Experimental determination of wind speed and direction using a three microphone array

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Recent studies indicate that the major sources of wind noise (under 50 Hz) measured on outdoor microphones is due to turbulent eddies moving across the microphone [S. Morgan and R. Raspet, J. Acoust. Soc. Am. **92**, 1180–1183 (1992)]. Taylor's frozen turbulence hypothesis states that these eddies retain their shape over a distance large compared to the size of the eddy. Thus it may be reasonable to assume that each eddy presents a specific acoustic signature that remains somewhat stable over a finite distance and time. If this is true, the cross correlation time for signals from two microphones a known distance apart should correspond to the travel time for an eddy to traverse the distance between the microphones. Assuming that the speed and direction of the eddy is the same as the ambient wind, enough information exists to calculate the wind speed and direction.

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INTRODUCTION

The purpose of the experiment was to test a hypothesis that wind speed and direction could be determined using microphones. This hypothesis was based on recent research on wind noise from a microphone in a spherical windscreen that indicates that wind noise is due mainly to turbulent eddies entrained in the wind.[1,2] The observed noise is most intense below 50 Hz. To determine the wind speed acoustically the travel time between microphones for a turbulent eddy must be established and the distance between the microphones must be known. The travel time is determined from a cross correlation between pairs of microphones.

I. EXPERIMENTAL

The location of the microphone array was adjacent to an east west runway at a small airport. The ground was relatively flat, covered with grass, and relatively free of obstructions. The winds were light and gusty and out of the south. The array consisted of three B & K $\frac{1}{2}$-in. microphones with 180-mm windscreens arranged in a 0.61-m (2-ft) equilateral triangle approximately 0.6 m above the ground (Fig. 1). The acoustic signal was passed through a preamp to a power supply to a differential amplifier, a low-pass filter (typically set at 50 Hz), and then recorded on an eight-channel digital recorder with a sampling rate of 20 kHz. A hot wire anemometer was placed above one microphone to record the wind speed.

A Scientific Atlanta SD 380 spectrum analyzer was used to perform a cross correlation between channel pairs that resulted in a value for the time lag. The number of averages and the frequency for the low-pass filter setting on the analyzer were varied. When the low-pass filter was set below about 10 Hz, the correlation peak was not well defined. When the low-pass filter was set above 100 Hz, the peak became ragged; we suspect this was due to background acoustic noise. A setting of 40 Hz seems optimal for our conditions. The averaging time was varied from about 30 s (one sample) to several minutes. One sample gave a poorly defined (but usable) correlation peak. As the number of averages increased, the peak generally becomes better defined, but after a very long time, the peak begins to move and broaden. We assume this is due to changes in wind speed. For comparisons to the hot wire anemometer, 15 min of data were analyzed in sections of 5 min with a low-pass setting of 40 Hz. Several plots of the cross correlation are shown in Fig. 2 and for each plot, the time lag is taken at the point where the cross correlation reaches a maximum.

Referring to the three triangles (1-2), (2-3), (1-3) shown in Fig. 3 the following equations can be written

$$a\ \sin(60-\theta)=Vt_{12}, \tag{1}$$

$$a\ \sin\ \theta=Vt_{23}, \tag{2}$$

and

$$a\ \sin(60+\theta)=Vt_{13}, \tag{3}$$

By defining an error function E as

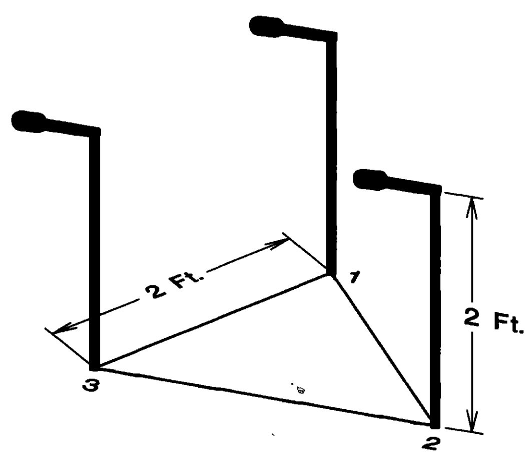

FIG. 1. Experimental setup.

