NOTES AND CORRESPONDENCE

A Simple Instrument for the Measurement of Reynolds Stress by Eddy Correlation

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1. Introduction

In micrometeorological analyses the direct measurement of shear stress is of indisputable importance. Recent studies of wind-gradient data obtained over good sites have shown that uncertainty continues to exist about the mathematical description of the low-level wind profile. Much of the discussion concerns the validity of the reported friction velocities, which are usually deduced from wind data after assuming either neutrality near the surface (Swinbank, 1964) or some description of the profile such as the KEYPS function (Panofsky, 1963). Progress would be accelerated by the development of equipment for Reynolds stress measurement of a type more robust and convenient to operate than previously available.

Direct measurement of the surface stress has often been attempted using drag plates. These need to be carefully installed and planted with vegetation to provide a proper representation of the general area. Their use is severely handicapped by these considerations. As obvious examples, it is difficult to see how the method could be applied to a forest or to a water surface. Measurement of the momentum flux using the eddy-correlation technique, as employed in the Fluxatron for evaluating the sensible heat transfer (Dyer *et al.*, 1967) offers many inherent advantages. The instrument to be described here is simple to set up and operate. It provides a continuous measure of the Reynolds stress.

2. Instrumental description

The Fluxatron was designed around a rapid-response propeller anemometer, used as a vertical component wind sensor. Output from the anemometer[1] takes the form of a dc voltage. Typical response lengths are of the order 0.6 m. This instrument employs two of these anemometers, as vertical and horizontal component sensors. The anemometer responding to vertical wind components is altered by extending the shaft beyond the propeller in the manner shown by Dyer *et al.* (1967, Fig. 3). This alteration improves the cosine response of the instrument. The sensing head is aligned into the wind by a light-weight vane.

The output of the vertical (w) anemometer fluctuates about zero. The horizontal (u) anemometer gives fluctuations proportional to u' about a mean voltage determined by $\bar{u}$, where as is usual, a variable x is composed of fluctuations x' about a mean $\bar{x}$. It is required to compute the instantaneous product $\rho u'w'$, assuming that changes in the air density ρ are negligible, and to integrate over a sufficient period to obtain a representative sample of all eddies which contribute to the flux.

The anemometer dc outputs usually contain high-frequency "spikes" due to the commutation system employed in the tachometer generators of the sensors. In the present context, this feature is of negligible significance, since the u and w spikes will only contribute to the covariance if they are correlated. In practice, their contribution cannot be detected.

The block diagram (Fig. 1) shows how the instrument operates. Capacitive filters are used to remove the dc level of both anemometers. The filter time constant, determined by R and C_1 in the diagram, is adjusted to be 60 sec. In this way, a band-pass filter is constructed, of lower frequency limit controlled by the circuitry and whose upper limit is a function of the sensor separation (about 30 cm) and distance constants. Fig. 2 shows the effective filter characteristics for a range of wind speeds.

On the basis of wind tunnel studies, the anemometer response lengths are assumed to be 0.6 m in both configurations.

Voltage fluctuations transmitted by the filters are converted to 400 Hz amplitude modulated sine waves using high-impedance choppers, amplifiers and high Q LC circuits. These signals are multiplied and integrated on a modified watt-hour meter (described by Dyer and Maher, 1965). Phasing circuits are included to provide the integrator with its correct driving signals.

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[1] Supplied by R. M. Young and Co., Ann Arbor, Mich.

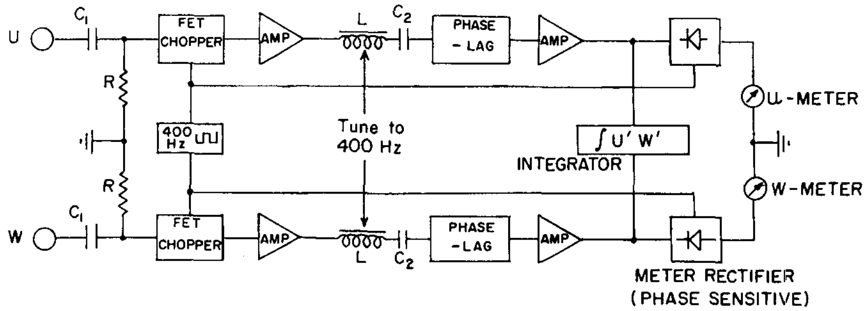

FIG. 1. Block diagram of Reynolds stress instrumentation; R and C_1 determine the high-pass input filter characteristic, while L and C_2 are tuned to the oscillator frequency.

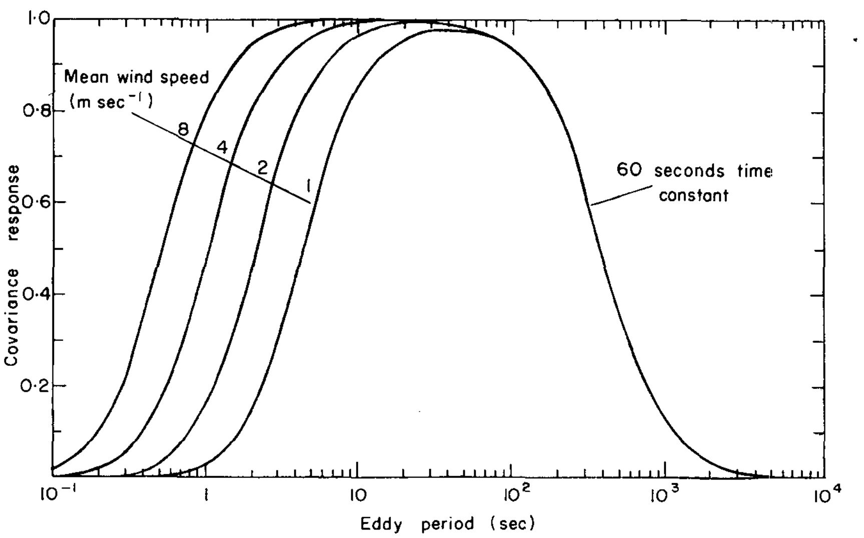

FIG. 2. The effective covariance response of the system to eddies of various periods. The low period cut-off is determined by the sensor characteristics, the high period by the electronic time constant.

