Experimental Evidence of Turbulent Source Coherence Affecting Jet Noise

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Abstract

THIS study is a follow-up to a theoretical and experimental investigation by Armstrong et al.[1] aimed at directly coupling jet turbulence and noise. Since the numerical calculation of the far-field pressure from measured pressure correlations in the jet near field has not been achieved yet, both fields are analyzed separately and their respective space-time structures compared herein. Azimuthal coherence data of model jets and a jet engine reveal that the pressure field is always governed by a few lower-order azimuthal constituents. This underlines the importance of "coherent structures" in the jet mixing zone.

Contents

The near-field pressure fluctuations of a SNECMA Atar-D2A jet engine (Fig. 1) are recorded on tape at the microphone positions shown in Fig. 2. The coherence $S_\omega/(\tilde{p}_{\omega 1}\tilde{p}_{\omega 2})$ of two simultaneous signals is determined, with the aid of a digital computer, from cross spectra $C_\omega + iQ_\omega = S_\omega \exp(i\psi_\omega)$ and power spectra $\tilde{p}^2_\omega$. For given displacements Δx, Δr, and $\Delta\phi$, this normalized coherence depends strongly on Strouhal number $St = fD/U$ (D = exit diameter, U = exit velocity) but little on Mach number $M = U/a_0$. Figure 3 illustrates that the circumferential coherence is strongest at frequencies that also dominate in the radiated noise spectrum.

If the mean jet flow properties can be assumed as axisymmetric, the coherence of azimuthally displaced pressure signals is a function of $\Delta\phi$ only. Furthermore, for constant x and r it was verified experimentally that $Q_\omega = 0$, and hence $S_\omega/(\tilde{p}_{\omega 1}\tilde{p}_{\omega 2}) = |C_\omega|/\tilde{p}^2_\omega$. Curves such as those in Fig. 4, which can be continued symmetrically for 180 deg $< \Delta\phi < 360$ deg, may be Fourier-analyzed to determine the azimuthal constituents $C_{\omega,m}$ of a given frequency component $\tilde{p}^2_\omega$ in the way described in Ref. 2. For the engine data at $x = 3D$ and $St = 0.375$, the result of such an analysis is shown on the right of Fig. 4; 68% of the fluctuating energy there is contained in the axisymmetric ($m = 0$) constituent, with less than 1% left for any single mode with $m > 2$.

The far-field pressure can be decomposed similarly into its azimuthal constituents. Since each of these may be related to the corresponding near-field mode and the acoustic efficiency of these large turbulence structures tends to decrease with m, we expect the lower m constituents also to dominate in the jet noise field. The broadband correlations in Fig. 11 of Ref. 1 support this view. More recently, Maestrello[3] has reported some narrow-band azimuthal correlations at $\theta = 90$ deg to the axis (Fig. 5). We analyzed these data on our computer. The resulting distributions of azimuthal constituents (Fig. 6) show a considerable variation with St, but in all cases the low-order constituents dominate. From theoretical considerations, an even more pronounced dominance of the lower-order constituents can be expected at smaller angles θ to the axis.[2]

In the case of a small-scale turbulence structure, the coherence in the near field would decrease rapidly with increasing $\Delta\phi$. This would result in a more even distribution of the fluctuating energy over a larger number of constituents. In contrast to this, there is ample experimental evidence to

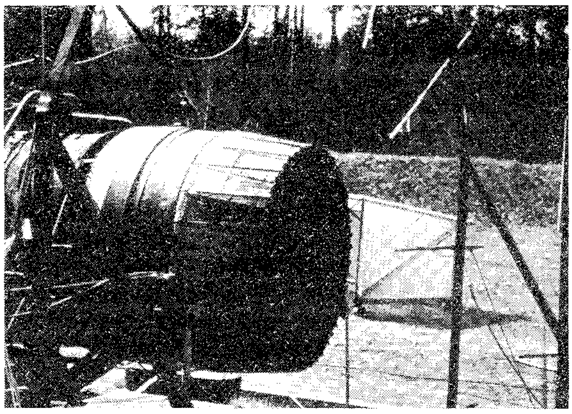

Fig. 1 Jet engine, on test stand at DFVLR Trauen, with microphone boom mounted for circumferential correlations.

