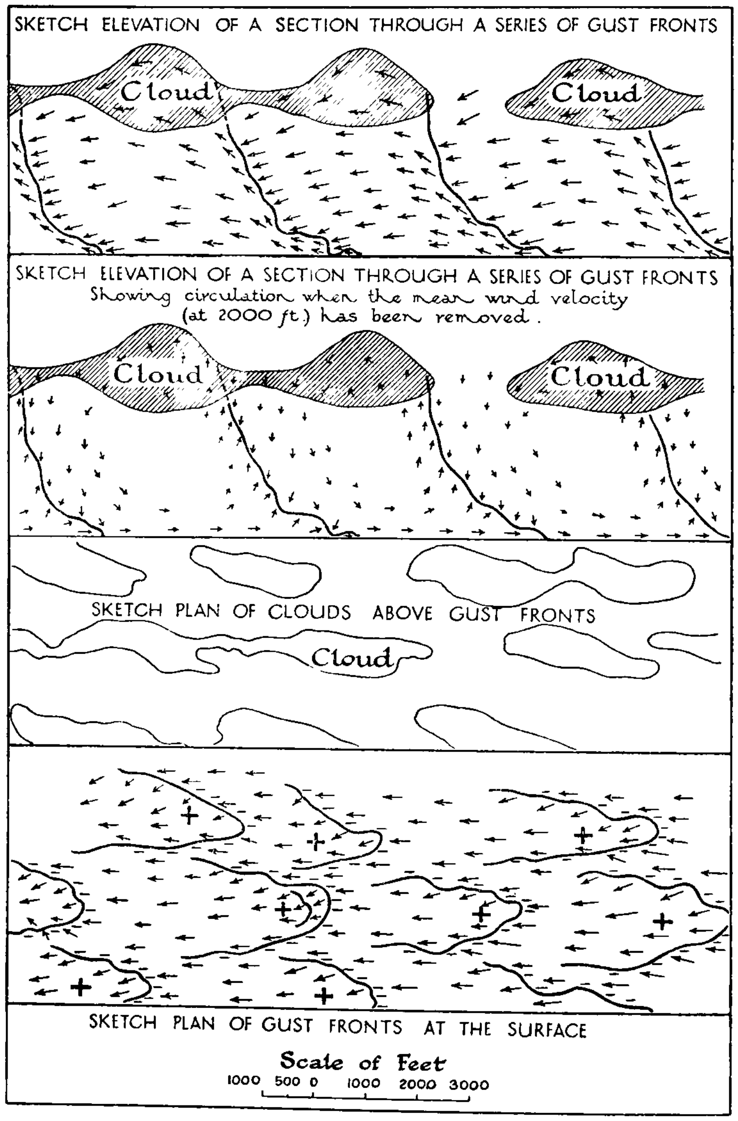


FIG. 81.—SKETCH OF IDEALISED WIND PATTERN.

may be called "gust fronts." These are seen in the lower diagram as horseshoe-shaped lines which are drawn as though travelling along with the wind. Within these horseshoes the air is warm and tending to rise, while on the outside of the horseshoes the air is cold and tending to sink (the positive sign in the lower diagram indicates rising air, the negative sign sinking air). The rising air having recently lost momentum by contact with the ground is slow-moving ; the sinking air brings down with it the momentum, humidity, turbulence and direction of the wind at a higher layer. Hence, as a gust front passes an observer there will be a sudden fall in temperature, a fall in humidity, a sudden rise in wind velocity and veer of wind direction and also a decrease in the small-scale turbulence. After the gust front has passed there will be a gradual decrease of wind velocity as the friction with the ground surface retards the air flow, an increase in temperature due to the heating up by contact with the surface and an increase of humidity, if the ground surface is damp. The elevation is drawn diagrammatically in the upper part of Fig. 81. The gust fronts are considered to have sloping surfaces. There is a certain amount of evidence that this is true, for on the occasion of April 10, 1929 the wind was blowing very nearly from the high anemometer to the low ; and an attempt was made to calculate the time taken by the highest gusts to travel from the one to the other. Eleven high gusts on the high anemometer were found to be related to high gusts on the low anemometer within a range of about 7 minutes. The differences in time of arrival were (in minutes) 2·6, 4·4, 4·7, 4·7, 6·7, −1·1, −2·3, 3·8, 5·1, 5·7, 2·6. The large variation in these times must be due to the gusts at the two points not having been composed of the same air, a result which is entirely concordant with the other observations contained in this paper, but these times give a mean value for the time lag which is considerably in excess of that which would be expected if the gusts had moved on a vertical front, since the time taken for air travelling with the mean speed of the wind to pass from one point to the other would have been under 2 minutes. To account for the higher figures it is necessary to assume a front sloping upwards from the ground across the direction of the wind, so that big gusts arrived at the high anemometer considerably before they arrived at a point vertically below it. On this supposition the average angle of slope on the occasion under discussion would have been about 3 or 4 in 100 which, it is interesting to note, is comparable with the angle of the slope of the cold air in line squalls derived by Giblett.[1]

If such a picture is true the retardation of flow at the earth's surface will cause the warm air to be trapped and the vertical section of the gust front will take on an irregular shape as is indicated, with " gust tongues " striking downwards. Such a feature is often to be recognised on the ultra-quick anemograms, showing a peak of fast-moving air followed rapidly by a brief lull which gives place to a more solid mass of air with high velocity (e.g., Fig. 35, Plate VII, station A, at a point marked d on the record).

When such gust tongues strike the ground they will form splashing eddies, which are seen on the anemographs as the increase of small-scale turbulence which precedes the gust front, and continues for a few seconds after it is past. It is, moreover, natural that in the main body of the descending air frictional eddies should be less than in the air, which has been slowed down and warmed by contact with the ground.

In the diagram cloud caps have been shown at the tops of the rising columns of air. These cloud caps will reproduce in plan the pattern of the convectional columns as is shown in the centre diagram.

§ 27—TWO PIECES OF EVIDENCE IN CORROBORATION OF THE PICTURE OF THERMAL EDDIES

After the completion of the diagrams shown in Fig. 81, two further pieces of evidence were found which go to corroborate that this picture is a true one of the structure of wind.

(a) *The pattern of convective fluid in which direction as well as velocity varies with height.*—As has been mentioned earlier the form which convection takes in a moving fluid that varies with height, both in direction and velocity, has not been discussed either mathematically or experimentally. It was thought that the horse-

[1] Giblett, M.A., *London, J. R. Aeron. Soc.*, **31**, 1927, pp. 509–549.

shoe patterns shown in the diagrams of Fig. 81 were due to the change of direction in the wind near the surface, and an attempt was made to reproduce this condition in an unstable fluid. Instability was introduced by the evaporation of amyl acetate (in which aluminium particles were in suspension). At the bottom of the dish containing the fluid there was placed a corrugated surface which tended to make the fluid move in one direction in its lowest layers across the dish. A flow was then induced in another direction at the upper surface by blowing with a fan. Figs. 82 and 83 (facing p. 58) show the resulting pattern. In the first case the depth of the fluid was ·2 in. and in the second ·45 in.

The horseshoe pattern is quite definite in both cases with rising fluid within the horseshoes, descending fluid on the peripheries.

There appear to be two modes in which the horseshoes are formed. In the one the end of each shoe is based on the forward curve of the next, in the other the horseshoes follow one another in line, this latter form being more nearly akin to the strip mode of convection.[1]

(b) *The pattern of clouds.*—The second piece of evidence is the pattern of clouds. It has already been stated that on May 28–29, 1929 it was noticed that fracto-cumulus clouds were lying in strips parallel to the wind direction. This feature was found to be of frequent occurrence, and an attempt was made to make a photographic survey of the sky on certain days when small cumulus or strato-cumulus cloud was present. This was done by making photographs of the clouds at short intervals with the camera pointed at right angles to the gradient wind direction. When these photographs were suitably mounted and viewed through a stereoscope, an exaggerated perspective was given (as though the eyes were some miles apart) owing to the drift of the clouds during the interval. This effect showed up quite clearly the elongation of the clouds in the direction of the wind and a more or less regular pattern. Some specimens of these stereoscopic photographs are shown in Figs. 84 to 88. In two cases, June 7, 1929 and July 5, 1929, rough measurements of the distances between the clouds gave about 2 miles and 3½ miles respectively. These values give, on Rayleigh's analysis, a depth of the instability layer of respectively, 5000 feet (for lines of convection 2 miles apart) and 5700 feet (for cells 3½ miles in diameter). Measurements of the heights of the tops of the clouds on the two days made from the photographs gave 6000 feet and 7000 feet respectively, which is sufficiently close considering how rough the measurements must necessarily be.

§ 28—FRICTIONAL EDDIES

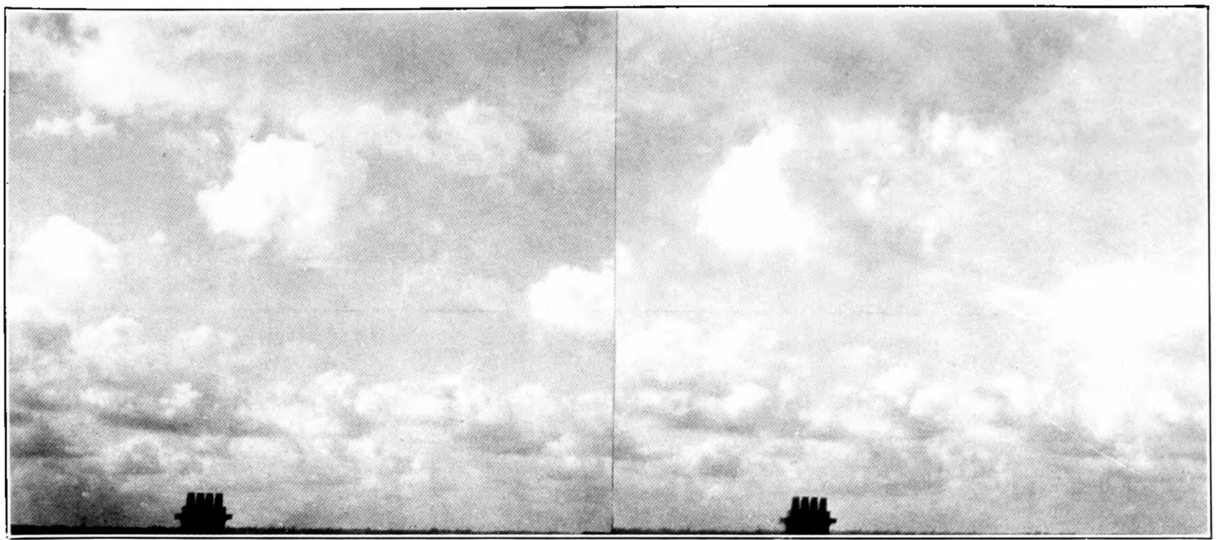
When an inversion has formed at the surface the addition of heat from the ground to the air near it is no longer taking place, and consequently convection will no longer be present in the lower layers. The convectional eddies will then be absent and frictional eddies will be predominantly the cause of wind fluctuations. The effects of these eddies have been exhibited in Figs. 50 to 57 (p. 48 and Plates IX to XII), and are such as give rise to wind fluctuations of equal amplitude both down wind and across wind.

The mode of formation of these frictional eddies is by the striking of the wind stream against objects ranging in size from blades of grass to houses and trees.

When the inversion extends upwards from the ground it seems probable that there is a slipping surface in the wind between the cold air beneath and the warm air above, and under those conditions any object projecting through this interface sets up undamped eddying, while below the interface eddies will be

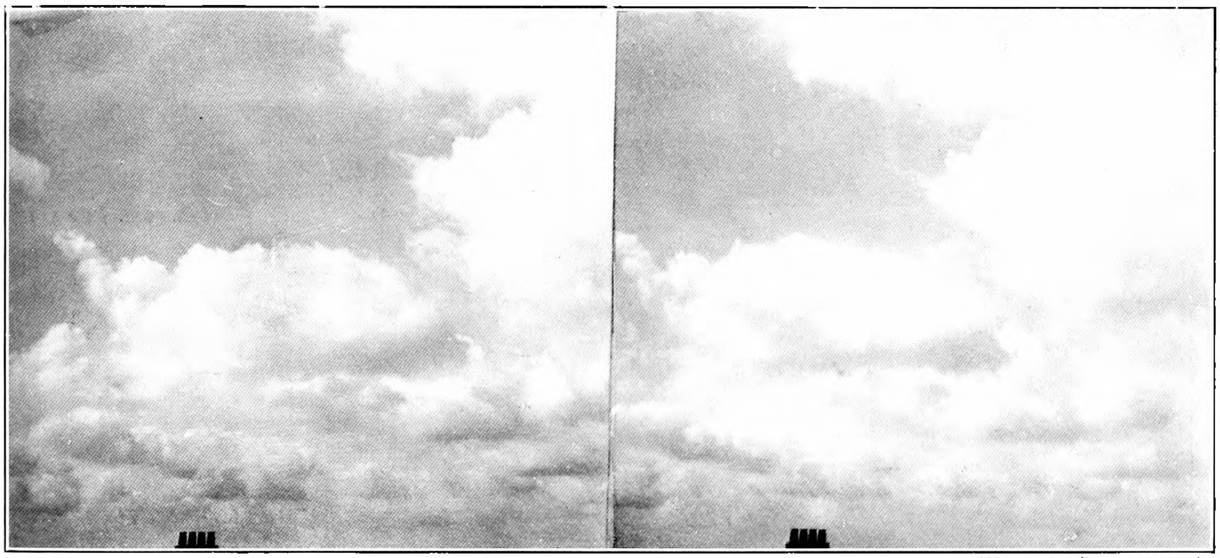
[1] This same pattern of horseshoes may be seen in cirro-cumulus and alto-cumulus cloud.

NOTE.—Since writing the above a paper has been published by Sobhag Mal (Forms of stratified clouds, *Beitr. Physik. Atmosph., Leipzig*, **17**, 1930) in which he records the observation of the horseshoe-shaped pattern in an unstable fluid. He attributes the occurrence of the pattern to cases in which the shear in the fluid was small and does not connect it with a change of direction as well as velocity with height. It would seem, however, that in his experiments there was no control to prevent a small amount of change of direction with height, and that the reason that he found the horseshoes forming with small amounts of shear was that as the shear decreased the slight changes of directional flow became of more importance.



(8h. 30m. *June* 7, 1929)

Fig. 84.



(8h. 30m. *June* 7, 1929)

Fig. 85.

(10h. *July* 5, 1929)

Fig. 86.

Stereoscopic photographs showing the pattern of strato-cumulus and fracto-cumulus clouds.

To face page 63

(15h. 30m. *July* 5, 1929)

FIG. 87.

(15h. 30m. *July* 5, 1929)

FIG. 88.

STEREOSCOPIC PHOTOGRAPHS SHOWING THE PATTERN OF STRATO-CUMULUS AND FRACTO-CUMULUS CLOUDS.

damped down by the stratification of the air. When, however, the interface has risen up above the majority of the surrounding obstacles the wind will flow without eddies forming above the interface, and those that form below will be damped, so that when an inversion extends nearly up to the height of the high anemometer there is presented the phenomenon of a steady flowing wind. But in these circumstances the wind increases rapidly with height. A tabulation of the light winds was made for certain occasions during October, 1929. These occasions were divided into two groups (a) when there was a slight eddying on the high anemometer and (b) when there was practically no eddying. This tabulation showed that, in the former case, the decrease of wind on the low anemometer was less pronounced than in the latter. When there was no eddying, out of the 29 selected hours there were 13 in which the mean hourly wind on the low anemometer was less than 3 miles per hour. The tabulation also showed that the decrease of temperature between the 143-foot thermometer and the 4-foot was generally considerably greater in this case than when there was eddying.

Frictional eddies, though more segregated when there is a surface inversion, are seen under adiabatic and superadiabatic conditions as the oscillations of shorter period on the records of ultra-quick runs shown in Figs. 33 to 36 (Plates V to VIII). Under adiabatic conditions, however, the wind flow over obstacles will follow streamlines more easily than under inversion conditions. Hence, the frictional eddies under adiabatic conditions will not form so frequently, but once formed will persist without the same tendency to damping. This is probably the explanation of the contrast in the wind shadow of the airship sheds, which is shown on Fig. 57 (Plate XII).

PART IV—THE VARIATION OF WIND WITH HEIGHT

§ 29—THE MATERIAL AVAILABLE

For the discussion of the variation of wind with height there are available :—

(a) Normal anemograms for 150 feet above ground (station F), and for 50 feet above ground (station B). The series of these records start from May 17, 1928 and July 27, 1927 respectively. Owing to the lie of the land the difference in height of the two anemometer heads is 132 feet.

(b) Ultra-quick runs which have been made on a number of occasions at station C with (i) two anemometer heads side by side 4 feet apart at 50 feet, (ii) one anemometer head at 50 feet and one at 40 feet, (iii) one anemometer head at 50 feet and one at 30 feet.

§ 30—THE TREATMENT OF THE DATA AND ITS DEGREE OF ACCURACY

(a) The normal anemograms have been reduced to hourly means (centred at the hour). These means have been compared at the two heights by forming ratios of the values at 150 feet to those at 50 feet. The same procedure has also been applied to values of the maximum gusts during each hour (centred at the hour). The hourly mean values and the maximum gust values at 150 feet at the four main hours of meteorological observation have also been similarly compared with values of the geostrophic wind deduced from synoptic pressure charts. These comparisons are shown in the tables contained in Appendix V.

Initially it was decided that these calculations should be made for the period March 1929 to February 1930, but after the computations had been made it was found that there was a discordance between the records of the two anemometers up to the beginning of the year 1930. This discordance was most pronounced in showing the wind speed at 50 feet to be somewhat frequently greater than that at 150 feet. During a general overhaul of the 50-foot anemometer early in January, 1930 it had been noticed that the recorder was very slightly out of the vertical, but at the time it was believed that this would be immaterial in affecting the accuracy of the records. The fault, however, was immediately corrected. In view of the discordance mentioned above,[1] ratios were calculated for one or two specimen months during 1930 to see if they also showed the wind at the lower anemometer to be occasionally stronger than that at the higher. This was not found to be the case except on a negligible number of occasions, and therefore it was decided to reject the records for the period March 1929 to December 1929 and to calculate the months March to December 1930, so that the tables given should be for a complete year (1930) for which the records were thoroughly reliable.

Tables E, F, and G of Appendix V were not affected by the errors of the recorder of the 50-foot anemometer, and hence were allowed to stand for the period March 1929 to February 1930, and Table D was also allowed to stand since the errors of the 50-foot anemometer were probably proportional to the wind speed, and hence would not affect the ratios in this particular table.

The connecting pipes at station B (the 50-foot anemometer) are together about 100 feet in length, while those at station F (the 150-foot anemometer) are about 200 feet in length. The damping effect due to this dissimilarity will not affect the mean wind ratios given in Tables A, C, and E of Appendix V, but will affect the maximum gust ratios in Tables B, D and F, as the damping for short-period fluctuation will be greater in the 200 feet of piping than in the 100 feet (*vide* § 12f of Part I). No allowance has been made for this damping and it is believed to be small.

It will be noticed that the corrections to be applied to the anemometer records, which are given in § 12 of Part I as Table XVI, do not extend below a speed of 10 mi./hr. At low wind speeds the corrections become increasingly doubtful and for this reason it was decided not to form ratios for Tables A, B, C and D of Appendix V when the wind speed at 150 feet was less than 10 mi./hr.

It has been mentioned in § 19 of Part II (page 47), that a pronounced wind wake from the airship sheds appears on the records of the 150-foot anemometer when there is a south-easterly wind. It was found that with these winds there was a perceptible decrease in the ratios shown in Table A. It was, therefore, decided to exclude winds between NNE. and SSE. from Table C so that it should refer only to occasions when the 150-foot anemometer had an exposure comparable with the 50-foot anemometer.

(b) The records of the dual ultra-quick runs at station C have been measured and the mean values of wind speed and direction so obtained are tabulated in Appendix VI together with measurements of the simultaneous wind speeds and directions made on the normal records at station F, estimates of the geostrophic wind speed and direction and the vertical temperature gradient.

In the normal records the directions are obtained from a Dines helical direction recorder. The tolerance of error allowed on these instruments is 5°, and though it is believed that in the instrument at station F this figure is not reached the values of the mean directions obtained from the normal records may be liable to considerable errors due to this cause and to imperfections in the printing of the charts.

The exposures of the anemometer at 50 feet and that at 150 feet are not strictly comparable as is shown in § 3 of Part I, and Fig 2. Station F is surrounded by houses and trees which do not, however, rise to a greater height than 100 feet below the anemometer vane (except in the case of the airship sheds) while stations A, B, C and D have a very open exposure over arable land.

§ 31—THE DISCUSSION OF THE RELATION OF WIND SPEED AT 150 FEET TO THAT AT 50 FEET, AND TO THE GEOSTROPHIC WIND

In Table A of Appendix V are shown the ratios of mean wind speed at 150 feet to mean wind speed at 50 feet grouped according to the mean wind speed at 150 feet. Table A is given for each group of three months throughout the year and also for the 12 months combined. This table (for the 12 months combined) gives sufficiently smooth results for the modes to be estimated with some degree of accuracy for conditions prevailing at night and those prevailing by day. The values of these modes are given below in the second and third columns of Table XX.

[1] It appears that the tilt of the recorder was such that it altered the level in the water gauge and consequently the level of the water in the float chamber was too high.

In Table B of Appendix V ratios of the maximum gusts at the two heights are given for the summer and winter periods. These two periods have been combined and values of the modes have been estimated and are given in the fourth and fifth columns of Table XX.

TABLE XX.—VALUES OF THE MODES OF THE RATIOS OF WIND AT 150 FEET TO THAT AT 50 FEET FOR VARIOUS WIND SPEEDS

Mean wind speed at 150 ft.	Value of the mode of ratios of mean winds		Value of the mode of ratios of maximum gusts	
mi./hr.	Day	Night	Day	Night
10–14	1·02	1·08	1·02	1·03
15–19	1·07	1·17	1·08	1·18
20–24	1·16	1·19	1·12	1·13
25–29	1·17	1·20	1·13	1·15
30–34	1·20	1·20		

This table shows a regularly increasing ratio with increasing wind speed in the case of the mean hourly values of wind speed. Though the ratio of the mean wind at 150 feet to that at 50 feet is greater for wind speeds under 30 mi./hr. by night than by day, the values of the ratios both by night and by day tend to a value of about 1·2 with higher wind speeds.

Somewhat similar features are shown by the modes of ratios of maximum hourly gusts, though in this case the value to which the ratio tends with higher wind speeds is somewhat less (about 1·15).

The general conclusion to be drawn from Table XX and Table A of Appendix V is that with stronger winds the wind at 150 feet exceeds that at 50 feet by 20 per cent by day and by night, but with lighter winds it is usual for the wind speeds at the two levels to be more nearly equal; this, however, is more generally so by day than by night. At night there may be a rapid increase of wind with height and this effect is shown in Table C of Appendix V to be related closely to the vertical temperature gradient.

In Table C there are given the frequencies of ratios in relation to the difference in temperature between the 143-foot level and the 4-foot level. It is at once seen that for wind during the day, when inversions are rare and small, the vertical temperature gradient does not affect the ratio of the wind speeds at 150 feet and 50 feet, but by night, especially with winds between 10 and 14 mi./hr., there is a pronounced relationship.

On theoretical grounds the ratio of wind speeds at the two heights should be related primarily to the speed of flow and the temperature gradient, hence it was considered to be justifiable to combine the frequencies of winter and summer and day and night. This was done for each wind speed and a fair curve was drawn through the values of greatest frequency. The values derived from these fair curves are given in Table XXI and the curves themselves are reproduced in Fig. 89.

TABLE XXI.—RATIO OF WIND SPEED AT 150 FEET TO THAT AT 50 FEET IN RELATION TO WIND SPEED AT 150 FEET AND VERTICAL TEMPERATURE GRADIENT

Wind speed at 150 ft.	Vertical temperature difference 143 ft.—4 ft. (°F)												
	−5·0	−4·0	−3·0	−2·0	−1·0	0·0	1·0	2·0	3·0	4·0	5·0	6·0	7·0
(mi./hr.)													
10–14	1·01	1·02	1·03	1·04	1·07	1·15	1·23	1·35	1·50	1·60	1·73	1·85	1·98
15–19		1·05	1·07	1·09	1·12	1·17	1·23	1·32	1·40	1·49	1·58		
20–24			1·16	1·16	1·18	1·20	1·20	1·21					
25–29			1·17	1·15	1·14	1·16	1·18	1·20					

In Table D of Appendix V there are shown the ratios of the maximum gust to the mean wind in the months of June and December. The general conclusion to be drawn from this table is that the gusts at 50 feet have a greater ratio to the mean wind speed by day than those at 150 feet, but a smaller ratio by night. It must be remembered, however, that the high anemometer is influenced to some extent by the trees and houses in its neighbourhood so that the ratio of gusts to mean wind speed may be in excess of that which would have been found if it had been in as open an exposure as the 50-foot anemometer.

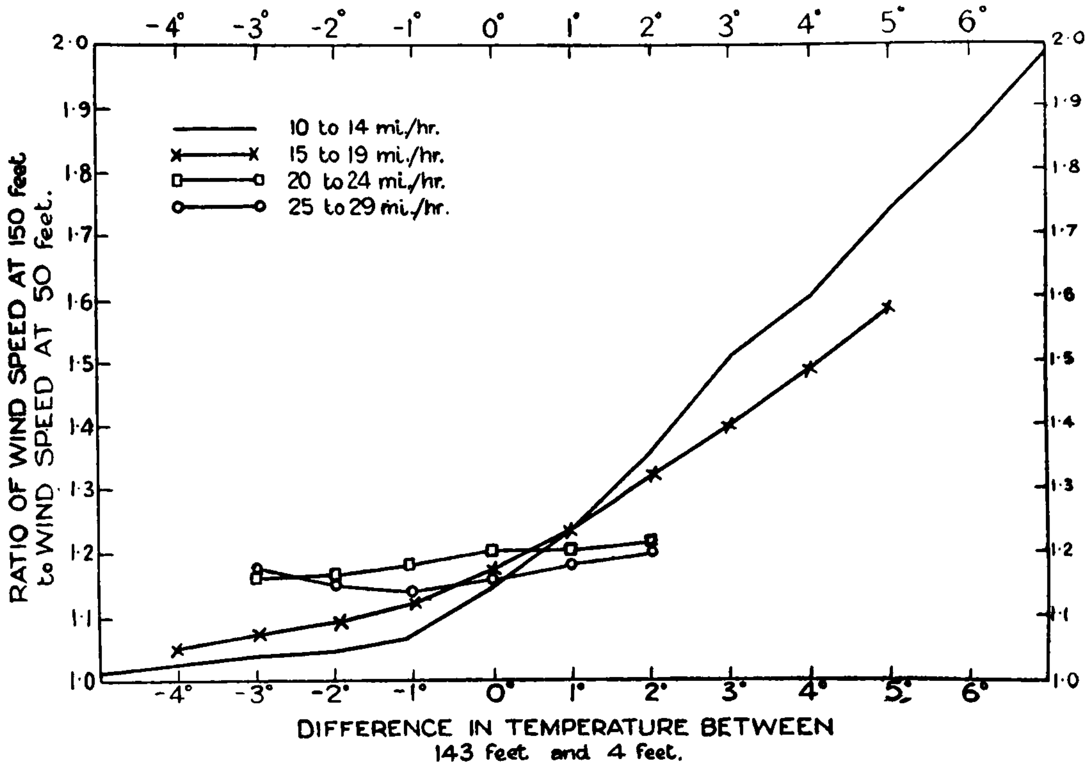


FIG. 89.—RATIO OF WIND SPEED AT 150 FEET TO THAT AT 50 FEET IN RELATION TO THE WIND SPEED AT 150 FEET AND THE VERTICAL TEMPERATURE GRADIENT.

In Table E of Appendix V there are shown the ratios of the mean wind to the geostrophic wind speeds (as obtained by measuring the distance apart of isobars on the synoptic charts). These ratios are greater by day than by night, and also show a very definite seasonal variation. In summer the ratios by day are decidedly greater than in winter.

In Table F of Appendix V there are shown similarly the ratios of the maximum gusts to the geostrophic wind speeds, and similar diurnal and seasonal variations are apparent. This table was compiled for the practical purpose of ascertaining how far the geostrophic wind served as an accurate estimate of the maximum gust likely to be experienced. It is seen that with gales it serves as a fairly satisfactory upper limit, but for lighter winds, especially in summer and by day, the gusts may be greatly in excess of the geostrophic wind speed.

In Table G of Appendix V there are shown the diurnal and seasonal variations of the angle formed by the wind at 150 feet to the isobars. This table shows that there is a definite diurnal variation in this angle, the mode (for all months and all wind speeds combined) being 30° to 34° in the early hours and 20° to 24° in the afternoon.

§ 32—WIND EDDIES AT 50 FEET, 40 FEET AND 30 FEET ON CERTAIN OCCASIONS

In Fig. 90 (Plate XVIII) is given an example of the traces obtained from two anemometers, the heads of which were side by side four feet apart at 50 feet above ground (at station C). For comparison is shown a synchronous record made at station B. The direction of the wind during the making of the records was about 245°, i.e., about 10° off the line of stations B and C. The similarity of the traces at station C and their dissimilarity with that made at station B is striking.

In Fig. 91 (Plate XIX) is given an example of the traces obtained from the anemometers when the heads were at 40 feet and 50 feet above ground and four feet apart in the horizontal direction.

In Figs. 92 (Plate XX) and 93 (Plate XXI) are given two examples of the traces obtained from the anemometers when the heads were at 30 feet and 50 feet above ground. The conditions under which these three examples were recorded were somewhat different as is shown below.

TABLE XXII

Record no.	Date	Time	Speed at 50 ft.	Direction at 50 ft.	Cloud and weather	Geostrophic wind	Temp. Diff. 143 ft.–4 ft.
		h. m.	mi./hr.			° mi./hr.	
525x	Mar. 21, 1929	16 7	17	209°	St.Cu.2 / A.St.7, c.	225 30	− 0·6
571	Oct. 8, 1930	14 38	31	235°	Nb.10, r_0	250 45	− 0·4
579	Oct. 16, 1930	22 22	19	169°	— b	220 40	1·2

The mean values of 5-second intervals for these records are given in Appendix VI.

The method of correlation has been applied to these values and the results are given below :—

TABLE XXIII—CORRELATION COEFFICIENTS : DUAL RUNS

	Record	Heights of heads (ft.)	(ft.)		Mean values (sec.)	Time interval in seconds −10	−5	0	+5	+10
1	525x	50	40	Speed	5	+·47	+·65	+·87	+·62	+·59
2		50	40	Direction	5		+·45	+·92	+·68	
3		50	40	Speed	5−160		+·53	+·69	+·48	
4		50	40	Direction	5−160		+·37	+·84	+·46	
5	571	50	30	Speed	5	+·54	+·76	+·94	+·82	+·63
6		50	30	Direction	5	+·11	+·44	+·80	+·58	+·31
7		50	30	Down wind component	5−20	−·29	+·11	+·64	+·09	−·39
8		50	30	Down wind component	5−160			+·86		
9		50	30	Cross wind component	5−20	−·33	+·04	+·70	+·02	−·37
10		50	30	Cross wind component	5−160			+·82		

An explanation of the method of computation is given in Appendix III, p. 99.

The most striking features of this table are :—

(a) The persistence of high correlation coefficients for simultaneous intervals on the two anemometers even when the longer-period swings of velocity and direction are removed.

(b) The rapid falling off in the correlation coefficients in items 7 and 9 for small time displacements when oscillations of the period of 20 seconds are removed. This last result may be interpreted to mean that the eddies of a period between 5 and 10 seconds have a correlation as high as + ·6 or + ·7 between 30 and 50 feet. The wind speed on this occasion was about 30 mi./hr. and hence the wind pattern for a period between 5 and 10 seconds had a linear measurement of between 20 and 40 feet. Hence, the falling off noticed above is in conformity with the eddies of this size being frictional circular eddies of a magnitude of 50-feet diameter.

§ 33—THE VARIATION OF WIND WITH HEIGHT BETWEEN 150 FEET, 50 FEET, 40 FEET AND 30 FEET

In Appendix VII are shown the wind speeds and directions during certain 10 minutes of time on anemometers at heights of 40 and 50 feet, and 30 and 50 feet. The mean wind speeds (when reliable), measured from the normal records obtained at 50 feet and 150 feet, are given for comparison (except in certain cases when measurements from quick runs were available for the high anemometer). The table also includes data with regard to cloud, weather, geostrophic wind and temperature difference between high and low thermometers.

In certain cases (October 14, 1930, October 16, 1930, November 19, 1930 and February 26, 1931) ultra-quick records were made at 30 feet and 50 feet, and at the same time a quick run was made on the high anemometer.

The mean values for these are given in Table XXIV.

TABLE XXIV

Record number	Date	Time G.M.T.	At 30 ft.		At 50 ft.		At 150 ft.		Temp. Difference at 143 ft.–4 ft.
			Speed	Dir.	Speed	Dir.	Speed	Dir.	
		h. m. h. m.	mi./hr.	°	mi./hr.	°	mi./hr.	°	
572–577	Oct. 14, 1930	14 30–16 25	15·9	167	17·2	168	20·4	172	0·5
579–583	Oct. 16, 1930	22 22–23 55	14·4	170	16·9	170	21·1	176	1·3
593–597	Nov. 19, 1930	10 00–11 56	24·4	258	26·6	257	29·1	255	0·1
604–605	Feb. 26, 1931	11 32–12 08	25·7	234	27·8	239	28·3	240	−1·3
606–607	Feb. 26, 1931	15 19–15 53	18·5	311	19·9	311	21·9	317	−0·6

The results shown in Appendix VI have been grouped for wind speeds at 50 feet with the result shown in Table XXV.

TABLE XXV

Wind speed at 50 ft. (mi./hr)	No. of obs.	Mean wind speed at 30 ft. (mi./hr.)	Mean wind speed at 40 ft. (mi./hr.)	Mean wind speed at 50 ft. (mi./hr)	Mean wind speed at 150 ft. (mi./hr.)
Under 20	8	—	17·3	16·8	18·8
Under 20	14	14·4	—	15·9	17·2
Over 20	7	—	25·4	25·2	29·1
Over 20	7	23·1	—	24·9	28·4

In the computation of this table, when two or more runs have been made on the same day and under the same conditions, the mean values of those runs have been substituted for the individual values in order that the results should not be biased in favour of the days when there were many observations.

The greater value of wind speed at 40 feet than at 50 feet is probably accidental, and suggests that there may be a small residual error after all other corrections have been made.

§ 34—SUMMARY OF PART IV

Tables are given showing the comparison of wind at 150 feet and at 50 feet, and also the comparison of wind at 150 feet with the pressure gradient. The main results obtained are :—

(i) The vertical gradient of wind speed is in general smaller with light winds and by day than with strong winds and by night.

(ii) With the stronger winds the wind speed at 150 feet is about 20 per cent greater than at 50 feet.

(iii) The variation of the vertical gradient of wind speed is associated with the vertical temperature gradient, and a table is given of this relationship.

(iv) With winds of gale velocity the geostrophic wind serves as a fairly satisfactory upper limit to the gusts to be expected, but for lighter winds the gusts may be greatly in excess of the geostrophic wind speed.

(v) There is a definite diurnal variation in the angle which the wind at 150 feet makes to the isobars.

Certain ultra-quick runs made at heights of 30 feet, 40 feet and 50 feet are examined and correlation coefficients are formed for the short-period fluctuations on these records.

The mean wind speeds and directions are given for certain ten-minute periods when ultra-quick runs were made at 50 feet and at 30 feet or 40 feet.

PART V—THE THEORY OF THE VARIATION OF WIND WITH HEIGHT AND THE EFFECT OF THE VERTICAL TEMPERATURE GRADIENT ON THE COEFFICIENT OF TURBULENCE

§ 35—A STATEMENT OF THE EFFECT OF THE PRESENT THEORY OF WIND STRUCTURE ON THE THEORETICAL VARIATION OF WIND WITH HEIGHT

The classical treatment of the variation of wind with height is that due to Taylor[1] in which he has assumed that the equations of motion of a turbulent fluid are similar to those of a viscous fluid, provided that the coefficient of viscosity is replaced by a much larger coefficient, which he has termed the coefficient of eddy viscosity. This assumption has given results which are in conformity with observed facts as to the transference of both momentum and heat in the atmosphere, provided that the layer of the atmosphere investigated has not been near the surface.

A further assumption has had to be made with regard to the boundary conditions in the neighbourhood of the ground. Taylor has assumed a slipping layer such that the slipping is in the direction of stress in the fluid at the surface and he has found, when this is so, that the relationship between wind variation with height near the surface, and surface wind speed may be represented by the formula[2]

$$K \left(\frac{\partial w}{\partial z}\right)_{z=0} = \varkappa W^2_{\;z=0} \qquad (1)$$

where K is the coefficient of turbulence, W the wind speed, and $\varkappa$ has a constant value ·002.

Ekman[3], who had investigated the same equations of motion previously to Taylor, arrived at similar conclusions.

Ekman[4] has further examined the assumptions and has concluded that " the notion of skin friction should be allowable ", but he suggested that the subject deserved a fuller quantitative examination.

In Part III of this report it has been concluded that eddying of wind may be classified as (i) that due to friction within the air itself and between the air and obstacles such as houses and trees over the land, and water waves over the sea and (ii) that due to convectional currents from the warm earth's surface. Broadly speaking the former may be considered to be present under all conditions, except where there is a sufficiently strong inversion near the ground to damp down the frictional eddies as soon as they are formed. The latter (ii), however, will only be pronounced with superadiabatic conditions and so will have a decided diurnal variation. The size too of the eddies of the two types will be of a very different order, up to about 50 feet in the case of frictional eddies, but ranging up to the order of 2000 feet in the case of convectional eddies.

[1] Taylor, G. I., Eddy motion in the atmosphere, *London, Phil. Trans. R. Soc. A.*, **215**, 1914, p.1.
[2] Taylor, G. I., *Proc. R. Soc. A.*, **92**, p.196.
[3] Ekman, V. W., *Stockholm, Arkiv. Mat. Astr. Fys.*, **2**, 1905.
[4] Ekman, V. W., *Mem. R. Meteor. Soc.*, **2**, No. 20.

With eddies such as these it is not at once clear whether the assumption that eddy viscosity may be treated in a similar manner to ordinary viscosity can be upheld for regions within some hundreds of feet of the ground by day, though by night, when as a rule only frictional eddies are present, the theory should satisfy the facts down to at least a height of 50 feet from the ground level.

§ 36—THE DERIVATION OF THE EQUATIONS OF MOTION OF A TURBULENT FLUID

In order to see what limitations must be imposed on the equations of wind variation with height derived by Taylor, it is necessary to derive these equations from an extension of a transformation due to Reynolds[1].

The ordinary dynamical equations of the form

$$\rho \frac{du}{dt} = \rho X - \frac{\partial p}{\partial x} + \mu \nabla^2 u \tag{2}$$

are usually derived from the form

$$\rho \frac{du}{dt} = \rho X + \frac{\partial p_{xx}}{\partial x} + \frac{\partial p_{yx}}{\partial y} + \frac{\partial p_{zx}}{\partial z} \tag{3}$$

which may be rearranged as

$$\rho \frac{\partial u}{\partial t} = \rho X + \frac{\partial}{\partial x}(p_{xx} - \rho uu) + \frac{\partial}{\partial y}(p_{yx} - \rho uv) + \frac{\partial}{\partial z}(p_{zx} - \rho uw) \tag{4}$$

in virtue of the equation of continuity

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0. \tag{5}$$

Here (u,v,w) are the instantaneous velocities at (x,y,z) at time t, and

$$p_{xx} = -p + 2\mu \frac{\partial u}{\partial x}; \quad p_{yx} = \mu\left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right); \text{ etc.} \tag{6}$$

where μ is the coefficient of molecular viscosity.

Now define the mean values of u,v,w, by the formulæ

$$\bar{u} = \frac{1}{\tau}\int_{t-\frac{1}{2}\tau}^{t+\frac{1}{2}\tau} u\,dt; \quad \bar{v} = \frac{1}{\tau}\int_{t-\frac{1}{2}\tau}^{t+\frac{1}{2}\tau} v\,dt; \quad \bar{w} = \frac{1}{\tau}\int_{t-\frac{1}{2}\tau}^{t+\frac{1}{2}\tau} w\,dt \tag{7}$$

and put $u = \bar{u} + u'$; $v = \bar{v} + v'$; $w = \bar{w} + w'$. Let us take the mean value of each member of equation (4). It is assumed that without sensible error the mean values of $\bar{u}$, $\bar{u}u'$, $\bar{u}v'$, $\bar{u}w'$ . . . . , are $\bar{u}$, o, o, o, ... respectively.

This is not exact, but is permissible provided the fluctuations of u, v, w about their mean values are sufficiently numerous within the time interval τ. It follows that

$$\overline{uu} = \bar{u}\,\bar{u} + \overline{u'u'}; \quad \overline{uv} = \bar{u}\,\bar{v} + \overline{u'v'}; \quad \overline{uw} = \bar{u}\,\bar{w} + \overline{u'w'}, \tag{8}$$

so that we obtain

$$\rho \frac{\partial \bar{u}}{\partial t} = \rho X + \frac{\partial}{\partial x}(\bar{p}_{xx} - \rho\bar{u}\bar{u} - \rho\overline{u'u'}) + \frac{\partial}{\partial y}(\bar{p}_{yx} - \rho\bar{u}\bar{v} - \rho\overline{u'v'}) + \frac{\partial}{\partial z}(\bar{p}_{zx} - \rho\bar{u}\bar{w} - \rho\overline{u'w'}) \tag{9}$$

while (5) gives

$$\frac{\partial \bar{u}}{\partial x} + \frac{\partial \bar{v}}{\partial y} + \frac{\partial \bar{w}}{\partial z} = 0 \tag{10}$$

We see that equation (9) is of the same form as (4), except that in (9) and the two corresponding equations there is an additional force per unit volume which is just that which would be given by the following system of stresses:

$$\left.\begin{aligned} \widehat{xx} &= -\rho\overline{u'u'}, & \widehat{yy} &= -\rho\overline{v'v'}, & \widehat{zz} &= -\rho\overline{w'w'} \\ \widehat{xy} &= -\rho\overline{u'v'}, & \widehat{yz} &= -\rho\overline{v'w'}, & \widehat{zx} &= -\rho\overline{w'u'} \end{aligned}\right\} \tag{11}$$

These are the eddy stresses of Osborne Reynolds.

So far no assumptions have been made about the eddies, except that the fluctuations of u,v,w about their mean values are sufficiently numerous within the

[1] *vide* Lamb H., *Hydrodynamics*, 4th edit., p. 661.

time interval τ; hence, the less frequent the eddies passing any particular point, the bigger τ will have to be; and in general the less frequent the eddies are the bigger they are. Hence with this limitation on the frequency or size of eddies, equation (9) gives a fairly exact representation of the mean motion, so soon as we know the value of the terms $\frac{\partial}{\partial x}(\rho\overline{u'u'})$, $\frac{\partial}{\partial y}(\rho\overline{u'v'})$, etc. It should be noticed that there has so far been no assumption that the eddies are, on the whole, evenly disposed; they may be quite unevenly distributed, and may form in particular ways and pursue particular paths, provided only that a sufficient number pass any given point in a given time interval. In this case, however, the values of the terms $\frac{\partial}{\partial x}(\rho\overline{u'u'})$, $\frac{\partial}{\partial y}(\rho\overline{u'v'})$, etc. may vary considerably from point to point of the fluid. But let us now assume that the eddies are distributed in an entirely haphazard manner. Then the eddy motion regarded statistically may be considered to be symmetrical about any point in the fluid, and the same considerations that lead to the determination of the stresses in a viscous fluid may be applied by analogy to determine the stresses due to the eddies in an eddying fluid, the difference between the two cases being only one of scale. Hence, we are led to introduce a coefficient of eddy viscosity μ_1, and an "eddy-pressure" p_1, and to express the eddy stresses (11) by the formulæ

$$-\rho\overline{u'u'} = -p_1 + 2\mu_1\frac{\partial\bar{u}}{\partial x};\ -\rho\overline{u'v'} = \mu_1\left(\frac{\partial\bar{u}}{\partial y} + \frac{\partial\bar{v}}{\partial x}\right);\ -\rho\overline{u'w'} = \mu_1\left(\frac{\partial\bar{w}}{\partial x} + \frac{\partial\bar{u}}{\partial z}\right),\ \text{etc.} \quad (12)$$

We have also

$$\bar{p}_{xx} = -\bar{p} + 2\mu\frac{\partial\bar{u}}{\partial x};\ \bar{p}_{yx} = \mu\left(\frac{\partial\bar{u}}{\partial y} + \frac{\partial\bar{v}}{\partial x}\right);\ \bar{p}_{zx} = \mu\left(\frac{\partial\bar{w}}{\partial x} + \frac{\partial\bar{u}}{\partial z}\right),\ \text{etc.} \quad (13)$$

whence on substituting into (9) from (12) and (13) and making use of (10) we obtain

$$\rho\frac{d\bar{u}}{dt} = \rho X - \frac{\partial}{\partial x}(\bar{p} + p') + (\mu + \mu_1)\nabla^2\bar{u} + 2\frac{\partial\mu_1}{\partial x}\frac{\partial\bar{u}}{\partial x} + \frac{\partial\mu_1}{\partial y}\left(\frac{\partial\bar{u}}{\partial y} + \frac{\partial\bar{v}}{\partial x}\right) + \frac{\partial\mu_1}{\partial z}\left(\frac{\partial\bar{w}}{\partial x} + \frac{\partial\bar{u}}{\partial z}\right), \quad (14)$$

in which $\frac{d}{dt}$ is to be interpreted as $\frac{\partial}{\partial t} + \bar{u}\frac{\partial}{\partial x} + \bar{v}\frac{\partial}{\partial y} + \bar{w}\frac{\partial}{\partial z}$.