Values of u' and of w' are displayed on panel meters, the sign of the signal being retrieved using phase-sensitive rectification.

3. Calibration and operation

During calibration, the anemometers are mounted in their field configuration. The w sensor is mounted upright in a horizontal flow and the inclination altered to give a range of normal wind components. The u anemometer is calibrated using a range of wind speeds. Typical anemometers give outputs of the order 50 mV per m sec^{-1}.

Voltage sources simulating constant u and w inputs of 1 m sec^{-1} are substituted for the anemometers before each run and gain controls adjusted to give predetermined meter readings. With such constant level inputs, the integrator is calibrated to give a direct reading facility (dyn cm^{-2}) over periods of 30 min.

To minimize disturbance of the air flow around the instrument due to the presence of an operator, cable lengths of the order 100 m are normally employed.

4. Field testing

During August 1967, the instrument was tested during an extensive meteorological experiment conducted at Hay, N. S. W. (Wangara). The site was flat grazing land, sparsely vegetated and uniform for 2 km in all directions. The sensors were located 85 m from a central instrumental complex. A complete set of micrometeorological data was obtained and will be published elsewhere. Runs were of 30-min duration. The sensing head was at a height of 10 m, to minimize high frequency loss.

Friction velocities u_* were estimated from wind data in a manner similar to that adopted by Swinbank (1964).

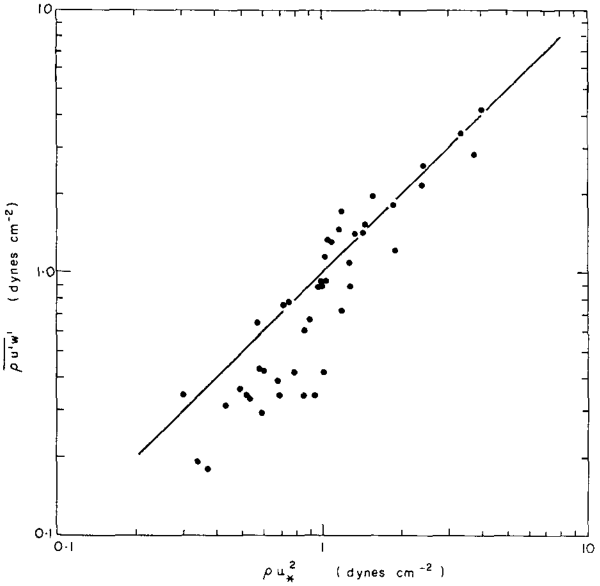

Fig. 3. Comparison between the measured Reynolds stress and the computed stress ρu_*^2 from low-level winds.

When compared with values of ρu_*^2, the values obtained showed good overall agreement. A large random scatter is evident (see Fig. 3) which cannot be ascribed to tilting of the sensing head (discussed later). It is probable that the critical factor here is the performance of the integrator, which is fragile and very susceptible to mechanical interference. The integrator performs best with high signal levels, corresponding to u' or w' of the order 1 m sec^{-1}.

5. Discussion

A disturbing feature of the results is the large amount of scatter thought to be due to the multiplication and integration system employed. In conditions when the signal levels are high, the machine gives a good estimate of the average value of the Reynolds stress. At low values, there is evidence in Fig. 3 of a significant reduction in performance.

The instrument contains no check on verticality. In the field experiment described here, it was aligned against the horizon and checked with spirit levels and plumb lines. This system would not be generally applicable. In a more advanced design, this omission could easily be rectified by integrating the w signal. Any deviation from the applicable local "vertical" would then be obvious as a mean $\bar{w}$, and appropriate mast adjustment could be made quickly in the field.

The importance of verticality of the sensing head has been the subject of recent discussion (Kraus, 1968; Deacon, 1968). Assuming that the approach by Deacon is correct (it is in agreement with the author's independent assessment), it is possible to be in error by as much as 10% for each degree of sensor tilt. Consequently, the importance of obtaining a true local vertical cannot be overemphasized.

6. Conclusions

The instrument described here is capable of directly measuring the Reynolds stress with a random error of ~20% associated with each 30-min average. Further improvements are envisaged and it is hoped that this error can be reduced.

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REFERENCES

Deacon, E. L., 1968: The levelling error in Reynolds stress measurement. *Bull. Amer. Meteor. Soc.*, **49**, 836.

Dyer, A. J., B. B. Hicks and K. M. King, 1967: The Fluxatron—A revised approach to the measurement of eddy fluxes in the lower atmosphere. *J. Appl. Meteor.*, **6**, 408–413.

——, and F. J. Maher, 1965: The "Evapotron": An instrument for the measurement of eddy fluxes in the lower atmosphere. CSIRO, Div. Meteor. Phys., Tech. Paper No. 15, 31 pp.

Kraus, E. B., 1968: What do we not know about the sea-surface wind stress. *Bull. Amer. Meteor. Soc.*, **49**, 247–253.

Panofsky, H. A., 1963: Determination of stress from wind and temperature measurements. *Quart. J. Roy. Meteor. Soc.*, **89**, 85–94.

Swinbank, W. C., 1964: The exponential wind profile. *Quart. J. Roy. Meteor. Soc.*, **90**, 119–135.