ANISOTROPY OF THE AMPLITUDE FLUCTUATIONS OF THE ACOUSTIC WAVES PROPAGATED THROUGH THE TURBULENT ATMOSPHERE NEAR GROUND

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Temporal structure of the amplitude fluctuations of an acoustic wave, propagated in two mutually perpendicular directions (along the average wind velocity and perpendicularly to it) was investigated. The measurements conducted have shown significant dependence of the temporal characteristics of the amplitude fluctuations on mutual orientation of the path and the direction of the wind velocity vector.

The amplitude fluctuations of an acoustic wave, propagating in the ground layer of the turbulent atmosphere under conditions of reflection from the Earth's surface, were studied theoretically[1–3] and experimentally.[4–6] In theory the peculiarities of an acoustic wave propagation in a randomly inhomogeneous moving medium were not taken into account while experimental investigations were conducted, as a rule, at a fixed path orientation relative to the wind velocity vector. In the experiment conducted we have developed and refined investigations, described in Ref. 8.

The difference of the results presented in this paper from those published in Ref. 8 is as follows. We used more precise equipment. In the experiment, described in Ref. 8, for different directions different types of microphones and loudspeakers were used. There was also used an analog detecting of signals, with their following smoothing by low-frequency analog filters of the second order with further discretization at a frequency of 100 Hz. This could introduce additional error in the estimation of spatial anisotropy of the acoustic wave propagation. In this study we have used quite identical measuring condenser microphones and dynamic speakers. A 2-channel 12-bit high-speed ADCs (conversion time was 3 ms) were used for digitizing signals and correspondingly very high frequency of discretization of the signals themselves from the microphones. Also we used practically new method of the amplitude separation. The fast computer enabled using the programs working in real time and giving more exact results. All this allowed us to reach the identity of the through channels (emitter-microphone-recording accurate to 1% in the operating frequency band).

The approach to experimental data processing using low-frequency filtration with the following decimation (without smoothing) is quite different than that used in Ref. 8 and it allowed more exact study of the low-frequency portion of the spectrum.

In contrast to the study presented in Ref. 8 we arranged full meteorological measurements.

We analyzed the data acquired at different wind-temperature stratification, whereas in Ref. 8, the data obtained only at one (unstable) stratification were available. The synchronous measurements we have conducted of the relative amplitude fluctuations of an acoustic wave show significant anisotropy of fluctuations, depending on the average wind velocity, other conditions being the same. The diagram of the experiment is shown in Fig. 1.

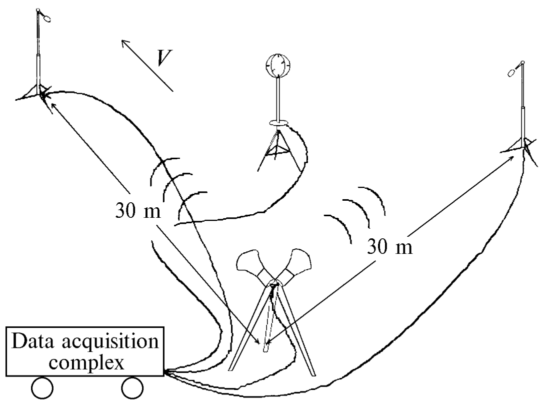

FIG. 1. Block-diagram of the experiment.

Two quasi-spherical waves directed along the average wind velocity and perpendicularly to it were measured simultaneously. Receiving microphones were at $L = 30$ m from the emitting horns. Emitters and receivers were located at the height $h = 1.5$ m. The loudspeaking horns with an output of 50 W used as the emitters, and as the receivers were used measuring condenser microphones MV201 by RFT, with the antiwind protection shields. Each microphone was

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connected to an ac pre-amplifier. The width of the receiver's directional pattern was close to 60°, and receiving microphones have the directional pattern of the cardioid shape. Signals from the amplifiers of the microphones entered the third-octave filters with the central frequency at 1.25 kHz. The output signals from the filters were digitized with a 12-bit ADC at a sampling frequency of 160 kHz and after the amplitude detection their values were entered in the computer memory at a frequency of 100 Hz. The amplitude detection was organized programmly using the following algorithm: 1600 digital values of the ADC codes were memorized in a buffer, then they were detected and the maximum value which was recorded as the instantaneous value of the amplitude was found from the obtained data array. This algorithm was realized on the assembler using the register addressation, thus enabling its real time operation.

