DETERMINATION OF JET NOISE RADIATION PATTERNS AND SOURCE LOCATIONS USING 2-DIMENSIONAL INTENSITY MEASUREMENTS

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- Results
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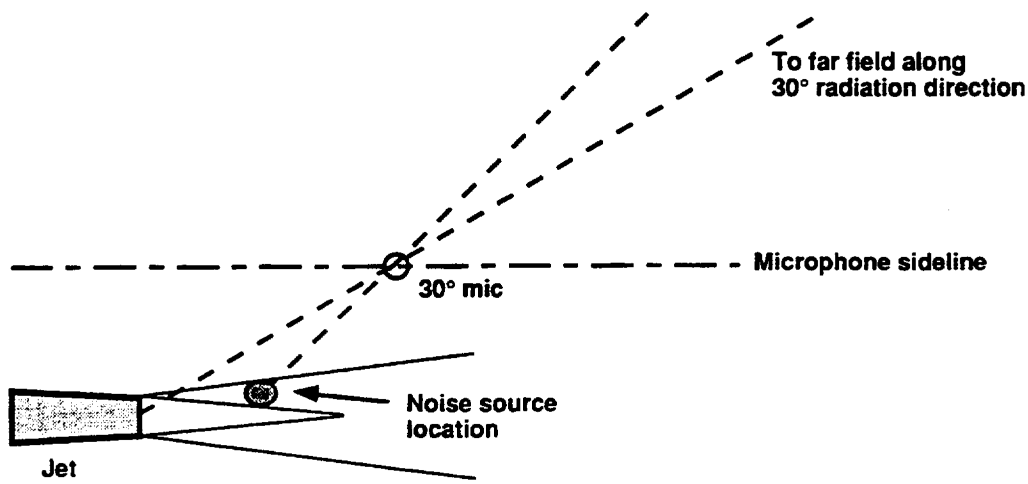
  - Source location centroids
  - Directivity
- Conclusions

Jet Noise Extrapolation



An inaccurate assumption for a noise source location will have an effect on the ability to extrapolate to the far field. In this figure, the sound pressure level seen at a near field microphone is extrapolated to the far field under the assumption that the source lies at the nozzle exit. This result will be in error since the actual source location is downstream. The jet plume will appear as a point source if measurements are made at a far field location. However, in a wind tunnel, it is not always possible to place microphones far enough away from the jet. Therefore it is advantageous to have a method for measuring the correct jet noise radiation pattern.

Extrapolation to Far Field

- Knowledge of sound pressure distribution at far field traverse location

- Knowledge of radiation angles at far field traverse location

- Extend sound along radiation vector to requested observer location assuming spherical spreading

The apparent noise sources and directivities for given frequencies are identified at a far field location along the jet axis. Therefore, the sound level at any observer position can be determined by applying radial spreading and atmospheric attenuation along the path from the noise source through the traverse position.

Sound Intensity Theory

- **Acoustic Intensity is a measure of the net flow of acoustic power per unit area**

P is the acoustic pressure at a point

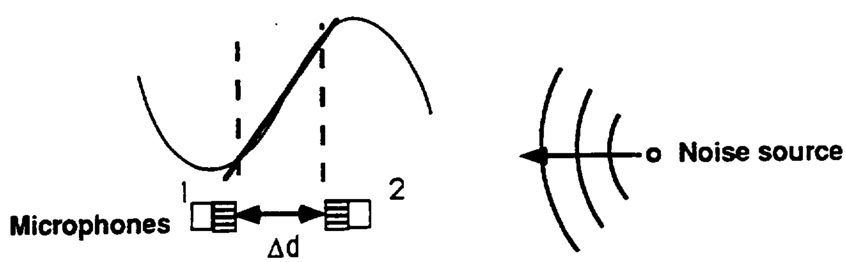
v is the particle velocity at a point

$$I = \overline{P \cdot v}$$

The acoustic intensity is a vector quantity that describes the net flow of acoustic power that passes through a unit area. Sound intensity can also be defined as the time-averaged product of the acoustic pressure and the particle velocity at a given point.

Sound Intensity Theory (continued)

- Acoustic particle velocity is obtained with a finite difference approximation



$$v_n = -\frac{1}{\rho}\int \frac{P_2 - P_1}{\Delta d}\,dt$$

- The units of sound intensity are dB (ref. 1×10^{-12} Watts/square meter)
- For a perfect point source in a free-field environment, the sound pressure level in dB (L_P) is equivalent to the sound intensity level in dB (L_I)

Two phase-matched pressure microphones separated by a known distance can measure sound intensity. The acoustic particle velocity is measured indirectly by applying a finite difference approximation to the pressures measured at each microphone.

Sound intensity is measured in decibels referenced to 1.0 picoWatts per square meter. The units of sound pressure level and sound intensity level are defined such that a perfect radial source in a free-field environment will have equivalent sound pressure and sound intensity levels.

Sound Intensity Theory (continued)

- **Acoustic Intensity can be measured in the frequency domain using the cross-spectrum between the two microphones (G_{12})**

