ULTRASONIC TRAVEL-TIME TECHNIQUE FOR DIAGNOSTIC OF GRID-GENERATEDTURBULENCE

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Summary The study utilizes an ultrasonic travel-time technique to diagnose grid-generated turbulence produced in a wind tunnel. The statistics of the travel-time variations of ultrasonic wave propagation along a path are used to determine some metrics of the turbulence.

EXPERIMENTAL SET-UP

In this section we shortly discuss experimental technique and equipment. Detail description of the experimental apparatus can be found in Andreeva and Durgin [2003][1].In the experimental part of the study we utilize ultrasonic pulses traveling in straight paths as shown in Fig. 1. The sound propagates across a grid-generated turbulence from a transmitter to a receiver separated by a distance *s*. The flowmeter equation may be used to derive an expression for a travel time t of a wave traveling from the speaker to microphone.

$$t = \int_s \frac{dy}{c-u} \approx t_0 + \frac{1}{c^2}\int_s u' dy; u = U\sin\beta + u' \quad (1)$$

where t_0 is a travel time in the undisturbed media, U is a mean velocity, c is a sound speed, u' are fluctuations of the mean flow velocity.

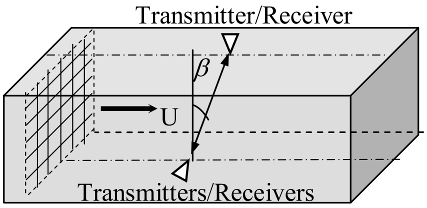

Figure 1. Sketch of wind-tunnel test section with ultrasonic flowmeter.

In the experiment the only parameter that is measured is a travel time of ultrasound pulses. The experiments were carried out in the $1.75'' \times 11.62'' \times 45.25''$ test section of low turbulence, low speed open circuit type wind tunnel. The velocity and temperature fluctuations were generated simultaneously using a heated grid. Nine cases of different distances S for two different temperatures $T = 59^\circ F$ and $T = 159^\circ F$, are studied.

EXPERIMENTAL RESULTS

Non-heated Grid Experiments

In Fig. 2 we compare our experimental data for travel time variance firstly with theoretical results obtained by Iooss et al.[2] In their work authors were investigating travel time using geometrical optics approach, which neglects all diffraction phenomena. Secondly, we compare our results with solution of the parabolic equation for the travel time variance of a plane wave in a moving random media, derived by means of the Rytov method and Markov approximation for the Gaussian spectrum of medium inhomogeneities.[3] Comparison reveals that some of the results of geometric acoustics are acceptable even beyond the area of the validity of the approach, which was shown analytically by Rytov.

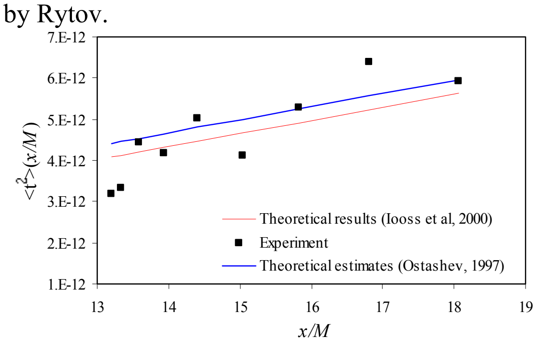

Figure 2 Experimental data for the travel time variance versus normalized travel distance x/M. Rytov solution and theoretical model by Iooss et al., are plotted for qualitative comparison. $U = 3.5 m/s$.

However, nonlinear effects at a certain propagation distance were observed in numerical experiments by Karweit et al.[4] In Fig. 3 we compare the travel-time variance with Chernov[Error! Reference source not found.] estimates and with theoretical estimations of second-order travel time variance by Iooss et al.[Error! Reference source not found.] The experiment performed for large distances. The departure from the linear Chernov prediction increases with travel distance. Probability densities for the occurrence of caustics were calculated theoretically. For our experimental data we estimate the probability density of occurrence of caustics using theory developed by Klyatskin[5] and explored by Iooss[2].