Instantaneous values of the wind and temperature components were measured with a three-component ultrasonic anemometer-thermometer[9] located at the height of $h = 1.5$ m at the bisectrix of the angle between the microphones. The flat field of flattened oats 15–20 cm high was the underlying surface. The frequency of the emitted wave was $f = 1.25$ kHz. Measurements were conducted both at stable and unstable stratification of the atmosphere and the time of an individual sampling was 300 s. The range of variation of the average temperature during the measurements at the height of $h = 1.5$ m was 1.5–6.8°, relative humidity of the air 99–75%, and the pressure 752–755 mm of the mercury column.

Further statistical processing of the obtained time series of the instantaneous values of the amplitude included the removal of rough errors using Chebyshev inequality, low-frequency filtration using Butterwort filter of the 6th order[10] and agreed with it decimation of the data with the index 8. Then the removal of the trend was conducted and autospectra were calculated after the FFT processing. The effect of infiltration was removed by the GEO window[10] after the calculation of the Fourier coefficient. In parallel with the autospectra the average values of the amplitudes, their variances and autocorrelation functions were also calculated.

$$\beta^2 = \frac{\langle A^2\rangle - \langle A\rangle^2}{\langle A\rangle^2} = \frac{\langle A^2\rangle}{\langle A\rangle^2} - 1$$

In Fig. 2 are shown the values of the relative rms deviation β of the amplitude fluctuations A, depending on the value of the average wind velocity V for longitudinal and transverse relative to the wind direction paths. The straight lines, constructed as the best linear approximation of the experimental data are also shown in the figure. As the obtained data show much stronger dependence of the amplitude fluctuations on the wind speed is observed for the cross-wind path as compared to that for the path along the wind.

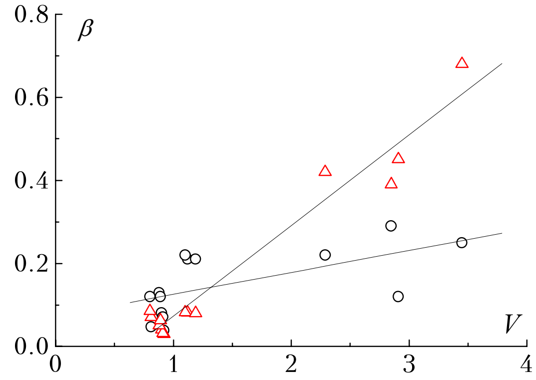

FIG. 2. The dependence of the relative rms deviation β *on the average wind velocity* V *for the paths along (o) and across (Δ) the wind.*