The eddy pressure p_1, is of a much lower order than $\bar{p}$ and may be omitted. Actually, if the mean resultant eddy velocity is 5 mi./hr., then p_1 is only ·02 mb. Further, if the eddies are distributed in the same manner throughout the fluid, so that the fluid may be said to be homogeneous in regard to its eddies, then μ_1 will not vary with position, except within a distance from a boundary comparable with the size of the eddies. Also the calculation of μ_1 from wind observations shows that it is so much larger than μ, that μ may be neglected. Equation (14) reduces then for the free fluid to

$$\rho\frac{d\bar{u}}{dt} = \rho X - \frac{\partial p}{\partial x} + \mu_1\nabla^2\bar{u} \quad (15)$$

This is the equation of mean motion. It is of the same form as that of the ordinary equations of hydrodynamics, but its application is limited, as we have seen, by the following considerations:

(1) The time interval over which the mean velocities are calculated must be large enough to allow of sufficiently numerous fluctuations of the instantaneous velocities about the mean values to occur within it;

(2) The eddies must be evenly distributed throughout the whole portion of the fluid to which equation (15) applies. This equation does not hold near a boundary; in such a region equation (14) would have to be used. Similarly equation (14) would be used throughout any fluid in which changes of eddy characteristics with position may occur, though in this case also the distribution of eddies in the neighbourhood of any point must be dense enough for statistical

consideration. If this last condition is not realised, then we must have recourse to the more fundamental equation (9).

We have seen then under what conditions the equation (15) for "smooth" eddy motion may be derived from the exact equation (2) for purely viscous motion. Now let us assume that there are two sets of eddies present in a fluid, arising from different causes, such that the mean motion of the fluid with only the one set present is fairly accurately represented by (15) with a certain value of μ_1, and suppose further that the other eddies are of a much larger scale than these. The modification of equation (15) when these larger eddies enter into the motion will be similar to that found in changing over from equation (2) to equation (9). Consequently, the form of equations required to describe the motion when there are present many small eddies and fewer large ones will be three like

$$\rho\frac{du}{dt} = \rho X - \frac{\partial p}{\partial x} + \mu_1 \nabla^2 u - \left\{ \frac{\partial}{\partial x}(\rho\overline{u'u'}) + \frac{\partial}{\partial y}(\rho\overline{u'v'}) + \frac{\partial}{\partial z}(\rho\overline{u'w'}) \right\} \qquad (16)$$

in which μ_1 is the eddy viscosity appropriate to the small eddies; u,v,w, mean velocities taken over an interval of time τ so large that the effects of the small eddies are smoothed out; and u', v', w' are the departures of the observed velocities from the mean values u, v, w, owing to the effect of the large eddies. It is assumed that the large eddies may be too few or too irregularly disposed to allow of proceeding further with the equation (16) as was done with a similar equation earlier. Also it must be remembered that equation (15), and hence also (16), was shown to be inapplicable within a distance of the boundary comparable with the size of the frictional eddies, so that these equations should not be rigorously applied to motion within about 50 feet of the surface; moreover, if the large convectional eddies can be considered statistically so that equation (15) may be applied to this case also, with a suitable value of μ, which will be considerably larger than that appropriate to frictional eddies, then the equation will not apply within some 1500 feet of the earth's surface.

§ 37—THE VALUES OF THE COEFFICIENT OF TURBULENCE

Various estimates of the value of the coefficient of turbulence have been made by various workers using various methods. The magnitudes arrived at differ widely but for the type of turbulence which affects the variation of wind with height the variations are from about 10^5 to 10^2 in c.g.s. units. It must be recognised that the diversity of these coefficients is due not only to the type of surface over which the air flows, but also to the vertical temperature gradient. Indeed, this latter factor may be even more important than the former, for instance over the Newfoundland Banks Taylor[1] found values ranging from $3{\cdot}4 \times 10^3$ to $5{\cdot}7 \times 10^2$ by means of the estimation of the upward flux of temperature, while he obtained a value of $6{\cdot}2 \times 10^4$ from the consideration of pilot-balloon ascents over Salisbury Plain. It is, however, to be observed that the method used by Taylor in examining the observations over the Newfoundland Banks required that there should be considerable stratification in the atmosphere which would tend to damp out the eddies while the Salisbury Plain observations were made in daylight when convection would be present to a greater or less degree. There is indeed an observation quoted by Richardson[2] where a coefficient of turbulence of 10^5 was obtained in the unstable surface air of the NE. trade.

In view of what has been said in § 36 it is not considered to be rigidly correct to compute coefficients of turbulence from the measurements of wind at three heights near the surface of the ground except when there is an inversion such as would prevent convective eddies forming, but it has been possible to obtain estimates of the values of the coefficients of turbulence for frictional eddies when such inversions have formed near the surface.

(a) *A determination by wind measurements.*—In Table XXIV there are given values of the direction and speed of the wind observed at three heights on certain

[1] Taylor G. I. Eddy motion in the atmosphere, *London, Phil. Trans. R. Soc.*, A, **215**, 1914, p.1.
[2] Richardson L. F., "Weather Prediction by a Numerical Process," Cambridge, 1922.

occasions when quick runs or ultra-quick runs were made on the anemometers at 150 feet, 50 feet and 30 feet. In the cases of October 14 and 16 and November 19 1930 there were small inversions near the surface and it is therefore legitimate to substitute values obtained from the observations at these heights in equations of the type of (15) of §36.

The values of the various terms in such equations are given in Table XXVI on the assumptiom that $\frac{\partial u}{\partial x}$, $\frac{\partial u}{\partial y}$, w, etc., are all zero. When substitution is made two values of the coefficient of turbulence are derived, the one (K_x) from equation (15) and the other (K_y) from a similar equation for $\frac{dv}{dt}$. The agreement between the two values of the coefficient of turbulence affords a certain criterion of their truth. The coefficients are shown in the last two columns of Table XXVI. In the cases of October 14 and 16 and November 19 they show a fairly satisfactory agreement and they are of the same order of magnitude as those found by Taylor over the Newfoundland Banks.[1]

For comparison an attempt was made to calculate in a precisely similar way the coefficients for two periods on February 26, 1931, when there was no inversion. The results which are shown in the last two lines of Table XXVI show such disagreement in the values of K_x and K_y that it is quite clear that there is no physical significance in those values.

TABLE XXVI.

Record number.	Date.	Hour G.M.T. (h.m. to h.m.)	$\frac{\partial^2 u}{\partial z^2}$	$\frac{\partial^2 v}{\partial z^2}$	$\frac{\partial u}{\partial t}$	$\frac{\partial v}{\partial t}$	X	Y	$\frac{1}{\rho}\frac{\partial p}{\partial y}$	K_x	K_y
572–577	Oct. 14, 1930	14 30 to 16 25	$-1{\cdot}8\times10^{-5}$	$-1{\cdot}9\times10^{-5}$	$-2{\cdot}3\times10^{-2}$	$5{\cdot}6\times10^{-2}$	$7{\cdot}26\times10^{-2}$	$-5{\cdot}8\times10^{-2}$	$-2{\cdot}03\times10^{-1}$	$5{\cdot}3\times10^{3}$	$7{\cdot}3\times10^{3}$
579–583	Oct. 16, 1930	22 22 to 23 55	$-3{\cdot}0\times10^{-5}$	$-5{\cdot}1\times10^{-5}$	$-1{\cdot}16\times10^{-2}$	$3{\cdot}4\times10^{-2}$	$6{\cdot}73\times10^{-2}$	$-6{\cdot}02\times10^{-2}$	$-1{\cdot}63\times10^{-1}$	$2{\cdot}6\times10^{3}$	$1{\cdot}3\times10^{3}$
593–597	Nov. 19, 1930	10 00 to 11 56	$-3{\cdot}7\times10^{-5}$	$-4{\cdot}5\times10^{-5}$	$2{\cdot}6\times10^{-2}$	$2{\cdot}6\times10^{-1}$	$9{\cdot}6\times10^{-2}$	$-10{\cdot}4\times10^{-2}$	$-2{\cdot}88\times10^{-1}$	$1{\cdot}9\times10^{3}$	$4{\cdot}0\times10^{3}$
604–605	Feb. 26, 1931	11 32 to 12 08	$-1{\cdot}0\times10^{-4}$	$1{\cdot}4\times10^{-5}$	$7{\cdot}1\times10^{-2}$	$3{\cdot}6\times10^{-2}$	$9{\cdot}5\times10^{-2}$	$-1{\cdot}07\times10^{-1}$	$-2{\cdot}88\times10^{-1}$	$2{\cdot}4\times10^{3}$	$-1{\cdot}0\times10^{4}$
606–607	Feb. 26, 1931	15 19 to 15 53	$-2{\cdot}8\times10^{-5}$	$-3{\cdot}4\times10^{-5}$	$-2{\cdot}4\times10^{-2}$	$5{\cdot}9\times10^{-2}$	$4{\cdot}7\times10^{-2}$	$-9{\cdot}2\times10^{-2}$	$-1{\cdot}57\times10^{-1}$	$2{\cdot}5\times10^{3}$	$1{\cdot}8\times10^{2}$

(b) *A determination by temperature measurements.*—When the temperature distribution in the atmosphere is controlled by turbulence, the relevant equation is

$$\frac{\partial\theta}{\partial t} = K\frac{\partial^2\theta}{\partial z^2} \qquad (17)$$

in which θ is the temperature, as a function of the time t and the vertical co-ordinate z, and K the coefficient of turbulence.

The electrical temperature recorder at Cardington gives the temperature at heights of 4, 100 and 143 feet above the ground. From these $\frac{\partial\theta}{\partial t}$ and $\frac{\partial^2\theta}{\partial z^2}$ can be calculated, and hence also K. If equation (17) be integrated in regard to t from t_1 to t_2, and then be divided by the time interval $t_2 - t_1 = \Delta t$, we find

$$\frac{\Delta\theta}{\Delta t} = K\frac{\partial^2\bar{\theta}}{\partial z^2} \qquad (18)$$

on assuming K constant in the interval, where $\Delta\,\theta$ is the change in θ and $\bar{\theta}$ the mean value of θ during the interval. This is the equation that has actually been used with $\Delta\,t = 1$ hour, but it is really of the same form as (17) and shows that mean values of θ can be used instead of instantaneous values, provided K does not vary during the interval.

[1] See Taylor, G. I., Eddy motion in the atmosphere, *loc. cit.*, and Brunt, D., The transfer of heat by radiation and turbulence in the atmosphere, *London, Proc. R. Soc.*, **124A**, 1929, pp.201–218.

TABLE XXVII.—VALUES OF COEFFICIENTS OF HEAT TRANSFERENCE DERIVED FROM TEMPERATURES AT THREE HEIGHTS

Date	G.M.T. 16h.–17h.	17h.–18h.	18h.–19h.	19h.–20h.	21h.–22h.	22h.–23h.	23h.–24h.
Oct. 12, 1930	$7{\cdot}1\times10^3$	$2{\cdot}9\times10^3$	$1{\cdot}0\times10^3$	$1{\cdot}2\times10^3$	—	$1{\cdot}4\times10^3$	—
Oct. 9, 1930	$4{\cdot}0\times10^3$	$2{\cdot}3\times10^3$	—	$1{\cdot}5\times10^3$	$1{\cdot}2\times10^3$	$1{\cdot}3\times10^3$	$1{\cdot}8\times10^3$

It has been pointed out by Brunt[1] that the coefficient of heat transference calculated above is in part due to radiation and only that in excess of 10^3 is due to eddy conductivity.

In both the cases evaluated above in Table XXVII an inversion began to form shortly before 16h. so that between 16 and 17h. the damping of eddies by the inversion would not have reached the height of trees and houses. The figures show the damping in the subsequent hours. The values for the hours 16 to 17 and 17 to 18 are sufficiently in excess of the value 10^3 to show that an appreciable portion of them is due to eddy viscosity and the resulting values for the coefficient of eddy viscosity ranging between 7×10^3 and 10^3 is in close agreement with the values found from wind in Table XXVI.

§ 38—THE EFFECT OF THE VERTICAL TEMPERATURE GRADIENT ON THE COEFFICIENT OF TURBULENCE

From equation (1) of § 35 it is possible to compute the value of K (the coefficient of turbulence) provided that the vertical wind gradient and the "surface wind speed" are known sufficiently near the ground and provided that it is legitimate to assume that $\varkappa$ has a constant value.

A value of 2×10^{-3} was found for $\varkappa$ by Taylor[2] from pilot-balloon observations over Salisbury Plain and approximately the same figure by Ekman[3] from the storage of water by wind in the Baltic. Both these estimates were, however, made when the vertical temperature gradient did not give a pronounced inversion so that the agreement does not necessarily imply that the value of $\varkappa$ is independent of temperature conditions.

If, however, $\varkappa$ is assumed to have the value 2×10^{-3}, it then becomes possible to calculate the effect of the vertical temperature gradient on the turbulence from the figures given in Table XXI of Part IV. This has been done and the results are given in Table XXVIII, the tables being confined to cases where the vertical temperature gradient is less than superadiabatic.

TABLE XXVIII—COEFFICIENTS OF TURBULENCE IN RELATION TO WIND SPEED AND VERTICAL TEMPERATURE GRADIENT

Wind speed at 150 ft. (mi./hr.)	Difference in temperature at 143 ft. and 4 ft. (°F.)								
	$-1{\cdot}0$	$0{\cdot}0$	$1{\cdot}0$	$2{\cdot}0$	$3{\cdot}0$	$4{\cdot}0$	$5{\cdot}0$	$6{\cdot}0$	$7{\cdot}0$
10–14	$4{\cdot}8\times10^4$	$2{\cdot}8\times10^4$	$1{\cdot}4\times10^4$	$6{\cdot}9\times10^3$	$4{\cdot}0\times10^3$	$2{\cdot}9\times10^3$	$1{\cdot}9\times10^3$	$1{\cdot}4\times10^3$	$1{\cdot}0\times10^3$
15–19	$4{\cdot}2\times10^4$	$2{\cdot}8\times10^4$	$1{\cdot}9\times10^4$	$1{\cdot}2\times10^4$	$8{\cdot}0\times10^3$	$6{\cdot}0\times10^3$	$4{\cdot}3\times10^3$		
20–24	$3{\cdot}3\times10^4$	$2{\cdot}8\times10^4$	$2{\cdot}8\times10^4$	$2{\cdot}7\times10^4$					
25–29	$5{\cdot}5\times10^4$	$4{\cdot}4\times10^4$	$4{\cdot}0\times10^4$	$3{\cdot}6\times10^4$					

The coefficients of turbulence have been plotted logarithmically against the vertical temperature differences in Fig. 94 and for the different wind speeds (at 150 feet) the curves are nearly straight lines.

[1] Brunt, D., *London Proc. R. Soc.* A. **124**, 1929, p.201, and **130**, 1930, p. 98.
[2] Taylor, G. I., *London, Proc. R. Soc.* A. **92**, p.196.
[3] Ekman, V. W., *Stockholm, Arkiv. Mat. Astr. Fys.*, **2**, 1905.

In the formation of Table XXVIII it was necessary to obtain an estimate of the " surface wind speed." This was assumed as the value of the wind speed at 50 feet less one third of the difference between the wind speeds at 150 feet and 50 feet.

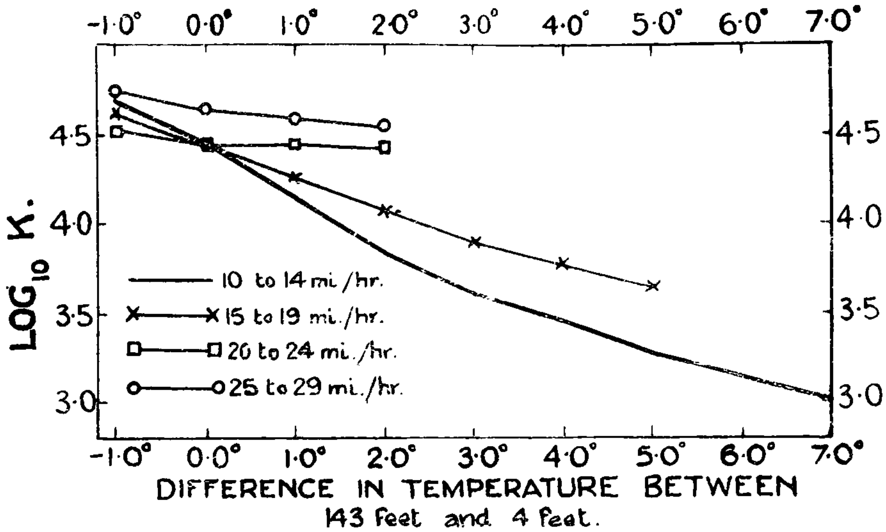


FIG. 94.—RELATION OF THE COEFFICIENT OF TURBULENCE TO THE TEMPERATURE GRADIENT WHEN THE WIND SPEED AT 150 FEET LIES BETWEEN CERTAIN VALUES.

In Fig. 95 is shown the result of plotting the logarithm of the coefficient of turbulence against the " surface wind speed " so obtained. Curves are drawn for each value of the difference in temperature between 143 feet and 4 feet, and these curves devolve into straight lines meeting at the point where the surface speed is 17 mi./hr. and the coefficient of turbulence is $2 \cdot 8 \times 10^4$.

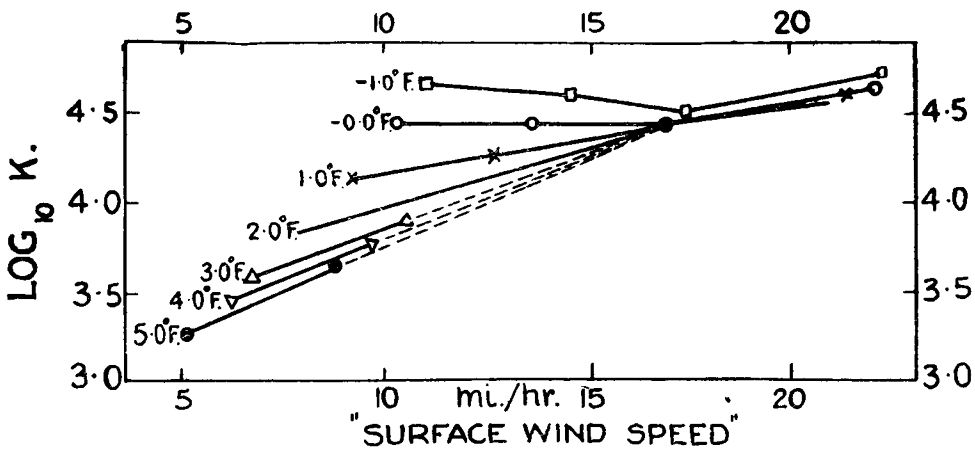


FIG. 95.—RELATION OF THE COEFFICIENT OF TURBULENCE TO THE SURFACE WIND SPEED FOR DIFFERENT VALUES OF THE VERTICAL TEMPERATURE GRADIENT.

§ 39—SUMMARY OF PART V

The effect of the present theory of eddies on the variation of wind with height is discussed, and it is found that simple equations of motion are only applicable to the atmosphere above a height of about 50 feet when there is an inversion. When superadiabatic conditions are present the simple equations can only be rigorously used above a height of some 1500 feet.

Values of the coefficient of turbulence are derived under certain conditions and a table is formed showing the effect which the temperature gradient in an inversion has in reducing the value of the coefficient of turbulence.

APPENDIX I—TABULATIONS OF 5-SECOND MEAN VALUES OF WIND SPEED AND DIRECTION DURING CERTAIN PERIODS OF TEN MINUTES WHEN THREE AND FOUR-POINT RUNS WERE IN OPERATION

NOTES ON THE WEATHER DURING THE MAKING OF THE THREE AND FOUR-POINT RUNS TABULATED

Ref. No. 314. Sept. 29, 1927, 13h. 45m.—13h.55m. G.M.T. Approx. mean speed 23 mi./hr. Approx. mean direction 185°; weather orr; cloud Nb. 8, A.St.2; geostrophic wind 230°, 40 mi./hr. Between 14h. 10m. and 14h. 20m. a front passed over the anemometer with a wind veer of nearly 90° and a great decrease in wind velocity. Prior to the passage of the front the appearance of the 24-hour wind record indicates that the vertical temperature gradient was approximately adiabatic.

Ref. No. 344. November 2, 1927, 14h. 53m.—15h. 1m. G.M.T. Approx. mean speed 19 mi./hr.; approx. mean direction 233°, cloud St.Cu.8,A.Cu.1; geostrophic wind 245°, 33 mi./hr. The 24-hour wind record indicates that the vertical temperature gradient was approximately adiabatic (which is, moreover, borne out by the presence of St. Cu. cloud).

Ref. No. 351. November 12, 1927, 10h. 56m.—11h. 6m. G.M.T. Approx. mean speed 20 mi./hr.; approx. mean direction 7°; cloud St.Cu.2, Cu.Nb.3; geostrophic wind 30°, 45 mi/hr. The 24-hour wind record shows considerable gustiness, the vertical temperature gradient probably being slightly super-adiabatic. This gustiness increased during the afternoon. The bimetallic thermograph shows considerable fluctuations from noon.

Ref. No. 357. January 4, 1928, 15h. 5m.—15h. 18m. G.M.T. Approx. mean speed 28 mi./hr.; approx. mean direction 226°; cloud Nb. 5, St.Cu.5; geostrophic wind 270°, 70 mi./hr. The 24-hour wind record is of the type associated with approximately adiabatic conditions.

Ref. No. 360. January 6, 1928, 12h. 32m.—12h. 39m. G.M.T. Approx. mean speed 41 mi./hr.; approx. mean direction 272°; cloud Fr.Cu.3, A.Cu.1, Ci.1; geostrophic wind 310°, 90 mi./hr.

Ref. No. 361. January 6, 1928, 12h. 53m.—13h. G.M.T. Approx. mean speed 40 mi./hr.; approx. mean direction 271°; cloud Fr.Cu.2, Ci.2; geostrophic wind 310°, 90 mi./hr. The 24-hour wind record exhibits oscillations of a type that is probably associated with super-adiabatic conditions. The bimetallic thermograph also shows frequent small fluctuations.

Ref. No. 371. January 24, 1928, 11h. 2m.—11h. 12m. G.M.T. Approx. mean speed 28 mi./hr.; approx. mean direction 235°; cloud A.St.2, A.Cu.5, Cu.2; geostrophic wind 250°, 55 mi./hr. The 24-hour wind record indicates that the vertical temperature gradient was approximately adiabatic during the morning. There are no small fluctuations on the bimetallic thermograph.

Ref. No. 391. February 11, 1928, 11h. 16m.—11h. 26m. G.M.T. Approx. mean speed 34 mi./hr.; approx. mean direction 249°; weather cr_0, cloud St.Cu.4; geostrophic wind 295°, 85 mi./hr. The 24-hour record is of the type associated with a slight super-adiabatic vertical temperature gradient.

Ref. No. 393. February 17, 1928, 12h.—12h. 10m. G.M.T. Approx. mean speed 27 mi./ hr.; approx. mean direction 275°; cloud Cu., Cu.Nb. and St.Cu.8; geostrophic wind 300°, 50 mi./hr. The 24-hour wind trace is of the type associated with super-adiabatic conditions, the type becoming more pronounced during the afternoon.

Ref. No. 400. February 21, 1928, 14h. 34m.—14h. 44m. G.M.T. Approx. mean speed 11 mi./hr.; approx. mean direction 180°; no cloud.

Ref. No. 401. February 21, 1928, 14h. 54m.—15h. 04m. G.M.T. Approx. mean speed 11 mi./hr.; approx. mean direction 175°; no cloud; geostrophic wind 200°, 30 mi./hr. The 24-hour wind record is of the type associated with super-adiabatic conditions.

Ref. No. 402. February 24, 1928, 11h. 23m.—11h. 32m. G.M.T. Approx. mean speed 10 mi./hr.; approx. mean direction 74°; cloud St.Cu.4, St.6; geostrophic wind 310°, 30 mi./hr. The 24-hour wind record at the time of making this ultra-quick run was of the type associated with adiabatic conditions, but after noon the eddying became more extensive, and it is probable that super-adiabatic conditions then prevailed.

Ref. No. 427. March 21, 1928, 10h. 22m.—10h. 31m. G.M.T. Approx. mean speed 23 mi./hr.; approx. mean direction 110°; cloud St.Cu.3, A.St.7; geostrophic wind 125°, 40 mi./hr. The 24-hour wind record is of the type associated with adiabatic conditions.

APPENDIX I—*continued.*—ULTRA-QUICK RUN, FOUR-POINT RECORD

September 29, 1927. Duration 10 min. Commencing 13h. 45m. G.M.T.
Approx. mean speed 23 mi./hr. Approx. mean direction 185°
Ref. no. 314

Half min.	Five-second means.								Half min.	Five-second means.							
	Speed mi./hr.				Direction.					Speed mi./hr.				Direction.			
	A	B	C	D	A	B	C	D		A	B	C	D	A	B	C	D
1	24	28	27	18	166°	176°	186°	176°	11	26	26	21	28	183°	188°	178°	192°
	21	32	26	18	180	180	197	182		26	22	23	27	188	184	181	190
	26	31	23	22	179	173	187	183		25	22	22	23	186	176	188	182
	27	26	24	23	181	177	182	182		29	22	20	28	176	184	176	183
	26	24	26	19	187	172	186	184		29	22	20	27	181	194	178	187
	28	28	26	18	178	177	189	184		29	24	26	27	183	195	182	180
2	28	27	23	20	184	179	182	182	12	30	23	33	27	179	180	183	188
	23	25	23	19	184	180	178	181		29	22	30	27	177	178	184	190
	25	30	24	19	177	182	181	184		26	21	28	28	181	179	183	186
	27	29	19	22	179	180	178	183		29	22	27	27	184	180	183	185
	27	27	29	21	182	184	189	178		28	22	23	29	183	183	193	187
	27	27	27	21	186	179	190	178		27	22	28	29	179	180	182	185
3	26	25	28	20	185	182	188	179	13	30	25	28	23	182	178	187	181
	27	23	26	17	179	182	181	180		28	22	27	28	187	175	180	186
	25	23	26	21	189	183	182	180		28	18	27	27	189	185	187	185
	24	24	26	20	186	175	180	188		25	20	23	27	183	185	183	186
	23	27	24	21	189	187	176	183		24	24	22	27	183	174	183	182
	21	24	23	24	189	195	176	182		24	22	23	25	185	182	182	178
4	22	23	20	22	189	196	184	180	14	23	23	24	24	185	185	187	183
	21	23	18	24	178	190	185	178		22	20	25	25	184	190	183	183
	23	26	20	24	184	189	189	185		20	24	23	25	181	186	187	183
	20	27	17	25	188	186	180	181		23	24	23	24	183	185	185	187
	19	27	21	24	184	189	181	187		18	24	20	23	185	180	181	188
	18	27	22	25	189	190	184	186		19	23	20	26	180	183	185	191
5	20	25	19	25	184	190	192	181	15	19	21	24	25	193	185	183	188
	18	26	18	25	187	189	192	181		21	20	26	23	182	188	187	190
	19	26	19	24	183	191	186	181		26	20	24	21	178	185	186	182
	20	23	19	23	185	193	182	181		19	20	22	23	179	187	188	181
	24	24	23	21	188	187	181	188		18	19	23	23	189	186	183	190
	27	23	23	18	192	184	188	194		18	16	21	23	186	184	182	190
6	26	23	24	18	189	189	192	191	16	20	17	23	20	187	183	177	178
	25	22	22	19	188	187	194	190		21	18	24	19	185	191	177	185
	22	22	19	20	187	187	185	187		21	27	27	21	185	186	183	182
	23	26	18	21	188	183	192	186		21	24	24	17	183	194	181	184
	22	26	20	22	183	186	196	185		20	18	23	25	193	180	185	182
	25	22	18	23	178	188	183	188		24	16	21	22	182	184	190	188
7	25	22	17	23	187	185	184	184	17	21	23	21	18	185	186	188	188
	22	21	16	22	191	186	180	180		24	19	18	19	187	185	184	186
	22	21	16	21	181	187	186	185		26	20	16	19	188	188	192	185
	23	22	18	22	184	182	189	180		25	19	21	18	187	184	189	188
	22	22	22	19	183	185	188	190		24	26	25	21	189	181	191	186
	21	24	22	18	186	189	184	190		24	27	26	24	187	181	184	188
8	18	24	25	24	185	184	181	189	18	21	27	23	17	195	180	184	195
	19	24	24	18	188	181	180	199		20	20	22	15	188	194	186	198
	23	24	23	24	183	179	183	194		20	21	21	14	188	191	190	196
	22	23	25	24	187	184	184	191		16	20	20	19	183	190	191	200
	21	22	24	24	192	185	192	188		16	21	18	17	184	193	187	188
	23	22	21	25	195	192	192	187		16	23	19	19	182	193	185	186
9	19	21	17	26	188	186	179	177	19	17	20	18	23	187	191	183	183
	21	20	19	30	182	193	185	178		19	20	19	23	187	191	183	187
	21	20	20	26	185	195	187	177		22	18	20	23	187	189	189	188
	18	22	17	26	183	190	187	178		21	21	23	22	179	188	186	188
	20	25	18	26	189	191	180	179		25	19	23	19	194	186	189	185
	20	23	15	26	186	187	188	183		22	19	25	20	187	187	179	182
10	17	20	19	24	187	185	182	186	20	22	19	25	21	195	177	182	186
	18	21	19	23	187	183	188	186		21	19	25	22	194	181	182	186
	18	22	19	22	180	180	182	187		23	20	20	22	191	180	178	183
	22	24	19	21	181	185	184	182		24	25	19	18	183	184	180	176
	29	25	23	21	185	185	176	183		25	27	20	20	186	187	176	178
	28	23	22	25	182	189	183	184		26	27	18	24	179	188	178	189

APPENDIX I—*continued*.—ULTRA-QUICK RUN, THREE-POINT RECORD

November 2, 1927. Duration 8½ min. Commencing 14h. 53m. G.M.T.
Approx. mean speed 19 mi./hr. Approx. mean direction 233°
Ref. no. 344

Half min.	Five-second means.								Half min.	Five-second means.							
	Speed mi./hr.				Direction.					Speed mi./hr.				Direction.			
	A	B	C	D	A	B	C	D		A	B	C	D	A	B	C	D
1	18	23	18	—	238°	241°	239°	—	11	18	20	18	—	226°	234°	227°	—
	20	23	20	—	236	241	237	—		20	18	19	—	229	235	230	—
	16	22	21	—	238	244	239	—		20	17	19	—	229	235	234	—
	22	22	20	—	239	239	237	—		19	14	19	—	230	234	233	—
	21	21	22	—	239	239	240	—		19	15	19	—	234	233	239	—
	22	21	20	—	236	237	239	—		19	19	16	—	232	230	231	—
2	22	20	22	—	235	234	239	—	12	21	18	16	—	231	231	232	—
	22	22	22	—	238	235	240	—		19	18	19	—	229	233	230	—
	22	18	22	—	235	237	240	—		20	19	18	—	228	234	230	—
	23	19	19	—	235	235	240	—		21	18	17	—	234	228	234	—
	20	18	21	—	239	241	240	—		19	16	18	—	235	236	228	—
	19	20	19	—	239	240	238	—		18	17	16	—	235	230	233	—
3	19	19	21	—	238	237	237	—	13	18	17	17	—	232	230	232	—
	19	18	21	—	243	244	241	—		17	18	18	—	227	232	232	—
	23	20	20	—	239	243	239	—		16	17	16	—	233	227	231	—
	22	19	17	—	236	236	237	—		14	16	16	—	235	233	228	—
	22	17	20	—	239	237	235	—		18	16	18	—	229	228	221	—
	21	17	20	—	240	238	242	—		17	17	17	—	230	227	227	—
4	20	17	18	—	239	236	242	—	14	17	16	17	—	227	235	228	—
	19	17	16	—	242	240	240	—		16	16	18	—	228	233	220	—
	19	16	18	—	238	241	243	—		16	14	19	—	228	228	234	—
	18	16	19	—	235	238	238	—		17	15	20	—	229	228	235	—
	22	18	19	—	235	240	236	—		18	15	19	—	228	227	228	—
	20	18	16	—	234	244	234	—		15	17	17	—	232	225	235	—
5	20	19	16	—	236	241	237	—	15	13	15	17	—	233	230	232	—
	17	15	19	—	241	235	234	—		15	20	18	—	230	233	231	—
	18	16	19	—	238	231	238	—		18	20	18	—	242	230	228	—
	19	17	18	—	238	236	239	—		16	20	15	—	235	232	233	—
	19	17	20	—	236	239	239	—		17	18	17	—	229	230	234	—
	18	18	21	—	230	236	242	—		18	18	20	—	232	228	229	—
6	18	18	20	—	236	238	238	—	16	21	18	19	—	232	235	235	—
	17	17	19	—	237	236	233	—		19	19	19	—	226	228	231	—
	18	16	22	—	235	241	230	—		18	17	19	—	221	227	228	—
	17	16	21	—	230	232	231	—		20	17	18	—	223	230	224	—
	18	20	19	—	234	240	234	—		19	16	19	—	226	235	225	—
	17	20	18	—	242	239	237	—		18	17	20	—	232	228	227	—
7	17	21	18	—	240	228	232	—	17	18	17	18	—	233	230	227	—
	18	20	22	—	242	230	232	—		19	16	18	—	232	225	228	—
	17	20	22	—	231	231	233	—		19	14	21	—	239	227	232	—
	18	21	24	—	232	234	234	—		23	13	18	—	234	226	234	—
	16	21	22	—	235	233	235	—		19	14	16	—	234	230	230	—
	17	20	22	—	234	230	232	—		17	16	18	—	234	228	230	—
8	17	21	22	—	239	234	233	—	18	15	20	16	—	232	—	229	—
	18	20	21	—	236	233	232	—		14	18	16	—	227	—	229	—
	22	23	21	—	233	234	232	—		15	16	18	—	228	—	233	—
	20	23	23	—	232	234	236	—		19	16	17	—	232	—	233	—
	18	22	22	—	234	233	237	—		19	17	17	—	234	—	232	—
	18	23	20	—	233	234	230	—		19	15	16	—	228	—	231	—
9	16	22	22	—	238	233	231	—	19	19	—	—	—	—	—	—	—
	17	23	22	—	236	237	231	—		19	—	—	—	—	—	—	—
	20	22	21	—	237	235	230	—		18	—	—	—	—	—	—	—
	20	20	21	—	231	234	229	—		17	—	—	—	—	—	—	—
	14	20	21	—	237	230	229	—		17	—	—	—	—	—	—	—
	16	19	20	—	231	232	229	—		19	—	—	—	—	—	—	—
10	18	20	21	—	226	230	230	—	20	—	—	—	—	—	—	—	—
	17	21	20	—	223	232	233	—		—	—	—	—	—	—	—	—
	18	19	18	—	228	230	235	—		—	—	—	—	—	—	—	—
	17	21	18	—	232	230	237	—		—	—	—	—	—	—	—	—
	14	20	18	—	231	230	233	—		—	—	—	—	—	—	—	—
	14	20	19	—	230	228	228	—		—	—	—	—	—	—	—	—

APPENDIX I—*continued.*—ULTRA-QUICK RUN, FOUR-POINT RECORD

November 12, 1927. Duration 9½ min. Commencing 10h. 56m. G.M.T.
Approx. mean speed 20 mi./hr. Approx. mean direction 7°
Ref. no. 351

Half min.	Five-second means.								Half min.	Five-second means.							
	Speed mi./hr.				Direction.					Speed mi./hr.				Direction.			
	A	B	C	D	A	B	C	D		A	B	C	D	A	B	C	D
1	24	20	13	22	1°	10°	357°	5°	11	26	21	23	20	5°	11°	14°	2°
	24	17	14	23	1	5	4	5		19	25	22	20	10	10	20	4
	24	21	14	23	353	11	12	359		21	22	21	20	21	8	9	14
	22	22	17	22	358	10	12	6		23	16	16	21	11	20	7	10
	24	23	17	19	11	3	11	3		20	15	18	17	1	19	5	4
	20	20	19	17	16	2	7	7		20	21	22	19	352	14	7	11
2	20	17	19	17	8	8	6	17	12	17	26	20	16	16	12	7	23
	24	21	21	20	1	13	10	10		14	26	19	13	19	12	5	20
	22	22	20	21	355	8	358	10		17	25	20	21	14	9	10	16
	24	21	14	22	4	6	353	15		14	19	22	24	8	19	13	12
	25	20	16	21	360	11	360	10		22	19	19	22	4	30	21	12
	19	22	16	20	10	13	4	11		21	21	19	22	2	36	18	7
3	18	22	16	19	8	3	9	11	13	20	18	22	20	12	14	14	16
	18	20	18	21	4	6	13	8		15	18	22	18	22	9	20	21
	17	19	16	19	10	359	3	10		21	23	23	17	30	6	17	15
	22	17	14	17	6	1	359	3		20	22	22	20	12	9	9	7
	23	16	15	15	345	4	10	5		19	22	24	25	17	10	8	4
	24	21	14	18	5	360	359	3		19	19	22	29	14	12	15	358
4	22	17	12	19	9	359	11	2	14	19	19	20	23	10	9	15	357
	15	16	13	25	13	358	4	357		24	19	22	18	2	8	10	7
	16	15	14	19	9	3	13	358		20	18	21	16	356	1	10	357
	16	14	18	16	2	360	12	1		22	17	21	19	7	3	357	2
	16	15	17	19	357	355	7	359		19	16	19	19	7	358	358	358
	20	17	15	19	1	358	360	356		18	17	23	22	13	1	356	1
5	13	14	17	16	359	6	359	344	15	16	19	22	22	15	4	356	2
	16	14	18	20	4	12	353	347		19	23	22	22	14	3	358	11
	15	11	22	20	2	8	347	359		18	23	20	20	12	360	353	352
	16	14	16	17	5	7	358	2		16	20	21	17	14	352	357	350
	19	14	17	17	6	15	2	356		14	24	19	18	19	359	356	2
	19	13	21	15	23	17	351	360		17	20	17	18	17	359	1	1
6	17	14	22	13	21	10	354	1	16	16	19	18	17	22	359	10	7
	18	15	21	14	16	22	355	10		15	18	17	17	20	360	348	3
	18	21	21	14	10	20	357	5		15	18	22	17	8	5	355	354
	22	23	22	15	7	8	12	5		14	17	24	23	18	7	1	357
	19	22	19	16	11	7	6	3		12	18	22	23	4	7	9	7
	15	19	20	14	6	352	3	357		11	16	23	22	355	8	21	7
7	16	16	17	14	6	357	10	7	17	15	17	24	20	12	9	14	9
	17	18	16	19	7	1	360	3		14	16	23	20	12	14	15	20
	18	19	15	19	5	2	6	2		12	26	24	18	5	9	18	17
	20	20	19	19	2	357	7	4		13	27	23	18	13	12	11	13
	19	18	16	20	2	359	358	350		18	26	21	21	7	4	16	13
	18	18	19	25	3	358	4	356		20	26	20	19	6	1	14	3
8	20	17	18	21	359	355	24	356	18	23	28	25	27	3	357	17	17
	22	23	18	22	359	352	11	357		29	32	24	22	6	359	11	4
	19	17	14	24	357	5	2	12		29	27	21	30	359	358	9	8
	17	17	18	23	5	10	358	1		25	25	24	28	1	357	14	360
	18	25	24	19	2	10	6	358		22	24	29	24	356	360	15	357
	19	20	18	23	354	2	4	1		23	26	27	20	358	4	15	357
9	21	24	17	23	6	12	5	22	19	20	25	22	17	360	1	11	3
	19	21	20	22	16	19	20	22		23	24	26	23	358	6	6	12
	16	22	18	15	24	21	10	11		23	23	25	26	357	9	14	12
	16	20	18	19	19	21	13	20		27	25	25	26	1	10	14	8
	16	23	24	20	41	26	12	12		22	26	28	27	6	11	17	10
	15	13	22	26	29	22	20	20		26	26	26	24	10	9	13	15
10	20	14	23	21	21	28	13	7	20	24	24	23	22	—	358	9	16
	22	14	25	21	21	27	9	21		27	20	23	27	—	356	10	9
	20	14	22	17	21	10	9	7		27	18	25	28	—	6	10	358
	18	14	26	15	22	13	14	11		32	15	23	24	—	357	4	—
	22	21	25	19	22	10	19	10		26	17	24	—	—	1	11	—
	24	19	23	24	360	14	19	4		22	19	21	—	—	1	14	—

APPENDIX I—*continued.*—ULTRA-QUICK RUN, THREE-POINT RECORD

January 4, 1928. Duration 7½ min. Commencing 15h. 5m. G.M.T.
Approx. mean speed 28 mi./hr. Approx. mean direction 226°
Ref. no. 357

Half min.	Five-second means.							
	Speed mi./hr.				Direction			
	A	B	C	D	A	B	C	D
1	33	22	—	23	229°	224°	—	227°
	32	25	—	23	224	227	—	225
	32	28	—	29	222	224	—	227
	32	28	—	28	227	228	—	226
	31	26	—	31	221	226	—	225
	34	28	—	31	219	229	—	227
2	37	32	—	30	224	228	—	227
	35	30	—	26	223	227	—	232
	33	28	—	27	219	231	—	228
	31	24	—	23	223	235	—	225
	32	24	—	27	221	228	—	225
	33	26	—	28	224	227	—	227
3	29	27	—	28	234	227	—	232
	29	28	—	31	230	233	—	230
	28	28	—	31	227	230	—	227
	26	29	—	30	224	228	—	225
	26	28	—	32	223	227	—	228
	33	29	—	31	222	228	—	227
4	30	31	—	29	230	229	—	227
	31	30	—	35	227	227	—	225
	31	28	—	31	224	229	—	220
	30	32	—	31	224	225	—	225
	26	30	—	32	223	226	—	225
	30	31	—	30	221	226	—	226
5	29	32	—	31	224	225	—	229
	26	30	—	28	225	224	—	227
	27	27	—	28	228	226	—	227
	29	27	—	29	232	227	—	222
	27	32	—	32	232	223	—	225
	24	33	—	32	233	221	—	225
6	22	32	—	30	220	225	—	229
	23	32	—	34	228	224	—	222
	28	31	—	33	226	226	—	225
	35	30	—	30	227	226	—	225
	32	32	—	32	225	225	—	224
	31	32	—	33	226	223	—	223
7	29	31	—	34	228	223	—	217
	29	33	—	29	225	224	—	219
	30	33	—	31	225	224	—	223
	29	31	—	28	228	223	—	228
	27	31	—	28	224	227	—	228
	25	32	—	27	228	229	—	225
8	28	30	—	28	232	224	—	226
	29	29	—	27	231	228	—	227
	33	29	—	29	232	229	—	226
	30	29	—	27	237	231	—	232
	27	28	—	30	233	229	—	230
	26	26	—	27	231	231	—	232
9	25	26	—	25	224	230	—	227
	25	23	—	25	228	231	—	225
	24	24	—	24	225	226	—	224
	26	26	—	31	227	222	—	225
	29	32	—	30	230	224	—	232
	30	33	—	29	226	227	—	230
10	32	30	—	30	226	233	—	224
	27	31	—	34	225	231	—	226
	30	34	—	28	227	227	—	223
	29	30	—	27	228	224	—	227
	31	30	—	27	229	226	—	226
	29	26	—	27	231	230	—	229

Half min.	Five-second means.							
	Speed mi./hr.				Direction.			
	A	B	C	D	A	B	C	D
11	28	28	—	27	229°	228°	—	222°
	29	25	—	27	234	224	—	222
	29	28	—	30	227	225	—	222
	27	28	—	27	233	226	—	227
	28	26	—	27	229	226	—	232
	28	29	—	29	226	225	—	227
12	27	28	—	27	224	231	—	227
	28	27	—	26	228	228	—	226
	24	24	—	24	224	227	—	226
	24	24	—	25	223	228	—	224
	26	26	—	28	220	228	—	224
	29	21	—	28	225	227	—	222
13	30	26	—	23	220	229	—	217
	29	24	—	23	221	219	—	217
	28	22	—	24	229	217	—	226
	25	28	—	20	219	218	—	225
	30	27	—	19	221	226	—	228
	30	25	—	19	225	221	—	224
14	29	21	—	23	223	231	—	227
	26	19	—	27	227	229	—	225
	25	23	—	26	228	235	—	226
	24	27	—	27	225	226	—	227
	25	22	—	26	219	221	—	229
	28	26	—	24	234	227	—	224
15	23	25	—	23	232	229	—	229
	21	25	—	23	226	227	—	228
	29	24	—	26	223	225	—	227
	27	22	—	29	231	226	—	227
	34	25	—	27	232	229	—	230
	32	27	—	28	234	229	—	224
16	31	26	—	27	226	—	—	223
	35	26	—	28	227	—	—	225
	33	27	—	30	227	—	—	227
	30	27	—	27	230	—	—	226
	28	26	—	28	233	—	—	222
	25	23	—	24	220	—	—	227
17	23	24	—	23	218	—	—	229
	25	26	—	23	221	—	—	227
	28	25	—	29	231	—	—	226
	29	27	—	29	228	—	—	226
	26	30	—	34	228	—	—	226
	27	34	—	36	231	—	—	224
18	24	33	—	34	226	—	—	232
	26	34	—	32	227	—	—	228
	25	32	—	33	229	—	—	225
	26	31	—	33	227	—	—	222
	26	29	—	31	222	—	—	225
	28	31	—	30	219	—	—	230
19	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
20	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—

APPENDIX I—*continued*—ULTRA-QUICK RUN, FOUR-POINT RECORD

January 6, 1928. Duration 7 min. Commencing 12h. 32m. G.M.T.
Approx. mean speed 41 mi./hr. Approx. mean direction 272°
Ref. no. 360

Half min.	Five-second means.								Half min.	Five-second means.							
	Speed mi./hr.				Direction.					Speed mi./hr.				Direction.			
	A	B	C	D	A	B	C	D		A	B	C	D	A	B	C	D
1	40	28	35	38	275°	269°	269°	275°	11	32	48	32	41	274°	272°	269°	276°
	41	37	31	36	278	272	268	277		31	41	42	46	281	275	279	275
	39	33	26	39	277	269	265	281		41	36	46	46	281	273	274	278
	31	28	30	35	263	279	265	278		37	36	40	43	277	277	267	276
	29	25	31	40	264	281	261	276		35	37	42	34	279	277	272	277
	28	25	32	39	269	273	264	272		30	43	42	36	262	273	280	275
2	33	35	36	41	265	269	277	274	12	31	39	36	35	277	274	277	280
	36	31	38	36	267	271	280	274		33	42	32	35	280	272	278	275
	33	40	41	37	268	270	274	269		32	37	34	42	270	272	269	271
	35	42	33	35	261	271	272	262		34	38	33	38	269	275	275	282
	28	40	33	33	273	263	281	269		29	42	36	38	269	272	275	273
	28	32	30	31	269	261	275	269		32	42	40	38	275	271	272	265
3	32	36	29	33	260	273	265	277	13	32	29	40	37	280	269	270	271
	30	36	31	32	261	272	267	276		37	32	38	42	280	270	270	271
	33	39	34	32	270	271	270	272		29	31	34	39	273	271	265	274
	38	39	42	36	269	276	280	273		33	43	28	43	270	276	277	275
	32	41	35	38	271	270	279	277		41	48	44	50	267	264	273	271
	37	45	33	39	282	272	288	272		51	44	44	39	267	263	274	269
4	38	33	37	36	276	272	273	269	14	48	43	41	46	271	268	277	269
	40	29	43	39	277	271	269	266		51	43	50	47	269	274	281	261
	38	31	40	39	277	270	274	271		52	43	49	46	273	264	275	268
	37	36	47	41	267	272	264	285		49	46	48	51	274	266	276	267
	36	40	48	41	279	282	275	280		52	42	46	48	277	272	277	269
	32	41	41	33	273	280	288	280		50	39	54	52	277	272	279	271
5	45	42	33	46	272	279	270	281	15	48	35	51	45	278	—	271	273
	42	39	35	49	272	280	273	275		46	34	44	41	275	—	270	276
	35	43	37	44	268	280	275	278		45	47	43	47	276	—	268	277
	47	43	44	43	256	276	278	274		44	46	40	49	279	—	267	277
	46	44	42	40	265	274	274	277		49	51	40	45	278	—	270	274
	38	45	39	43	279	270	275	270		42	48	48	46	274	—	273	277
6	34	38	55	39	282	262	267	269	16	48	44	45	38	284	—	277	275
	31	32	54	40	282	267	278	268		40	42	43	44	276	—	271	274
	26	30	44	50	281	272	268	271		42	42	41	36	275	—	269	269
	39	34	42	42	272	278	267	273		39	46	42	37	272	—	260	269
	39	36	41	43	265	265	268	270		40	42	39	44	274	—	264	266
	40	36	47	43	279	265	269	266		38	39	46	43	272	—	274	271
7	46	41	48	51	269	270	275	269	17	43	37	47	41	274	—	267	263
	47	37	47	47	276	264	270	272		40	37	45	42	273	—	258	272
	46	36	45	53	280	267	270	273		40	39	43	44	268	—	263	270
	49	40	50	56	271	277	271	273		41	39	37	41	261	—	267	266
	47	39	41	49	271	274	270	270		32	39	37	43	273	—	272	264
	42	40	43	44	274	274	265	266		38	38	39	39	271	—	268	264
8	63	35	52	46	277	275	267	276	18	41	41	37	40	261	—	272	277
	57	38	53	45	277	271	267	275		47	47	34	40	267	—	267	281
	50	44	51	43	271	266	267	264		47	39	41	41	263	—	268	267
	48	45	53	41	269	274	269	270		43	35	34	41	267	—	265	270
	52	40	49	47	266	275	269	266		39	38	31	42	267	—	263	270
	50	41	54	54	275	266	272	268		35	31	33	39	265	—	271	273
9	50	33	50	44	271	268	277	262	19	36	40	37	39	269	—	—	280
	50	34	52	49	273	269	274	263		39	31	39	37	264	—	—	275
	41	43	48	48	272	259	276	261		48	32	38	32	267	—	—	272
	46	41	50	48	275	269	276	265		40	36	40	28	264	—	—	275
	49	40	44	46	270	272	282	263		43	38	37	27	267	—	—	273
	42	39	42	40	271	275	280	267		40	39	36	29	276	—	—	276
10	47	31	44	38	270	275	275	268	20	—	—	—	—	—	—	—	—
	44	31	42	39	264	270	278	268		—	—	—	—	—	—	—	—
	39	34	43	35	269	272	276	275		—	—	—	—	—	—	—	—
	42	32	38	40	265	280	269	274		—	—	—	—	—	—	—	—
	42	36	40	36	265	278	273	275		—	—	—	—	—	—	—	—
	37	37	36	35	274	279	277	282		—	—	—	—	—	—	—	—

APPENDIX I—*continued*—ULTRA-QUICK RUN, FOUR-POINT RECORD.

