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Quantifying Errors in Jet Noise Research Due to Microphone Support Reflection

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Quantifying Errors in Jet Noise Research Due to Microphone Support Reflection

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Abstract

The reflection coefficient of a microphone support structure used in jet noise testing is documented through tests performed in the anechoic AeroAcoustic Propulsion Laboratory. The tests involve the acquisition of acoustic data from a microphone mounted in the support structure while noise is generated from a known broadband source. The ratio of reflected signal amplitude to the original signal amplitude is determined by performing an auto-correlation function on the data. The documentation of the reflection coefficients is one component of the validation of jet noise data acquired using the given microphone support structure. Finally, two forms of acoustic material were applied to the microphone support structure to determine their effectiveness in reducing reflections which give rise to bias errors in the microphone measurements.

Introduction

Upon examination of fine structures of the sound pressure spectrum of a subsonic jet, Richarz [1] remarked that they were due in large part to the phenomenon of diffraction, or reflection from multiple surfaces in the jet noise facility. These fine structures appear as dips in the spectrum level as a result of acoustic wave reflections arriving out of phase with the incident waves, canceling a portion of the incident wave to be measured. While the corresponding mild fluctuations in spectrum level can be ignored by using a large bandwidth presentation (such as third octave spectrum), diffraction nonetheless results in a bias error, causing spurious increases in acoustic energy levels. For this reason, the amount of diffraction error that occurs as a result of a prominent feature of the jet noise testing facility, such as the microphone support structure, must be documented. In addition, the efficacy of two kinds of absorptive material applied to the microphone support structure was tested in an attempt to reduce resultant bias errors. In the present study, the diffraction effect is quantified in terms of the ratio of the relative magnitudes of the incident and reflected signals, or reflection coefficient, as determined by an autocorrelation function.

Experimental Facility and Test Setup

All tests were performed in the anechoic AeroAcoustic Propulsion Laboratory at NASA Glenn Research Center. A full description of the facility is given in [2]. The facility is rendered anechoic down to 200 Hz.

A schematic diagram of the test setup is shown in Figure 1. White noise from a Bruël & Kjær Type 1405 Noise Generator is passed to a Kenwood KR-5060 receiver to power a homemade cabinet speaker with 1" ribbon tweeter. The speaker produced relatively uniform sound at frequencies from 3kHz to 25kHz as shown in Figure 2. A 1/4" Bruël & Kjær model 4939 microphone with integrated 1/2" Bruël & Kjær model 2669L pre-amp, mounted in a microphone support structure located 19 feet (5.8m) away from the speaker, was used to gather data. A B&K NEXUS conditioning amplifier served as its power supply and signal conditioner. An Ono Sokki CF5220 spectrum analyzer was used to do time-domain calculations on the data gathered. All tests were performed with an ambient temperature of 85 °F (29.4 °C) and a corresponding speed of sound of 1144 ft/s (348m/s). Ambient temperatures were monitored over the coarse of the final data acquisition period and varied by less than 1 °F, resulting in variations of sound speed, and hence reflection time, of less than 1/2%.

The microphone support structure tested consisted of a 3/4" (19mm) OD tube 11.0 foot (3.35m) tall supporting a 4.0 foot (1.22m) long 3/4" OD crossbar which in turn supported 4 microphones on 1/2" (12.7mm) OD stingers. The microphone pre-amps were mounted in a plastic sleeve at the end of the tubes. The crossbar and microphone stinger assembly is shown in Figure 5. The microphone was located 2.00 feet (0.61m) from the crossbar. The four microphone stingers were 10 inches (254mm) apart.

