Conditional Sampling for Jet Noise Sources Characterization

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Abstract

WHILE the analog representation for jet noise studies allows the prediction of the dimensional laws for acoustic emission, a better understanding of the acoustic far field requires a more physical picture of the acoustic-generating mechanisms. In particular, in a previous work[1] a direct experimental estimation of the acoustic intensity associated with the large-scale structure of turbulence was obtained, on the basis of the same assumptions allowing the full use of the second-order analysis on signals recorded inside and outside the jet. Here, a more general method, based on conditional sampling, is proposed for jet noise source localization. It consists of selecting, through a detection criterion imposed on a selected signal, a set of samples representative of the passage of wave packets, and working on an ensemble of these sets rather than on time averages. In this manner, each generating mechanism can be selected by a proper choice of the detection criterion, and its acoustic efficiency computed. In addition, ensemble averages avoid the limitations due to time averages, and lead to a better signal/noise ratio when the classical correlation function is very weak.

Contents

When using a conditional sampling method, the first task is to consider the relevance of the detection criterion chosen to select some particular phenomenon. For instance, the most natural criterion for selecting the large-scale structure of turbulence, which corresponds to the passage of large vortices convected along the mixing layer, is a threshold detection eliminating the small-scale fluctuations. A way to assess the relevance of this criterion is the visualization of what is selected. Starting from a conventional schlieren device with a flash illumination of a hot subsonic jet ($U_E = 420$ m/s, $T_E = 900$ K), this system was extended by a threshold detector controlling the flash operation. The threshold is applied on a radiometer signal sensitive to the temperature fluctuations through the infrared emission of the jet, and focused in the mixing layer. (For discussion of the diagnostic of the turbulence by its infrared emission, see Refs. 4 and 5.) The passage of a vortex gives rise to a short flash ($\sim 1 \mu s$) and the superimposition on the same film of 200 flashes gives an image enhancing the large-scale structure. The resulting picture (Fig. 1) reveals clear regions of great spatial extent, in accordance with the searched for vortices, which are in this case dominated by an axisymmetric mode, in accordance with the modal decomposition of azimuthal correlations in the near field.[5] In the same manner, wavefronts in the near field associated with the vortices are also visualized. This fact is corroborated by placing a microphone on a line in phase with the radiometer and setting the threshold on it—the pictures are the same in both cases. Finally, the displacement of the vortices is simulated by inserting a variable delay between the detection and the flash operation. The convection speed deduced from the displacement agrees with the value measured by other diagnostics.

Once the detection criterion is chosen and assessed, quantitative information can be extracted from signals recorded inside and outside the jet. Considering a set of signals $s_i\ (t)\ (i = 1,2,...)$, first translated in time to provide the compensation of propagation delay times, these signals are recorded during time intervals T synchronized by the instants selected by the detection criterion. On these samples, the conditional ensemble averages $m_i(t) = \langle s_i(t) \rangle$, $\sigma_i^2(t) = \langle s_i^2(t) \rangle$, $\gamma_{ij}(t) = \langle s_i(t) s_j(t) \rangle$ are computed, giving their conditional signatures. A conditional coherence coefficient[2]

$$C_{ij}(D,T) = \left[\left(\int_T \gamma_{ij}^2 \mathrm{d}t \right)^2 \Big/ \left(\int_T \sigma_i^2 \mathrm{d}t \right) \left(\int_T \sigma_j^2 \mathrm{d}t \right) \right]^{1/2}$$

a function of the detection criterion D and the time duration T, points out the similarity of the two signals, and allows the comparison of the various detection criteria and their efficiency, with regard to a standard correlation coefficient.

When applied to the large-scale structure radiating properties, this method leads to the acoustic efficiency of the vortices selected by the radiometer. It consists first in calculating the conditional averages of signals obtained, on the one hand, from the radiometer whose detection is limited to a high threshold and, on the other hand, from microphones placed at various angular positions in the far field, then in extracting the common features of the two signals. For a microphone placed at 30 deg from the jet axis, the conditional coherency coefficient reaches 0.72, as compared with a classical correlation coefficient of 0.23 (Fig. 2). At 90 deg

