Technical Notes

TECHNICAL NOTES are short manuscripts describing new developments or important results of a preliminary nature. These Notes cannot exceed 6 manuscript pages and 3 figures; a page of text may be substituted for a figure and vice versa. After informal review by the editors, they may be published within a few months of the date of receipt. Style requirements are the same as for regular contributions (see inside back cover).

Fine Structure of Subsonic Jet Noise

W.G. Richarz*
Carleton University, Ottawa, Canada

Introduction

EFFICIENT time series analysis techniques such as the fast Fourier transform (FFT) have provided the experimenter with rather fine detail. For acoustic spectrum measurements in the audio range, typical bandwidths are of the order of a few Hertz: the effective bandwidth scaling in inverse proportion to the number of data points. Often the wealth of information is not examined in detail. The use of a logarithmic scale for the spectrum level compresses the fine structure, leaving only prominent features. This Note examines the fine structure of the sound pressure spectrum of a subsonic jet. The principal motivation was the possibility of correlating the fine structure with the sound from large-scale structures in the jet flow.

Measurement

Figure 1 shows typical noise spectra of a Mach 0.64, 1.91 cm diam air jet measured in the anechoic room of the University of Toronto Institute for Aerospace Studies. Conventional one-third octave measurements are displayed along with narrowband FFT data plotted in logarithmic and linear format. The fine structure is effectively suppressed in all but the latter. This structure is not a result of finite averaging time; it is persistent and repeatable. Similar patterns are evident in jet noise measurements taken at other laboratories. Most researchers appear to pay no attention to this fine structure. Some have suggested that the observed fine structure is evidence of the existence of large-scale structures in the jet flow. This hypothesis is tested here.

Discussion

It is well known that large-scale structures contribute to both the flow and the sound field of jets when the Reynolds number (based on nozzle diameter) is sufficiently low.[1,2] At Reynolds numbers in excess of 50,000, signal averaging is required, in most instances, to make the structures identifiable.[3,4]

If one were to speculate that the measured spectra contain quasi-periodic and random components, then, according to data presented in Fig. 1, up to 60% of the energy is contained in the quasi-periodic (large-scale) structure. Tests conducted with the identical jet flow, however, suggest that the large-scale structures contribute no more than 3% of the overall acoustic energy.[3]

The conflict is resolved when measurements at different Mach numbers are examined. For each of the spectra shown in Fig. 2, the Strouhal scaling of the peak frequency is evident. The pattern of the fine structure, on the other hand, is independent of the jet exit velocity. Thus, it cannot be generated by any sensible process in jet flow.

Received Sept. 5, 1985.

*Associate Professor. Member AIAA.