January 6, 1928. Duration 7 min. Commencing 12h. 53m. G.M.T.
Approx. mean speed 40 mi./hr. Approx. mean direction 271°
Ref. no. 361

Half min.	Five-second means.								Half min.	Five-second means.							
	Speed mi./hr.				Direction.					Speed mi./hr.				Direction.			
	A	B	C	D	A	B	C	D		A	B	C	D	A	B	C	D
1	45	41	—	44	274°	274°	—	276°	11	46	42	48	41	270°	268°	272°	264°
	39	44	—	41	269	274	—	276		50	37	47	42	271	271	276	262
	34	39	—	35	263	264	—	268		37	31	47	43	276	270	276	270
	45	37	—	34	271	277	—	271		36	31	45	45	267	272	275	274
	46	35	—	34	269	264	—	273		43	33	38	40	272	279	275	271
	43	35	—	38	272	264	—	273		41	45	35	44	271	274	269	280
2	43	35	41	45	272	272	272°	269	12	43	45	44	39	273	266	272	269
	37	38	41	44	271	273	263	276		38	44	44	40	267	267	268	272
	37	41	35	43	270	271	274	275		35	39	42	40	271	281	275	282
	42	35	39	44	278	272	271	271		46	40	39	39	276	288	272	280
	39	34	42	48	267	267	270	269		51	34	35	42	269	280	281	277
	40	39	40	43	269	266	261	269		52	46	40	40	274	272	277	277
3	40	38	36	42	258	266	267	265	13	43	45	47	42	282	271	273	267
	38	39	37	46	265	265	268	268		45	40	44	38	283	269	279	263
	41	36	32	35	262	277	264	270		45	35	47	36	279	268	272	283
	39	40	30	34	264	279	271	269		43	38	46	41	274	276	273	275
	39	42	35	28	266	284	274	272		38	43	36	45	269	277	273	272
	47	42	41	26	264	272	272	271		43	41	35	43	266	277	272	273
4	40	41	43	40	273	271	271	270	14	37	43	38	41	272	281	275	273
	39	41	40	34	278	271	264	264		46	45	41	38	273	274	273	271
	40	40	38	36	268	267	254	259		43	41	42	42	278	275	281	281
	42	34	44	33	272	268	259	258		42	53	33	46	273	278	274	285
	46	33	40	29	265	268	265	262		41	54	30	43	274	279	276	281
	34	28	42	25	271	260	270	266		39	51	38	39	271	271	275	275
5	42	23	37	37	271	277	279	265	15	33	44	42	37	272	—	271	269
	44	30	40	44	272	271	273	270		41	42	40	33	267	—	272	269
	42	36	40	45	265	270	271	278		37	43	37	34	272	—	267	264
	41	28	44	40	269	269	274	273		32	43	40	33	271	—	270	273
	46	39	48	42	271	272	274	281		33	41	37	33	270	—	268	280
	44	47	41	49	283	275	290	287		37	43	35	30	270	—	272	273
6	40	50	37	49	278	273	281	278	16	38	37	33	32	270	—	278	277
	42	43	42	53	285	273	271	274		33	38	37	29	276	—	273	276
	41	44	45	54	274	269	270	274		34	41	37	31	267	—	279	266
	42	51	41	53	276	270	275	276		35	41	35	37	269	—	273	270
	41	54	40	52	276	272	276	280		35	37	37	38	267	—	271	267
	42	51	48	46	272	274	274	270		33	33	37	37	267	—	275	269
7	36	47	48	47	270	268	265	268	17	33	31	34	31	267	—	271	276
	38	45	42	46	264	266	265	268		33	31	31	30	269	—	261	269
	32	46	38	42	270	263	255	271		30	38	31	29	260	—	257	273
	37	45	42	36	270	269	262	259		36	37	31	28	261	—	269	271
	47	51	43	47	263	259	271	271		34	33	28	32	260	—	270	271
	49	43	45	37	267	271	271	258		26	32	29	31	267	—	266	269
8	45	46	42	47	267	266	275	276	18	28	29	35	30	268	—	265	267
	46	49	40	46	270	271	270	280		33	27	35	34	273	—	268	257
	43	46	40	40	270	274	276	275		36	30	40	36	263	—	266	263
	44	48	48	41	266	271	279	272		34	28	50	32	263	—	271	258
	42	51	40	44	262	267	275	273		37	32	49	36	264	—	279	261
	36	44	42	47	271	272	270	271		36	33	45	31	275	—	269	271
9	36	46	39	43	271	272	269	267	19	37	34	47	36	277	—	276	266
	31	45	41	48	277	265	275	265		46	31	46	37	277	—	276	266
	44	43	48	46	273	262	264	266		46	31	46	44	275	—	271	273
	43	42	50	41	272	264	272	266		42	38	49	43	265	—	276	269
	46	45	53	52	273	267	274	263		35	44	51	41	270	—	274	271
	46	44	45	50	275	266	265	266		35	43	46	43	276	—	276	271
10	43	38	46	45	277	265	274	272	20	44	41	42	47	271	—	268	273
	69	41	40	38	267	267	267	274		46	46	45	40	272	—	265	268
	67	50	39	41	265	272	268	276		42	41	36	44	271	—	268	272
	66	49	42	39	264	282	268	267		41	42	37	45	270	—	276	275
	69	45	36	40	267	265	267	263		39	39	42	44	272	—	276	275
	73	41	43	38	271	265	266	269		38	34	38	40	269	—	269	275

APPENDIX I—*continued.*—ULTRA-QUICK RUN, FOUR-POINT RECORD

January 24, 1928. Duration 10 min. Commencing 11h. 2m. G.M.T.
Approx. mean speed 28 mi./hr. Approx. mean direction 235°
Ref. no. 371

Half min.	Five-second means.								Half min.	Five-second means.							
	Speed mi./hr.				Direction.					Speed mi./hr.				Direction.			
	A	B	C	D	A	B	C	D		A	B	C	D	A	B	C	D
1	29	32	28	30	239°	241°	241°	239°	11	25	35	31	31	240°	231°	236°	232°
	28	31	25	30	234	238	237	239		25	31	31	31	234	233	235	236
	32	31	24	28	238	239	233	235		23	31	29	32	232	234	234	233
	32	28	24	28	237	241	226	235		24	31	28	33	232	235	236	236
	43	28	22	26	241	236	237	231		28	33	27	29	231	236	235	234
	40	27	23	24	237	236	238	236		29	31	29	26	231	235	234	233
2	35	26	20	23	240	235	240	240	12	28	27	30	26	231	235	234	234
	37	24	22	25	240	239	243	242		26	25	29	28	230	235	237	232
	36	24	24	25	238	241	245	242		29	25	30	27	230	235	230	238
	34	28	28	26	238	241	236	240		29	27	30	27	226	233	230	233
	32	29	23	28	234	241	229	241		32	26	29	31	230	239	232	226
	35	30	28	29	235	242	234	233		31	25	35	30	232	234	239	235
3	33	30	31	26	233	239	234	232	13	31	31	31	29	234	228	226	237
	27	29	29	29	236	235	235	231		31	29	34	32	224	232	228	226
	26	29	27	28	238	233	236	236		26	28	31	33	241	234	233	228
	27	30	28	29	238	233	237	238		24	29	30	31	248	221	231	231
	30	23	28	29	239	237	236	233		23	31	28	31	236	229	236	233
	31	26	25	26	238	238	236	237		28	32	29	27	243	233	237	233
4	31	27	24	26	235	235	234	237	14	31	31	30	27	242	232	236	239
	31	25	27	25	237	242	236	236		29	29	30	27	228	239	236	237
	33	23	26	23	241	243	238	236		26	26	35	29	234	238	237	237
	30	25	26	26	238	241	233	239		29	24	32	34	238	238	240	237
	29	23	26	26	234	239	237	234		29	28	32	34	238	236	239	241
	29	25	30	26	235	237	233	239		29	35	31	31	238	236	238	237
5	30	23	31	25	233	239	237	233	15	28	33	30	33	236	240	232	238
	30	25	32	31	234	238	236	230		28	32	30	31	232	237	236	233
	29	29	31	30	235	234	236	241		23	33	31	30	231	237	236	235
	28	31	29	31	234	236	236	235		31	31	31	32	233	234	236	236
	27	28	27	31	232	239	238	236		31	30	29	31	234	235	234	236
	27	31	30	30	233	234	239	234		31	32	29	30	233	237	232	235
6	25	33	32	27	238	236	234	237	16	32	32	29	29	231	236	234	231
	28	31	29	29	234	238	231	236		29	31	27	29	235	234	235	233
	27	25	30	31	237	235	237	231		25	29	27	30	237	231	239	239
	27	32	29	30	239	232	235	235		25	29	29	27	235	231	235	236
	26	31	28	30	237	230	228	236		25	30	29	29	232	233	235	231
	33	30	27	29	237	238	232	232		27	29	28	29	233	238	235	233
7	31	26	26	29	239	236	231	232	17	29	30	22	29	241	232	227	233
	29	29	28	27	239	231	232	235		30	30	23	28	236	234	230	229
	28	28	29	27	238	233	240	234		30	27	21	22	239	235	228	231
	27	26	26	29	238	237	238	235		27	25	21	21	239	232	231	228
	26	28	26	29	235	234	243	238		26	25	28	22	233	231	233	231
	29	30	27	28	232	235	240	238		25	21	26	23	233	231	234	236
8	28	25	23	29	236	241	231	238	18	26	24	24	27	232	228	235	234
	28	27	27	27	232	239	229	234		24	22	24	27	232	230	235	231
	27	23	30	27	235	242	231	230		26	25	24	25	233	236	233	230
	27	27	30	28	234	235	233	227		26	28	28	24	239	238	228	230
	29	28	28	29	235	227	231	236		26	27	29	27	235	234	230	229
	27	26	32	29	236	231	234	235		25	27	29	28	232	230	233	233
9	35	30	31	28	235	236	243	233	19	25	29	28	30	235	237	235	233
	35	29	27	33	233	232	238	236		24	25	28	28	227	231	231	233
	32	32	25	31	233	232	234	243		26	29	26	26	234	233	232	233
	34	34	29	27	235	243	231	236		28	28	27	26	232	234	237	233
	33	30	25	27	241	241	230	231		23	25	27	26	230	235	234	238
	31	29	28	23	234	236	237	229		30	25	28	25	236	236	237	240
10	30	27	29	26	233	230	238	233	20	27	27	28	26	238	234	230	238
	30	24	31	28	236	235	233	236		25	27	27	26	230	236	228	237
	27	27	31	31	235	235	232	235		28	24	30	29	236	236	241	223
	30	30	33	30	232	234	235	234		30	26	30	27	238	230	237	238
	26	31	32	33	240	230	232	232		28	26	29	31	233	224	232	237
	27	33	30	31	239	234	237	233		29	27	28	29	234	236	231	236

APPENDIX I—*continued*.—ULTRA-QUICK RUN, FOUR-POINT RECORD

February 11, 1928. Duration 10 min. Commencing 11h. 16m. G.M.T.
Approx. mean speed 34 mi./hr. Approx. mean direction 249°
Ref. no. 391

Half min.	Five-second means.								Half min.	Five-second means.							
	Speed mi./hr.				Direction.					Speed mi./hr.				Direction.			
	A	B	C	D	A	B	C	D		A	B	C	D	A	B	C	D
1	33	41	42	34	246°	249°	259°	243°	11	30	34	40	42	254°	256°	254°	254°
	29	41	34	36	253	250	252	254		33	40	36	42	244	250	252	252
	29	33	30	39	253	251	249	257		33	44	33	40	248	244	251	251
	31	36	31	34	244	254	250	254		32	44	34	38	249	252	253	251
	34	39	33	34	248	254	251	253		33	36	39	36	252	250	249	250
	33	40	30	30	249	256	257	253		34	36	34	40	250	252	248	256
2	31	38	31	34	253	254	257	261	12	29	35	37	36	248	242	254	248
	27	36	35	33	247	254	250	265		31	36	30	34	251	252	253	256
	32	32	35	31	246	267	246	253		29	32	30	35	240	250	256	254
	27	32	32	34	252	265	242	246		34	34	28	36	246	256	253	254
	26	31	32	28	252	262	256	247		38	37	26	38	247	260	255	253
	27	30	30	30	248	247	253	249		37	35	28	36	248	250	249	261
3	29	41	34	32	247	255	247	252	13	37	39	32	34	248	254	251	254
	33	33	31	30	255	247	247	247		36	42	30	33	252	253	254	254
	35	38	38	32	256	253	253	252		36	37	32	30	243	252	252	251
	41	42	40	31	252	255	251	250		40	38	29	34	241	252	253	249
	42	36	39	38	246	247	253	250		39	35	28	33	245	248	249	249
	43	40	36	38	247	240	254	250		33	33	28	34	246	251	248	248
4	39	36	32	36	251	251	245	252	14	30	34	32	34	251	250	247	251
	43	42	34	34	247	257	248	248		30	30	36	32	256	246	248	247
	41	38	36	30	252	249	256	247		35	32	40	34	253	246	245	247
	39	36	30	34	248	247	237	251		32	38	44	40	254	242	240	240
	37	32	32	36	248	250	253	251		33	44	40	42	.58	239	245	238
	35	29	28	30	250	251	253	243		33	42	40	40	259	236	246	244
5	39	32	34	30	252	247	247	255	15	33	38	36	36	258	242	244	245
	39	30	31	32	254	248	259	250		37	34	37	36	253	240	249	246
	39	39	31	35	254	252	247	251		37	36	40	38	252	244	249	243
	41	39	30	36	251	245	250	250		39	34	36	38	253	245	250	249
	43	37	30	36	249	250	244	254		36	38	36	40	255	242	246	248
	39	38	34	38	253	252	249	255		30	31	34	39	249	249	241	243
6	37	39	36	34	253	254	245	253	16	31	34	32	34	252	246	247	246
	38	40	36	29	248	252	246	247		35	34	30	36	251	244	248	251
	37	32	34	27	253	251	247	246		31	36	34	34	245	243	244	247
	43	30	36	36	250	246	251	246		31	36	34	34	241	245	243	248
	43	28	32	34	251	247	244	244		25	34	34	31	243	249	246	246
	39	28	36	40	254	245	248	247		29	30	35	30	242	248	251	249
7	45	27	34	34	250	251	247	246	17	30	27	32	35	238	254	248	245
	37	28	34	33	248	248	251	247		34	29	31	30	241	244	248	248
	41	30	34	31	249	247	252	249		37	30	29	30	244	250	242	246
	40	32	36	31	249	257	251	251		31	27	34	34	247	251	241	246
	37	28	38	30	247	260	249	252		28	32	31	33	251	246	246	252
	39	28	41	32	247	250	249	246		34	30	30	28	252	251	256	250
8	36	30	41	38	249	246	254	248	18	34	27	34	32	247	250	251	253
	35	30	39	40	250	254	252	251		33	30	30	28	252	251	248	248
	34	30	38	40	249	248	253	248		31	34	30	34	246	249	253	256
	33	34	33	36	254	246	253	248		29	35	30	32	249	247	252	261
	32	38	33	41	252	249	249	250		29	34	26	30	244	252	241	247
	30	36	36	40	253	248	252	250		35	37	31	32	252	251	242	240
9	25	36	34	35	242	245	253	249	19	35	33	33	30	251	240	243	241
	30	36	32	36	247	246	247	252		34	30	31	31	252	243	250	241
	31	34	31	34	249	252	241	252		33	29	30	36	246	244	241	246
	31	36	28	30	250	257	254	253		39	32	33	38	242	243	246	246
	40	38	32	31	251	251	240	249		43	35	32	32	242	245	249	248
	33	34	34	32	248	248	245	250		37	30	31	33	241	249	253	246
10	33	37	35	28	249	245	252	244	20	33	32	38	36	248	241	250	251
	35	36	40	30	252	247	246	245		33	31	38	36	250	251	257	251
	37	31	42	38	248	245	251	248		30	40	37	40	249	247	251	250
	39	34	42	35	252	244	254	246		31	36	35	37	254	248	253	250
	34	38	37	38	255	240	256	254		23	34	34	36	251	249	247	253
	29	29	42	38	262	244	257	263		33	36	31	33	249	256	249	247

APPENDIX I—*continued.*—ULTRA-QUICK RUN, FOUR-POINT RECORD

February 17, 1928. Duration 9 min. Commencing 12h. G.M.T.
Approx. mean speed 27 mi./hr. Approx. mean direction 275°
Ref. no. 393

Half min.	Five-second means.								Half min.	Five-second means.							
	Speed mi./hr.				Direction.					Speed mi./hr.				Direction.			
	A	B	C	D	A	B	C	D		A	B	C	D	A	B	C	D
1	26	19	33	25	262°	272°	—	263°	11	24	19	29	21	270°	273°	276°	279°
	35	19	29	24	270	268	—	255		25	22	34	22	271	277	272	272
	35	19	31	23	282	275	—	268		25	22	31	23	269	280	270	281
	29	19	32	25	274	275	—	270		25	23	34	23	283	287	272	283
	34	20	30	21	274	281	—	280		21	20	29	23	273	287	272	283
	35	21	29	23	274	279	—	278		23	24	25	23	272	291	273	283
2	34	22	31	24	276	277	—	270	12	24	34	26	28	268	287	269	285
	32	23	37	28	271	276	—	265		27	37	23	24	271	28[illegible]	270	284
	26	22	41	36	277	267	—	266		29	34	20	38	274	288	284	293
	29	18	36	32	278	271	—	270		31	27	20	29	276	277	285	281
	29	21	31	32	281	277	—	275		28	35	23	29	278	276	285	280
	32	21	31	31	282	281	—	274		29	34	23	30	274	276	285	282
3	31	24	33	28	281	274	286°	268	13	23	3[illegible]	22	27	275	275	290	282
	30	24	34	27	274	287	269	266		21	31	19	31	288	276	288	276
	32	20	28	29	278	285	273	267		25	30	19	32	292	272	286	279
	32	17	33	37	283	268	275	268		25	32	18	31	288	272	287	285
	29	18	31	30	276	281	272	273		25	33	18	31	292	272	289	287
	27	24	33	26	276	281	276	280		28	30	17	29	283	271	286	278
4	31	36	30	28	275	282	282	280	14	24	29	18	27	283	276	280	280
	39	36	31	32	274	278	285	278		26	29	19	28	279	272	278	281
	37	35	28	41	279	272	283	276		27	30	18	29	276	274	280	286
	25	31	32	38	287	270	279	273		24	30	19	29	274	273	275	283
	38	37	34	35	293	272	279	275		21	28	20	28	267	282	275	288
	35	35	32	30	287	275	274	275		21	22	21	28	267	287	275	280
5	31	35	29	30	272	277	272	277	15	25	26	21	26	268	282	275	281
	27	36	30	28	272	282	271	279		19	24	23	27	273	280	268	282
	27	31	29	26	276	287	273	270		24	23	20	27	264	281	273	275
	25	33	29	25	277	284	274	272		27	22	22	28	263	277	272	277
	31	35	29	31	273	278	275	272		27	23	28	27	269	274	272	272
	35	33	26	33	277	279	275	268		24	25	24	25	267	274	27	278
6	33	31	27	32	279	279	272	272	16	23	28	28	24	266	274	274	275
	35	25	27	31	280	269	270	270		22	32	32	21	278	277	266	275
	32	28	26	29	276	269	270	272		23	27	30	19	268	277	270	269
	31	24	26	26	272	268	271	269		25	25	32	21	269	277	270	274
	32	23	26	26	277	271	272	269		24	26	30	20	266	272	282	275
	32	23	26	29	275	272	269	265		23	28	29	19	263	271	287	275
7	31	26	26	30	274	272	270	270	17	24	30	28	24	264	272	285	282
	32	27	30	27	272	273	264	270		21	30	27	29	266	268	285	277
	30	28	33	29	269	272	268	272		23	28	23	27	270	271	267	273
	31	25	33	30	269	273	272	273		21	29	29	23	271	271	261	269
	30	26	29	2[illegible]	272	275	277	275		22	23	25	23	266	276	265	262
	29	26	26	29	275	282	275	277		20	24	33	19	264	272	266	264
8	30	24	25	28	281	282	283	275	18	22	26	32	23	273	269	266	260
	27	30	24	27	277	277	282	280		24	27	22	26	273	269	267	260
	28	27	22	31	277	267	280	288		24	26	25	27	269	262	265	267
	25	30	22	30	276	273	273	286		30	24	27	24	274	262	265	260
	25	36	20	27	279	278	275	284		28	24	28	22	277	266	268	268
	26	33	24	31	278	281	277	281		26	22	26	25	274	271	266	267
9	22	29	28	33	279	290	274	279	19	23	27	—	31	272	283	272	282
	21	25	32	31	284	287	272	277		27	31	—	29	268	260	276	277
	23	23	31	31	276	282	268	277		20	32	—	36	271	265	284	277
	21	29	27	29	282	277	273	278		29	36	—	37	274	270	285	279
	24	29	29	28	277	277	282	280		31	33	—	32	274	273	285	284
	32	31	30	27	277	270	282	279		26	32	—	35	276	272	280	276
10	32	27	26	24	284	273	280	276	20	27	—	—	36	281	—	—	272
	28	26	26	22	281	277	268	276		26	—	—	27	287	—	—	272
	26	26	23	23	275	272	272	278		24	—	—	31	280	—	—	275
	26	23	23	23	275	272	268	280		31	—	—	33	279	—	—	278
	24	23	23	24	268	272	270	273		27	—	—	31	275	—	—	278
	19	24	31	22	269	254	268	279		25	—	—	28	276	—	—	280

APPENDIX I—*continued.*—ULTRA-QUICK RUN, FOUR-POINT RECORD

February 21, 1928. Duration 9½ min. Commencing 14h. 34m. G.M.T.
Approx. mean speed 11 mi./hr. Approx. mean direction 180°
Ref. no. 400

Half min.	Five-second means.								Half min.	Five-second means.							
	Speed mi./hr.				Direction.					Speed mi./hr.				Direction.			
	A	B	C	D	A	B	C	D		A	B	C	D	A	B	C	D
1	11	11	9	11	178°	174°	174°	173°	11	10	11	11	10	189°	174°	189°	176°
	11	13	10	10	182	161	172	168		12	10	11	11	196	174	189	175
	11	11	10	11	177	158	175	168		11	9	11	11	194	179	194	183
	11	10	9	11	177	161	176	166		11	11	10	13	196	181	199	178
	10	9	10	12	174	159	174	170		10	10	10	13	196	181	196	185
	10	10	11	13	179	159	167	170		10	11	10	12	197	181	196	194
2	10	9	10	13	174	169	176	168	12	10	9	11	10	192	197	194	196
	11	9	10	12	174	176	174	168		10	12	13	9	194	197	191	192
	13	10	10	13	173	171	174	168		11	11	15	11	195	199	192	192
	13	10	10	12	169	174	169	170		11	9	16	11	204	189	189	193
	12	10	9	12	172	177	164	166		11	8	15	11	204	189	186	188
	12	9	9	11	173	175	156	168		12	8	15	11	196	189	189	199
3	12	10	9	13	174	169	164	163	13	11	11	15	11	196	191	189	203
	12	11	12	13	174	176	166	163		11	13	15	15	199	199	192	202
	12	9	12	12	172	168	163	164		12	13	14	13	194	196	192	198
	12	11	12	13	171	174	164	163		12	12	14	12	199	189	193	196
	11	14	12	12	174	167	166	162		11	13	15	14	197	200	192	191
	11	12	11	12	174	165	164	162		11	12	13	13	197	199	192	198
4	11	12	11	12	174	161	161	163	14	10	13	13	13	190	197	192	195
	11	12	12	12	172	166	161	160		9	12	13	13	194	204	193	196
	11	12	12	13	170	169	161	160		12	12	13	14	197	202	196	195
	11	13	12	13	167	169	161	161		13	12	12	14	194	202	196	195
	10	13	12	13	171	169	162	161		11	13	13	14	194	201	201	198
	10	12	12	12	172	166	166	163		11	13	13	14	193	204	197	198
5	10	12	11	12	172	166	166	163	15	10	13	12	12	194	200	197	201
	10	11	11	12	167	167	163	163		10	12	11	13	194	202	199	201
	11	10	10	11	169	169	170	161		10	13	12	13	192	202	200	194
	11	10	10	11	172	168	169	161		9	13	11	13	193	199	201	193
	10	11	11	11	174	170	166	161		9	13	10	12	188	197	186	192
	10	11	11	11	169	164	166	162		10	13	11	12	190	197	189	189
6	10	11	11	11	174	164	163	165	16	10	12	11	12	189	199	192	193
	10	11	11	11	174	167	167	163		9	12	11	12	192	196	199	199
	10	11	12	10	176	168	166	164		9	12	11	12	192	197	199	196
	11	12	11	10	176	168	165	166		11	12	12	13	194	196	197	192
	11	12	12	10	174	167	165	163		11	12	13	13	194	195	199	194
	11	11	12	11	174	166	165	163		11	11	13	12	195	193	202	196
7	11	12	11	11	172	167	166	164	17	11	11	13	11	196	189	199	193
	11	11	11	11	171	170	167	170		10	11	13	11	194	191	197	188
	11	10	11	11	172	174	166	168		10	10	13	11	196	192	197	190
	11	8	11	11	172	167	172	169		11	10	12	11	185	191	196	193
	11	10	10	11	166	174	171	171		9	11	12	11	186	191	195	198
	11	10	10	11	169	174	171	171		9	10	12	11	189	194	194	200
8	11	11	10	11	173	171	172	171	18	10	9	11	11	194	197	191	198
	11	11	10	11	169	175	171	165		10	10	12	11	186	191	186	206
	11	11	9	10	171	176	172	163		9	10	12	10	182	188	189	203
	11	11	9	8	169	171	174	168		9	9	12	10	184	185	190	200
	11	12	9	9	167	170	173	172		9	11	13	11	189	184	190	198
	11	12	11	9	167	170	164	171		9	11	13	11	183	186	190	188
9	11	12	11	9	169	169	166	168	19	10	12	13	13	184	187	190	190
	11	12	11	9	171	166	175	162		10	12	13	13	182	186	184	191
	11	12	11	9	169	170	175	171		11	11	13	12	184	183	185	196
	11	12	13	9	167	169	173	175		11	11	12	11	184	188	183	196
	11	12	12	9	166	171	172	173		11	11	12	10	179	184	181	189
	11	12	13	9	164	180	172	173		12	11	13	10	178	181	181	187
10	11	12	12	10	174	169	179	174	20	14	—	13	10	170	—	179	191
	11	11	11	10	176	167	184	172		13	—	12	11	174	—	176	185
	10	11	11	10	182	166	186	176		13	—	12	11	179	—	174	191
	9	11	12	9	191	171	182	176		14	—	12	11	178	—	176	187
	9	11	11	9	190	176	184	180		13	—	11	13	171	—	179	187
	9	10	12	9	187	182	182	179		13	—	11	14	174	—	174	183

APPENDIX I—*continued.*—ULTRA-QUICK RUN, FOUR-POINT RECORD

February 21, 1928. Duration 9½ min. Commencing 14h. 54m. G.M.T.
Approx. mean speed 11 mi./hr. Approx. mean direction 175°
Ref. no. 401

Half min.	Five-second means.								Half min.	Five-second means.							
	Speed mi./hr.				Direction.					Speed mi./hr.				Direction.			
	A	B	C	D	A	B	C	D		A	B	C	D	A	B	C	D
1	11	12	10	9	172°	176°	167°	172°	11	11	11	10	14	172°	176°	171°	175°
	10	12	10	9	167	172	167	180		10	10	10	14	174	178	168	177
	11	11	10	9	172	173	179	178		11	10	11	13	177	181	172	178
	11	11	10	9	170	180	183	178		11	12	12	12	176	179	170	178
	11	10	10	9	177	183	183	178		10	11	13	12	175	177	169	176
	11	9	10	9	179	175	180	175		8	11	13	12	175	181	169	174
2	10	8	11	10	181	175	180	177	12	8	12	13	12	183	180	167	175
	11	9	11	11	173	172	180	175		8	12	13	12	172	180	165	178
	13	8	11	10	168	176	181	176		8	11	12	13	175	179	163	178
	13	8	12	11	170	175	177	174		9	10	13	12	173	176	161	172
	13	7	11	11	173	179	177	174		9	10	12	12	176	174	164	177
	13	8	10	10	174	174	170	171		10	9	12	12	172	169	172	174
3	13	8	10	11	169	174	170	172	13	11	9	13	12	178	173	180	170
	13	7	11	12	170	171	177	168		11	9	14	12	178	180	183	174
	10	9	11	10	168	167	173	175		11	10	14	11	177	179	182	175
	11	9	12	12	180	168	177	175		11	10	14	11	177	177	179	174
	10	8	12	11	178	174	178	175		12	11	14	11	177	180	177	174
	12	12	12	10	172	169	181	176		12	11	13	11	178	178	175	180
4	12	12	11	10	177	173	175	168	14	12	11	13	11	176	178	173	177
	12	12	11	10	174	174	167	170		12	11	12	10	173	174	170	177
	12	13	10	10	173	168	173	168		12	11	11	10	176	173	174	177
	13	12	13	11	172	169	172	174		12	12	12	10	174	175	171	174
	12	10	13	11	168	181	169	177		12	10	11	11	177	174	172	174
	11	9	13	11	173	173	169	174		13	12	12	12	177	174	174	176
5	13	9	12	12	173	175	167	177	15	14	12	12	11	174	175	178	175
	13	10	12	12	171	181	170	178		13	13	13	12	177	176	177	172
	13	10	12	12	170	170	171	176		13	12	13	12	177	180	177	172
	14	10	12	11	169	177	174	172		13	12	13	12	172	177	179	171
	14	10	12	11	173	171	173	173		12	12	13	12	172	173	181	170
	13	11	12	12	173	176	171	174		13	12	12	12	178	174	179	168
6	13	11	12	12	176	171	170	174	16	13	11	11	12	178	177	179	170
	13	11	13	10	170	173	169	170		12	10	10	12	176	175	179	177
	13	13	11	10	176	172	166	173		13	10	11	12	173	174	178	176
	12	12	11	9	180	170	165	172		11	12	11	12	176	177	179	174
	11	13	11	9	178	171	161	171		11	12	11	11	174	173	182	172
	11	14	10	9	172	170	173	170		12	12	12	11	175	177	182	174
7	11	13	10	10	173	170	167	169	17	12	12	12	12	173	177	182	174
	11	13	10	10	171	171	168	170		12	12	11	12	178	174	180	178
	11	13	10	12	172	174	167	175		10	13	11	12	180	176	178	175
	11	13	10	12	172	172	167	172		12	12	11	10	183	173	178	174
	12	12	10	11	172	176	172	172		13	12	14	10	179	172	179	174
	12	12	9	11	174	175	179	173		13	11	14	9	179	174	177	170
8	12	12	9	11	177	175	172	175	18	12	12	12	11	178	175	174	173
	11	11	8	11	180	173	176	175		12	12	11	12	180	172	171	173
	11	11	8	12	176	168	181	175		11	11	11	12	180	173	170	179
	11	11	8	13	173	170	180	174		11	12	11	12	173	177	169	178
	11	11	8	12	174	174	175	172		10	13	11	12	176	179	170	179
	10	12	9	12	175	176	180	173		10	12	11	12	174	181	171	178
9	10	12	8	12	174	174	177	174	19	9	12	10	12	173	184	172	180
	10	12	7	12	173	174	175	177		9	11	9	12	175	178	180	180
	11	12	7	12	173	175	177	174		9	10	9	13	177	180	175	182
	13	12	8	11	172	173	176	174		9	11	10	13	178	181	179	188
	12	12	9	10	172	174	172	176		8	10	13	13	182	180	182	185
	11	11	9	10	171	177	182	179		8	10	13	14	181	179	183	178
10	10	10	9	10	177	174	176	172	20	11	—	13	14	184	—	184	182
	11	10	11	11	178	175	174	173		12	—	12	13	183	—	182	179
	11	10	13	11	180	175	177	180		12	—	12	13	183	—	180	177
	11	11	13	11	181	176	172	171		11	—	12	12	185	—	178	179
	11	11	12	13	178	174	172	178		12	—	12	11	182	—	178	177
	11	11	10	13	168	172	170	178		12	—	12	11	176	—	185	184

APPENDIX 1—*continued*—ULTRA-QUICK RUN, FOUR-POINT RECORD

February 24, 1928. Duration 9½ min. Commencing 11h. 23m. G.M.T.
Approx. mean speed 10 mi./hr. Approx. mean direction 74°
Ref. no. 402

Half min.	Five-second means.								Half min.	Five-second means.							
	Speed mi./hr.				Direction.					Speed mi./hr.				Direction.			
	A	B	C	D	A	B	C	D		A	B	C	D	A	B	C	D
1	10	12	7	7	67°	77°	76°	76°	11	9	8	9	10	79°	74°	71°	75°
	9	11	7	7	72	75	76	72		9	9	9	11	78	75	68	77
	9	12	8	8	73	72	76	73		8	8	9	11	76	77	74	79
	9	11	9	9	73	69	78	73		8	9	10	11	76	66	76	77
	9	11	9	11	73	67	81	71		8	9	10	11	77	66	77	73
	8	12	9	11	73	70	77	71		9	9	10	10	79	75	75	74
2	8	12	10	11	73	70	71	71	12	10	10	11	10	79	72	74	76
	9	12	9	11	72	70	72	72		10	10	11	11	79	72	74	77
	9	12	9	10	70	71	73	76		10	10	11	11	79	71	75	76
	9	12	9	9	68	71	69	68		10	10	11	10	76	70	75	72
	9	12	9	10	62	71	66	65		10	9	11	10	69	69	75	66
	9	12	8	11	63	71	77	67		10	10	11	9	70	72	74	72
3	8	12	8	11	63	71	69	68	13	9	10	11	10	80	72	73	71
	8	11	8	11	66	70	69	69		9	10	11	10	79	74	75	72
	8	11	10	10	69	70	72	68		9	10	11	10	75	68	74	78
	8	10	11	10	73	68	71	68		10	9	11	9	72	74	75	72
	9	10	11	11	76	69	71	69		10	10	11	10	74	84	75	66
	9	11	11	10	79	69	68	69		10	10	11	9	71	77	76	76
4	9	11	11	10	77	73	69	70	14	10	11	12	9	72	76	74	60
	9	10	11	10	70	72	67	70		11	11	11	10	73	72	76	72
	9	10	11	10	70	71	66	75		11	11	10	10	75	74	76	70
	9	9	11	9	70	77	64	73		11	11	10	10	76	70	69	69
	9	9	10	9	71	69	72	75		11	11	10	11	76	70	72	68
	9	10	10	8	71	78	74	69		11	11	10	10	76	72	70	66
5	9	10	10	8	71	76	75	72	15	10	11	10	10	77	77	72	64
	9	11	10	10	72	74	77	75		10	12	10	9	72	71	71	69
	9	11	9	10	72	70	82	70		10	12	10	8	70	72	69	71
	9	11	10	9	72	70	76	75		9	12	10	8	70	74	69	72
	9	11	10	9	72	73	74	71		10	13	10	8	71	74	73	73
	9	11	10	10	71	72	72	73		11	12	10	10	71	75	74	74
6	9	10	10	9	71	72	72	72	16	11	12	9	11	71	73	71	74
	8	10	10	10	72	74	72	68		11	11	9	12	71	74	75	75
	9	10	10	9	76	73	73	71		12	11	10	11	72	75	82	68
	9	11	10	9	75	72	73	72		12	11	10	11	74	76	79	68
	9	11	10	9	69	72	73	71		12	11	9	11	75	76	75	69
	9	10	10	9	67	70	72	72		12	11	9	11	77	76	68	70
7	9	10	10	9	70	69	73	70	17	11	11	9	11	77	77	68	70
	10	10	10	9	70	70	74	72		11	11	11	11	77	77	75	71
	10	10	10	8	69	72	75	74		11	11	11	11	75	77	74	71
	10	10	10	9	75	73	75	75		11	11	11	11	74	77	73	71
	10	10	9	10	81	72	70	73		10	11	10	11	74	78	71	71
	10	11	9	10	80	72	72	67		10	12	11	11	74	80	71	72
8	10	11	9	11	80	72	76	72	18	10	11	11	10	73	80	72	71
	10	11	10	11	80	75	75	72		10	12	11	10	73	81	73	73
	10	11	10	10	75	74	73	70		11	12	11	10	73	81	74	74
	10	11	10	9	72	72	73	68		11	11	11	10	72	79	73	74
	9	11	10	8	72	74	71	65		10	11	11	11	72	79	74	74
	9	11	10	9	74	73	70	63		9	11	11	11	71	79	74	74
9	9	11	10	9	76	74	69	65	19	9	11	11	11	77	78	74	76
	8	11	10	9	76	76	67	69		10	11	11	10	76	78	75	74
	9	11	10	8	75	77	67	72		10	10	11	10	75	80	76	77
	10	11	10	8	79	78	72	70		10	10	11	10	75	83	77	75
	10	11	10	8	85	78	71	67		10	10	11	9	75	79	76	73
	10	10	10	8	82	74	74	71		10	10	11	10	75	75	76	77
10	10	9	10	8	80	79	79	75	20	10	—	11	10	75	—	76	72
	10	9	10	8	80	72	81	76		10	—	11	10	75	—	76	74
	10	9	10	8	78	76	82	78		10	—	11	10	74	—	75	73
	10	9	11	9	75	81	81	88		10	—	11	10	76	—	76	78
	10	8	11	10	78	79	78	80		10	—	11	10	77	—	76	72
	10	8	9	10	79	77	77	74		10	—	11	10	77	—	70	71

APPENDIX I—*continued.*—ULTRA-QUICK RUN, FOUR-POINT RECORD

March 21, 1928. Duration 9 min. Commencing 10h. 22m. G.M.T.
Approx. mean speed 23 mi./hr. Approx. mean direction 110°
Ref. no. 427

Half min.	Five-second means.								Half min.	Five-second means.							
	Speed mi./hr.				Direction.					Speed mi./hr.				Direction.			
	A	B	C	D	A	B	C	D		A	B	C	D	A	B	C	D
1	22	26	24	24	109°	107°	117°	105°	11	26	24	27	25	112°	109°	111°	107°
	20	24	22	24	101	111	106	104		27	25	21	24	100	109	115	117
	19	26	20	24	101	109	110	108		31	26	18	23	111	111	110	113
	19	25	19	28	112	113	103	108		29	25	23	22	114	106	103	111
	22	24	18	26	112	107	101	110		28	25	20	22	108	106	103	115
	19	24	26	26	104	112	104	113		29	23	28	18	108	106	110	109
2	22	24	25	25	106	110	102	116	12	27	24	29	21	114	117	109	117
	21	27	21	23	106	105	104	115		28	23	25	24	107	117	111	112
	26	26	20	21	104	107	117	115		27	26	28	26	110	121	111	110
	24	22	26	19	104	118	107	116		30	28	24	29	110	120	103	109
	27	23	28	22	108	110	108	113		26	26	24	25	106	115	106	113
	26	22	28	23	112	112	109	105		23	27	24	26	108	118	110	113
3	20	20	26	22	104	108	110	112	13	26	24	26	25	109	112	113	111
	22	22	27	21	114	105	108	118		25	23	26	29	102	114	111	112
	20	20	28	22	106	116	107	118		22	26	29	28	113	119	108	117
	21	23	24	25	123	113	109	117		23	24	27	25	109	114	105	107
	19	21	23	25	109	114	112	110		25	21	24	24	112	114	112	113
	20	22	23	23	113	107	108	114		22	21	28	22	115	119	104	113
4	25	22	24	24	114	102	106	107	14	22	19	28	20	112	118	110	113
	24	25	21	22	113	101	108	102		21	22	23	25	111	119	111	117
	22	22	21	22	114	92	121	98		21	24	25	24	103	119	110	109
	21	22	19	20	110	89	108	99		23	26	22	23	111	116	117	116
	18	24	18	19	107	89	115	98		26	24	28	24	106	116	111	113
	23	27	24	21	119	92	113	103		26	24	24	24	114	115	109	113
5	23	25	23	16	110	98	110	105	15	25	26	18	26	111	119	112	117
	19	23	20	18	103	99	104	104		25	24	27	27	109	119	108	115
	19	23	18	22	101	97	108	98		21	24	26	26	116	116	108	117
	18	21	17	22	109	99	101	101		18	22	26	26	117	113	111	115
	22	20	17	24	110	104	108	109		18	21	25	25	110	119	111	117
	20	19	14	21	106	104	106	111		20	19	24	21	107	117	107	110
6	22	19	18	20	114	99	98	102	16	22	20	21	19	111	109	109	111
	22	24	22	21	107	93	106	100		19	25	19	19	116	109	116	109
	25	24	19	21	106	88	105	97		22	26	23	22	107	110	110	110
	24	24	18	24	102	92	117	92		23	23	23	26	109	117	106	113
	25	26	19	21	102	91	106	104		20	23	22	24	112	113	107	115
	24	24	17	21	103	96	103	109		18	23	16	23	113	114	113	114
7	23	23	19	22	101	98	106	108	17	18	21	21	21	112	122	108	121
	21	19	21	23	96	113	103	112		18	19	23	24	113	120	110	120
	23	18	25	21	102	103	104	105		18	21	18	24	124	120	117	121
	20	17	22	16	117	103	105	101		22	21	19	25	115	120	119	122
	19	16	22	19	110	104	102	102		25	21	19	25	122	118	119	114
	21	18	23	18	102	109	101	101		26	22	18	23	119	125	123	116
8	23	23	23	21	109	107	105	106	18	22	22	23	23	124	116	125	126
	28	22	24	21	107	101	111	104		26	24	27	22	123	122	118	122
	29	20	23	17	106	109	109	105		26	21	20	19	117	122	116	122
	23	20	24	20	105	111	106	99		24	21	23	20	116	123	121	123
	24	22	26	22	104	110	109	102		21	25	24	21	121	121	125	116
	22	21	28	26	111	112	111	104		21	22	20	18	121	124	119	117
9	25	20	28	24	97	110	105	106	19	21	—	25	17	122	123	118	119
	23	20	26	19	104	116	101	117		23	—	24	23	112	121	115	111
	24	20	26	21	121	113	110	107		24	—	22	25	112	122	112	116
	24	19	22	20	112	102	114	114		24	—	18	25	111	117	119	119
	20	18	19	20	109	101	108	112		23	—	20	25	112	118	125	124
	21	21	24	19	118	109	102	114		21	—	22	29	118	120	113	127
10	22	24	24	20	113	112	117	111	20	23	—	23	23	118	—	110	121
	24	22	23	26	107	109	115	111		22	—	22	25	112	—	110	119
	26	24	22	27	110	105	108	107		22	—	26	27	113	—	112	119
	23	24	22	28	116	112	106	105		17	—	24	25	97	—	112	111
	25	25	20	28	106	105	116	104		21	—	22	24	101	—	109	98
	27	26	24	25	106	111	114	109		22	—	19	24	108	—	117	99

APPENDIX II—TABULATIONS OF 5-SECOND MEAN VALUES OF WIND SPEED AND DIRECTION DURING CERTAIN PERIODS OF TEN MINUTES WHEN SINGLE-POINT (AND ONE TWO-POINT) RUNS WERE IN OPERATION

TABLE SHOWING WEATHER, CLOUD AND GEOSTROPHIC WIND DURING THE MAKING OF THE SINGLE-POINT RUNS TABULATED.

