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THE AZIMUTHAL STRUCTURE OF JET PRESSURE NEAR AND FAR FIELDS

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Introduction

In our quantitative jet noise approach the acoustic pressure is directly related to the turbulent pressure fluctuations. Both fields are separately analysed and their respective space-time structure compared. Azimuthal coherence data of model jets and a jet engine reveal that the pressure is always governed by a few lower-order azimuthal Fourier constituents. This underlines the importance of 'coherent structures' in the jet mixing region and will facilitate the numerical evaluation of the source integral which is under way.

Direct coupling of pressure near and far fields

By using Lighthill's equation, one may write the far field pressure power spectral density as

$$W_{pp}(R,\theta,M,St\ldots) = \frac{\pi^2}{R^2} M^4 St^4 \int_V \int_V W_{Q1Q2} \cdot \exp\left[-2\pi i\, He \frac{x_i}{R} (y_{i2}-y_{i1})\right] dV_1 dV_2 \qquad (1)$$

with Mach number $M = u_0/a_0$, Strouhal number $St = f \cdot D/u_0$, Helmholtz number $He = f \cdot D/a_0 = St \cdot M$, sound field coordinates x_i, source field coordinates y_i, far field distance R, and radiation angle θ. W_{Q1Q2} is the cross spectral density of the quantity $Q = (x_i x_j/R^2)(\rho c_i c_j - \tau_{ij}) + p - \rho a_0^2$, and the exponential is an interference function. The equations are made dimensionless with the density ρ_0 outside the jet, the exit velocity u_0 and the nozzle diameter D.

The occurrance of He as a characteristic parameter reflects interference mechanisms typical of a coherently radiating source volume.

In the case of an axisymmetric jet the azimuthal ϕ-dependence of the integrand may be described by a Fourier series [1], and hence W_{pp} composed by a sum of azimuthal constituents of order m

$$W_{pp,m} = \frac{\pi^2}{R^2} M^4 St^4 \int_V \int_V W_{Q1Q2,m} \cdot F_m \cdot dV_{a1} dV_{a2} \;. \qquad (2)$$

$W_{Q1Q2,m}$ is the m^{th} azimuthal constituent of the cross spectral density W_{Q1Q2} of Q, and F_m is an interference function which depends on m and on the axial and radial positions of the two annular volume elements dV_{a1} and dV_{a2}. As F_m varies with m, it causes different directivities for each constituent and, in particular, a very poor overall radiation efficiency for larger m.

For the mean flow-turbulence (MT) interaction of an unheated jet, each azimuthal constituent $W_{Q1Q2MT,m}$ can be related to a corresponding constituent $W_{p1p2,m}$ of the pressure field inside the jet [2].

$$W_{Q1Q2MT,m} \cdot F_m = W_{p1p2,m} \cdot F_{r,m} \cdot F_x \;, \qquad (3)$$

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In contrast to W_{Q1Q2} the cross spectral density W_{p1p2} is directly measurable [3]. The new interference functions $F_{r,m}$ and F_x depend on He and θ. $F_{r,m}$ is a function of m and the radial positions of the two annular volume elements dV_{a1} and dV_{a2}, and, in addition, of the mean velocity gradient within these elements. $F_{r,m}$ becomes zero if at least one of the two volume elements is located outside the jet. F_x also depends on the axial displacement of the ring elements.

Near field results

The pressure cross spectral density measurements in the source region prove the description by azimuthal constituents to be a very useful one, since a small number of constituents is sufficient. Figure 1 shows two measured distributions $W_{p1p2}(\Delta\phi)$ at $St = 0.45$ inside a model jet with and without a centerbody as shown.