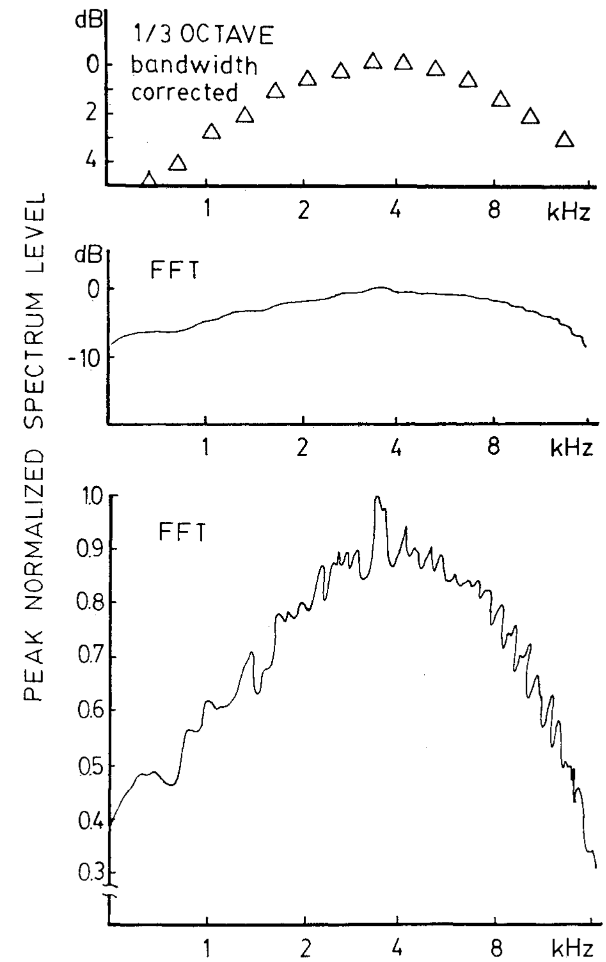

Fig. 1 Influence of analysis technique on the appearance of far-field sound pressure spectra of a Mach 0.64 airjet at 90 deg to jet axis.

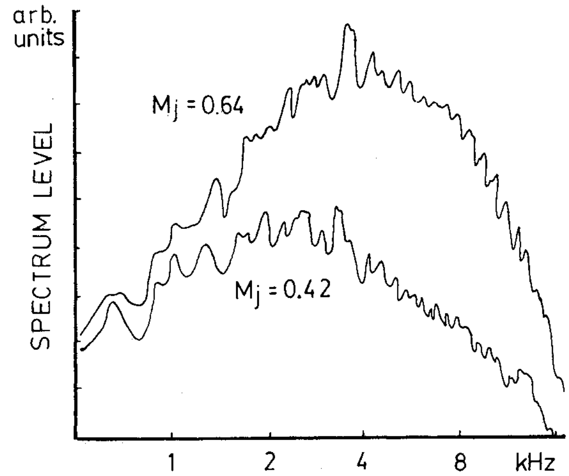

Fig. 2 Fine structure of sound pressure spectra of an airjet at 90 deg to jet axis.

A detailed examination of spectra $P(f,M)$ at various Mach numbers M reveals that the pattern of the fine structure remains largely unchanged. The degree of similitude is tested over the frequency band spanning 1-6 k Hz. The ensemble average of the suitable normalized fine structures, $(P(f,M)-\bar{P}(M))/[(P(f,M)-\bar{P}(M))^2]^{1/2}$, is found to be independent of Mach number and has a value of 0.85.

Summary

It appears that the phenomenon of diffraction is largely responsible for the observed fine structure. Despite precautions of wrapping the jet nozzle and the microphone boom with fiberglass blankets, some acoustic energy is reflected.

Acknowledgments

The research was supported by a grant from the Natural Sciences and Engineering Research Council of Canada.

References

[1]Bruun, H. H., "A Time-Domain Analysis of the Large-Scale Flow Structure in a Circular Jet: Part I—Moderate Reynolds Number," *Journal of Fluid Mechanics*, Vol. 83, No. 4, 1977, pp. 641-671.

[2]Ho, C. M. and Lafouasse, B., "Hydrodynamic Pressure Field of an Axisymmetric Jet," AIAA Paper 84-2319, 1984.

[3]Richarz, W. G. and Keith, S. E., "Direct Measurement of Sound from Large Scale Structures in Jet Flows," AIAA Paper 83-0662, 1983.

[4]Emani, S. and Morrison, G. L., "Phase Averaged Acoustic Measurements for a Mach Number 0.6 Jet," AIAA Paper 84-1657, 1984.

