Presentations of Surface Wind and Turbulence Using the Cathode-Ray Tube

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1. Introduction

Wind is a vector quantity, i. e., it has both magnitude and direction, each of which must be specified to give a full description of its instantaneous or mean value. Conventional instruments for indicating the surface wind employ separate displays, usually in the forms of a calibrated voltmeter for wind speed and a rotary position motor (a magslip) for wind direction. These are simple and reliable instruments and in many instances may be all that the user requires. The clarity and ease of observation may, however, be improved by directly viewing the vector wind on a cathode-ray tube. By the use of suitably designed wind sensors and a simple electronic circuit, both speed and direction can be presented on an oscilloscope as a single luminous line. The system also has the advantage of being adaptable to display in real time the more complex properties of the wind, such as wind fluctuation vectors, "running mean" vector winds and shear vectors. Furthermore, by the use of time-division-multiplexing (t. d. m.) and beam switching, wind vectors from a number of different sensors can be viewed, in effect simultaneously, in the required positions on a single tube. This enables the two-dimensional wind structure, often of considerable interest in aviation and micrometeorology, to be observed directly in an easily interpretable form. With the aid of suitable electrical filtering, the characteristics of wind eddies and the formation of vortices may be recorded photographically.

The linear distribution of wind speed, or of the wind velocity-component in a specified direction, is also of some importance in the fields of aviation and meteorology. In the practical case of airfield operation, for example, a detailed knowledge of the velocity distribution along the runway would often be of value, especially during aircraft take off in light winds; and in meteorology, Eulerian presentation on the microscale along lines of chosen orientation should assist in the development of turbulence theory. Such information may also be presented in real time on the cathode-ray tube by multiplexing the outputs from a number of matched wind sensors uniformly spaced along a line. The spatial variation of the wind is again viewed in effect at one instant of time, but in this case in the graphical form of velocity versus distance. In practice the display illustrates the wave-like motions taking place near the ground and enables the movements of gusts to be observed when instrument arrays are along the wind. Simulated three-dimensional oscillograms may be obtained with the aid of timelapse photography; some examples are presented in the paper. It is noted here that if turbulence is regarded as a fixed pattern of eddies moving with the mean wind[1], such oscillograms give a pictorial impression of the velocity distribution over an area when the line of observation is perpendicular to the direction of the wind.

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[1] This assumption may be investigated by using a longitudinal array of sensors.

2. *The wind sensors*

The system of vector presentation to be described requires two dc voltages, representing the vector components in mutually perpendicular directions, from each position of measurement. The sensors employed to produce these voltages for wind displays consist of photoelectric anemometers and wind component resolvers designed as portable instruments suitable for operating in wind speeds greater than 0.5 m sec^{-1} The anemometer provides an output voltage proportional to the wind speed in the horizontal plane and supplies directly a vane-driven sine-cosine potentiometer which resolves its input voltage into orthogonal components. Full details of these instruments have been given elsewhere by the writer (1965).

The same sensors are employed for the graphical presentation of wind velocity, though with this type of display the anemometers may be used without the resolvers when the vector magnitude only is required.

3. *Single vector display*

Direct application of the component voltages to the matched *X-Y* amplifiers of a dc oscilloscope displaces the spot on the screen to the end-point of the vector. MacCready (1953) used this method, in conjunction with linearizing circuits and hot-wire sensors, to record the effects of small scale turbulence at a fixed point.

The full vector may, however, be produced by causing the spot to reciprocate at a relatively high frequency between its origin and the vector end-point, a system employed in radar PPI presentations where a radial time-base, in this case of fixed length, rotates at constant angular velocity. A similar technique is also used in thunderstorm location (Adcock and Clarke, 1947), where the instantaneous direction of a line on a long persistence cathode-ray tube is used to indicate the direction of thunderstorm activity. These displays are, however, not intended as true vector presentations and the lengths of the traces are not used as indications of magnitude.

In the present system (Fig. 1), after filtering to pass only fluctuations in the desired frequency range, the two varying dc input voltages are "chopped" by means of synchronized electronic switches. The voltages are brought exponentially to zero through closely matched integrating circuits and allowed to return exponentially to their input values, the decay rates being identical for both signals. A minimum chopping frequency of approximately 50 cps is used. Blanking pulses, initiated by the chopper driver (a bistable multivibrator or a mains transformer), and of duration slightly less than half the period of one cycle, are applied to the *Z* (brightness) input of the oscilloscope to suppress the beam during the greater part of the signal rise-time. A radial line of tapering brilliance but terminating in a brightened dot or short stroke is then produced on the tube and may be displayed, without direction ambiguity of 180°, using an ac coupled deflection system. Compared with the dc system, this provides the advantages of greater maximum vector length and lower drift. The non-uniform brightness of the line, also a desirable feature of a multi-vector display, may be varied for particular requirements by adjusting the phase and duration of the blanking pulses.

4. *Multi-vector presentation*

The block diagram of a multi-vector display system is given in Fig. 2, where for simplicity, six pairs of inputs only are shown. By the use of t. d. m., each pair of input voltages is connected in turn to the choppers at a frequency sufficiently high to avoid visible trace flicker on the cathode-ray tube. Complete scanning of all inputs fifty times a second gives a satisfactory visual display in most cases, but a higher frequency may be used to advantage when photographic recording is required and would be essential for detailed studies of the smallest wind eddies. In the figure, the master oscillator (for convenience a free-running multivibrator),

