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Characteristics of Residual Mixing Noise From Internal Fan/Core Mixers

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CHARACTERISTICS OF RESIDUAL MIXING NOISE FROM INTERNAL FAN/CORE MIXERS

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SUMMARY

The jet mixing noise from two fan/core mixer nozzles is studied. Acoustic data from two fan/core mixer nozzles are analyzed to determine the properties of the noise signatures. It was assumed that there were three major contributors to the total noise signature: noise from mixing of the fan and core streams internal to the nozzle; noise from residual mixing of the fan and core streams external to the nozzle; and the noise associated with the fully mixed jet. In general. the low frequency portion of the noise spectra can be associated with the fully mixed jet and can be predicted using an empirical correlation for single round nozzle jet noise. The properties of the noise in excess of the fully mixed levels are studied.

INTRODUCTION

Increased concern regarding aircraft noise has increased noise reduction research and has led to consideration of new concepts for noise reduction. In particular, research on jet noise reduction has led to a variety of concepts to reduce peak exhaust velocities. Such concepts include mixing of the fan and core streams and mixing of engine exhaust with ambient air through the use of ejectors. For both concepts, the noise signature is significantly more complex than that of simple nozzles. In particular, the noise signature of these nozzles may include the noise due to internal mixing as well as noise due to exhaust profiles that are nonuniform with significant turbulence levels. Proper modeling of the noise signatures of these noise reduction concepts must include the effects of these additional noise sources.

As part of the Noise Reduction element of the NASA Advanced Subsonic Technology program, tests were conducted to investigate the use of fan/core mixers to reduce jet noise from turbofan engines. By mixing the fan and core streams within the exhaust nozzle, the peak exhaust velocity is reduced to that of the mixed velocity, thus potentially reducing the jet noise. Complete mixing should result in noise levels due to the fully mixed external jet plus any noise due to the internal mixing process. However, due to length and weight constraints, mixer nozzle geometries that result in complete mixing may not be practical. Hence, noise due to residual mixing of the fan and core streams external to the nozzle is a potential source of additional noise. Tests of several internal fan/core mixers were conducted at the NASA Lewis Research Center's Aeroacoustic Propulsion Laboratory (APL). These tests were conducted in support of a contract with Pratt & Whitney to develop an improved mixer for the JT8D turbofan engine. The potential impact of an improved mixer nozzle on the jet noise of the JT8D turbofan engine was judged to be of the order of 3 EPNdB by Montuori and Saiyed (1995). Aerodynamic (including detailed flow surveys) and acoustic data were obtained during the tests. Analysis of the data from these tests has identified the contribution of noise sources in excess of that due to the fully mixed jet. Saiyed et al. (1996) concluded that this excess noise was attributed to the residual mixing of the fan and core streams external to the nozzle. His conclusion was based on the dependence of this source on the simulated flight velocity. The more detailed analysis in this report confirms the conclusion of Saiyed.

In this paper a more complete analysis of this data is presented. Jet noise for the fully mixed jet is predicted and subtracted from the measured total noise. The characteristics of this residual noise are studied. Variation of spectral shape, directivity and level with flow conditions are presented.

DATA BASE

In this section a brief summary of the experiment to obtain the acoustic data being analyzed in this report is presented. More detailed descriptions of the tests are provided in Saiyed (1996).

Tests of several fan/core mixer geometries were conducted at the NASA Lewis Aeroacoustic Propulsion Laboratory (APL). A photograph and a schematic of this facility are shown in figure 1. In this facility a free jet is used to provide a simulated flight environment for nozzles to be tested. The free jet is a 53 in. round duct capable of providing air at Mach numbers up to 0.3. A contraction, with a 7° contraction angle, was used to reduce the boundary layer thickness on the model. The contraction reduced the duct diameter to 40 in. Acoustic measurements are made on a radius of 48 ft from the test nozzle. Microphones are placed at 5° intervals from 50 to 150° from the inlet. The microphones were at the height of the nozzle centerline which was 10 ft above the floor. Wedges on the facility walls and floor provide an anechoic environment for the acoustic measurements. The air supply to the test nozzle is provided by means of a Jet Exit Rig (JER) which can provide two streams of pressurized air; one to simulate the fan flow and the other to simulate the hot core flow. A schematic of the JER is shown in figure 2(a). A photograph of a model installed in the free jet is shown in figure 2(b). Details of the facility are provided by Cooper (1993) and Castner (1994).

Figure 3(a) shows a perspective view of the 12 lobe mixer nozzle. Heated core air is mixed with ambient temperature bypass air within the nozzle and the mixing process is enhanced by the use of lobed mixers. Data from two mixer geometries, a 12 lobed mixer and a 20 lobed mixer, which produced significantly different levels of mixedness at the nozzle exit were analyzed. Views of these mixers are shown in figures 3(b) and (c). Data were obtained over a range of conditions simulating an engine cycle operating line. For this data set, however, the fan stream temperature was ambient. Simulated flight Mach numbers ranged from 0 to 0.27.

DATA ANALYSIS

The data are analyzed by assuming that the noise signature can be described in terms of three noise sources; internal mixing noise, external residual mixing noise, and fully mixed jet noise. The internal mixing noise is due to the mixing of the fan and core streams internal to the nozzle. Thus it is expected that forward flight would have no effect on the strength of this source, although dynamic amplification effects should still exist. In contrast, the residual mixing noise could be expected to be affected by the free jet velocity, even at 90° where dynamic amplification and convection effects are zero. The fully mixed jet noise is expected to behave in a manner similar to that of a simple round jet of uniform velocity and temperature. Estimates for the fully mixed jet noise were made using the jet noise prediction method of Stone et al. (1981). This report contains a single jet prediction method which the author claims to contain slight improvements of his method published in 1980. The prediction is made using a jet velocity based on the measured total flow and exit nozzle area. It was assumed that the mixed jet Mach number was subsonic, and thus the static pressure was that of the ambient conditions. Mass averaged total temperature was calculated using measured flow rates and total temperatures of the two streams. Although the method of Stone did a reasonably good job of predicting the data in regions where the fully mixed jet noise was expected to dominate, some small discrepancies did exist. Review of Stone's reports indicate that the magnitude of the discrepancies are similar to those found for data sets reported by Stone. This is not unexpected since the methodology was derived to represent a large number of data sets while not necessarily matching each set exactly. Rather than ignore these discrepancies, adjustments were made to the fully mixed predictions to better match the data. The magnitude of the adjustment consisted of a shift in frequency of one to two one-third octaves. The nature of the adjustment was based on the subjective judgment of the author. These adjusted predictions were then subtracted from the total measured noise. The difference represents the sum of the other two possible sources; internal mixing noise and external residual mixing noise. Failure to adjust the fully mixed levels would have resulted in errors in the assessment of the levels of the other sources. An example of predicted and adjusted prediction as compared with data is shown in figure 4. A typical set of plots for a given nozzle geometry and test condition is shown in figure 5. For each plot, measured levels, predicted fully mixed levels and calculated excess noise are shown.

RESULTS AND DISCUSSION

Typical excess noise spectra at 90° are shown in figures 6(a) and (b) for the 12 and 20 lobed mixer nozzles, respectively. Spectra for a range of mixed velocities are shown. The 90° spectra were chosen because at this angle the effects of source convection and dynamic amplification are zero. Thus, changes in level due to jet velocity and flight simulation represent source strength changes and not source/flow interaction effects. As can be seen in figure 6, the levels of the spectra increase with increasing mixed velocity and the peak frequency also increases as velocity increases. The 90° spectra of the 12 and 20 lobe mixer nozzles are compared in figure 7. The 20 lobe mixer is quieter at all velocities. This result is not surprising, since the smaller lobe width of the 20 lobe mixer should produce more rapid mixing of the fan and core streams and should result in a more mixed velocity profile at the nozzle exit. This was confirmed by flow field measurements made at the nozzle exit (Podboy et al., 1995 and Zysman et al., 1995). There is no evidence in the acoustic data that the more rapid internal mixing of 20 lobe mixer resulted in increased internal mixing noise that contributed to the total noise signature. Perhaps, for this nozzle, the internal mixing noise is not a significant noise source for this nozzle compared to the two external sources. It is interesting to note that in comparing the spectra of the two nozzles no frequency shift is obvious. Although there is a slight trend toward higher peak frequency for the 20 lobe mixer, it is not of the magnitude that one might expect. One might think that the smaller lobe width of the 20 lobe mixer would produce smaller scales turbulence and hence higher frequency noise. This effect is not evident in the data.

The variation of the peak sound pressure level (SPL) at 90° with mixed jet velocity is shown in figure 8. Data for the 12 and 20 lobe mixer nozzles are presented. Again the reduction associated with the 20 lobe mixer is evident. The 20 lobe mixer is about 2 dB quieter than the 12 lobe mixer at lower velocities and about 3 dB quieter at higher velocities. It should be kept in mind that the use of the mixed velocity in these plots is mostly for convenience. While the levels tend to vary with the mixed velocity, there is no reason to believe that Vmix is the key variable is determining the source strength. Unlike a jet of uniform initial velocity where the velocity gradients and hence source strengths are directly related to mean jet velocity, the source strength associated with the residual mixing should be related to the unmixedness of the flow and not necessarily Vmix.

The effect of free jet Mach number on the residual noise spectra is shown in figures 9 and 10 for the 20 lobe mixer at mixed jet velocities of 1018 and 1260 ft/sec. For both velocities, the effect of increased free jet velocity is to decrease the noise levels. The effect is less at forward angles and greater at aft angles. This result was observed by Saiyed et al. (1996). Plots of peak SPL at 90° versus mixed velocity for two free jet Mach numbers are shown in fig-ure 11. The reduction in peak SPL at a free jet Mach number of 0.27 is relatively constant at about 3 dB over the range of velocities tested. Note that internal mixing noise would show no change at 90° as the free jet Mach number is varied.

A plot of peak SPL versus an effective velocity, as defined by Stone (1981), is shown in figure 12. Here the effective velocity is defined as:

$$\mathrm{Veff} = \mathrm{Vmix}*(1. - \mathrm{Vo}/\mathrm{Vmix})^{2/3}$$

where Vmix is the fully mixed velocity and Vo is the free jet velocity. This parameter was defined by Stone to capture the effect of flight velocity on jet mixing noise. It can be seen that this quantity over-corrects for the effect of simulated flight on the excess noise for the nozzles tested.

In figure 13, plots of excess noise spectra are shown as a function of angle for several jet velocities for both the 12 and 20 lobe mixers. In general the levels are low in the forward quadrant and increase at further aft angles. The levels decrease again (not shown in figure 13) near the jet axis. This is most likely due the "zone of silence" that exists near the jet axis. A plot of peak level as a function of angle is shown in figure 14. Also shown in the plot is the directivity that would be expected based on Stone's correlation. At angles forward of 110° Stone predicts that the levels should vary as

$$-15*\mathrm{Log}((1-\mathrm{Mc}*\mathrm{Cos}(\mathrm{Theta}))^2 +.04*\mathrm{Mc}^2) - 10*\mathrm{Log}(1- \mathrm{Mo}*\mathrm{Cos}(\mathrm{Theta}))$$

where Mc is the convective Mach number defined by:

$$\mathrm{Mc} = 0.62*(\mathrm{Vmix} - \mathrm{Vo})/\mathrm{Ca}$$

where Ca is the ambient speed of sound. The data plotted in figure 14 appear to follow this trend up to 110°.