Experimental Procedure

The effect of microphone reflection on microphone measurements was evaluated by applying a broadband sound field (see Figure 2) to the microphone and its supports and computing the autocorrelation of the microphone signal. Ideally, the autocorrelation would be a single spike at zero time delay, decaying rapidly, with separate spikes at later time delays corresponding to echoes of the initial signal reflected back to the microphone from reflective elements of the support. By taking into account the speed of sound and the time required for the sound to echo back to the microphone, the location of the reflective element could be determined. The reflection coefficient would be the ratio of the autocorrelation at this delay relative to its value at zero time delay. From the reflection coefficient, the amount of error in the jet noise measurement could be determined.

In practice the autocorrelation showed significant oscillations near the origin due to the off-white spectra of the incident sound field. These features in the autocorrelation could be confused with reflections. To determine which features were reflections and which were details of the signal autocorrelation itself, the microphone support was modified so that the reflective elements would change while the source autocorrelation remained constant. Hence, several control test were performed to pinpoint the microphone support structure elements which were the primary cause of reflection.

First, the measurements were made using a large reflective surface and the reflection was positively identified at the proper time delay in the autocorrelation. The test established the accuracy of the measurement method through comparison of the theoretical and observed reflection times. Next, the microphone support structure was tested as built, and the reflections determined by examining the autocorrelations at the proper delay times for the reflection. Finally, the microphone support was modified by adding sound absorbing material and noting the change in the autocorrelation at the expected time delay.

Results

The control case used the B&K white noise generator and a 40 x 30 inch (1.0 x 7.6m) piece of white foam-board as the reflective surface located 23.5 inches (600mm) behind the microphone (just in front of the crossbar) as shown in Figure 3. The auto-correlation computed by the Ono Sokki spectrum analyzer shows a reflected signal 3.41 milliseconds after the incident signal. This agrees well with the calculated reflection time of 3.42 milliseconds based on measurements of distance and air temperature. The agreement of the theoretical and observed numbers assures that the peak observed at a time coordinate of 3.41 corresponds to the appropriate reflective surface. The amplitude of the reflected signal was 0.275 relative to the original signal, yielding a reflection coefficient of 0.275 for the foam board.

With the control test complete, the microphone support structure that is the subject of this study was tested. The criticality of the control case becomes evident when one considers the data for the microphone support structure alone. As shown in Figure 6, the reflection is very small, and it was important to validate that the computed time-delay is correct. The basic microphone support structure demonstrated a reflection from the crossbar and pole at a time delay of 3.58 milliseconds. This shows fair agreement with the theoretical reflection time of 3.49 milliseconds. The amplitude of the reflected signal was 0.0337.

In an attempt to further reduce the magnitude of the diffraction effect in the laboratory setup, two types of acoustic absorptive wrapping were subsequently tested. The first type of wrapping used was a simple, smooth surfaced open-cell polyurethane foam cylinder applied to the crossbar of the microphone holder (see Figure 7). The foam cylinder, while having a more absorptive surface than the bare metal tubing, also had significantly greater surface area for reflection. The reflection from the foam cylinder occurred at a reflection time of 3.73 milliseconds (see Figure 8), while the theoretical reflection time was 3.35 milliseconds. The amplitude of the reflected signal was 0.0305, a slight reduction from the bare microphone case.

The second acoustic absorptive material used was an egg crate foam panel material, also applied to the crossbar as shown in Figure 9. Again, this provided an absorptive surface and a larger reflective surface; however, this treatment having an uneven surface provided better attenuation of the reflected sound than the smooth surface foam. The egg crate treatment demonstrated an amplitude of reflection of 0.0118, significantly lower than that of the smooth-surface cylindrical wrapping. The reflected signal is observed at a time coordinate of 3.55 milliseconds, while the theoretical reflection time was 3.28 milliseconds.