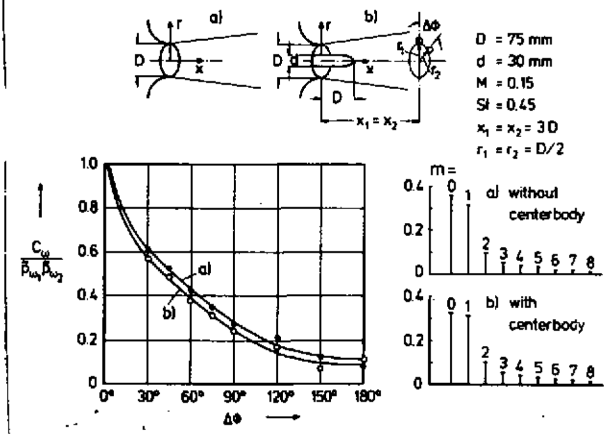

Figure 1. Real part of normalized cross spectral density within the pressure field of a jet with and without a centerbody and corresponding azimuthal constituents.

With $M = 0.15$ the jet Mach number is low but in ref. [4] it was shown that the structure of a subsonic jet is hardly influenced by M.

The curves decay only gradually with increasing $\Delta\phi$ which results in a low number of relevant azimuthal constituents. Thus, not only are the higher order constituents particularly poor radiators but also their magnitude in the jet pressure field is found to be small. This holds true for the most relevant range of Strouhal numbers $0.2 < St < 0.7$.

The mode distribution of the case with centerbody has changed a little in favour of the $m > 1$ constituents with a corresponding reduction of the axisymmetric component. This may be taken as evidence of how difficult it is to influence these large scale structures.

Figure 2 shows a comparison of the near field of a cold jet and a 28 kN thrust jet engine which was operated at 12 kN [5]. The engine results show a very strong zero and first component. The higher order modes seem to have already decayed somewhat.

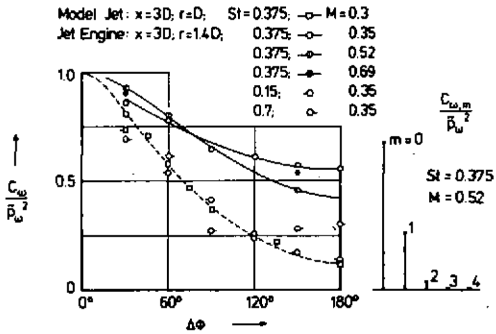

Figure 2. Real part of normalized cross spectral density within the pressure nearfield of a laboratory jet and a jet engine and corresponding azimuthal constituents.

Far field results

Figure 3 shows far field correlations by MAESTRELLO [6] at $\theta = 90^\circ$. Their Fourier analysis revealed [5] a dominant $m = 2$ constituent for $St = 0.375$ at this angle θ. More recent measurements by JUVÉ [7] at $\theta = 60^\circ$ and 30°, however, show again strong $m = 0$ and 1 constituents at these smaller angles in accordance with ref. [1].

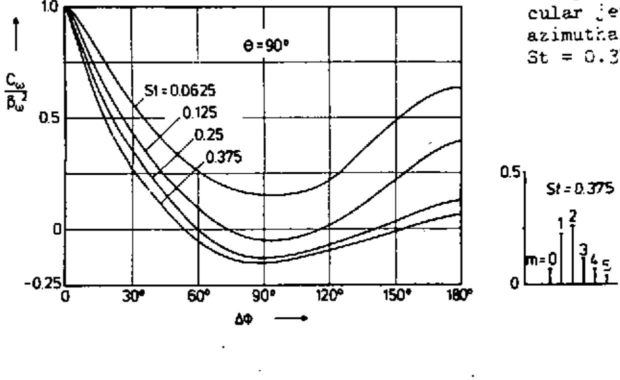

Figure 3. Real part of normalized cross spectral density in the pressure far field of a circular jet (MAESTRELLO 1977) and azimuthal constituents for $St = 0.375$.

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Conclusions

(1) A small number of azimuthal constituents dominates the pressure near field. Jet turbulence therefore appears as large scale structured.

(2) An equally small number is found to dominate the far field.

(3) Each far field constituent is directly coupled to the corresponding constituent within the jet.

(4) As the higher order constituents show no relevant contribution to the far field, only the low order constituents in the source region have to be measured. This reduces the amount of measurements necessary for solving the Lighthill integral.

(5) Because of the large scale sources of the near field, the Helmholtz number $He = St \cdot M$ comes in as a scaling parameter in jet noise prediction schemes.

References

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