In figure 15, the effect of free jet Mach number on directivity is shown. Again the predicted directivity, based on the above equation, is also plotted. The level of the prediction was set to best math the data. The prediction indicates that there should be a larger variation with angle for the static case than for the simulated flight case. The data confirm that to be true. Unlike the argument made regarding the appropriateness of the jet velocity as a source strength indicator, Vmix is the appropriated variable, along with free jet Mach number, to be used for directivity correlations. Theoretical analysis by Goldstein (1973) has shown that the convection velocity determines the directivity of convecting sources. In fact, it is this analysis that was the basis for the terms in Stone's correlation. The fact that the directivity of the excess noise follows the directivity predicted for a convecting external source is further evidence that the source of the excess noise is the residual mixing of the fan and core streams external to the nozzle.

CONCLUSIONS

The noise from two internal fan/core mixers was analyzed. The measured low frequency portion of the spectra was predicted using a prediction for a single jet having the properties of the fully mixed jet. The measured high frequency portion of the spectra exceeded that of the fully mixed jet. Properties of this excess noise were studied. Based on variation of this excess noise with simulated forward velocity. it was concluded that this excess noise results from the residual mixing of the fan and core streams external to the nozzle. Although levels of the excess noise varied with mixed velocity, the mixed velocity did not appear to be a correlating parameter. Convection and dynamic amplification effects due to the mixed and free jet Mach numbers did, however, predict the excess noise directivity forward of the zone of silence. Correlation of this noise with the features of the flow field due to incomplete mixing is needed.

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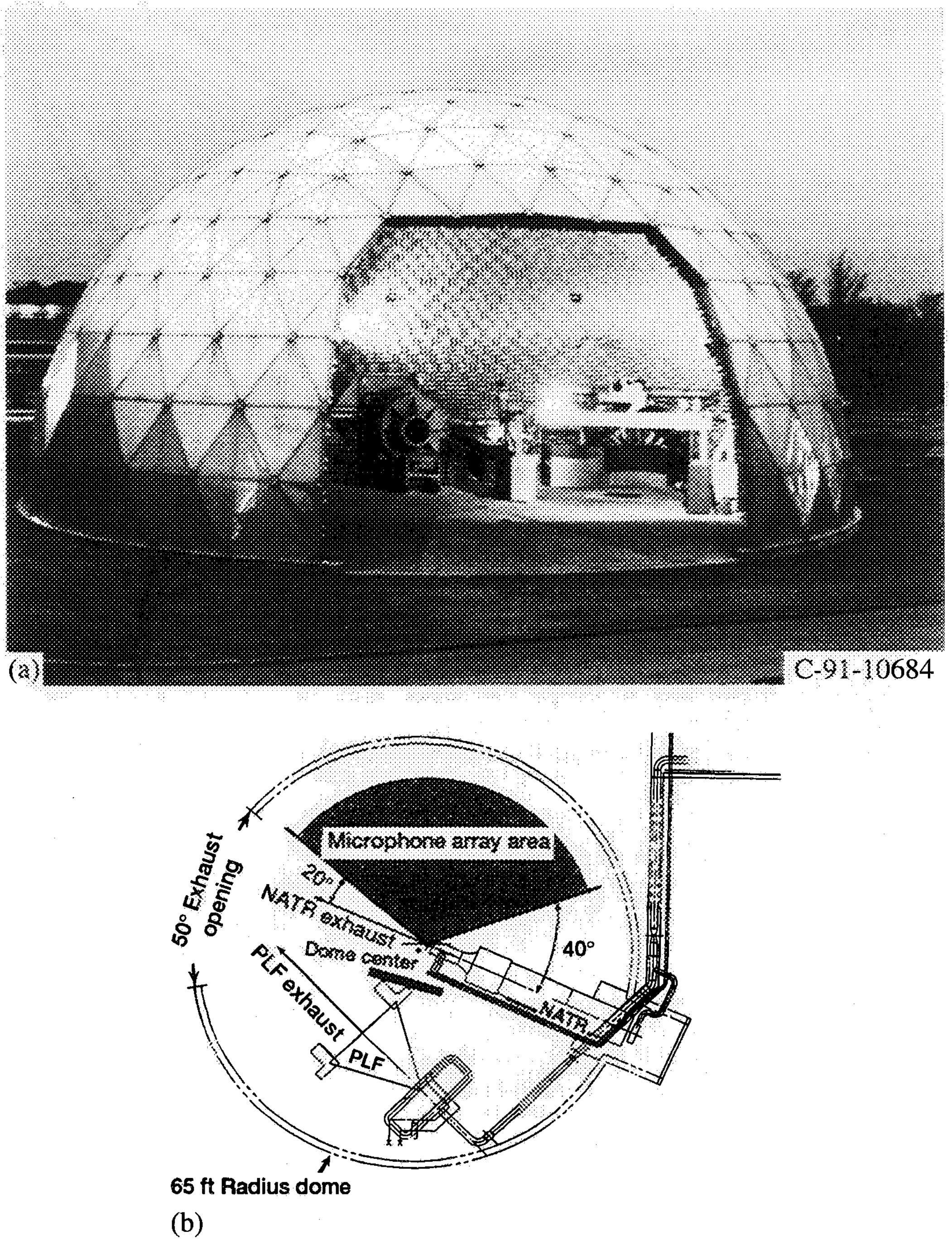


Figure 1. Aeroacoustic Propulsion Laboratory. (a) Photograph. (b) Schematic of floor plan.

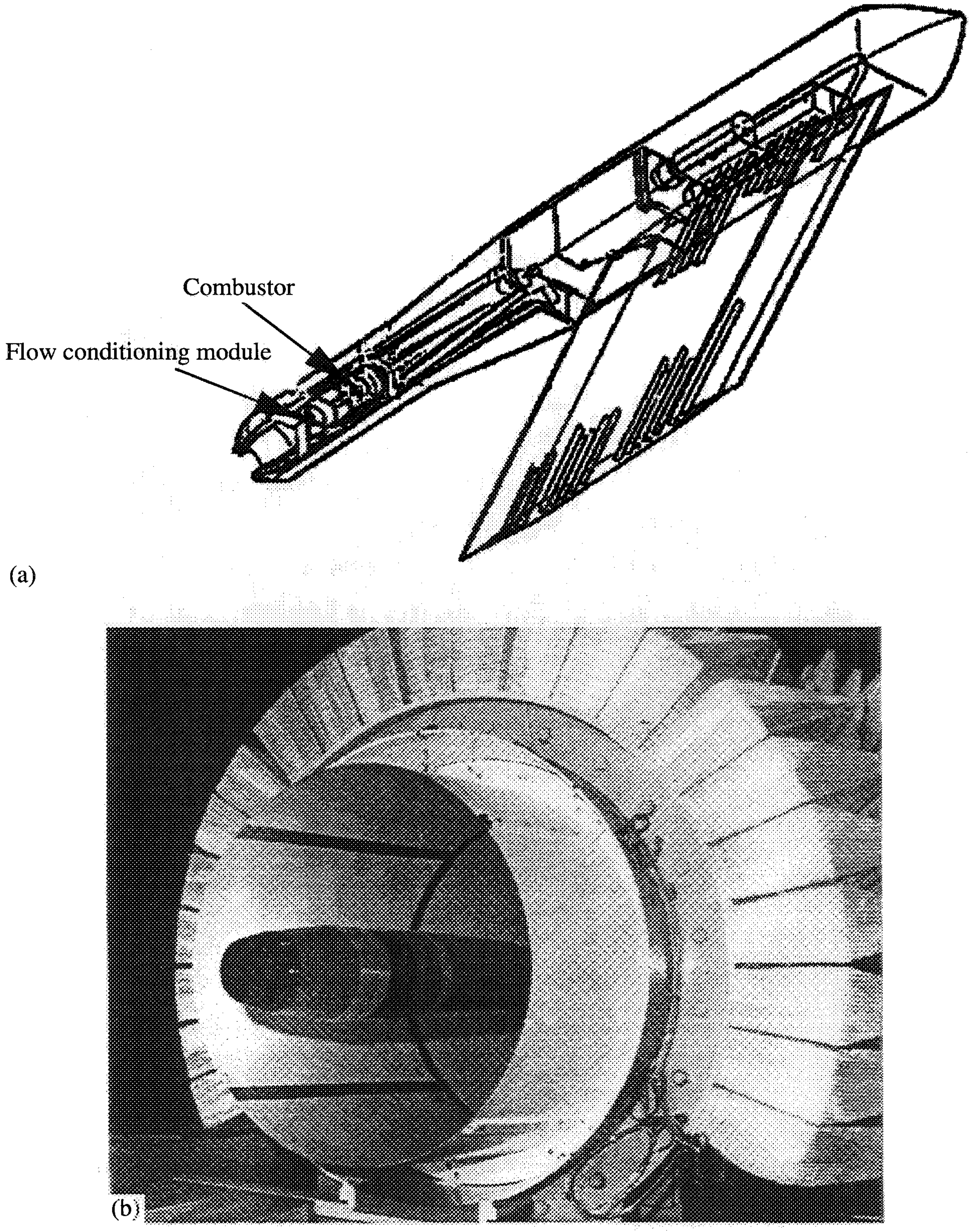
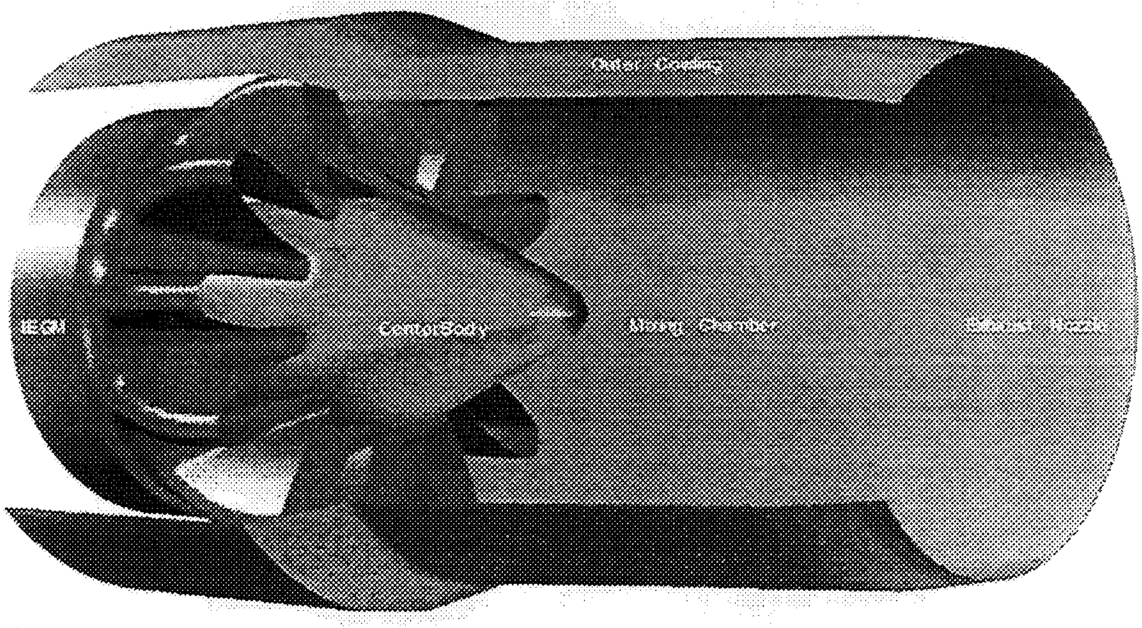
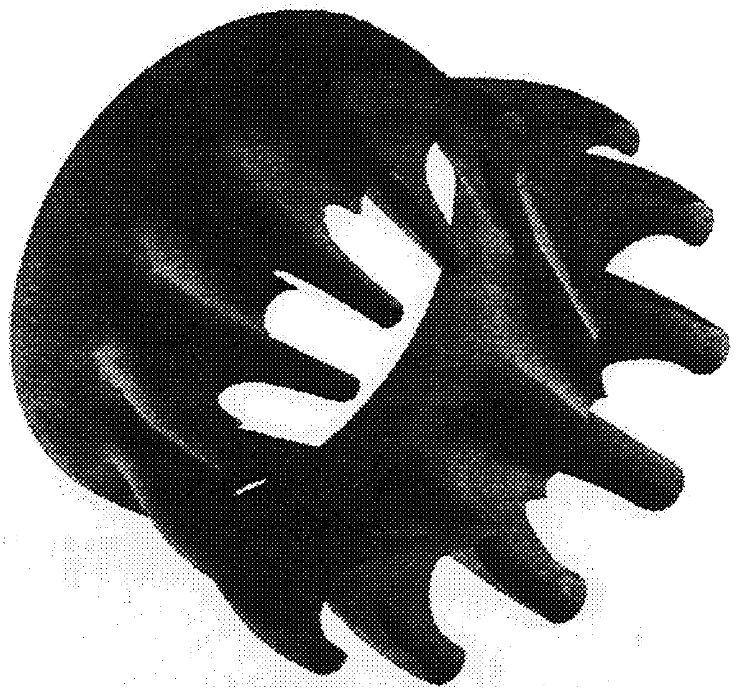