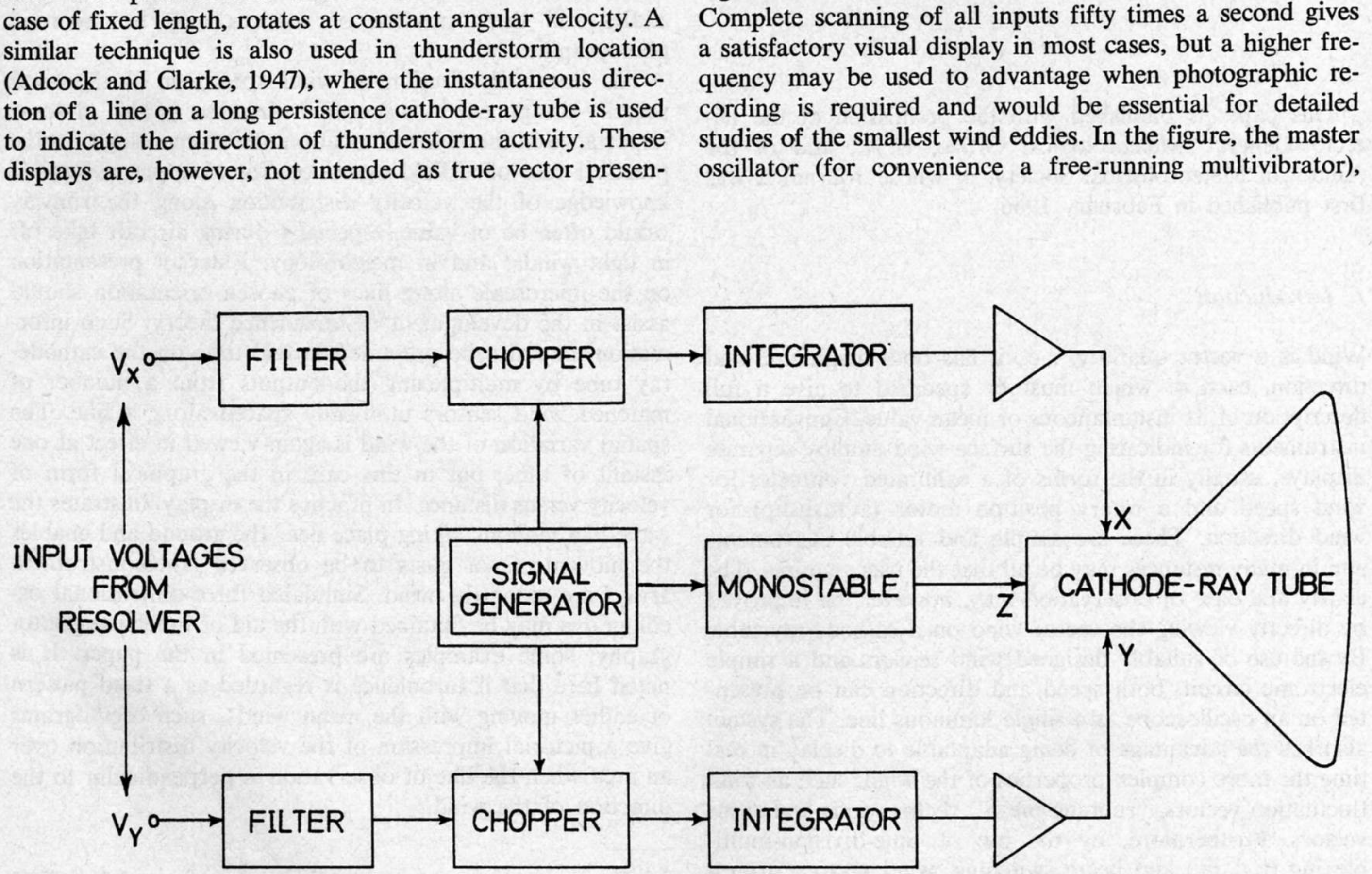


Fig. 1. Block diagram of a single vector cathode-ray tube display system

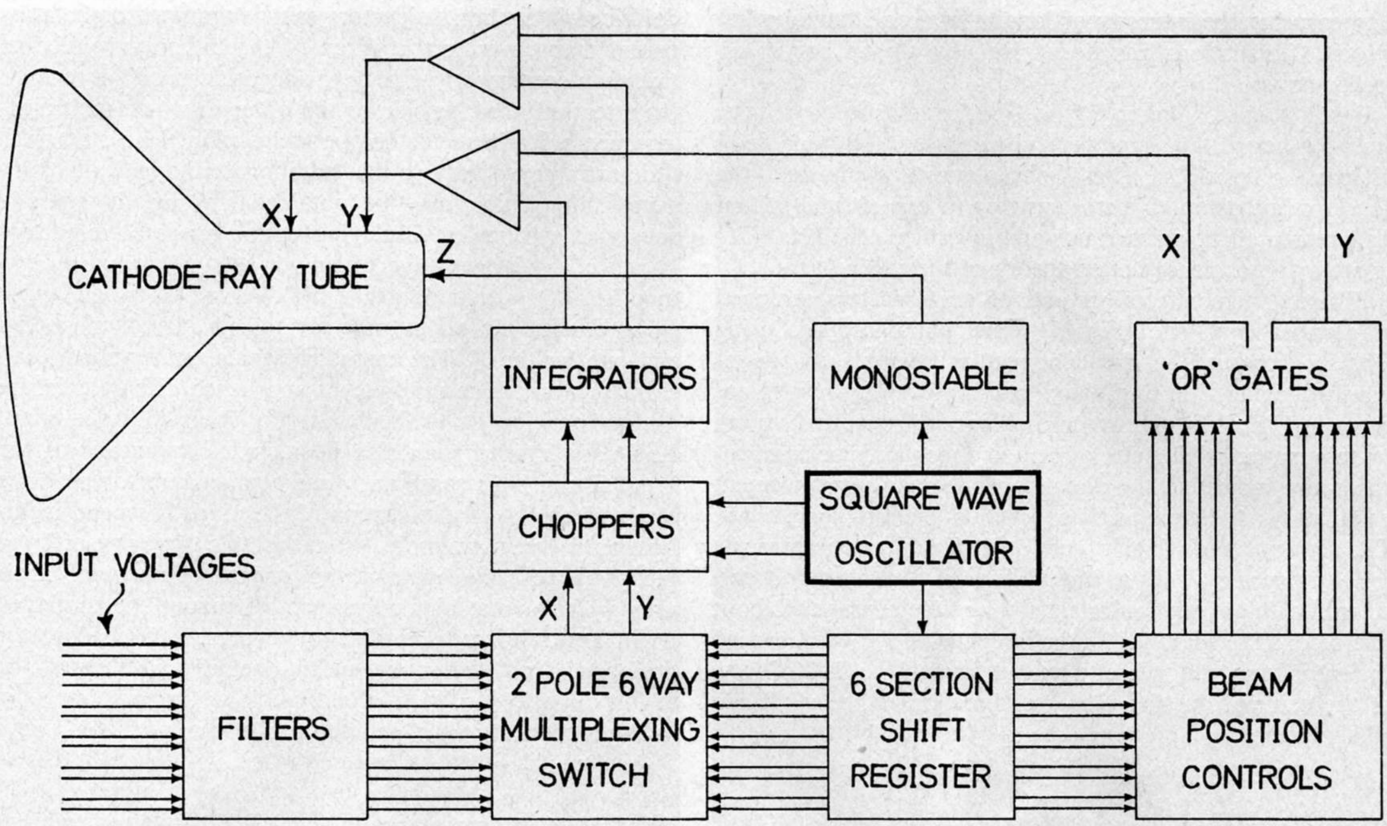


Fig. 2. Block diagram of a multi-vector cathode-ray tube display system

operates at the product of the scanning frequency and the number of vectors to be displayed, say 300 cps in the circuit presented. The multivibrator performs three separate but synchronized functions; it triggers the six-section ring-connected shift register, operates two choppers, and supplies the blanking circuit (monostable) with its input pulses. The shift register itself performs two separate, but again synchronized tasks. With each input pulse received, it simultaneously operates two electronic switches thereby connecting sequentially each pair of input voltages to the choppers. The shift register also supplies voltages in turn to six pairs of potentiometers, each pair being connected in parallel. The outputs from the potentiometers pass through OR gates and provide two repetitive step voltages with six voltage levels per cycle, individual levels in each being controllable separately by the appropriate potentiometer.

The outputs from the choppers, time-integrated to form exponential wave voltages, are each added to one of the repetitive step voltages and form two final X and Y input signals for the matched deflection systems of the cathode-ray tube. An example of one cycle of the two input signals is shown in Fig. 3. Each exponential section of the waveforms gradually changes in amplitude (and polarity) relative to its fixed zero displacement as the component input voltages change. Each vector is produced in sequence on the tube and its position controlled by its corresponding added step voltage. Adjustment of the appropriate potentiometer alters the position of the vector along the X-axis of the tube while adjustment of the potentiometer in parallel alters its position along the Y-axis. Blanking pulses from the monostable circuit automatically suppress the spot during movement from one vector position to the next and pulse duration is set to produce the desired non-uniformity of line brightness.