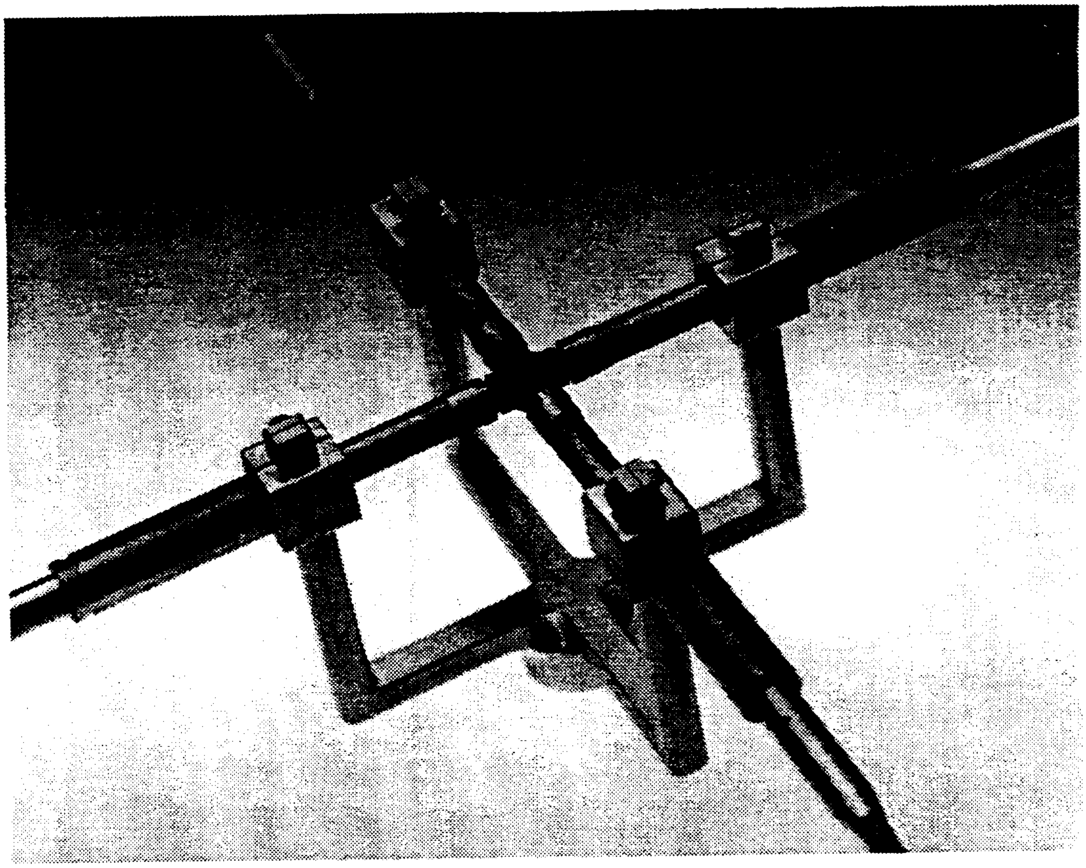
  Where,

$$I(f) = \frac{Im[G_{12}(f)]}{2\pi f \rho \Delta d}$$

- **With four in-plane microphones the components of sound intensity in two directions can be measured**

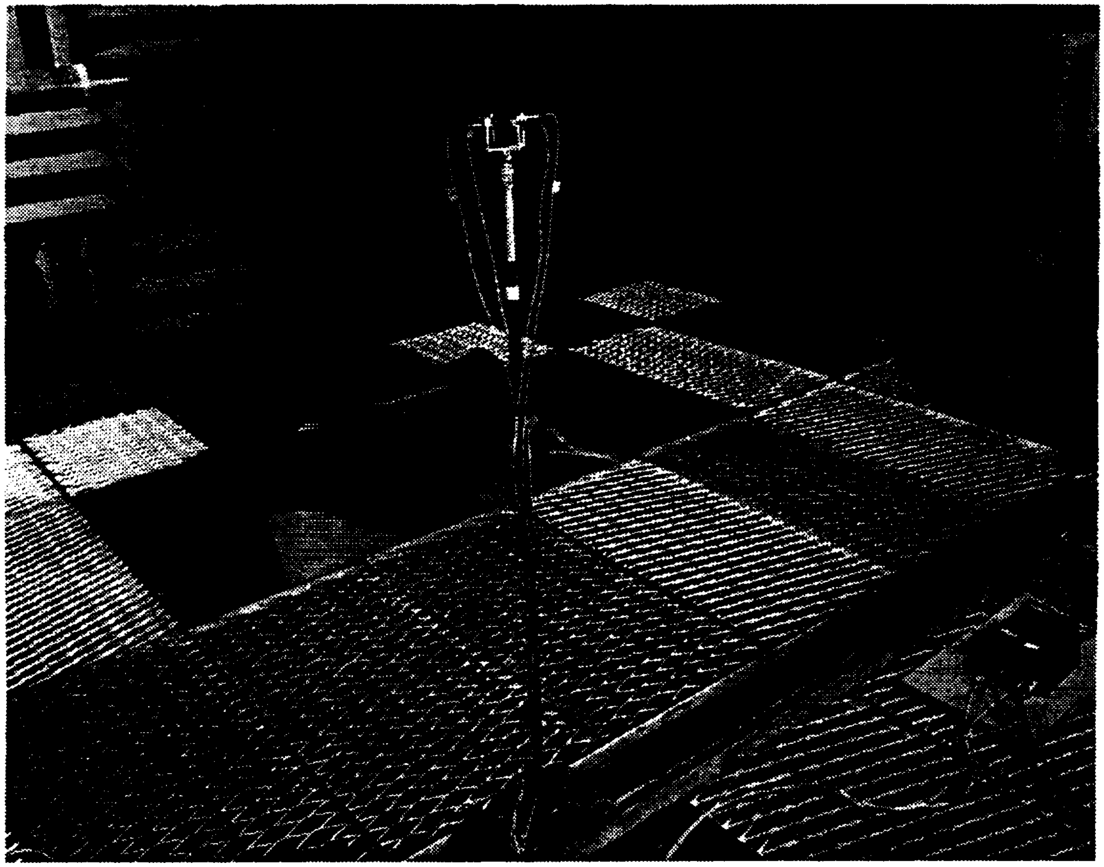
Each component of the sound intensity at a given frequency is obtained in the frequency domain from the cross-spectra between two microphones. Four in-plane microphones can measure the x- and y- components of the total sound intensity in the plane. The angle between the x- and y- components is taken to be the angle of incidence of the sound intensity at the probe center. A computer program controls the analyzer which measures the cross-spectrum for each microphone pair, adjusts the result for microphone phase differences and determines the sound intensity.

