Acoustic Interaction with a Turbulent Plane Jet—Some Effects on Turbulent Structure

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Abstract

RESULTS of a study to determine the nature of the interaction mechanism linking an applied sound field and an incompressible turbulent plane jet are reported. Measurements of the effects of applied sound on the jet mean flow behavior and measurements of turbulence intensities, Reynolds shear stresses, and turbulent energy spectra were performed and reported by Chambers and Goldschmidt.[1,2] The results of some of the turbulence measurements and the conclusions that may be drawn about the interaction mechanism are presented here.

Contents

The experimental system is described in detail by Chambers.[3] The nozzle had a contraction ratio of 16:1 and exit dimensions of 6.35×305 mm. The jet flowfield was constrained to two-dimensional behavior by horizontal walls. The nozzle, an acoustically absorbent baffled plenum assembly, and the flowfield were located inside a 3.7 m^3 anechoic room. The disturbing pure-tone acoustic field approximated a plane traveling wave applied normal to the axis of the jet at a sound pressure level of 105 dB SPL re 20 μPa at the monitoring microphone. The sound pressure level along the jet axis from the nozzle to 80 nozzle widths downstream varied by no more than 7 dB.

Hot-wire anemometers were employed for turbulence measurements using no corrections for finite levels of turbulence or three-dimensional effects. Energy spectra were measured using a fast Fourier analyzer. Measurements were obtained at a jet Reynolds number of approximately 6000 in the undisturbed jet and at disturbance frequencies of 700 and 1600 Hz, corresponding to Strouhal numbers of 0.30 and 0.69, respectively. Reynolds and Strouhal numbers were based upon nozzle exit mean velocity and slot width. The two frequencies increased the mean profile widening rates approximately 22 and 9% above the average no-sound rates, respectively.

Turbulence Intensities on the Centerline

The longitudinal turbulence intensities measured on the jet centerline are shown in Fig. 1. The three cases have approximately the same intensities in the exit plane of the nozzle, indicating that the sound fields did not produce large changes in the flow within the nozzle. Measurements of the nozzle boundary layer and the initial jet velocity profile confirm this result. The two cases of applied sound exhibit faster turbulence intensity growth than the no-sound case, reaching peaks near $X/D=12$. Note that at larger distances from the nozzle, the three cases appear to be converging. The widening rates of the disturbed cases were also found to converge by $X/D=80$. The lateral turbulence intensities on the centerline exhibit similar trends, although with smaller differences in magnitude. Transverse profiles of the intensities measured at 20, 40, and 60 slot widths downstream of the nozzle exhibit magnitude changes similar to the centerline intensities with small changes in shape.

Turbulent Energy Production

The product of the Reynolds stress and the velocity gradient gives the rate of energy transfer from the mean flow to the turbulence. This production of turbulence energy was calculated using curves fit to the measured Reynolds shear stresses at $X/D=40$ and 60 and the mean velocity profiles that were found similar for the three cases. It may be observed in Fig. 2 that there are significant differences in magnitude, but only small differences in profile shape. Measured Reynolds shear stress correlations exhibited no large overall increases for the disturbed cases. These results indicate that the sound field does not distort the production of turbulent energy by in some way interacting preferentially with particular areas in the main region of the jet.

Turbulent Energy Spectra

The mean flow results of Ref. 1 showing that the effects upon the jet have a strong frequency dependence and the turbulence results here showing that the disturbed case intensities increased rapidly in the initial region suggest that shear-layer instability phenomena might play a role in the interaction. Energy spectra of the longitudinal turbulence fluctuations were measured at one location in the shear layer near the nozzle and on the centerline from a X/D of 0-40. Centerline spectra measured at $X/D=3$ are presented in Fig. 3. The no-sound case spectrum is broad with three maxima, while the 700 Hz case spectrum exhibits major peaks at frequencies which are all harmonics, subharmonics, or the harmonic of the subharmonic. The spectrum of the 1600 Hz case has a broad base and a large number of peaks, with the three lowest frequencies roughly equivalent to those in the undisturbed shear-layer spectrum. Note that the 800 Hz subharmonic is not present. The 1600 Hz disturbance is nearly the second harmonic of the natural shear-layer frequency (545 Hz) and may feed energy into it. The other peaks correspond to various sums of the first three peaks and their difference with the disturbance frequency. Sharp spectral peaks close to the nozzle fade into broadbands at larger distances downstream, with the spectra beyond $X/D=15$ appearing to approach similarity.