Ref. No.	Date.	Hour of start G.M.T.	Approx. mean Speed.	Approx. mean direction.	Weather.	Cloud.	Geostrophic wind.	
							Speed.	Direction.
	1927.	h. m.	mi./hr.	°			mi./hr.	°
97	Jan. 28	14 51	42	201	cr	Nb. 9	90	235
147	Feb. 25	11 42	12	128	c	St. Cu. 2, Nb. 8	35	160
187	Mar. 15	10 28	11	136	bc	Fr. Cu. 1	30	180
199	Mar. 26	10 0	28	201	c	St. Cu. 5, Ci. 3	60	265
223	April 20	12 17	22	249	bc	Ci. 3	28	290
265	July 5	17 56	16	198	bc	A. St. 6, Cu. Nb. 1	30	240
277	July 21	10 15	11	180	o	Nb. 10	24	180
305	Sept. 21	10 4	24	234	c	St. Cu. 8, A. Cu. 1	60	250
328	Oct. 19	11 5	23	235	c	St. Cu. 6, Cu. 3	30	260
341	Oct. 26	14 51	27	219	c	St. Cu. 9	60	245
	1928.							
368	Jan. 10	14 59	32	216	orr	Nb. 10	85	242
372	Jan. 24	11 34	27	226	c	A. St. 1, A. Cu. 4, Cu. 4	75	250
389	Feb. 1	12 13	31	246	bc	A. St. 1, Cu. Nb. 1, Cu. 1, Fr. Cu. tr.	40	290
392	Feb. 16	9 43	30	222	or$_o$	Nb. 10	70	255
487	July 22	17 0	10	302	c	A. St. 10	10	295
489	Aug. 5	11 30	7	350	b	A. St. 1	16	350
490	Aug. 7	15 30	18	207	c	St. 4, St. Cu. 4	45	240
491	Aug. 13	15 12	24	208	bc	A. St. 3, Cu. 4	65	245
492*	Aug. 20	16 5	24	241	c	A. St. 1, Cu. Nb. 3, St. Cu. 4	35	290
495	Aug. 31	14 37	17	280	bc	Cu. 6	18	330
496	Sept. 4	13 55	16	230	b	—	25	255
497	Sept. 13	15 20	12	82	bc	Cu. 4	18	125
498	Sept. 24	14 0	11	295	c	Ci. 2, A. St. 4, Cu. 3	17	315
499	Oct. 4	14 33	13	123	b	—	20	158
501	Oct. 11	11 21	22	265	bc	Cu. 5	25	280
502	Oct. 11	11 43	23	260	bc	Cu. 5	25	280
	1929.							
547	Oct. 8	22 12	18	311	o	St. 10	33	345
548	Oct. 9	03 39	19	277	b	—	33	330

* Two-point run B and C.

APPENDIX II—*continued*.—ULTRA-QUICK, SINGLE-POINT RUNS

January 28, 1927, from 14h. 51m. G.M.T. to 15h. 1m. G.M.T.
Approx. mean speed 42 mi./hr. Approx. mean direction 201°
Ref. no. 97

Five-second means.

	Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °
1	50	198	6	42	201	11	33	178	16	37	196
	44	201		44	210		33	201		37	200
	40	199		43	196		41	196		36	204
	45	197		48	207		39	196		36	200
	46	204		44	201		39	200		44	197
	39	201		43	203		39	201		42	202
2	41	194	7	45	209	12	42	198	17	45	202
	39	202		48	204		46	193		39	205
	43	197		47	200		47	190		37	207
	37	211		47	200		47	198		31	208
	36	197		45	202		44	200		31	212
	46	199		51	200		40	198		36	206
3	44	205	8	49	204	13	33	205	18	39	204
	42	208		47	203		40	195		43	204
	45	207		45	199		38	205		47	203
	44	210		43	198		43	204		45	199
	47	209		39	198		52	200		44	202
	47	210		39	204		46	190		43	201
4	40	200	9	37	205	14	45	190	19	46	198
	41	208		35	209		47	195		43	197
	46	201		34	206		49	193		42	204
	51	199		31	205		46	200		43	199
	49	199		33	198		51	193		39	200
	51	206		34	201		47	190		37	200
5	47	211	10	39	197	15	45	202	20	40	—
	51	209		37	201		41	207		37	—
	49	209		35	198		39	204		37	—
	49	206		35	201		37	210		39	—
	47	206		39	200		41	206		47	—
	42	199		37	194		40	204		51	—

March 15, 1927, from 10h. 28m. G.M.T. to 10h. 38m. G.M.T.
Approx. mean speed 11 mi./hr. Approx. mean direction 136°
Ref. no. 187

Five-second means.

	Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °
1	12	145	6	10	145	11	12	133	16	11	138
	13	145		10	145		11	130		11	144
	15	144		9	149		11	136		10	133
	15	143		10	141		14	139		11	151
	15	141		10	145		14	144		11	146
	15	140		10	141		12	137		10	143
2	15	142	7	9	136	12	12	136	17	10	142
	15	139		9	135		12	134		11	142
	14	140		9	128		12	136		11	138
	14	143		9	123		11	133		11	138
	14	142		10	128		11	134		11	140
	14	145		10	128		11	131		11	136
3	13	148	8	10	134	13	11	131	18	9	131
	13	143		10	141		10	133		7	131
	12	139		9	119		10	131		8	130
	13	141		9	122		10	140		9	128
	13	135		10	122		9	138		11	130
	13	133		11	128		9	133		11	127
4	13	137	9	11	122	14	9	136	19	11	127
	11	143		11	129		9	134		11	132
	11	141		11	131		11	136		12	136
	13	144		10	121		11	133		12	134
	13	149		10	120		11	132		13	133
	12	145		10	120		12	130		11	140
5	11	149	10	10	123	15	12	131	20	12	140
	11	145		11	125		13	134		13	134
	10	143		9	135		14	140		13	133
	9	144		11	140		13	140		13	132
	9	147		13	134		13	147		13	131
	9	147		14	133		13	146		—	—

February 25, 1927, from 11h. 42m. G.M.T. to 11h. 52m. G.M.T.
Approx. mean speed 12 mi./hr. Approx. mean direction 128°
Ref. no. 147

Five-second means.

	Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °
1	16	122	6	13	116	11	10	128	16	11	120
	13	127		11	126		11	129		9	132
	13	124		14	117		12	120		9	129
	13	126		15	114		10	129		11	133
	13	127		15	119		11	125		11	122
	13	127		15	119		13	128		11	122
2	13	125	7	14	119	12	12	126	17	14	122
	13	128		15	115		12	121		15	118
	12	132		14	117		14	119		13	118
	11	129		13	123		15	123		13	132
	12	136		14	128		12	130		15	140
	12	130		14	129		13	130		15	139
3	12	136	8	12	128	13	12	126	18	14	138
	13	130		12	129		13	122		13	134
	11	121		12	127		13	114		14	127
	11	119		11	132		13	122		14	133
	11	119		11	133		11	139		15	150
	11	115		12	130		9	140		16	150
4	9	115	9	13	132	14	8	127	19	13	149
	11	124		13	134		9	132		12	148
	13	122		13	125		9	122		11	126
	13	120		11	120		10	132		12	135
	13	123		13	120		10	129		11	134
	11	130		15	130		11	129		9	129
5	11	131	10	14	130	15	11	131	20	9	127
	11	136		13	124		11	140		9	127
	11	134		12	132		11	133		10	131
	11	127		12	128		11	133		9	135
	11	123		11	118		12	135		9	125
	11	123		11	123		11	129		11	125

March 26, 1927, from 10h. G.M.T. to 10h. 9m. G.M.T.
Approx. mean speed 28 mi./hr. Approx. mean direction 201°
Ref. no. 199

Five-second means.

	Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °
1	28	210	6	31	212	11	33	217	16	31	210
	29	213		29	206		33	219		27	209
	34	210		30	212		30	221		25	214
	31	214		31	217		30	219		25	215
	30	213		31	215		26	217		27	214
	30	213		27	218		29	226		26	221
2	29	213	7	28	218	12	33	215	17	28	225
	27	212		31	217		33	214		31	221
	27	205		28	211		29	210		31	217
	22	204		29	212		27	217		29	216
	27	207		27	214		29	216		29	219
	28	202		30	224		32	210		27	228
3	33	212	8	29	225	13	27	204	18	—	—
	34	213		29	219		29	207		—	—
	31	214		31	215		29	211		—	—
	29	209		31	215		27	210		—	—
	31	212		34	214		31	213		—	—
	28	214		31	215		31	211		—	—
4	25	214	9	29	208	14	28	214	19	—	—
	24	215		38	218		21	223		—	—
	22	216		35	217		28	224		—	—
	24	219		35	215		31	226		—	—
	27	220		38	213		30	226		—	—
	33	223		39	216		30	224		—	—
5	25	208	10	38	214	15	31	220	20	—	—
	24	207		39	220		25	217		—	—
	24	208		37	216		27	212		—	—
	26	204		36	220		26	222		—	—
	29	209		37	214		27	221		—	—
	30	205		34	217		28	220		—	—

APPENDIX II—*continued*.—ULTRA-QUICK, SINGLE-POINT RUNS.

April 20, 1927, from 12h. 17m. G.M.T. to 12h. 27m. G.M.T.
Approx. mean speed 22 mi./hr. Approx. mean direction 249°
Ref. no. 223

Five-second means.

	Speed mi./hr.	Direction. °		Speed mi./hr.	Direction. °		Speed mi./hr.	Direction. °		Speed mi./hr.	Direction. °
1	23	263	6	25	255	11	23	251	16	23	252
	21	252		27	245		22	241		22	255
	20	250		25	244		21	248		21	254
	19	249		23	250		23	246		19	249
	23	244		20	250		22	238		21	250
	23	245		21	253		21	247		24	248
2	21	255	7	20	254	12	21	245	17	25	246
	24	253		22	243		21	247		25	248
	24	253		22	246		23	245		26	250
	23	254		21	245		24	233		26	260
	22	251		24	244		27	237		23	260
	21	247		23	243		27	238		21	254
3	21	255	8	24	250	13	27	238	18	19	249
	19	250		20	254		25	241		19	246
	22	252		19	258		25	243		18	247
	23	251		17	253		25	247		18	247
	26	251		20	258		25	249		20	248
	27	248		20	260		27	250		19	247
4	24	245	9	19	252	14	26	252	19	19	243
	23	244		17	255		23	247		18	248
	22	248		17	252		22	248		20	243
	23	247		17	251		23	250		23	245
	25	248		19	246		23	252		23	242
	20	243		20	244		24	251		24	243
	23	249	10	19	255	15	23	249	20	23	243
	22	248		20	250		25	253		20	249
	20	248		19	248		25	249		19	249
	23	245		21	249		26	250		21	251
	23	251		23	254		26	248		23	253
	23	253		22	254		25	250		22	256

July 21, 1927, from 10h. 15m. G.M.T. to 10h. 25m. G.M.T.
Approx. mean speed 11 mi./hr. Approx. mean direction 180°
Ref. no. 277

Five-second means.

	Speed mi./hr.	Direction. °		Speed mi./hr.	Direction. °		Speed mi./hr.	Direction. °		Speed mi./hr.	Direction. °
1	11	185	6	9	169	11	14	174	16	11	184
	11	186		9	179		15	179		13	184
	9	179		9	173		15	171		12	181
	9	189		8	181		15	172		12	178
	9	179		8	181		15	174		11	177
	9	183		7	175		15	176		11	178
2	9	181	7	7	186	12	15	177	17	11	188
	9	181		7	177		14	177		10	175
	9	181		7	185		12	177		10	187
	8	182		7	181		14	185		11	188
	9	174		5	179		15	185		10	173
	8	180		5	182		15	190		11	180
3	8	178	8	5	173	13	15	190	18	15	184
	7	171		5	172		15	193		18	165
	7	171		5	186		15	192		16	166
	7	175		5	180		17	195		15	166
	9	176		5	168		16	197		14	180
	9	178		5	180		14	194		12	189
4	8	174	9	6	174	14	13	190	19	13	194
	8	170		7	180		13	184		15	199
	8	165		8	190		13	186		15	192
	9	165		8	182		11	187		14	178
	9	174		9	183		11	185		15	181
	8	187		11	182		13	185		15	183
5	8	172	10	15	179	15	13	187	20	13	182
	9	174		14	179		13	191		14	177
	9	168		14	180		12	189		17	175
	8	177		12	178		11	181		16	80
	8	172		14	170		12	181		16	175
	9	176		15	170		10	198		17	179

July 5, 1927, from 17h. 56m. G.M.T. to 18h. 06m. G.M.T.
Approx. mean speed 16 mi./hr. Approx. mean direction 198°
Ref. no. 265

Five-second means.

	Speed mi./hr.	Direction. °		Speed mi./hr.	Direction. °		Speed mi./hr.	Direction. °		Speed mi./hr.	Direction. °
1	15	198	6	14	191	11	13	196	16	15	189
	17	193		19	191		13	199		15	187
	19	201		16	195		12	206		23	179
	20	198		17	191		11	200		20	190
	19	202		17	194		11	193		13	199
	21	201		18	196		11	195		13	212
2	19	194	7	18	191	12	13	197	17	11	202
	16	191		17	197		13	183		13	205
	17	194		17	197		14	200		13	204
	15	189		18	200		13	190		13	198
	15	185		20	197		15	196		15	194
	16	191		21	197		15	198		19	195
3	17	193	8	19	190	13	15	188	18	19	207
	17	193		17	198		13	196		17	200
	17	194		18	202		20	196		19	199
	1	205		23	196		15	202		15	195
	17	197		22	202		15	207		14	199
	22	205		21	202		15	219		15	196
4	21	205	9	20	209	14	14	195	19	15	204
	20	206		19	211		13	202		19	210
	19	205		18	204		14	194		17	201
	17	205		19	203		13	201		13	202
	17	193		19	202		13	198		15	204
	14	194		17	200		16	198		21	207
5	14	197	10	15	198	15	19	193	20	18	200
	15	196		17	204		19	196		17	200
	14	198		15	190		18	199		19	203
	13	198		13	192		19	200		17	209
	11	198		16	198		20	200		19	210
	15	196		15	194		17	202		17	199

September 21, 1927, from 10h. 4m. G.M.T. to 10h. 14m. G.M.T.
Approx. mean speed 24 mi./hr. Approx. mean direction 234°
Ref. no. 305

Five-second means.

	Speed mi./hr.	Direction. °		Speed mi./hr.	Direction. °		Speed mi./hr.	Direction. °		Speed mi./hr.	Direction. °
1	23	231	6	23	235	11	23	237	16	27	236
	21	234		25	239		20	237		28	240
	22	235		25	235		18	231		27	240
	26	234		25	231		23	238		26	235
	23	230		26	233		21	230		27	236
	21	233		25	232		23	232		26	237
2	21	230	7	22	236	12	28	231	17	26	238
	23	231		19	239		27	228		24	236
	24	231		23	238		31	228		22	239
	25	227		27	241		28	228		29	239
	27	229		23	233		25	235		27	238
	27	230		22	227		27	239		25	236
3	23	225	8	21	228	13	28	235	18	25	231
	23	227		19	228		29	235		22	229
	23	228		19	233		31	232		25	232
	23	230		16	226		28	230		26	238
	23	234		15	234		27	233		26	245
	20	230		17	237		29	234		26	248
4	23	226	9	18	235	14	27	236	19	24	249
	23	222		19	246		24	228		25	245
	22	227		21	244		24	230		23	244
	23	228		22	232		22	230		20	245
	21	232		23	227		23	235		19	245
	24	228		19	224		27	236		21	238
5	22	233	10	23	227	15	29	241	20	21	239
	23	238		21	240		30	239		20	238
	22	237		26	240		31	238		17	232
	24	236		26	237		30	233		17	229
	23	231		23	233		26	229		18	235
	25	231		25	236		27	233		17	225

APPENDIX II—*continued*.—ULTRA-QUICK, SINGLE-POINT RUNS

October 19, 1927, from 11h. 5m. G.M.T. to 11h. 15m. G.M.T.
Approx. mean speed 23 mi./hr. Approx. mean direction 235°
Ref. no. 328

Five-second means.

	Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °
1	26	231	6	25	235	11	23	233	16	23	233
	27	236		27	237		21	230		24	236
	27	240		26	237		21	231		25	234
	27	238		27	234		21	235		24	235
	27	236		25	233		21	234		23	230
	27	230		24	232		21	234		25	234
2	25	227	7	23	234	12	23	234	17	24	235
	23	235		22	236		24	236		25	232
	25	237		23	236		23	237		25	230
	23	239		25	237		22	236		25	235
	25	237		27	236		22	234		25	229
	27	237		26	231		23	235		27	230
3	26	239	8	24	232	13	24	236	18	24	230
	26	241		24	233		26	241		23	229
	25	238		21	229		27	243		25	230
	25	238		21	236		25	243		23	231
	26	241		20	234		25	243		19	231
	24	237		19	230		25	244		19	229
4	23	232	9	19	228	14	22	249	19	21	228
	21	236		17	234		21	243		20	227
	21	234		24	233		20	240		23	229
	24	235		24	235		20	232		25	230
	23	236		26	233		17	236		23	233
	24	235		24	233		17	234		23	238
5	26	231	10	25	236	15	21	239	20	25	237
	25	235		25	238		21	234		23	234
	25	234		21	232		21	233		23	239
	24	239		18	226		18	235		23	238
	22	238		20	232		20	238		23	243
	22	238		21	232		22	237		20	239

January 10, 1928, from 14h. 59m. G.M.T. to 15h. 9m. G.M.T.
Approx. mean speed 32 mi./hr. Approx. mean direction 216°
Ref. no. 368

Five-second means.

	Speed mi./hr.	Direction °		Speed mi. hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °
1	33	214	6	33	214	11	31	213	16	29	220
	33	215		31	208		33	218		30	218
	30	217		35	210		33	219		27	223
	28	209		32	213		29	219		30	219
	27	214		33	207		32	209		32	222
	27	213		30	210		37	214		33	230
2	33	216	7	31	214	12	37	212	17	31	228
	33	218		29	220		35	224		31	224
	31	209		31	214		34	224		30	223
	35	215		35	215		29	218		29	222
	35	213		35	203		31	220		28	223
	38	218		47	211		33	220		30	228
3	33	212	8	43	218	13	30	215	18	32	222
	33	212		41	213		29	224		33	223
	29	214		38	213		27	214		34	221
	29	210		35	215		28	213		39	223
	29	211		35	209		29	215		36	224
	31	219		36	210		29	217		33	219
4	35	217	9	37	211	14	31	213	19	29	215
	31	211		35	209		37	218		33	221
	29	212		36	203		38	216		36	220
	31	210		30	215		35	216		35	224
	33	214		28	220		33	217		33	225
	30	208		30	214		34	217		34	226
5	33	211	10	31	211	15	29	217	20	—	—
	32	213		29	214		29	218		—	—
	31	210		25	212		30	219		—	—
	27	206		28	208		31	217		—	—
	27	212		27	209		25	223		—	—
	37	215		29	205		27	220		—	—

October 26, 1927, from 14h. 51m. G.M.T. to 15h. 1m. G.M.T.
Approx. mean speed 27 mi./hr. Approx. mean direction 219°
Ref. no. 341

Five-second means.

	Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °
1	27	227	6	26	215	11	31	210	16	23	213
	29	222		25	217		31	218		23	209
	30	226		27	214		32	228		21	207
	28	223		30	215		34	223		22	200
	27	222		33	218		33	226		23	205
	23	220		29	218		32	228		25	209
2	21	222	7	28	222	12	30	223	17	30	215
	23	227		29	217		31	222		31	213
	24	225		31	224		27	223		31	210
	21	220		31	222		28	225		26	212
	25	214		27	220		25	222		30	213
	19	213		31	223		27	220		33	218
3	21	222	8	30	225	13	26	222	18	35	220
	22	229		27	227		25	226		31	218
	21	227		27	226		24	225		27	214
	21	224		25	217		27	220		29	219
	22	225		30	214		29	216		26	215
	23	226		30	208		32	218		25	216
4	21	219	9	27	223	14	27	217	19	24	208
	19	218		27	221		30	217		23	212
	19	218		27	222		29	215		21	214
	19	217		29	222		26	220		25	209
	21	220		28	223		29	225		29	223
	21	223		31	223		27	221		33	225
5	23	224	10	31	225	15	30	223	20	—	—
	27	223		25	218		29	221		—	—
	25	223		23	214		26	213		—	—
	25	225		31	211		25	218		—	—
	23	227		33	209		25	217		—	—
	24	223		32	209		25	217		—	—

January 24, 1928, from 11h. 34m. G.M.T. to 11h. 44m. G.M.T.
Approx. mean speed 27 mi./hr. Approx. mean direction 226°
Ref. no. 372

Five-second means.

	Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °
1	—	—	6	25	226	11	27	220	16	26	223
	—	—		27	226		25	220		28	224
	—	—		29	220		25	227		30	220
	—	—		28	224		24	225		31	220
	—	—		27	223		21	223		30	218
	—	—		25	224		29	222		30	218
2	27	229	7	27	225	12	33	227	17	31	221
	29	235		27	227		29	231		28	220
	27	232		29	226		27	230		29	222
	25	231		27	225		27	226		28	223
	26	232		25	225		26	226		27	223
	27	231		25	222		23	224		27	226
3	27	231	8	23	228	13	26	222	18	26	227
	29	229		23	222		26	222		24	228
	28	228		25	222		27	221		24	227
	29	234		23	229		27	224		27	229
	28	234		27	222		25	232		26	228
	31	233		23	230		27	225		29	232
4	30	228	9	24	234	14	29	224	19	26	223
	28	228		24	228		29	223		27	222
	29	230		25	228		29	227		26	225
	27	227		29	231		29	224		27	224
	27	228		25	227		29	226		27	224
	27	229		27	233		29	230		31	224
5	27	226	10	29	229	15	29	220	20	31	220
	29	227		29	230		28	218		31	225
	30	226		27	230		26	223		29	225
	28	229		25	224		25	222		29	220
	27	224		26	226		24	218		27	224
	24	231		28	224		25	220		26	225

APPENDIX II—*continued.*—ULTRA QUICK, SINGLE-POINT RUNS

February 1, 1928, from 12h. 13m. G.M.T. to 12h. 23m. G.M.T.
Approx. mean speed 31 mi./hr. Approx. mean direction 246°.
Ref. no. 389

Five-second means.

	Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °
1	29	250	6	33	250	11	29	246	16	33	245
	26	244		29	251		28	250		33	240
	28	251		31	248		31	238		27	243
	31	250		30	241		27	242		31	242
	35	253		33	248		27	245		34	243
	30	253		32	249		29	241		32	241
2	40	252	7	28	250	12	33	249	17	31	243
	39	249		29	248		33	245		31	243
	37	250		32	245		31	245		28	247
	33	248		29	247		33	248		25	249
	37	249		29	248		31	244		30	248
	37	250		29	246		27	236		30	253
3	37	249	8	27	252	13	25	235	18	33	255
	34	253		26	251		26	238		33	250
	33	250		26	240		23	239		31	245
	36	248		27	245		26	242		25	239
	33	250		26	244		31	241		25	246
	32	250		29	239		34	240		28	244
4	34	246	9	30	242	14	37	242	19	32	250
	30	243		28	244		31	242		33	254
	31	244		27	246		29	240		30	242
	31	242		30	243		31	242		27	245
	33	243		28	249		33	249		31	247
	31	241		32	251		35	247		34	248
5	34	243	10	29	254	15	37	250	20	31	243
	31	237		32	248		37	257		35	241
	29	235		32	246		36	253		32	242
	25	240		35	247		35	248		29	242
	23	241		37	247		36	248		30	240
	25	248		33	242		33	251		30	240

July 22, 1928, from 17h. 0m. G.M.T. to 17h. 10m. G.M.T.
Approx. mean speed 10 mi./hr. Approx. mean direction 302°.
Ref. no. 487

Five-second means.

	Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °
1	11	295	6	10	306	11	7	305	16	9	326
	11	304		10	304		8	302		9	317
	12	305		11	299		9	299		11	323
	12	297		11	302		8	300		11	322
	12	291		12	298		6	307		11	312
	12	296		10	312		9	296		13	312
2	12	302	7	9	309	12	9	295	17	13	307
	11	302		8	310		9	295		12	307
	12	297		8	305		9	309		11	297
	11	299		7	294		9	314		11	299
	12	304		7	289		7	295		10	305
	13	302		6	291		8	297		11	297
3	13	292	8	6	299	13	9	305	18	11	305
	10	292		7	299		8	312		13	307
	11	294		7	302		9	308		12	317
	12	294		8	290		8	299		10	320
	12	296		7	316		8	297		10	318
	12	289		9	306		8	295		10	315
4	12	287	9	9	313	14	8	290	19	13	317
	11	298		9	312		8	297		12	310
	12	293		9	307		7	299		8	305
	12	295		9	305		8	299		9	297
	11	299		9	310		8	305		8	307
	9	292		8	314		8	299		10	309
5	9	299	10	7	305	15	11	299	20	10	306
	9	297		8	309		14	295		8	304
	9	289		9	317		12	289		8	307
	12	292		5	307		13	289		10	313
	12	297		6	297		10	297		10	305
	12	302		8	295		10	309		8	295

February 16, 1928, from 9h. 43m. G.M.T. to 9h. 53m. G.M.T.
Approx. mean speed 30 mi./hr. Approx. mean direction 222°
Ref. no. 392

Five-second means.

	Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °
1	32	225	6	28	220	11	31	225	16	31	220
	32	227		27	222		29	223		31	210
	29	218		25	222		30	220		33	214
	31	214		27	227		33	224		31	217
	33	211		30	227		31	224		32	220
	31	217		27	223		34	227		31	219
2	30	226	7	32	224	12	32	222	17	31	220
	30	225		35	223		32	220		29	222
	31	228		34	223		31	220		31	220
	30	224		33	223		28	223		30	221
	32	219		33	221		29	220		28	225
	31	223		32	222		35	224		24	229
3	29	227	8	33	220	13	33	220	18	21	235
	30	223		34	220		37	223		25	220
	29	220		32	218		37	218		26	226
	33	218		29	217		35	223		29	223
	30	221		28	221		33	217		33	221
	29	223		27	220		30	222		33	224
4	26	233	9	27	219	14	29	215	19	31	222
	27	223		27	222		27	214		29	224
	31	218		27	224		27	216		29	224
	27	212		25	223		28	216		31	225
	34	219		25	220		29	219		30	223
	33	224		21	220		30	219		29	220
5	29	223	10	25	219	15	25	213	20	31	230
	27	224		25	220		27	214		31	227
	29	229		21	225		34	224		29	222
	31	224		23	220		33	221		31	223
	33	226		24	225		30	222		32	227
	32	220		27	223		28	222		27	221

August 5, 1928, from 11h. 30m. G.M.T. to 11h. 39m. G.M.T.
Approx. mean speed 7 mi./hr. Approx. mean direction 350°
Ref. no. 489

Five-second means.

	Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °
1	4	34	6	7	329	11	10	346	16	11	343
	5	8		7	335		10	348		11	344
	5	11		6	334		10	344		9	342
	5	5		6	333		9	346		8	340
	6	351		8	328		7	351		8	336
	6	344		8	332		8	345		8	335
2	6	350	7	7	327	12	11	336	17	8	335
	6	352		6	321		10	3		7	338
	9	5		6	324		8	343		7	332
	10	10		6	333		8	344		7	340
	8	11		5	333		7	345		6	343
	7	10		5	333		8	340		6	343
3	6	9	8	5	328	13	9	349	18	7	—
	6	10		4	328		9	355		6	—
	7	10		4	331		8	4		6	—
	5	6		5	348		7	7		5	—
	5	357		8	349		7	9		5	—
	6	335		9	356		6	9		5	—
4	8	345	9	9	12	14	6	10	19	—	—
	9	347		10	17		7	7		—	—
	9	348		10	3		8	6		—	—
	9	348		9	350		8	10		—	—
	9	350		11	353		6	17		—	—
	8	346		9	357		5	20		—	—
5	7	350	10	10	351	15	6	14	20	—	—
	6	344		10	339		7	3		—	—
	6	345		10	337		7	356		—	—
	6	344		10	343		6	355		—	—
	6	339		10	342		7	350		—	—
	6	344		10	348		8	346		—	—

APPENDIX II—*continued.*—ULTRA-QUICK, SINGLE-POINT RUNS.

August 7, 1928, from 15h. 30m. G.M.T. to 15h. 40m. G.M.T.
Approx. mean speed 18 mi./hr. Approx. mean direction 207°
Ref. no. 490

Five-second means.

	Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction. °
1	21	213	6	20	211	11	16	211	16	17	207
	20	208		20	210		16	208		19	202
	21	204		20	216		20	209		16	204
	20	212		19	213		19	207		14	206
	22	212		18	212		19	207		15	206
	22	208		18	205		15	204		14	210
2	23	211	7	17	202	12	18	209	17	12	212
	19	208		18	202		21	212		14	208
	21	208		17	205		19	212		14	209
	20	210		13	201		19	203		15	214
	22	211		12	200		16	206		17	215
	19	204		12	203		17	213		20	210
3	16	201	8	14	201	13	20	210	18	16	215
	18	207		14	201		18	210		15	206
	18	200		14	208		17	208		21	200
	21	203		19	208		18	201		19	204
	22	202		19	209		19	197		14	212
	21	202		19	207		18	206		13	204
4	18	213	9	20	205	14	16	203	19	14	—
	18	210		22	204		18	205		16	—
	19	210		22	204		16	214		20	—
	19	211		21	207		19	208		18	—
	21	210		20	211		21	203		14	—
	20	210		19	212		20	194		19	—
5	19	210	10	21	206	15	16	196	20	—	—
	19	211		22	202		14	201		—	—
	20	215		20	207		15	199		—	—
	20	212		16	207		15	210		—	—
	20	213		17	210		15	206		—	—
	19	212		15	211		20	201		—	—

August 13, 1928, from 15h. 12m. G.M.T. to 15h. 22m. G.M.T.
Approx. mean speed 24 mi./hr. Approx. mean direction 208°
Ref. no. 491

Five-second means.

	Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °
1	25	214	6	18	209	11	23	200	16	24	200
	25	204		21	213		25	190		23	206
	21	206		20	199		26	199		24	210
	24	212		21	206		30	198		24	212
	27	206		20	211		27	198		24	208
	29	209		20	201		28	197		27	213
2	25	216	7	20	202	12	28	200	17	27	216
	24	210		27	195		29	191		25	214
	20	218		28	202		23	199		26	221
	19	220		27	196		29	199		23	221
	18	211		23	203		24	189		24	226
	18	203		21	205		28	195		23	217
3	19	206	8	21	199	13	32	195	18	25	222
	21	213		21	205		30	200		24	222
	24	208		23	205		27	201		31	225
	27	212		22	212		24	201		33	227
	23	208		20	211		24	204		33	225
	22	208		19	204		25	197		32	225
4	20	211	9	22	210	14	26	197	19	30	222
	21	205		23	208		23	202		29	219
	24	210		24	209		24	206		27	217
	22	209		25	212		28	199		27	224
	22	213		26	210		26	199		28	225
	21	215		27	210		26	197		26	220
5	24	220	10	27	212	15	25	194	20	25	217
	25	222		23	203		25	195		25	215
	21	222		22	201		25	199		22	214
	21	216		21	201		23	206		25	214
	21	220		22	201		24	216		24	209
	20	218		21	200		23	198		23	208

ULTRA-QUICK RUN, TWO-POINT RECORD

August 20, 1928, from 16h. 5m. G.M.T. to 16h. 14m. G.M.T.
Approx. mean speed 24 mi./hr. Approx. mean direction 241°
Ref. no. 492

	Five-second means.					Five-second means.					Five-second means.					Five-second means.			
	Speed mi./hr.		Direction			Speed mi./hr.		Direction			Speed mi./hr.		Direction			Speed mi./hr.		Direction	
	B	C	B	C		B	C	B	C		B	C	B	C		B	C	B	C
1	28	28	240°	239°	6	25	25	235°	235°	11	20	27	240°	245°	16	25	28	231°	238°
	29	27	242	239		21	27	240	237		22	26	237	247		23	28	242	236
	30	27	242	238		22	23	238	239		23	25	236	246		23	26	237	240
	27	32	244	243		24	21	236	242		23	28	247	246		20	26	249	240
	27	31	243	245		23	21	236	240		29	28	244	245		21	24	246	241
	26	28	242	238		25	21	239	240		28	29	244	243		19	22	240	245
2	28	29	237	237	7	25	29	241	242	12	29	28	240	242	17	17	23	—	247
	30	25	242	232		25	27	246	240		27	27	240	246		19	21	—	249
	29	25	241	242		23	27	240	242		26	27	242	245		19	21	—	251
	28	26	238	243		20	27	232	236		19	27	242	246		16	20	—	245
	23	29	239	245		21	28	244	242		19	25	248	243		19	18	—	242
	23	30	239	249		23	28	240	244		21	25	241	245		22	25	—	242
3	25	27	243	247	8	26	25	239	242	13	21	25	240	237	18	20	25	—	242
	26	27	239	236		27	24	239	241		23	25	245	243		19	22	—	247
	25	24	249	230		26	23	240	242		21	24	247	242		21	21	—	247
	24	29	242	229		24	22	242	249		21	22	245	238		24	25	—	243
	20	29	231	238		26	22	244	237		20	24	236	242		23	26	—	251
	27	24	233	242		24	25	245	242		23	23	242	245		23	23	—	250
4	27	29	235	239	9	24	26	245	243	14	20	25	247	246	19	—	—	—	—
	21	27	238	232		25	26	240	245		25	24	244	245		—	—	—	—
	21	27	239	237		25	21	249	242		26	23	245	245		—	—	—	—
	21	23	239	225		22	26	243	237		26	25	245	247		—	—	—	—
	24	26	236	232		23	27	242	241		25	20	244	249		—	—	—	—
	26	25	236	235		24	28	247	241		23	21	245	245		—	—	—	—
5	24	23	233	231	10	27	24	238	244	15	22	19	243	232	20	—	—	—	—
	23	27	237	233		22	24	235	237		19	25	239	232		—	—	—	—
	21	30	234	231		23	22	239	232		22	26	244	235		—	—	—	—
	21	26	234	237		20	25	236	242		21	27	241	235		—	—	—	—
	22	26	234	237		26	27	245	243		18	28	235	238		—	—	—	—
	23	26	236	236		23	30	240	240		22	27	232	242		—	—	—	—

APPENDIX II—*continued.*—ULTRA-QUICK, SINGLE-POINT RUNS

August 31, 1928, from 14h. 37m. G.M.T. to 14h. 47m. G.M.T.
Approx. mean speed 17 mi./hr. Approx. mean direction 280°
Ref. no. 495

Five-second means.

	Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °
1	15	290	6	15	285	11	17	277	16	13	273
	13	293		14	282		17	280		15	272
	13	296		14	286		16	276		18	278
	15	295		17	284		16	274		19	278
	15	281		16	289		17	268		18	278
	19	284		17	287		18	274		17	283
2	18	284	7	15	289	12	19	270	17	17	281
	20	276		17	289		18	272		15	278
	17	277		16	286		18	276		14	276
	16	279		15	283		19	279		16	283
	14	280		15	283		20	269		15	279
	16	280		14	283		18	268		13	276
3	17	285	8	15	284	13	19	267	18	13	271
	19	276		15	297		18	265		13	263
	21	283		16	285		18	264		18	270
	23	285		16	282		19	270		17	271
	24	286		15	286		18	277		16	280
	22	286		16	290		17	276		15	278
4	18	284	9	18	288	14	15	279	19	15	—
	18	282		16	282		17	280		20	—
	18	281		15	287		18	287		17	—
	18	281		12	283		14	283		15	—
	15	281		14	281		14	284		16	—
	19	285		13	280		14	286		19	—
5	20	285	10	13	286	15	15	284	20	—	—
	19	284		14	274		15	280		—	—
	18	281		15	278		16	278		—	—
	17	278		15	276		15	281		—	—
	18	279		18	273		14	273		—	—
	18	285		17	272		14	268		—	—

September 4, 1928, from 13h. 55m. G.M.T. to 14h. 5m. G.M.T.
Approx. mean speed 16 mi./hr. Approx. mean direction 230°
Ref. no. 496

Five-second means.

	Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °
1	16	238	6	20	216	11	13	228	16	17	237
	16	235		20	215		13	232		17	228
	14	236		19	218		14	230		20	234
	16	239		18	220		13	226		16	238
	16	240		16	217		12	233		16	234
	16	240		17	215		11	224		17	235
2	17	240	7	18	218	12	10	228	17	17	236
	17	237		18	216		13	230		17	240
	16	238		16	214		12	221		18	243
	16	243		15	220		12	222		17	246
	15	247		14	219		16	221		17	247
	16	245		15	218		16	230		17	245
3	17	243	8	14	220	13	17	225	18	18	244
	19	244		15	223		19	233		18	248
	19	243		16	225		17	228		19	246
	18	234		16	228		15	230		18	243
	16	233		16	223		15	223		18	248
	16	236		15	220		13	234		18	243
4	16	233	9	13	218	14	15	238	19	16	239
	18	228		16	226		15	233		19	241
	18	222		15	223		16	235		19	241
	18	225		13	208		14	218		20	241
	19	231		13	218		12	215		20	240
	20	231		14	215		12	230		19	237
5	21	229	10	16	217	15	14	238	20	17	231
	20	223		15	213		14	232		16	233
	19	218		15	218		16	239		16	235
	19	217		16	217		17	234		16	240
	18	212		17	213		17	232		16	235
	18	213		16	218		15	232		18	238

September 13, 1928, from 15h. 20m. G.M.T. to 15h. 30m. G.M.T.
Approx. mean speed 12 mi./hr. Approx. mean direction 82°
Ref. no. 497

Five-second means.

	Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °
1	13	75	6	9	74	11	10	89	16	12	87
	13	70		10	80		10	90		12	87
	15	75		10	71		10	90		12	90
	14	75		10	70		11	93		12	87
	14	74		11	71		14	88		12	87
	14	78		11	72		12	92		13	90
2	14	78	7	10	64	12	14	95	17	13	88
	13	74		10	64		12	91		12	84
	13	77		11	77		12	95		11	79
	13	75		10	83		11	89		10	80
	13	76		10	83		12	91		10	92
	14	72		10	79		11	83		11	87
3	13	73	8	10	82	13	11	83	18	12	83
	12	72		10	90		10	83		12	81
	11	74		10	95		11	91		12	91
	11	72		10	98		10	92		12	80
	11	73		8	91		12	91		14	75
	11	74		8	89		12	91		12	66
4	11	74	9	10	103	14	12	93	19	12	70
	11	74		10	100		13	94		11	75
	11	76		10	101		13	90		13	70
	11	78		11	98		14	93		12	76
	11	77		11	99		14	91		13	75
	11	74		10	89		12	92		16	70
5	11	70	10	10	89	15	12	93	20	14	65
	11	73		10	95		11	93		14	63
	10	79		9	97		12	93		13	64
	9	85		9	92		13	91		15	66
	9	78		8	90		13	87		14	67
	9	71		9	84		13	78		14	64

September 24, 1928, from 14h. 0m. G.M.T. to 14h. 10m. G.M.T.
Approx. mean speed 11 mi./hr. Approx. mean direction 295°
Ref. no. 498

Five-second means.

	Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °
1	11	311	6	11	312	11	11	283	16	10	294
	12	308		9	307		11	285		10	299
	12	309		8	306		10	288		12	297
	11	308		10	323		9	285		13	295
	10	309		9	319		9	287		13	292
	9	312		12	289		10	291		13	292
2	9	315	7	15	285	12	10	291	17	14	294
	9	317		16	284		10	282		13	294
	9	318		16	284		10	287		12	289
	9	320		15	284		9	295		11	282
	9	339		14	284		9	294		11	288
	9	321		14	289		9	291		11	292
3	9	315	8	13	286	13	9	287	18	11	282
	10	330		13	286		9	286		11	277
	10	337		13	284		11	282		11	285
	10	334		12	283		12	278		10	284
	10	323		12	282		12	278		12	289
	8	319		13	283		11	279		13	287
4	9	311	9	13	285	14	11	281	19	14	296
	9	318		12	279		10	283		13	300
	9	315		12	282		10	284		14	297
	11	304		12	275		10	285		15	296
	12	305		12	277		11	291		15	289
	13	301		11	279		11	289		17	289
5	12	304	10	11	281	15	10	272	20	16	288
	12	304		13	292		11	283		16	286
	12	304		12	291		12	280		14	293
	12	304		12	289		14	272		13	289
	11	304		11	295		12	287		13	288
	11	314		11	291		9	291		13	283

APPENDIX II—*continued.*—ULTRA-QUICK, SINGLE-POINT RUNS

October 4, 1928, from 14h. 33m. G.M.T. to 14h. 40m. G.M.T.
Approx. mean speed 13 mi./hr. Approx. mean direction 123°
Ref. no. 499

Five-second means.

	Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °
1	13	127	6	13	117	11	13	124	16	—	—
	13	113		13	114		12	123		—	—
	11	127		13	114		11	117		—	—
	11	116		13	137		10	128		—	—
	11	126		14	133		10	117		—	—
	10	136		15	131		13	130		—	—
2	11	142	7	14	127	12	15	109	17	—	—
	12	127		14	120		15	122		—	—
	13	138		14	111		15	115		—	—
	11	133		16	120		14	113		—	—
	10	131		15	117		14	112		—	—
	10	124		13	120		14	117		—	—
3	12	127	8	14	115	13	14	115	18	—	—
	11	128		12	116		14	116		—	—
	11	129		13	116		13	121		—	—
	11	120		12	115		16	120		—	—
	12	123		12	127		15	111		—	—
	12	120		12	127		14	113		—	—
4	14	129	9	14	120	14	14	120	19	—	—
	17	120		11	118		17	123		—	—
	18	126		11	126		17	127		—	—
	17	127		12	128		17	119		—	—
	15	123		13	133		16	112		—	—
	15	126		12	146		16	112		—	—
5	14	130	10	12	141	15	15	—	20	—	—
	14	127		15	150		14	—		—	—
	13	122		15	157		13	—		—	—
	13	124		13	147		15	—		—	—
	12	121		14	110		17	—		—	—
	14	115		14	105		14	—		—	—

October 11, 1928, from 11h. 43m. G.M.T. to 11h. 53m. G.M.T.
Approx. mean speed 23 mi./hr. Approx. mean direction 260°
Ref. No. 502

Five-second means.

	Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °
1	29	274	6	21	259	11	20	258	16	21	258
	30	267		24	261		22	257		22	263
	27	265		23	261		20	260		17	249
	23	253		23	252		20	260		17	254
	22	256		21	257		20	278		16	266
	20	256		20	261		17	271		17	260
2	18	252	7	22	264	12	24	265	17	21	251
	19	251		20	259		24	260		23	256
	24	253		19	254		25	266		25	256
	22	259		19	255		24	263		27	253
	23	263		19	261		25	258		27	253
	20	257		20	267		24	262		22	255
3	19	251	8	21	266	13	24	263	18	19	253
	19	257		22	260		28	262		23	257
	20	265		26	259		29	264		26	263
	23	265		21	263		27	262		26	262
	22	264		27	267		25	262		27	262
	20	262		27	264		25	262		25	265
4	19	266	9	28	262	14	24	265	19	26	264
	17	265		25	266		24	264		27	266
	20	253		22	270		22	263		25	263
	19	252		19	266		22	262		24	260
	22	253		25	270		22	262		21	260
	21	256		26	265		23	263		19	258
5	29	260	10	23	264	15	23	261	20	21	254
	29	256		24	263		22	264		21	257
	28	254		24	265		20	265		21	259
	27	256		21	261		18	267		24	254
	23	259		17	255		18	265		29	255
	22	259		16	249		17	261		29	253

October 11, 1928, from 11h. 21m. G.M.T. to 11h. 31m. G.M.T.
Approx. mean speed 22 mi./hr. Approx. mean direction 265°
Ref. no. 501

Five-second means.

	Speed mi./hr	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °
1	28	267	6	22	257	11	21	260	16	20	271
	26	265		20	257		24	254		22	276
	25	260		22	252		24	261		18	260
	27	262		16	265		25	262		21	272
	24	269		15	267		25	261		22	266
	21	276		17	268		24	262		25	263
2	19	272	7	16	274	12	26	264	17	24	266
	18	274		16	279		25	264		22	256
	19	265		15	281		26	265		21	256
	20	263		18	268		27	265		20	259
	22	262		21	272		27	262		19	264
	21	260		20	270		24	259		19	260
3	17	265	8	21	268	13	17	244	18	18	256
	21	262		21	263		21	254		23	259
	25	258		21	267		20	251		24	269
	27	260		22	265		16	253		28	269
	26	257		20	272		19	256		25	272
	27	258		19	266		21	267		25	274
4	25	264	9	24	273	14	20	262	19	26	257
	21	265		25	272		21	262		24	270
	27	265		23	277		23	268		24	263
	26	257		22	271		18	264		29	269
	27	261		17	276		18	254		29	265
	28	262		18	270		16	263		29	270
5	26	269	10	22	269	15	20	263	20	29	269
	25	273		20	263		19	265		27	273
	23	272		16	260		19	267		30	273
	23	265		18	259		19	269		29	266
	22	267		16	262		22	268		25	271
	21	263		19	262		21	269		24	277

October 8, 1929, duration 10 min., commencing 22h. 12m. G.M.T.
Approx. mean speed 18 mi./hr. Approx. mean direction 311°
Ref. no. 547

Five-second means.

	Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °
1	20	—	6	22	310	11	14	302	16	18	306
	19	—		25	310		16	312		17	307
	22	325		24	308		19	308		20	318
	19	312		18	310		15	310		18	318
	19	302		18	312		14	312		17	316
	20	296		19	315		16	312		13	305
2	20	303	7	20	313	12	19	318	17	15	298
	23	305		20	310		19	305		16	312
	23	315		20	312		21	316		19	305
	20	323		19	335		18	316		19	310
	21	330		18	325		17	309		20	308
	16	313		18	320		18	317		15	316
3	17	308	8	17	333	13	16	308	18	18	312
	16	328		15	305		16	312		18	303
	19	330		13	310		15	313		16	308
	10	307		13	300		15	307		21	307
	14	312		12	313		15	303		19	304
	14	322		14	310		14	313		21	306
4	18	315	9	17	315	14	13	305	19	22	298
	15	322		21	312		13	312		24	301
	23	307		20	313		14	303		29	300
	24	317		20	303		15	300		22	303
	23	320		20	303		11	285		21	309
	22	313		21	306		13	282		19	310
5	24	322	10	18	306	15	11	308	20	20	302
	22	317		17	308		13	309		21	308
	21	307		16	323		14	306		17	302
	22	312		19	320		21	304		19	311
	18	308		18	312		22	298		18	316
	18	308		16	322		19	313		19	313

APPENDIX II—*continued.*

ULTRA-QUICK SINGLE-POINT RUN

October 9, 1929, duration $9\frac{1}{2}$ min., commencing 3h. 39m. G.M.T.
Approx. mean speed 19 mi./hr. Approx. mean direction 277°
Ref. no. 548

Five-second means.

	Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °		Speed mi./hr.	Direction °
1	20	278	6	19	280	11	24	286	16	18	268
	23	275		24	282		18	276		18	281
	22	273		18	285		19	278		17	270
	21	273		22	272		17	275		13	272
	19	282		25	279		20	273		13	279
	19	277		21	270		22	274		19	284
2	19	278	7	23	280	12	22	276	17	20	287
	20	270		21	273		24	281		18	278
	21	270		21	282		20	282		19	267
	18	275		22	284		19	270		17	281
	18	278		20	279		21	270		14	286
	19	287		16	271		17	280		18	280
3	19	290	8	21	272	13	21	280	18	20	276
	18	280		19	274		19	276		17	276
	19	270		17	283		20	283		20	280
	17	265		23	281		19	276		20	278
	19	268		20	280		20	271		18	274
	21	277		21	278		15	278		20	271
4	20	271	9	18	278	14	15	276	19	18	270
	17	268		24	272		20	282		21	273
	16	295		20	276		19	288		16	273
	17	295		20	267		17	283		16	274
	19	283		20	267		22	277		20	282
	17	277		23	273		19	274		22	280
5	18	275	10	25	269	15	23	276	20	—	—
	24	272		17	279		21	274		—	—
	22	270		18	277		20	281		—	—
	21	266		24	280		17	272		—	—
	16	273		24	280		17	270		—	—
	19	280		21	284		19	274		—	—

APPENDIX III—TABULATION SHOWING THE CORRELATION COEFFICIENTS OBTAINED FROM THE EXAMINATION OF CERTAIN FOUR-POINT AND SINGLE-POINT RUNS

In this Appendix correlation coefficients are given for certain of the ultra-quick wind records.

In the first column of the table are given two letters denoting at which stations the records were made, and in the second column the elements used for the correlation, e.g., " DD speed and fluctuation of wind vane" denotes that the correlation has been made between the wind speed at D and the fluctuation of the wind vane at the same station.

Five-second mean values of the elements have been used in general, but these five-second values have, where necessary, been reduced to mean values over 10 seconds, 20 seconds, 40 seconds, etc., by combining consecutive values. In the third column headed " period of means " is entered the appropriate figure. In some cases, the longer period means (e.g. those for 80 seconds) have been subtracted from the five-second mean values thereby leaving only the wind fluctuations of periods between 80 seconds and 5 seconds. That this has been done is denoted in column three by the entry 5-80 sec.

Two series of mean values are dealt with for the formation of each group of correlation coefficients. Let them be :

$$W_0, W_1, W_2 \ldots\ldots\ldots\ldots W_n \ldots\ldots\ldots\ldots \text{ and}$$
$$V_0, V_1, V_2 \ldots\ldots\ldots\ldots V_n \ldots\ldots\ldots\ldots$$

Correlation may be applied to the two series so that W_0 is correlated to V_0, W_1 to V_1, etc., or with a time lag so that W_0 is correlated to V_1, W_1 to V_2, etc. This procedure has been adopted and in the table the heading " time interval in seconds " shows the displacement from simultaneity with which the two series have been correlated. In all cases except items 4, 5, 8 and 9 of record 371, 90 values have been used for each series correlated, i.e., values over a period of 7½ minutes.

CORRELATIONS

Record 123.—This record was correlated for speed and small-scale turbulence (as shown by fluctuations of the wind vane). It shows high negative correlation with a lag of about 10 seconds implying that high speed is related to low turbulence. The wind speed was approximately 28 miles per hour from a southerly direction, the cloud being cumulus 3/10 and A.St. 2/10.

Record 314.—Correlations made for this record were generally insignificant. The correlation between stations A and C reached ·50 for simultaneous observations, which is somewhat remarkable as the wind was blowing across that line. Speed and direction at the same station (A) gave a high negative correlation for 40-second mean values, but this is due largely to a long-period variation in wind speed and direction.

Record 344.—This record was correlated for speed and small-scale turbulence and showed a negative correlation with a decided lag of the turbulence after the speed.

Record 351.—The correlations made for this record were mainly insignificant.

Record 360. The correlations made for this record do not show any pronounced feature, the high correlations between speed at stations C and D and C and A being due largely to long-period fluctuations.

Record 371.—This record was correlated most extensively as it was one obtained when the wind was directly along the line of stations C, D and B. It shows the high correlation between speed at C and D and C and B with the lag appropriate to the mean wind speed. The variation in correlation between speeds at stations A and D, which is negative for the first 6 minutes and positive for the last four minutes, is striking. All of these features are reproduced in the correlations of small-scale turbulence as shown by the fluctuations in the wind vanes.

Correlations have also been made between the wind speed at D and C and the small-scale turbulence which are discussed at length in the report.

Record 391.—Correlations were made between speeds at the different stations as well as directions, and again showed the travel of the wind pattern at the speed of the mean wind.

Record 401.—This record is an example made in a low wind speed and again showed the wind pattern travelling with approximately the mean speed of the wind.

For the weather, etc., during the making of the records referred to above *vide* Appendix I, page 76.

APPENDIX III—*continued.*

	Station	Elements correlated	Period of means (sec.)	Time interval in seconds -60	-50	-45	-40	-30	-20	-10	-5	0	5	10	15	20	25	30	35	40	45	50	60
	Record 123D																						
1.	DD	Speed and fluctuation of wind vane	40						-·17	-·40		-·62		-·70	-·63					-·20			
2.	DD	,, ,,	5											-·29									
3.	DD	,, ,,	10											-·44									
	Record 314																						
1.	CD	Speeds	5			·17	·24	·23	·08	·04		-·02		·22	·15	·26		·13		·09			
2.	AB	,,	5									·16		·12	·14	·02	·12	·30		·11			
3.	AC	,,	5						·24	·35		·50		·46		·31							
4.	AB	,,	40–5									·11		-·03		-·21							
5.	AA	Speed and direction	5									-·28		-·18		-·26							
6.	AA	,, ,,	40						-·63	-·67		-·66		-·64									
7.	AA	Acceleration of speed and direction	5									-·01		·00		-·05							
8.	AA	,, ,,	40									-·04				-·14				-·31			
9.	AA	Speed and rate of veer	5							·00		·06		-·07									-·37
10.	AA	,, ,,	40						·18			·05				-·15							
11.	AA	Acceleration and rate of veer	5							·00		·13		·00									
12.	AA	,, ,,	40						Small neg.			·27				·09							
	Record 344																						
1.	BB	Speed and fluctuation of wind vane	40									-·35		-·38		-·39		-·43					
	Record 351																						
1.	BA	Speeds	5–80									·04		-·08		·05		-·18					
2.	BD	,,	5–80									-·18		·19	·11	·00							
3.	BC	,,	5–80									-·02		-·36		-·25	-·15						
4.	DC	,,	5–80									-·04		·07		·04							
5.	BA	Directions	5–80									·13		·23		·31							
	Record 360																						
1.	CD	Speeds	5								·60		·43		·48								
2.	CB	,,	5									·19		·22		·06							
3.	CA	,,	5						·52			·67	·61	·51	·55	·51				·36			
4.	BA	Comp. across wind to comp. with wind	5									·07		-·13		-·24							
	Record 371																						
1.	CD	Speeds	5	·08	·01		·01	-·04	·03	·20													
2.	CB	,,	5	-·14	-·01		-·03	-·12	-·10	-·02		·47	·68	·76	·58	·42		·14		·10		·18	·18
3.	CA	,,	5	-·16	-·14		-·28	-·12	-·27	-·36		·16	·29	·44	·56	·51	·41	·32		·00		·05	·14
4.	CA	Speeds commencing at 2nd minute	5									-·47	-·51	-·52	-·48	-·37		-·35		-·16		-·07	-·10
												·04	·07	·08									
5.	CD	Speeds commencing at 2nd minute	5											·76									
6.	AB	Speeds	5																				
7.	AD	,,	5									-·22	-·27	-·19		-·16							
8.	AD	Speeds (i.) first 6 minutes	40							-·30		-·46		-·39									
												-·58											
9.	AD	Speeds (ii.) last 4 minutes	40									·71											
10.	CC	Speeds	5																				
11.	CD	,,	40									1·00	·69	·55		·35		·18		·13			·14
12.	CD	,,	40–5						·35	·60		·78	·88	·91	·87	·79	·70	·45		·55			
13.	CB	,,	40–5									-·08	·37	·58	·23	-·04		-·21					
14.	CA	,,	40									-·17	-·10	-·04	·34	·27	·10						
15.	CA	,,	40–5									-·46	-·47	-·46	-·45	-·34							
16.	CD	Directions	5									-·04	-·08	-·08						-·22			
17.	CA	,,	5				·03	·06	-·14	-·04		·27	·72	·56	·04	-·14		-·09		·02		·13	-·08
18.	DD	Comp. of departure of speed down and across mean wind	5						·21	·29		·16		-·19		·00							
												-·01		-·02		-·01							
19.	CD	Fluctuation of wind vane	5									·17	·51	·31	·10								

NOTE.—In column II, CD (e.g.) means C before D when the time interval is +ve, C after D when the time interval is −ve. For two elements at one instrument the first mentioned element precedes the second in time for +ve time interval.

APPENDIX III—*continued.*

	Station	Elements correlated	Period of means (sec.)	−60	−50	−45	−40	−30	−20	−10	−5	0	5	10	15	20	25	30	35	40	45	50	60
	Record 371 *contd.*																						
20.	CB	Fluctuation of wind vane	5										−·04	·04	·18	·13							
21.	DB	,, ,,	5									·05	·21	·23	·16								
22.	CD	,, ,,	40						·39	·58		·69	·72	·69		·60		·40					
23.	CB	,, ,,	40									·26		·23	·21								
24.	AD	Fluctuation of wind vane (i) first 6 minutes	40									·35											
25.		Fluctuation of wind vane (ii.) last 4 minutes	40									−·41											
26.	DD	Speed and fluctuation of wind vane	40												−·58	−·70	−·63	−·56					
27.	DC	,, ,,	40							−·57	−·66	−·70	−·78	−·80	−·80	−·78	−·70	−·68					
28.	CD	,, ,,	40									−·10	−·22	−·29	−·37	−·44	−·48	−·42		−·47			
29.	CC	,, ,,	40								−·47	−·57	−·63	−·72	−·77	−·80	−·79	−·77		−·70			
	Record 391																						
1.	CD	Speeds	5	−·05	−·20		−·26	−·28	−·20	−·08	·08	·27	·42	·56	·48	·42	·33	·28	·18	−·04		−·20	−·30
2.	CB	,,	5	·23				−·32			−·02			−·01	−·07	·00		·03					−·04
3.	CC	,,	5									1·00	·69	·50		·11		−·08		−·19		−·42	−·38
4.	CA	,,	5	−·01				−·02				·04		−·10	−·11	−·12		−·22					−·18
5.	CD	Directions	5	−·01	·07		·25	−·08	·16		·20	·27	·51	·53	·23	·29		·14		·15		·05	·02
6.	CB	,,	5	−·07	−·04		·15	·17	·40	·30		·08	·17	·15	·09	·10		·14		·18		·03	−·12
7.	CC	,,	5									1·00		·17		·05		·05		−·06			
	Record 401																						
1.	DB	Speeds	5											·07		·14		·23		·30		·22	
2.	CD	,,	5						·09	·12		·12		·10		·08		−·07					
3.	CB	,,	5													·00		·00					
4.	AC	,,	5					·23	·24	·13		·08		·02		·00		−·13					
5.	AB	,,	40																	·55			
6.	AB	,,	5															·35	·46	·49	·48	·42	·29

NOTE.—In column II, CD (e.g.) means C before D when the time interval is +ve, C after D when the time interval is −ve. For two elements at one instrument the first mentioned element precedes the second in time for +ve, time interval.

APPENDIX IV—CHANGES RECORDED DURING THE PASSAGES OF CERTAIN FRONTS AND SQUALLS

In this table are given a list of the " fronts " and squalls during which quick (or ultra-quick) runs were made at Cardington. There are given the wind changes during the fronts and the estimated maximum changes of direction and speed in both fronts and squalls during one minute, two minutes and three minutes. The changes in direction and speed are not synchronous. In estimating these changes minor fluctuations of under about 15 seconds duration have been neglected.

TABLE SHOWING CHANGES IN SPEED AND DIRECTION OF THE WIND WHICH OCCURRED DURING THE PASSAGE OF CERTAIN FRONTS AND SQUALLS

FRONTS

	Date	Time G.M.T.	Record No.	Wind before squall		Wind after squall		Wind change		Max. change in one minute		Max. change in two minutes		Max. change in three minutes	
				Dir. °	Speed mi./hr.	Dir. °	Speed mi./hr.	Dir. °	Speed mi./hr.	Dir. °	Speed mi./hr.	Dir. °	Speed mi./hr.	Dir. °	Speed mi./hr.
	1927	h. m.													
1.	Sept. 29	14 15	UQR 315–317	190	17	270	12	+ 80	− 5	30	+ 8	40	+ 8	45	+ 9
	1928														
2.	Oct. 18	16 10	19	180	25	240	28	+ 60	+ 3	15	+18	17	+14	20	+22
3.	Oct. 20	01 35	20	190	35	230	32	+ 40	− 3	17	+10	32	+ 9	43	+12
4.	Nov. 10	20 45	33	220	30	255	15	+ 35	−15	20	+ 8	30	+12	30	+12
5.	Nov. 15	10 50	42	180	24	240	23	+ 60	− 1	15	+ 4	22	+ 7	25	—
6.	Nov. 19	19 00	48	180	33	260	25	+ 80	− 8	22	+18	24	+13	37	+16
7.	Nov. 23	15 50	53	240	50	265	42	+ 25	− 8	15	+18	10	+21	12	+19
8.	Dec. 6	15 30	54	210	36	270	18	+ 60	−18	10	+ 6	15	+ 6	22	+ 8
	1929														
9.	Feb. 10	18 40	83	330	15	50	11	+ 80	− 4	10	—	15	—	20	—
10.	April 1	12 10	89	250	30	310	35	+ 60	+ 5	15	+12	25	+12	35	+ 7
11.	April 3	17 55	92	330	15	60	8	+ 90	− 7	15	+ 8	27	+10	40	+13
12.	April 5	18 15	94	25	20	50	15	+ 25	− 5	17	+10	22	+10	30	+13
13.	April 24	15 05	102	295	27	10	15	+ 75	−12	32	+11	43	—	50	—
14.	May 6	17 10	113	215	40	255	25	+ 40	−15	15	+19	25	+23	20	+14
15.	June 4	14 30	122	270	15	30	8	+120	− 7	25	—	45	—	45	—
16.	June 6	18 35	124	245	30	310	15	+ 65	−15	35	—	55	—	60	—
17.	June 8	19 25	125	240	8	280	14	+ 40	+ 6	25	+ 8	20	+15	45	+11
18.	July 31	15 20	138	205	35	225	25	+ 20	−10	15	+18	20	+16	25	+16
19.	Aug. 4	12 15	139	205	23	240	23	+ 35	0	30	+12	35	+ 8	35	+ 8
20.	Aug. 11	14 35	145	260	24	315	18	+ 55	− 6	55	+12	65	+12	70	+10
21.	Aug. 28	18 30	146	215	25	240	12	+ 25	−13	35	+10	40	+11	50	+12
22.	Oct. 8	15 20	156	195	12	255	8	+ 60	− 4	25	+ 7	30	+ 7	37	+ 7
23.	Oct. 24	15 05	174	185	37	320	10	+135	−27	60	−18	75	−14	85	−16
24.	Nov. 8	10 40	200	285	11	330	23	+ 45	+12	20	+10	27	+12	32	+15
25.	Nov. 10	08 25	203A	190	20	330	15	+140	− 5	52	+ 5	65	+ 7	95	+ 7
26.	Nov. 12	01 10	211	215	40	330	22	+115	−18	135*	−14	*	−16	*	−20
27.	Nov. 23	14 15	217	180	35	210	32	+ 30	− 3	12	+10	22	+12	30	+10
28.	Dec. 2	15 45	232	190	38	250	20	+ 60	−18	15	—	20	—	25	—
29.	Dec. 8	12 50	245	210	38	240	35	+ 30	− 3	22	+12	30	+11	40	+11
30.	Dec. 9	13 55	248	180	30	260	30	+ 80	0						
31.	Dec. 14	21 50	249	255	27	350	10	+ 95	−17	35	—	55	—	75	—
	1930														
32.	Jan. 1	15 05	254	235	20	290	10	+ 55	−10	40	+10	60	+10	65	—
33.	Jan. 12	18 25	255	190	33	240	47	+ 50	+14	Gradual veer of about 3° per minute and increase of about 3 mi./hr. per minute.					
34.	Jan. 15	02 00	256	190	22	340	10	+150	−12	85	—	105	—	112	—
35.	Jan. 24	23 20	260	165	22	230	9	+ 65	−13	35	− 5	55	− 5	55	− 5
36.	July 21	02 15	293	190	18	240	12	+ 50	− 6	15	—	25	—	30	—

* Record incomplete ; figure doubtful.

SQUALLS

	Date	Time G.M.T.	Record No.	General direction and speed of wind		Max. change in one minute		Max. change in two minutes		Max. change in three minutes	
				Direction	Speed mi./hr.	Dir. °	Speed mi./hr.	Dir. °	Speed mi./hr.	Dir. °	Speed °
	1927										
37.	Mar. 25	17 27	UQR 197	SW'S	15	+ 18	+ 12	+ 18	+15	+ 20	+17
	1928										
38.	Nov. 15	01 20	38	S'W	35	—	+ 20	—	+19	—	+30
	1929										
39.	May 14	13 15	116	SW	35	+ 20	—	+ 30	—	+ 42	—
40.	May 14	13 40	116	SW	35	—	+ 17	—	+28	—	+24
41.	July 4	15 10	131	NNW	10	+130	+ 16	+165	+16	+215	+10
42.	July 5	13 15	132	SW	25	+ 15	+ 18	+ 25	+20	+ 30	+24
43.	July 20	20 30	134	W	10	+ 25	+ 16	+ 40	+28	+ 45	+44
44.	Nov. 12	15 50	214A	W'S	18	+ 22	+ 14	+ 32	+12	+ 32	+14
45.	Dec. 7	00 05	237	SSW	45	+ 20	+ 14	+ 22	+20	+ 40	+24
46.	Dec. 9	11 00	247	S'W	30	—	+ 12	—	+12	—	+11
	1930										
47.	May 5	15 30	264	SE	10	+ 12	+ 12	+ 20	+22	+ 25	+24
48.	June 19	17 05	280	SW	15	—	+ 9	—	+13	—	+13

The times given in the third column are approximate only. A hyphen denotes that no important sudden change occurred in speed (or direction). The maximum changes recorded in the above table are not necessarily synchronous for speed and direction. The speed changes and veers during intervals of one, two and three minutes are not taken to the maximum values of short-period gusts but to a general average over about 15 seconds.

APPENDIX V—THE COMPARISON OF WIND AT THE HEIGHTS OF 150 FEET AND 50 FEET, AND THE COMPARISON OF WIND AT 150 FEET WITH THE HORIZONTAL PRESSURE GRADIENT

Table A.—Frequencies of ratios of wind at 150 feet to wind at 50 feet. Mean hourly wind speeds, variation of frequencies of ratios with wind speed under day conditions and under night conditions.

Table B.—Frequencies of ratios of wind at 150 feet to wind at 50 feet. Maximum gust in each hour, variation of frequencies of ratios with wind speed under day conditions and under night conditions.

Table C.—Frequencies of ratios of wind at 150 feet to wind at 50 feet in relation to the vertical temperature gradient. Mean hourly wind speeds, variation at different wind speeds and under day conditions and night conditions.

Table D.—Frequencies of ratios of hourly maximum gusts to hourly mean wind under day conditions and night conditions.

Table E.—Frequencies of ratios of mean hourly wind speed at 150 feet to the geostrophic wind speed. Variation with geostrophic wind speed at the four primary hours of observation.

Table F.—Frequencies of ratios of maximum gusts at 150 feet (during the hour centred at the hour) to the geostrophic wind speed. Variation with geostrophic wind speed at the four primary hours of observation.

Table G.—Frequencies of backing of the wind at 150 feet from the direction of the isobars. Variation with geostrophic wind speed at the four primary hours of observation.

TABLE A.—FREQUENCIES OF RATIOS OF WIND AT 150 FEET TO WIND AT 50 FEET FOR DIFFERENT MEAN HOURLY WIND SPEEDS

Season	Time	Wind speed at 150ft. mi./hr.	Ratio													
			0·8	0·9	1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	>2·0
Winter	10h.	10—14		16	**48**	28	7	1		1						
	to	15—19		7	**36**	29	18	7	~~1~~ 1							
	15h.	20—24			4	24	**34**	5	1							
January 1930		25—29			3	13	**29**	8								
February, 1930		30—34				1	**7**	1								
December, 1930		35—39				1	**3**	1								
		40—44					**2**									
	22h.	10—14	3	5	**52**	49	24	7	1	5	1	2	2		1	
	to	15—19			4	**26**	22	15	8	5						
	3h.	20—24				5	**32**	5	1							
		25—29				10	**16**	5								
		30—34				3	**7**	4								
		35—39				6	**10**									
		40—44					1	1								
		45—49					1	3								
		50—54				1										
	10h.	10—14		11	**54**	29	14	3	1							
Spring	to	15—19		3	58	**73**	18	8								
March, 1930	15h.	20—24		1	13	**41**	18	3								
April, 1930		25—29			1	**15**	13	4	4							
May, 1930		30—34				4	**6**	1								
	22h.	10—14		2	26	**29**	**29**	**29**	15	8	9	2	1		3	2
	to	15—19			5	25	**45**	15	24	8	2	3	3			
	3h.	20—24				6	**18**	5	1	2	1					
		25—29				1	**5**	**5**	1							
		30—34					**2**									
	10h.	10—14		3	**77**	32	22	18	6	2						
Summer	to	15—19		2	40	**80**	26	12	5	1						
June, 1930	15h.	20—24			9	18	**31**	7	4							
July, 1930		25—29			6	7	**8**	4	1							
August, 1930		30—34				1										
	22h.	10—14			15	28	22	**36**	22	16	8	14	7		14	8
	to	15—19			6	**30**	**30**	17	24	10		3				
	3h.	20—24					**13**	5	1							
		25—29					**6**									

APPENDIX V—*continued*

TABLE A.—FREQUENCIES OF RATIOS OF WIND AT 150 FEET TO WIND AT 50 FEET FOR DIFFERENT MEAN HOURLY WIND SPEEDS

Season	Time	Wind speed at 150ft. mi./hr.	Ratio													
			0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	>2.0
Autumn	10h. to 15h.	10—14	3	17	**56**	24	5									
September, 1930		15—19		9	**71**	53	14	2	1							
October, 1930		20—24			15	**44**	40	4	1							
November, 1930		25—29		1	8	**13**	12	3	1							
		30—34			1	**5**	**5**	1	1							
		35—39					1	**2**								
		40—44				2	3	**4**								
		45—49					1									
	22h. to 3h.	10—14	1	1	9	**36**	25	26	13	7	7	6	3		1	2
		15—19			3	39	**56**	19	12	4					1	
		20—24			2	10	**19**	6	2							
		25—29			3	9	**17**	4	1	1						
		30—34				4	**9**	5	1	1						
		35—39				1		4								

Season	Time	Wind speed at 150 ft. mi./hr.	Ratio														Value of mode
			0·8	0·9	1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	>2·0	
Year	10h. to 15h.	10–14	3	47	**235**	113	48	22	7	3							1·02
		15–19		21	205	**235**	76	29	7	1							1·07
		20–24		1	41	**127**	123	19	6								1·15
		25–29		1	18	48	**62**	19	6								1·16
		30–34			1	11	**18**	3	1								1·16
		35–39				1	**4**	3									
		40–44				2	**5**	4									
		45–49					1										
	22h. to 3h.	10—14	4	8	102	**142**	100	98	51	36	25	24	13		19	12	1·08
		15—19			18	120	**153**	66	68	27	2	6	3		1		1·17
		20—24			2	21	**82**	21	5	2	1						1·19
		25—29			3	20	**44**	14	2	1							1·20
		30—34				7	**18**	9	1	1							1·20
		35—39				7	**10**	4									
		40—44					1	1									
		45—49					1	3									
		50—54				1											

TABLE B.—FREQUENCIES OF RATIOS OF WIND AT 150 FEET TO WIND AT 50 FEET

Maximum gust in each hour (centred at the hour)

June, July and August, 1930.

Mean windspeed at 150 ft. mi./hr.	10h. to 15h. G.M.T. Ratio										22h. to 3h. G.M.T. Ratio														
	0·7	0·8	0·9	1·0	1·1	1·2	1·3	1·4	1·5	1·6	0·7	0·8	0·9	1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	>2·0
10–14	2	2	20	**54**	47	17	7		4			3	9	25	**34**	**34**	24	28	12	4	11	5	2	2	1
15–19		2	10	52	**62**	33	5						5	12	27	**37**	21	4	3	3					
20–24			1	12	**34**	15	6							2	4	**5**	**5**	1							
25–29				3	**16**	2	1								2	**3**	1								
30–34						1																			
December, January and February, 1930.																									
10–14		1	23	**35**	27	7	5	1	2			3	15	**50**	38	26	11	6	3	1				1	
15–19		1	13	28	**37**	11	9	1						10	26	**30**	12	3		1					
20–24				14	**32**	18	3							7	**21**	10	4	1							
25–29				6	21	**23**	4							4	**13**	11	3								
30–34					4	**5**	1								**8**	4	2	1							
35–39				1	3	1								1	**12**	3									
40–44					2										1	1									
45–49															1	2	1								
50–54														1											

M.O. 331d

METEOROLOGICAL OFFICE

GEOPHYSICAL MEMOIRS No. 54

THE STRUCTURE OF WIND OVER LEVEL COUNTRY

By the late M. A. GIBLETT, M.Sc., and other Members of the Staff of the Office.

ERRATA

PAGE 103, Table A.—Frequencies of ratios of wind at 150 feet to wind at 50 feet for different mean hourly wind speeds: Winter, 10h. to 15h., speed 15–19, ratio 1·4, *for* " 11 " *read* " 1 ".

PAGE 104, Table A: Autumn, 22h. to 3 h., speed 35–39, ratio 1·5, *delete* " 1 ".

PAGE 104, Table A: Year, *delete* the figures for 10h. to 15h. and *substitute* the following :—

APPENDIX V—*continued*

TABLE C.—FREQUENCIES OF RATIO OF WIND AT 150 FEET TO WIND AT 50 FEET IN RELATION TO THE VERTICAL TEMPERATURE GRADIENT

Mean hourly wind speeds (easterly winds omitted)

June, July, August, 10h. to 15h.

Temp. diff. 150 ft.–4 ft.	Wind speed at 150 feet 10 to 14 mi./hr.													Wind speed at 150 ft. 15 to 19 mi./hr.												
	0·8 or 0·9	Ratio 1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	>2·0	0.8 or 0·9	Ratio 1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	>2·0
−6·0 to −5·1																1										
−5·0 to −4·1	1	2													2	3	3									
−4·0 to −3·1	1	**5**	3	2	1	3									**8**	6	3	4								
−3·0 to −2·1		**21**	6	13	2	1									11	**17**	3	1	1							
−2·0 to −1·1	1	**23**	9	3	6	2								1	6	**30**	10	2	2	1						
−1·0 to −0·6		**7**	2		3										2	**8**	2	4								
−0·5 to −0·1		**4**	3	1	2		1								3	3			1							
0·0 to 0·4		1	2													1										
0·5 to 0·9					1																					

June, July and August, 10h. to 15h.

Temp. diff. 150ft.–4ft.	Wind speed at 150 ft. 20 to 24 mi./hr.													Wind speed at 150 ft. 25 to 29 mi./hr.												
	0·8 or 0·9	Ratio 1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	>2·0	0·8 or 0·9	Ratio 1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	>2·0
−5·0 to −4·1				1													1									
−4·0 to −3·1		1	1	2		1										1	1									
−3·0 to −2·1		2	**7**	3	1											1	1	2								
−2·0 to −1·1		4	3	**11**	1	1									2	1	1	1								
−1·0 to −0·6				2	2	1									3		2	1								
−0·5 to −0·1		1		4	3	1									1											
−0·0 to −0·4				1													1		1							

June, July and August, 22h. to 3h.

Temp. diff. 0ft.–4ft.	Wind speed at 150 ft. 10 to 14 mi./hr.													Wind speed at 150 ft. 15–19 mi./hr.												
	0·8 or 0·9	Ratio 1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	>2·0	0·8 or 0·9	Ratio 1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	>2·0
to −1·1					1					1							2	2								
to −0·6																	1									
to −0·1			2		1												1	2	2							
to 0·4		3	**11**	5	7	2		1							2	**7**	5	3	**7**	1						
to 0·9			2	4	**5**	3	1	1							1	3	5	**7**	2							
to 1·9			**5**	**5**	4	**5**	2	1	2	1						**5**	4	3	3	1						
to 3·9				4	6	6	**9**	2	6	2		4	1			1	1		**7**	6		1				
to 5·9					2	2	1	1	3	1		**4**	3						1	2		2				
to 7·9								1	1	1		3														
to 9·9												3	3													
to 11·9										1																

June, July and August, 22h. to 3h.

1p. diff. ft.–4ft.	Wind speed at 150 ft. 20 to 24 mi./hr.													Wind speed at 150 ft. 25 to 29 mi./hr.												
	0·8 or 0·9	Ratio 1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·8	2·0	>2·0	0·8 or 0·9	Ratio 1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	>2·0
−2·0 to −1·1					1																					
−1·0 to −0·6					1	1																				
+0·5 to −0·1				1																						
−0·0 to −0·4				1													2									
0·5 to 0·9				2	1												3									
1·0 to 1·9				**7**	2												1									

APPENDIX V—*continued*

TABLE C.—FREQUENCIES OF RATIO OF WIND AT 150 FEET TO WIND AT 50 FEET IN RELATION TO THE VERTICAL TEMPERATURE GRADIENT (*continued*).

Mean hourly wind speeds (easterly winds omitted)

December, January and February, 10h. to 15h.

Temp. diff. 150ft.–4ft.	Wind speed at 150 ft. 10 to 14 mi./hr.													
	0·8 or 0·9	Ratio 1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	>2·0	
−2·0 to −1·1	1	**3**	1	1										
−1·0 to −0·6		5	**7**	1										
−0·5 to −0·1			**7**	3	1									
0·0 to 0·4		2	**4**	1										
0·5 to 0·9			3											
1·0 to 2·9							1							

Temp. diff. 150ft.–4ft.	Wind speed at 150 ft. 15 to 19 mi./hr.													
	0·8 or 0·9	Ratio 1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	>2·0	
−2·0 to −1·1	1	2	2	1	**3**									
−1·0 to −0·6		1	**7**	4	1									
−0·5 to −0·1		1	2	3										
0·0 to 0·4	1	1	3	**4**		1								
0·5 to 0·9		1	2	1		2								
1·0 to 2·9			1											

December, January and February, 10h. to 15 h.

Temp. diff. 150ft.–4ft.	Wind speed at 150 ft. 20 to 24 mi./hr													
	0·8 or 0·9	Ratio 1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	>2·0	
−2·0 to −1·1		1	1	**5**	1									
−1·0 to −0·6		1	5	**7**	1									
−0·5 to −0·1			6	**9**	2									
0·0 to 0·4		1	2	**6**	1									
0·5 to 0·9			2	1										

Temp. diff. 150ft.–4ft.	Wind speed at 150 ft. 25 to 29 mi./hr.													
	0·8 or 0·9	Ratio 1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	>2·0	
−2·0 to −1·1				1										
−1·0 to −0·6		1	2	3										
−0·5 to −0·1		1	3	**10**	2									
0·0 to 0·4		1	2	**10**	3									
0·5 to 0·9			1	3	2									

December, January and February, 22h. to 3h.

Temp. diff. 150ft.–4ft.	Wind speed at 150 ft. 10 to 14 mi./hr.													
	0·8 or 0·9	Ratio 1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	>2·0	
−2·0 to −1·1														
−1·0 to −0·6	1	**8**	6											
−0·5 to −0·1	1	4	**5**	2										
0·0 to 0·4		1	**3**	1		1								
0·5 to 0·9			**4**	**4**	1	1								
1·0 to 1·9		3	3	**7**	4	2	3							
2·0 to 3·9		1	2	4	**5**	1		1						
4·0 to 5·9						1	1		1					
6·0 to 7·9												1		

Temp. diff. 150ft.–4ft.	Wind speed at 150 ft. 15 to 19 mi./hr.													
	0·8 or 0·9	Ratio 1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	>2·0	
−2·0 to −1·1						1								
−1·0 to −0·6				1	1									
−0·5 to −0·1			1	2										
0·0 to 0·4			4	**10**	3		1							
0·5 to 0·9	1		2	**10**	2	4								
1·0 to 1·9			6	**11**	1	2								
2·0 to 3·9			1		2	1								
4·0 to 5·9														
6·0 to 7·9														

December, January and February, 22h. to 3h.

Temp. diff. 150ft.–4ft.	Wind speed at 150 ft. 20 to 24 mi./hr.													
	0·8 or 0·9	Ratio 1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	>2·0	
−1·0 to −0·6					1									
−0·5 to −0·1														
0·0 to 0·4			2	**9**										
0·5 to 0·9			1	**10**	2									
1·0 to 1·9			1	**9**	2	1								

Temp. diff. 150ft.–4ft.	Wind speed at 150 ft. 25 to 29 mi./hr.													
	0·8 or 0·9	Ratio 1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	>2·0	
−1·0 to −0·6														
−0·5 to −0·1			1											
0·0 to 0·4			2	2										
0·5 to 0·9			5	**9**	2									
1·0 to 1·9				3	1									

APPENDIX V—*continued*

TABLE D.—FREQUENCY OF RATIOS OF THE MAXIMUM GUST TO THE MEAN WIND

G.M.T.	Wind Speed at 150ft. (mi./hr.)	Height 50ft.—Ratio.												Height 150ft.—Ratio.											
		1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	2·1	2·2	2·3	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	2·1	2·2	2·3
													June, 1929												
1h. to 3h.	10—19	2	4	8	**13**	11	6	1	1					8	6	10	**12**	6	2	1					
	20—29			2	1			1									1	3							
13h. to 15h.	10—19		2	1	7	**16**	7	12	6	2	2					3	9	7	**12**	8	5	5	3	2	1
	20—29			1	**9**	6	2								1	3	**5**	3	4	1	1				
	30—39			1	1	1											2	1							
													December, 1929												
1h. to 3h.	<10	1		2		2			1	1															
	10—19		3	4	**5**	2	4	1		1				2	2	**7**	3	2	3	1					
	20—29			7	**14**	2	1	1							1	**10**	7	4	1	2					
	30—39			2	6	**9**	1									8	**9**	1							
	40—49				1											1	1								
	50—59			1	2											3									
13h. to 15h.	10—19	1	1	8	10	**11**	1	3	1				1		1	6	9	**10**	6	2		1		1	
	20—29			2	7	**8**	2		1							4	**7**	4	2	1	1				1
	30—39			2	**6**	2	1	1					2				4	**7**	1	1	1				
	40—49				1	1	3									1	1	1	1	1					
	50—59				1	1										2									

TABLE E.—FREQUENCY OF RATIOS OF MEAN HOURLY WIND AT 150 FEET TO GEOSTROPHIC WIND

Time G.M.T.	Geo-strophic wind speed	Ratio																			
		0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	In-deter-minate
	(mi./hr.)								March, April, May												
1h.	<10			1		1			1	2											19
	10—19		1	3	7	5	7	2	3	1			1		1						
	20—29	1	2	3	8	2	4	2	3												
	30—39			1	3	1		1													
	40—49			2	1	1															
	50—59				1	1															
	Total	1	3	10	20	11	11	5	7	3			1		1						19
7h.	<10							1	1	2											20
	10—19		3	4	3	8	7	2	1												
	20—29		2	1	9	12		2		1											
	30—39				4	2	2														
	40—49				1		2														
	50—59				1																
	60—69																				
	70—79			1																	
	Total		5	6	18	22	11	5	2	3											20
13h.	<10						1					3									12
	10—19			3	2	2	3	4	4	2	6	1	1	1							
	20—29	2	2	3	5	4	6	3	1	2	1										
	30—39				2	1	3	2	1	1											
	40—49			1			2	1													
	50—59						1														
	60—69				1		1														
	Total	2	2	7	10	7	17	10	6	5	7	4	1	1							12
18h.	<10						1		1		1	3	2	1							11
	10—19		1	1	5	1	4	6	2	2	3		2	1							
	20—29	1	1	3	7	4	4	4	1		1										
	30—39		1		6	1	4	2													
	40—49							1													
	50—59			1		1															
	60—69				1																
	Total	1	3	5	19	7	13	13	4	2	5	3	4	2							11

APPENDIX V—*continued*

TABLE E—FREQUENCY OF RATIOS OF MEAN HOURLY WIND AT 150 FEET TO GEOSTROPHIC WIND—*continued*.

Time G.M.T.	Geostrophic wind speed	Ratio 0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	Indeterminate
	(mi./hr.)	June, July, August																			
1h.	< 10			3				1			2	2									18
	10—19		2	3	4	6	7	1	4	3	1	1									
	20—29	3		1	2	5	6		1												
	30—39		1	2	1	3		1													
	40—49			4	2	1															
	50—59																				
	60—69				1																
	Total	3	3	13	10	15	13	3	5	3	3	3									18
7h.	< 10							2	2	2	1										13
	10—19		1	8	5	4	3	8	5	1	1										
	20—29			1	1	6	5	6	3	2											
	30—39		1	2	2	3	1	1													
	40—49					1															
	50—59																				
	60—69		1																		
	Total		3	11	8	14	9	17	10	5	2										13
13h.	< 10					1				1	2			1		1	1	1			7
	10—19		2		4	2	8	4	9	2	5	4					1				
	20—29				2	3	4	4		3	2	1									
	30—39		1			1	3	2	1												
	40—49				1	4	1		1												
	50—59			1																	
	60—69																				
	70—79																				
	80—89			1																	
	Total		3	2	7	11	16	10	11	6	9	5		1		1	2	1			7
18h.	< 10						1	1	2	1	3		1	1						1	12
	10—19			1		4	4	1	4	1	6		1	1	2	2	1	1			
	20—29		1		4	6	9	4	1		2		1								
	30—39						3	2													
	40—49		1		1	1	2														
	50—59					1															
	60—69				1																
	Total		2	1	6	12	19	8	7	2	11		3	2	2	2	1	1		1	12
	(mi./hr.)	September, October, November																			
1h.	< 10				1					4	1										10
	10—19		1	3	1	6	5	1		1	2										
	20—29		2	6	6	2	4		2	1											
	30—39			3	6		1	1													
	40—49		1		2	3															
	50—59		3	1	1	2	1														
	60—69			2	1																
	70—79																				
	80—89			3																	
	90—99			1																	
	Total		7	19	18	13	11	2	2	6	3										10

APPENDIX V—*continued*

TABLE E—FREQUENCY OF RATIOS OF MEAN HOURLY WIND AT 150 FEET TO GEOSTROPHIC WIND—*continued*.