Discussion

For the purpose of comparison, the error (in dB) in jet noise measurements that would result from reflection was calculated (see Table 1) for each of the four test cases using the formula

$$error = 10\log\left(\frac{(reflection + incident)^2}{(incident)^2}\right).$$

For the control case involving the board, the resultant error was 2.11 dB. The basic microphone support structure had a resultant error of 0.288 dB. This error level, while acceptable, is still higher than would be liked for a bias error. This error level was decreased slightly to 0.261 dB by using the smooth cylinder foam wrapping. It is likely that the large surface area of the smooth cylinder foam wrapping counteracted the effects of its absorptive surface. When using the egg crate foam wrapping, with its undulating surface, however, the error as a result of microphone support structure reflection was reduced significantly to 0.102 dB. This low level of error is more easily tolerated than that of the bare microphone support structure alone.

Test Scenario	Resultant Error Level (dB)
Board used as reflective surface	2.11
Microphone support alone	0.288
Microphone support with foam wrapping	0.261
Microphone support with egg crate wrapping	0.102

Table 1. Resultant error levels in jet-noise measurements for the four test scenarios used.

Conclusions

In this work, the reflection coefficient and the resultant jet-noise measurement error was documented for a microphone support structure design that is to be used in the AeroAcoustic Propulsion Laboratory at NASA Glenn Research Center. These measurements are of interest in determining the quality of data that can be obtained in the facility. The reflection coefficient (0.0337) and corresponding error level (0.288 dB) found for the new microphone support structure are satisfactory in that they are low enough to allow the usage of the microphones without concerns of data quality. Based upon the significant decrease in resultant error (error was reduced to 0.102 dB) observed when the structure was wrapped with egg crate acoustic material, however, it is advisable that such wrapping be utilized in jet-noise testing facilities as a means of ensuring data quality.

References

1 Richarz, W.G., "Fine Structure of Subsonic Jet Noise," AIAA Technical Notes, Vol. 24, No. 5, 1986, pp. 849–850.

2 Castner, R.S., 1994, "The Nozzle Acoustic Test Rig: An Acoustic and Aerodynamic Free-Jet Facility," *NASA TM–106495.*

Figures

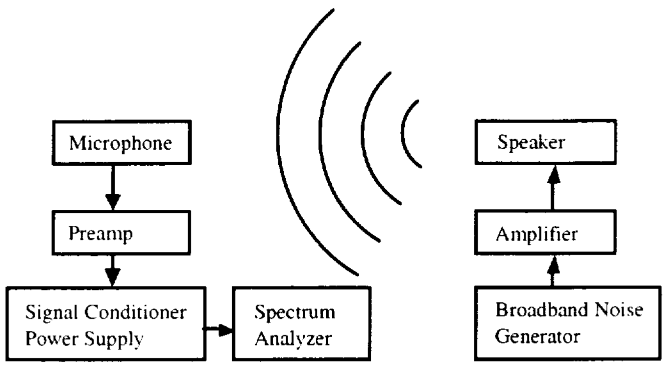

Figure 1. Schematic of experimental setup.

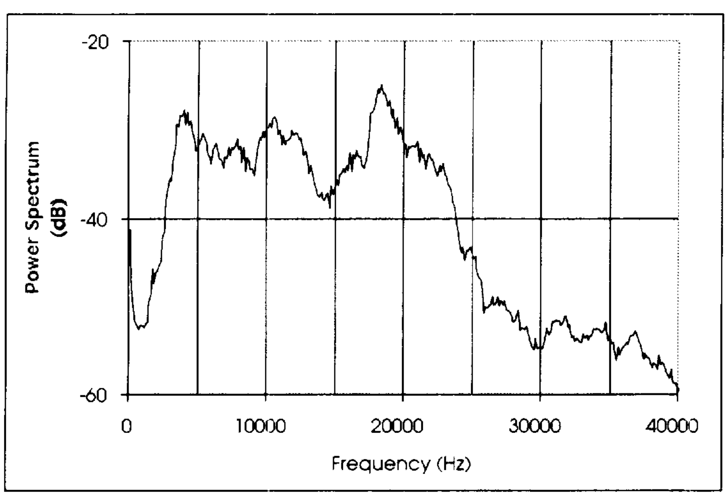

Figure 2. Sound spectra of source used in study. Units are dB relative to arbitrary reference.