Figure 2. (a) Schematic of Jet Exit Rig. (b) Photograph of model installed in Nozzle Acoustic Test Rig.

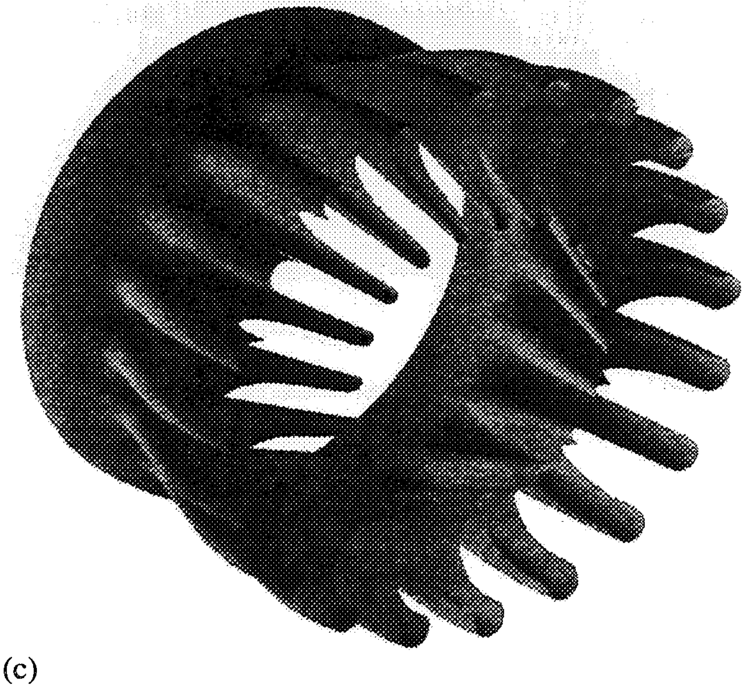


(a)

Figure 3. (a) Perspective view of internal mixer nozzle with 12 lobe mixer.



(b)



(c)

Figure 3. (b) Perspective view of 12 lobe mixer.
(c) Perspective view of 20 lobe mixer.

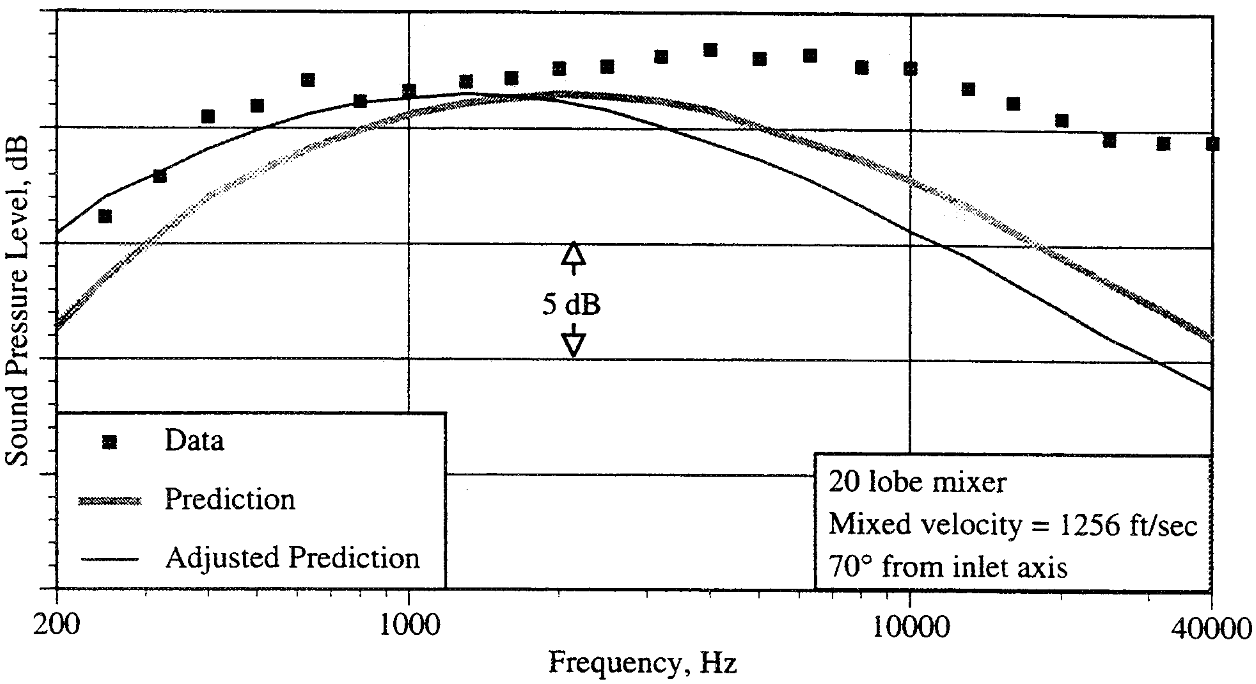
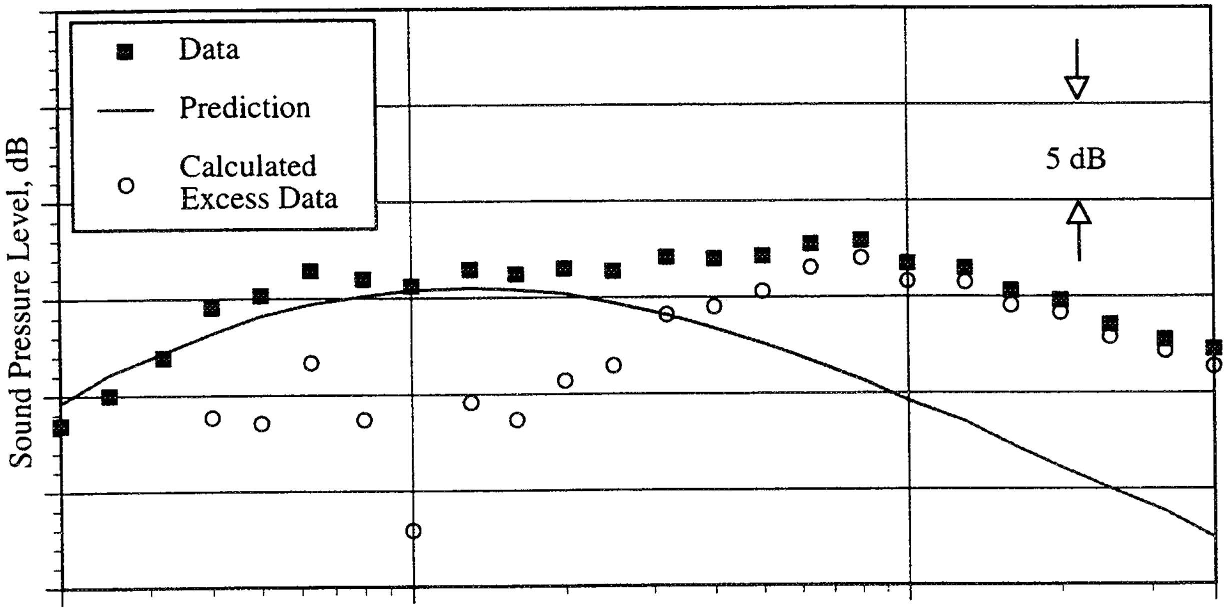


Figure 4. Comparison of measured noise spectra with prediction and adjusted prediction of fully mixed jet noise.