TWO-DIMENSIONAL SOUND INTENSITY PROBE



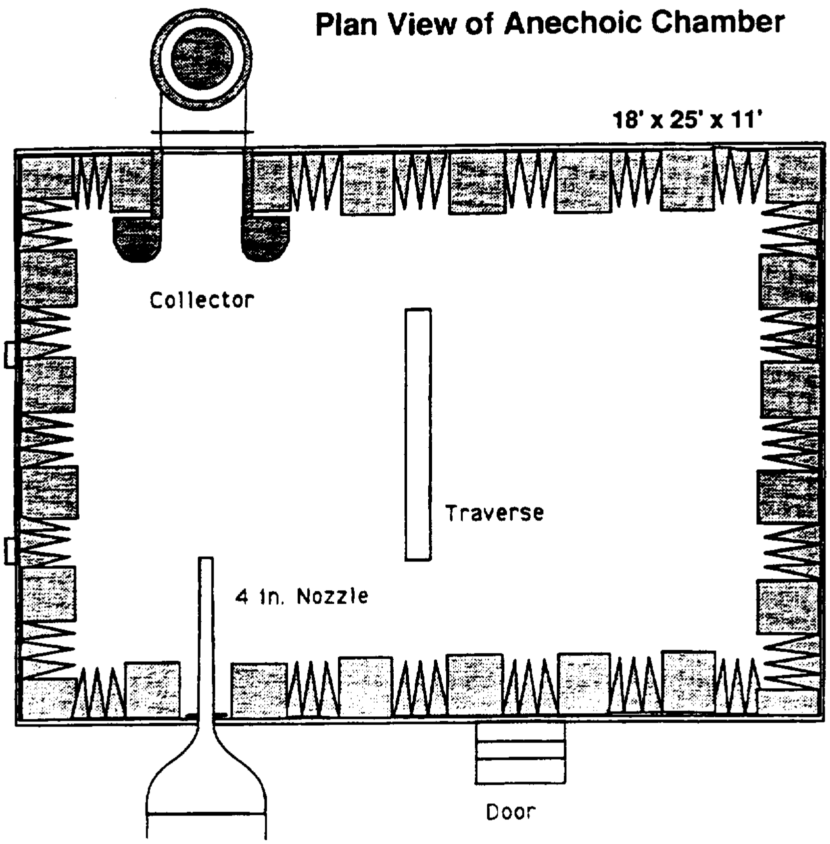
The probe holds four 1/4" microphones in a face to face arrangement. A 12 mm spacer separates each microphone pair. The separation distance between the microphones sets the frequency range at 150 Hz to 5000 Hz.

SOUND INTENSITY PROBE IN ANECHOIC CHAMBER



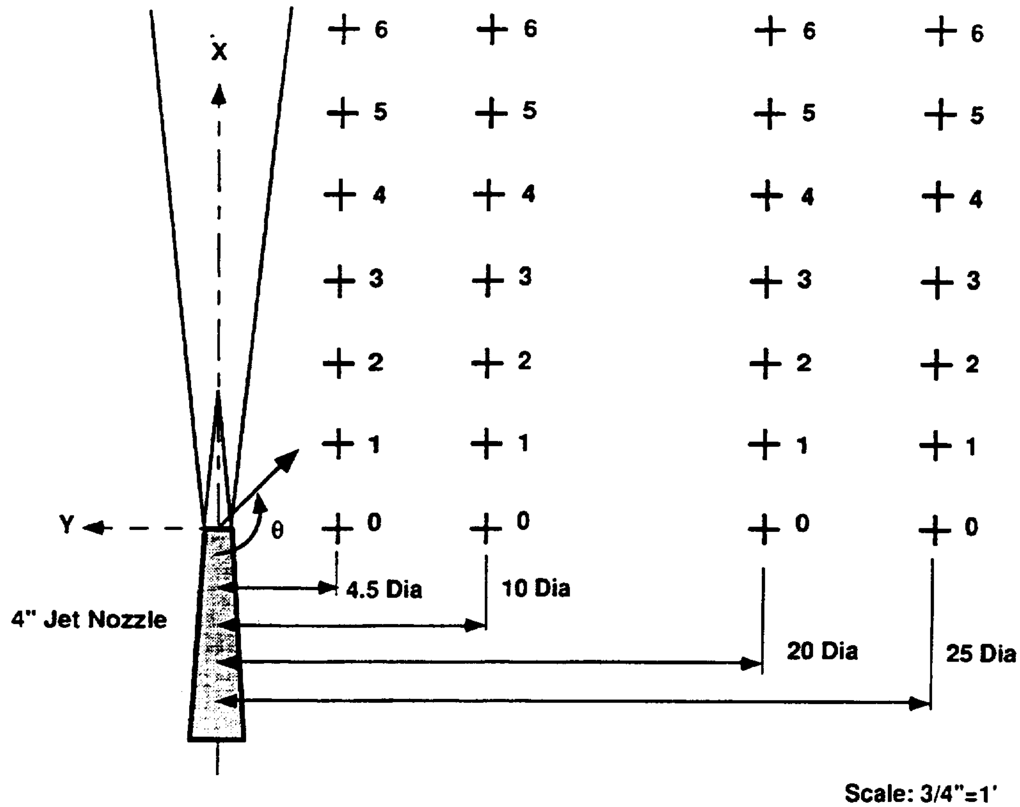
The 4" jet nozzle is in the left background of the photo. The probe was mounted at the level of the jet centerline on a traverse which could be operated during the test to move the probe parallel to the jet centerline.

