DETERMINATION OF JET NOISE SOURCE LOCATIONS USING A DUAL SIDELINE CROSS-CORRELATION/SPECTRUM TECHNIQUE

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OUTLINE

- **Problem**
- **Experimental Set Up**
- **Technique**
- **Results**
- **Discussion**
- **Conclusions**

The above is a basic outline of the presentation.

PROBLEM

Extrapolation of Jet Noise to Far Field Requires

1. **Source Locations**
2. **Radiation Pattern**
3. **Sound Pressure Level (Lp) Distribution**

1 and 2 Are Not Obtainable from a Single Microphone Measurement

The goal of our efforts is to extrapolate nearfield jet noise measurements to the geometric far field where the jet noise sources appear to radiate from a single point. To accomplish this, information about the location of noise sources in the jet plume, the radiation patterns of the noise sources and the sound pressure level distribution of the radiated field must be obtained. Since source locations and radiation patterns can not be found with simple single microphone measurements, a more complicated method must be used.

Cross-correlation/Spectrum Technique

- **Uses Correlation Coefficient and Coherence to**
  - **- Determine Jet Radiation Field**
  - **- Find Source Locations**
- **Information May Be Extrapolated To Far Field**
- **Can Theoretically Be Used In Wind**

The dual sideline cross-correlation/spectrum technique uses the correlation coefficient and coherence functions to determine a jet plumes radiated acoustic field and source centroid locations. This information can then be extrapolated to the extreme far field with accurate results. The reason for investigating this technique is its applicability to measurements in flow.

SOUND INTENSITY

- **Directly Measures**
  - **Radiation Angle**
  - **Lp**
- **Source Location Easy to Obtain**
- **Frequency Limited**
- **Wind Velocity Not Allowed**

Another method of obtaining the necessary information is sound intensity. This method directly provides the radiation angle and sound pressure level that describes the entire acoustic field. Source centroid locations are also easily obtainable with this method. However, sound intensity is frequency limited with a given microphone spacing, but more importantly, is difficult to implement in a moving acoustic medium. Since one of the major goals of the High Speed Research Program (HSRP) is to determine the radiated acoustics of suppressor nozzle configurations with forward flight, another method must be developed for this case.

DEFINITIONS

Correlation Coefficient

$$\rho^2_{xy}(\tau)=\frac{R_{xy}(\tau)^2}{R_{xx}(0)R_{yy}(0)}$$

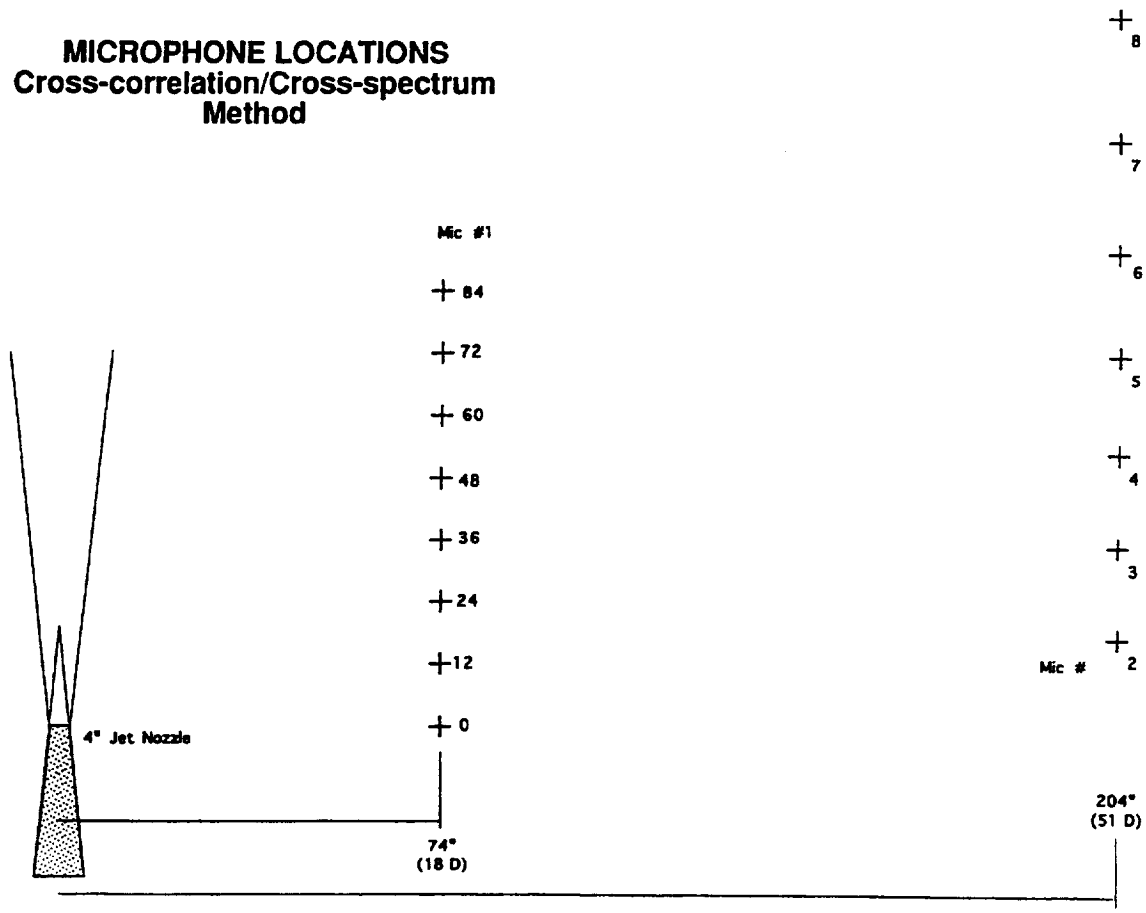
Coherence

$$\gamma^2_{xy}(f)=\frac{\left|G_{xy}(f)\right|^2}{G_{xx}(f)G_{yy}(f)}$$

The method investigated during this study is based on the correlation coefficient and coherence functions of two signals x and y. These functions are defined on the opposite page. The square of the correlation coefficient is defined as the square of the cross-correlation normalized by the product of the two autocorrelations evaluated at a time delay, *t*, of 0. The square of the coherence is defined as the square of the absolute value of the cross-spectrum normalized by the product of the two autospectrums. Note that these two functions contain the same information as they are related to each other by the Fourier Transform. Where the cross-correlation coefficient is a function of time delay, the coherence is a function of frequency, *f*.

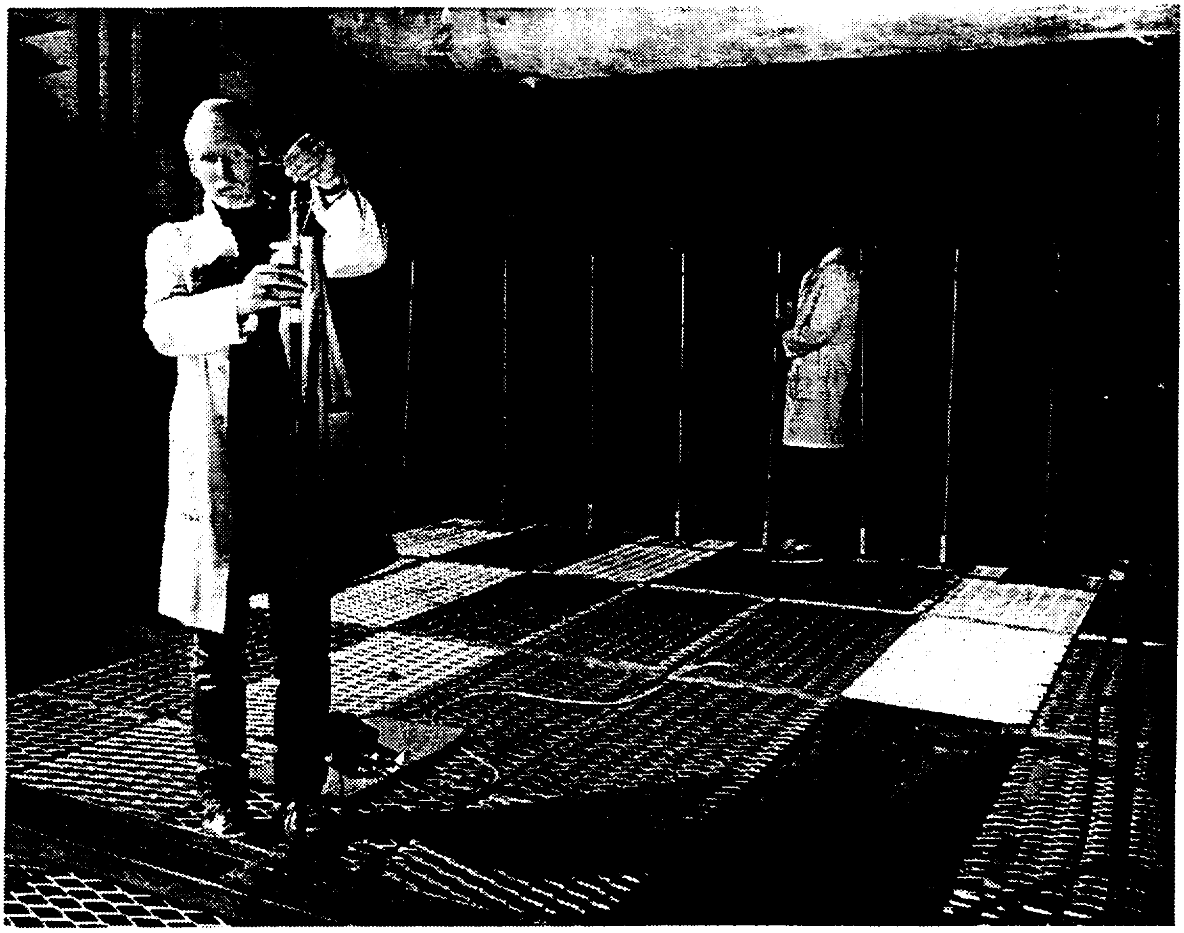
Both of the coefficients are obtained by normalizing a function by the highest possible value, theoretically, of that function. This implies that a perfect correlation would have a correlation coefficient value of 1. A value of 1 also indicates a perfect coherence.