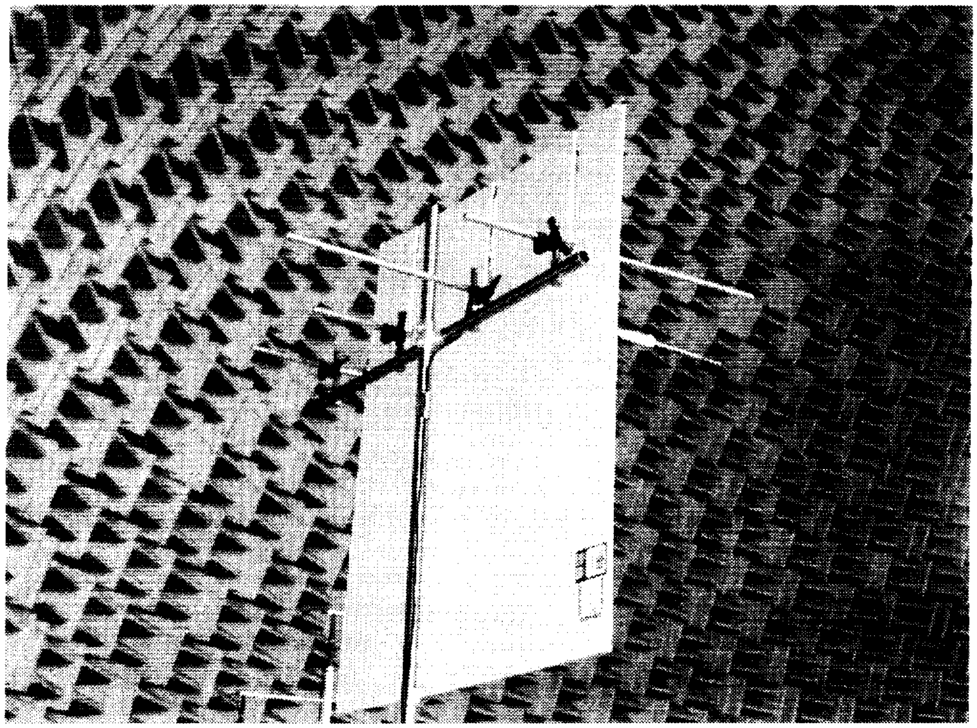

Figure 3. Microphone support structure with reflective plate used as a control case.