NASA AMES ANECHOIC CHAMBER



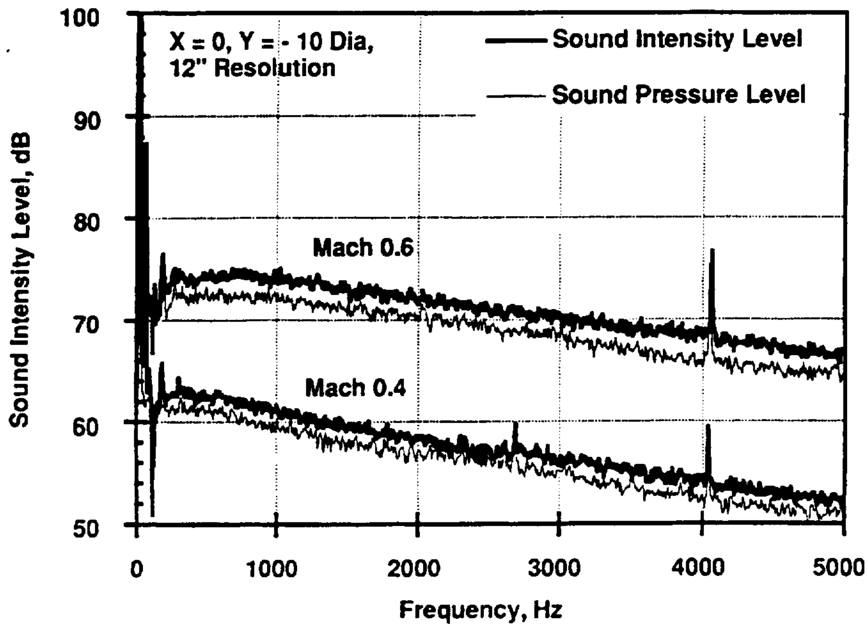
The chamber is anechoic for all frequencies above 150 Hz. A compressor, powered by two 400 HP electric motors forces air through the chamber jet's 4" nozzle. The jet is capable of reaching velocities up to Mach 0.8. The traverse motor control and data acquisition is in done in the acoustics lab next to the chamber.

Anechoic Chamber Jet and Traverse Positions

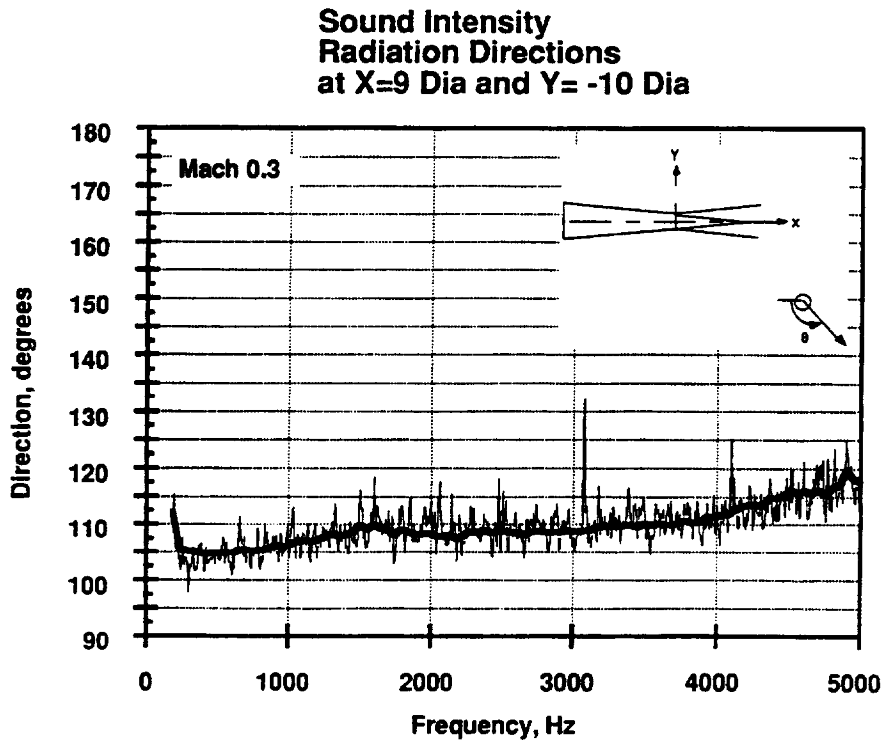


The angle of intensity incidence was referenced to the jet exit plane and the jet centerline where 180● was downstream along the x-axis and 90● in the -y direction. The motorized traverse moved the intensity probe parallel to the jet axis. The traverse was placed at four parallel positions relative to the jet centerline: (y = -17 3/4", -39 1/4", -79" and -104").