MICROPHONE LOCATIONS
Cross-correlation/Cross-spectrum Method



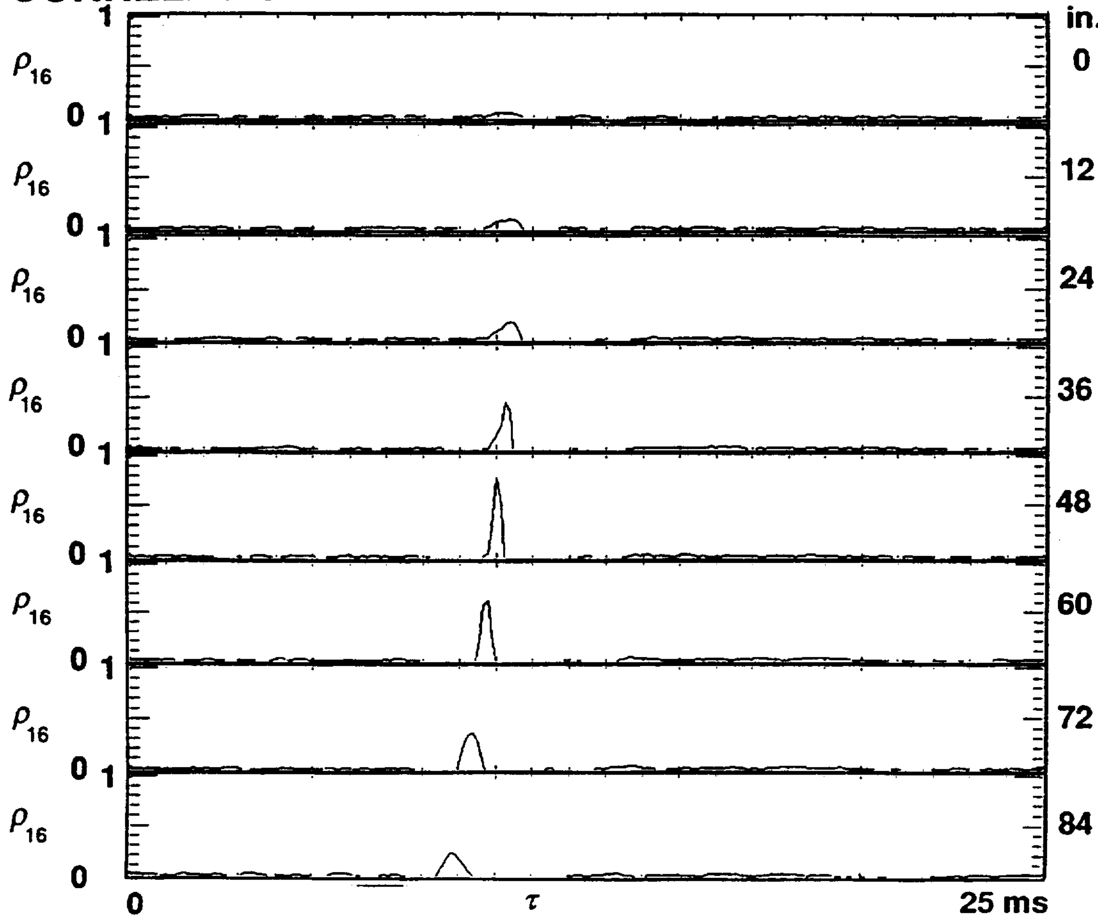
This diagram shows the microphone locations used in the anechoic chamber experiment. The 4 inch conical nozzle was used at Mach numbers up to 0.6 to simulate a jet nozzle. Microphone #1 was traversed to 8 positions along the close sideline which was located 74 in. from the axis of symme try of the nozzle. The stations of Mic. #1 are given as the axial locations in inches downstream of the nozzle exit plane.

There were 7 stationary microphones located along the far sideline which was located 204 in. from the axis of symmetry of the nozzle. The stationary microphone positions are denoted by microphone numbers 2- 8. The stationary positions correspond to radiation angles every 5 degrees from 95 to 125 deg., centered at nozzle centroid where 0 deg. points directly upstream. All microphone locations lie in the same plane as the horizontal plane of symmetry of the jet.

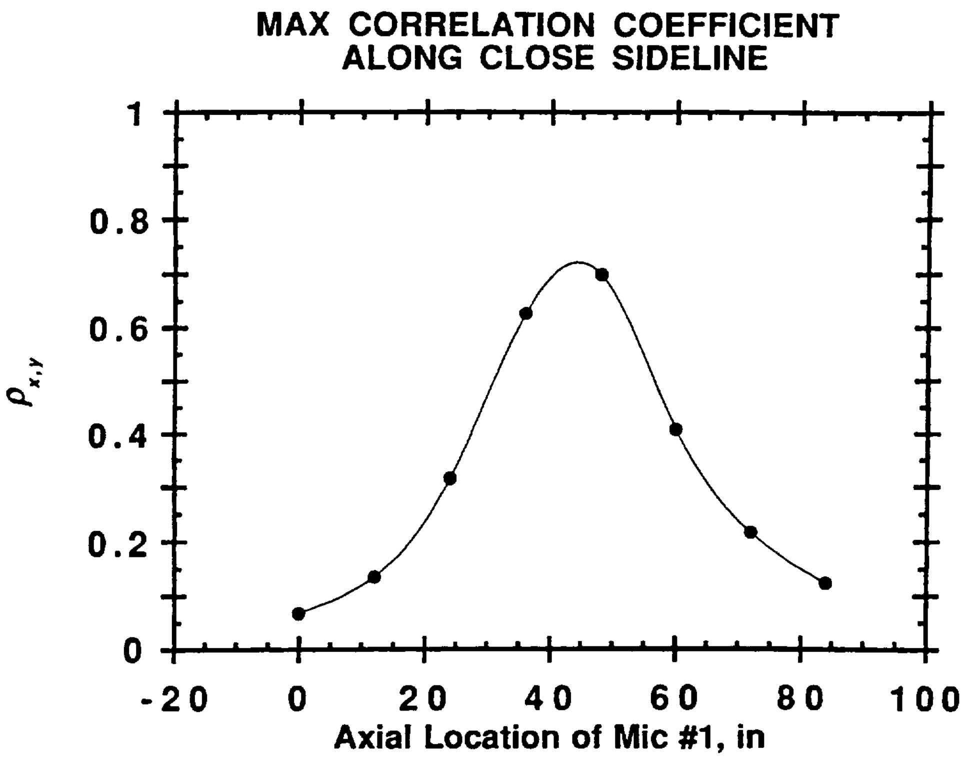


This photograph shows the experimental set up. The nozzle in the forefront is at the top of the picture, Mic. #1 mounted on the traverse is on the left and the far sideline microphones are in the background of the picture.

