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A COMPARATIVE OBSERVATION OF A SONIC ANEMOMETER AND TRADITIONAL METHODS OF VERTICAL VELOCITY MEASUREMENT

By

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Abstract

For the purpose of comparative studies of vertical wind component sensors, an observation was made by the use of a new sonic anemometer with sound path length of 1.2 meters, a hot wire anemometer and a bivane-anemometer. On the process of the data analysis, corrections for dynamic characteristics of sensors are applied. Power spectra of the observational results of sensors on the simultaneous sampling duration are compared. The spectra from the sonic anemometer and the hot wire method are in good agreement but the spectra of the bivane-anemometer method were less consistent with the results by other two methods. Coherence and phase lag of the Fourier components of every trace are also studied.

1. Introduction

The sonic anemometer has been remarkably developed in the last decade to fulfill the requirement for improving the accuracy and dynamic response in anemometry, especially in the measurement of vertical velocity component. It has many advantages principally and practically compared with traditional methods, such as a hot wire anemometer (Swinbank [1951]) or a bivane-anemometer (Cramer *et al.* [1961]), as is pointed out by several authors (Suomi [1957], Gurvich [1960]). The present authors have also planned to make use of the sonic anemometer in micrometeorological studies and succeded in making ones of their own type (Mitsuta and Mizuma [1964] and Mitsuta [1966a]).

Before the practical use of the new sensors in the field experiments, their characteristics were compared with those of the traditional methods through the field experiments. A study of the same purpose was also carried out in the United States (Kaimal *et al.* [1964]). But their experiment was restricted only to the comparison of sonic anemometers and a bivane-anemometer. In the present study, the hot wire anemometer was included to be compared as well as bivane-ane-

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mometer.

The indications of the sonic anemometer are instantaneous wind velocities (averaging time being the order of 0.01 sec) averaged over a definite sound path length. While the readings of the other methods are wind velocities averaged over a certain time interval which depends on their thermal or mechanical inertia at a point. The importance and difficulty of the comparison are caused from this point.

The present paper contains the description of the measuring techniques, details of the experiment and the results of comparison of the power spectral and cospectral estimates of each traces.

2. Description of the instruments

Sonic anemometer: The sonic anemometer used in this study is the first testing apparatus of the working group of Kyoto University. In this instrument wind speed is measured as the transit time difference of sound pulses propagating in the opposite directions on the sound path of 1.2 meters in length. The sound frequency is 80 kc and wind measurements are made 200 times in a second. The instrumentation is the improved type of the one made by Suomi and Businger [1959], the details of which are shown in the previous paper (Mitsuta and Mizuma [1964]).

The rough estimations of response character of the sonic anemometer were proposed by Gurvich [1960] and Mitsuta [1966]. The fundamental ideas are the

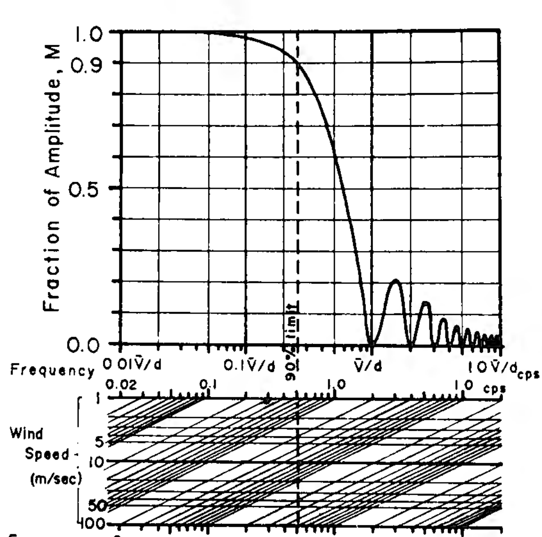

Fig. 1. Frequency response of sonic anemometer (after Mitsuta [1966]).

same and that the line averaged value can be transformed into the time averaged value by the idea of isotropic frozen eddy. This idea might be valid for small scale eddies comparable to the sound path length in dimension. Expectation of the frequency response proposed by Mitsuta is shown in Fig. 1.