5. *Vector-wind oscillograms*

Various techniques for the photography of vector displays have been tried and two of the methods are presented below. Fig. 4 shows oscillograms of "simultaneously" recorded wind-fluctuation vectors and mean-wind vectors in the horizontal plane. These wind "daffodils" were produced by duplexing two pairs of filtered input voltages from the same source using both low-pass and band-pass filters and a circuit similar to that shown in Fig. 2. A fast response anemometer and resolver with rotor and vane constructed of expanded polystyrene were used as wind sensors.

The groups of vectors forming the "stems" correspond to sliding 70 sec mean vector winds while the "flowers" represent the fluctuations of (a) 3 sec and (b) 0.2 sec sliding averages relative to the 70 sec means (see Jones [1963] for corresponding filter transfer characteristics). Fluctuation and mean vectors were displayed alternately at a repetition rate of 200 per second (400 cps chopping frequency) and continuous exposures were made on stationary film. The individual closely spaced lines were produced by the electronic chopping, blanking phase and duration being adjusted so that the beam was suppressed during spot movements towards the origin. This type of presentation gives a clear indication of both the intensity and direction of the wind fluctuations relative to the mean vector wind and should find application in the detailed study of isolated phenomena rather than the acquisition of statistics. A statistical method of measuring the intensity of longitudinal and lateral wind velocity fluctuations has been given by the author in an earlier paper (1964).

Oscillograms of fluctuation vectors from a single position, recorded using steadily traversing film, gave the impression of passing vortices. These observations stimulated the development of multi-vector systems to explore the spatial distribution of the fluctuations and investigate the feasibility of a two-dimensional vortex theory of turbulence[2].