CORRELATION COEFFICIENT ALONG CLOSE SIDELINE

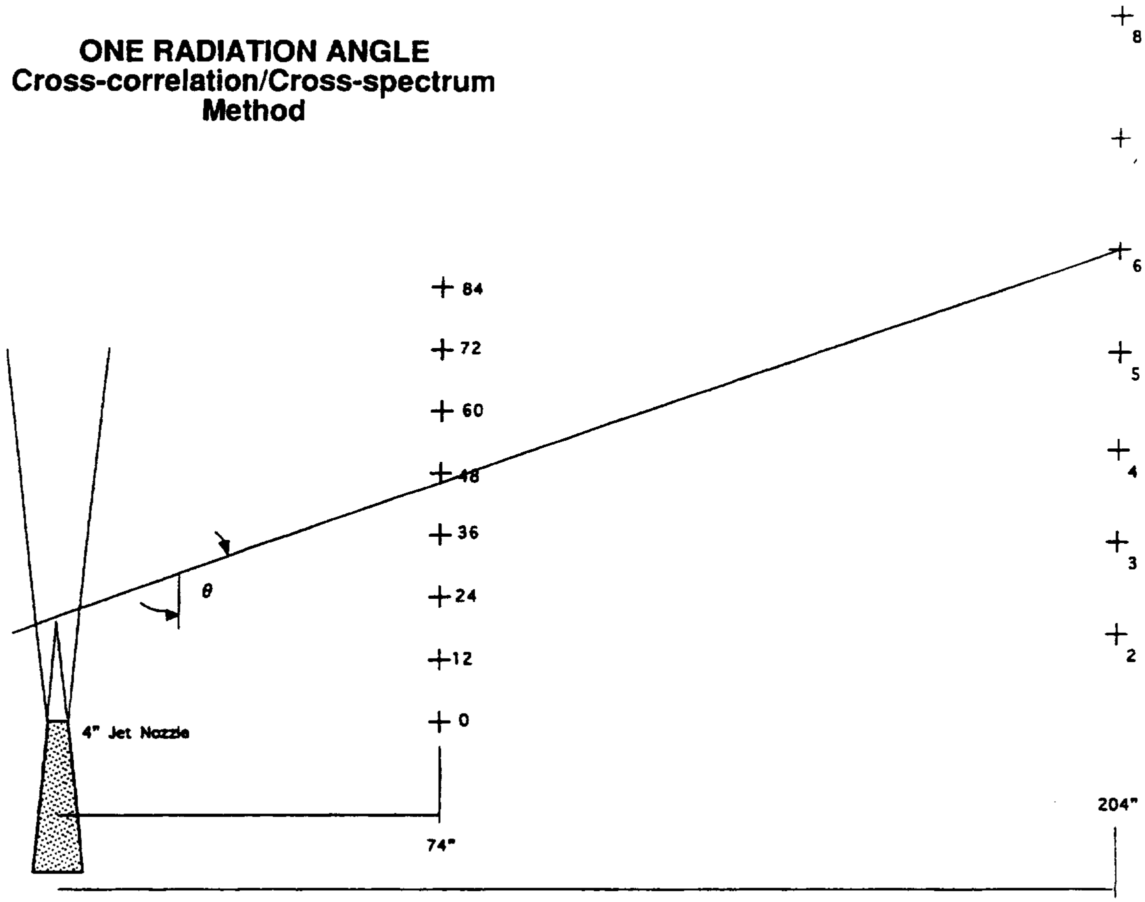


The data were reduced by comparing correlation coefficients of a far sideline microphone correlated to Mic. #1 at each of the positions along the close sideline. The resulting correlation coefficient plots for Mic. #6 are shown on the opposite page. Note that the value of the maximum correlation coefficient of each graph increases to a maximum and then decreases as the correlation procedure moves along the close sideline. This procedure was repeated for each far sideline microphone position.

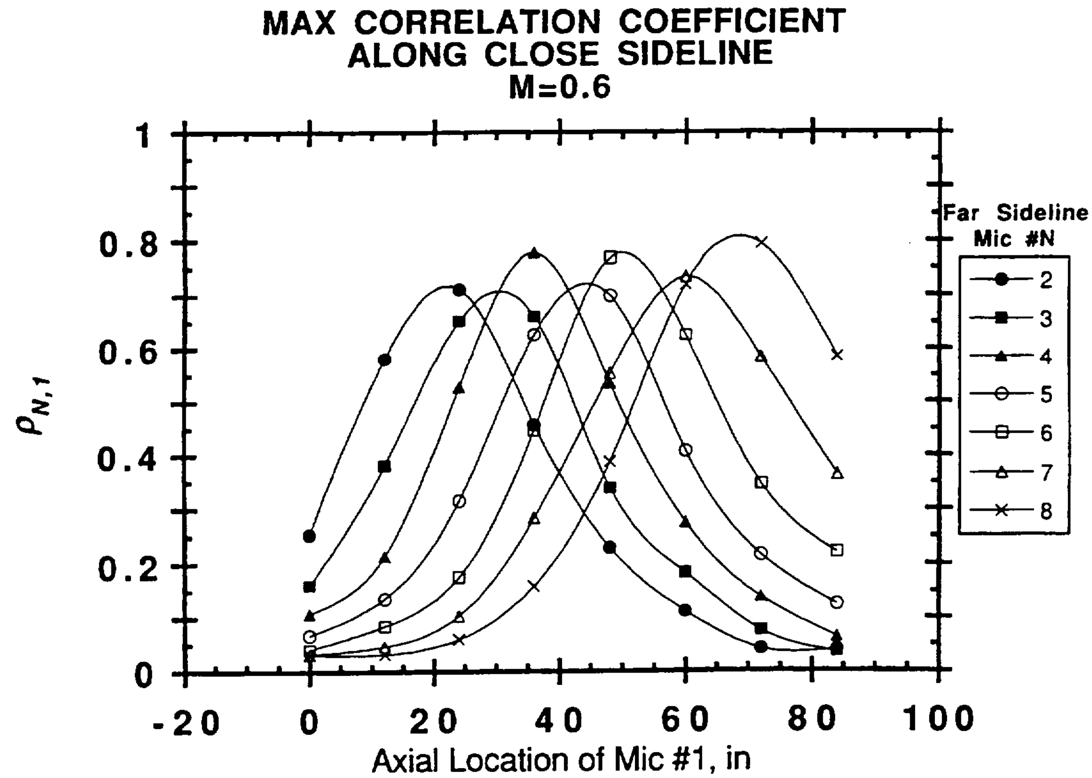


Plotting the maximum correlation coefficient of each cross-correlation of a far sideline microphone against the close sideline microphone location shows where most of the acoustic energy radiated from. A cubic spline curve fit is used to increase the accuracy of the maximum correlation coefficient location.

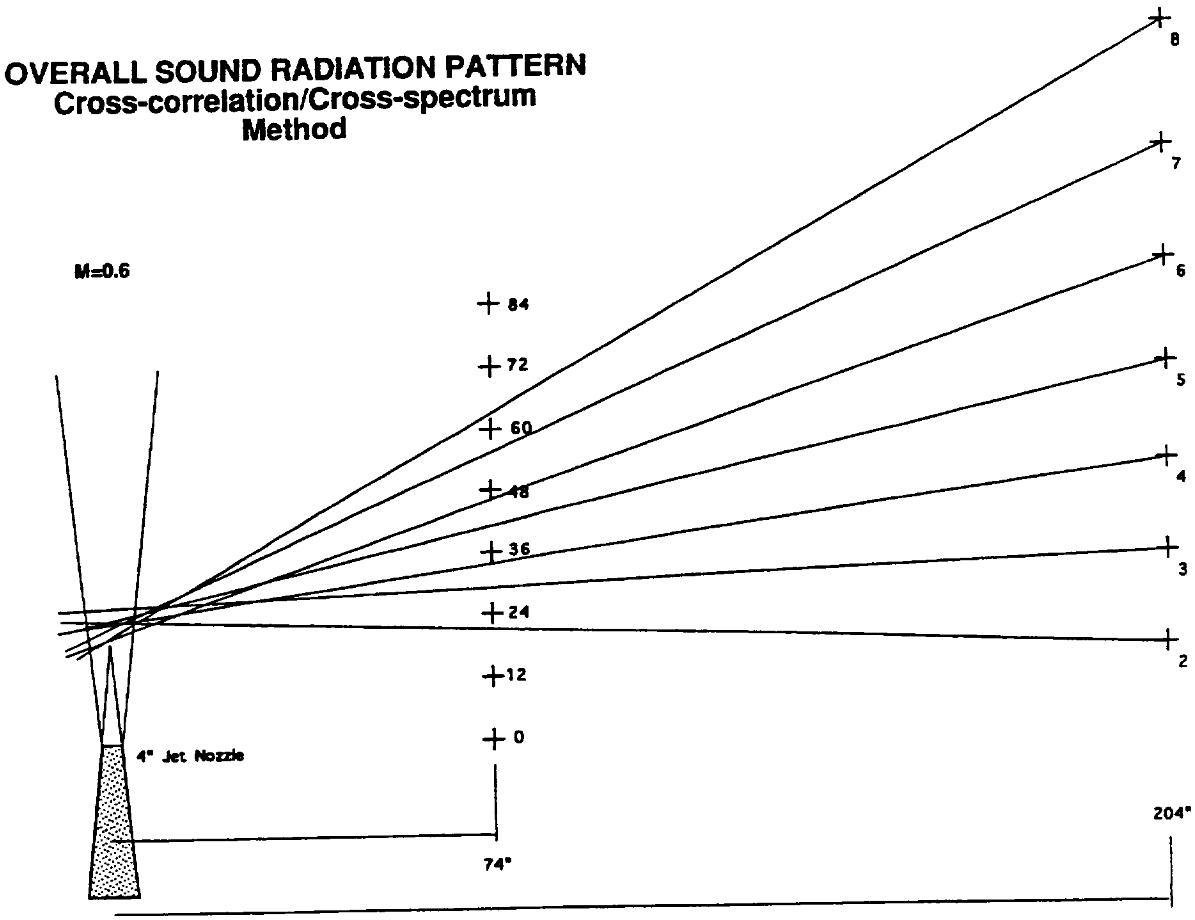
ONE RADIATION ANGLE
Cross-correlation/Cross-spectrum Method