Hot wire anemometer: Hot wire anemometer commonly used in vertical velocity measurement is the one proposed by Swinbank [1951], which was also used in this study. The present one is improved from the original instrument of Swinbank's in the sensing element of total wind speed. This is composed of four hot wires of the same dimension and two of them are connected in series making an arm of a bridge circuit and the rests are connected in parallel making the other arm of the bridge to compensate the effect of air temperature. The time constant of this hot wire itself is estimated to be 1.55×10^{-2} sec for wind speed of 1.0 m s and 0.82×10^{-2} sec for 4.0 m/s after the procedure proposed by Hinze [1959]. Recording of the signal was made by the use of oscillograph with criti cally damped galvanometers whose free period are 0.7 sec. The overall frequency response of the sensor and recorder is shown in Fig. 2.

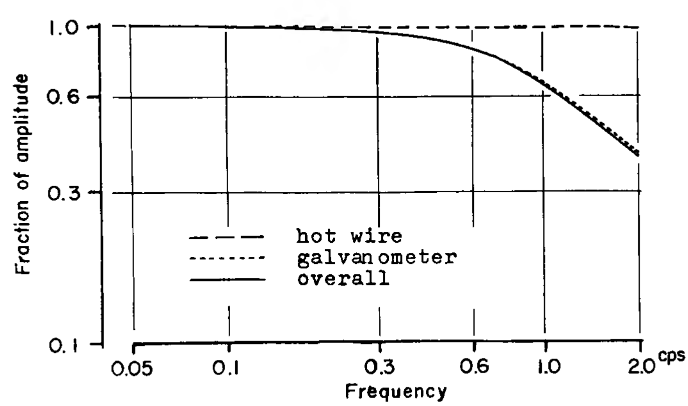

Fig. 2. Frequency response of hot wire method.

Bivane-anemometer: The combination of bivane and anemometer was used in this study. The bivane was originally designed for the measurement of vertical gusts in high winds (Mitsuta [1964]), therefore it is rather sluggush when used in light wind. The vane consists of two crossing wings of about 30 to 30 cm in dimension, the center of which is about 60 cm from the axis of rotation. An ordinary aerovane type anemometer was used with the bivane.

The dynamic response of wind vane in changing wind direction can be written in the following equation (Sanuki [1953])

$$\frac{d^2\beta}{dt^2}+2K\left(\frac{2\pi}{T_0}\right)\frac{d\beta}{dt}+\left(\frac{2\pi}{T_0}\right)^2\beta=\left(\frac{2\pi}{T_0}\right)^2\alpha, \tag{1}$$

where β is angular position of the vane and α is true wind direction, K damping ratio and T_0 period of free oscillation. K is constant for wind speed. T_0 is inversely proportional to wind speed and is expressed by characteristic length L as follows

$$T_0=L/V.$$

Table 1. Characteristics of the bivane

Wind speed V (m/s)		5.0	10.0	18.5	29.5	Mean
Vertical	Free period (sec)	2.78	1.52	0.77	0.57	15.2/V
	Damping ratio	0.15	0.15	0.15	0.15	0.15
	Time constant (sec)	2.9	1.6	0.8	0.6	15.7/V
Horizontal	Free period (sec)	2.80	1.52	0.85	0.58	15.2/V
	Damping ratio	0.15	0.14	0.14	0.13	0.14
	Time constant (sec)	2.9	1.6	1.0	0.7	17.4/V

These two parameters had been determined by wind tunnel experiment (Mitsuta [1964]) as shown in Table 1. They are almost the same for both direction and L is estimated to be about 15 meters. As is clear from this table, free period is too long for the bivane to be used in light wind as in this case, therefore a new correction method (Mitsuta [1966b]) was developed and used in this study.

3. Details of observations

Simultaneous measurements of vertical velocity component with the sonic

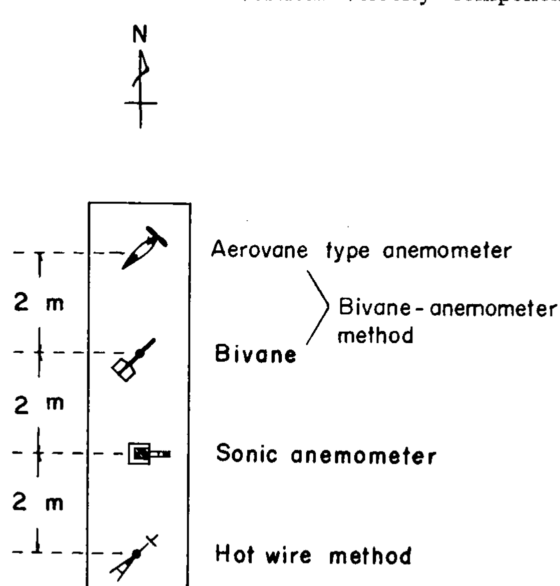

Fig. 3. Arrangement of sensors.