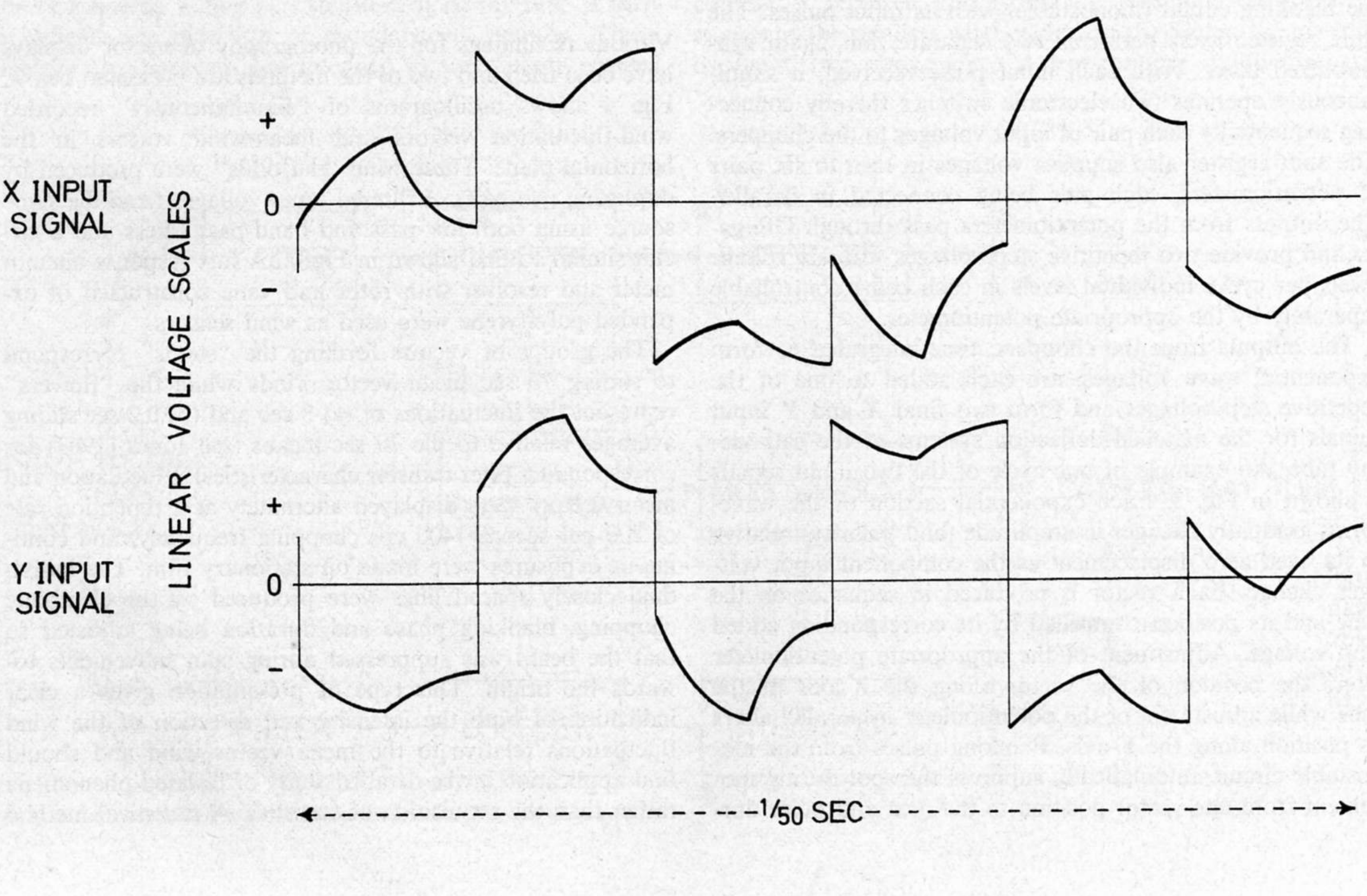
Filtered vectors from six sets of anemometers arranged in a cross-wind line (Fig. 5) were photographed, using 1/50 sec exposures, at frequent regular intervals on continuously moving film and some examples of the results are given in Fig. 6. In the lower oscillogram, suggested vortex centers marked C for clockwise and A for anticlockwise rotation are indicated, the direction of relative air movement being along the tapered line towards the brightened dot. The larger vector, which occurs every fourth row, represents the full vector wind averaged for all six positions and smoothed to give an equivalent sliding time-average of about one second. In many cases the strength of the wind caused the end of this vector line to extend beyond the field of view of the camera, but the averaged direction of the wind can still be seen.

6. *Area coverage*

The wind field over an area may be presented directly on the cathode-ray tube by the use of the basic techniques described in Section 4. Vectors can be arranged on a transparent map covering the screen of the cathode-ray tube so that they correspond with the field positions of the sensors. No attention need be paid to the order in which multiplexing occurs. Refinements can be included in the system with little extra complexity so that additional automatically computed information may be obtained. In Fig. 7, where a suggested system for displaying vector winds at important places near the runways of an airfield is presented, two modifications are made to the basic circuit. Analogue averaging circuits are added, one for the *X* component inputs and one for the *Y*. The averaged signals are supplied to an extra section of the multiplexer and hence displayed in the desired position on the screen as the space-averaged wind. Low-pass filtering may also be included by means of the input filters. This space and time averaged vector provides a remarkably steady indication of the wind. A second modification is the inclusion of two adjustable "backing off" (or bias) voltages, one for each multiplexed component. Their uses are two fold; bias adjustment to reduce the displayed mean vector to zero results in the presentation of vector deviations from the spatial mean (the residual vectors) for all field positions, and secondly, by setting up opposing voltages to extract the components of the predicted wind, all vectors on the screen represent variations from the expected conditions. These latter two applications may be considered of minor importance in an airfield display system but they are tests which need take only seconds to conduct. The main uses of residual vector displays vould lie in eddy structure examination, especially if numerous data transmission points were available. Automatic mean-vector subtraction would be possible by purely electronic techniques.

[2] To be published.

Fig. 3. A typical cycle of X and Y input waveforms to the cathode-ray tube for the display of six vectors