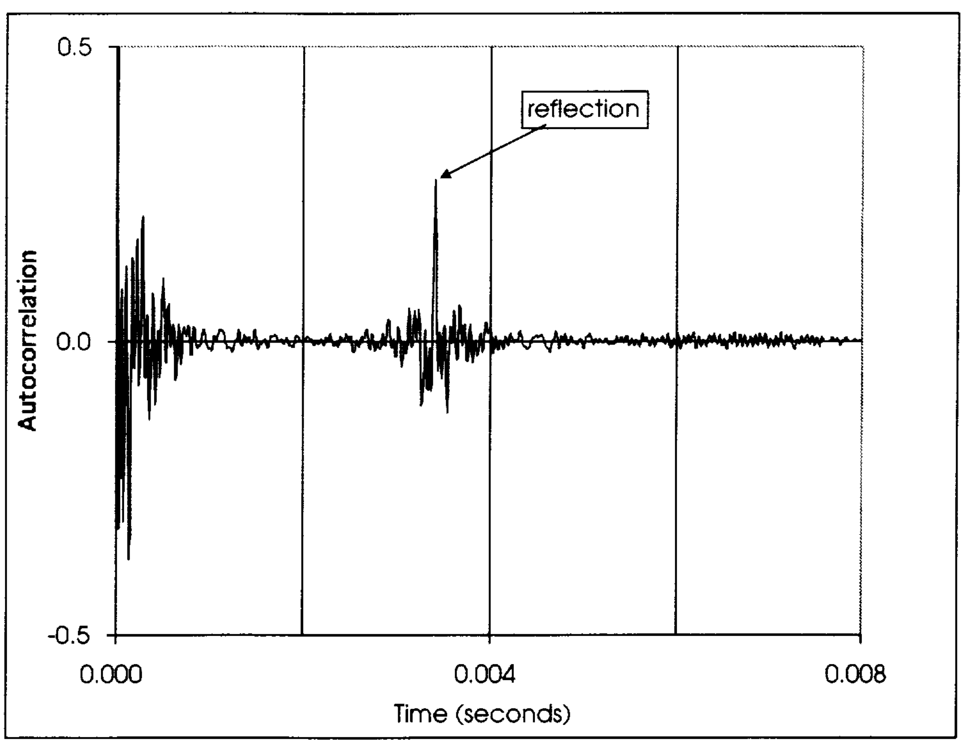

Figure 4. Autocorrelation of microphone signal showing reflection from foam board used as control case.

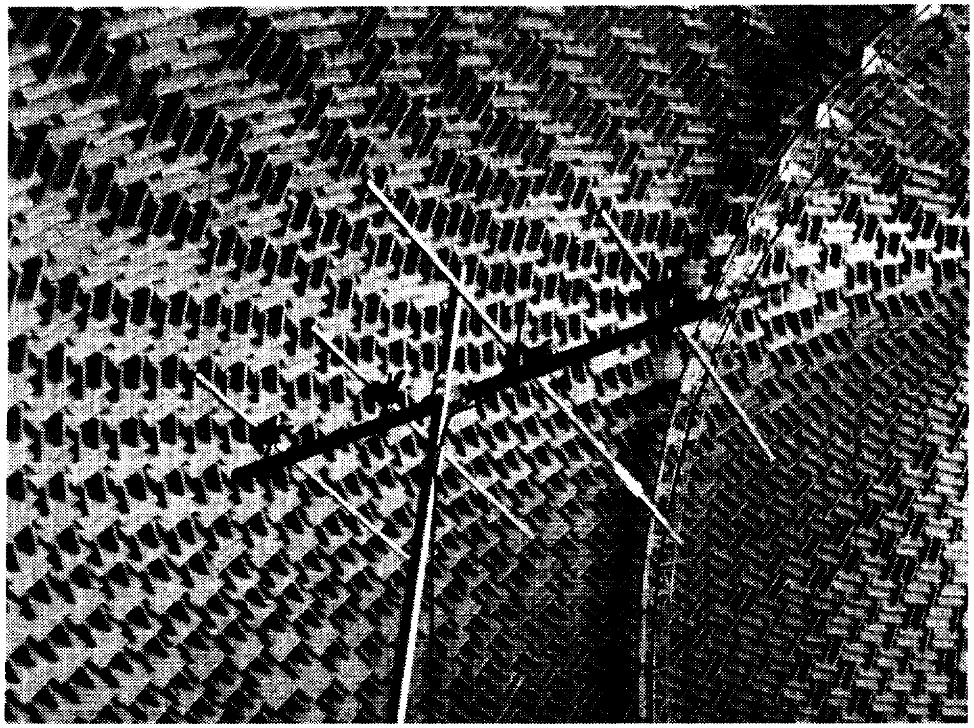

Figure 5. Basic microphone support structure atop 10' pole.