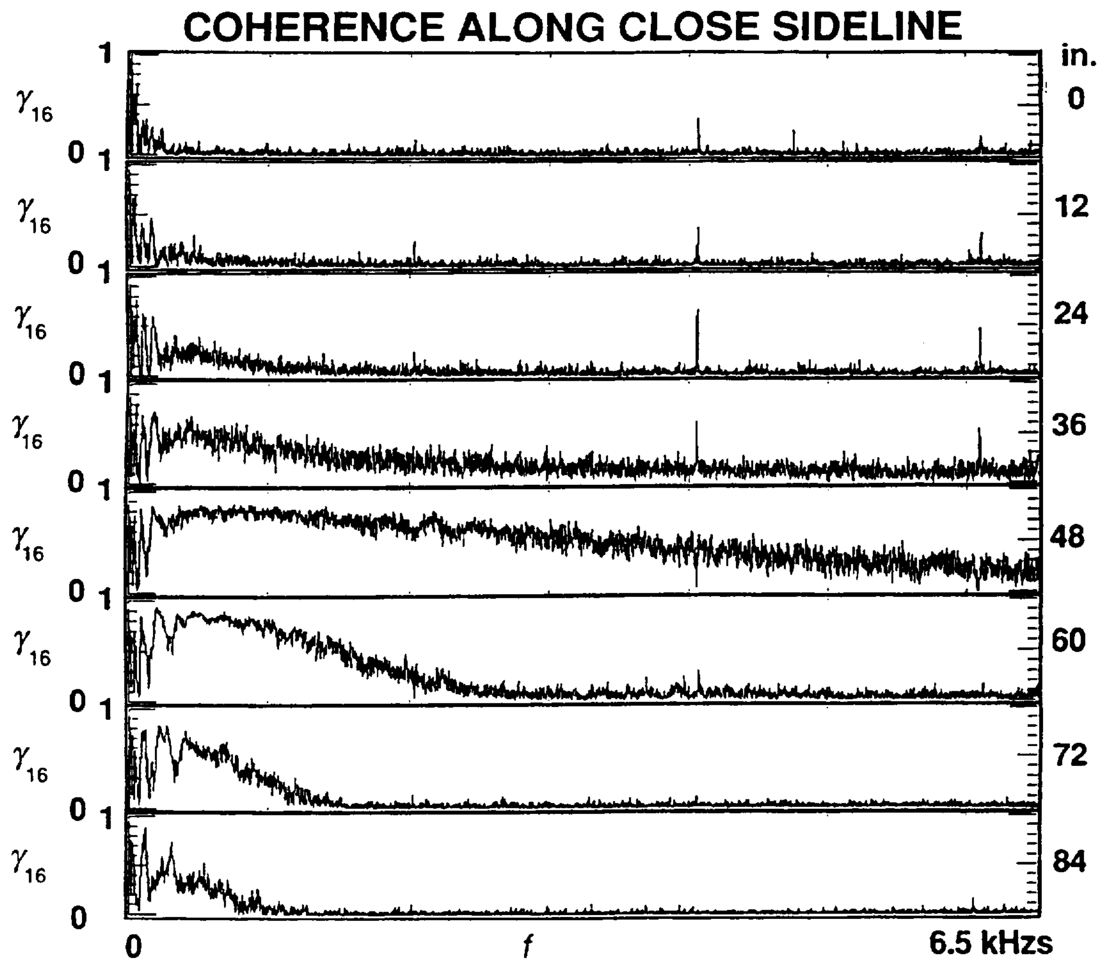
The radiation angle is drawn from the far sideline microphone position through the location of the maximum correlation coefficient given by the curve fit along the close sideline and extending through the jet plume. The intersection of the radiation line and the jet plume gives the approximate location of the centroid of sources radiating in the specified direction.



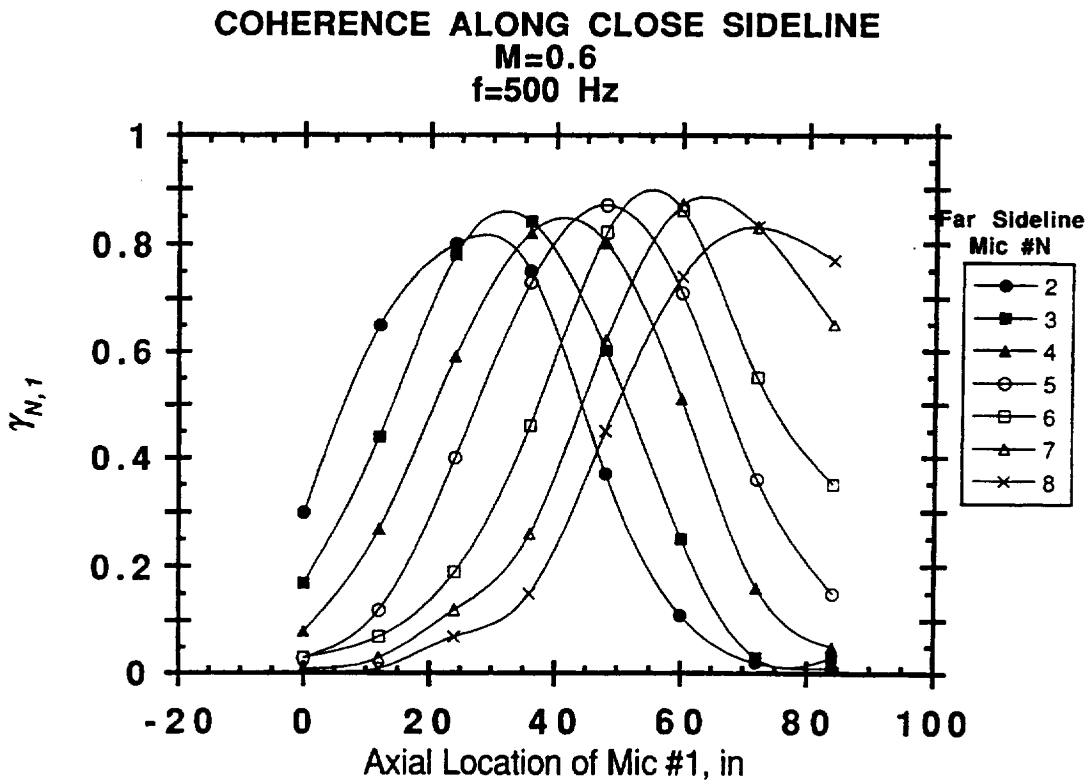
The maximum correlation coefficients for each far sideline microphone location are plotted against close sideline microphone location to determine the radiation angle for each far sideline microphone position.