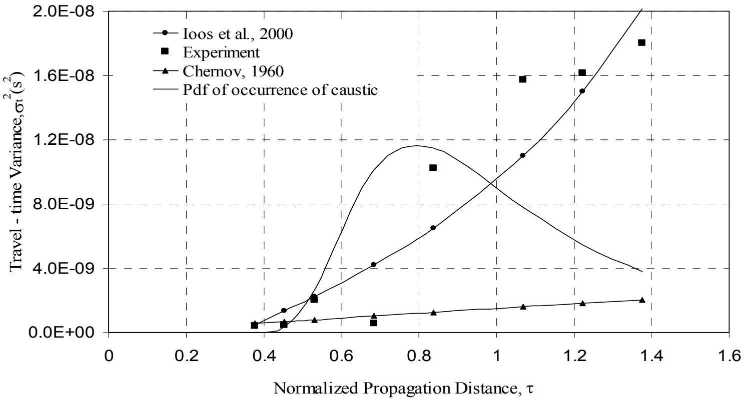

Figure 3 Probability density function of occurrence of caustic along with nonlinear dynamics of the travel time variance. $U = 18m/s$, $M = 6 \cdot 10^{-3} m$.

Heated grid Experiments

We have developed a methodology for determination of correlation functions of turbulent velocity and sound speed fluctuations. In order to do that the ultrasonic flowmeter equation (1) is reconsidered, where the effects of turbulent velocity and sound speed fluctuations are included. The result is the integral equation in terms of correlation functions for travel time, turbulent velocity and sound speed fluctuations. Experimentally measured travel time statistic data with and without grid heating are approximated by Gaussian function and used to solve integral equation analytically in terms of the turbulent velocity and sound speed correlations functions. Figs. 4 and 5 demonstrates correlation functions of turbulent velocity and sound speed fluctuations obtained using developed semi-analytical methodology.

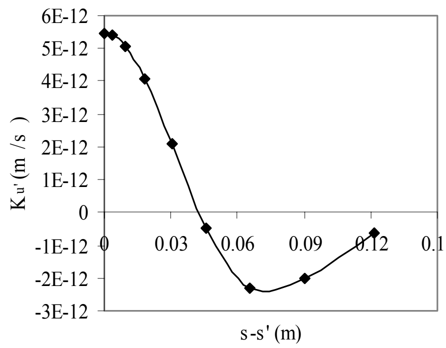

Figure 4 Experimentally obtained correlation function of turbulent velocity. $U = 3.5m/s$, $T = 59^{\circ} F$.

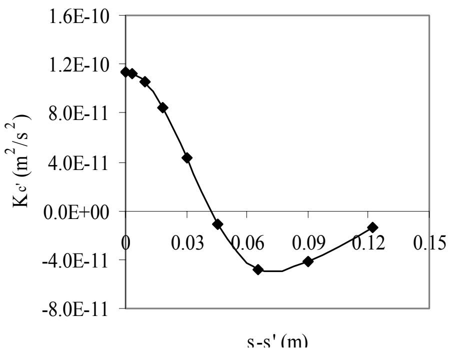

Figure 5 Correlation function of sound speed fluctuations. $U = 3.5m/s$, $T = 159^{\circ} F$.

Fourier Transform allows determination of spectrum of the turbulent velocity and sound speed fluctuations shown in Fig. 6.

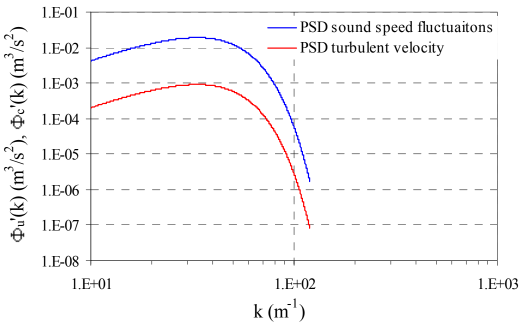

Figure 6 1-D energy spectra of turbulent velocity and sound speed fluctuations $U = 3.5m/s$.

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