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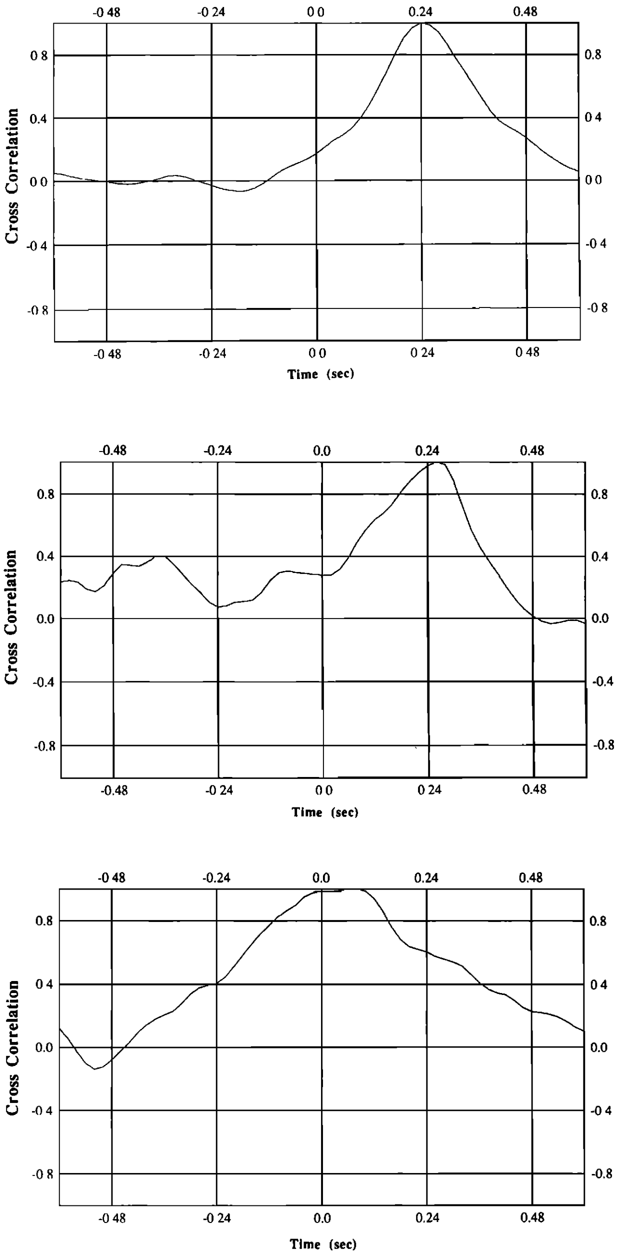

FIG. 2. Typical cross-correlation plots. This figure gives the actual data corresponding to row 1 in Table I. Each row in the table is an average for 5 min of data.

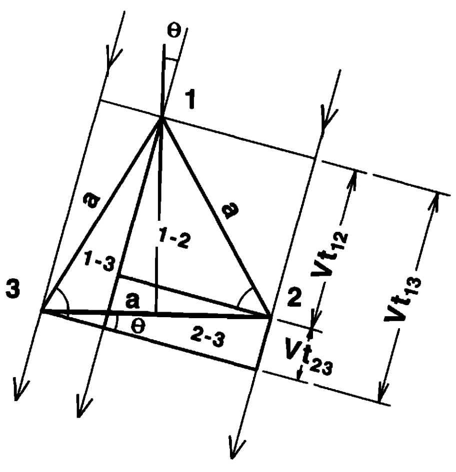

FIG. 3. Geometry used to derive equations for wind speed and direction.

TABLE I. Results of wind velocity measurements.

Run	T_{12} (s)	T_{23} (s)	T_{13} (s)	Theta (deg)	v (m/s)	% Error in v	Anemom. (m/s)
1	−0.24	0.04	−0.26	176	2.1	19	2.6
2	−0.26	0.08	−0.26	170	2.0	9.1	2.2
3	−0.22	−0.04	−0.22	−174	2.4	4.3	2.3

$$E^2=[a\ \sin(60-\theta)-Vt_{12}]^2+[a\ \sin\ \theta-Vt_{23}]^2 +[a\ \sin(60+\theta)-Vt_{13}]^2, \tag{4}$$

and by minimizing this function with respect to θ and V separately, the following equations results:

$$\tan\ \theta=\frac{t_{23}+\cos\ 60(t_{13}-t_{12})}{\sin\ 60(t_{13}+t_{23})} \tag{5}$$

and

$$V=\frac{a[t_{12}\ \sin\ \theta+t_{23}\ \sin(60+\theta)t_{13}\ \sin(60-\theta)]}{(t_{12}^2+t_{23}^2+t_{13}^2)}. \tag{6}$$

Here, θ is measured positive clockwise from the perpendicular bisector of the line joining microphones 2 and 3, t_{12} is the time of travel from microphone 1 to microphone 2; and $t_{12}=-t_{21}$, etc.

Table I lists the measured values for the time lags for the channel pairs and the measured value for the wind speed taken from the hot wire anemometer. The calculated values for θ and V are also listed. Theta was not measured independently but the calculated values agree well with the observed direction of the wind.

II. CONCLUSION

Initial results indicate that average wind speed and direction can be determined from the wind noise on a microphone array. The signal processing required is minimal; the sampling speed could be much lower than used for this study. This procedure for determining wind speed and direction could be particularly useful in applications where moving parts are prohibited.

ACKNOWLEDGMENTS

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[1] S. Morgan and R. Raspet, "Investigation of the mechanisms of low-frequency wind noise generation outdoors," J. Acoust. Soc. Am. **92**, 1180–1183 (1992).

[2] S. Morgan and R. Raspet, "A theoretical and experimental study of low frequency wind noise: microphone inside a spherical foam windscreen," submitted to J. Acoust. Soc. Am.