a. 55° from inlet axis



b. 70° from inlet axis

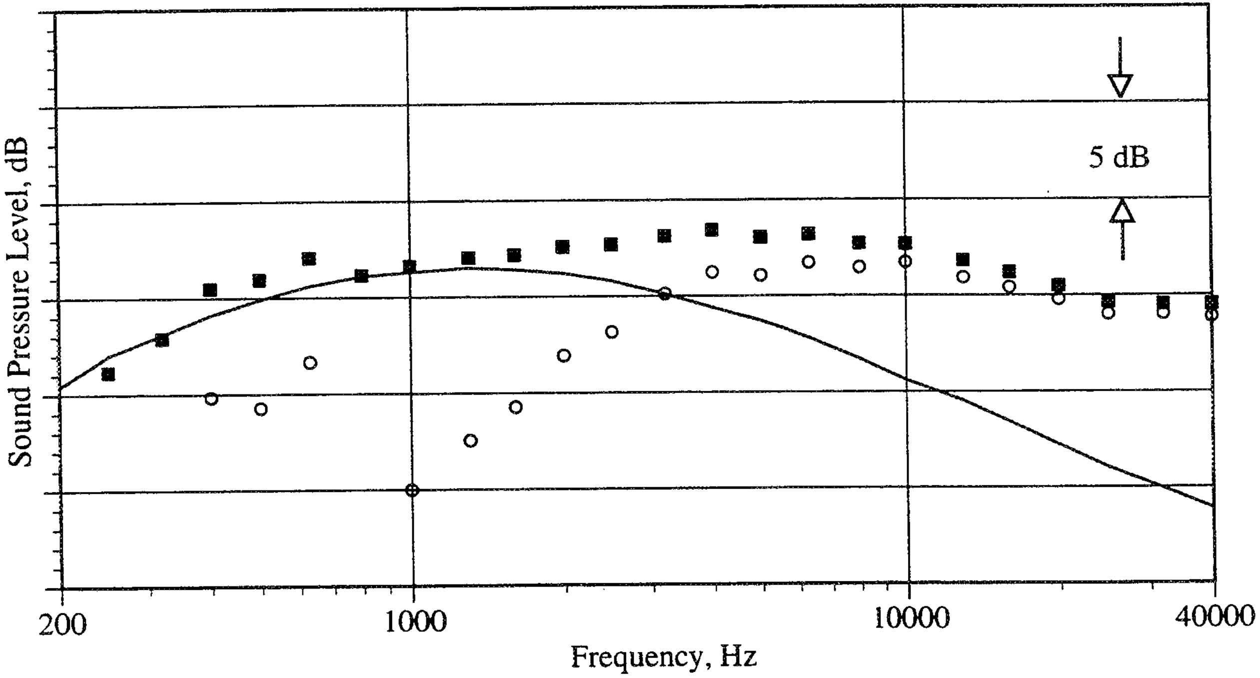
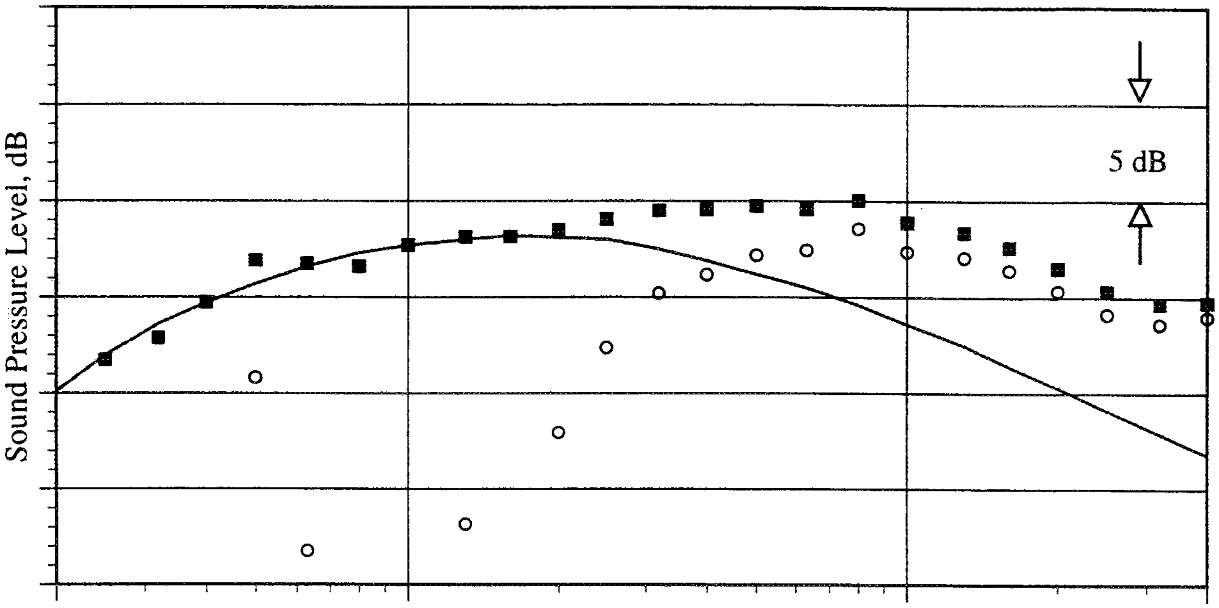


Figure 5. Typical set of plots showing measured spectra, calculated excess noise and predicted spectra for fully mixed jet.

c. 90° from inlet axis



d. 110° from inlet axis

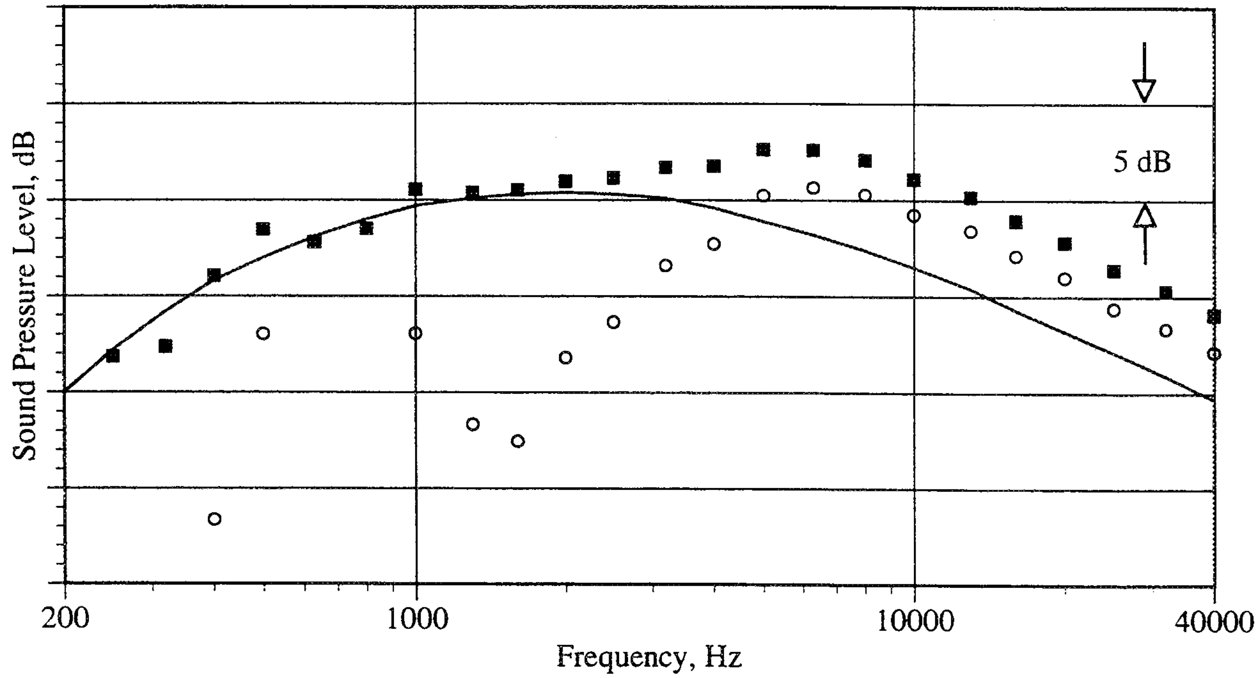
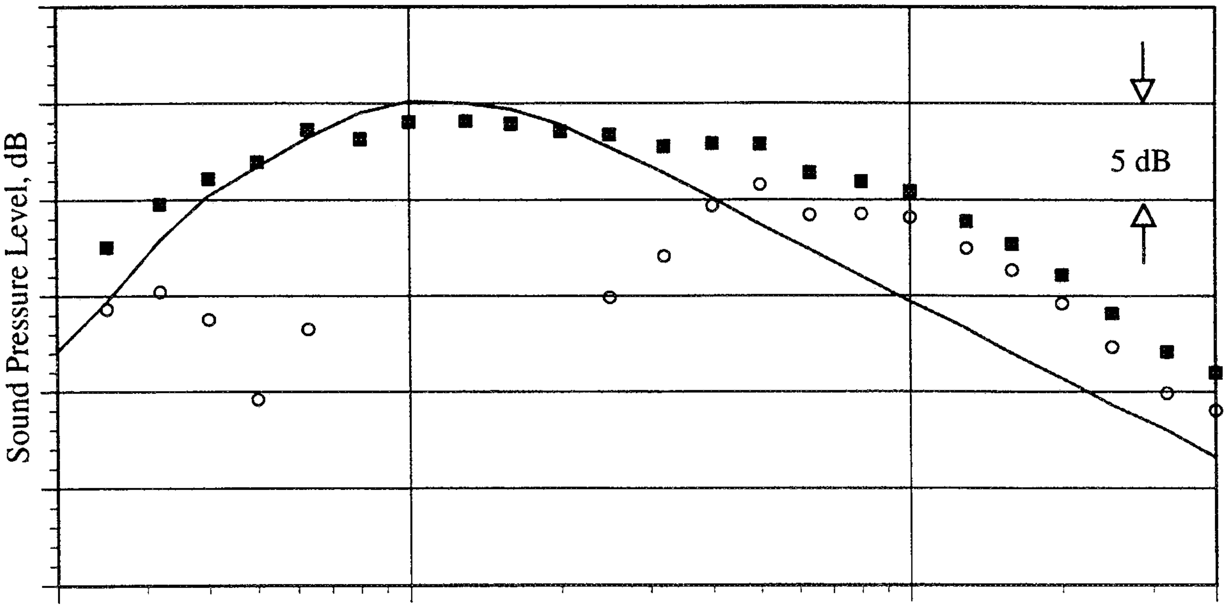


Figure 5. Continued

e. 130° from inlet axis



f. 150° from inlet axis

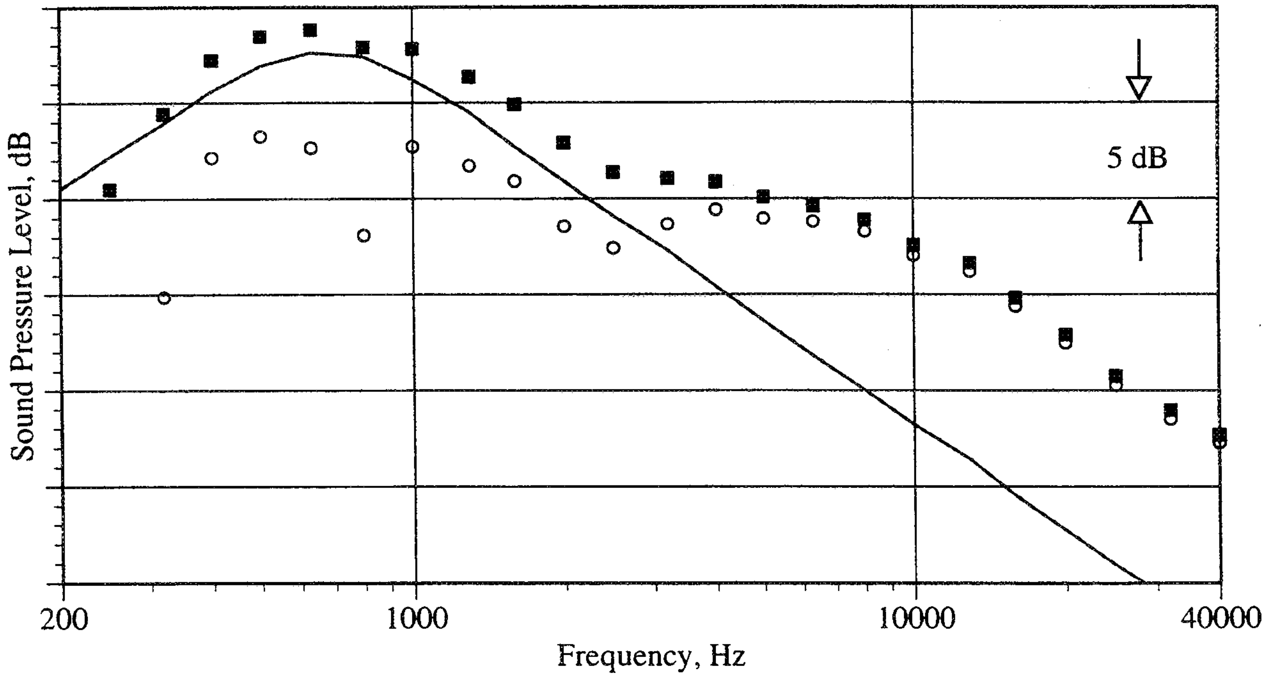
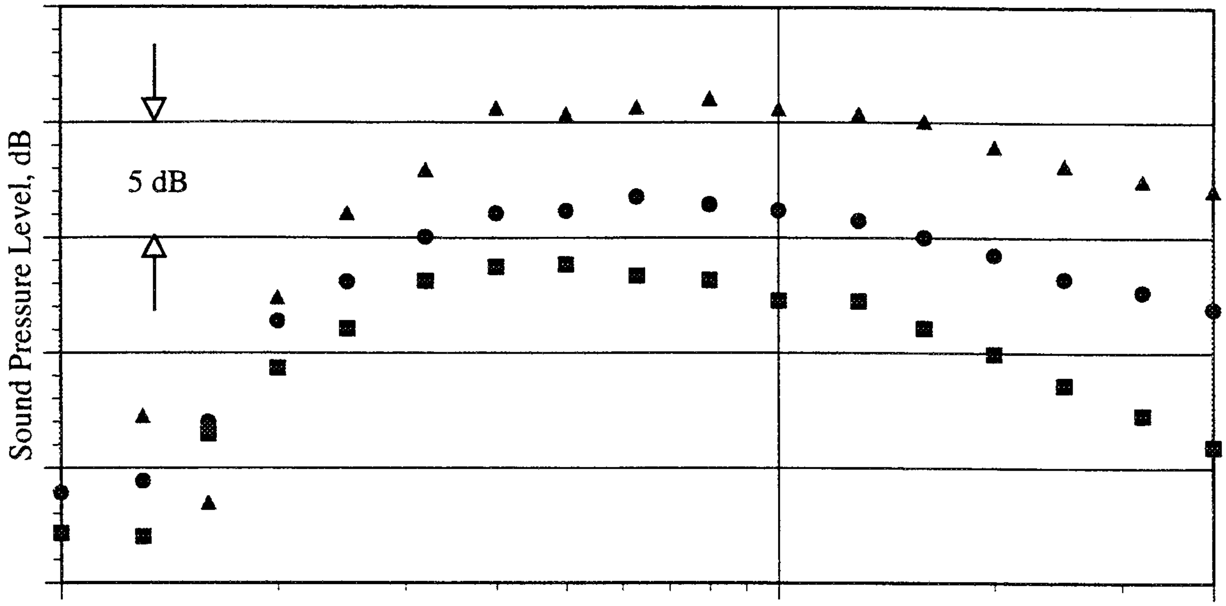


