Turbulence and Acoustic Characteristics of Screen Perturbed Jets

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Theme

THE placement of a screen across a jet flow results in a substantial noise reduction. This was first observed by Lassiter and Hubbard[1] with further studies initiated by Callaghan and Coles[2] and Coles and North.[3] This study extends the previous work on the subject by attempting to relate the aeroacoustics of the perturbed jet with its turbulent structure. The investigation consisted of three phases: a) a study of various configurations to determine if the effect could be optimized, b) a detailed investigation of the acoustic signal from the best configuration, and c) measurement of the flow characteristics of perturbed and unperturbed jets to determine the mechanism of attenuation. Although this method of suppression is impractical, a deeper understanding of the basic phenomenon could lead to effective and practical techniques of jet noise attenuation.

Contents

Two different facilities were utilized to meet the goals of this study. Acoustic data were obtained with a 2-in. diam air jet operating from a compressed air supply and exhausting into an anechoic chamber. The air supply system was extensively muffled and vibration isolated from the jet nozzle to minimize the influence of upstream disturbances on the basic jet noise radiation pattern. In order to permit precise collection of turbulence data over relatively long averaging times, a 12-in. open jet wind tunnel was utilized. The larger flowfield was particularly necessary for accurate measurement of pressure fluctuations within the flow.

Turbulence and acoustic data are compared at equal Reynolds number and screen size. Thus the Mach number differed in the two facilities. Justification for such a comparison is based on the observation that the turbulence Mach number is always much less than unity and never more than about 0.1. The influence of radiation damping is therefore small and *relative* changes in the turbulent structure can be compared to *relative* changes in the acoustic far field.

The relative influence of three different screen configurations was first determined. Analysis of the data indicated that a straight screen placed across the jet nozzle is most effective. Further detailed study was limited to this configuration. As shown in Fig. 1, the influence of the screen on the spectral content of the noise signal is quite pronounced. Noise attenuation occurs over a broad range of frequencies and is significant even at the low frequency end of the spectrum where the noise contribution is primarily from the adjustment region. Self noise from the screen itself is evident in two noise peaks at the high end of the spectrum. The fundamental tone is observed to have a constant Strouhal frequency of 0.15 based on mesh size and jet velocity. As shown in Fig. 2, the contamination of the radiation pattern by the screen self noise produces an almost omnidirectional characteristic to the over-all noise signal. The dotted line passing through the measured data from the unperturbed jet corresponds to the directivity pattern reported by Chu et al.,[4] whereas the solid curve passing through the screen perturbed data corresponds to a hypothetical pattern consisting of reduced quadrupole radiation and superimposed dipole radiation. As expected,

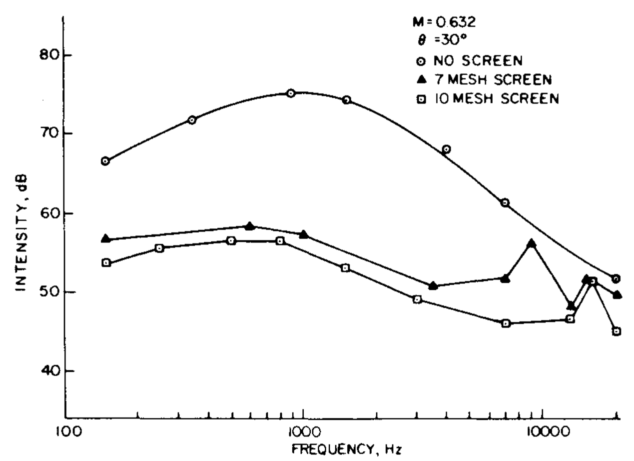

Fig. 1 Effect of screen on noise spectrum.

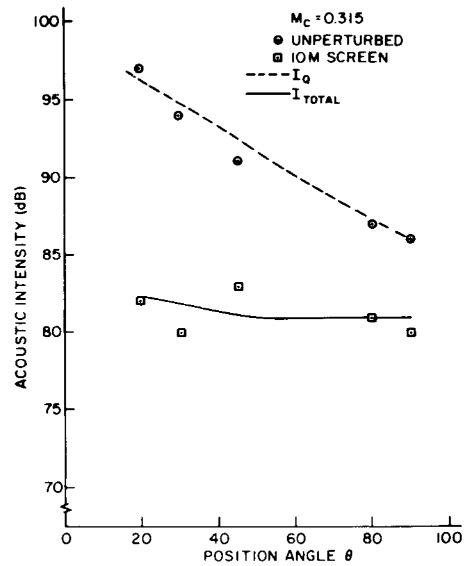

Fig. 2 Influence of screen perturbation on directivity pattern.