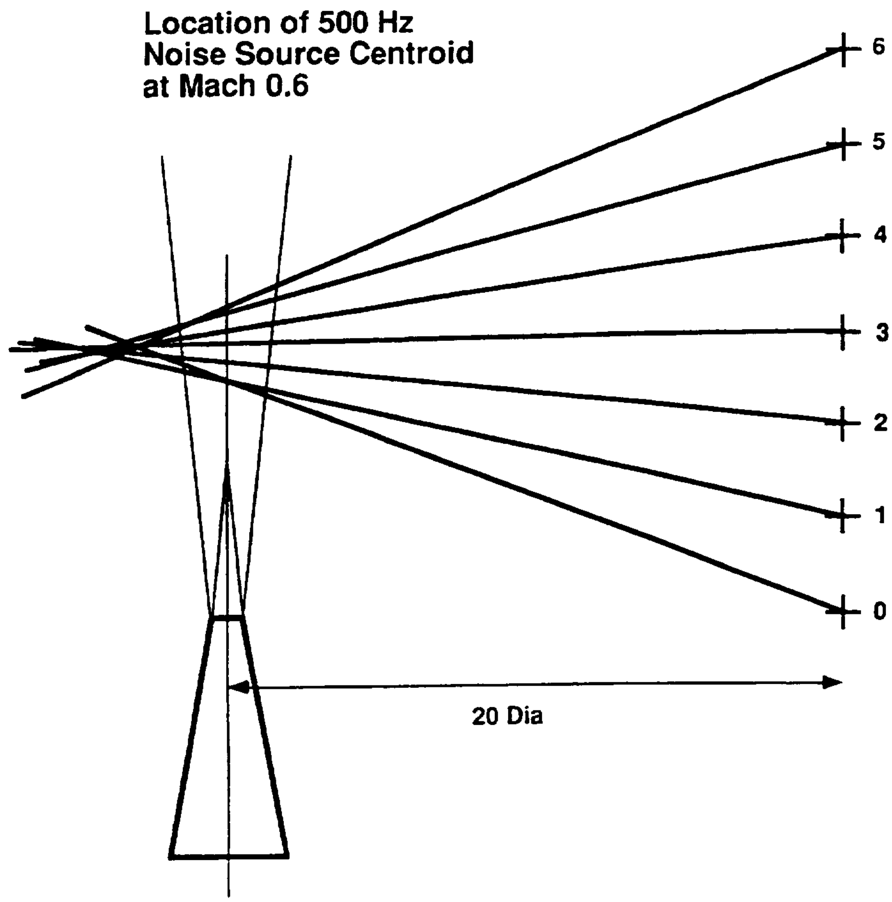
Sound Intensity Spectra



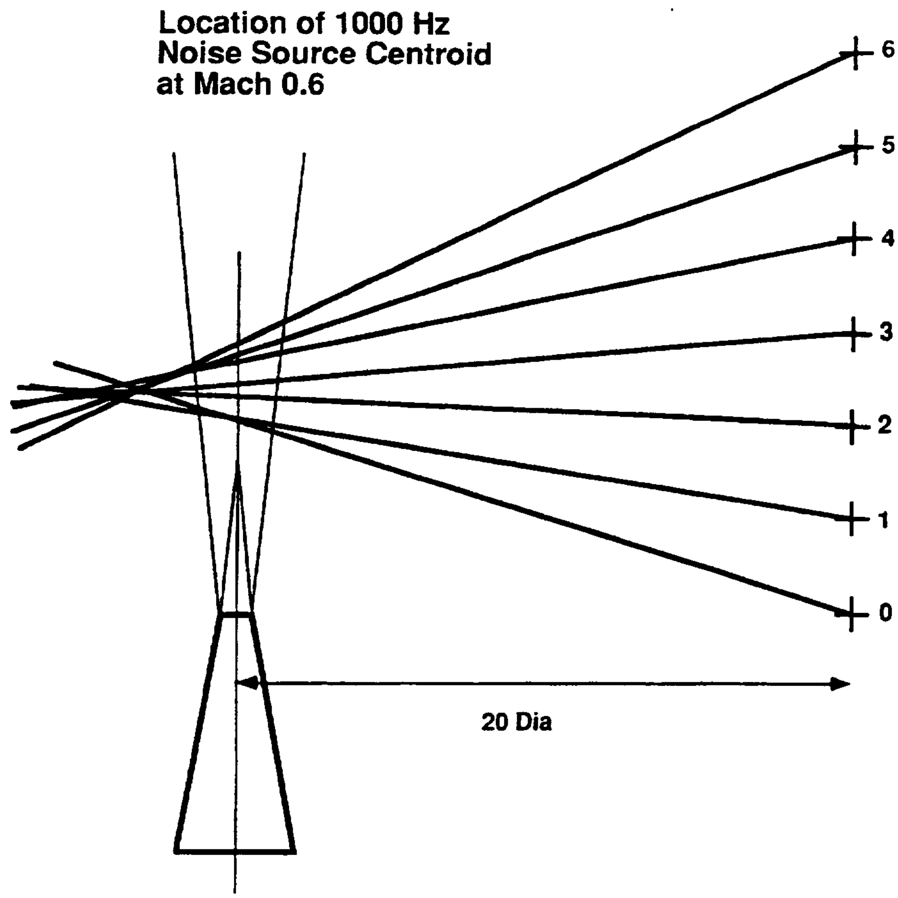
The figure shows typical sound intensity spectra for Mach 0.4 and Mach 0.6. This is the vectorally combined sound intensity of the x- and y- components. The results are typical for jet noise, where most of the noise is concentrated at low frequencies and then rolls off at higher frequencies. Note that below 200 Hz, the sound intensity becomes unreliable. The spikes are harmonics of the blower frequency. Also shown is the sound pressure level taken from one of the four microphones. The difference in levels between the sound intensity and the sound pressure is attributed to the distributed nature of the jet noise sources.