Figure 5. Concluded

6a. 12-lobe Mixer



6b. 20-lobe Mixer

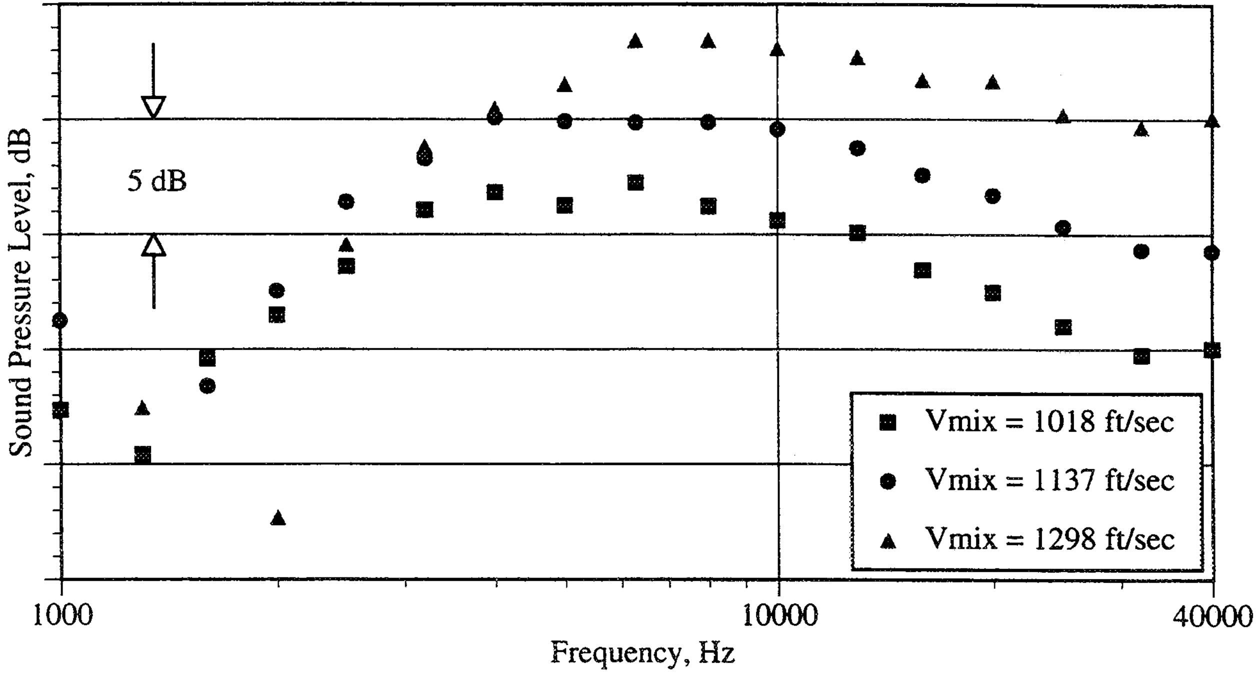


Figure 6. Excess noise spectra at 90° for various mixed jet velocities
(Mo = 0.27)

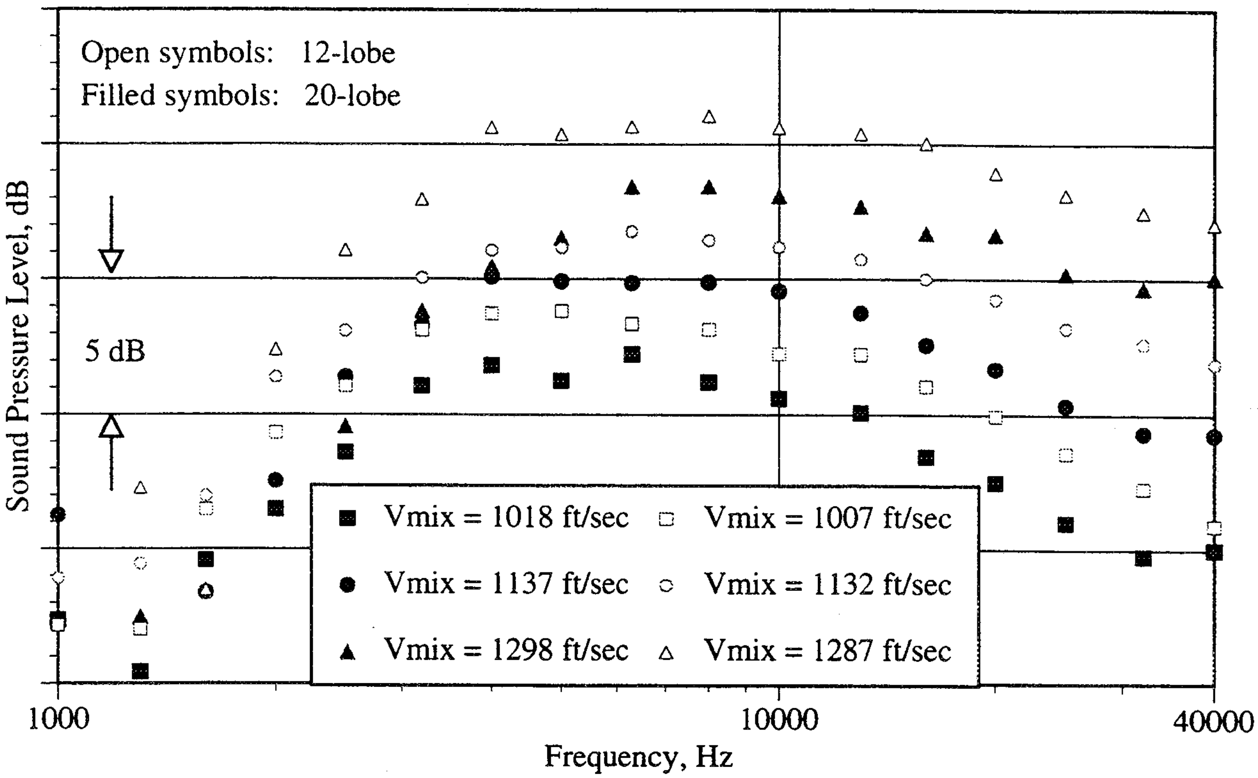


Figure 7. Comparison of 12 and 20 lobe mixer spectra at 90° as a function of mixed jet velocity. (Mo = 0.27)

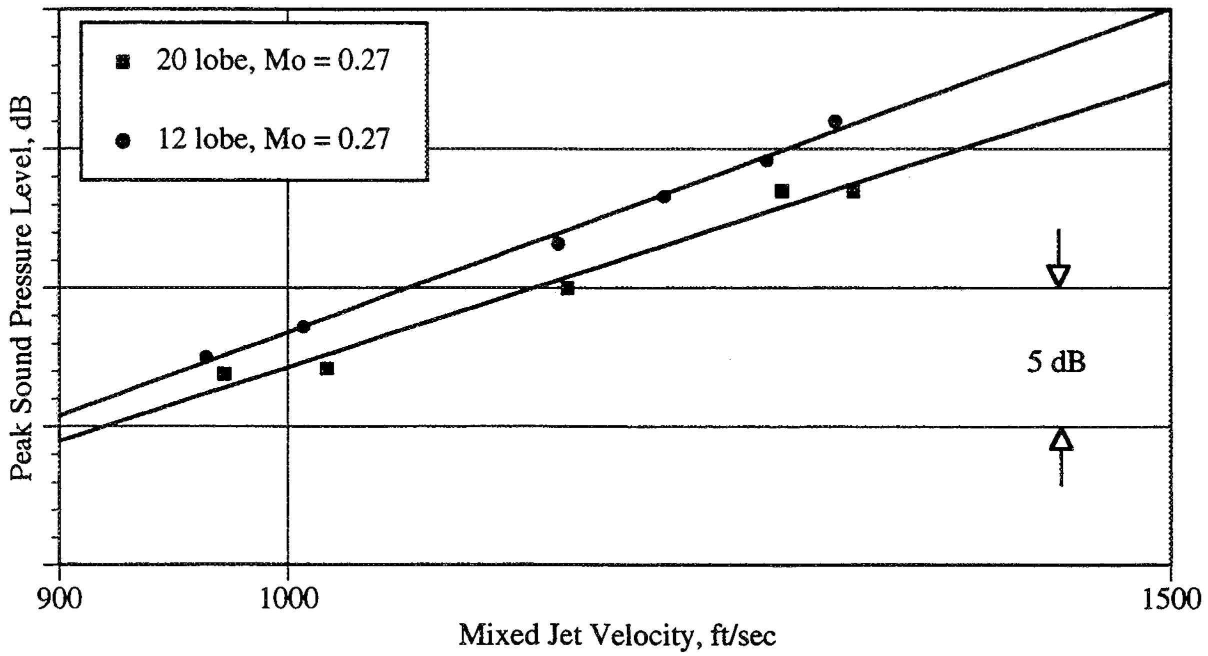
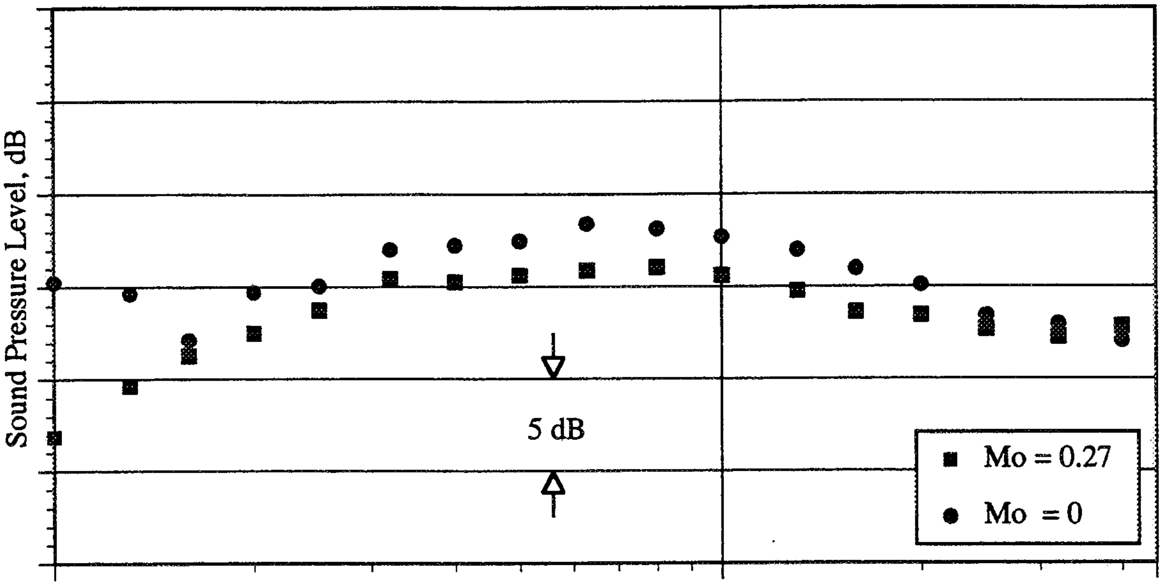


