ties[3]: $E_L = 30\times10^6$ psi $= 20.80\times10^4$ MPa, $E_T = 0.75\times10^6$ psi $= 0.52\times10^4$ MPa, $G_{LT} = 0.375\times10^6$ psi'0.26×10^4 MPa, and $\nu_{LT} = 0.25$. The variation of the coating stresses with the orientation of the calibration beam is shown in Fig. 1. The coating stresses are in general relatively high in comparison to the calibration beam stresses for angles greater than 45 deg. It is interesting to note that $\sigma_x^c/\sigma_x^* = 0.0177$ and $\sigma_y^c/\sigma_x^* = 0.0024$ for a steel beam; such low coating stresses (relative to calibration beam stresses) prevail only for $\theta\approx0$ deg for the composite material. The coating stress transverse to the beam axis is compressive in the case of the graphite-epoxy composite up to about $\theta = 57$ deg.

The variation of the angle between the major reinforcement direction and the major principal strain direction with the angle between the major reinforcement direction and the calibration beam axis is shown in Fig. 2. The difference between the two angles is considerable for θ' between 0 and 60 deg.

The failure conditions given by Eqs. (10-12) depend on the fiber orientation angle θ. These equations are plotted in Figs. 3, 4, and 5 for $\theta = 0$, 45, and 90 deg, respectively, for $K = 4$. It should be noted that the scales are different in these figures. For $\theta = 0$ and 90 deg, the failure envelopes are similar to those for isotropic materials. For the 45 deg orientation, the failure envelope is very narrow and close to the line of symmetry, which is at 45 deg as for isotropic materials.

It is thus seen that the failure of the brittle coating is influenced by the biaxiality of the stress field in the composite structure that is being determined. An exact analysis is much more difficult in the case of the composite structure as the failure envelope is different for each angle of fiber orientation. However, the approximate analysis, based on Eq. (1), can still be performed on a composite structure and the accurate information regarding the principal strain directions can be used in conjunction with other experimental methods, such as strain gaging.

References

[1]Dally, J. W. and Prabhakaran, R., "Photo-Orthotropic-Elasticity, Parts I and II," *Experimental Mechanics*, Vol. 11, Aug. 1971, pp. 346-356.

[2]Dally, J. W. and Riley, W. F., *Experimental Stress Analysis*, McGraw-Hill Book Company, New York, 1965.

[3]Jones, R. M., *Mechanics of Composite Materials*, McGraw-Hill Book Company, New York, 1975.

Filtered Azimuthal Correlations in the Acoustic Far Field of a Subsonic Jet

Daniel Juvé,* Michel Sunyach,† and Geneviève Comte-Bellot‡
Ecole Centrale de Lyon, Ecully, France

Introduction

THE azimuthal structure of the acoustic field of circular jets has recently drawn the attention of several workers. For the near field, Armstrong et al.[1] have studied the coherence between two microphones placed on a circle centered on the jet axis; the spatial Fourier analysis of the coherence has shown that the major part of the energy is concentrated in the first three azimuthal modes. In the far field, azimuthal cross correlations have been measured by Maestrello[2] for a large range of Mach numbers ($0.6 \leq M \leq 1$), and by Juvé and Sunyach[3] for $M = 0.4$, but only *broad-band* results are available. Interpretations in terms of azimuthal modes have been attempted by Fuchs and Michel[4] for two values of the observation angle θ to the jet axis, $\theta = 30$ deg and $\theta = 60$ deg. A much more extensive analysis including $\theta = 90$ deg is given in Ref. 3. In the vicinity of the jet axis the first two modes ($m = 0,1$) give a satisfactory description of the acoustic field, but when the observation angle is increased more modes have to be taken into account, mode $m = 2$ being especially significant.

Since the last result may be misinterpreted because of the increase with θ of the high-frequency components in the acoustic spectra, we report in this Note some results concerning the *filtered* cross correlations between circumferentially displaced microphones in the acoustic far field and the associated modal expansion.

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*Research Assistant, Mécanique des Fluides.
†Assistant Professor, Mécanique des Fluides.
‡Professor, Mécanique des Fluides.

Test Facilities

Measurements have been conducted in the anechoic room of the Ecole Centrale de Lyon (ECL), with a cold jet of exit diameter 2 cm and velocity 135 m/s ($M = 0.4$). Two microphones (B & K 4133, Ø 1.27 cm) have been set on a circle centered on the $0x_I$ axis of the jet, the azimuthal spacing being denoted by φ (Fig. 1). The pressure signals are filtered by two band proportional analyzers (B & K 2107, $\Delta f/f = 0.29$) and fed to a digital correlator (HP 3721 A). The spatial cross-correlation coefficients $\tilde{R}_{p1p2}(\theta, \varphi, f)$ have been obtained for three typical values of the observation angle $\theta = 30$, 60, and 90 deg, the distance between the microphones and the nozzle being, respectively, 100, 80, and 60 diam. The results obtained for three frequencies corresponding to Strouhal numbers ($St = fD/U$) of 0.15, 0.3, and 0.6 are reported here, as these values are representative of those which contribute most to the noise spectrum.