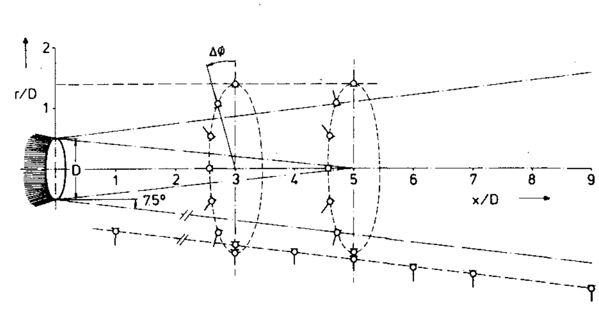

Fig. 2 Microphone positions for determining cross spectra in jet pressure near field.

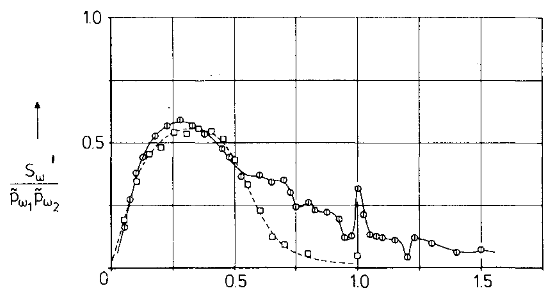

Fig. 3 Coherence of near-field pressure at azimuthally displaced points. --□-- Model jet: $x = 6D$, $r = 1.5D$, $\Delta\phi = 60$ deg, $M = 0.30$; —○— jet engine: $x = 5D$, $r = 1.4D$, $\Delta\phi = 60$ deg, $M = 0.52$.

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Index categories: Aerodynamics; Jets, Wakes, and Viscid-Inviscid Flow Interactions; Noise.

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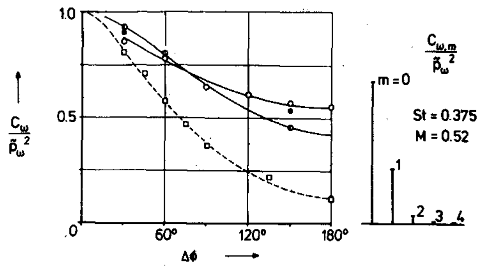

Fig. 4 Normalized azimuthal correlation and constituents of narrow-band near-field pressure. -- □ -- Model jet: $x=3D$, $r=1D$, $St=0.375$, $M=0.30$; jet engine: $x=3D$, $r=1.4D$, -- ○ --, $M=0.35$; —⊕—, $M=0.52$; •, $M=0.69$.

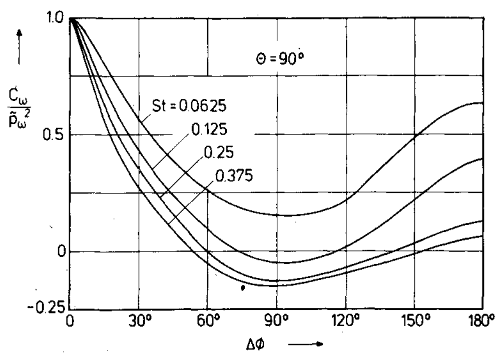

Fig. 5 Normalized azimuthal correlation of narrow-band far-field pressure ($M=0.76$, $\theta=90$ deg, far-field distance $R=173D$).[3]

justify the description of turbulence and noise of circular jets in terms of a very small number of characteristic mode structures $m=0$, 1, and 2.

These circumstances have prompted Chan[4] to study the downstream development of modes $m=0$, 1, and 2 when these are excited artifically in a model jet. The axial and radial coherence of these azimuthal frequency components of the pressure in a naturally excited jet were described in Ref. 1. The considerable effect of this coherence on an increasing or decreasing value of the far-field sound power (depending on characteristic parameters such as M, St, and Helmholtz number $He=M\,St$) was investigated by Michalke,[5] and the acoustic interference effects involved also were described by Fuchs.[6]

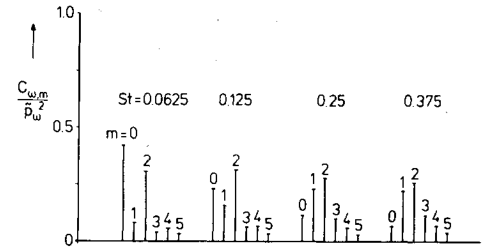

Fig. 6 Azimuthal constituents of far-field pressure (deduced from data in Fig. 5).

Our experimental finding of a coherent source field has an effect on several commonly accepted assumptions in jet noise research. The unit volume source strength approach has to be modified. The observed spectra, directivities, and the effect of Mach number variation at small angles to the jet axis may be explained without the assumption of moving sources, Doppler amplification, and sound refraction.

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