Proceedings of Meetings on Acoustics

ICA 2013 Montreal

Montreal, Canada

2 - 7 June 2013

Noise

Session 3aNSb: Aviaton, Aviation Engines, and Flow Noise

3aNSb7.   Preliminary analysis of acoustic intensity in a military jet noise field

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  Acoustic intensity measurements of the F-22A Raptor are analyzed as part of ongoing efforts to characterize the noise radiation from military jet aircraft. Data were recorded from a rig of microphones and an attached tetrahedral intensity probe at various locations to the sideline and aft of the aircraft. Numerical analysis of the intensity at one-third octave band center frequencies along various measurement planes and at a 23 m radius arc reveals the magnitude and directionality of the vector acoustic intensity. Differences in the trends for low-frequency and high-frequency data are discussed and, via a simple ray tracing back toward the source, interpreted in terms of source location and extent. [Work supported by ONR.]

Published by the Acoustical Society of America through the American Institute of Physics

INTRODUCTION

Jet noise source characteristics from military jet aircraft are needed to better understand near- and far-field propagation. Because it is difficult to obtain this information directly from turbulence measurements of high-temperature, supersonic, full-scale jet engines, array-based acoustical measurements outside of the jet plume have been used to help provide the necessary information. Techniques such as beamforming,[1] acoustical holography,[2-4] and equivalent source methods[5,6] have been applied previously in characterizing jet noise sources.

Acoustic intensity has been widely used in many areas of acoustics for source characterization but has not been heavily applied to aeroacoustics. Measurement of the vector intensity in the frequency domain, an indication of energy flow, can provide a map of the frequency-specific sound radiation from turbulent flows. Ventakesh *et al.*[1] used a one-dimensional intensity probe to validate the application of beamforming techniques in the analysis of a subsonic jet. The work of Jaeger and Allen[7], who used a two-dimensional intensity probe in characterizing Mach 0.2-0.6 jets, represents one of the most in-depth applications. However, their initial work differs significantly from high-amplitude jet conditions and resulting source characteristics typical of military aircraft. Recently, acoustic intensity has been employed in near-field investigations of solid rocket motor plume acoustics.[8-10] In recent measurements of the sound field of the F-22A Raptor, an acoustic intensity probe was attached to an array of microphones, which was moved to multiple locations.[11] This paper represents some preliminary results and analysis of the intensity data.

INTENSITY CALCULATIONS

Extensive measurements[11,12] were made of the noise produced by a tethered F-22A Raptor. One engine was held at idle while the other was fired at four engine conditions: idle, intermediate (80%), military, and afterburner. An array of microphones and an attached tetrahedral intensity probe were placed at multiple locations along near-field measurement planes and along a 23-m radius arc centered 5.5 m downstream from the nozzle exit of the active engine. Two of the near-field measurement planes were positioned so as to run parallel to the estimated shear layer of the jet plume. Measurements were made with the array at several locations in 2.4 m increments along the measurement planes and 10 degree increments along the arc, with the probe recording data at each of these locations.

FIGURE . F-22 engine firing with measurement array and intensity probe shown. The intensity probe is positioned on top of the array, on the far right.

FIGURE 2. Close-up of intensity probe atop the microphone array. The probe microphones were mounted at the vertices of the external frame, pointing inward and located 1.9 cm from the geometric center.

The probe itself has been used previously in near-field intensity measurements of solid rocket motors.[8-10] It was constructed as an inverted tetrahedral external frame with phase-matched microphones mounted at the vertices. For the F-22 measurements it was attached to the array so that two microphones were aligned parallel to the measurement array guide rail. In this paper, the centerline of the plume is considered the z-axis, and the orthogonal horizontal direction chosen to be along the x-axis. In the preliminary results considered hereafter, the height of the probe was located near the center of the nozzle, so the relatively small y-component (vertical) of the intensity is not presented.

Vector intensities were calculated using cross spectra from the individual microphone pairs, which account for the finite-sum and finite-difference pressure and velocity estimates. Weightings for the cross-spectral summations of each intensity component were determined according to a least-squares technique developed by Pascal and Li.[13]