Results

It has been checked, through space-time correlations, that the acoustic field is homogeneous in the azimuthal direction and nonswirling around $0x_I$. The correlation coefficient $\tilde{R}_{p1p2}$ is then a periodic and even function of the azimuthal spacing φ, which can be developed as an azimuthal Fourier series:

$$\tilde{R}_{p1p2}(\theta, \varphi, f) = \sum_{m=0}^{\infty} \tilde{a}_m(\theta, f)\cos m\varphi$$

with

$$\sum_{m=0}^{\infty} \tilde{a}_m(\theta, f) = 1$$

the $\tilde{a}_m$ coefficient represents the contribution of mode m to the acoustic energy for a given observation angle θ and frequency f. Such an expansion has been introduced by Michalke and Fuchs[5] as a basis for a theory on the noise generated by circular jets derived from Lightill's acoustic analogy. This approach is of some interest only when a few modes are sufficient to correctly describe the pressure field, which is what we are looking for.

In Figs. 2-4 the results for the three observation angles are given. Our previous broad-band data[3] have been included for comparison.

For $\theta = 30$ deg, the $\tilde{R}_{p1p2}$ correlation decreases monotonically with φ, whatever the Strouhal number, the pressure fluctuations being almost "in phase" on the whole circumference of the jet. From the modal point of view, modes of order 0 (axisymmetric) and 1 (antisymmetric) are largely dominant. When the frequency is raised, a slight

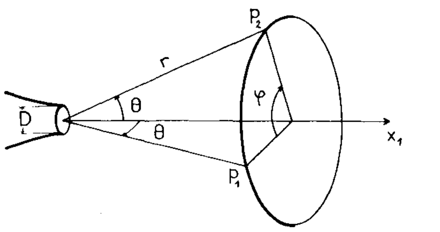

Fig. 1 Geometry for two microphone correlations.

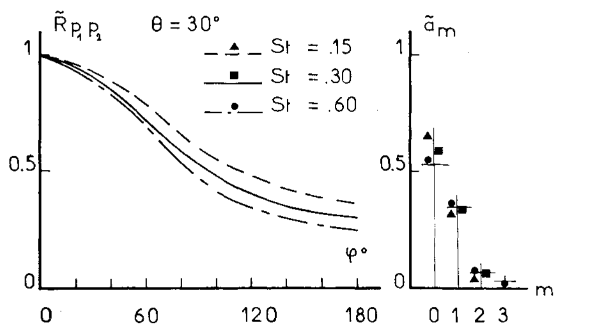

Fig. 2 Filtered azimuthal cross correlations and associated Fourier components for an angle of observation, $\theta = 30$ deg. ▲, ——— $St = 0.5$; ■, ——$St = 0.30$; ●, -·— $St = 0.60$; — broad-band data.

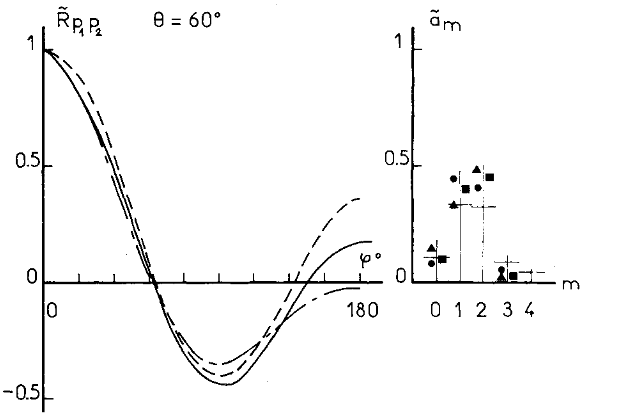

Fig. 3 Filtered azimuthal cross correlations and associated Fourier components for an angle of observation $\theta = 60$ deg (same symbols as in Fig. 2).

amplitude shift takes place from mode 0 to mode 1 and to a lesser extent to mode 2.

For $\theta = 60$ deg, the correlations decrease rapidly with φ and exhibit a large negative loop in the range 60 deg $\leq \varphi \leq$ 150 deg. This behavior is similar to that already noted in the broad-band experiment.[2,3] We can also observe that the rise of $\tilde{R}_{p1p2}$ for $\varphi = 180$ deg is much more pronounced when the frequency is low. The modal expansion shows that the axisymmetric mode now contains only 10% of the total energy and that modes of order 1 and 2 dominate, their levels being similar (around 40%). When filtering is applied, the most significant result is the enhancement of mode 2 for the lower part of the relevant frequency range ($St \simeq 0.10$). This enhancement and the maintenance of modes 0 and 1 are associated with the decrease of higher modes and therefore reveal that the acoustic field possesses a strong coherence.