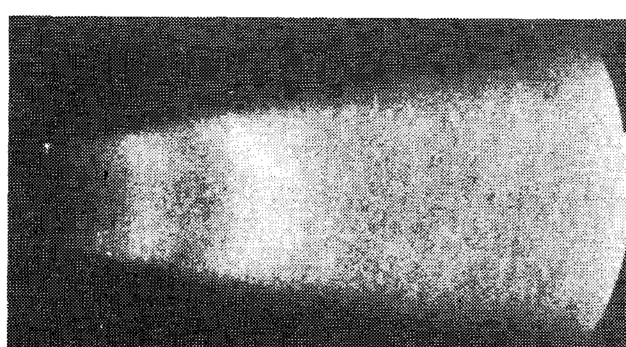
Fig. 1 Synchronized schlieren picture of the jet.

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

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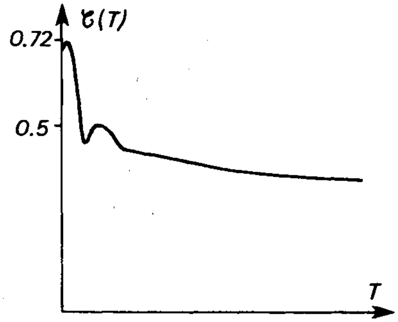

Fig. 2 Conditional coherency coefficient between the infrared signal and the microphone signal in the far field at $\theta = 30$ deg.

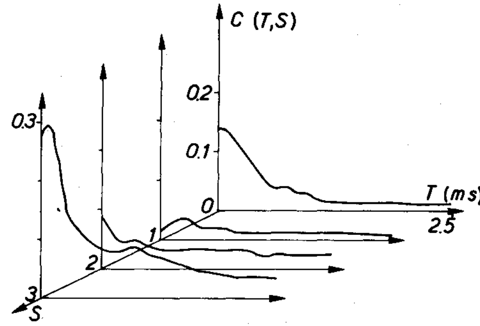

Fig. 4 Conditional coeherency coefficient for different values of the threshold s on the hot wire in the potential core.

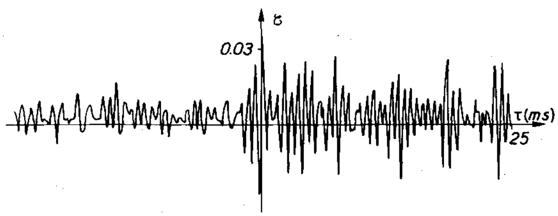

Fig. 3 Correlation function between a hot wire in the mixing layer and a microphone in the far field at $\theta = 30$ deg.

from the jet axis, this value reaches 0.34 (the classical correlation coefficient being very weak). The wave fronts visualized in the near field in association with the vortices therefore have an extension in the far field dominating the microphone signal. Unfortunately, it can be shown that this conclusion cannot be directly extended to the coherent phenomenon as a whole, due to the crudeness of the threshold detection criterion for this purpose.

Another class of applications for conditional sampling is the detection of weak correlations, such as those occurring in poor acoustical environments. In a cold jet, for instance, ($U_E = 100$ m/s), the correlation between a hot wire in the mixing zone and a microphone in the far field is weak.[3] Moreover, if the experiment is conducted in a closed wind tunnel without absorbing materials, this weak correlation shows the presence of multiple reflections (Fig. 3). Using the signal of a hot wire in the potential core as a synchronization signal (more sensitive than the former to the large-scale structures), a generating mechanism can be isolated, and proper choice of the time delays would allow the selection of one acoutical path. Conditional sampling applied on the hot wire and on the microphone, with various values of the threshold applied on the synchronization signal, would extract the common features in the two signals (Fig. 4) and improve the signal/noise ratio; starting from a standard correlation coefficient of 3%, the conditional coherency coefficient increases to 30%.

The few examples presented here point out the various advantages one has when using conditional sampling in jet noise studies. Recalling that the results were obtained by a simple amplitude criterion, which does not provide the best detection criterion for the passage of wave packets (mainly described by phase relationships), the developments of the method at this time are oriented toward: 1) the improvement of the detection criteria, to take into account the temporal and spatial phase relationships of wave packets; 2) the definition of ranges of criteria and statistical tools adapted to each sound-generating mechanism; and 3) the insertion of conditional sampling techniques in multimicrophonic antenna in order to get a map of acoustical sources, better coupled with the real sources than the usual virtual equivalent sources.

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