PRELIMINARY RESULTS

The eventual goal of this research is to characterize the source via analysis of the direction and magnitude of the intensities at various frequencies. In order to do this, the above methodology has been used to create *x-z* vector intensity maps at the one-third octave band center frequencies of 200, 500, and 1000 Hz, for military engine condition on the two measurement planes parallel to the shear layer and the 23-m arc. These are shown in Figures 3-5. The magnitudes have been cube-root scaled in order to have all vectors be visible on the same axes. Within each figure, the collection of vector magnitudes was internally scaled by the rendering program, which causes the scaling to be different from one figure to the next. For select one-third octave band center frequencies a simple ray-tracing technique was used to give an initial characterization of source location. For each frequency, the vector with the largest magnitude along the measurement plane nearest the shear layer was traced back to the centerline, where the intersection indicates a rough estimate for the maximum source location. These estimated source locations are listed in Table 1.
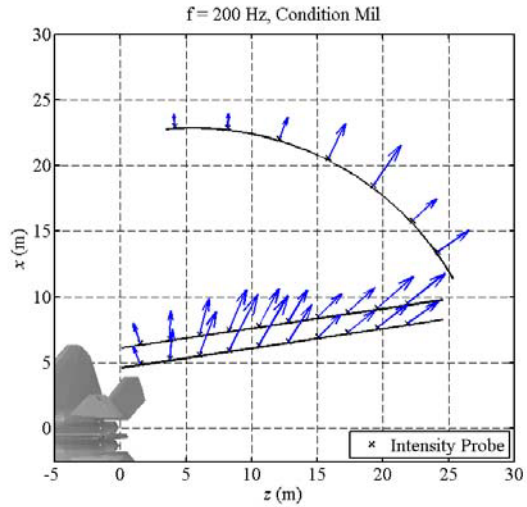
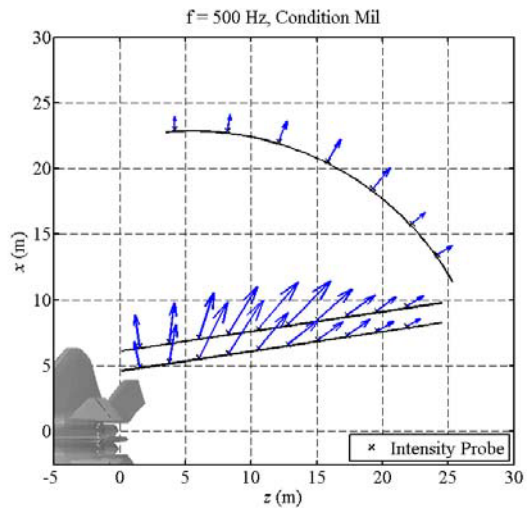**FIGURE 3.** Intensity mapping for 200 Hz, military engine conditions.

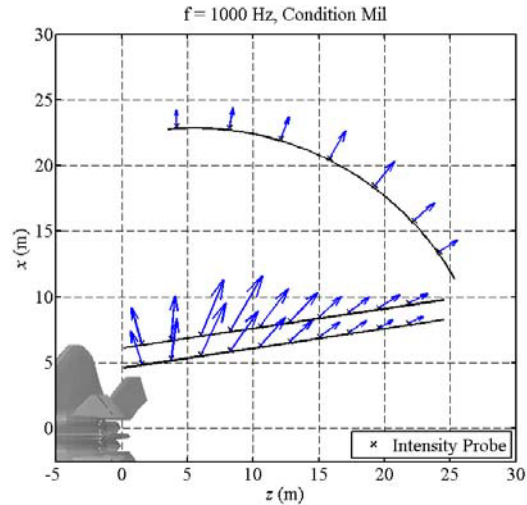**FIGURE 4.** Intensity mapping for 500 Hz, military engine conditions.

FIGURE 5. Intensity mapping for 1000 Hz, military engine conditions.

TABLE 1. For the listed one-third octave band center frequencies, the probe location (from the left) corresponding to the largest intensity on the closest measurement plane are given, along with the z-coordinate of ray-traced source location estimate.

Frequency (Hz)	Probe Location	Source Location (m)
125	8	12.3
160	8	10.7
200	4	5.7
500	4	4.9
1000	3	3.6

OBSERVATIONS

From the above mappings, some preliminary observations have been drawn regarding trends in apparent source location with respect to frequency. Both the relative magnitudes of the intensity vectors in Figures 3-5 and the maximum-ray-traced source estimates in Table 1 indicate that maximum sound generation region both contracts and moves upstream with increasing frequency. This is consistent with what is known about jet noise generation via other measurement methods. However, the vectors in Figures 3-5, particularly for 200 and 500 Hz, show an extended source region, which makes the trends in Table 1, based solely on tracing one intensity vector, more qualitative than quantitative at this point.

There are many factors still to be considered in the analysis of the data. The influence of ground reflections and engine nonstationarity may complicate the interpretation of the intensity vectors. Furthermore, a more rigorous method for characterizing source location is needed. Finally, trends between engine conditions and additional frequencies need to be examined to develop a better understanding of how intensity can be applied in jet aeroacoustic source characterization.

ACKNOWLEDGMENTS

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