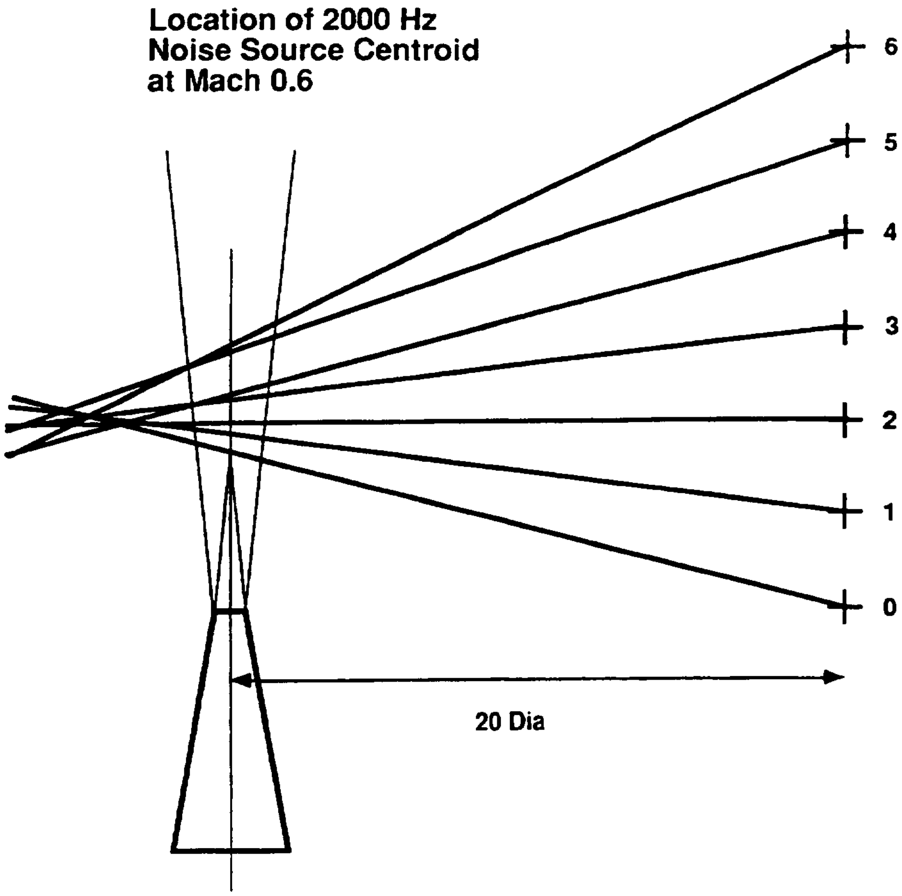
This figure shows sound intensity direction vs.. frequency for Mach 0.3. The traverse is at Y = -39 1/4" (10 jet diameters) from the jet centerline. The intensity probe is at X = 36" (9 jet diameters) from the nozzle exit. For this case with 150 time averages, the random error spread is about 5●. The results can be improved by using a curve fit as shown by the solid line. These results indicate that lower frequencies sources appear to emanate at smaller angles from the jet centerline, suggesting that they lie further downstream than higher frequencies sources. The peaks are harmonics of the blower frequency. They point toward the nozzle exit.



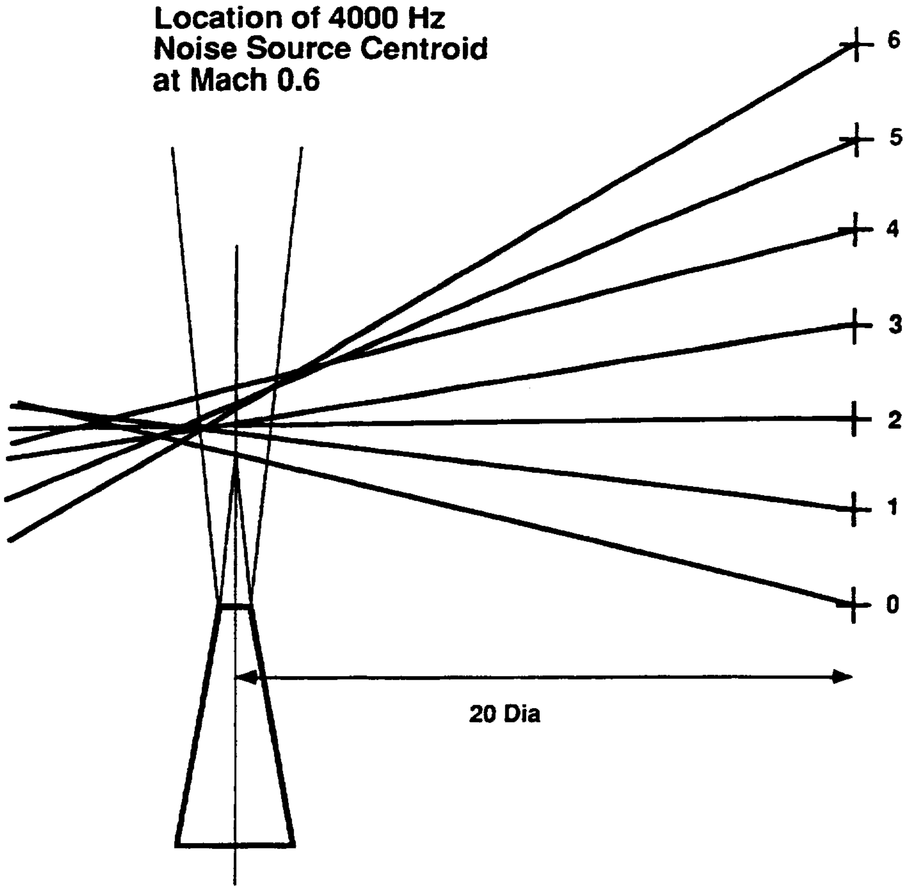
This figure shows the sound radiation pattern for 500 Hz at a Mach number of 0.6. These radiation directions are measured with the probe at 20 jet diameters from the jet centerline. The lines appear to coalesce on the opposite side of the jet plume. This is attributed to the fact that the noise source for this particular frequency is distributed over a finite region in the plume. The ability of the sound intensity probe to locate a noise source was tested by successfully locating a speaker mounted at various locations in the anechoic chamber.