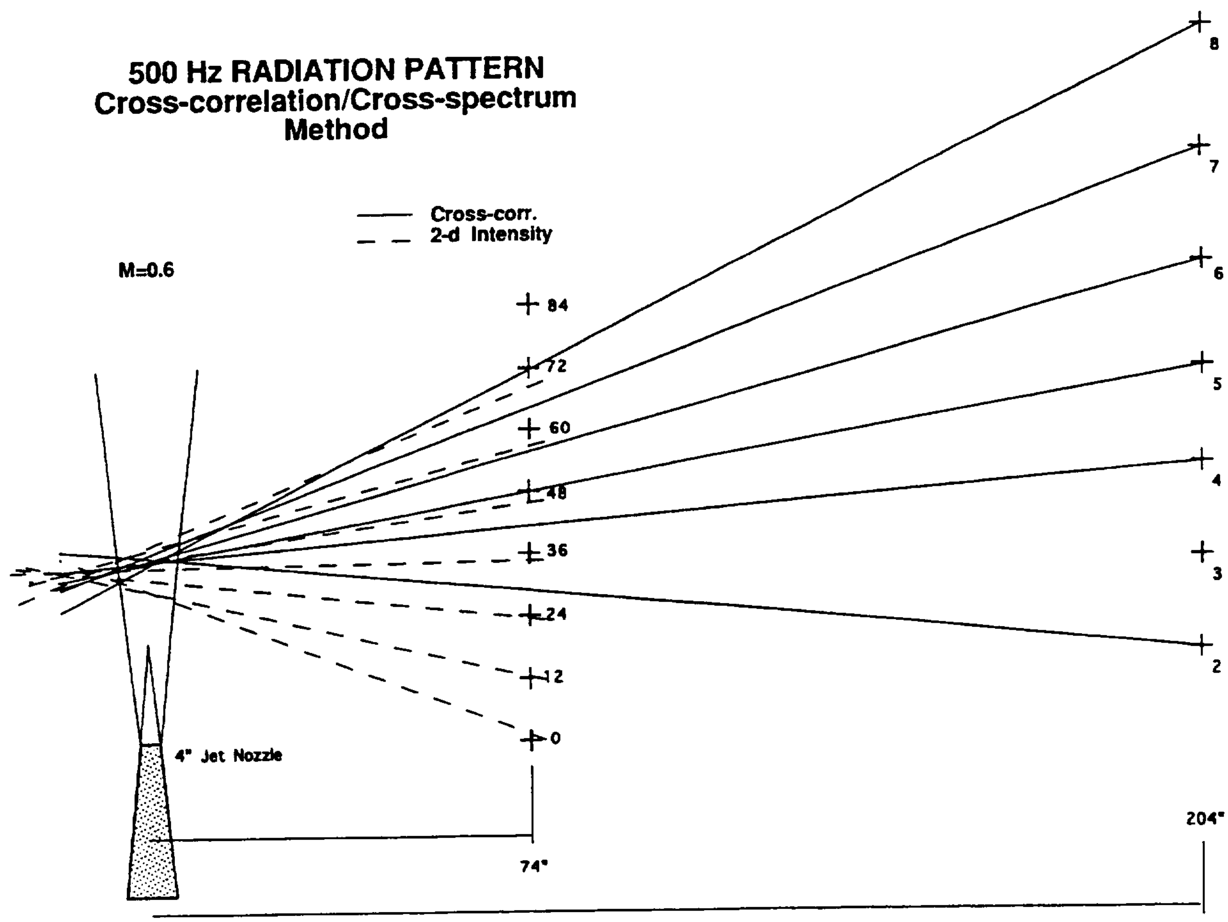
Drawing all of the radiation angles gives the radiation pattern of the jet plume for the given conditions. Note that since the correlation coefficient contains information over the entire frequency span, the resulting radiation pattern is valid for the overall noise only. To obtain frequency dependant radiation patterns, it is necessary to consider the coherence function of the different microphones.



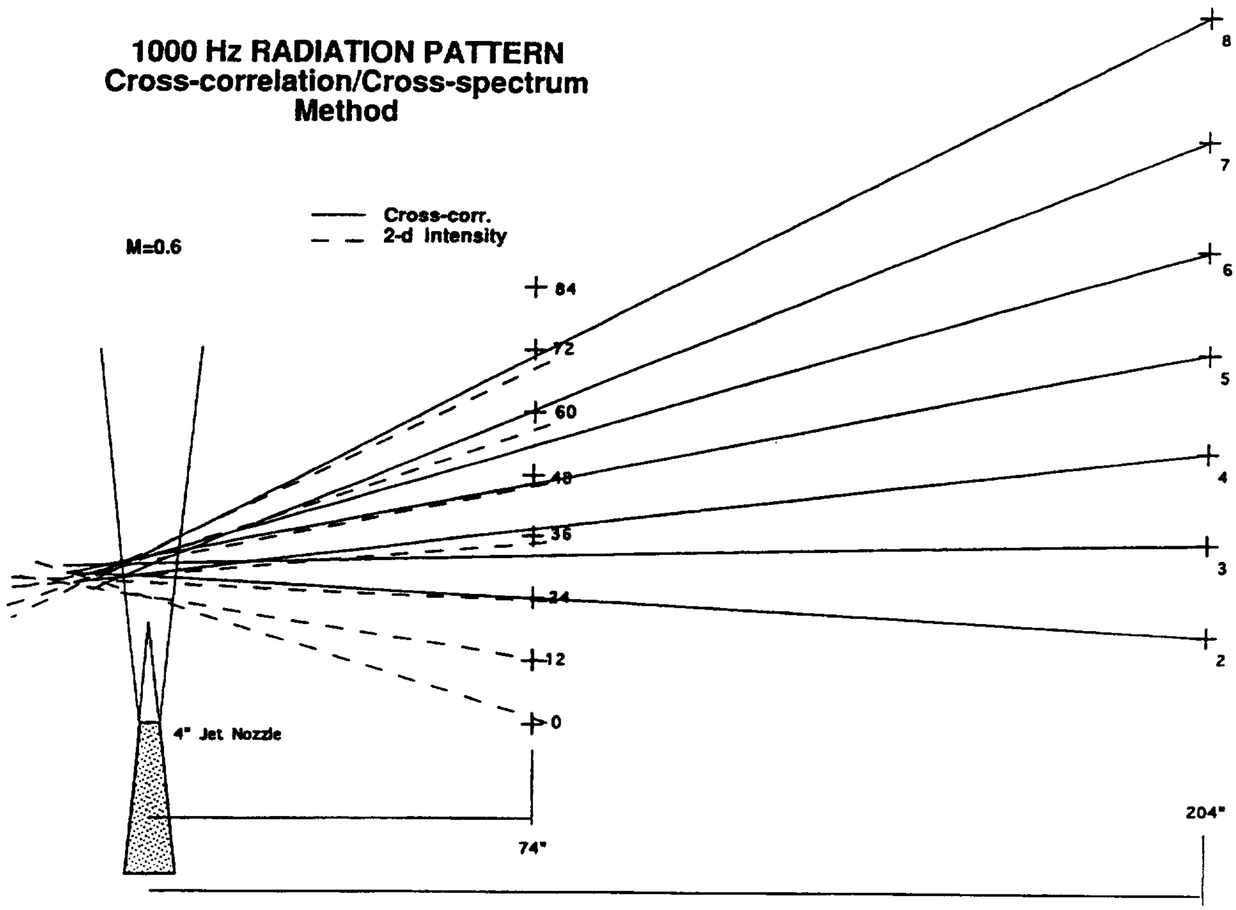
In the same manner as the correlation coefficients were obtained, the coherence is measured. These plots show the coherence of Mic. #6 with Mic. #1 at each of the close sideline locations. Again, this information is obtained for each far sideline microphone. To find the radiation angle as a function frequency, the coherence values of each graph at the desired frequency are plotted against the close sideline location.