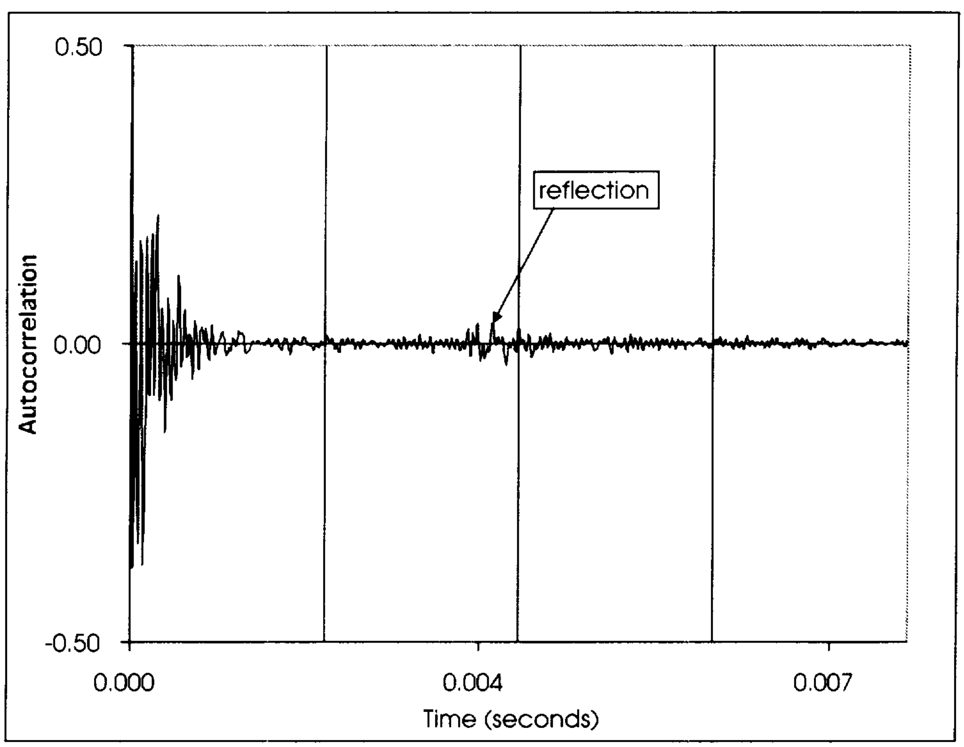

Figure 6. Auto-correlation showing reflection from basic microphone support structure.

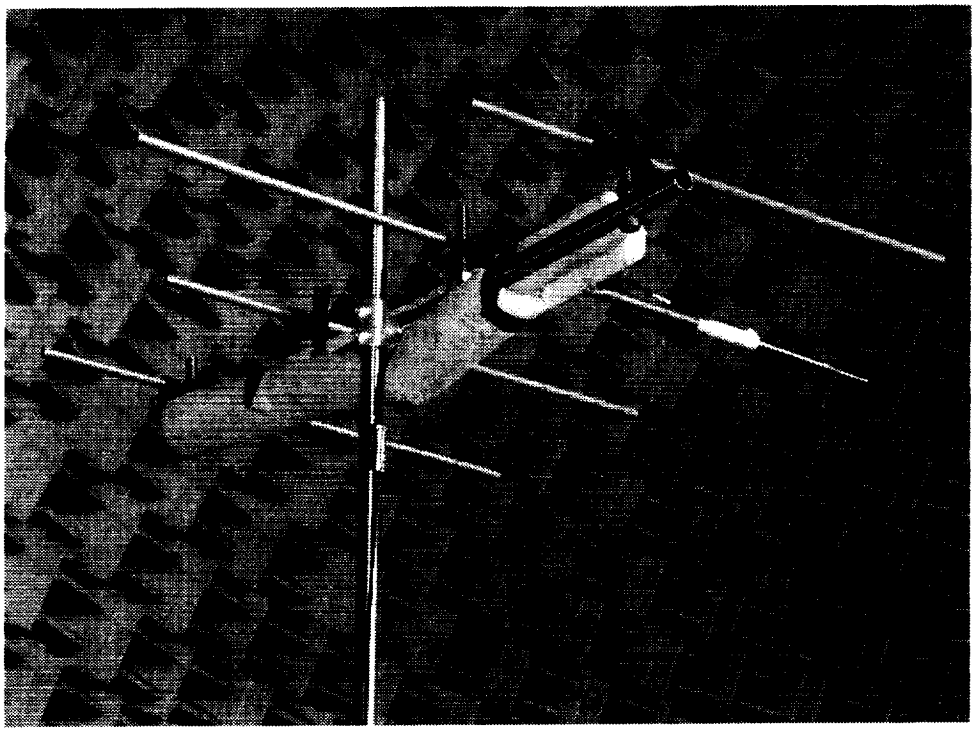

Figure 7. Smooth foam cylinder applied to crossbar for reflection reduction.