anemometer and other two methods mentioned above were carried out on Sept. 10, 1963, at Shionomisaki Wind Effect Laboratory of Disaster Prevention Research Institute, Kyoto University. All of the sensors were mounted on the top of the wind tower of 10 meters in height. Arrangement of the sensors is shown in Fig. 3 and description of the observational conditions in Table 2.

The outputs of each instruments were recorded in normal way, sonic anemometer on the strip film (the analogue output circuit had not been attached in

Table 2. Details of observational conditions

Date		September 10, 1963	
Run No.		3	5
Time of beginning		21h58m	23h00m
Sampling duration (sec)		153	158
Clouds		5/10(Ac, Cs)	6/10(Ac, Cs)
Wind direction		NE	NE
Mean wind speed at 10 m (m/sec)		3.6	4.1
Air temperature at 1 m	Dry bulb (°C)	—	21.4
	Wet bulb (°C)	—	21.2
at 10 m	Dry bulb (°C)	21.6	21.1
	Wet bulb (°C)	20.1	20.1

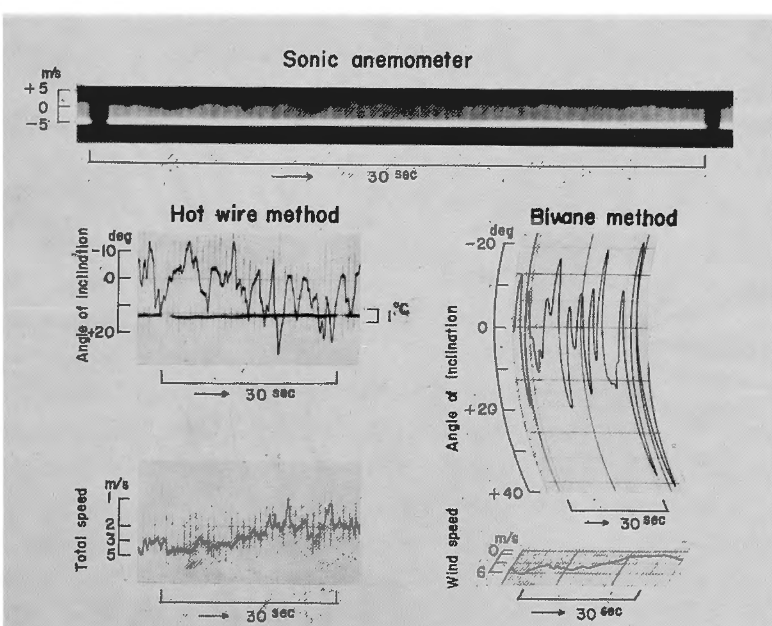

Fig. 4. Examples of simultaneous traces of three kinds of methods (A part of Run 3).

this case), hot wire anemometer on the oscillogram and bivane-anemometer on the chart record. The same time signal was supplied to every recorder and recorded with the traces. Fig. 4 shows an example of the traces. A nearly straight trace on the record of the hot wire method shows temperature variation at a point near the sound path.

4. Method of analysis

All the traces were digitized with 0.5 sec intervals for the whole sampling duration of about 150 sec. Power spectral analysis was made for each of the sonic and hot wire data in normal procedure (Tukey [1949]). And then, the high frequency ends of spectral estimates were somewhat modified as the correction of dynamic response of the sensors shown in the previous section. The maximum correction factor at 1 cps, the highest end of the frequency in this analysis, is about 2.2 for power spectral estimate obtained by the hot wire method and about 1.4 for the sonic anemometer. The frequency range, which does not require any correction for both, is that lower than 0.3 cps.

For the bivane data the new correction method mentioned above was applied before power spectral analysis on the way of obtaining the vertical velocity component. This method is digital computing method of true wind direction by the use of equation (1) with the estimates of angular position, rotating speed and accerelation of the vane obtained from bivane trace. The results of the spectral analysis in this case are only valid for the frequency range lower than 0.5 cps or so, because of finite difference approximation in the curvature estimating process in the correction.