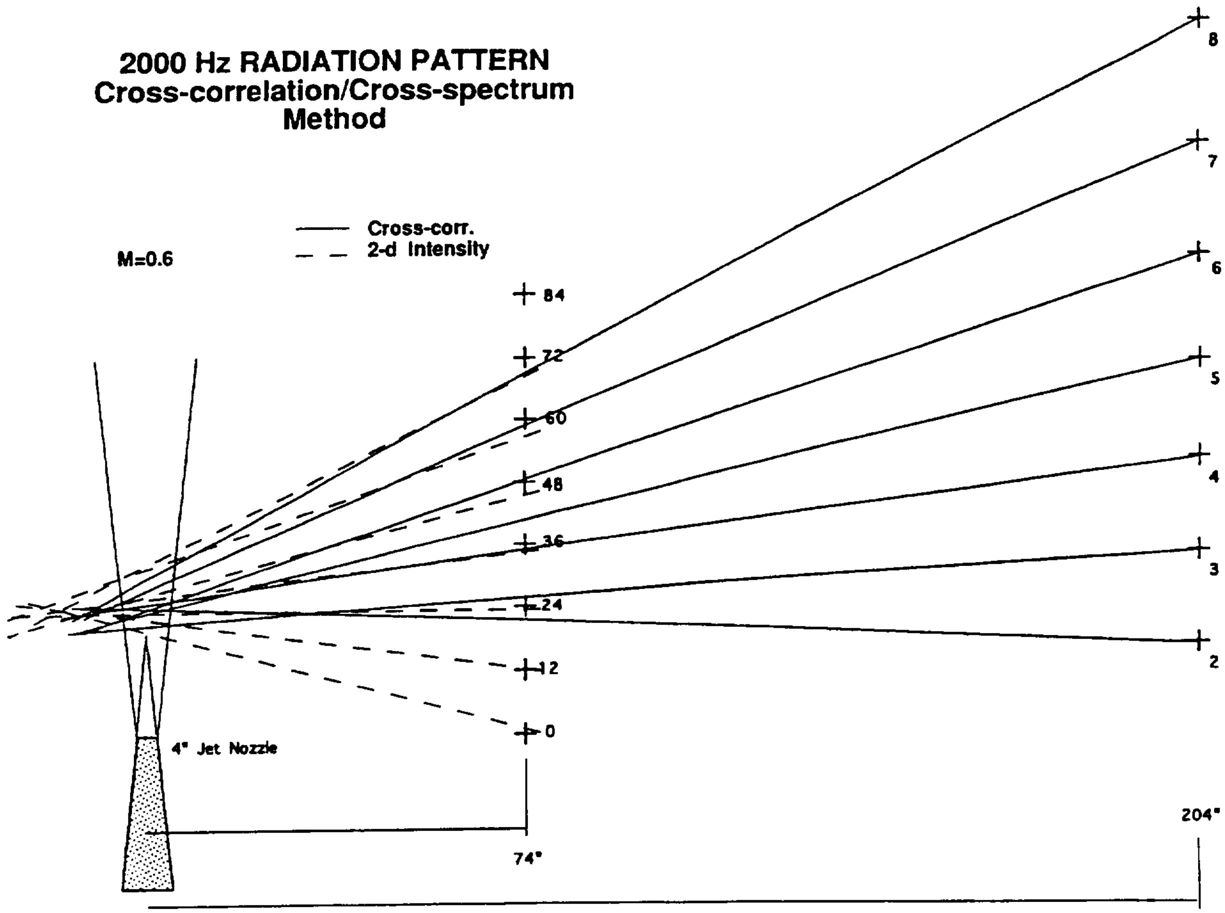
This plot shows how the maximum coherence value along the sideline is found. Again, the data were fit with a cubic spline to increase the accuracy of the determination. This plot is for a jet Mach number of 0.6 and a frequency of 500 Hz.



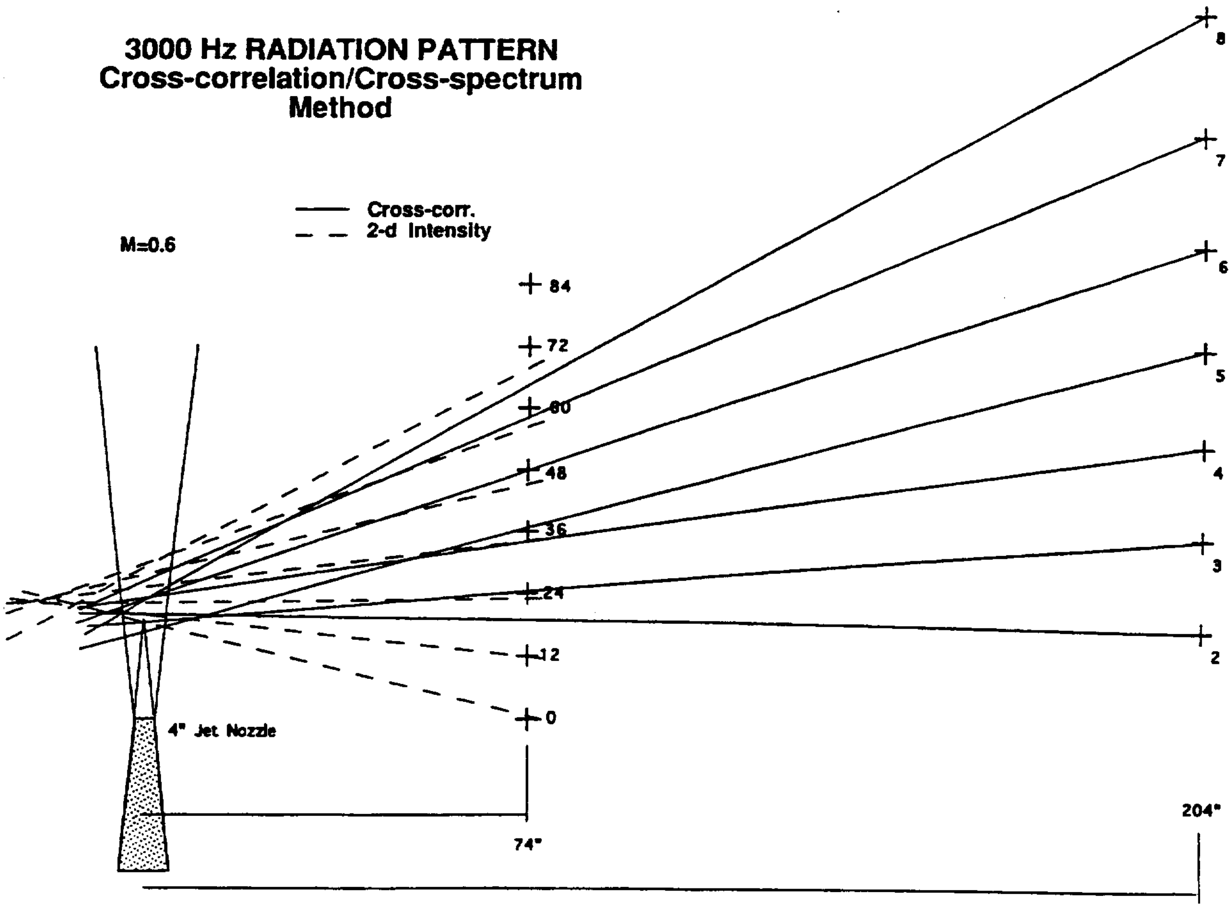
This figure shows the radiation pattern given by the method for a Mach number of 0.6 and a frequency of 500 Hz. Also shown in dashed lines is the radiation pattern found using the 2-d intensity technique for the same conditions and frequency. Note the good agreement between the two methods. The radiation angle for Mic. #3 was thrown out because it did not agree with the others.