Figure 8. Peak Sound Pressure Level at 90 degrees for the 12 and 20 lobe mixers as function of Mixed Jet Velocity, ft/sec

a. 70°



b. 90°

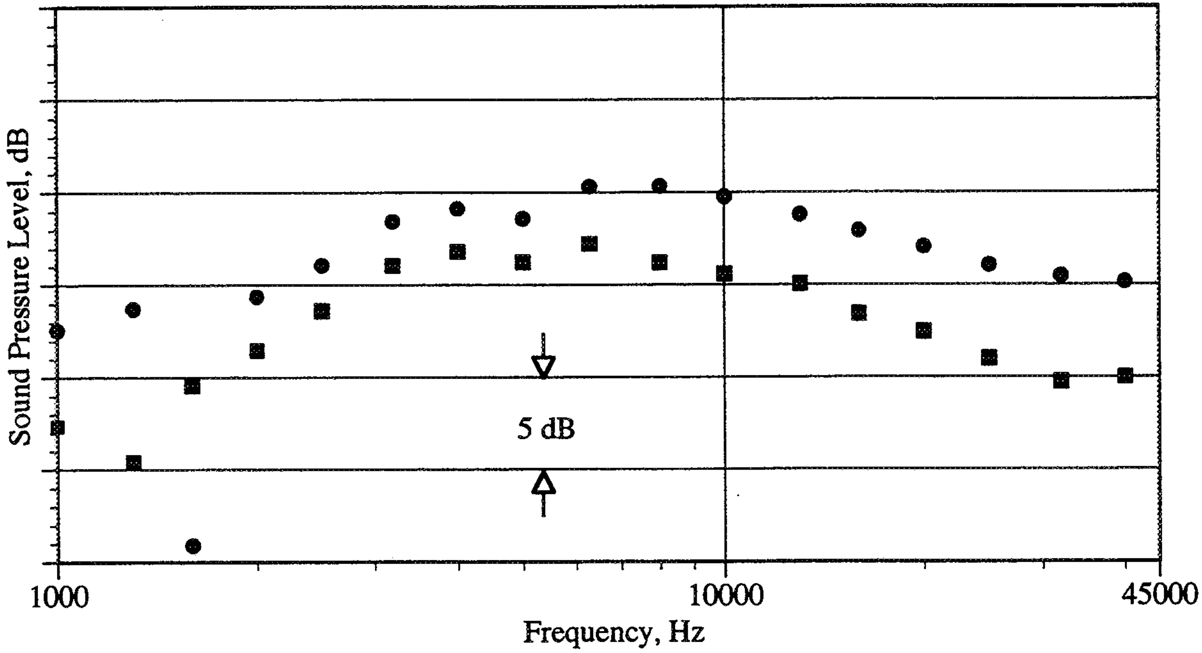
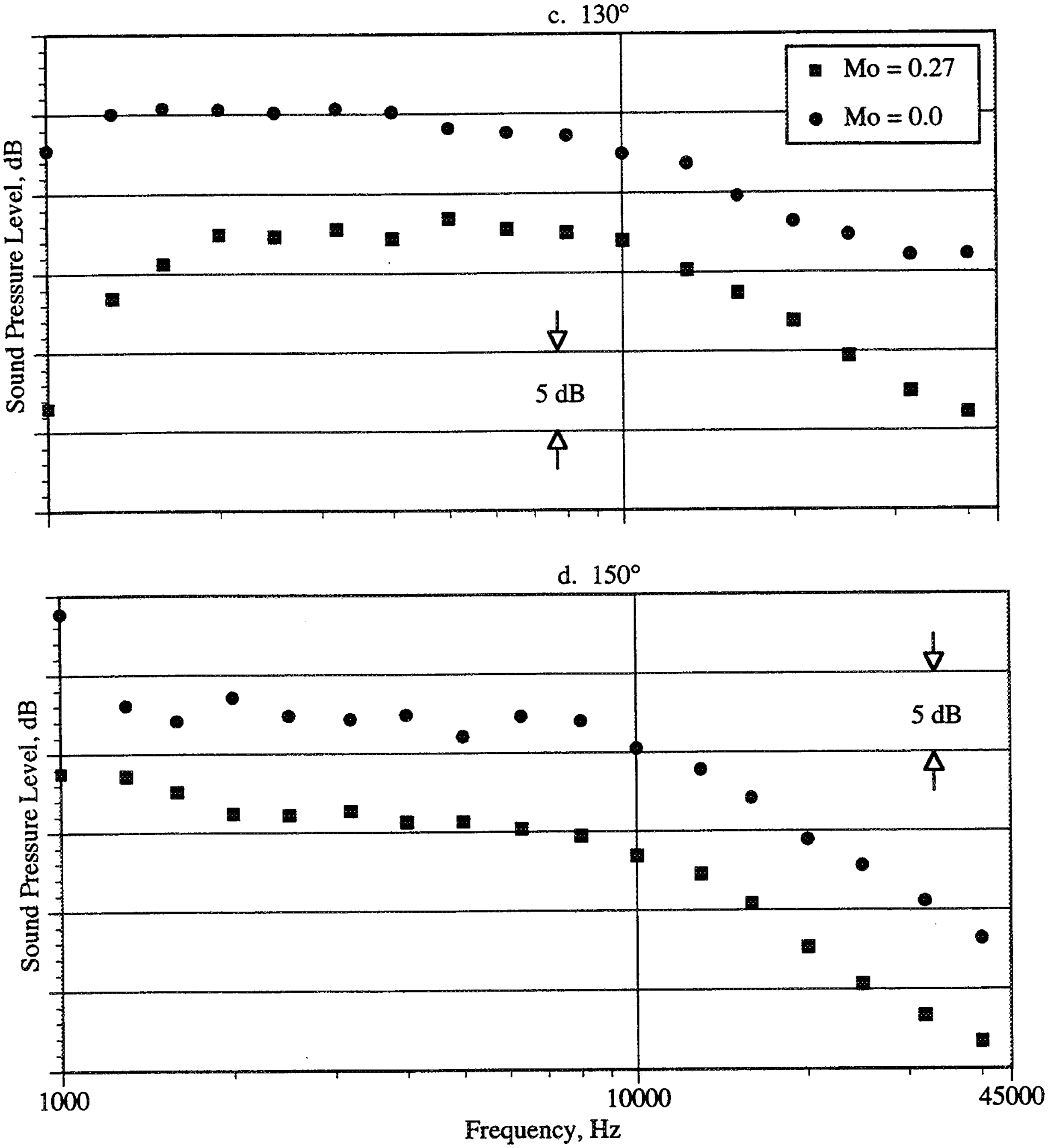