Time G.M.T.	Geo-strophic wind speed	Ratio																			
		0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	In-determinate
	(mi./hr.)	September, October, November—*continued*																			
	< 10					1	3	1													9
	10—19	1	1	4	6	2	2	3		1	1										
	20—29	1	7	2	7	5	4	1													
	30—39		1	2	2	2	2	1													
7h.	40—49		1	3	4	2															
	50—59		2		2	1															
	60—69		2		1																
	70—79																				
	80—89		1																		
	Total	2	15	11	22	13	11	6		1	1										9
	< 10					1				1		1			1					1	6
	10—19		1	3	3	3	2	4	5	1	1				1						
	20—29		1	3	2	7	2	2	6	1	1										
	30—39	1	1	1	4	3	4	2	1		1										
13h.	40—49					2	1	2													
	50—59			1		1	1	1													
	60—69					1															
	70—79		1																		
	80—89			1	1																
	Total	1	4	9	10	18	10	11	12	3	3	1			2					1	6
	< 10					1		1			1	1			1			1			10
	10—19		1	2	5	2	1	6	5	1	1		1								
	20—29			1	5	4	4	3	1	1											
	30—39		3	3	2	3	2	1	1												
18h.	40—49	1		1	3	1	1														
	50—59			1	1																
	60—69					1	1														
	70—79			1	2	1															
	80—89																				
	90—99			1																	
	Total	1	4	10	18	13	9	11	7	2	2	1	1		1			1			10
	(mi./hr.)	December, January, February																			
	< 10																				9
	10—19		2	3	3	3	1		3												
	20—29		3	2	7	4	3		1		1										
	30—39	1	3	2	4	3	1	2													
	40—49		1	2	1		1	1													
	50—59		1	2	2	3	1														
1h.	60—69			1	4	2															
	70—79		1	2	1																
	80—89			1																	
	90—99																				
	100				2																
	Total	1	11	15	24	15	7	3	4		1										9
	< 10												1								6
	10 19			1	4	5	4	4	2	3		1									
	20—29	1	2	4	3	4	3	1			1	1									
	30—39		2	1	4	2	2	2													
	40—49			2	3	3	1	1													
	50—59		1	3	2	1															
7h.	60—69					1															
	70—79			1																	
	80—89		1	3	1	1															
	90—99																				
	100				1																
	Total	1	6	15	18	17	10	8	2	3	1	2	1								6

APPENDIX V—*continued*

TABLE E—FREQUENCY OF RATIOS OF MEAN HOURLY WIND AT 150 FEET TO GEOSTROPHIC WIND—*continued.*

Time G.M.T.	Geostrophic wind speed	Ratio 0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	Indeterminate
	(mi./hr.)	December, January, February—*continued*																			
13h.	< 10						1		1												7
	10—19		2		1	4	4		3		2	1									
	20—29		1	1	4	3	4	6	4												
	30—39		1	1	2	2	4	3	2												
	40—49			3	2	3	3	1													
	50—59			1	1	2	2		1												
	60—69		1	1		1															
	70—79				1																
	80—89				2	1															
	Total		5	7	13	16	18	10	11		2	1									7
18h.	< 10				1				1	1		2									4
	10—19					8	2	5	1												
	20—29	1	1	5	3	5	3	5	1												
	30—39			1	7	4	2	1	1												
	40—49			2	2	2	1	1													
	50—59		1	3	2	1	1														
	60—69			2	3	1															
	70—79				3																
	Total	1	2	13	21	21	9	12	4	1		2									4

TABLE F—FREQUENCY OF RATIOS OF MAXIMUM GUSTS AT 150 FEET TO GEOSTROPHIC WIND.

Time G.M.T.	Geostrophic wind speed	Ratio. <0·5	0·5	0·6	0·7	0·8	0·9	1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	>2·0	Indeterminate
	(mi./hr.)	March, April, May																		
1h.	< 10		1			3		2	1					1					1	13
	10—19		2	4	5	7	2	3	1	2	1		2		1				1	
	20—29	1	3	5	5	2	1	2	2	2		2								
	30—39			1	1	2		1		1										
	40—49			3		1														
	50—59				1	1														
	60—69																			
	Total	1	6	13	12	16	3	8	4	5	1	2	2	1	1				2	13
7h.	< 10	2					2	1		4		1	2				1			9
	10—19	4	1	2	5	1	8	1	2	1	2		1							
	20—29	2		1	5	4	9	1	1	2	1			1						
	30—39					3	1	4												
	40—49					1	1	1												
	50—59						1													
	60—69																			
	70—79		1																	
	Total	8	2	3	10	9	22	8	3	7	3	1	3	1			1			9
13h.	< 10												2					1	8	7
	10—19		1	1		2	1		6				3	4	2	2	1	1	4	
	20—29		2	2	2	6	1	2	4	2	4	1	1	1	1					
	30—39					1	3	1	1		2	1		1						
	40—49				1				2			1								
	50—59								1											
	60—69				1				1											
	Total		3	3	4	9	5	3	15	2	6	3	6	6	3	2	1	2	12	7

APPENDIX V—*continued*

TABLE F—FREQUENCY OF RATIOS OF MAXIMUM GUSTS AT 150 FEET TO GEOSTROPHIC WIND—*continued.*

Time G.M.T.	Geostrophic wind speed	Ratio																		
		<0·5	0·5	0·6	0·7	0·8	0·9	1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	>2·0	Indeterminate
	(mi./hr.)	March, April, May—*continued*																		
18h.	<10								1	2			3	1	1		1		3	8
	10—19			2	2	1	2	2	4		2		2	4	2	2		1	2	
	20—29	1	2	1	6	1	4	4	2	2	2			1						
	30—39		1		5	1	2	3		2										
	40—49										1									
	50—59				1	1														
	60—69						1													
	Total	1	3	3	14	4	9	9	7	6	5		5	6	3	2	1	1	5	8
	(mi./hr.)	June, July, August																		
1h.	<10	1		2	2		1			2					1			1		11
	10—19	4	2		8	2	7	1	4	1	2	3	1			1				
	20—29	3		2	2	3	2	5	1	1										
	30—39			2	2		2	1			1									
	40—49		2	3	1			1												
	50—59																			
	60—69					1														
	Total	8	4	9	15	6	12	8	5	4	3	3	1		1	1		1		11
7h.	<10						1		2	2	1	1		1						7
	10—19	5	1	1	8	2	4	4	1	2	4	1	3	2	1	1				
	20—29	1			1	2	3	1	4	5	2	3	2		1					
	30—39		1	1	1	2	2	1		2										
	40—49						1													
	50—59																			
	60—69		1																	
	Total	6	3	2	10	6	11	6	7	11	7	5	5	3	2	1				7
13h.	<10													1				1	6	7
	10—19			1		1	1	2	1	4	3	5	5	2	4	1	4	3	4	
	20—29						2	1	2	3	2	2	1	2	3		1			
	30—39			1				1	3	2	1									
	40—49					1	3	1		1		1								
	50—59						1													
	60—69																			
	70—79																			
	80—89		1																	
	Total		1	2		2	7	5	6	10	6	8	6	5	7	1	5	4	10	7
18h.	<10								2		1		1	1	2	2	1		2	10
	10—19	1				1		2		4		2	2	3		3	1		9	
	20—29	1			1	1	4	8	2	3	4	1	1			1	1	1		
	30—39							2	2	1										
	40—49			1		1	1		1	1										
	50—59					1														
	60—69					1														
	Total	2		1	1	5	5	12	7	9	5	3	4	4	2	6	3	1	11	10
	(mi./hr.)	September, October, November																		
1h.	<10	1		1			1					2			1			1		6
	10—19	2		1	2	4	4	1	2		2		2							
	20—29	2	4	4	4	2	3	2	1		2									
	30—39			1	3	2	1	1	1	1										
	40—49		1		1	1	3	1												
	50—59		3	1	1	1	1	1												
	60—69			1	2															
	70—79																			
	80—89		1	1	1															
	90—99			1																
	Total	5	9	11	14	10	13	6	4	1	4	2	2		1			1		6

APPENDIX V—*continued*

TABLE F—FREQUENCY OF RATIOS OF MAXIMUM GUSTS AT 150 FEET TO GEOSTROPHIC WIND—*continued.*

Time G.M.T.	Geo-strophic wind speed	<0·5	0·5	0·6	0·7	0·8	0·9	1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	2·0>	In-deter-minate
	(mi./hr.)						September, October, November—*continued*													
7h.	<10		1	1		2	2	2						1						4
	10—19	1	1	1	2	5	4	2	1	1	1			1						
	20—29	7	3	3	5	3	3	3			1									
	30—39		2		2	2	1	1	2		1									
	40—49	1	3		1	3	1	1												
	50—59		1	1	2		1													
	60—69		2			1														
	70—79																			
	80—89		1																	
	Total	9	14	6	12	16	12	9	3	1	3			2						4
13h.	<10					1		1									1		3	4
	10—19	1		1	1	1	3	1	2	3	1	3	1	1	3	1			1	
	20—29		1	2	2	1	6	1	1	1	2	1	3	2	1			1		
	30—39		1		1	2	3	3	3	2		2				1				
	40—49						2	1		2										
	50—59				1		1	1	1											
	60—69						1													
	70—79			1																
	80—89			1	1															
	Total	1	2	5	6	5	16	8	7	8	3	6	4	3	4	2	1	1	4	4
18h.	<10				1				1							1			3	7
	10—19	2	1	1	2	3	3	2	1	3	3	2	2	1						
	20—29	1		2		2	3	7	2	1				1			1			
	30—39	2	1	2	2	2	1	3		1	1		1							
	40—49	1		2	1		2		1											
	50—59			1	1															
	60—69				1			1												
	70—79			1	2		1													
	80—89																			
	90—99			1																
	Total	6	2	10	10	7	10	13	5	5	4	2	3	2		1	1		3	7
	(mi./hr.)						December, January, February													
1h.	<10																			2
	10—19	6	3	2	1	3		2	1	2		2								
	20—29	2	3	2	3	3	2	3	1		1			1						
	30—39	1	3	2	4	1	1		2	2										
	40—49		1	2	1			1	1											
	50—59		1	2		4	1	1												
	60—69			1	2	4														
	70—79	1		1	1	1														
	80—89			1																
	90—99																			
	100				2															
	Total	10	11	13	14	16	4	7	5	4	1	2		1						2
7h.	<10	1		1										1						3
	10—19			2	2	4	5		3	2	4	1		1					1	
	20—29	1		2	6	2	1	3	2	1				1					1	
	30—39		1	1	3	1	3		2	1	1									
	40—49			1	3	3	1	2												
	50—59	1		4	1		1													
	60—69						1													
	70—79			1																
	80—89		1	1	3	1														
	100				1															
	Total	3	2	13	19	11	12	5	7	4	5	1		3					2	3

APPENDIX V—*continued*

TABLE F—FREQUENCY OF RATIOS OF MAXIMUM GUSTS AT 150 FEET TO GEOSTROPHIC WIND—*continued*.

Time G.M.T.	Geo-strophic wind speed	Ratio																		
		<0·5	0·5	0·6	0·7	0·8	0·9	1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	>2·0	In-deter-minate
	(mi./hr.)						December, January, February—*continued*													
	<10													1	1					3
	10—19			4	1	1	5	1	1			2	2	2		1				
	20—29	1		4		2	3	2	3	4	4	1								
	30—39			2	2	1		3	2	2	1	1	1							
13h.	40—49			1	2	1	3	3	1			1								
	50—59			1	1	1		3				1								
	60—69	1			1			1												
	70—79					1														
	80—89				1		2													
	Total	2		12	8	7	13	13	7	6	5	6	3	3	1	1				3
	<10								1	1		1	1			1				1
	10—19	2		1		1	2	4	3	3	2	1								
	20—29	4	2	1	2	2		6	3	2		1	1							
	30—39			2	2	6	2	1			1	1		1						
	40—49			1	1	2	2			1	1									
18h.	50—59		2	2	1	1	1		1											
	60—69				4	1	1													
	70—79					3														
	80—89																			
	90—99																			
	Total	6	4	7	10	16	8	11	8	7	4	4	2	1		1				1

APPENDIX V—*continued*

TABLE G.—FREQUENCY OF BACKING OF WIND AT 150 FEET FROM DIRECTION OF ISOBARS

G.M.T.	Geo-strophic wind	Veered	0°–4°	5°–9°	10°–14°	15°–19°	20°–24°	25°–29°	30°–34°	35°–39°	40°–44°	45°–49°	50°–54°	55° and over
	(mi./hr.)					March, April, and May, 1929								
1h.	10—29	4		1	2	2	4	2	5	9	8	2	2	14
	30—49	1			1		2	1	1	1	3			
	50 & over						1			1			1	
	Total	5		1	3	2	7	3	6	**11**	**11**	2	2	14
7h.	10—29	6	1	1	2	2	5	4	10	4	3	5	4	8
	30—49			1		1	5	2	1	1				
	50 & over							1			1			
	Total	6	1	2	2	3	10	7	**11**	5	4	5	4	8
13h.	10—29	6	5	3	4	6	1	8	2	5	4	2		11
	30—49			1		5	2		3	1		1		1
	50 & over			1	1			1						
	Total	6	5	5	5	**11**	3	9	5	6	4	3		12
18h.	10—29	10	5			5	4	8	2		5	4	3	9
	30—49	1	1	1	2		1		1	3		1		4
	50 & over		1			1			1					
	Total	11	7	1	2	6	5	**8**	4	3	5	5	3	13
	(mi./hr.)					June, July, and August, 1929								
1h.	10—29	4		4	7	6	3	6	2	5	2	4	3	5
	30—49		1	2	1	1	3	3	1	2			1	
	50 & over								1					
	Total	4	1	6	8	7	6	**9**	4	7	2	4	4	5
7h.	10—29	8	3	7	5	5	6	5	10	2	4	1	2	3
	30—49			1	1	3	1	1	1		2	1		
	50 & over		1											
	Total	8	4	8	6	8	7	6	**11**	2	6	2	2	3
13h.	10—29	11	2	4	6		7	6	3	2	5	6	1	4
	30—49	1		2	1	1	5		3	1	1			
	50 & over	1			1									
	Total	13	2	6	8	1	**12**	6	6	3	6	6	1	4
18h.	10—29	9	3	4	1	4	3	9	4	3	6	3	1	6
	30—49					2	4	2	1					
	50 & over		1			1								
	Total	9	4	4	1	7	7	**11**	5	3	6	3	1	6
	(mi./hr.)					September, October, and November, 1929								
1h.	10—29	4	1	2	3	3	2	5	8	4	1	3	3	5
	30—49	1			1	1	4	2	2	3	3			
	50 & over	1				1	4	2	4	2			1	
	Total	6	1	2	4	5	10	9	**14**	9	4	3	4	5
7h.	10—29	1		1	2	4	7	7	6	3	6	2	5	4
	30—49					4	1	4	2	4	2	2	2	
	50 & over				1	1	1	2	1	1	1			
	Total	1		1	3	9	9	**13**	9	8	9	4	7	4

APPENDIX V—*continued*

TABLE G.—FREQUENCY OF BACKING OF WIND AT 150 FEET FROM DIRECTION OF ISOBARS—*continued*

G.M.T.	Geo-strophic wind	Veered	0°–4°	5°–9°	10°–14°	15°–19°	20°–24°	25°–29°	30°–34°	35°–39°	40°–44°	45°–49°	50°–54°	55° and over
	(mi./hr.)			September, October, and November, 1929—*continued*										
13h.	10—29	5	5	5	6	6	1	5	5	5	1	2		2
	30—49	1	1	3	5	3	4	2	1	2	1			
	50 & over				1		5		1	1				
	Total	6	6	8	**12**	9	10	7	7	8	2	2		2
18h.	10—29	2	2	2	4	2	4	4	4	2	5	3	5	4
	30—49	1		1	2	4	2	3	1	3	1	1	2	1
	50 & over					2	1	2	2	2				
	Total	3	2	3	6	8	7	**9**	7	7	6	4	7	5
	(mi./hr.)				December, 1929, January and February, 1930									
1h.	10—29	3	6	1	4	1	1	2	7	4	3	3	1	4
	30—49					4	3	5	2	1	2	2	2	1
	50 & over			2		1	3	5	8	1	1	1	1	
	Total	3	6	3	4	6	7	12	**17**	6	6	6	4	5
7h.	10—29	1	1			4	4	4	8	9	4	4	1	2
	30—49				3		4	2	8	4	2			
	50 & over				3	2	5	4	1		1			
	Total	1	1		6	6	13	10	**17**	13	7	4	1	2
13h.	10—29		4	3	7	4	6	6	4	2	1	2	1	1
	30—49	1	1	1	3	3	8	2	1	2	2			
	50 & over					2	5	3	4					
	Total	1	5	4	10	9	**19**	11	9	4	3	2	1	1
18h.	10—29	1			3	7	4	2	9	7	3	2	4	2
	30—49			1	2	1		6	6	4	1	3	3	1
	50 & over					3	2	3	3	1				
	Total	1		1	5	11	6	11	**18**	12	4	5	7	3
	(mi./hr.)					Year (March 1929 to February, 1930)								
1h.	10—29	15	7	8	16	12	10	15	**22**	**22**	14	12	9	28
	30—49	2	1	2	3	6	**12**	11	6	7	8	2	3	1
	50 & over	1		2		2	8	7	**13**	4	1	1	2	
	Total	18	8	12	19	20	30	33	**41**	33	22	15	14	29
7h.	10—29	16	5	9	9	15	22	20	**34**	18	17	12	12	17
	30—49			2	4	8	11	9	**12**	9	6	3	2	
	50 & over		1		4	3	6	**7**	2	1	3			
	Total	16	6	11	17	26	39	36	**48**	28	26	15	14	17
13h.	10—29	22	16	15	23	16	15	**25**	14	14	11	12	2	18
	30—49	3	2	7	9	12	**19**	4	8	6	4	1		1
	50 & over	1		1	3	2	**10**	4	5	1				
	Total	26	18	23	35	30	**44**	33	27	21	15	13	2	19
18h.	10—29	22	10	6	8	18	15	**23**	19	12	19	12	13	21
	30—49	2	1	3	6	7	7	**11**	9	10	2	5	5	6
	50 & over		2			**7**	3	5	6	3				
	Total	24	13	9	14	32	25	**39**	34	25	21	17	18	27

APPENDIX VI—TABULATIONS OF 5 SECOND MEAN VALUES OF WIND SPEED AND DIRECTION AT 30 FEET (OR 40 FEET), AND 50 FEET DURING CERTAIN PERIODS OF 10 MINUTES DURING WHICH ULTRA-QUICK RUNS WERE OBTAINED WITH ANEMOMETER HEADS AT TWO HEIGHTS

ULTRA-QUICK RUN DUAL RECORD

(Anemometer heads at 50 feet and 40 feet).

March 21, 1929. Duration 10 min. Commencing 16h. 7m. G.M.T.
Approx. mean speed 17 mi./hr. Approx. mean direction 210°

Ref. no. 525X

	Five-second means					Five-second means					Five second means					Five-second means			
	Speed mi./hr.		Direction			Speed mi./hr.		Direction			Speed mi./hr.		Direction			Speed mi./hr.		Direction	
	C (50ft.)	C′ (40ft.)	C (50ft.)	C′ (40ft.)		C (50ft.)	C′ (40ft.)	C (50ft.)	C′ (40ft.)		C (50ft.)	C′ (40ft.)	C (50ft.)	C′ (40ft.)		C (50ft.)	C′ (40ft.)	C (50ft.)	C′ (40ft.)
1	15	17	203	206	6	16	18	208	211	11	15	16	204	205	16	18	19	215	215
	18	19	197	204		16	17	207	212		16	19	204	206		22	23	217	217
	15	17	196	202		16	19	209	212		14	16	208	211		21	22	222	224
	16	18	202	199		14	16	209	213		13	17	206	207		21	21	218	223
	15	17	203	203		14	16	208	211		15	15	205	208		18	19	214	217
	14	15	203	205		15	17	207	210		15	15	206	207		20	22	213	214
2	14	16	206	208	7	15	17	209	212	12	14	15	208	209	17	21	23	213	215
	14	15	203	207		15	16	209	212		14	16	203	205		22	22	217	216
	13	15	200	204		16	18	207	211		14	15	210	214		21	23	210	213
	16	16	194	196		15	16	207	208		14	15	213	213		22	22	213	216
	17	18	204	203		15	16	210	213		13	15	213	211		22	22	216	211
	17	17	208	210		14	15	203	206		12	13	212	213		21	20	219	221
3	16	17	205	208	8	16	16	202	201	13	13	13	212	214	18	19	20	215	216
	15	16	199	202		13	15	199	203		12	14	215	215		20	21	216	217
	20	20	203	204		13	15	210	213		12	14	205	209		20	21	222	220
	19	20	204	206		16	15	205	206		11	12	213	212		19	19	221	224
	18	20	200	203		14	13	209	213		11	12	214	215		17	19	216	218
	18	19	200	204		15	20	204	207		11	11	219	220		20	22	214	215
4	18	19	208	209	9	17	19	202	204	14	13	12	209	214	19	20	21	217	217
	16	19	202	207		18	20	200	201		15	17	213	214		20	21	215	217
	15	18	201	202		17	18	206	203		16	17	205	207		21	23	215	215
	14	17	198	203		15	16	212	209		17	17	205	209		21	22	218	217
	16	19	206	208		16	17	210	213		14	15	207	204		20	21	212	214
	14	17	207	212		16	17	207	209		14	15	215	217		20	22	216	214
5	14	17	208	211	10	16	17	209	210	15	16	16	218	220	20	19	22	218	214
	16	18	206	208		16	18	208	212		17	19	216	219		19	21	219	219
	18	20	209	212		15	18	209	210		16	18	209	214		20	21	217	220
	17	19	210	213		16	19	207	208		19	21	207	210		21	23	216	217
	17	18	209	212		16	18	202	204		19	19	213	211		21	24	215	216
	17	19	208	212		15	16	203	205		17	17	219	219		22	23	213	216

APPENDIX VI—*continued*

ULTRA-QUICK RUN DUAL RECORD

(Anemometer heads at 50 feet and 30 feet).

October 8, 1930. Duration 10 min. Commencing 14h. 38m. G.M.T.
Approx. mean speed 29 mi./hr. Approx. mean direction 235°

Ref. no. 571

	Five-second means					Five-second means					Five-second means					Five-second means			
	Speed mi./hr.		Direction			Speed mi./hr.		Direction			Speed mi./hr.		Direction			Speed mi./hr.		Direction	
	C (50ft.)	C′ (30ft.)	C (50ft.)	C′ (30ft.)		C (50ft.)	C′ (30ft.)	C (50ft.)	C′ (30ft.)		C (50ft.)	C′ (30ft.)	C (50ft.)	C′ (30ft.)		C (50ft.)	C′ (30ft.)	C (50ft.)	C′ (30ft.)
1	27	27	237	235	6	26	24	238	232	11	21	21	236	230	16	37	31	237	235
	29	28	240	234		24	23	230	227		31	24	238	234		36	34	233	232
	29	25	238	242		22	20	236	227		31	25	238	237		35	32	242	240
	30	31	239	237		22	19	233	227		32	30	234	228		35	32	242	243
	33	30	232	228		25	24	227	228		29	31	242	235		32	29	233	236
	30	29	226	236		24	24	234	233		30	26	242	243		29	29	236	233
2	30	28	231	230	7	22	22	240	237	12	25	25	237	238	17	28	28	237	234
	31	31	228	229		20	22	232	230		25	23	238	236		34	29	233	238
	30	29	227	225		25	24	234	235		26	25	233	234		31	28	230	228
	27	28	223	228		21	21	231	229		26	26	232	238		31	29	227	223
	26	26	229	223		23	23	233	231		22	23	233	232		30	31	228	224
	26	27	230	231		24	22	237	228		25	25	241	240		32	31	231	228
3	28	26	233	233	8	21	22	237	235	13	29	24	243	241	18	32	31	234	233
	28	28	240	234		25	22	227	226		34	33	242	239		33	30	229	222
	30	25	243	243		31	29	235	235		35	32	244	239		35	29	234	228
	32	35	247	249		30	28	244	239		31	28	237	237		36	30	234	232
	34	37	242	243		29	26	240	238		29	29	239	235		36	31	238	234
	35	33	230	231		33	31	240	235		33	33	246	246		35	31	237	236
4	29	29	221	221	9	32	31	238	239	14	35	32	241	240	19	32	28	231	229
	30	29	224	228		32	33	236	237		26	27	235	234		33	28	231	229
	31	30	232	227		27	25	224	231		27	24	233	231		31	28	235	237
	32	28	232	233		27	25	230	229		34	31	239	234		33	33	238	236
	37	37	230	229		23	22	233	233		41	39	240	240		37	30	240	239
	35	35	235	235		20	19	237	234		39	37	248	243		37	36	243	233
5	35	30	228	228	10	20	18	235	228	15	35	34	234	232	20	33	34	240	231
	33	30	226	224		20	17	236	238		35	34	236	234		29	31	243	237
	31	34	230	228		19	20	229	232		33	33	238	238		31	28	238	242
	32	32	233	229		25	23	233	230		35	30	234	234		31	—	243	—
	33	31	230	230		28	26	229	225		31	30	231	231		31	—	235	—
	30	29	239	236		25	23	235	227		37	30	238	232		27	—	233	—

APPENDIX VI—*continued*

ULTRA-QUICK RUN DUAL RECORD

(Anemometer heads at 50 feet and 30 feet)

October 16, 1930. Duration 10 min. Commencing 22h. 22m. G.M.T.
Approx. mean speed 16 mi./hr. Approx. mean direction 170°

Ref. no. 579

	Five-second means			
	Speed mi./hr.		Direction	
	C (50ft.)	C′ (30ft.)	C (50ft.)	C′ (30ft.)
1	18	17	174	175
	16	15	171	173
	16	13	168	165
	17	14	168	173
	17	12	170	163
	18	12	174	165
2	16	13	170	167
	16	13	178	175
	22	18	173	176
	19	14	170	175
	19	15	169	165
	21	15	176	171
3	17	16	170	174
	21	16	172	174
	17	16	173	173
	18	14	176	176
	19	14	173	174
	18	15	172	177
4	21	16	172	168
	20	18	177	176
	19	16	177	178
	19	17	171	174
	19	16	170	170
	18	14	168	172
5	17	15	175	171
	18	14	171	172
	17	12	170	172
	17	13	170	169
	18	13	171	168
	19	15	174	170

	Five-second means			
	Speed mi./hr.		Direction	
	C (50ft.)	C′ (30ft.)	C (50ft.)	C′ (30ft.)
6	17	14	173	172
	18	17	176	170
	17	15	176	173
	17	13	—	174
	17	15	—	171
	16	12	—	173
7	16	12	—	172
	14	12	175	171
	16	13	180	174
	20	13	175	173
	17	12	177	175
	17	11	179	179
8	18	15	177	175
	17	15	171	174
	14	14	173	174
	16	13	172	176
	16	12	175	175
	15	11	174	176
9	16	12	172	171
	20	16	176	178
	19	15	173	167
	16	12	178	164
	14	11	178	175
	15	12	180	172
10	17	13	170	170
	18	15	172	171
	19	15	178	176
	20	15	177	179
	20	17	177	180
	19	17	170	173

	Five-second means			
	Speed mi./hr.		Direction	
	C (50ft.)	C′ (30ft.)	C (50ft.)	C′ (30ft.)
11	19	15	171	170
	18	16	169	173
	18	14	174	173
	18	15	178	176
	17	15	175	176
	16	12	170	168
12	18	13	171	176
	17	12	174	173
	18	11	177	174
	17	12	177	172
	18	12	174	176
	17	13	168	172
13	16	15	173	178
	17	14	179	174
	20	17	178	176
	18	16	177	176
	14	15	169	181
	18	14	172	169
14	20	15	171	175
	20	19	170	173
	20	18	173	172
	20	17	173	175
	20	15	171	174
	21	16	171	170
15	20	16	178	172
	21	16	173	174
	20	17	174	173
	18	15	176	175
	17	14	177	178
	19	15	171	175

	Five-second means			
	Speed mi./hr.		Direction	
	C (50ft.)	C′ (30ft.)	C (50ft.)	C′ (30ft.)
16	19	16	168	172
	20	16	164	170
	17	15	178	161
	18	12	177	183
	18	13	177	175
	16	12	172	173
17	17	12	173	170
	16	13	172	176
	15	12	173	171
	17	13	172	174
	16	14	169	173
	16	14	170	173
18	18	14	173	173
	18	13	171	170
	16	13	173	171
	20	15	174	175
	17	17	167	177
	17	14	173	169
19	20	14	178	175
	19	15	173	176
	19	15	171	173
	19	15	171	170
	21	16	166	170
	21	15	168	167
20	20	18	170	169
	18	16	168	172
	19	13	170	168
	19	18	168	172
	16	14	174	171
	17	14	175	175

APPENDIX VII.—WIND SPEEDS AND DIRECTIONS AT THREE HEIGHTS AVERAGED OVER 10 MINUTES ON CERTAIN OCCASIONS WHEN RECORDS WERE OBTAINED AT 30 FEET (OR 40 FEET) AND 50 FEET.

Record No.	Date	Time	40 feet (C)		50 feet (C)		150 feet (F)		Cloud	Gradient wind		Temp. diff. (170 ft.)
			Speed	Dir.	Speed	Dir.	Speed	Dir.		Speed	Dir.	
			mi./hr.	°	mi./hr.	°	mi./hr.	°		mi./hr.	°	
525	21.3.29	1513	21·1	204?	18·3	202?	24·4	208	St.Cu.2, A.St.7.	30	225	−0·6
525X	21.3.29	1607	19·0	211	17·0	209	23·5	217	St.Cu.2, A.St.7	30	225	−0·6
526	22.3.29	1532	15·3	250?	14·2	248?	11·6	271	Fr.Cu. and St.Cu.	12	270	−1·6
527	25.3.29	1527	18·1	248	18·2	249	19·1	251	St.Cu.4 Cu.4, A.St.1	24	260	−0·7
527B	25.3.29	1549	20·8	252	21·3	251	20·0	253	Nb. and St.Cu.9, A.St.1,r.	24	260	−0·8
528	28.3.29	1442	11·2	47	11·4	46	10·4	63	Nil.	5	30	−0·9
529	28.3.29	1548	12·1	55	12·4	53	10·7	52	Nil.	5	30	−0·4
532	5.4.29	1146	18·3	10	18·4	9	22·4	3	Nb, St. and St.Cu.9	29	30	—
533	5.4.29	1211	19·2	28	19·1	25	25·6	23	Nb, St. and St.Cu.9	29	30	—
534	16.4.29	1205	13·5	33	13·9	34	15·5	23	St.Cu.7	25	60	−2·1
535	17.4.29	1457	19·4	230	19·2	232	22·6	225	St.Cu.8	18	230	−2·0
536	24.4.29	0939	19·3	284	20·8	283	22·1	280	St.Cu.2, Cu.tr.	18	290	—
537	6.5.29	1047	37·9	184	37·6	186	48·4	193	St.Cu.8, Fr.Cu.tr.	65	210	−0·2
538	6.5.29	1111	37·1	187	36·8	187	43·7	197	St.Cu.8, Fr.Cu.2	65	210	−0·3
556	20.3.30	1528	30·1	238	30·7	235	31·1	241	Cu.8	45	260	−0·9
557	21.3.30	1430	20·2	207	19·0	206	22·9	217	Cu.5, A.St.3	40	240	−1·7
558	31.3.30	1108	24·9	170	23·3	166	26·1	175	A.St.6, A.Cu.2	35	210	−0·8
559	1.4.30	1451	22·9	153	20·6	149	26·1	158	St.Cu.2. A.St.6	60	200	0·0
560	2.4.30	1001	21·1	232	20·8	228	23·5	239	Fr.Cu.2, A.St.8	25	225	−1·0
561	29.4.30	1352	22·1	37	22·8	32	29·1	24	Fr.Cu.1	45	70	−2·0

Record No.	Date	Time	30 feet (C)		50 feet (C)		150 feet (F)		Cloud	Gradient wind		Temp. diff. (170 ft.)
			Speed	Dir.	Speed	Dir.	Speed	Dir.		Speed	Dir.	
			mi./hr.	°	mi./hr.	°	mi./hr.	°		mi./hr.	°	
562	2.7.30	1355	14·3	222	14·8	223	16·2	225	Cu.6	17	205	−3·4
565	21.8.30	1054	20·6	176	23·2	178	28·3	185	St.Cu. and Cu.9	45	215	−0·8
566	21.8.30	1127	16·5	173	18·8	173	22·3	181	A.St.1.	45	215	−0·6
567	22.8.30	1122	13·5	241	15·3	243	18·3	240	Cu.5, A.Cu.tr.	20	250	−1·8
568	26.8.30	0949	8·7	162	10·8	166	10·9	177	Nil.	17	190	−2·3
569	26.8.30	1023	6·6	169	8·9	169	11·4	181	Nil.	17	190	−2·6
570	6.10.30	1530	19·6	266	21·2	269	24·5	275	Cu.Nb.4, Cu.4, Ci.1.J.P.	30	290	−0·2
571	8.10.30	1438	29·2	233	30·6	235	37·9	235	Nb.10, r_0	45	250	−0·4
572	14.10.30	1430	17·0	175	18·7	177	(20·8)	(181)	A.St. and A.Cu.9. ir_0			0·3
573	14.10.30	1450	17·5	166	18·3	167	(22·5)	(172)	A.St. and A.Cu.10			0·4
574	14.10.30	1510	16·9	165	18·2	166	(19·7)	(171)	A.St. and A.Cu.10			0·5
575	14.10.30	1535	14·3	164	16·2	165	(19·0)	(170)	A.St. and A.Cu. 9	40	220	0·5
576	14.10.30	1555	14·8	165	15·5	165	(19·4)	(171)	A.St. and A.Cu.9			0·6
577	14.10.30	1615	14·8	167	16·5	168	(20·8)	(170)	A.St. and Cu.9			0·6
578	16.10.30	1555	14·5	186	16·4	190	17·0	195	Nil.	27	220	0·5
579	16.10.30	2222	15·6	169	18·4	169	(23·5)	(176)	Nil.			1·2
580	16.10.30	2250	15·7	172	18·2	173	(23·5)	(175)	Nil.	40		1·3
581	16.10.30	2306	15·3	167	17·4	169	(21·1)	(176)	Nil.	to	220	1·3
582	16.10.30	2326	13·4	164	15·7	165	(18·0)	(173)	Nil.	50		1·3
583	16.10.30	2345	11·8	175	14·6	175	(19·2)	(181)	Nil.			1·3
584	29.10.30	1513	15·9	230	17·7	228	21·0	231	St.8, A.St.2	35	270	−0·6
585	30.10.30	1425	21·1	248	22·8	248	24·3	249	St.Cu.3, Cu.3, Ci.1	—	—	−0·9
586	3.11.30	1513	16·9	289	18·2	289	14·3	292	Cu.7	50	310	0·4
587	4.11.30	1441	10·6	303	11·7	302	11·9	305	Nil.	30	340	1·0
588	6.11.30	1444	14·7	60	16·1	60	15·4	65	Cu.tr.	30	80	−0·5
589	6.11.30	1512	12·8	54	14·5	53	12·5	54		30	80	0·1
590	11.11.30	1503	13·5	301	14·6	299	16·6	302	Ci.4	40	340	0·5
591	13.11.30	1434	16·9	259	17·9	261	15·0	255	St.Cu.9	40	280	−0·6
592	15.11.30	0936	23·0	243	24·6	244	29·7	239	St.Cu.10	60	260	−0·8
593	19.11.30	1000	21·3	255	23·4	252	(30·0)	(252)				0·0
594	19.11.30	1027	25·6	257	27·0	257	(29·3)	(257)				0·0
595	19.11.30	1054	23·8	258	26·2	259	(29·4)	(256)	St. and St.Cu.9	65	300	0·0
596	19.11.30	1119	25·6	257	28·2	257	(28·3)	(253)				0·1
597	19.11.30	1146	25·7	259	28·0	257	(28·5)	(259)				0·3
598	22.11.30	1010	14·9	184	16·4	186	22·6	188	Cu.Nb.9, r.	40	250	−0·6
604	26. 2.31	1132	24·6	233	26·8	238	(25·8)	(241)	St. and A.St.9, ir.	55	280	−0·9
605	26. 2.31	1158	26·7	235	28·8	241	(30·7)	(239)	St. and A.St.9, ir.	55	280	−1·6
606	26. 2.31	1519	19·1	314	20·1	314	(19·6)	(321)	St and A.St.10	30	340	−0·6
607	26. 2.31	1543	17·8	309	19·8	308	(22·2)	(314)	St. and A.St.10	30	340	−0·6

Note.—The figures in brackets in the columns for speed and direction at 150 feet refer to measurements made from quick-run records.

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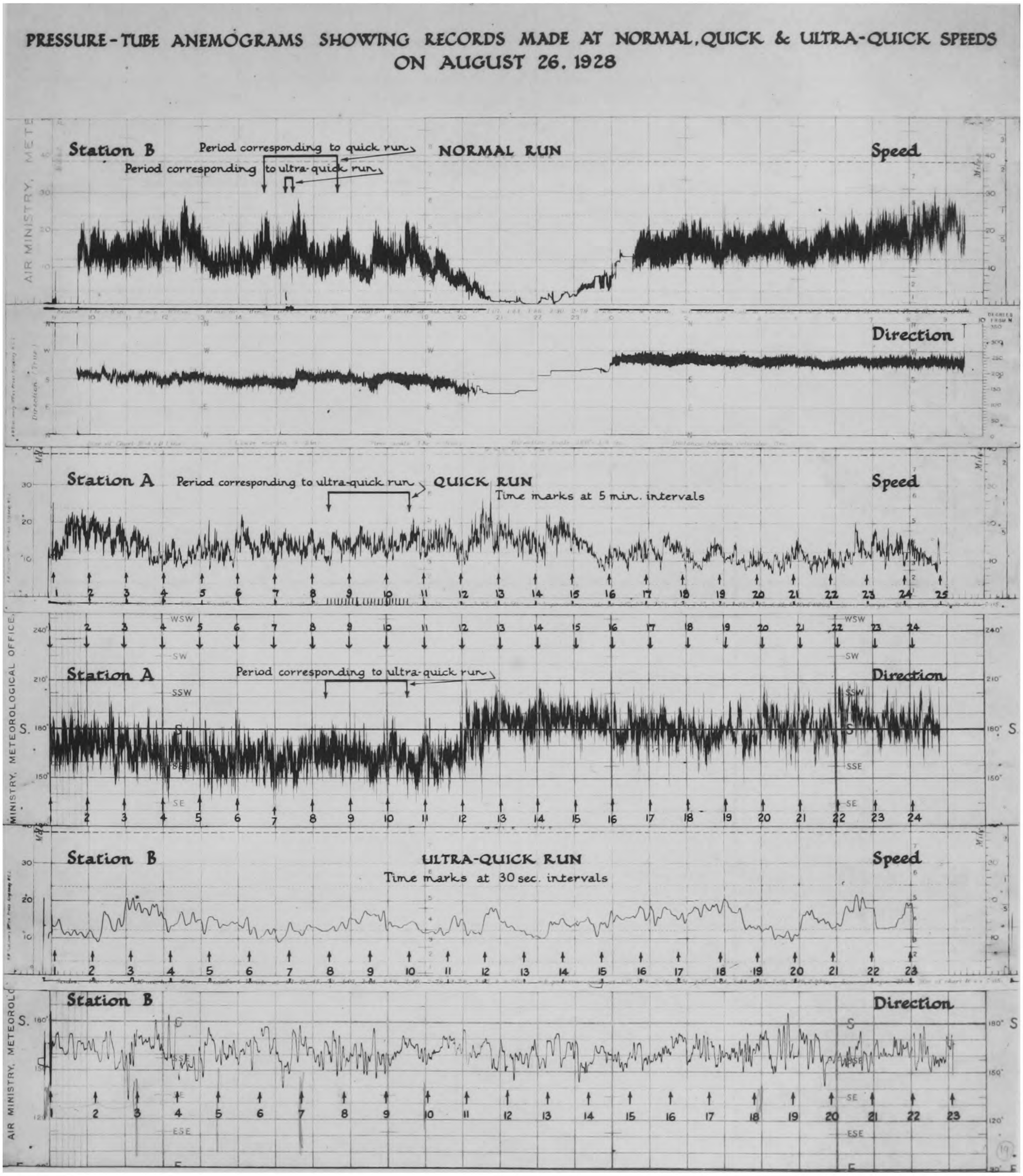

Fig. 19. This figure shows an example of normal, quick and ultra-quick runs made on the same occasion to illustrate the successive opening out of the trace when the time scale of the record is increased to 12 times and to 144 times the normal scale. The two upper traces show the speed and direction records on the normal time scale (i.e., the record shows 24 hours of wind). On this record two long arrows are marked to indicate the period during which the quick run record was being made and two short arrows to indicate the period during which the ultra-quick record was being made. The two middle traces show the quick run records for speed and direction (i.e., the record of 2 hours of wind), and arrows are placed on this record also to indicate the period during which the ultra-quick run record was being made. The two lowest traces show the ultra-quick records for speed and direction (i.e., the record of 10 minutes of wind).

CARDINGTON AUTOGRAPHIC RECORDS APRIL 10 - 11, 1929.

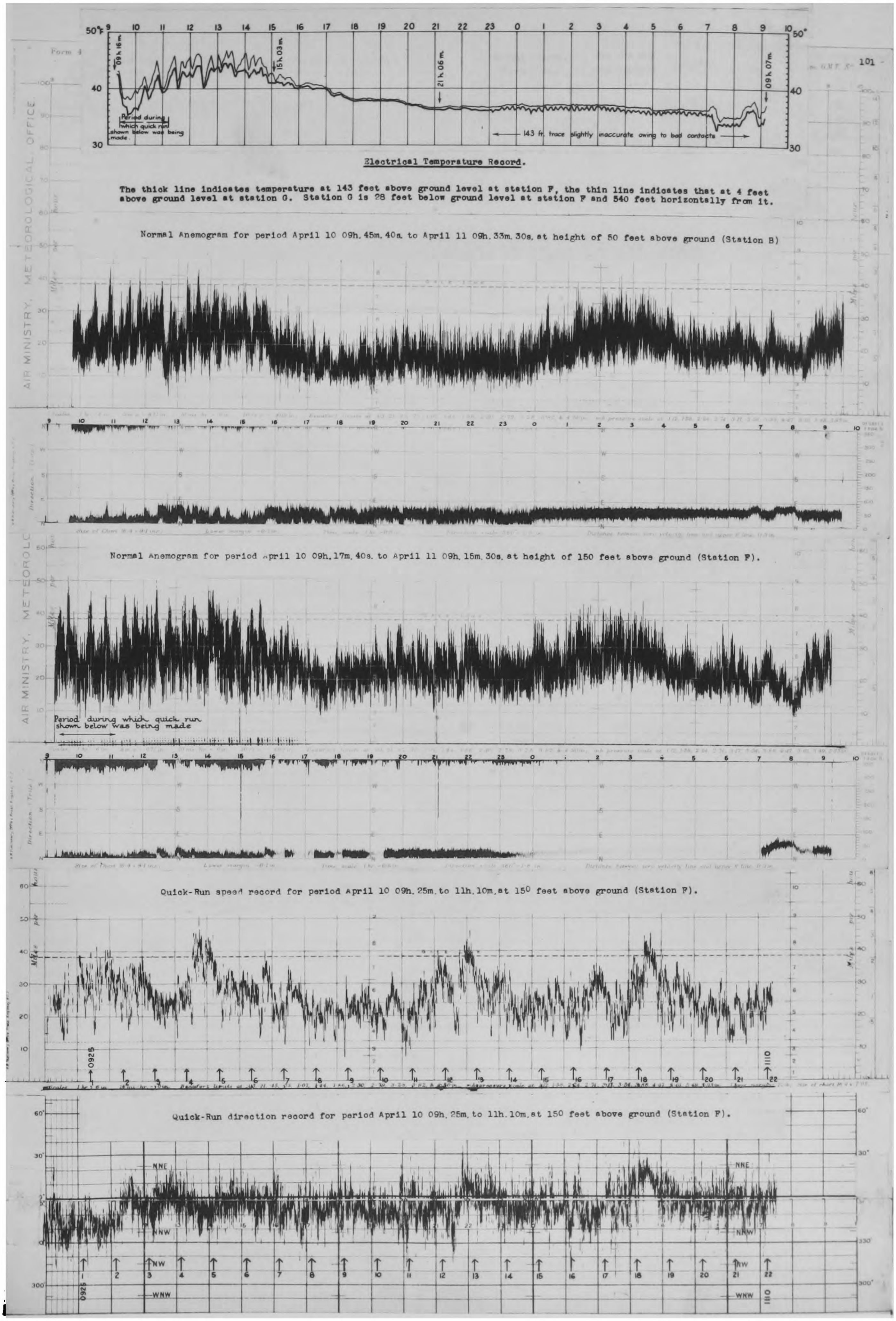

Fig. 29. April 10-11, 1929. The records illustrated above with those shown on Figs. 30 and 31 show examples of the different types of eddies which are found on the normal anemograms under differing conditions of the vertical temperature gradient.