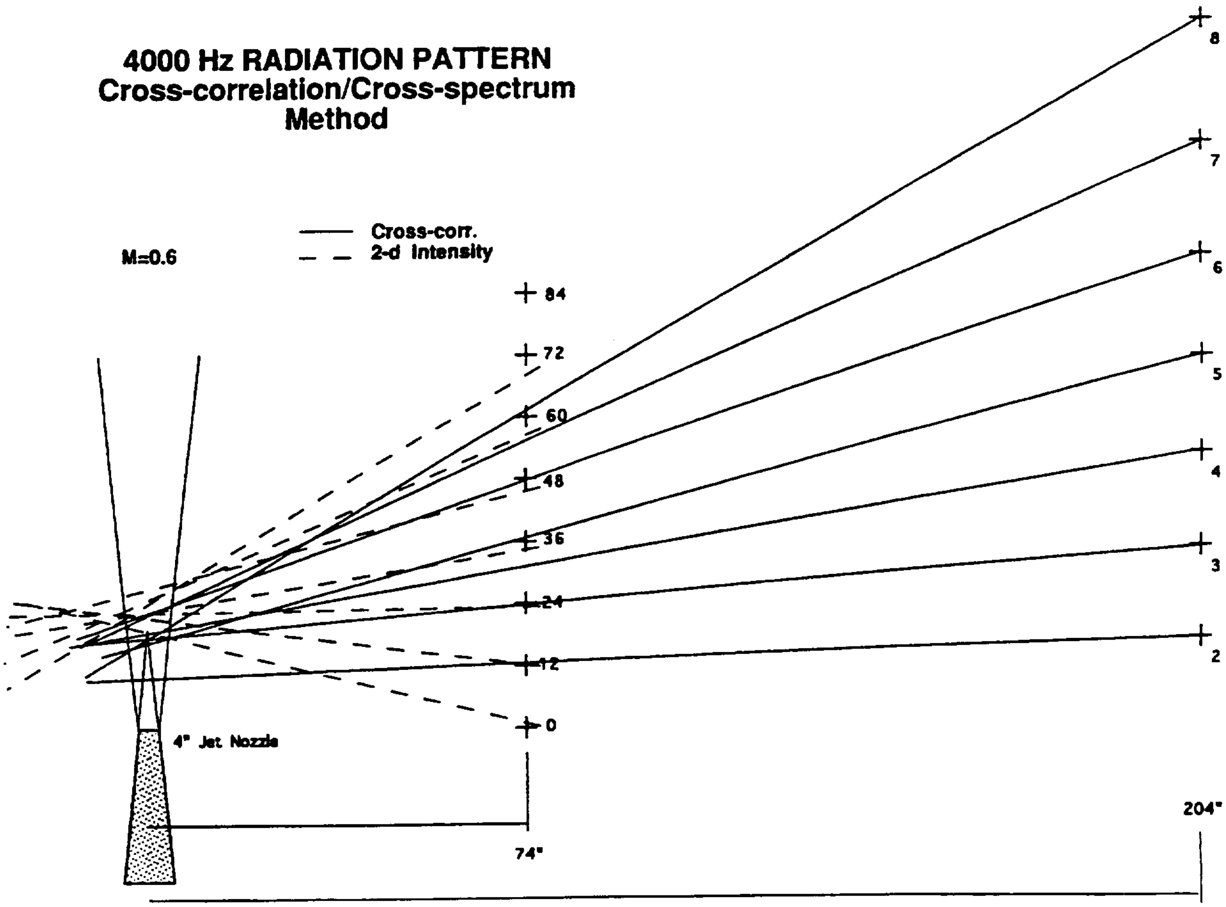
This figure shows the radiation pattern given by the method for a Mach number of 0.6 and a frequency of 1000 Hz. There is excellent agreement between the results using both the cross-correlation/spectrum technique and 2-d intensity techniques.



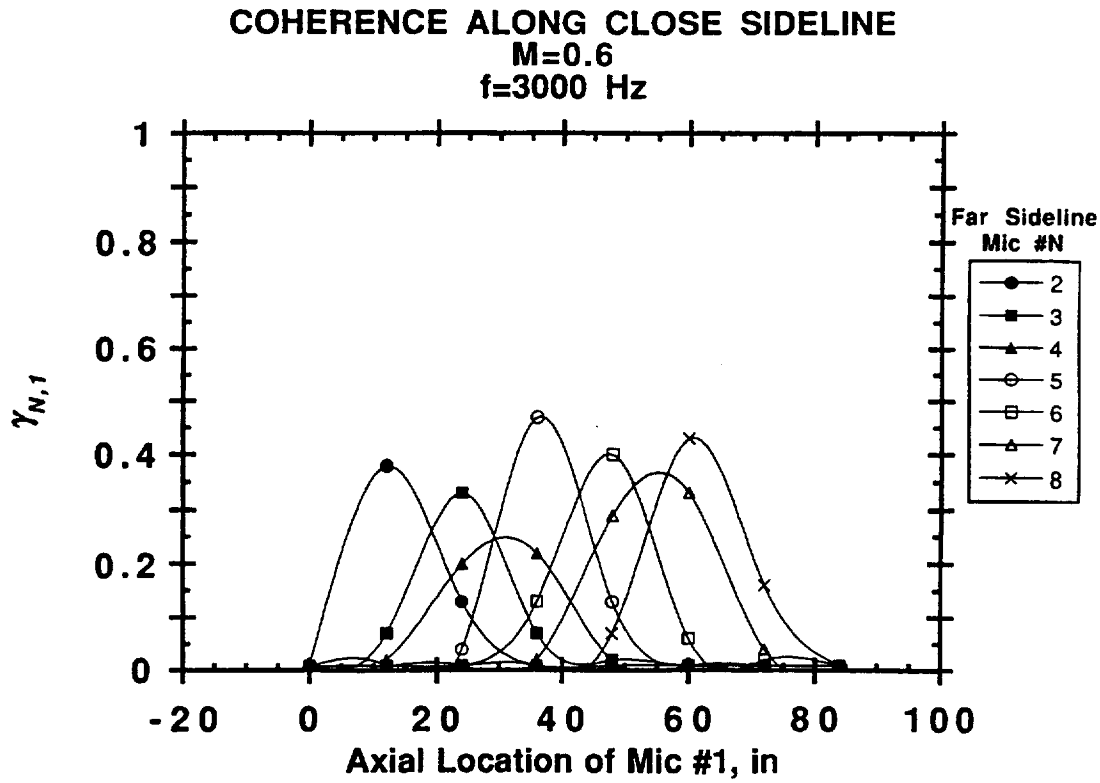
This figure shows the radiation pattern given by the method for a Mach number of 0.6 and a frequency of 2000 Hz. The agreement between the two methods is good but not quite as good as for the lower frequencies.



This figure shows the radiation pattern given by the method for a Mach number of 0.6 and a frequency of 3000 Hz. Again, the agreement is not as good as for the 500 and 1000 Hz cases but is still quite good.

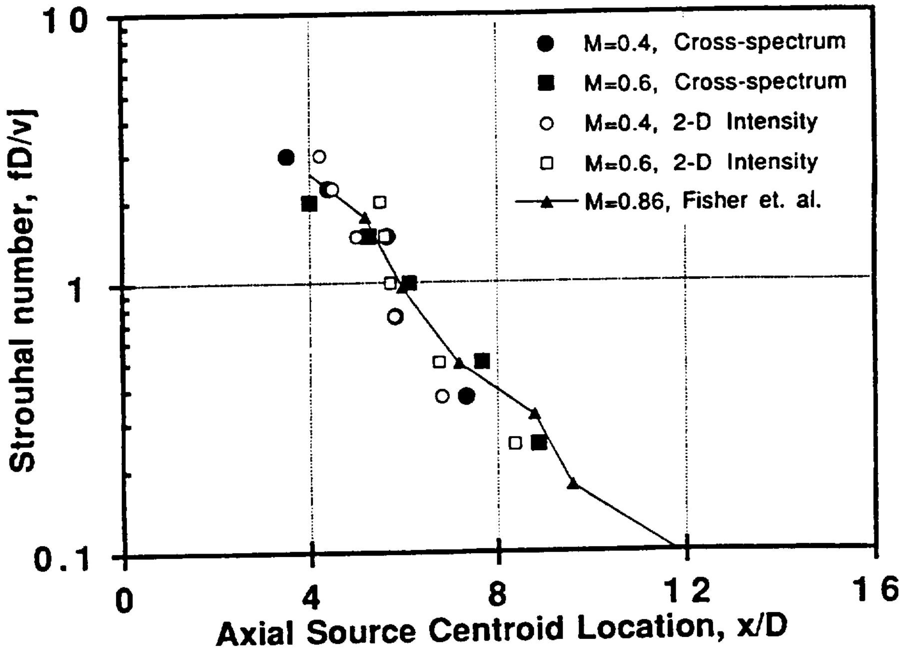


Finally, the radiation pattern given by the method for a Mach number of 0.6 and a frequency of 4000 Hz is shown. Except for a few radiation angles, the agreement between the two methods is very good and the location agreement on the source centroid location is excellent.



The inaccuracy of the higher frequency radiation angle results is due to the lower coherence values as shown in this plot. The lower coherence values decrease the number of points used in the curve fit thereby reducing the accuracy of the maximum coherence location prediction. This source of error can be overcome by increasing the spatial resolution along the close sideline so that more points may be used in the curve fit.