Figure 9. Impact of forward flight on 20-lobe spectra for Vmix of 1018 ft/sec


c. 130°

d. 150°

Figure 9. Concluded

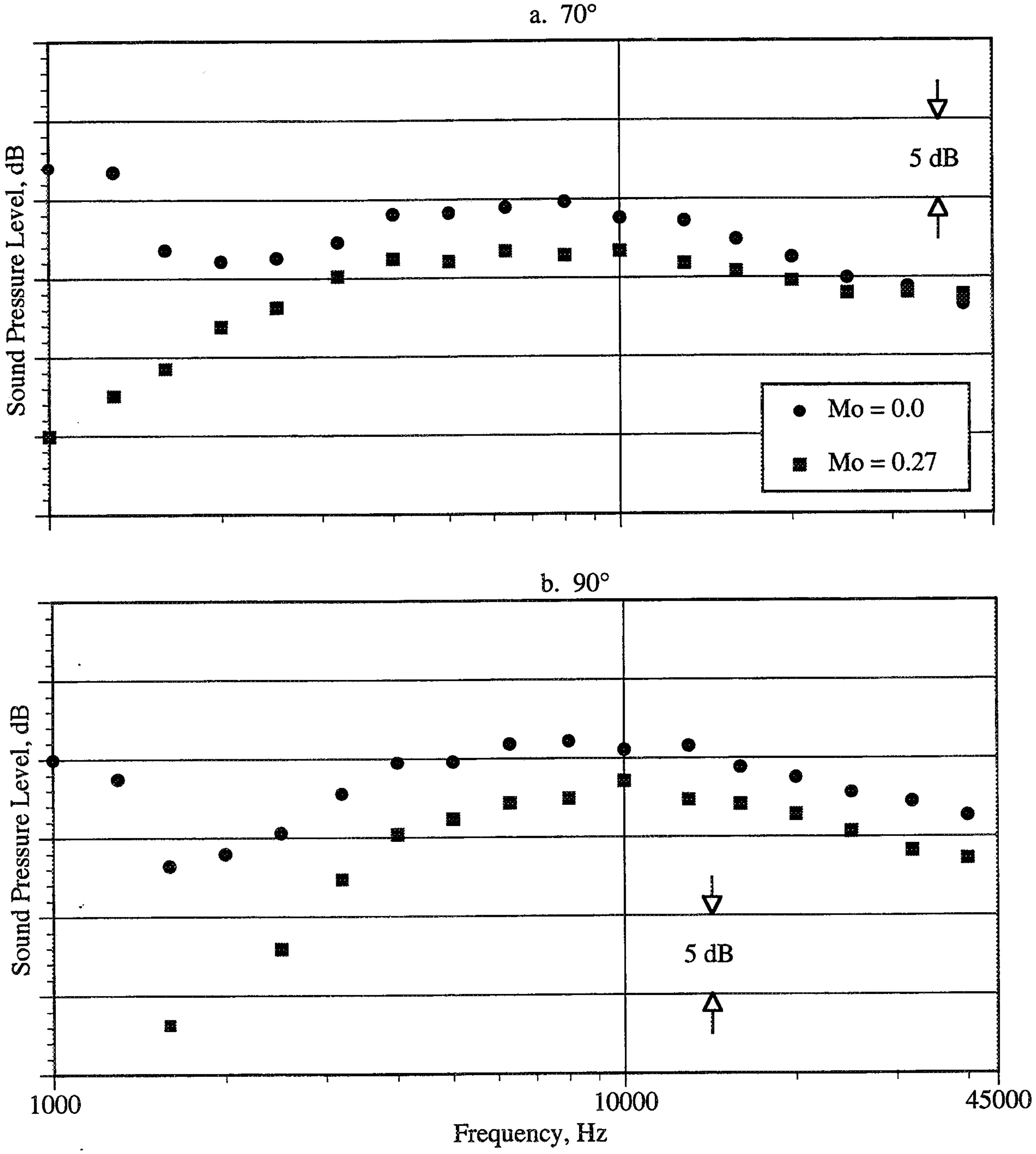
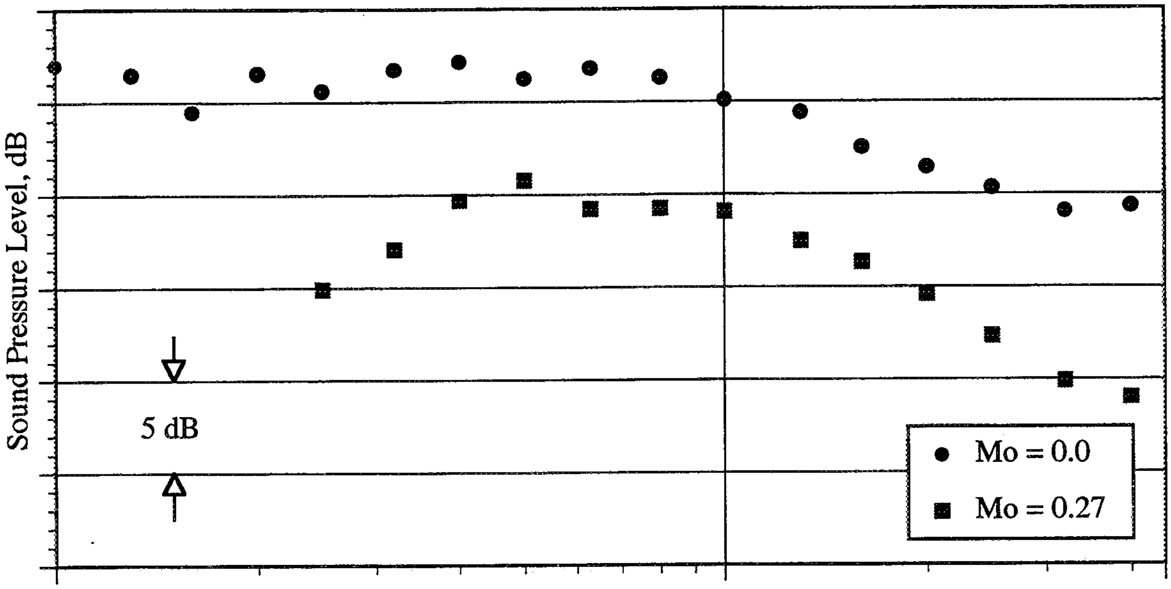


Figure 10. Impact of forward flight on 20-lobe spectra for Vmix of 1260 ft/sec

c. 130°



d. 150°

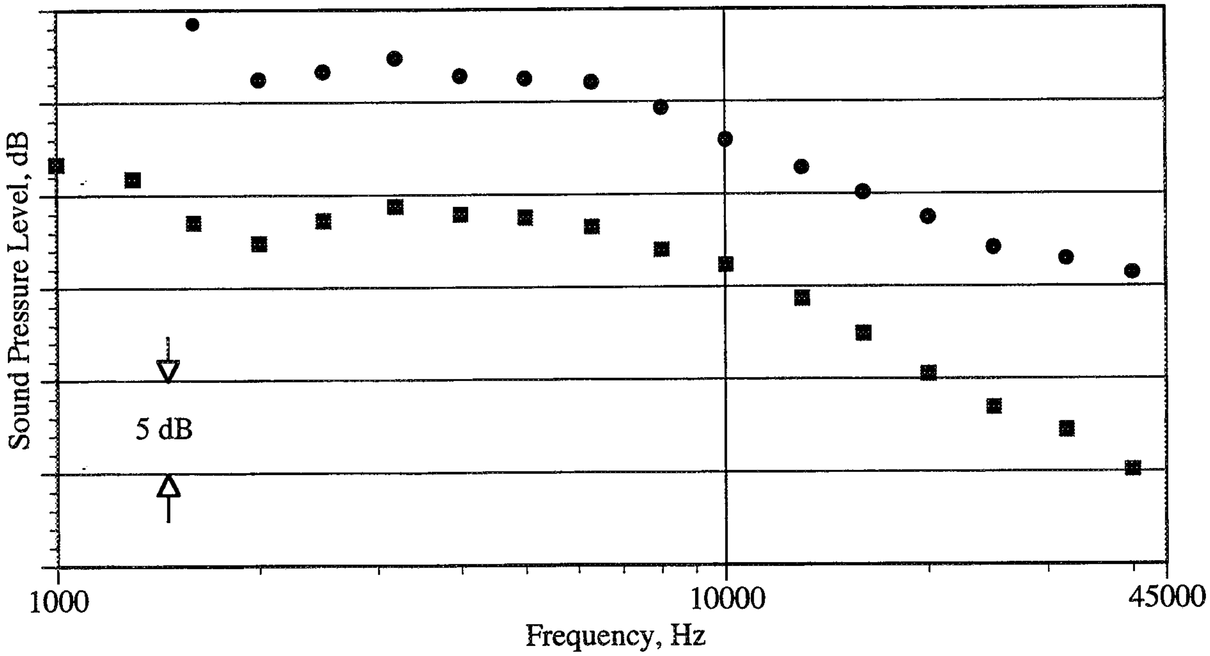


Figure 10. Concluded

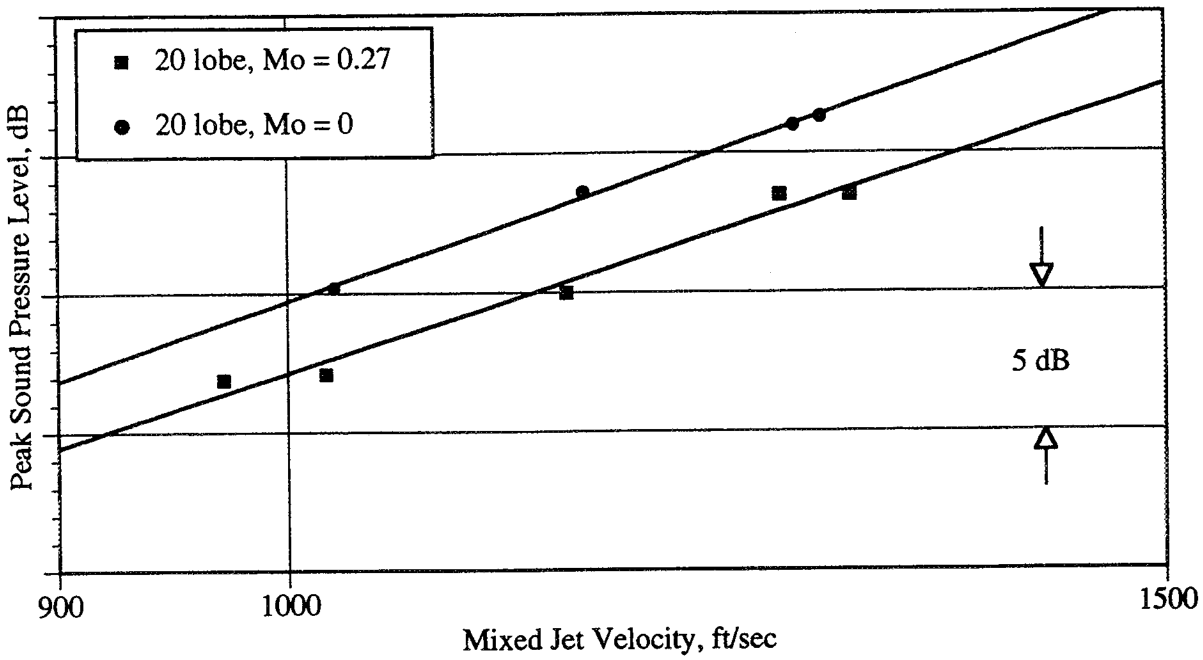


Figure 11. Impact of forward flight on peak sound pressure level at 90 degrees as function of Mixed Jet Velocity