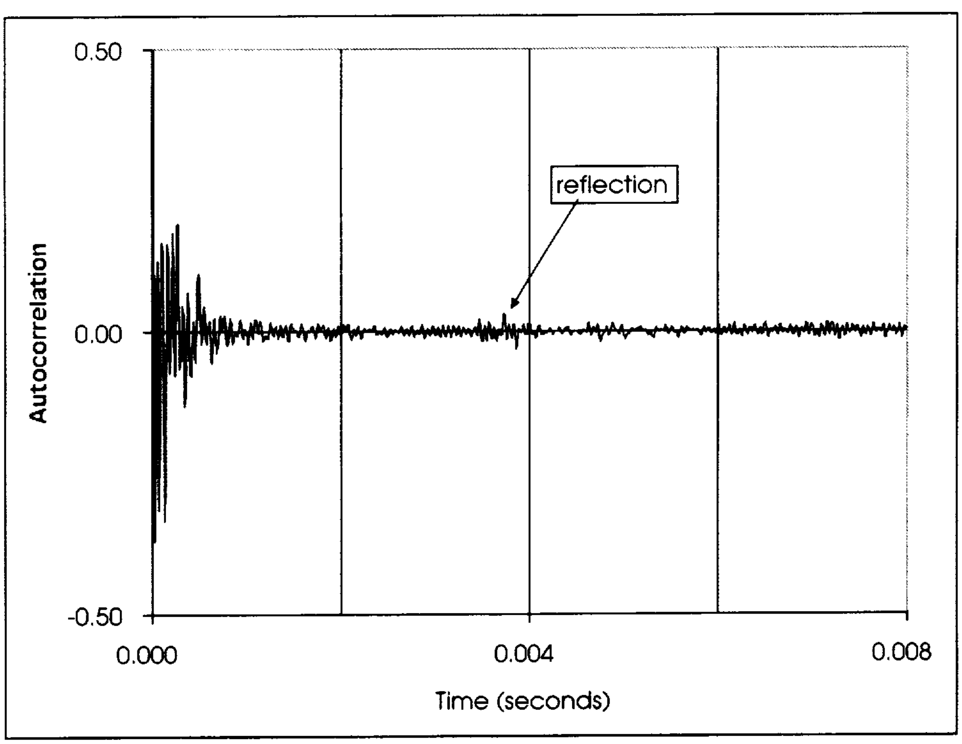

Figure 8. Autocorrelation showing reflection from smooth cylindrical foam wrapping on microphone support structure.