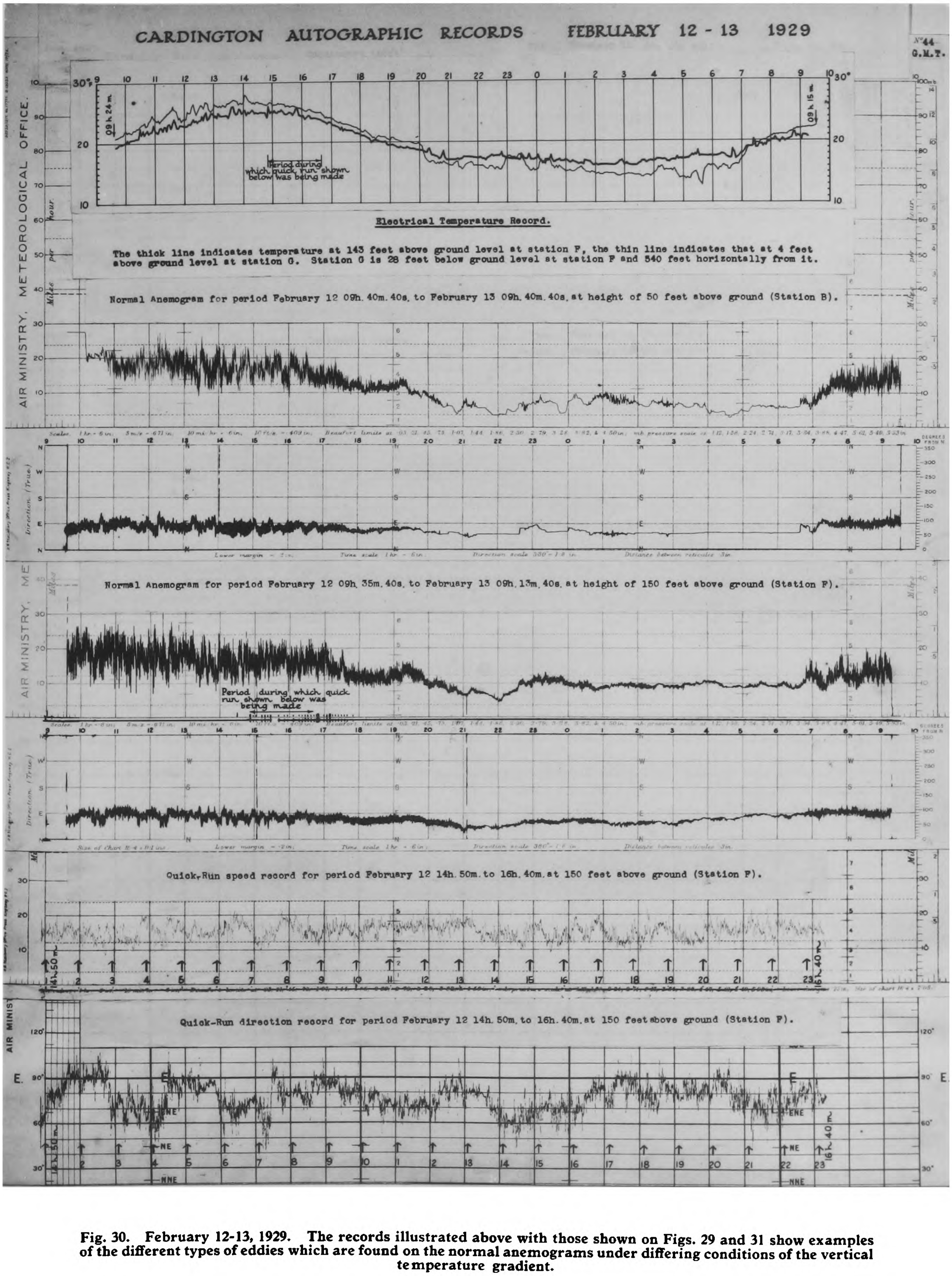

Fig. 30. February 12-13, 1929. The records illustrated above with those shown on Figs. 29 and 31 show examples of the different types of eddies which are found on the normal anemograms under differing conditions of the vertical temperature gradient.

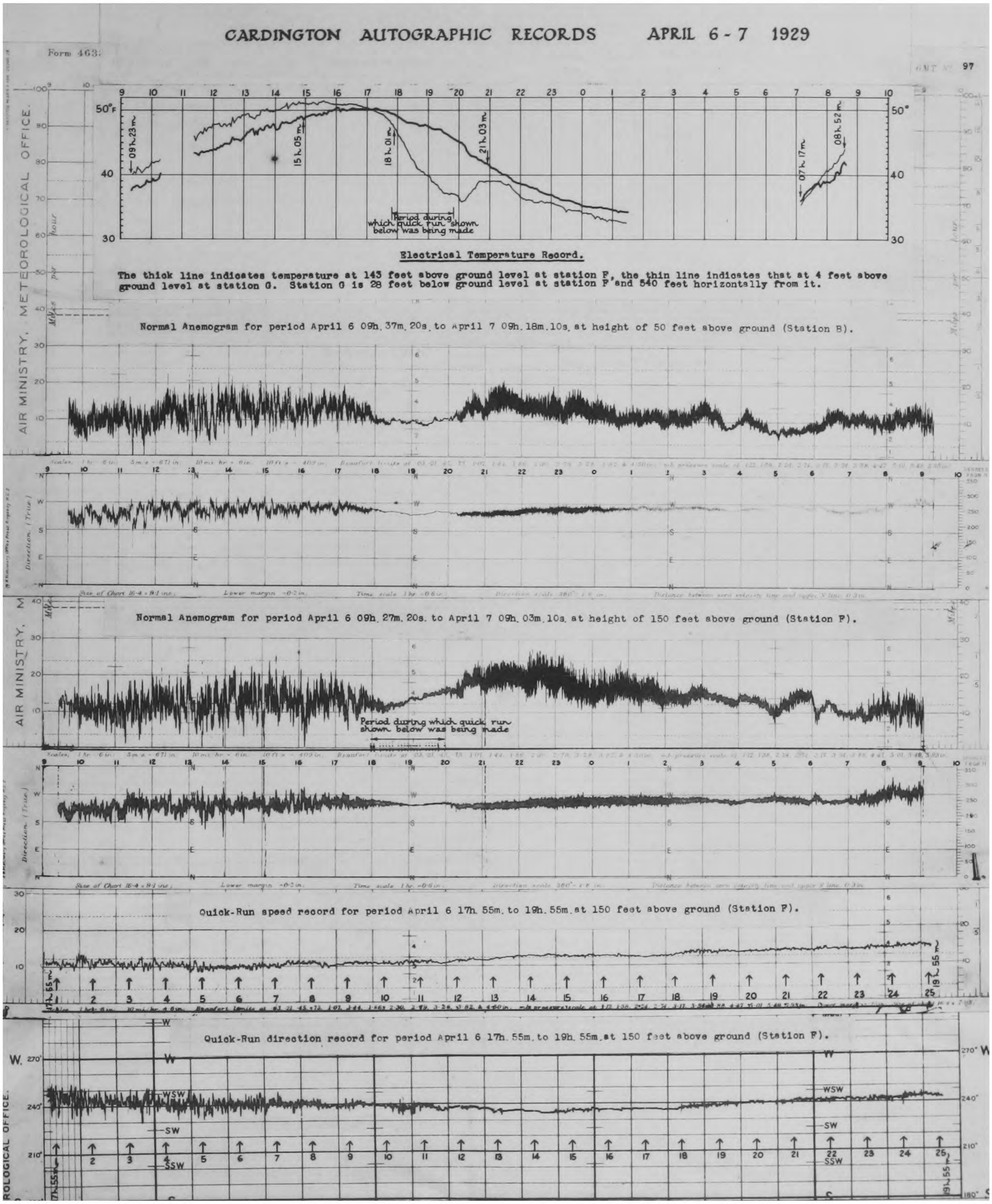

Fig. 31. April 6-7, 1929. The records illustrated above with those on Figs. 29 and 30 show examples of the different types of eddies which are found on the normal anemograms under differing conditions of the vertical temperature gradient.

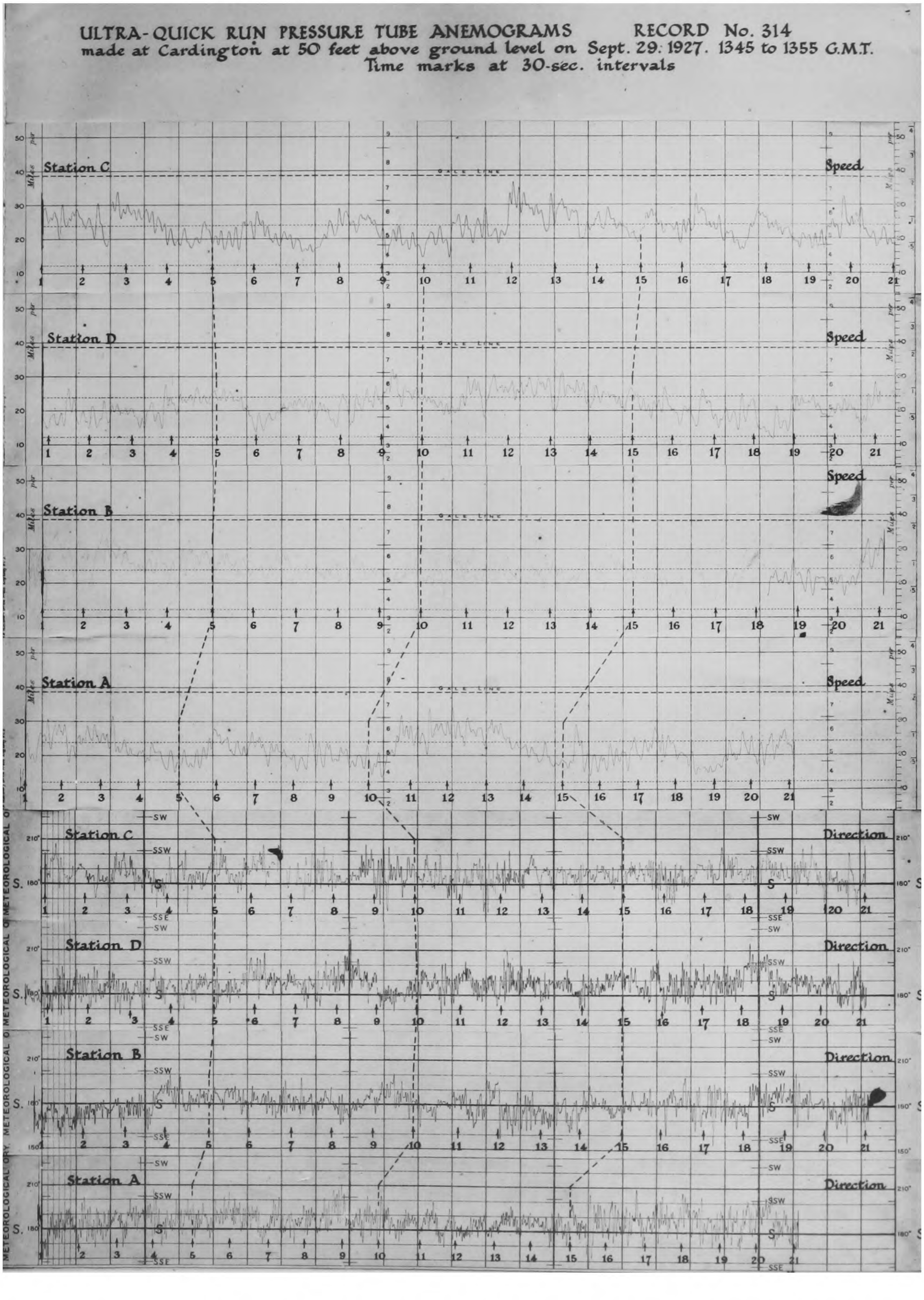

Fig. 33. Ref. No. 314. Sept. 29, 1927. These ultra-quick records illustrate the wind speeds and directions recorded at the four anemometers during ten minutes.

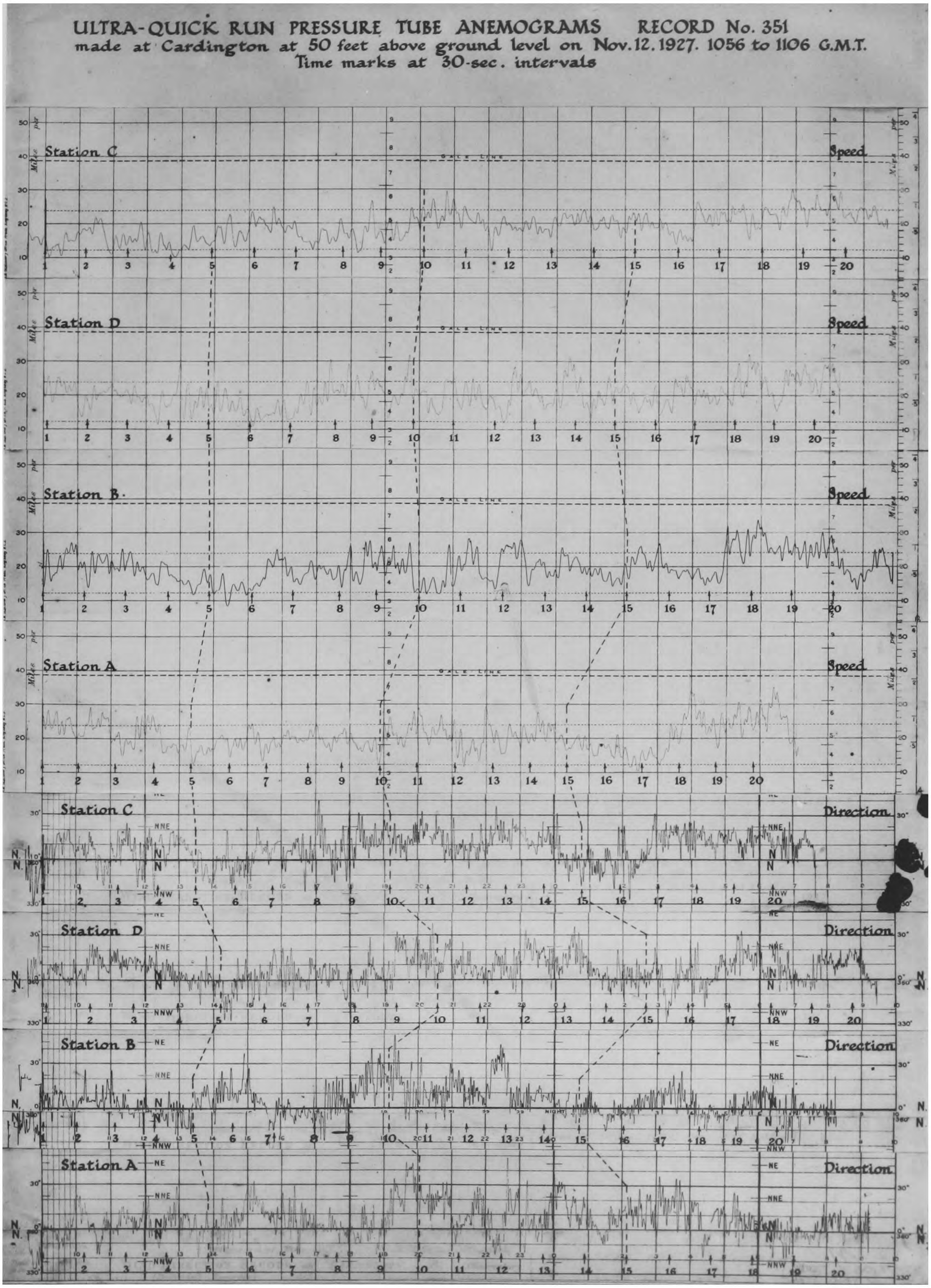

Fig. 34. Ref. No. 351. Nov. 12, 1927. These ultra-quick records illustrate the wind speeds and directions recorded at the four anemometers during ten minutes.

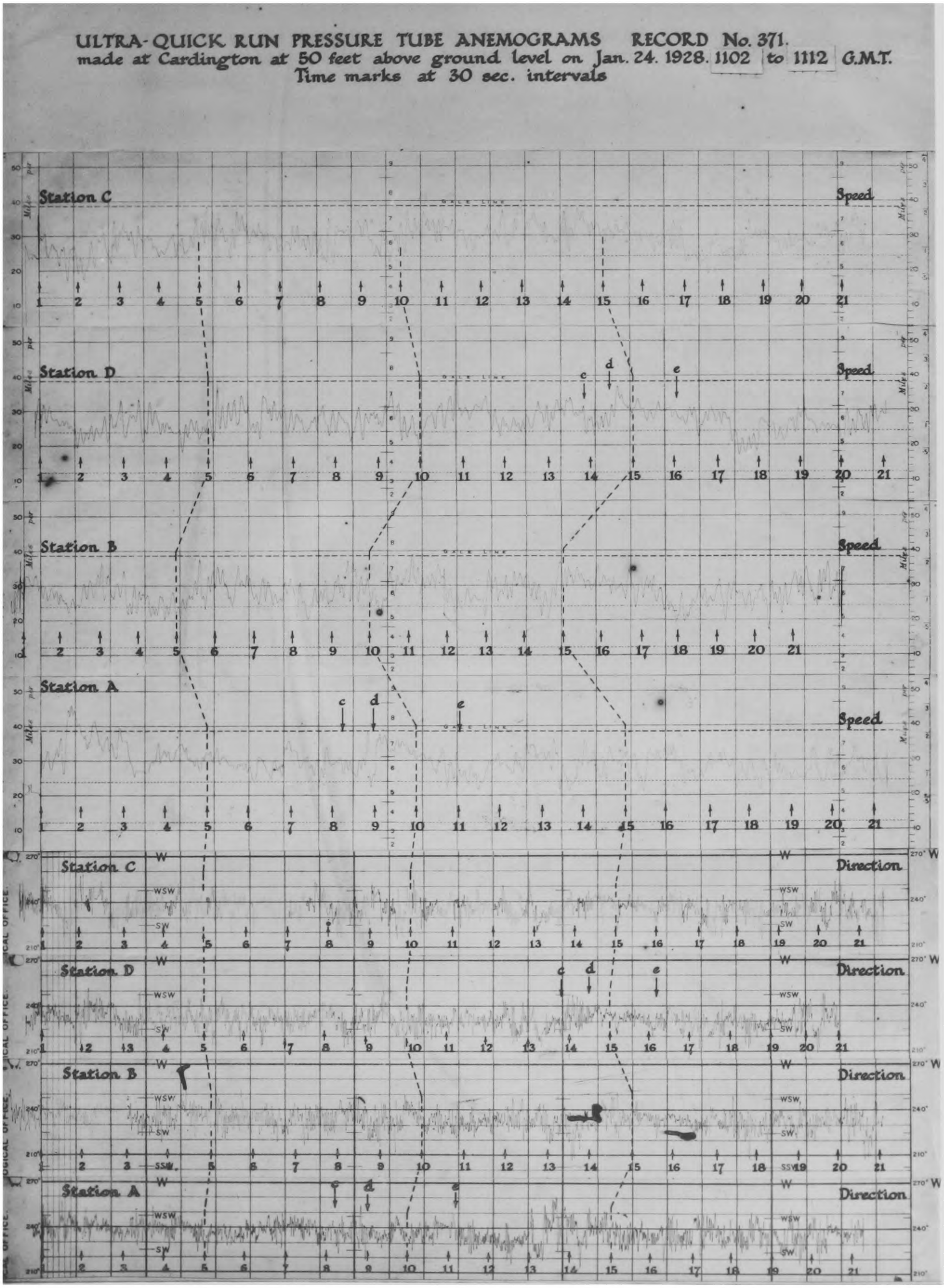

Fig. 35. Ref. No. 371. Jan. 24, 1928. These ultra-quick records illustrate the wind speeds and directions recorded at the four anemometers during ten minutes.

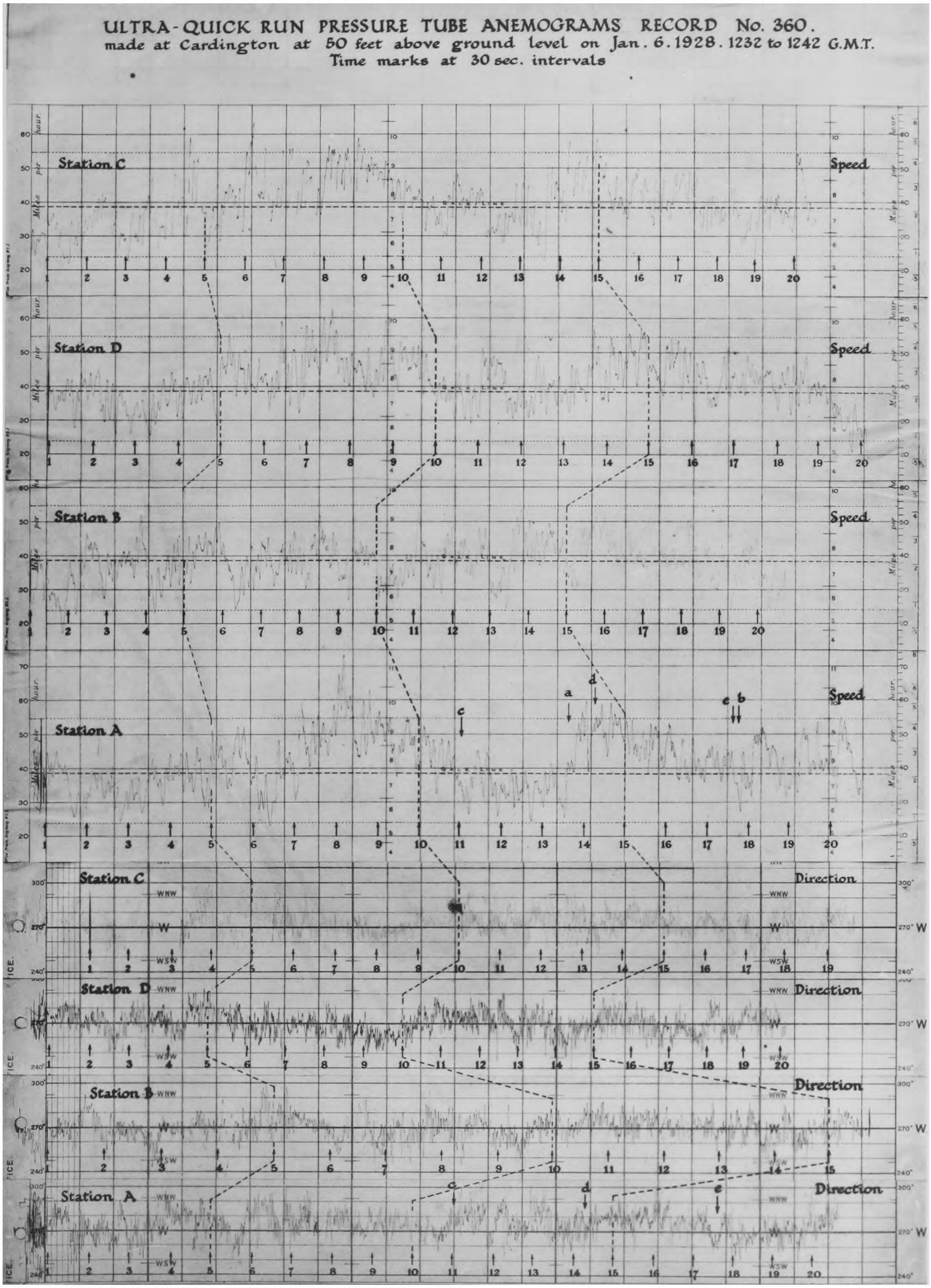

Fig. 36. Ref. No. 360. Jan. 6, 1928. These ultra-quick records illustrate the wind speeds and directions recorded at the four anemometers during ten minutes.

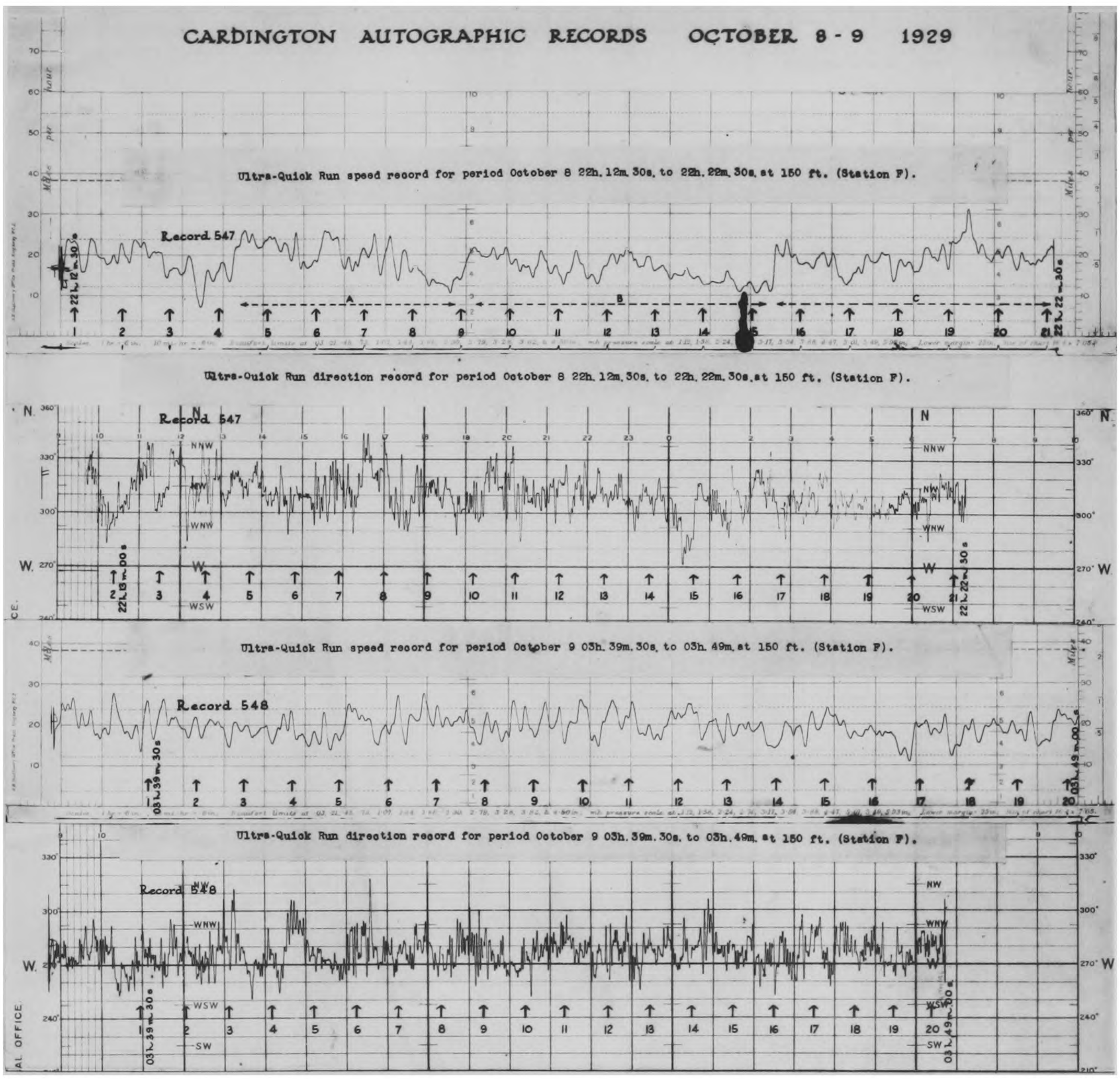

Fig. 50. Record 547, October 8, 1929, 22h. 12m. to 22h. 22m. and Record 548, October 9, 1929, 03h. 39m. to 03h. 49m. These ultra-quick runs, made on the high anemometer, show the contrast between eddies before and after a surface inversion has formed.

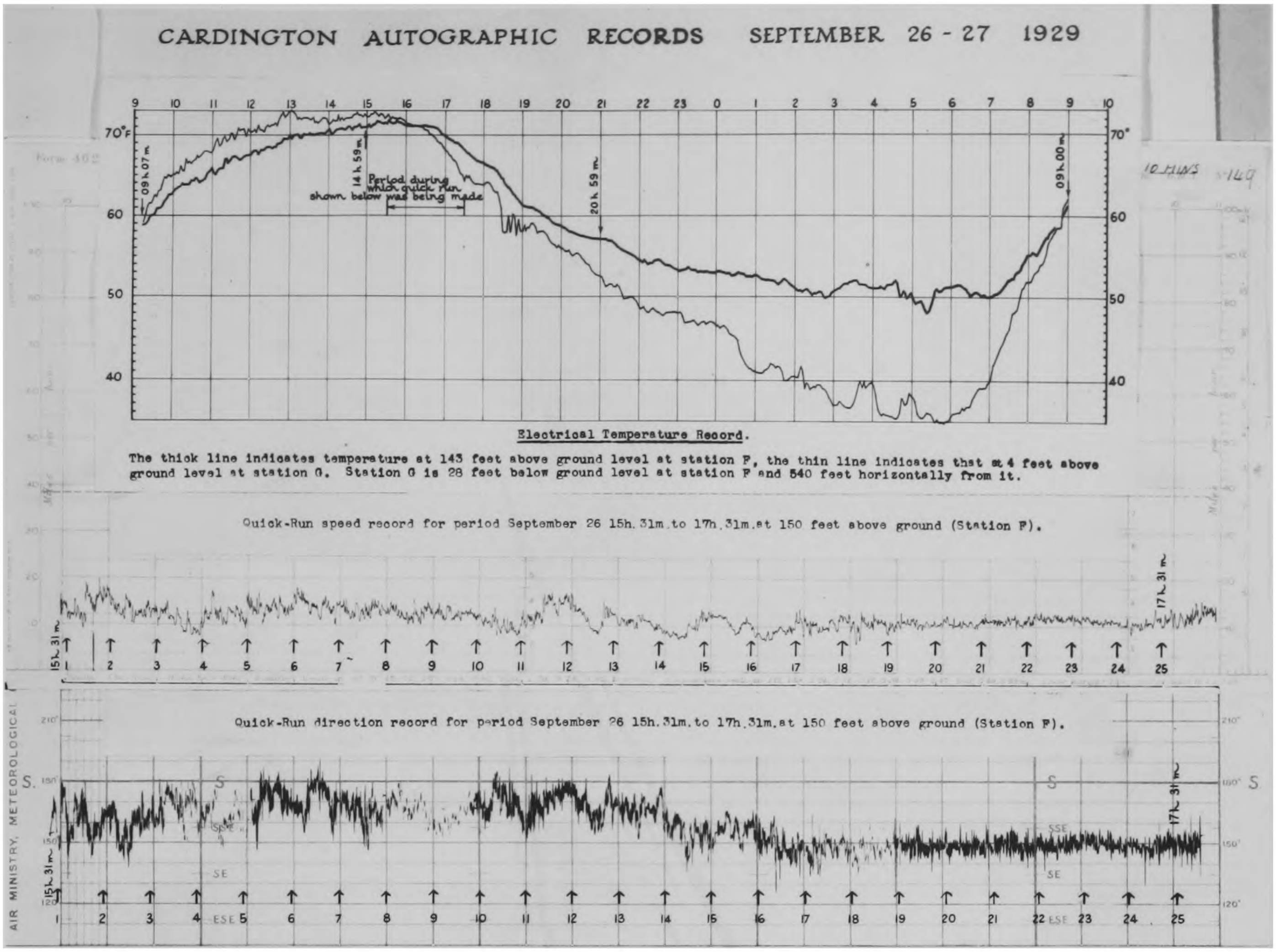

Fig. 52. Autographic records for September 26-27, 1929.

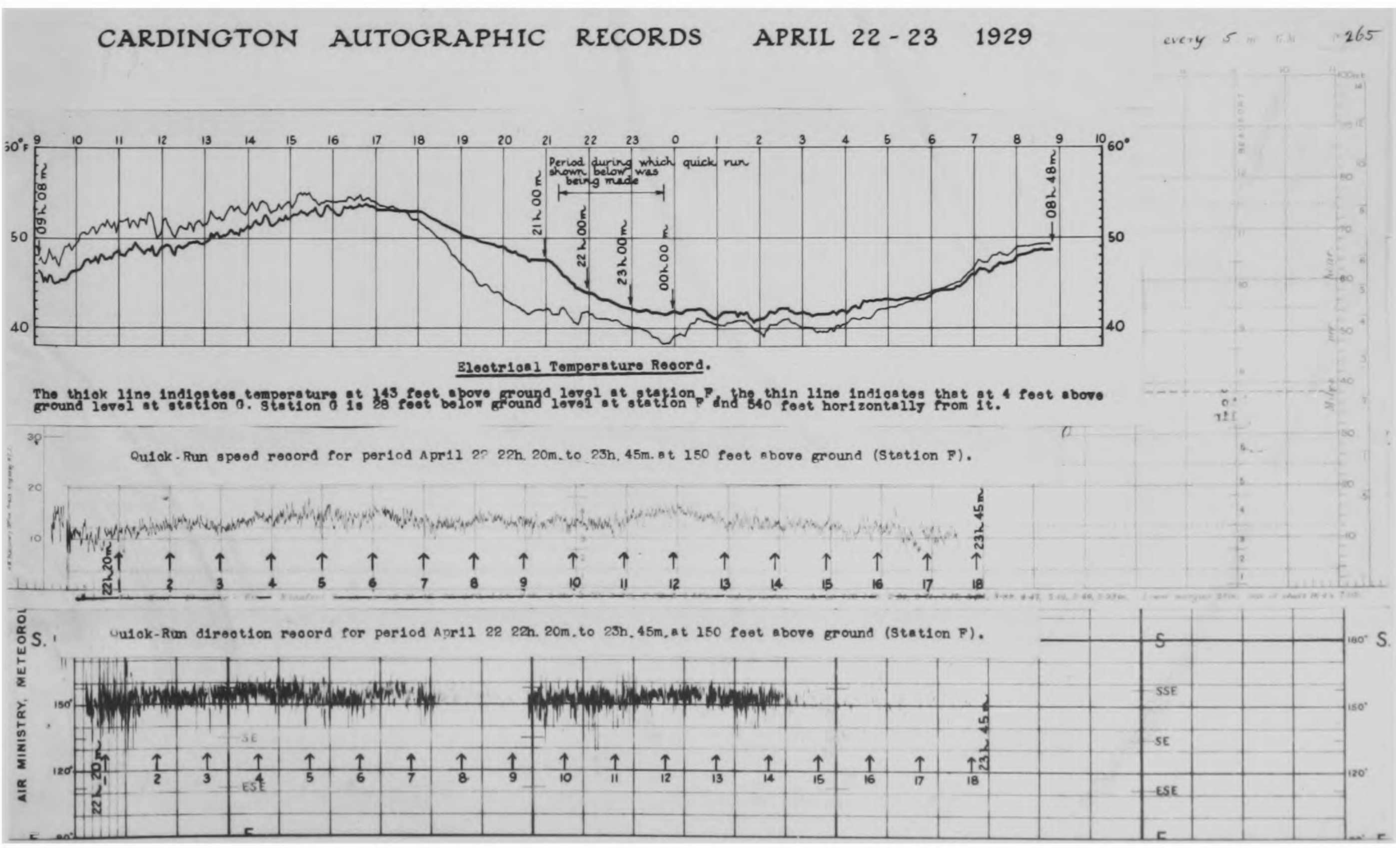

Fig. 53. Autographic records for April 22-23, 1929.

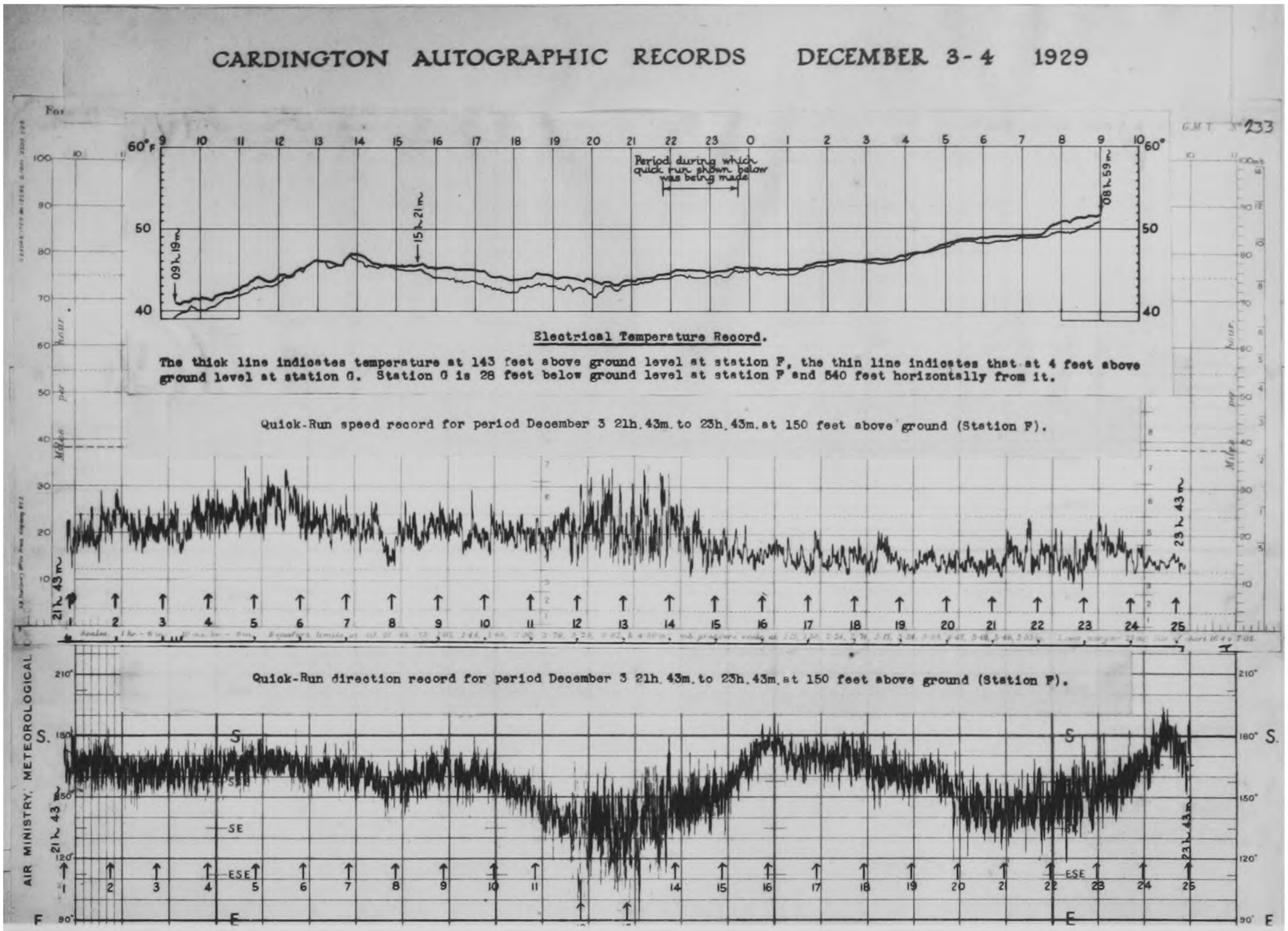

Fig. 54. Autographic records for December 3-4, 1929.

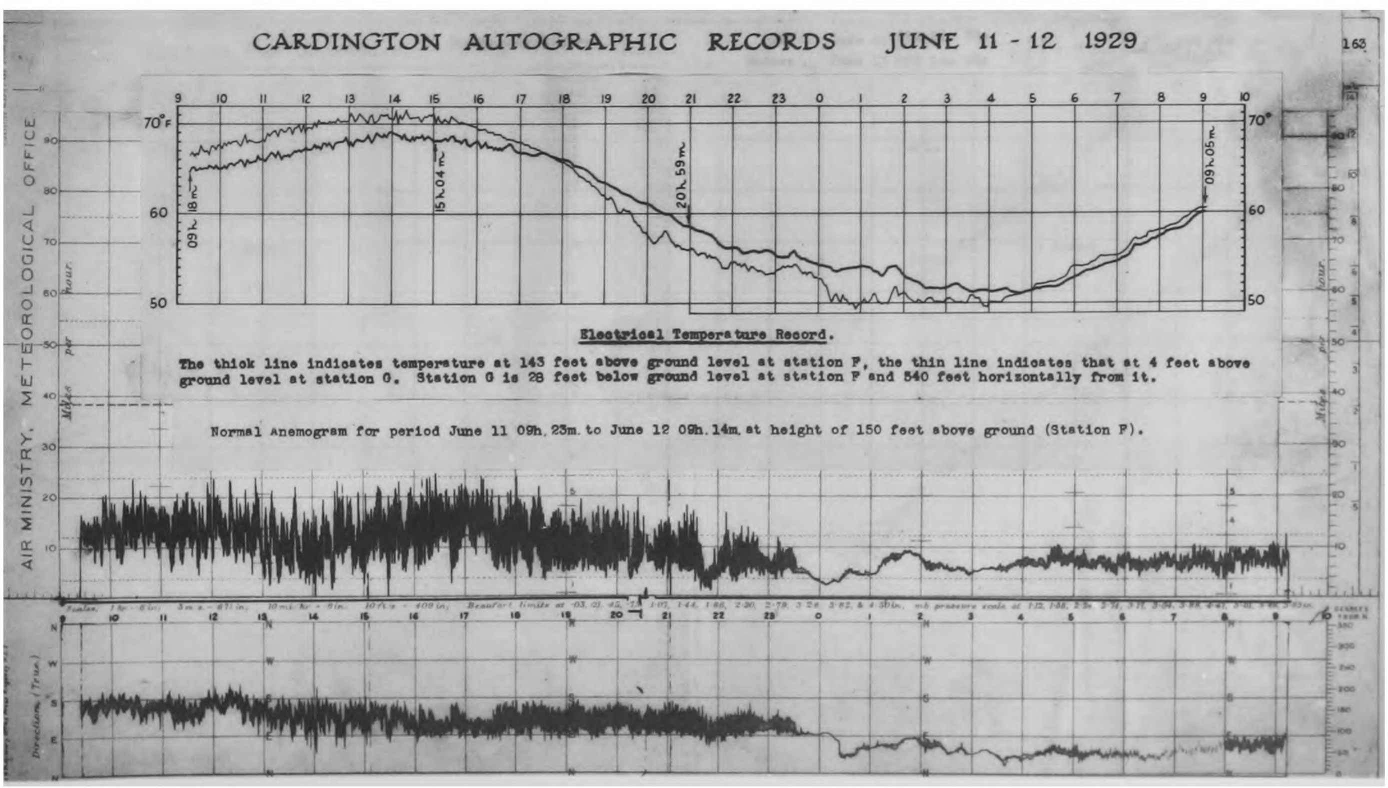

Fig. 55. Autographic records for June 11-12, 1929.

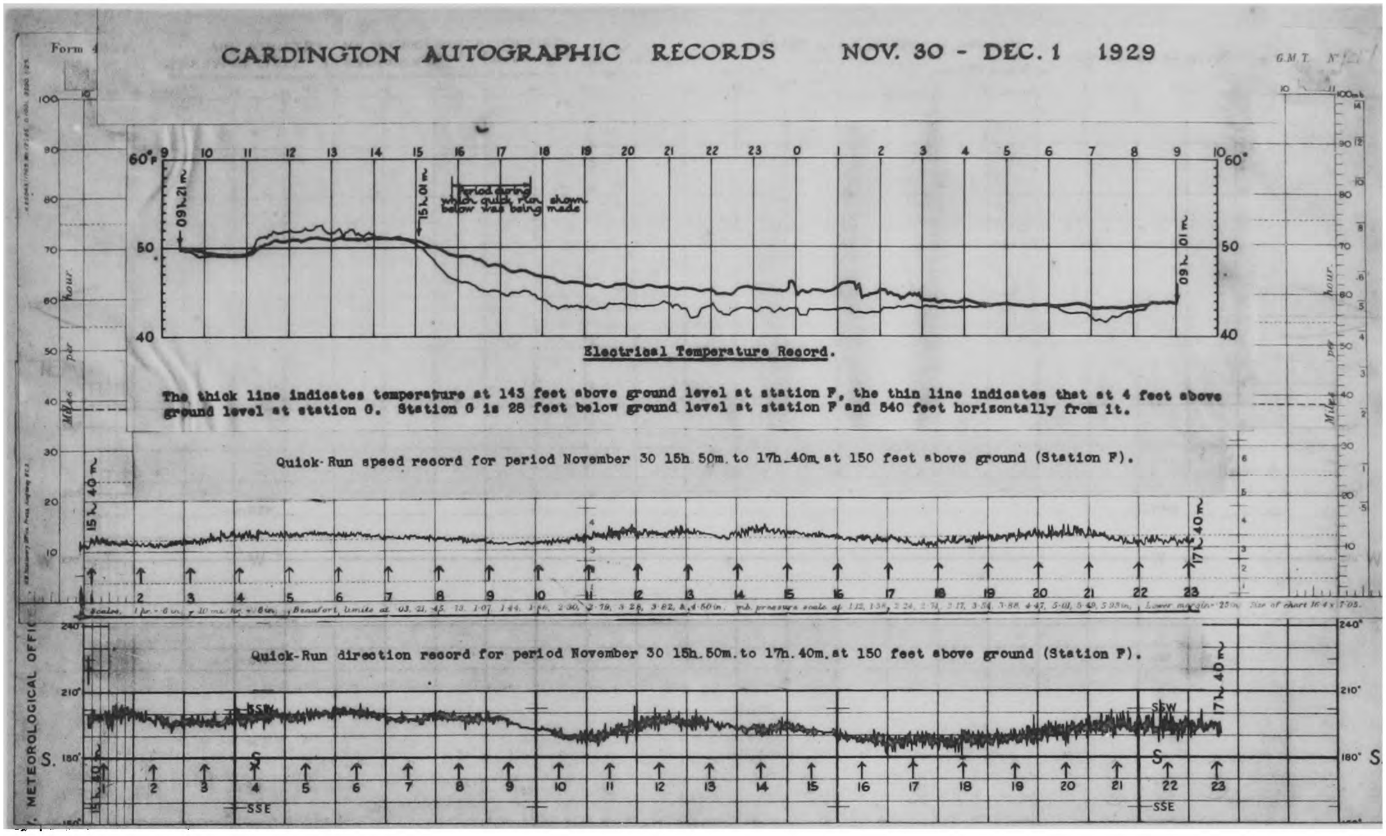

Fig. 56. Autographic records for November 30, 1929.