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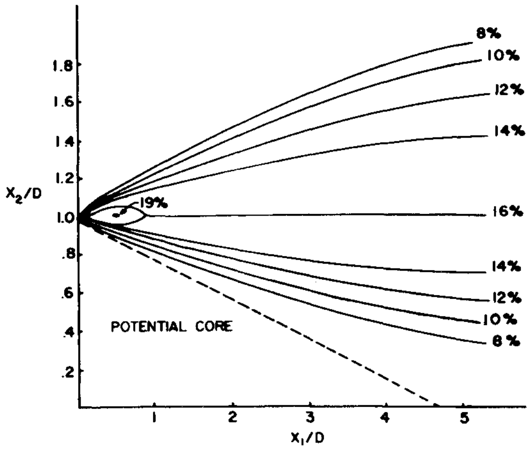

Fig. 3 Isocontours of turbulence intensity in unperturbed jets.

the screen self noise is more pronounced at lower Mach number.

Turbulence measurements indicate that screen induced perturbations influence the subsequent development of turbulent flow well into the adjustment region. This is exemplified by iso-contours of turbulence intensity displayed in Figs. 3 and 4 for the unperturbed and perturbed jet, respectively. A comparison of the data in these two figures will indicate that there are two distinct regions within the mixing region of the perturbed jet that are different from the unperturbed jet. The first region extends from the jet orifice out to about two jet diameters, where the effect of the screen is strongly felt. In this region the potential core decays faster than in the unperturbed jet which is caused by the high initial turbulence level generated by the screen in the "potential core." In the downstream region of the

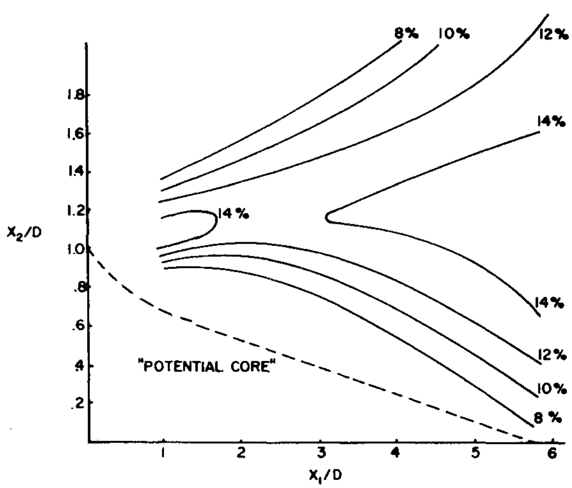

Fig. 4 Isocontours of turbulence intensity in perturbed jets.

mixing zone ($X_1/d > 2$) where the turbulence of the screen plays a minor role, the jet stream develops in a more normal manner. Here the mixing region grows linearly with distance. The potential core extends to about 6 diameters downstream compared with approximately 4.5 diameters for the unperturbed flow. In the unperturbed jet the maximum turbulence intensity was found to be 16% of the jet exit velocity, and it is found in the center of the mixing region ($X_2/R = 1$). A "hot spot" of 19% turbulence intensity is observed near the lip. In a more detailed study of this region, it was discovered that the flow is laminar very close to the lip and that, in a short distance, the transition to turbulence is very rapid, reaching its maximum value at $X_1/d = \frac{1}{4}$.

In the perturbed jet, the position at which turbulence intensity is a maximum was found to be approximately 10% further from the centerline (i.e., $X_2/R = 1.1$). The maximum turbulence level is now about 14%. Similar results are noted in the measurements of the lateral component of turbulence, Reynolds stress and pressure.

Retarded development of the screen perturbed mixing region is also evident in the comparison of measurements of integral scale. In the unperturbed case, the data agree nicely with results reported by Nayer, Siddon, and Chu.[5] As expected, the integral scale is a linear function of axial position

$$(L_{11}/d) = 0.055(X_1/d) + 0.020 \quad (1)$$

The insertion of a screen into the flow results in a reduction of integral scale

$$(L_{11}/d) = 0.041(X_1/d) + 0.020 \quad \text{(perturbed)} \quad (2)$$

A qualitative comparison is made between the predicted noise attenuation, based on turbulence measurements, and the measured power reduction obtained from the integrated directivity patterns utilizing the theory of Lilley.[6] A calculated 7.0 db reduction in sound power compares favorably with a measured reduction of 7.7 db. Thus it can be tentatively concluded that the suppression mechanism is traced to retarded development of the jet turbulence due to screen induced perturbations. A complete understanding of the phenomenon will require further study.

References

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