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M. Samimy
Associate Editor

Comment on "Jet Mixing Noise from Fine-Scale Turbulence"

M. J. Fisher*
University of Southampton,
Southampton, England SO17 1BJ, United Kingdom

IN a recent paper, Tam and Auriault[1] describe a semi-empirical theory for the prediction of the spectrum, intensity, and directivity of the fine-scale turbulence noise from jet mixing layers. The turbulence information is supplied by a $k-\varepsilon$ turbulence model. The authors conclude that "By comparison with experimental measurements over a wide range of jet velocity and temperature ratios, it is found that the theory can provide very accurate noise predictions."

An examination of those comparisons reveals that only Fig. 6 deals with a hot jet case. The combination of a Mach number of 2.0 and a stagnation temperature ratio of 1.8, however, yields a fully expanded jet temperature precisely equal to ambient temperature; the significance of this observation will become apparent next.

The extensive and systematic database from Tanna et al.[2] includes hot subsonic jets; it was apparently considered for comparison but "Only the jet data at supersonic Mach numbers are considered of good quality to be included for comparison."

One can only presume that this apparent lack of quality results from the observation that at subsonic jet Mach numbers the measured noise level, for a given jet velocity, increases with jet temperature instead of decreasing, as appears to be universally predicted by the current model.

However, the fact that subsonic jet mixing noise increases with jet exit temperature is well known and has been extensively described in the literature. An early report is contained in Ref. 3, where the authors went to considerable lengths to demonstrate that the effect was indeed a genuine feature of the jet mixing process and not associated with combustion or other noise production upstream of the jet nozzle. The first definitive attempt to model this component of mixing noise appears to be that from Morfey.[4] In brief, after rewriting Lighthill's acoustic analogy in the form

$$\frac{1}{c_0^2}\frac{\partial^2 p}{\partial t^2}-\nabla^2 p=\frac{\partial^2 \rho u_i u_j}{\partial x_i \partial x_j}-\frac{\partial^2}{\partial t^2}\left(\rho-\frac{p}{c_0^2}\right)$$

he argued that the second term on the right-hand side constituted an additional source, which would be zero only when the density in the source region was identical to that of the ambient fluid. Otherwise an additional dipole source, which in heated air jets scales as $U^6(\Delta T/T_s)^2$, where T_s is the temperature in the source region, must be considered in addition to the traditional quadrupole source, which scales as the eighth power of the jet exit velocity U. It follows that at lower velocities the dipole source will become progressively more apparent, reducing the velocity dependence from U^8 to U^6.

In a subsequent paper, Tester and Morfey[5] tested this model against an extensive database with convincing results. Perhaps of more importance in the current context was the consistency demonstrated between the Lockheed data[2] and that from the (then) National Gas Turbine Establishment and Institute of Sound and Vibration Research facilities in the United Kingdom and the Société Nationale d'Etude et de Construction de Moteurs d'Aviation in France.

The following is respectfully submitted:

1) The data of Ref. 2 should not be rejected on the basis of quality. They are consistent with quality data from other sources.

2) The model proposed in Ref. 1 includes only the quadrupole term in the preceding equation. It is suited, therefore, only to the prediction of noise from unheated jets or to jets of sufficiently high velocity that the dipole term is negligible. The single heated jet spectral comparison (Fig. 6) happens to correspond to a case where the fully expanded jet temperature, and hence density, is precisely equal to the ambient value.

3)Although it is an achievement to predict cold and isothermal jets to the accuracy demonstrated, the model will fail to predict jet mixing noise for subsonic exit velocities at practical jet temperature ratios.

Recent references to temperature effects on jet noise production may also be found in Refs. 6 and 7 in the context of coaxial jet noise prediction.

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M. Samimy
Associate Editor

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*Rolls–Royce Reader, Institute of Sound and Vibration Research.

Reply by the Authors to M. J. Fisher

Christopher K. W. Tam* and Laurent Auriault†
Florida State University, Tallahassee, Florida 32306-4510

PROFESSOR Fisher's comments on our paper[1] center on the effect of temperature on jet noise. He points out that in the

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*Distinguished Research Professor, Department of Mathematics. Associate Fellow AIAA.

†Graduate Student, Department of Mathematics.

literature there are investigations, carried out in the 1960s and 1970s, that conclude that subsonic jet mixing noise increases with temperature. However, a survey of the literature reveals that this conclusion is not unanimous. There are published data showing an opposite effect. In view of the improvements in experimental facility and instrumentation during the last 20 years, this may be a good issue to visit again experimentally and theoretically.

Professor Fisher cites the results of Fig. 6 of our paper, which offers a good comparison between the predicted noise spectrum and the measured spectrum at Mach 2 and a stagnation temperature ratio of 1.8. He then uses the fact that it is an isothermal jet to suggest that our theory will fail to predict jet mixing noise for subsonic exit velocities at practical jet temperature ratios. We wish to point out that Figs. 7 and 8 of our paper are also relevant to the effect of temperature on jet noise. Figure 8 contains comparisons with measurements at stagnation temperature ratios up to 4.9. Figure 7 gives the comparisons between the predicted and measured noise spectra for a Mach 2 jet at stagnation temperature ratios of 1.0, 1.12, 1.8, and 2.72. The agreement is good in all cases. For the stagnation temperature ratio 2.72 jet, the jet-to-ambient-temperature ratio is 1.5. This is definitely a hot jet, not an isothermal jet.

Concerning the quality of the data of Ref. 2, we would like to clarify that the data were measured in the $\frac{1}{3}$ octave band, as was the general practice in the 1970s. To analyze the data for comparison purposes, it was necessary to convert them to narrowband spectra. A $\frac{1}{3}$ octave band spectrum is weighted in favor of the high-frequency part of the band. The conversion invariably introduced inaccuracy. Also, the converted narrowband data points were spaced quite far apart. This prevented an accurate determination of the spectral peak. Upon analyzing the converted data, we found significant scattering and decided not to use the data in the subsonic-Mach-number range. We would certainly agree that we have, so far, not demonstrated whether the prediction of our theory agrees well with hot subsonic jet noise data. However, this is what we will try to find out as soon as a reliable set of narrowband data becomes available.

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M. Samimy
Associate Editor