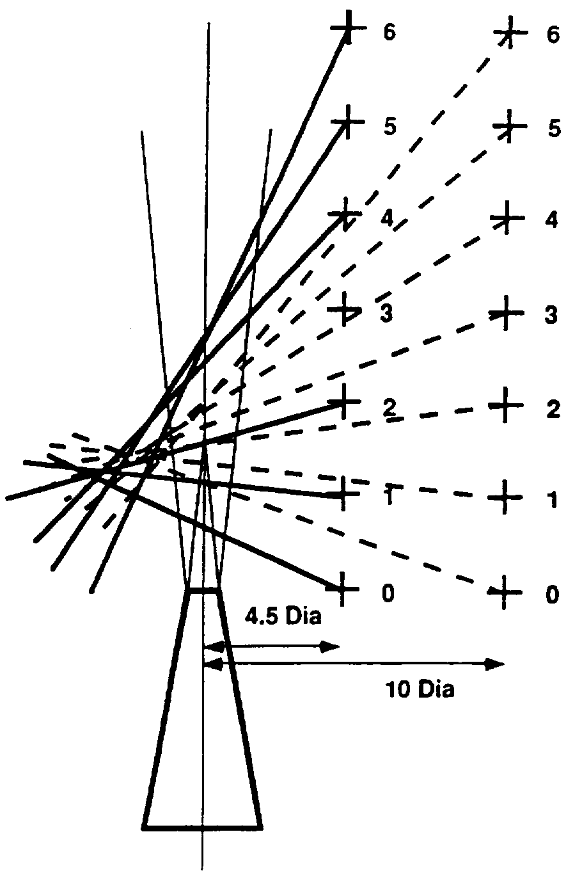
This figure shows the sound radiation pattern for 1000 Hz at a Mach number of 0.6. Note that the source centroid is closer to the jet nozzle exit than the 500 Hz noise source.



This figure shows the sound radiation pattern for 2000 Hz at a Mach number of 0.6.

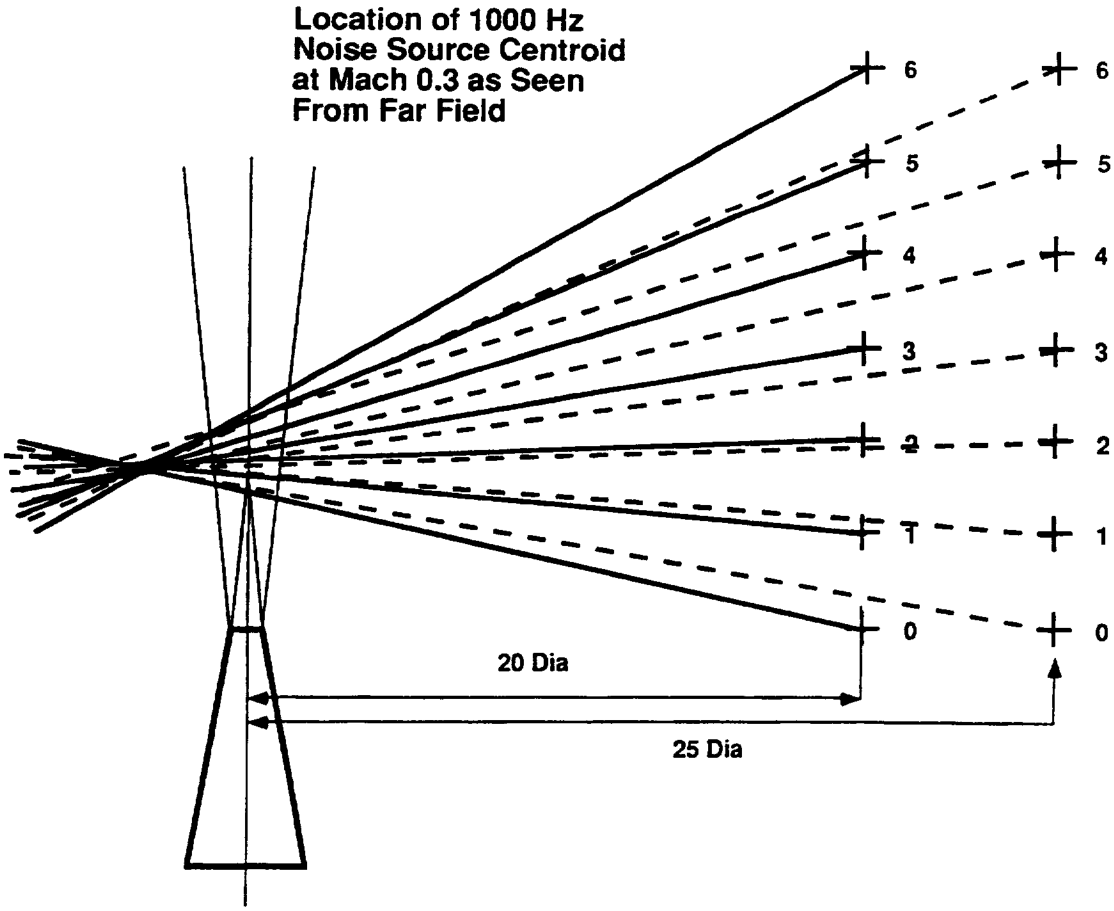


This figure shows the sound radiation pattern for 4000 Hz at a Mach number of 0.6.