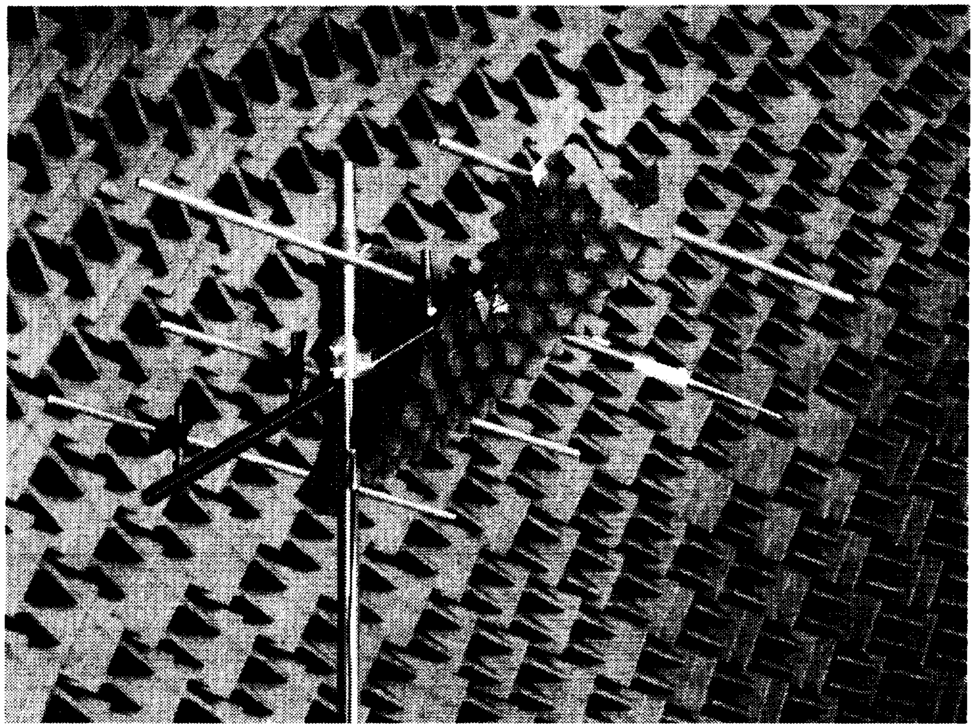

Figure 9. Egg crate acoustic foam treatment applied to microphone support structure.

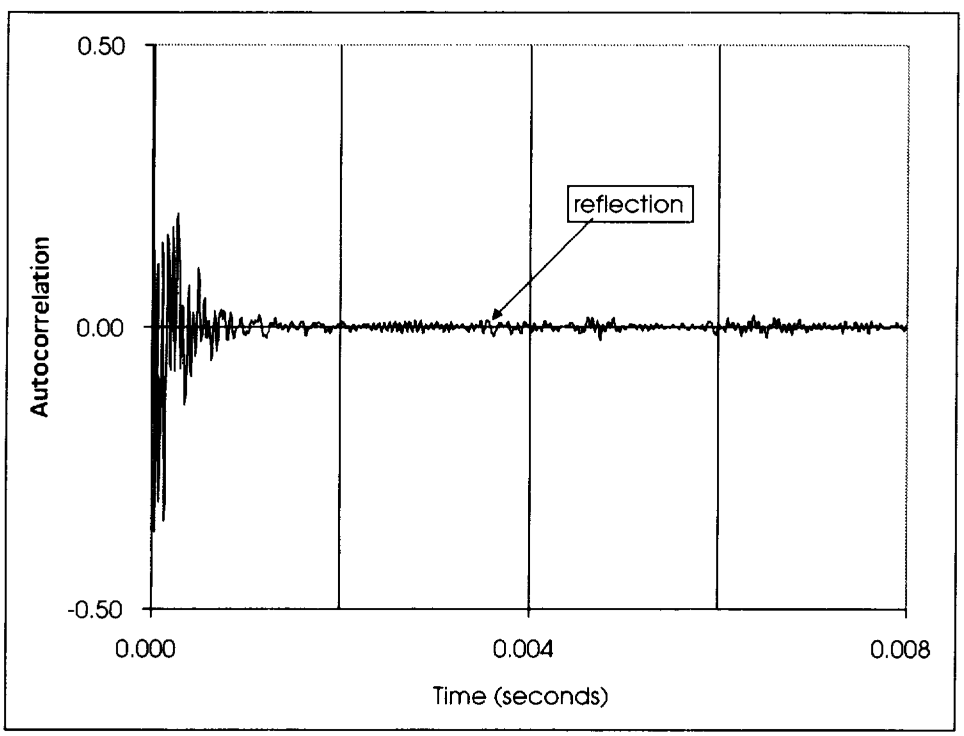

Figure 10. Autocorrelation showing reflection from egg crate wrapping on microphone support structure.

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13. ABSTRACT *(Maximum 200 words)*

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