To compare the fluctuating character of each traces in detail, coherence of two different kinds of traces was also studied. The computing procedure is also standard one (Lumley and Panofsky [1964]). In the present case, spectral correlation, which is the square root of coherence, and time lag ξ_n, which is defined by

$$\xi_n=\frac{1}{2\pi n}\theta_n=\frac{1}{2\pi n}\tan^{-1}\frac{Q_{xy}(n)}{C_{xy}(n)}+\frac{N}{2n} \quad (N=0,\ \pm 1,\ \pm 2\cdots\cdots), \tag{2}$$

where θ_n is phase lag deduced from cospectral and quadrature spectral density estimates (C_{xy} and Q_{xy}), were evaluated. In estimating coherence of Fourier components, no corrections for dynamic response of hot wire method and the sonic anemometer were applied. The whole computation was carried out by the use of the computer OKITAC 5090H of Research Reactor Institute, Kyoto University.

5. Results of analysis

The magnitude of rms values of vertical velocity component as obtained by

Table 3. Root mean square of vertical velocity component

Run	3	5
Sonic anemometer	0.78 m/s	0.67 m s
Hot wire method	0.49	0.43
Bivan-anemometer method	0.95	0.61

three different kinds of observational techniques are shown in Table 3. Those by the hot wire method are smaller than those by the sonic anemometer and the bivane-anemometer method for both runs. This may be resulted from calibration errors of hot wire anemometer. In fact, the mean values of total horizontal wind speeds obtained by the hot wire method in the process of data reduction were smaller by about 20% than those by aerovane type anemometer which are more reliable. In the following analysis the comparison of the relative amplitudes are discussed and this discrepancy is not so important.

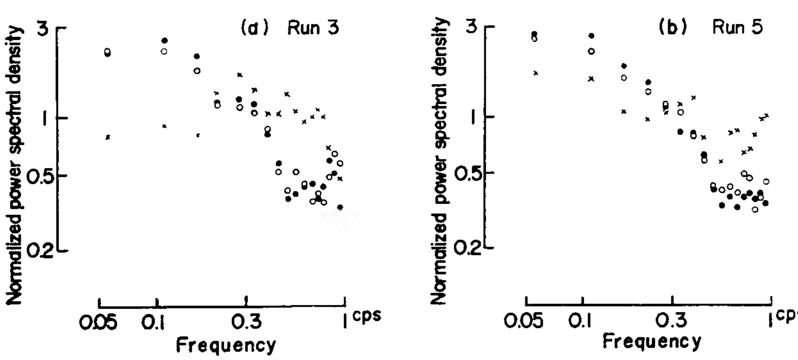

Fig. 5. Normalized power spectra of vertical velocity component.
○ : Sonic anemometer.
● : Hot wire method.
× : Bivane-anemometer method.

Power spectra of vertical velocity components by three methods with appropriate corrections are given in Fig. 5. The spectral shapes of the sonic anemometer and the hot wire method are generally in good agreement over the whole frequency range in spite of different nature of the sensors. But the spectral shape by the bivane-anemometer method are less consistent with those by other two methods especially for Run 3, though the energy peaks caused by the under damping dynamic response character of the bivane are eliminated by the new correction method. This result is different from the results of the comparison by Kaimal *et al.* [1964], which show good agreement between sonic and bivane data. This difference may be caused by the difference of the response of bivane. The present one is too sluggish to be used in light winds even