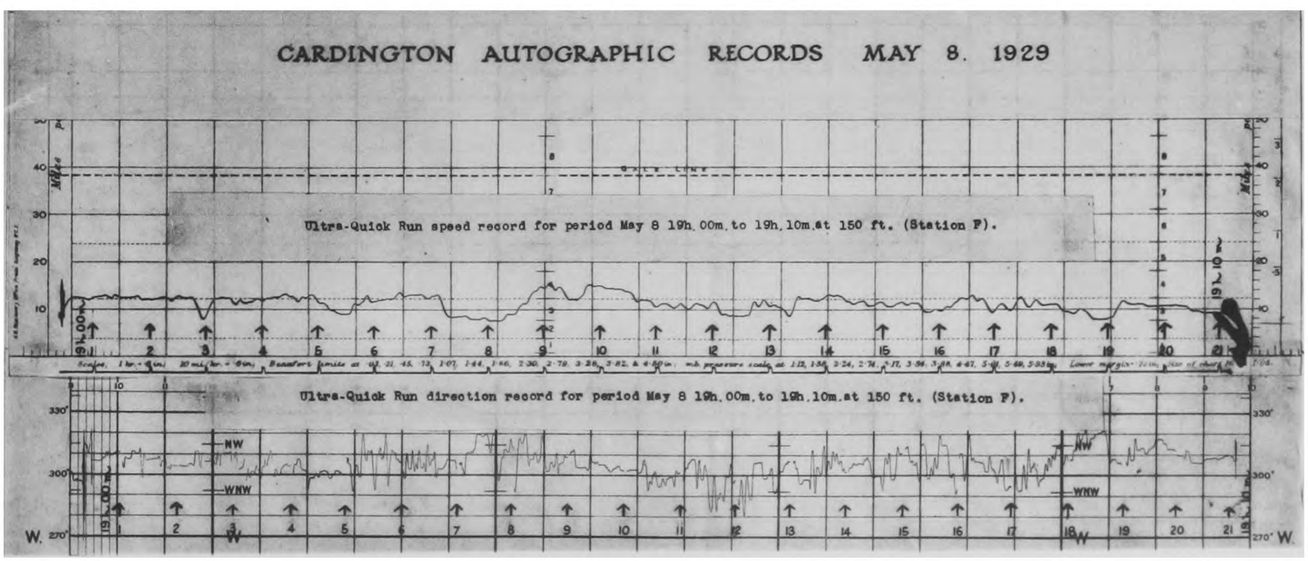

Fig. 57. Autographic records for May 8, 1929.

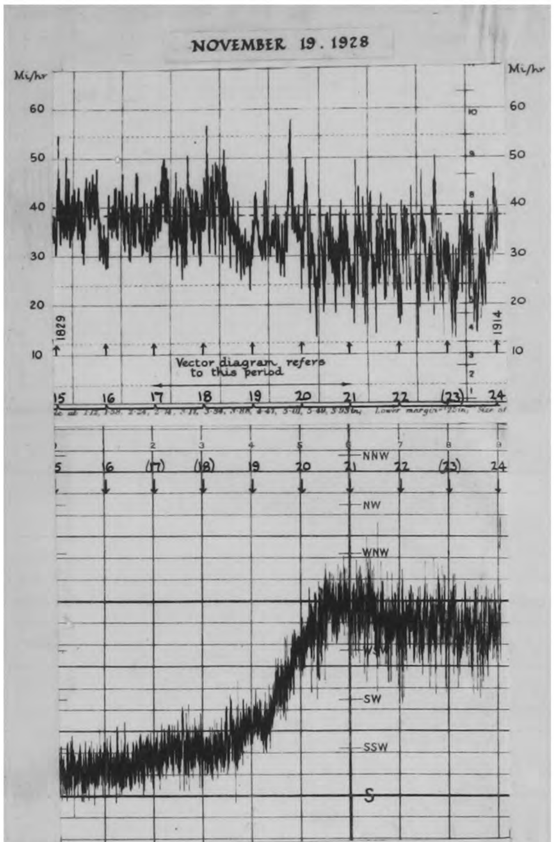

Fig. 61

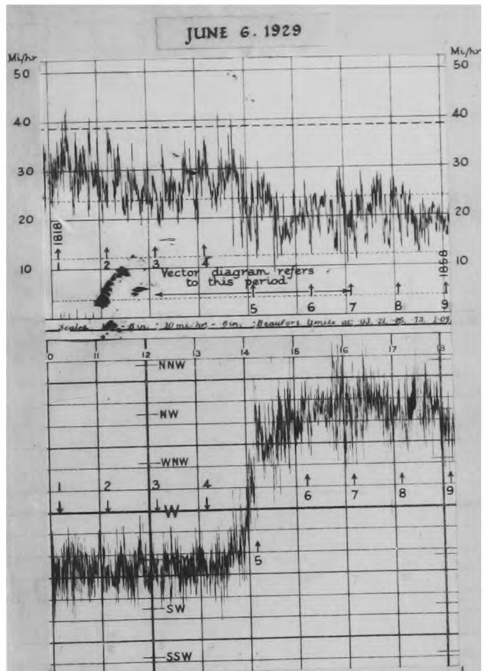

Fig. 63

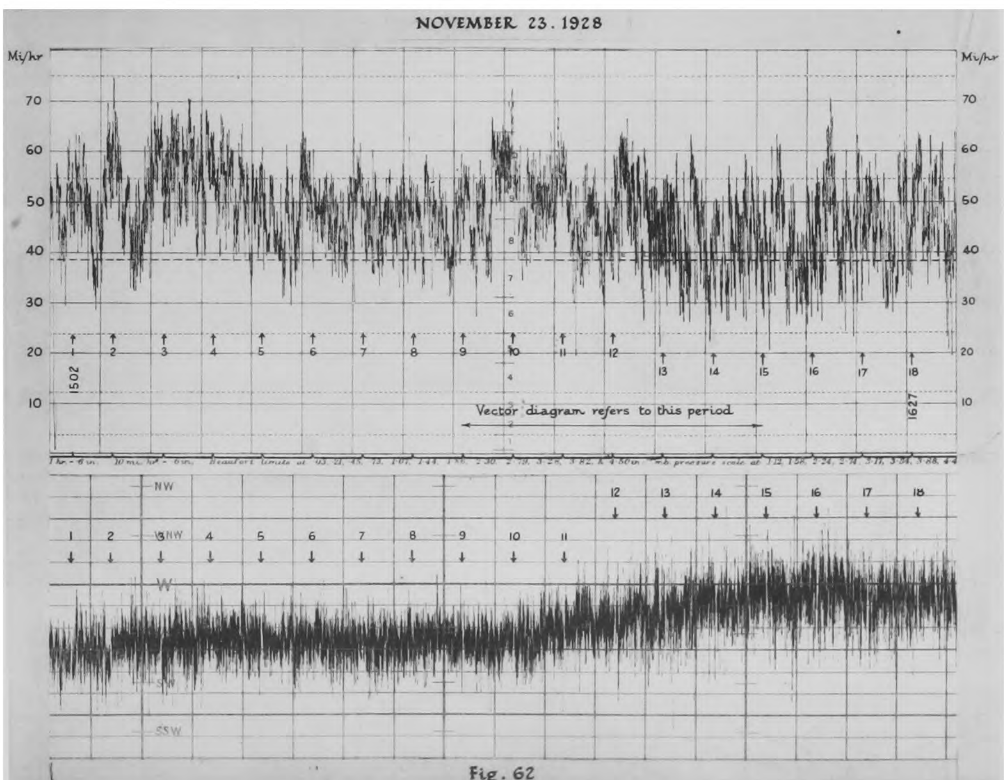

Fig. 62

PLATE XIV.

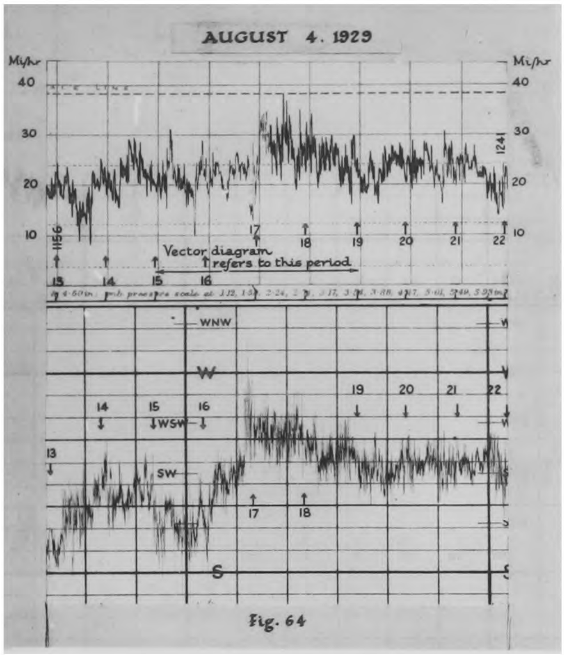

Fig. 64

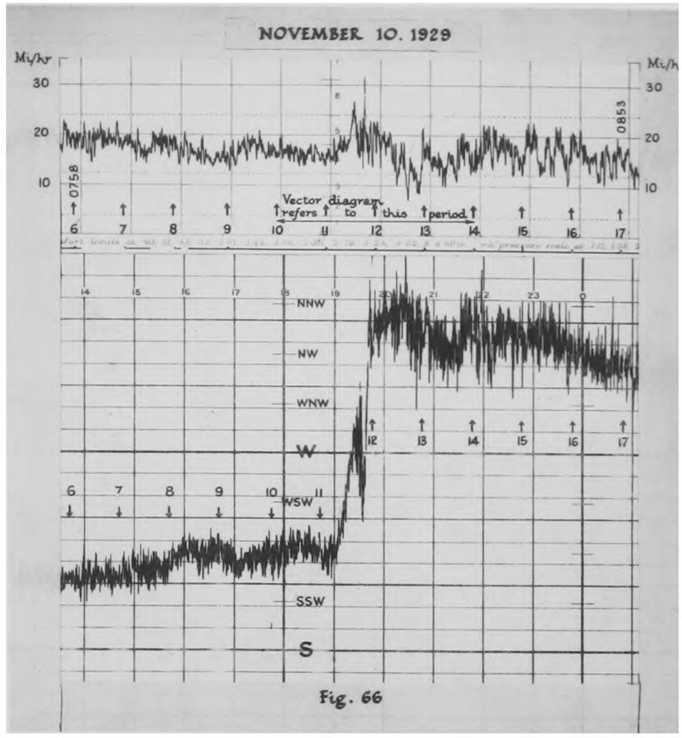

Fig. 66

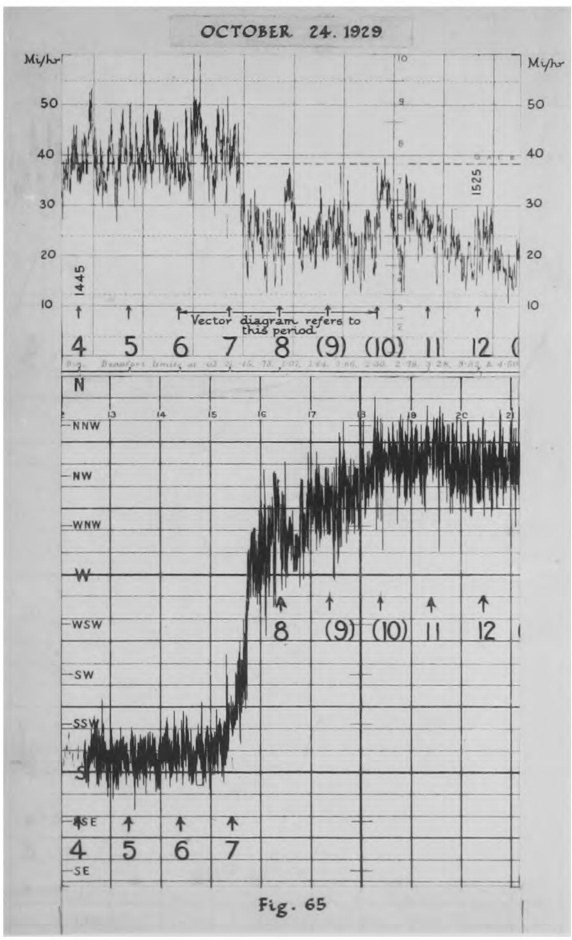

Fig. 65

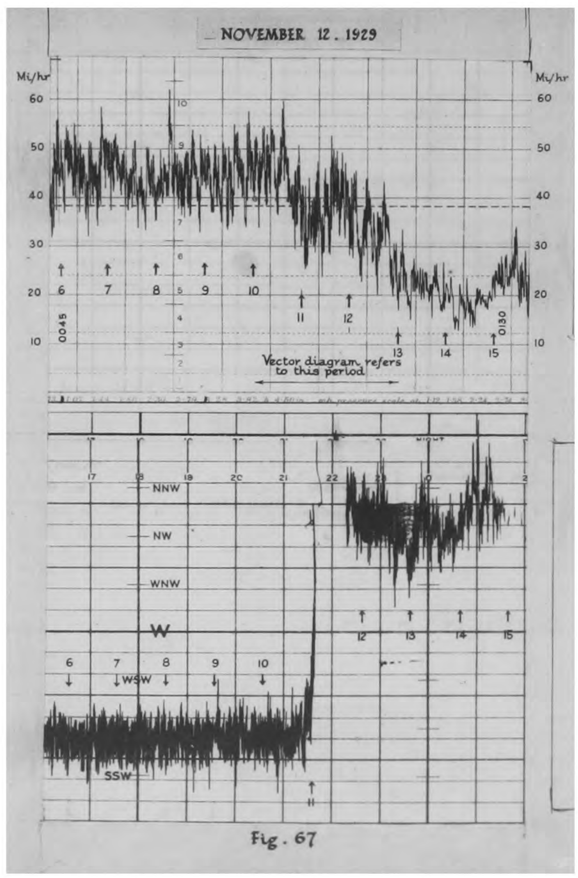

Fig. 67

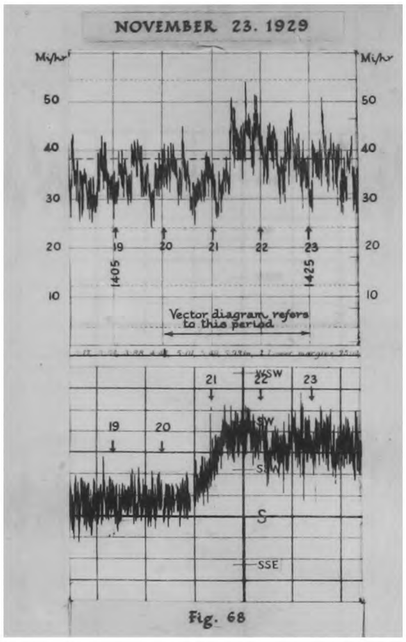

Fig. 68

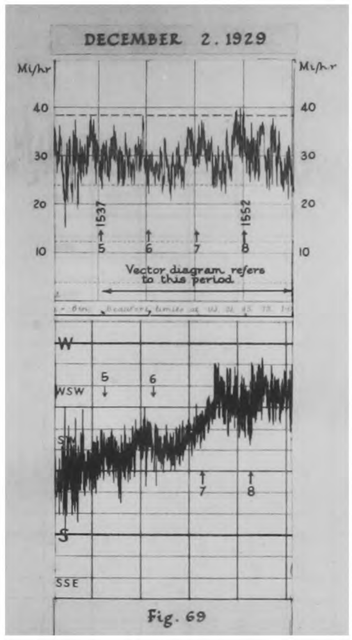

Fig. 69

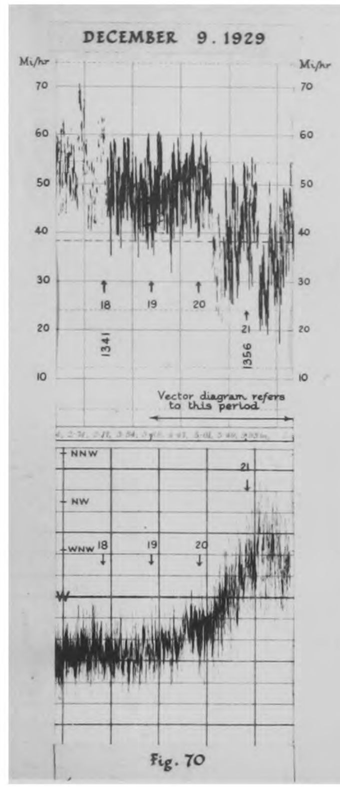

Fig. 70

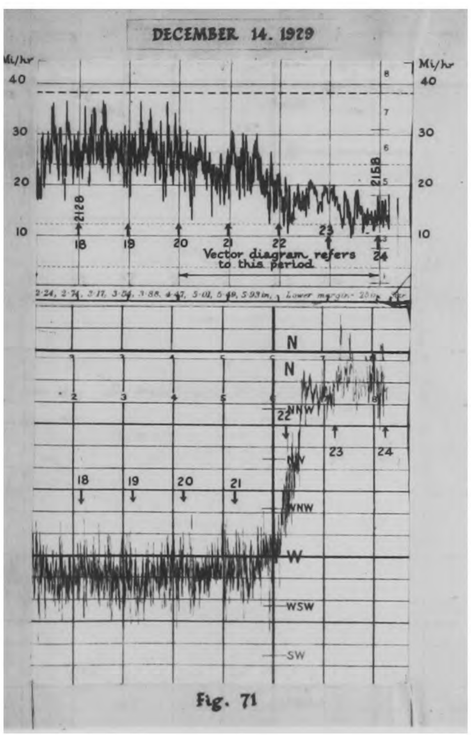

Fig. 71

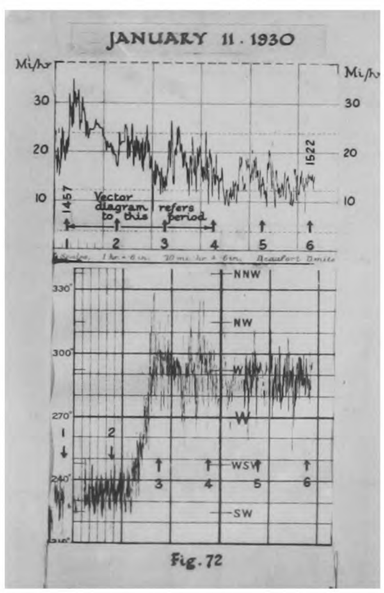

Fig. 72

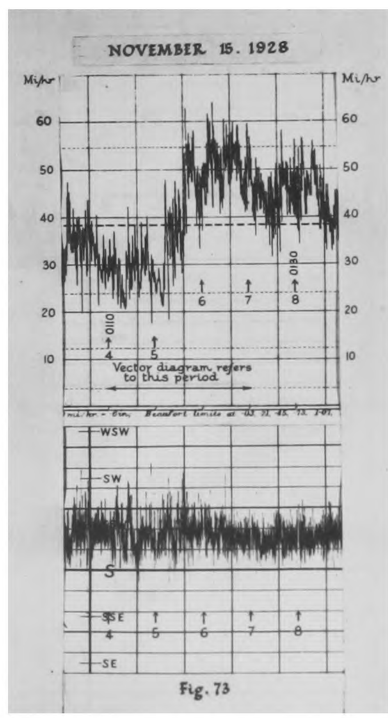

Fig. 73

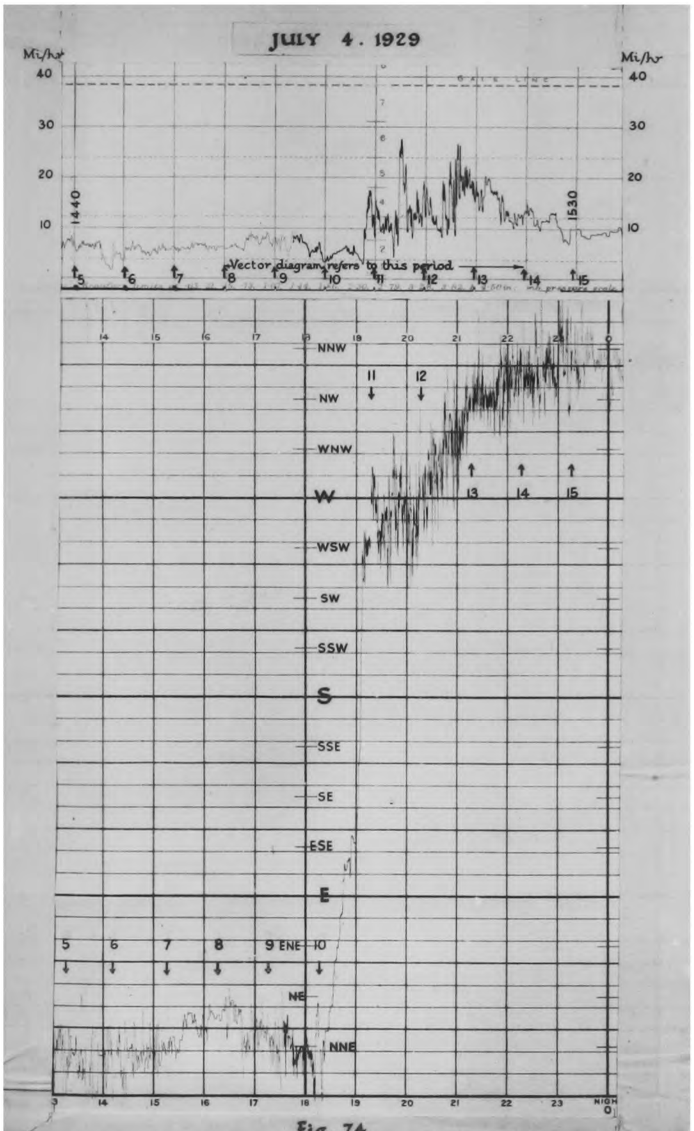
JULY 4. 1929
Mi/hr
1440
1530
Vector diagram refers to this period
NNW
NW
WNW
W
WSW
SW
SSW
S
SSE
SE
ESE
E
ENE
NE
NNE
NIGHT

Fig. 74

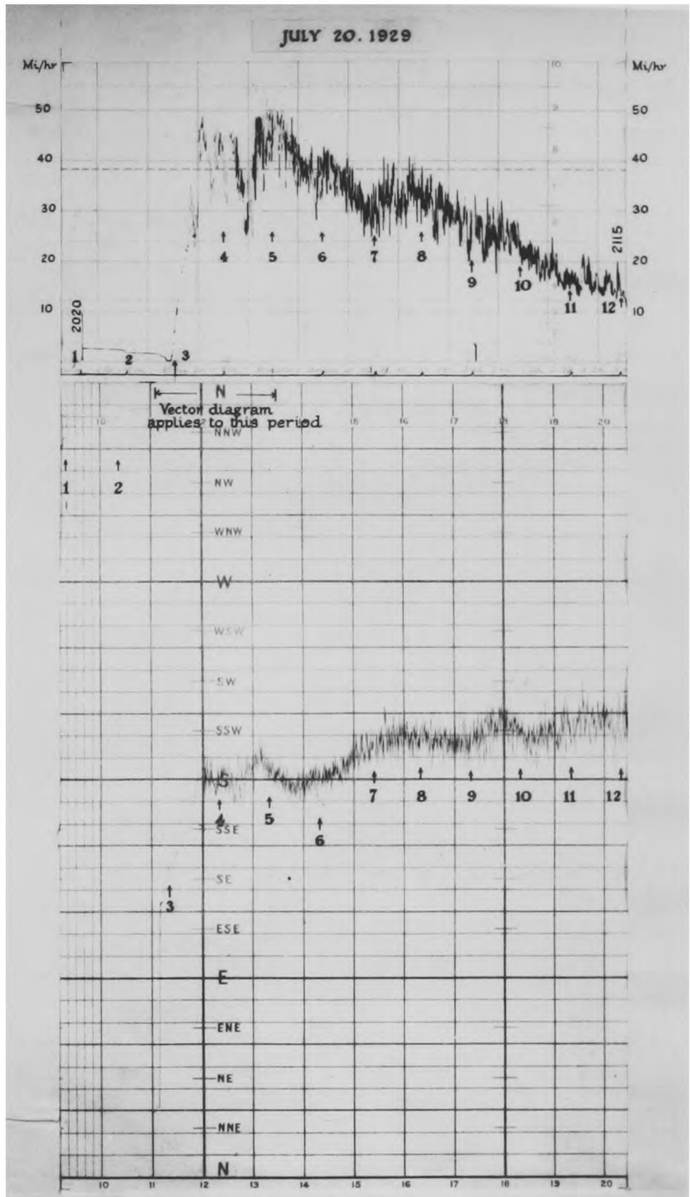
JULY 20. 1929
Mi/hr
2020
2115
Vector diagram applies to this period
N
NNW
NW
WNW
W
WSW
SW
SSW
S
SSE
SE
ESE
E
ENE
NE
NNE

Fig. 75

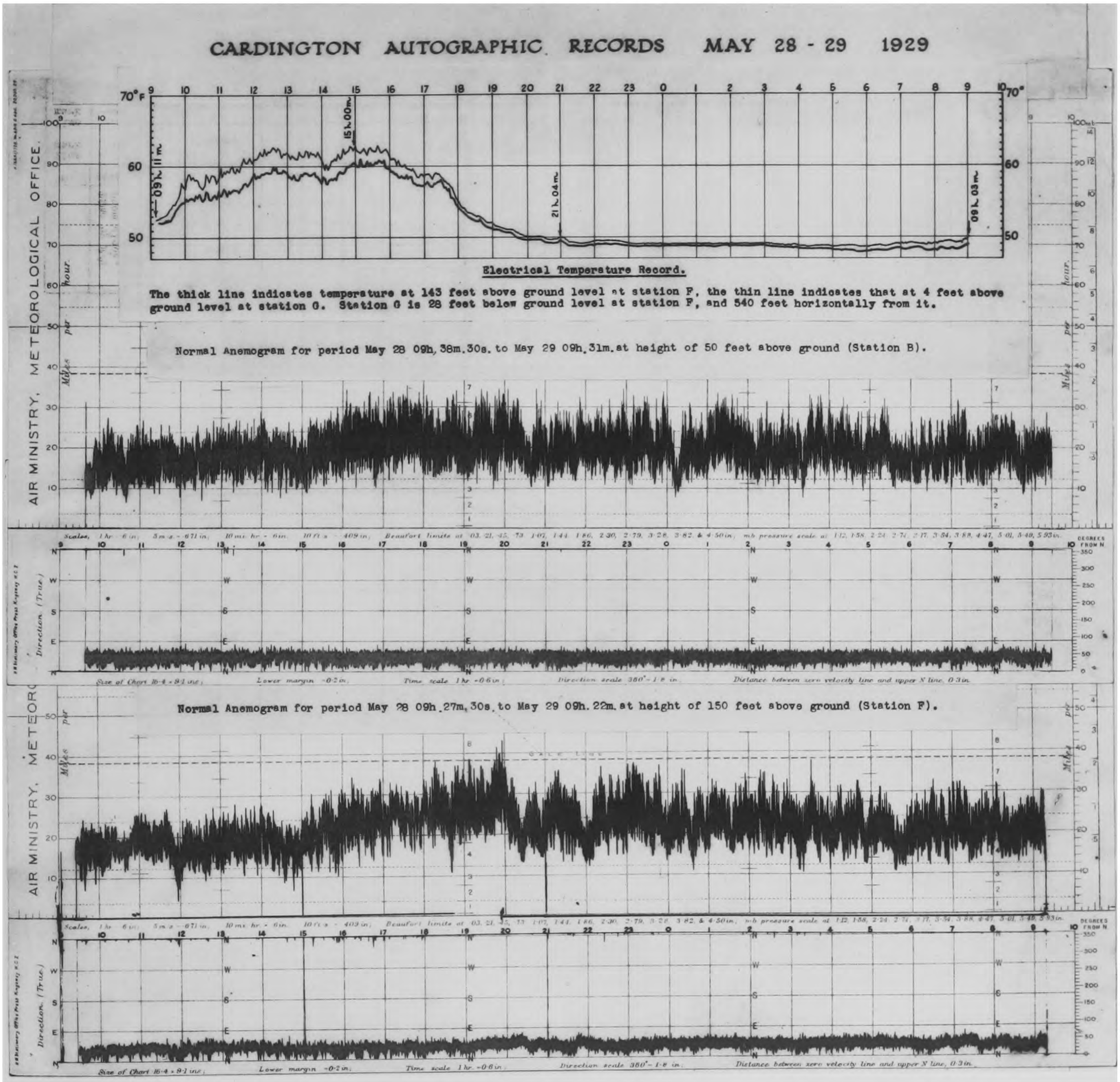

Fig. 80. Autographic records for May 28-29, 1929.

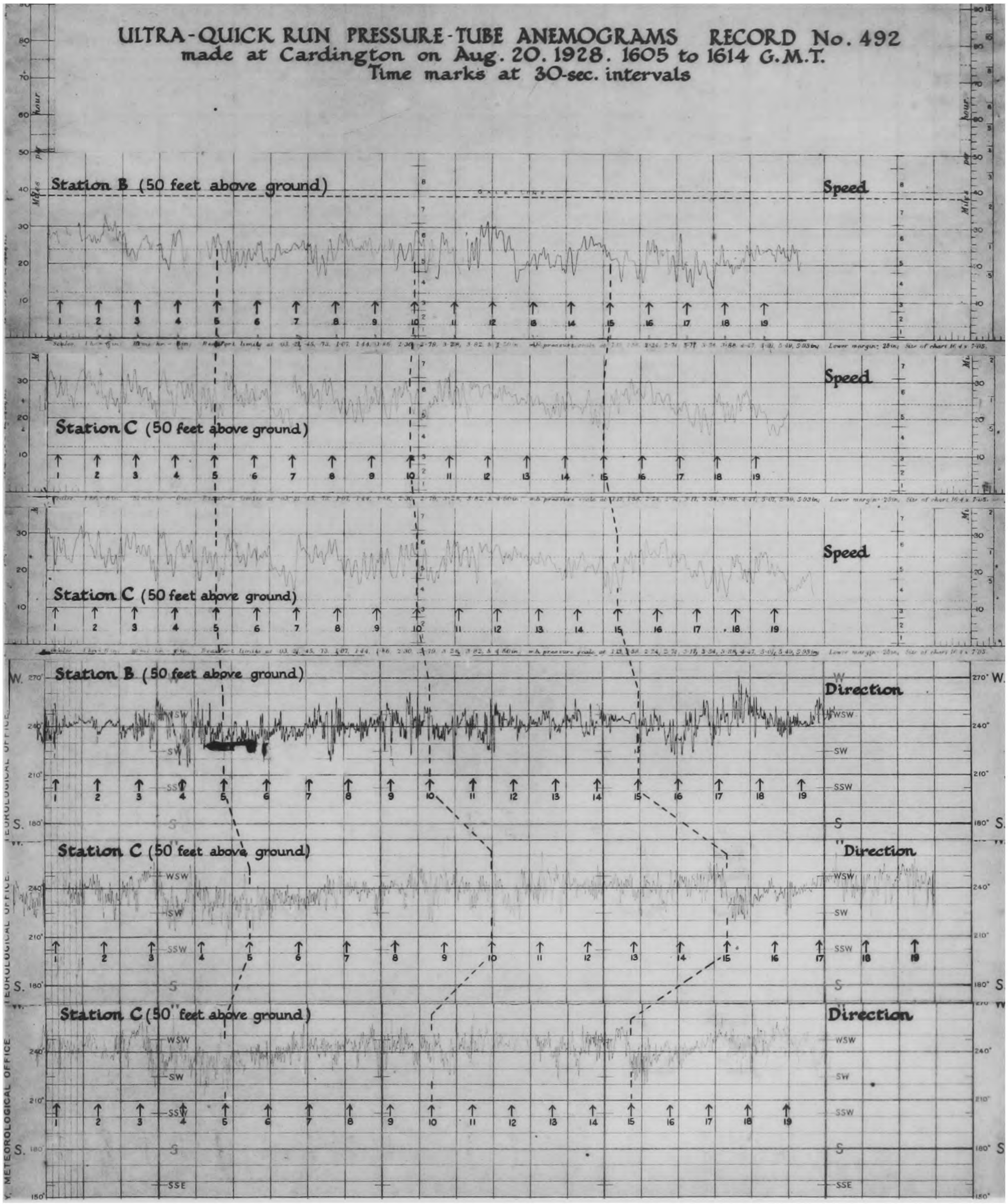

Fig. 90. Ultra-quick runs made at Cardington showing the similarity of two records made by anemographs situated side by side at 50 feet above ground, and 4 feet apart in the horizontal direction, and showing the dissimilarity with another record made simultaneously at a distance of 700 feet.

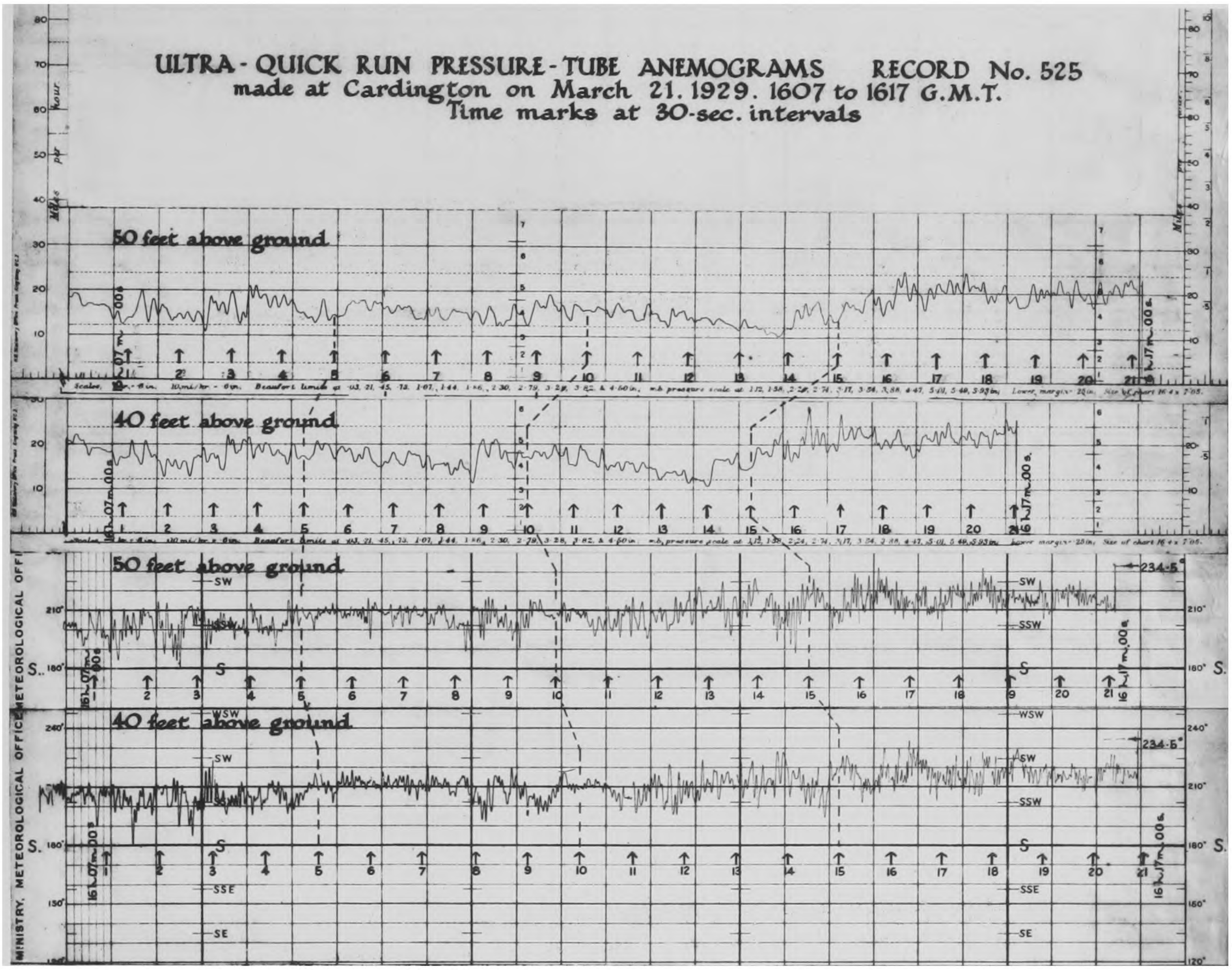

Fig. 91. Simultaneous ultra-quick runs at 50 feet and 40 feet made at Cardington.

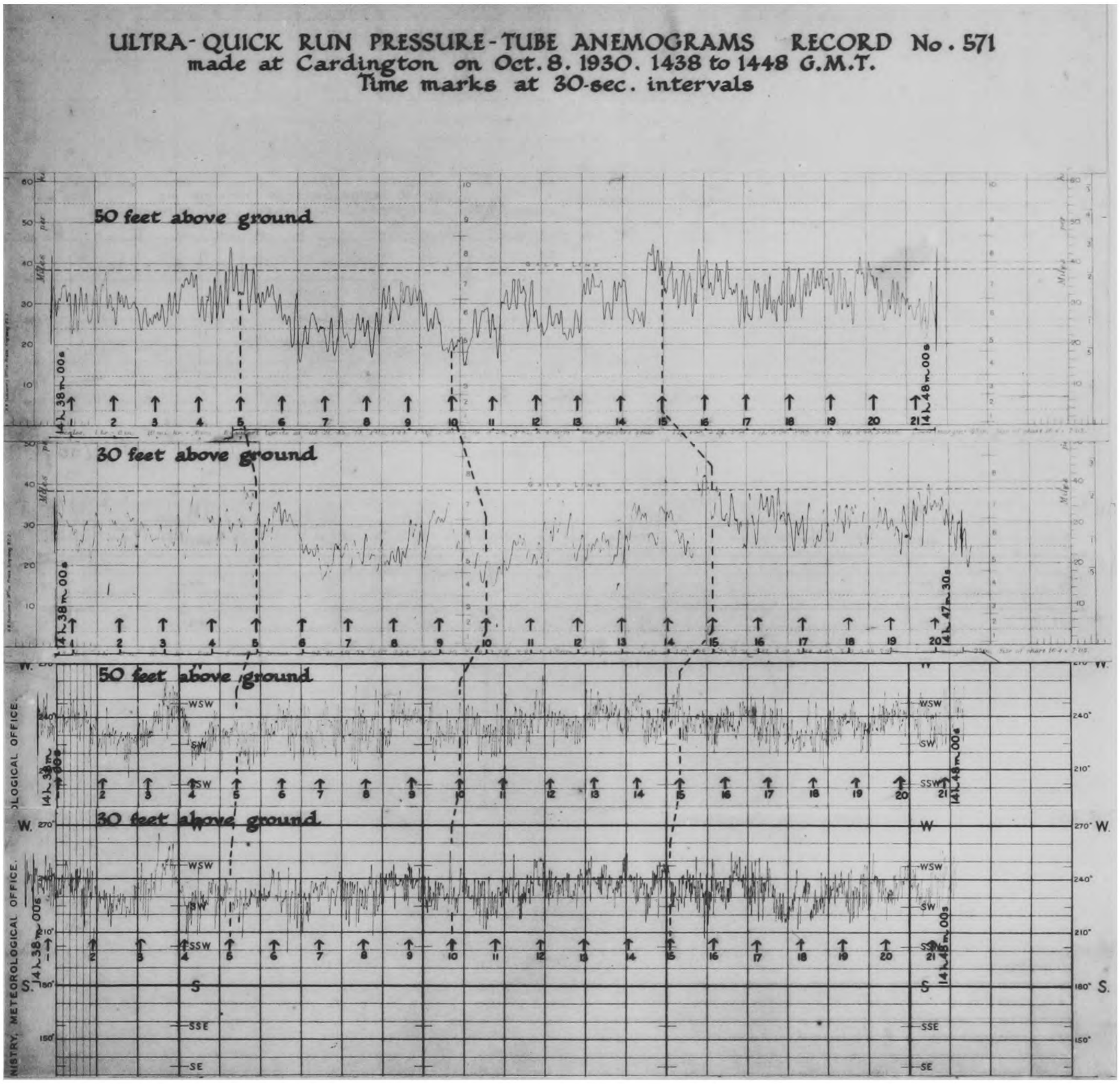

Fig. 92. Simultaneous ultra-quick runs at 50 feet and 30 feet made at Cardington.

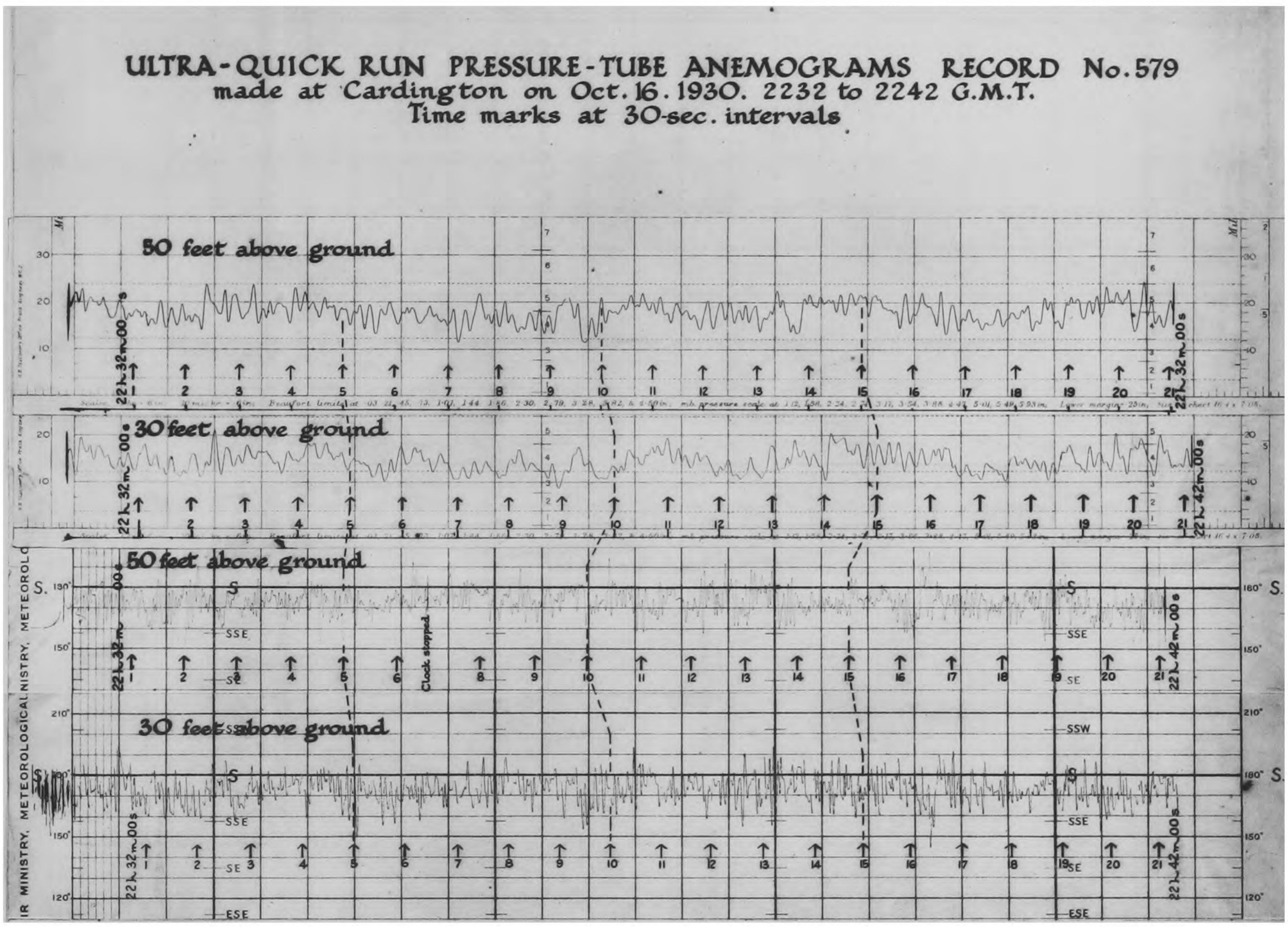

Fig. 93. Simultaneous ultra-quick runs at 50 feet and 30 feet made at Cardington.