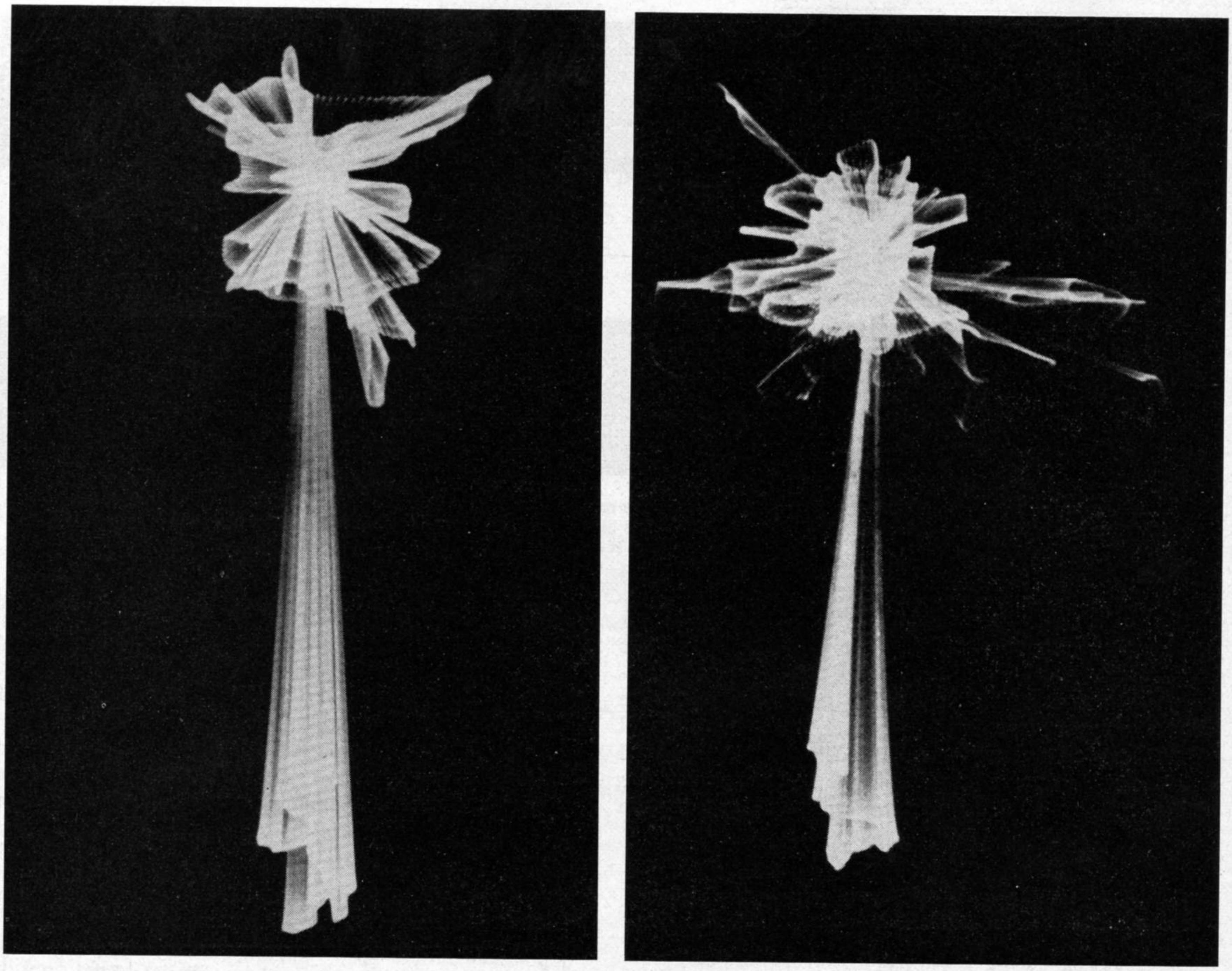


Fig. 4. Two vector oscillograms each showing both mean and fluctuation wind vectors over a period of approximately 30 sec. See text for averaging and sampling times

7. *Velocity-distance presentation in graphical form*

A system for directly viewing in graphical form the variation of wind velocity with distance is shown in Fig. 8. Voltages from the anemometers (or resolvers) spaced at regular intervals along a line are separately filtered to give equivalent time averaging approximately equal to d/u, where d is the distance of separation and u the wind speed[3]. Longer time averaging may be employed, if desired, to reject more of the higher frequencies, in which case a better correlation between the velocities at adjacent points is observed, but if much smaller eddy structure is to be examined, shorter time averaging should be accompanied by closer spacing of the instruments.

The filtered input voltages (14 are indicated in Fig. 8) are applied to a single pole multiplexing switch operating at a scanning frequency of approximately 50 cps. The multiplexed output, a 14-level repetitive step waveform of continuously changing shape, is filtered by a low-pass circuit with a sharp cut-off at the basic switching frequency (700 cps in the circuit presented), and applied to the Y input of the oscilloscope. A timebase circuit is triggered by the first

[3] Further investigations of optimum filter characteristics, which may be different for longitudinal and lateral line arrangements, have yet to be conducted.

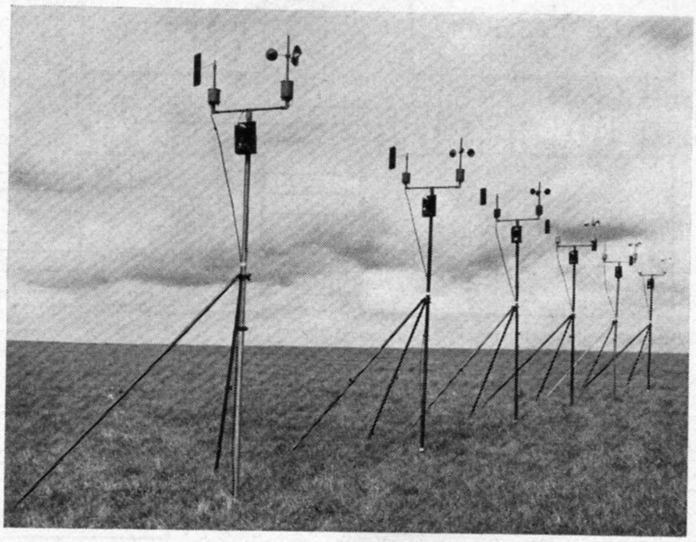


Fig. 5. Six anemometer-resolver sets at height 2 m, closely spaced in a line across-wind

(a)

(b)

