The Fluxatron—A Revised Approach to the Measurement of Eddy Fluxes in the Lower Atmosphere

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As a result of experience gained with the Evapotron in the measurement of eddy fluxes, a new instrument called the Fluxatron has been developed. The computing efficiency has been improved by filtering out slow eddies which do not contribute to the eddy flux.

The Fluxatron employs a propeller anemometer to detect the vertical wind component, and the response time of this device (0.3 sec) is suitable for measurements to be made at a height of 4 m. Only 2 W of battery power are consumed, in contrast to the Evapotron which uses 50–100 W.

The new instrument is extremely simple to operate in the field, and is thus suitable for use by relatively unskilled personnel.

In its present form, the Fluxatron measures only sensible heat transfer. The measurement of the evaporative flux presents no difficulty in principle, but it is hoped that an alternative humidity sensor may be found other than a fine-wire wet bulb as in the Evapotron.

1. Introduction

In a recent paper (Dyer and Maher, 1965), an account was given of the development of the Evapotron, an instrument designed to measure eddy fluxes in the lower atmosphere by the eddy-correlation technique. The Evapotron has been used in a number of field investigations and considerable experience has now been gained in the measurement of eddy fluxes.

On the basis of this experience, a number of revisions have been made in the practical form of the equipment. These have produced an instrument very much simpler to operate than the Evapotron. At the same time the power consumption has been greatly reduced and the efficiency of computing improved. The response time of the anemometer is such that it can be used for eddy flux measurements at heights of 4 m and above.

The new instrument has been given the name “Fluxatron,” in order to distinguish it from the Evapotron.

In its present form the Fluxatron has been used only for the measurement of sensible heat transfer, but an extension of the technique to the measurement of water vapor transfer presents no difficulty in principle.

2. Revision of the Eddy correlation method

The eddy flux of sensible heat \( H \) is defined by the equation

\[
H = c_p \left[ (\rho w)' T' \right],
\]

where \( \rho \) is air density, \( w \) vertical wind component, \( T \) air temperature, and \( c_p \) the specific heat of air at constant pressure. The prime denotes a departure from the mean value and the bar a time average.

Since the mean values cannot be known precisely in advance, the quantities \( (\rho w)' \) and \( T' \) cannot be assessed instantaneously in a field measurement. This difficulty is overcome in the Evapotron by the use of working means, and an exact transformation of Eq. (1) to

\[
H = c_p \left[ (\rho w)' T' \right] - \left( (\rho w)' \cdot T' \right],
\]

where \( (\rho w)' \) and \( T' \) represent departures from the working means.

Thus, one instantaneous multiplication and three integrations are called for.

An important difficulty encountered with the Evapotron was that long, slow fluctuations in temperature were frequently observed for which there appeared to be no counterpart in the wind component. Thus, no net contribution to the heat flux was made by these long eddies, but the computing devices had to handle signals of considerable magnitude.

The varying demand on the computing equipment is best illustrated by reference to Fig. 1 where the correlation of a single frequency of \( w \) and \( T \) fluctuations is considered. (Only fluctuations having an identical frequency will correlate and so contribute to the eddy flux.)

In Fig. 1a both \( w_{*} \) and \( T_{*} \) have zero mean values, and the term \( \overline{wT} \) can be readily assessed, \( \rho \) being omitted for simplicity. In Fig. 1b the \( T_{*} \) signal is offset from zero, and the computer is asked to handle a more difficult calculation. In Fig. 1c both \( w_{*} \) and \( T_{*} \) are
offset and the required heat flux term \( \overline{w'T'} \) appears as a small residual between \( \overline{w'T'} \) and \( \overline{w'T'} \).

These considerations suggest that an improvement could be made by selecting only those frequencies which contribute to the covariance and rejecting all others, i.e., those due to long eddies. The computing devices would now operate mainly under conditions similar to those of Fig. 1a with a consequent enhancement of performance.

It would be sufficient, in principle, to insert a high-pass filter into only one of the \( w \) or \( T \) channels (as in Fig. 1b), but it is clear that optimum performance would be obtained by filtering both channels to remove the slower components.

Two further benefits are derived. Firstly, the insertion of the high-pass filters has the effect of removing the mean terms \( \overline{w'} \) and \( \overline{T'} \), only one integration thus being necessary. Secondly, since only the revised form of the term \( \overline{w'T'} \) is now involved, the multiplication process can be easily and exactly performed by driving
the temperature bridge with the output signal from the anemometer circuit. The need for a conventional analogue multiplier is thus obviated.

3. Practical form of the instrument

A block diagram of the Fluxatron is shown in Fig. 2. The vertical wind component \( \omega \) is detected by a Gill propeller anemometer\(^1\) which supplies a small voltage from a dc generator. This was slightly modified to provide a symmetrical performance for positive and negative values of \( \omega \). (Air density \( \rho \) can be taken as a constant with acceptable accuracy.) The \( \omega \)-filter circuit consists of a simple RC network. The signal is converted to ac by a 400 cps transistor chopper which, after amplification, is applied to the temperature bridge. The latter contains two resistance thermometers, one, a fast response sensor of the original Evapotron design, and the second, a slow response sensor serving as the high pass filter of the temperature channel (Fig. 3). All of the sensors are operated at a height of 4 m.

The signal emerging from the temperature bridge is proportional to the fluctuations in both \( \omega \) and \( T \), and is thus the instantaneous heat flux. After further amplification, and phase sensitive detection, the signal is fed to a dc integrating motor.\(^2\)

The covariance response of the system for atmospheric eddies of various periods is illustrated in Fig. 4. At the small period, or high frequency end, the limit is provided by the response time of the propeller anemometer. This is set at a nominal value of 0.3 sec in the diagram, although in practice it exhibits a slight wind dependence. This is fortunately in a favorable sense, i.e., the response is faster for higher horizontal wind speeds.