Proposed Interaction Mechanism

Possible mechanisms of interaction between turbulent shear flows and acoustic disturbances have been proposed by many

Presented as Paper 82-0048 at the AIAA 20th Aerospace Sciences Meeting, Orlando, Fla., Jan. 11-14, 1982; submitted Jan. 22, 1982; synoptic received Dec. 15, 1982. Full paper available from AIAA Library, 555 W. 57th Street, New York, N.Y. 10019. Price: Microfiche, $4.00; hard copy, $8.00. **Remittance must accompany order.**

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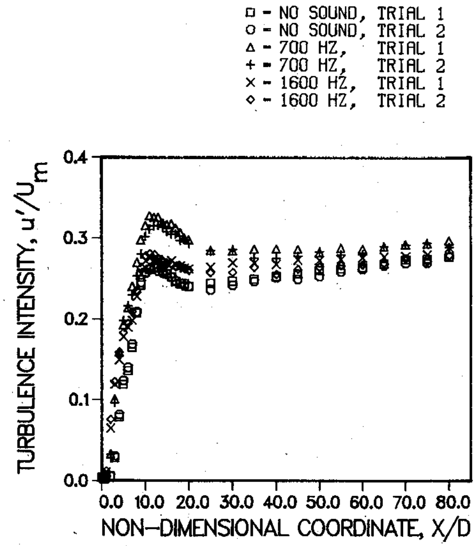

Fig. 1 Longitudinal turbulence intensities on jet centerline.

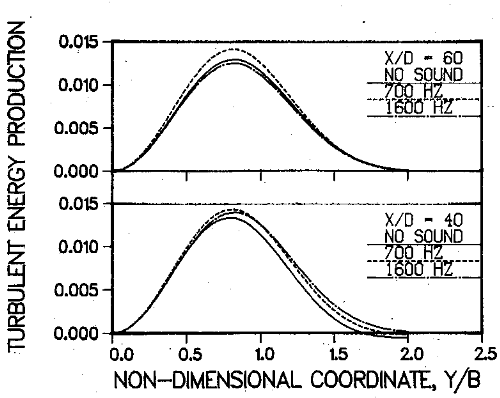

Fig. 2 Transverse distributions of turbulence production.

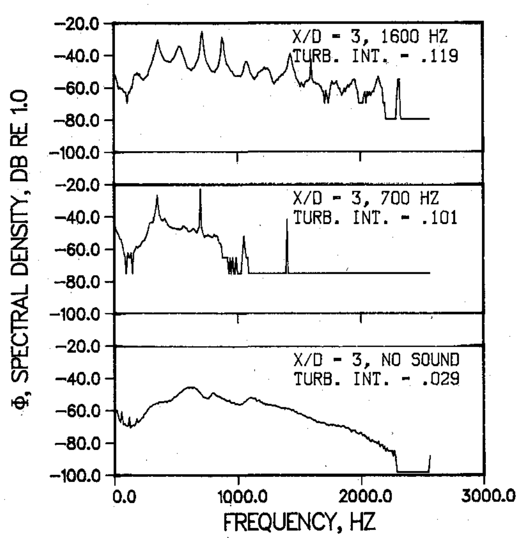

Fig. 3 Turbulent energy spectra on centerline at $X/D=3$.

authors.[4-8] Comparison of the results of the present study to the literature suggests a possible mechanism for the interaction of a disturbing acoustic field and the turbulent plane jet.

The interaction appears to originate in the shear layer in the vicinity of the nozzle mouth. Morkovin and Paranjape's[5] model of an acoustic pressure field oscillation of the stagnation point in the flow leaving the nozzle is one way that the disturbance may be introduced into the shear layer. The disturbance is then amplified and undergoes various nonlinear processes, resulting in the formation of harmonics and subharmonics in which the energy is highly organized. The shear layer then breaks down into fully turbulent flow, while maintaining greater organization than in the undisturbed case. The turbulence intensities produced in the potential core have grown faster than in the undisturbed case and have reached higher magnitudes. The two shear layers merge and the organized components may interact. The broadband turbulence grows, obscuring the orderly structure. The mean velocity profiles attain similarity, and the jet widens at a faster rate than the undisturbed case. The greater widening may be attributed to higher turbulence intensities, Reynolds stresses, and entrainment. As the flow proceeds, the intensities and Reynolds stresses decrease toward the undisturbed case values, and the greater widening and decay rates can no longer be sustained. Beyond $X/D=60$, the widening rates and centerline intensities approach the properties of the undisturbed flow. It may be speculated that at sufficiently large distances downstream, the flow appears identical to the undisturbed flow except for apparent virtual origins situated farther upstream.

Acknowledgments

The study reported was part of an overall program funded by ONR Grant 67-A-0226.0025 with partial support from the National Science Foundation, Grant GK 19317. Their support is gratefully acknowledged.

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