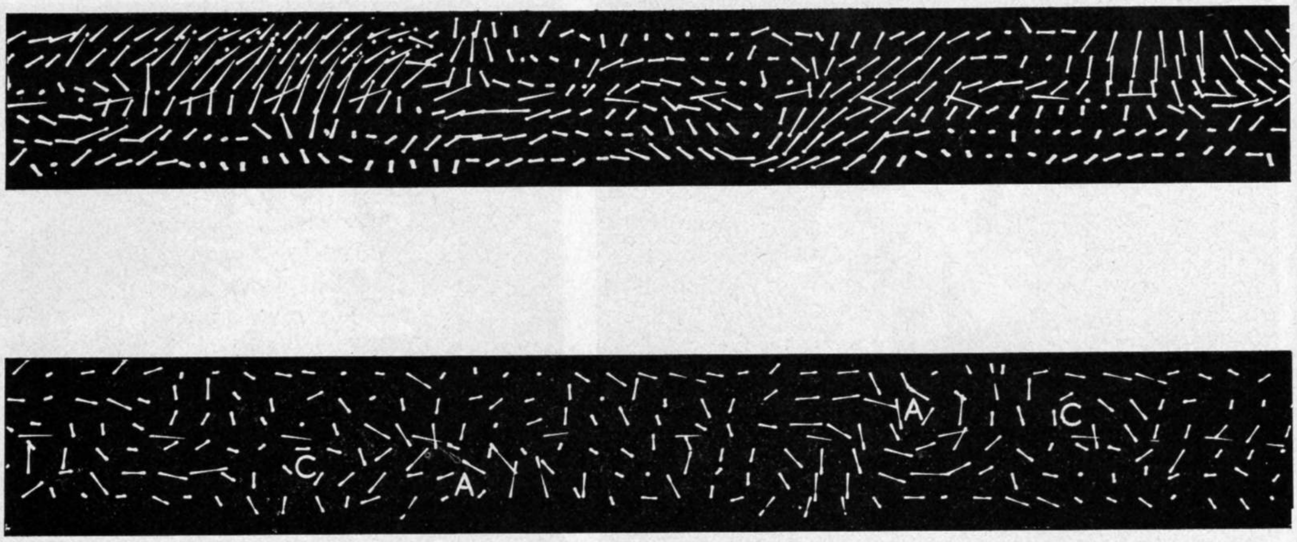


Fig. 6. Oscillograms showing wind fluctuation vectors produced as eddies pass through a cross-wind line. (a) 1600 GMT 15 May 1963, line 12,5 m, longitudinal scale 1.2 sec per row, wind speed 4.5 m/sec^{-1}. (b) 1245 GMT 5 March 1964, line 30 m, longitudinal scale 1.8 sec per row, wind speed 6 m/sec^{-1}

section of the shift register and produces a repetitive saw-tooth voltage of period equal to the scanning time of the multiplexer. This is applied to the *X* input of the oscilloscope to produce constant velocity beam deflection, the return voltage suppressing the fly-back in the conventional way. The internal timebase of the oscilloscope may be used in place of the external circuit, but the latter constructed as an integral part of the equipment, can have the advantage of positive synchronization without the need for adjustment. Because of the smoothing action of the low-pass filter on the *Y* input signal, the initial *Y* deflection of the display is affected by its final value and the first fourteenth section of the trace must be suppressed to give error-free presentation. Suitably timed blanking pulses for this operation are taken from the first section of the shift register and applied in the appropriate phase via a summing amplifier to the *Z* axis of