COMPARISON WITH PUBLISHED DATA

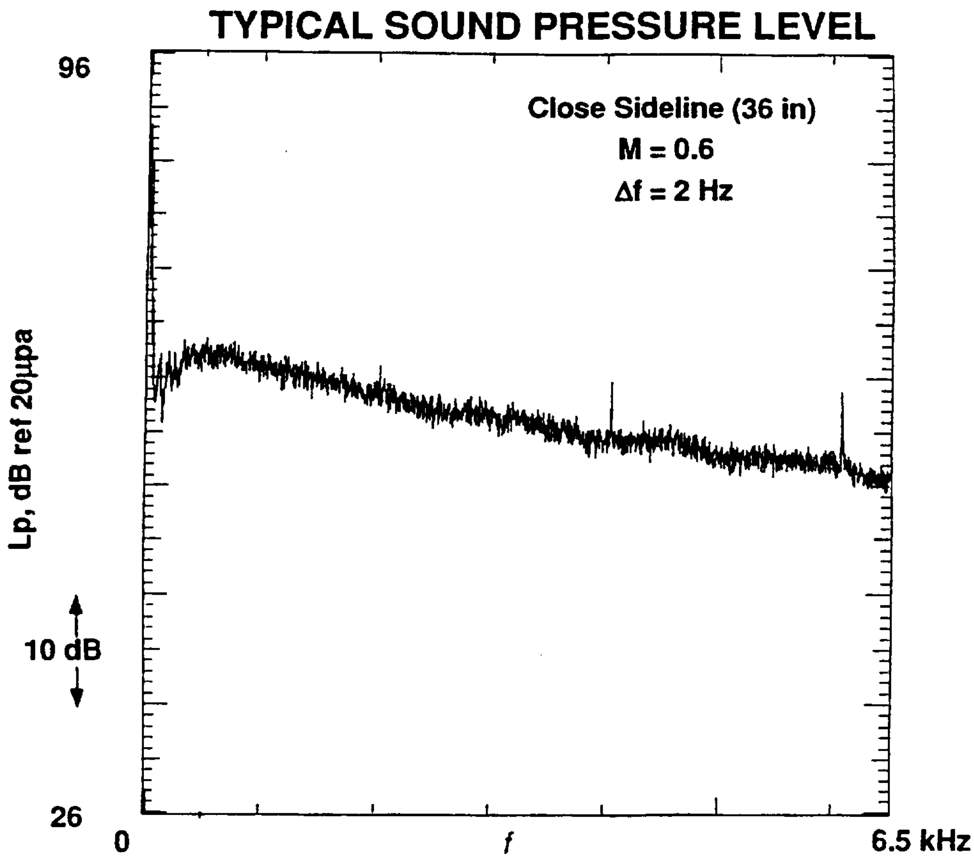


The variation of axial source location with Strouhal number is shown for the two different methods at two different Mach numbers. Also shown is the corresponding data gathered by Fisher et. al. using the polar correlation technique at a Mach number of 0.86. The agreement among the cross-correlation/spectrum technique, 2-d Intensity method and the polar correlation technique is excellent, validating the results of the former two methods.

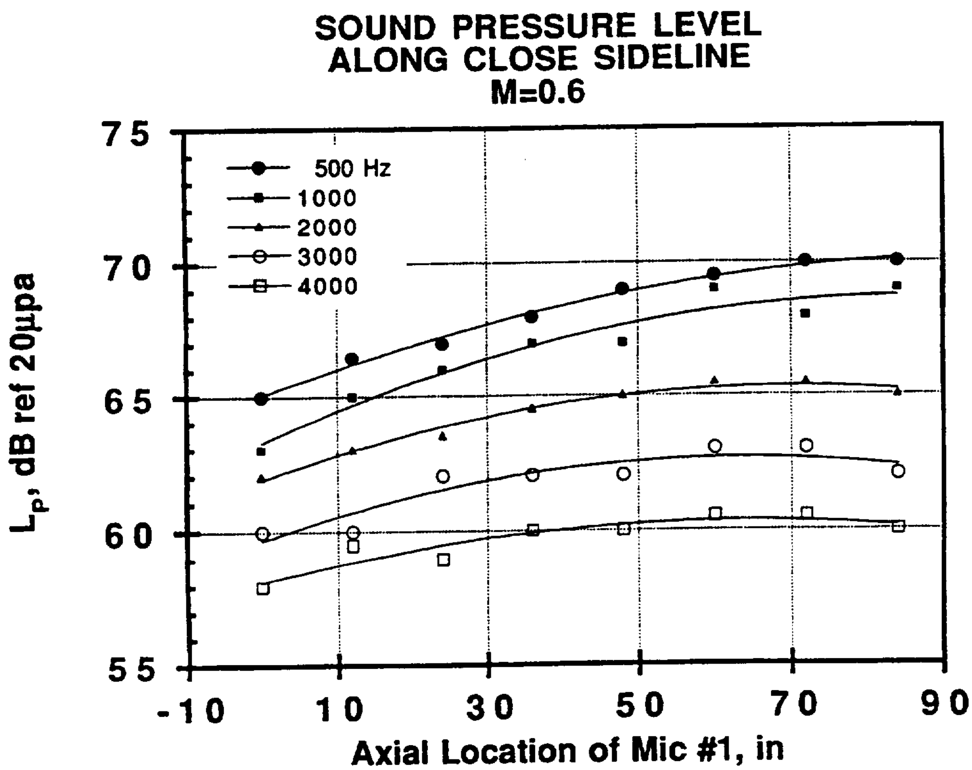
EXTRAPOLATION TO FAR FIELD

- Cross-correlation/spectrum Technique Gives
  - Source Location
  - Radiation Pattern
- Need Levels Measured at Sideline

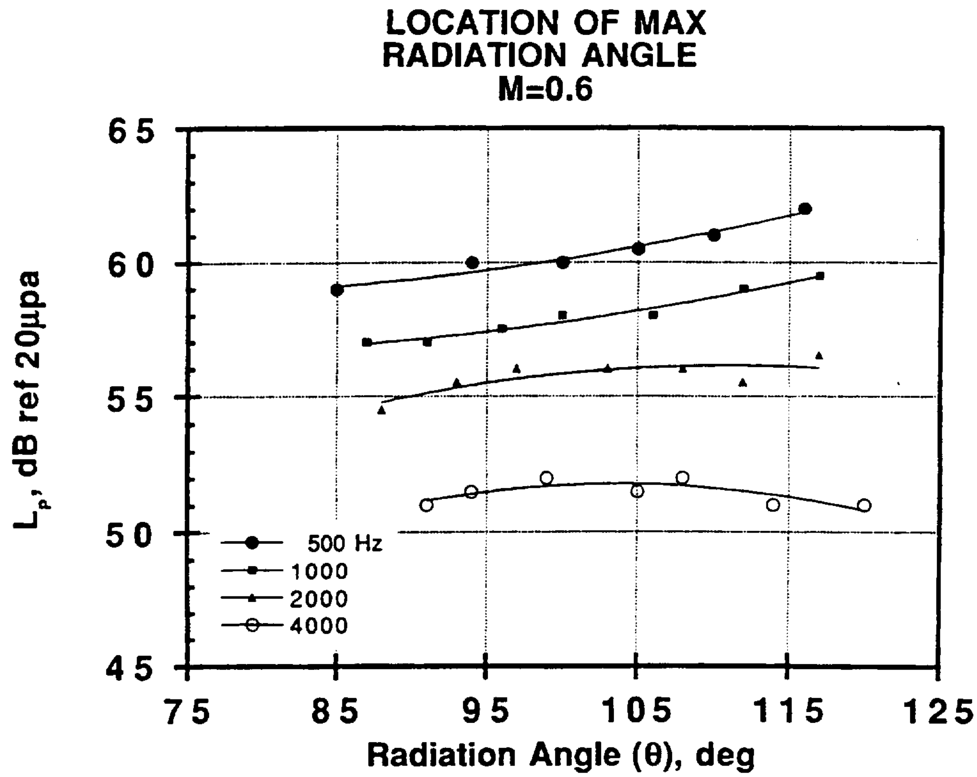
To extrapolate the results to far field, it is necessary to have a sound pressure level associated with each radiation angle. Combined with the source location,the extreme far field acoustics may then be determined.



Opposite are typical sound pressure levels as a function of frequency for a microphone from each sideline.



The sound pressure level variations along the close sideline are shown as a function of frequency. The data are fit with a polynomial curve to show the general trends. Note that as the frequency decreases, the location of the maximum sound pressure level moves downstream indicating a greater radiation angle or downstream shift of source centroid location.



The sound pressure level variations with radiation angle are shown as a function of frequency. Again the data are fit with curves to show the general trends. Notice that as the frequency decreases, the angle of maximum sound pressure level increases showing that the lower frequencies tend to radiate most of their energy further downstream than the higher frequencies.

IMPROVEMENTS / FUTURE WORK

- **Increase Spatial Resolution**
- **Time Delay and Phase Requires**
  - **- Phase Calibration**
  - **- Measurement of Ambient Temp**
- **Test in Flow**

Currently, the method shows encouraging results. A way to improve the results is to increase the spatial resolution along the sideline being varied.

Another way to perhaps improve the accuracy of the method is to use the time delays given by the cross-correlation measurements and to use the phase information contained in the cross-spectrum measurements. To obtain useful results from this information, however, would require phase calibrations between the correlated microphones as well as the measurement of the ambient temperature.

The next step in the development of this method is to test it in a moving acoustic medium.