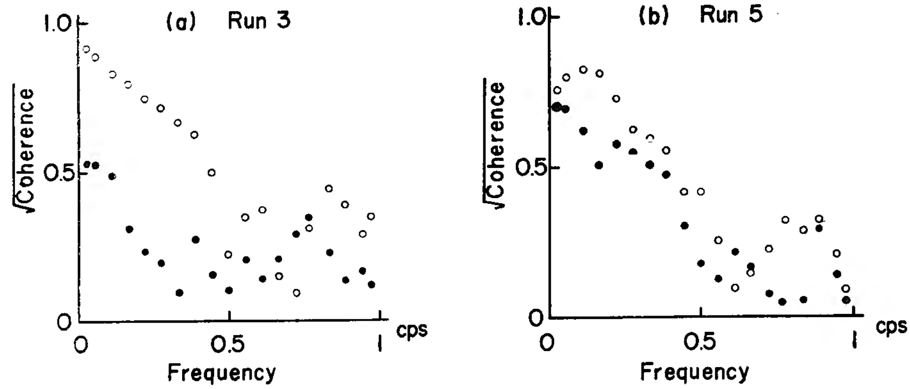

Fig. 6. Spectral correlation between vertical velocity components.
○ : Sonic anemometer—Hot wire method.
● : Sonic anemometer—Bivane-anemometer method.

though the appropriate correction is applied.

Spectral correlation between sonic and other data is shown in Fig. 6. The correlation of the Fourier components of the frequency lower than 0.4 cps is larger than 0.5, except the case with the sonic anemometer and the bivane-anemometer method in Run 3, which leads to the conclusion that sonic data have considerably proportional amplitudes with the hot wire or bivane-anemometer data in lower frequencies than 0.4 cps. The reason of the discrepancy of sonic and bivane-anemometer data in Run 3 is not clear.

Fig. 7 shows time lag between the Fourier components. The ○ is the time lag calculated with the first term of the right hand side of the equation (2) and

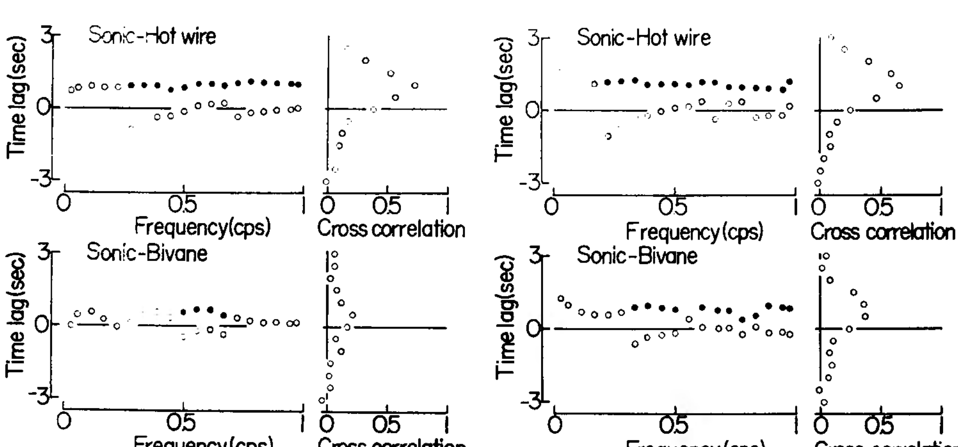

Fig. 7. Phase- spectra and cross correlation functions between vertical velocity components. Positive time lag indicates that measurements by sonic anemometer are advanced in phase. Left ; Run 3, right ; Run 5.

the ● the ones compensated for gap in the time lag using the second term of the right hand side of the equation. The time lag of about 1 sec is found between every Fouries components of traces by the sonic anemometer and the hot wire method. As wind directions during the observations are both NE, windward separation between the two sensors is 1.4 meters. Then transit times from the sonic anemometer to the hot wire sensor may be 0.3-0.4 sec. Besides, phase lag on account of mechanical inertia of galvanometer for the hot wire method is about 0.2 sec in time for all the frequencies. Consequently, apparent time lag between the sensors may be 0.5-0.6 sec. These approximately equal to the time lags found in Fig. 7. It is to be noted that the time lags are almost identical for all the frequencies in spite of the fact that the two instruments differ from each other and spectral correlation has rather small value for high frequencies. This result suggests that the concept of frozen turbulence holds good to vertical turbulence of frequency lower than 1 cps.

The bivane-anemometer data do not give so definite results as obtained in the case of the hot wire method, especially in Run 3.

6. Concluding remarks

The sonic anemometer prepared by the present authors worked satisfactorily throughout the experiment. From the point of view of power spectra of vertical velocity component, rather inexpensive and simple hot wire method gives results similar to those by the sonic anemometer provided that appropriate correction on the basis of frequency response is applied to power spectral estimate. It is found that the present bivane-anemometer method has little merits for use in such light wind as in the present observation even thouth appropriate correction is applied.

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