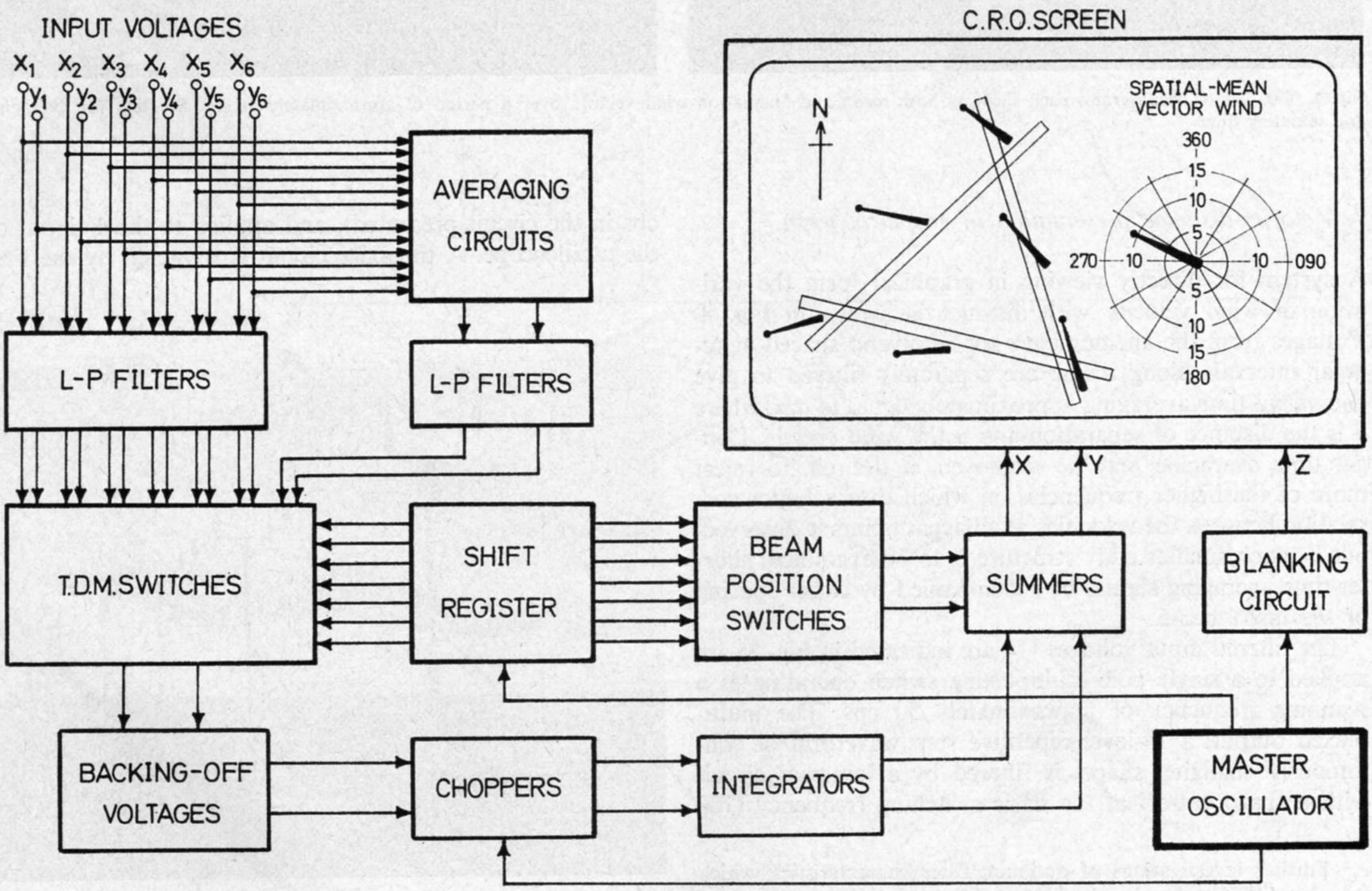


Fig. 7. A suggested system for displaying the vector winds on a cathode-ray tube from points near the runways of an airfield

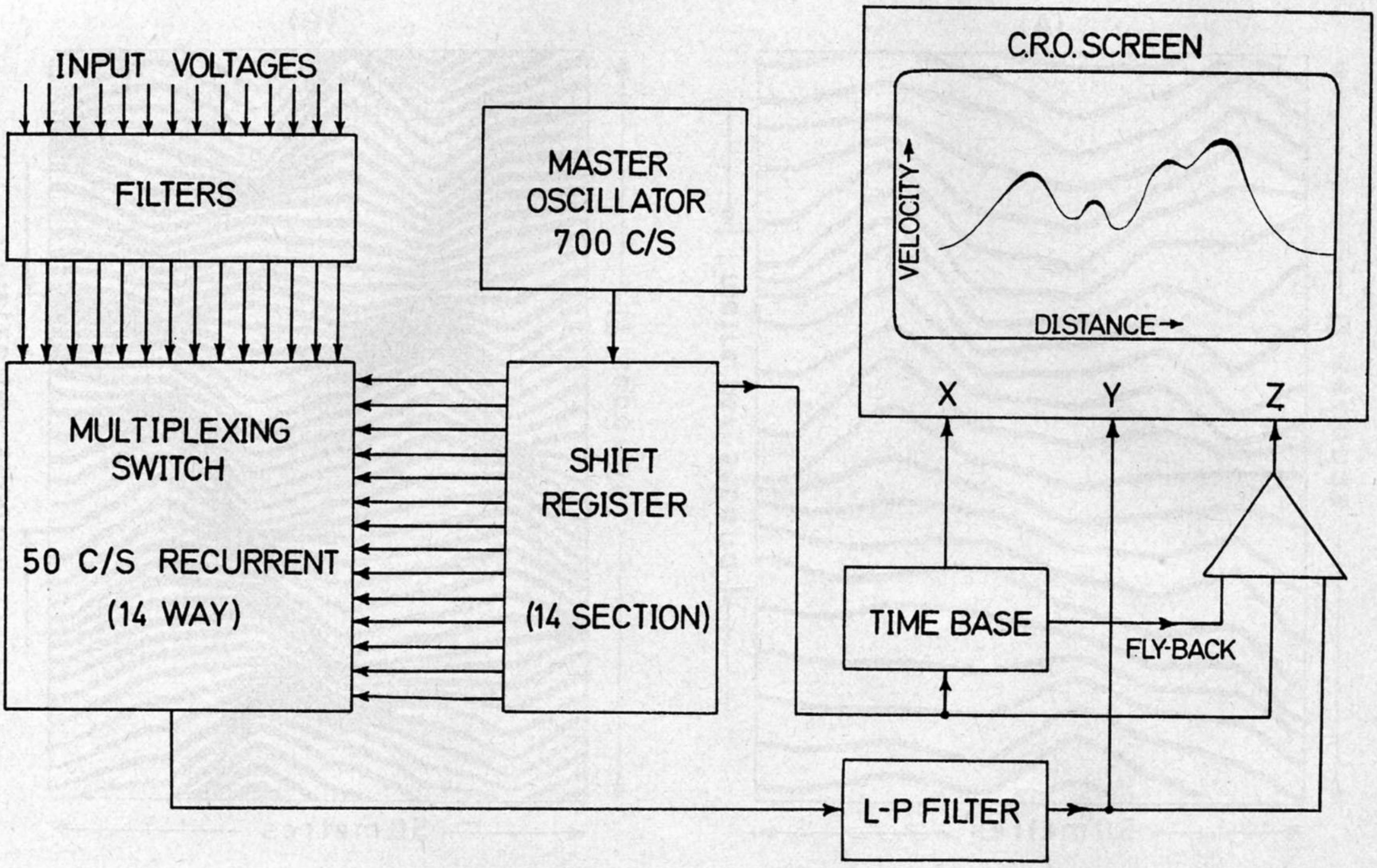


Fig. 8. Block diagram of a circuit for producing velocity-distance displays in graphical form on a cathode-ray tube

the tube. Trace brightness may also be proportionally controlled by the addition of part of the *Y* signal to the *Z* input voltages. Positive *Y* deflections (gusts) are then accompanied by increased brilliance and the brilliance is reduced during lulls.

8. *Simulated three-dimensional presentations*

The oscillograms in Fig. 9 show a series of velocity-distance graphs recorded by making 1/50 sec exposures on a continuously moving film at 0.6 sec intervals (A), and 0.3 sec intervals (B, C and D), film transport being normal to the timebase. Brightness modulation by the multiplexed and filtered wind speed signal was used during the recording of B and C.