Finally, for $\theta = 90$ deg, the correlations again become negative at $\varphi = 60$ deg, but return to positive values with very high levels for $\varphi = 180$ deg ($\simeq$ 0.7 for $St = 0.15$). In Fourier space, mode 1 has given its energy to modes 0 and 2, the last one exhibiting a large contribution, amounting to around 50% of the total field. The filtering effect is similar to that observed at $\theta = 60$ deg, the dominance of mode 2 occurring around $St = 0.20$.

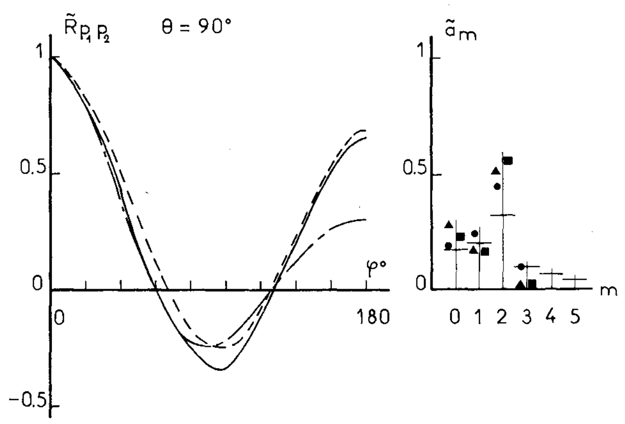

Fig. 4 Filtered azimuthal cross correlations and associated Fourier components for an angle of observation $\theta = 90$ deg (same symbols as in Fig. 2).

Table 1 Cumulative contributions to the acoustic field of the two and three first azimuthal modes vs Strouhal number for the three angles of observation, $\theta = 30$, 60, and 90 deg

θ	30 deg			60 deg			90 deg		
St	0.15	0.3	0.6	0.15	0.3	0.6	0.15	0.3	0.6
$\tilde{a}_0 + \tilde{a}_1$	0.95	0.92	0.90	0.47	0.50	0.53	0.44	0.40	0.43
$\tilde{a}_0 + \tilde{a}_1 + \tilde{a}_2$	0.98	0.97	0.96	0.97	0.98	0.94	0.97	0.95	0.88

The description of the acoustic far field through only a small number of modes is therefore possible, as suggested by Fuchs and Michel.[4] However, for large enough values of θ, for example $\theta = 60$ deg, mode 2 has to be taken into account, as shown in Table 1, which provides the cumulative contributions $\tilde{a}_0 + \tilde{a}_1$ and $\tilde{a}_0 + \tilde{a}_1 + \tilde{a}_2$.

Conclusion

The modal contribution to the acoustic far field exhibits a characteristic shape with observation angle. The dominant modes are : $m = 0$ for $\theta = 30$ deg, $m = 1$ and 2 for $\theta = 60$ deg, and $m = 2$ for $\theta = 90$ deg.

By frequency filtering in the range $0.15 \lesssim St \lesssim 0.60$, this shape is not strongly altered. There is only an enhancement of the dominant modes $m = 2$ and to a lesser extent of $m = 1$.

In every case, when the first three modes are considered it is clear from Table 1 that the total field is well approximated.

It is then tempting to relate the low-order azimuthal organization of the acoustic field and its near independence on frequency to a specific process which takes place during the downstream evolution of the coherent structures of the flow.

References

[1] Armstrong, R.R., Fuchs, H.V., and Michalke, A., "Coherent Structures in Jet Turbulence and Noise," AIAA Paper 76-490, Palo Alto, Calif., July 1976.

[2] Maestrello, L., "Two Point Correlations of Sound Pressure in the Far Field of a Jet: Experiment," NASA TM X-72835, April 1976.

[3] Juvé, D. and Sunyach, M., "Azimuthal Structure of the Acoustic Far Field of a Subsonic Jet," *Comptes Rendus Hebdomadaires des Seances de l'Academies des Sciences* (*Paris*), t. 164, Série B, Sept. 1978.

[4] Fuchs, H.V. and Michel, U., "Experimental Evidence of Turbulence Source Coherence Affecting Jet Noise," AIAA Paper 77-1348, Atlanta, Ga., Oct. 1977.

[5] Michalke, A. and Fuchs, H.V., "On Turbulence and Noise of an Axisymmetric Shear Flow," *Journal of Fluid Mechanics,* Vol. 70, July 1975, pp. 179-205.