Counterrotating Streamline Pattern in a Transitional Separation Bubble

R. L. Davis* and J. E. Carter†
United Technologies Research Center
East Hartford, Connecticut

Introduction

THE prediction of the interaction between a transitional separation bubble and the inviscid flowfield that often exists at the leading edge of an airfoil is a formidable problem that has recently been the subject of several theoretical studies based on interacting boundary-layer theory. Vatsa and Carter[1] developed a semi-inverse interaction technique—ALESEP (Analysis of Leading-Edge Separation)—for the calculation of airfoil leading-edge transitional separation bubbles in which an inverse finite-difference boundary-layer analysis was solved iteratively through displacement thickness coupling with a Cauchy intergral perturbation analysis for the inviscid flow. In this approach, the streamwise convection of momentum was set to zero (FLARE approximation[2]) in the reversed-flow region to provide a stable forward-marching boundary-layer calculation. It has been observed in the predictions of a number of transitional separation bubbles using this technique that the reversed-flow velocity can be as large as 28% of the boundary-layer edge velocity. For flows with large reversed-flow velocities that occur in transitional separation bubbles due to the intense vortex formed near reattachment, an evaluation of the FLARE approximation was made[3] to estimate the error, if any, that arose from its use. A windward difference scheme was implemented into the ALESEP code and the results were compared with those obtained previously using the FLARE approximation. It was found that even for large reversed-flow velocities, the FLARE approximation produced comparable results with the windward differencing approach for the predicted pressure, locations of separation and reattachment, and displacement thickness. However, use of of the windward differencing procedure has revealed a new separation bubble structure not found in previous inviscid-viscous interaction calculations. A second, counterrotating bubble was found to exist under the primary separation bubble for a case with high reversed-flow velocities.

Inviscid-Viscous Interaction Analysis

The viscous solution technique used in the ALESEP interaction analysis is the inverse boundary-layer procedure developed by Carter.[4] In this procedure, the boundary-layer equations are transformed through the use of Levy-Lees-type variables and the normal component of velocity is represented in terms of a perturbation stream function. The numerical solution of the transformed equations for the pressure gradient parameter and the boundary-layer edge velocity is performed using an implicit finite-difference technique which is first-order accurate in the stream direction and second-order accurate in the normal direction. The Cebeci-Smith[5] two-layer model is used for the turbulent eddy

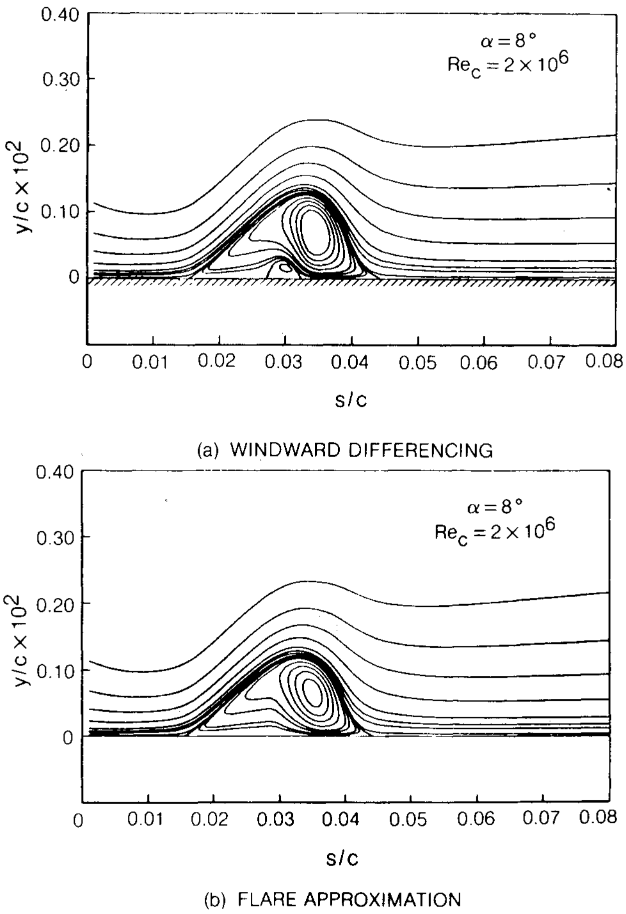

Fig. 1 Transitional separation bubble streamline pattern: NACA-0010 airfoil (modified).

Presented as Paper 84-1613 at the AIAA 17th Fluid Dynamics, Plasma Dynamics and Lasers Conference, Snowmass, CO, June 25-27, 1984; received March 8, 1985; revision received Sept. 15, 1985.

*Research Engineer. Member AIAA.
†Manager, Computational Fluid Dynamics. Member AIAA.