For the long period, or low frequency end, the time constant of the two high-pass filters has been set at 40 sec. In practice, the response time of the slow temperature element varies with the natural ventilation rate, but again in a favorable sense. Provision for changing the time constant of the RC filter of the anemometer was only found to be necessary in the exploratory stages.

Typical eddy spectra contributing to the heat flux at a height of 4 m have been inferred from measurements by Gurvich and Zwang (1960) at a height of 1 m (curve a), and by Cramer et al. (1962) at 16 m (curve b), by assuming a linear dependence of eddy period with height.

The spectrum is expected to change with wind speed, height, and stability, but a detailed specification in these terms has not yet appeared in the literature. It is merely a matter of engineering compromise to ensure that no significant fraction of the eddy flux is removed by the choice of the filter parameters. The present paper is more concerned with the scientific principles involved than in setting down a design that will be valid in all possible applications.

4. Circuit details

The full circuit diagram of the Fluxatron is represented in Fig. 5. Transistors are employed throughout.

A multivibrator set at 400 cps provides square waves for the anemometer chopper which converts the millivolt dc output of the anemometer and RC filter circuit to 400 cps square waves. Within the \( \omega \)-amplifier a tuned filter circuit changes the square waves to sine waves, and, at the same time, a small amount of out-of-phase signal is injected to compensate for a quadrature component introduced by switching transients in the chopper circuit.

The signal is then applied to the temperature bridge, the output of which is further amplified and converted to dc in the phase-sensitive rectifier. The totalized answer appears as a number on the integrating motor.

Prior to taking a run, an instantaneous heat flux of 100 mW cm\(^{-2}\) is simulated in Position 2 of the master switch by means of an artificial \( \omega \)-input and a pre-set attenuator replacing the temperature bridge. The output current is adjusted to 50 \( \mu A \) by the operator. For this output signal the integrator has been pre-set to give 10 rpm, thus making the instrument direct reading. (In future models, it may be possible to avoid the field adjustment of sensitivity with only a slight improvement in amplifier stability.)

\(^1\) Supplied by R. M. Young & Co., Ann Arbor, Mich.
\(^2\) Supplied by Fernsteuergeräte, 1 Berlin 47, Brüss, Jahnstrasse 68–72, Germany.
In Position 3 of the master switch, still with a steady simulated \( w \)-input, the actual temperature elements are switched in and the output signal balanced to zero. This adjustment corrects for minor irregularities in the calibration of the temperature sensing elements and is almost unnecessary. Any out-of-balance of the temperature bridge is equivalent to a small, residual mean in the temperature channel. The possibility of a similar, and undesirable, residual mean in the anemometer channel is avoided by using high quality capacitors in the RC filter circuit.

In Position 4 of the master switch, all sensors are operative, and the run is commenced by switching in the integrator. A running time of 30 min is usual, although periods as short as 5 min can be used if desired.

Alignment procedures and pre-set adjustments are performed in the laboratory following conventional practice. The stability of the circuitry is such that a drift in performance of only a few per cent occurs over a period of several months.

The Fluxatron consumes 2 W of battery power, in contrast to the Evapotron which uses 50–100 W. All of the electronics is housed in a single, readily portable, instrument cabinet.

The operation of the instrument in the field is exceedingly simple, to the extent that routine measurements could now be made by relatively unskilled personnel.

5. Field performance of the Fluxatron

The performance of the Fluxatron in a series of field trials has been excellent.

Fig. 6 is a typical recording of the instantaneous heat flux at a height of 4 m illustrating the contributions to the net heat flux. The simple nature of the...
information presented to the integrator is evident, thus confirming the underlying ideas regarding the improvement in computing efficiency.

A number of exploratory tests were conducted which indicated that for time constants of the RC filter less than 20 sec significant fractions of the heat flux were being removed. Although this effect is obviously dependent on wind speed and stability, a choice of 40 sec for this time constant seemed to represent a suitable value for most conditions. At other heights, a different choice would have to be made, bearing in mind that the response time of the anemometer (0.3 sec) is hardly rapid enough for lower heights to be used.

A number of comparisons were made at a good micrometeorological site between heat fluxes as recorded by the Evapotron, and by the Fluxatron at a height of 4 m, together with measurements of net radiation R and ground flux G. A typical example is shown in Fig. 7. The agreement between the two instruments is excellent, thus demonstrating that satisfactory heat flux measurements are being made. Although the evaporative flux was not measured, the values obtained are in

![Figure 5. Circuit diagram of the Fluxatron.](#)

![Figure 6. Typical recording of the instantaneous heat flux at a height of 4 m.](#)
suitable accord with the daily cycle of radiation and ground flux, and the prevailing moisture condition of the soil.

6. Concluding remarks

The instrument described in this paper provides a simple and accurate method for the measurement of the sensible heat flux. Only 2 W are consumed and this is easily provided from a battery source.

The addition of a fast response wet bulb, such as in the Evapotron, would permit a similar measurement of the evaporative flux to be made. One difficulty encountered with this technique is that where a small evaporative flux occurs in the presence of a large heat flux, the specific humidity emerges as the difference of two large fluctuations and is therefore not well determined. Furthermore, the fine-wire wet bulb requires special handling, and is not particularly suitable for use by an unskilled operator.

For the present, alternative approaches are being explored for a sensor having a response time of a fraction of a second which measures the vapor pressure directly. New types of humidity sensor are becoming available continually and there is some hope that this problem may shortly be solved. Further streamlining of the electronics using recent miniaturization techniques could possibly be envisaged.

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