Seven wind sensors only were available for the experiments and as the multiplexing equipment was built to accept 14 inputs, an averaging network was employed so that alternate input voltages were meaned to form intermediate voltages. Finer resolution would be obtained by the use of independent supplies to all 14 filters. In all four cases presented, short time constant ac coupling to the oscilloscope was used so that variations in the spatial mean speed of the wind are not indicated, the *mean* traverses on the film being separated by regular intervals. The use of dc coupling (not shown in the present paper) results in regular displacements of a fixed reference wind speed and greater trace separation is necessary to prevent excessive overlapping. The ac method registers speeds relative to the spatial mean of all positions while with dc coupling the traces record wind speed relative to a definable zero.

9. *Conclusions*

The vector display system described[4] provides a clear and direct indication of both wind speed and direction by means of a single line on the cathode-ray tube. More complex properties of the wind can also be clearly presented, including a display of several vectors on a single tube, appropriately arranged to represent the wind at selected positions in the field. The system should prove of use on airfields, either for single or multi-position displays, and the facility for the presentation of fluctuation or residual vectors over an area could be of value in the study of fundamental turbulent motion near the ground.

The graphical displays of surface wind speed or velocity-component versus distance give a visual demonstration of the atmospheric wave-like motions taking place and simulated three-dimensional oscillograms record the phenomena economically.

Adcock, F., and C. Clarke, 1947: The location of thunderstorms by radio direction-finding. *J. Inst. Elect. Eng.*, 94, 118—125.

MacCready, P. B., 1953: Structure of atmospheric turbulence. *J. Meteor.*, 10, 434—449.

Jones, J. I. P., 1963: A band-pass filter technique for recording atmospheric turbulence. *Brit. J. Appl. Phys.*, 14, 95—101.

— 1964: Continuous computation of the standard deviations of longitudinal and lateral wind velocity components. *Brit. J. Appl. Phys.*, 15, 467—480.

— 1965: A portable sensitive anemometer with proportional d.c. output and a matching wind velocity-component resolver. *J. Sci. Instr.*, 42, 414—417.

[4] U. K. Patent Application No. 21661/64.

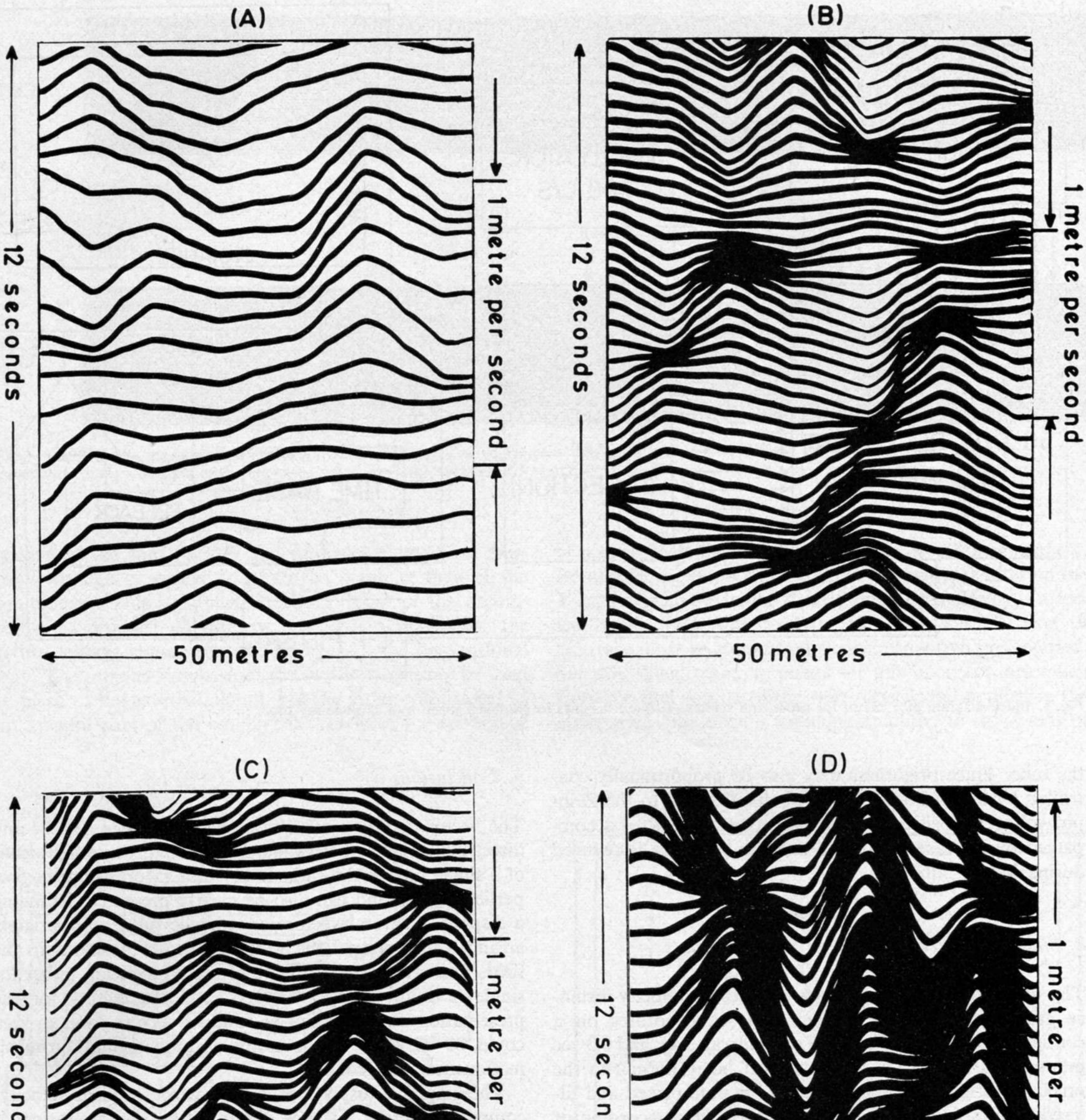


Fig. 9. Simulated three-dimensional oscillograms of wind speed fluctuations. Mean wind speeds, A and C, 5 m/sec^{-1}; B, 4.5 m/sec^{-1}; D, 2.5 m/sec^{-1}