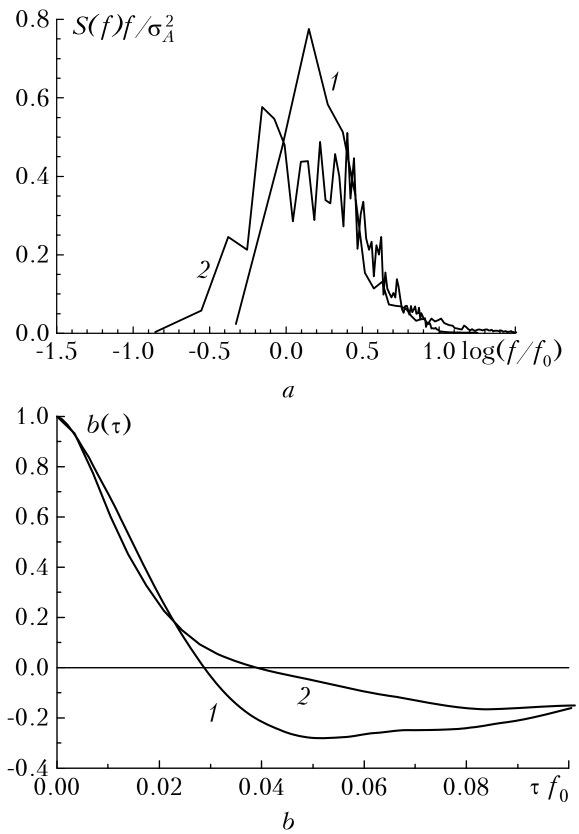

FIG. 3. The temporal spectra (a) and autocorrelation functions (b) of the amplitude fluctuations of an acoustic wave for the paths along (1) and across (2) the wind at a stable stratification of the atmosphere ($\xi = +0.1$): *1* – $V_\perp = 0.008$ m/s; $\sigma_\perp = 0.3$ m/s; *2* – $V_\perp = 0.9$ m/s; $\sigma_\perp = 0.4$ m/s.

In Figs. 3 and 4 are shown the dimensionless temporal spectra of the amplitude fluctuations for both paths and corresponding to this spectra normalized temporal autocorrelation functions obtained at stable (Fig. 3) and unstable (Fig. 4) stratifications of the atmosphere. The scale of similarity considering

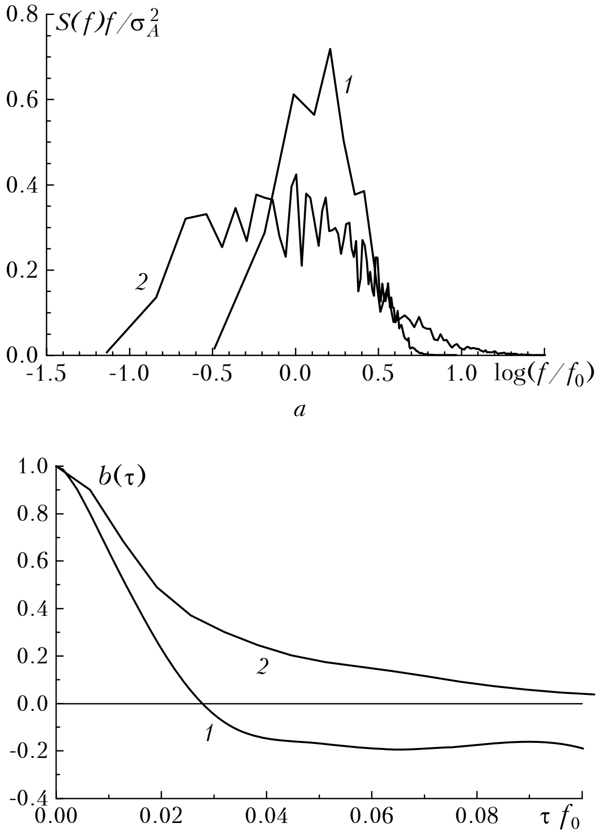

FIG. 4. The temporal spectra (a) and autocorrelation functions (b) of the amplitude fluctuations of an acoustic wave for the paths along (1) and across (2) the wind at an unstable stratification of the atmosphere ($\xi = -0.9$): *1* – $V_\perp = 0.06$ m/s; $\sigma_\perp = 0.27$ m/s; *2* – $V_\perp = 1.2$ m/s; $\sigma_\perp = 0.32$ m/s.

variations of the average, perpendicular to the wind velocity $V_\perp$, and fluctuational component $\sigma_\perp$, is the characteristic frequency $f_0 = [(V_\perp^2 + \sigma_\perp^2)/(\lambda L)]^{1/2}$,[10] where λ is the length of the wave of radiation, L is the length of the path. From the data presented one can see that the time spectrum for the path perpendicular to the average wind undergoes broadening to the low-frequency region as compared to the time spectrum obtained for the path, directed along the average velocity of the wind, and moreover, under unstable stratification the broadening is considerably more noticeable and forms approximately half an order of magnitude on the scale of the relative frequences.

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