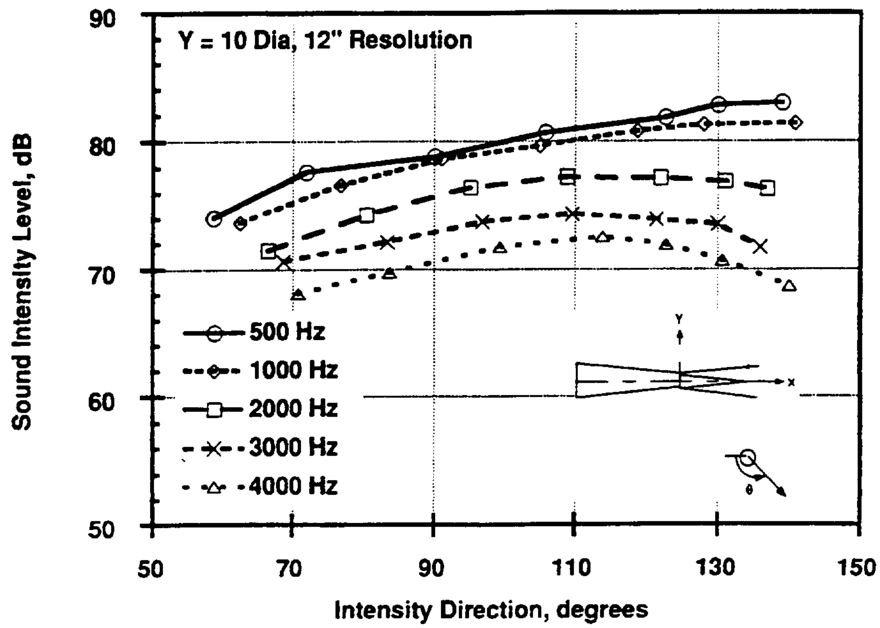
Location of 1000 Hz Noise Source Centroid at Mach 0.3 as Seen From Near Field

For each position along the traverse the radiation vector for 1000 Hz at Mach 0.3 is shown. The traverse was positioned at two near field location of y = -17 3/4" and -39 1/4". Note that the source position changes with traverse position. This indicates that near field effects distort the apparent location of the source centroid.



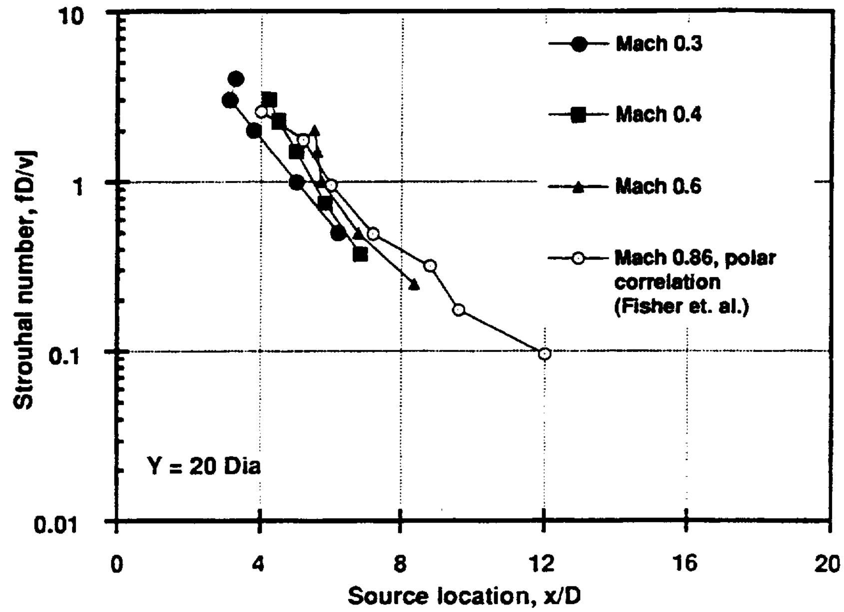
The radiation directions for 1000 Hz at Mach 0.3 are shown at two far field positions. The traverse locations are y = -79" and 104". Note that the Location of the jet source still appears to emanate from beyond the jet core. The source centroids appear at the same location for both traverse positions, indicating that near field effects are no longer an influence.

Peak Radiation Directions
for Mach 0.6



The figure shows sound intensity levels vs.. direction at each frequency for Mach 0.6. The traverse is about 10 nozzle diameters from the jet centerline. At 500 Hz the maximum level recorded of about 83 dB is found at almost 140° from the jet centerline while the maximum level for 4000 Hz is 72 dB at 113°.

Effect of Strouhal Number on
Noise Source Centroid Locations



Strouhal number is plotted with each corresponding source location. The traverse is 20 jet diameters from the jet centerline. Note that each Mach number collapses at near the same source locations. For comparison, results obtained by Fisher et. al. for a 25 mm jet at Mach 0.86 are shown. The source locations for the 0.86 case were obtained using polar correlation.

Disadvantages of Sound Intensity

- **Broad frequency range requires multiple spacings (150 - 5000 Hz with 12 mm spacer)**
- **Intensity probe, at present, can only work with no flow over the probe**
- **Requires precise phase calibration**

The separation distance between the microphones of the sound intensity probe limits the frequency range. By using several different separation distances, the frequency range can be expanded. The application of a finite difference approximation requires that there is no ambient flow over the probe. Finally, sound intensity measurements require careful phase calibrations to obtain phase-matched microphones.

Advantages of Sound Intensity

- **Can find centroid of apparent noise sources**
- **Can find sound intensity specifically for each frequency**
- **Can build sound field map about sources**
- **Does not require an anechoic environment**

A sound intensity probe can readily locate noise source centroids. Also, using a cross-spectrum, sound intensity can be found directly in the frequency domain. A sound intensity map can be used to describe the radiation characteristics of sources. And because of the vector characteristics of sound intensity, an anechoic environment is not necessary for most sound intensity measurements.

Conclusions

- **Two Dimensional Intensity is useful for finding jet noise radiation patterns**

- **Knowledge of radiation patterns and far field intensity levels can be extrapolated to any observer location**

- **Increased time averages and increased resolution can improve radiation angle accuracy**

Measurements of sound intensity at different locations in the vicinity of a jet can identify the radiation characteristics of the jet noise sources. A measured sound intensity levels can then be extrapolated along a known radiation direction to a given far field location assuming spherical spreading and applying the appropriate atmospheric attenuation.