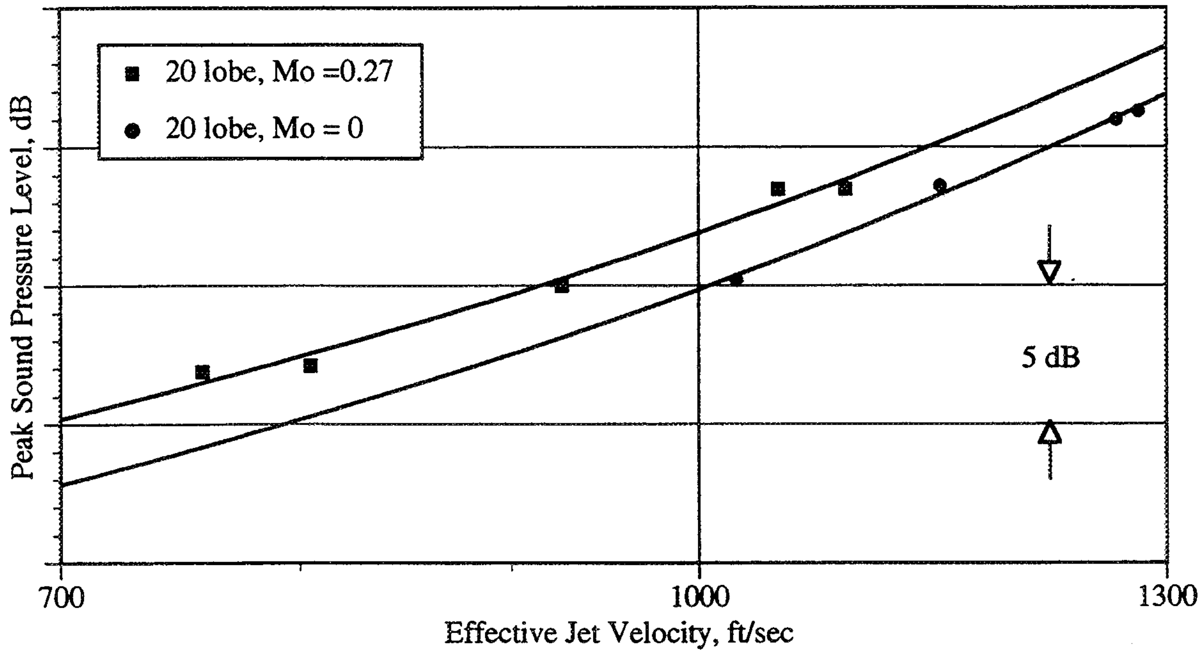
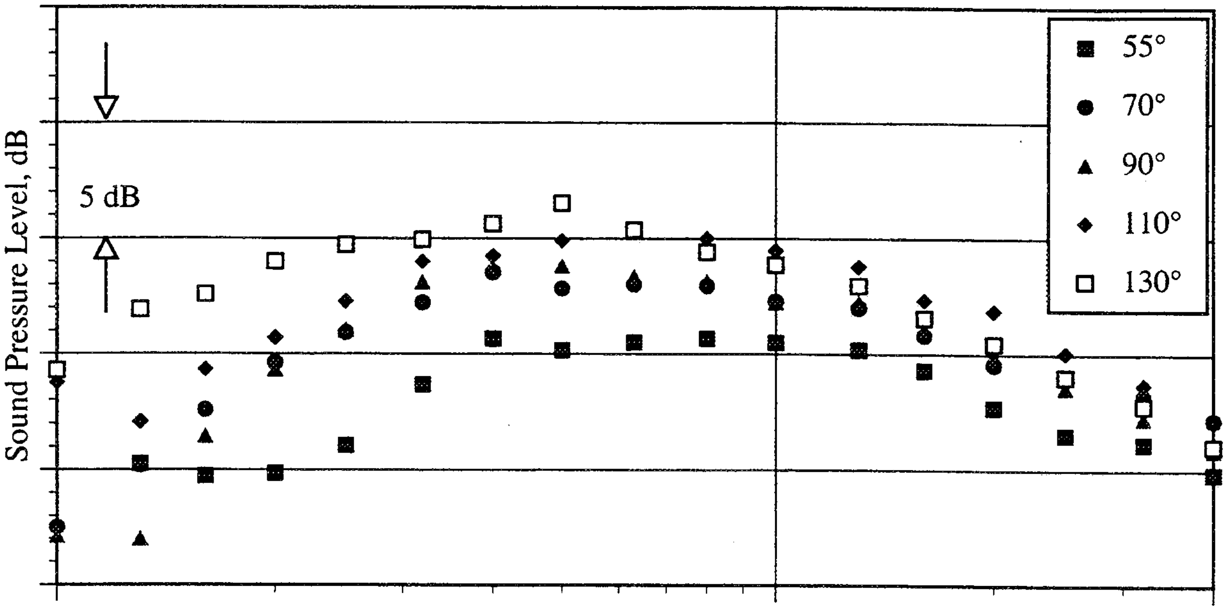


Figure 12. Impact of forward flight on peak sound pressure level at 90 degrees as function of Effective Jet Velocity

a. 12 lobe mixer, Vmix = 1007 ft/sec



b. 20 lobe mixer, Vmix = 1018, Mo = .27

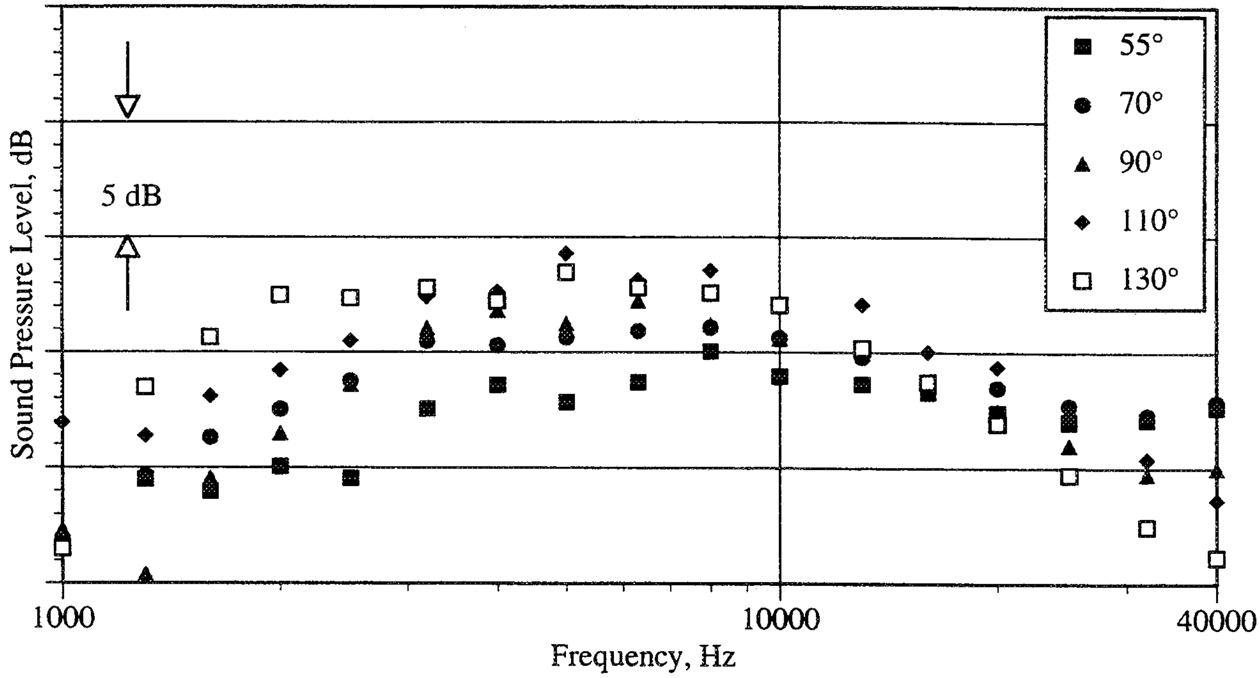
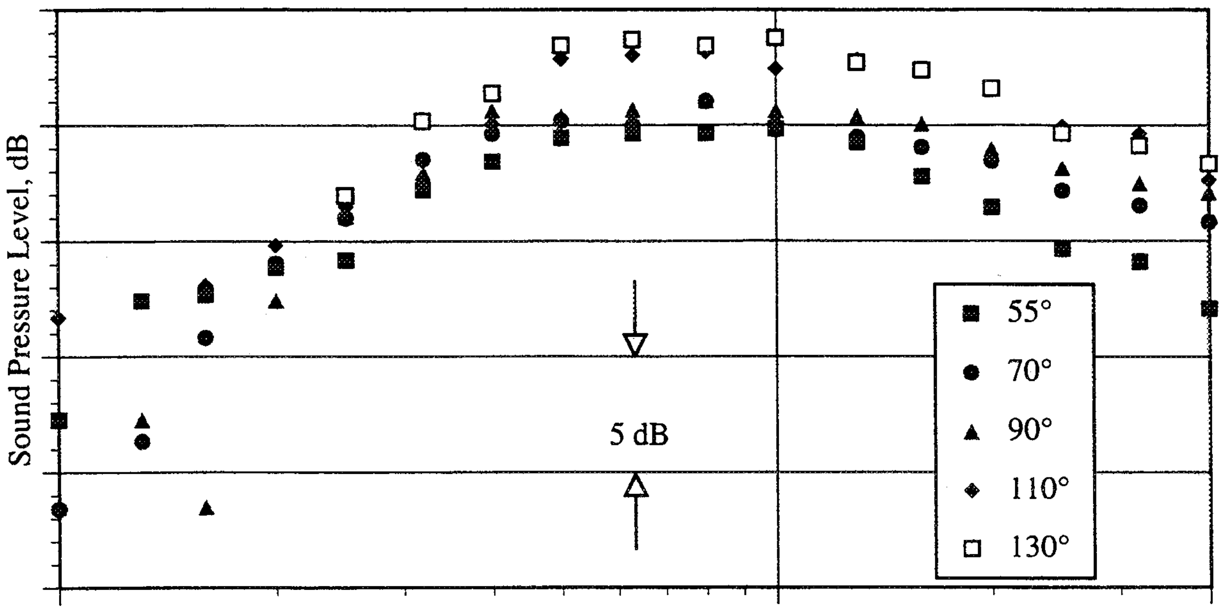


Figure 13. Excess noise spectra as a function of angle for the 12 and 20 lobe mixer for low and high velocities. (Mo = .27)

c. 12 lobe mixer, Vmix = 1287 ft/sec



d. 20 lobe mixer, Vmix = 1298 ft/sec

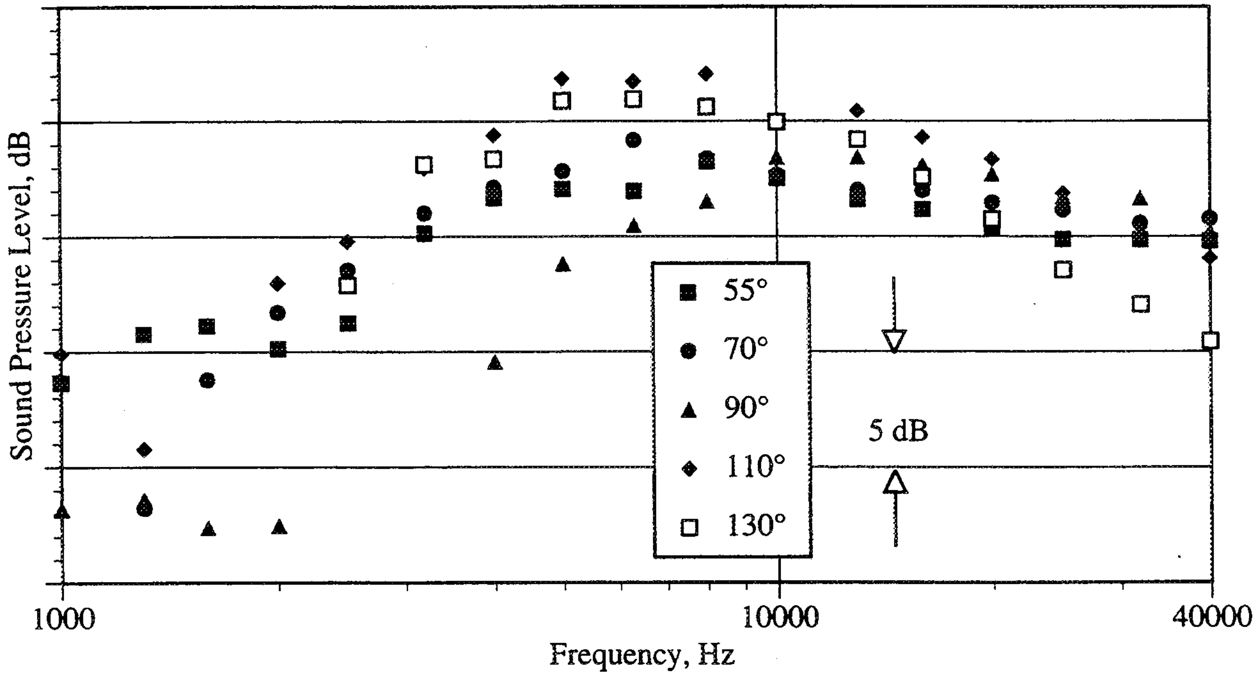


Figure 13. Concluded

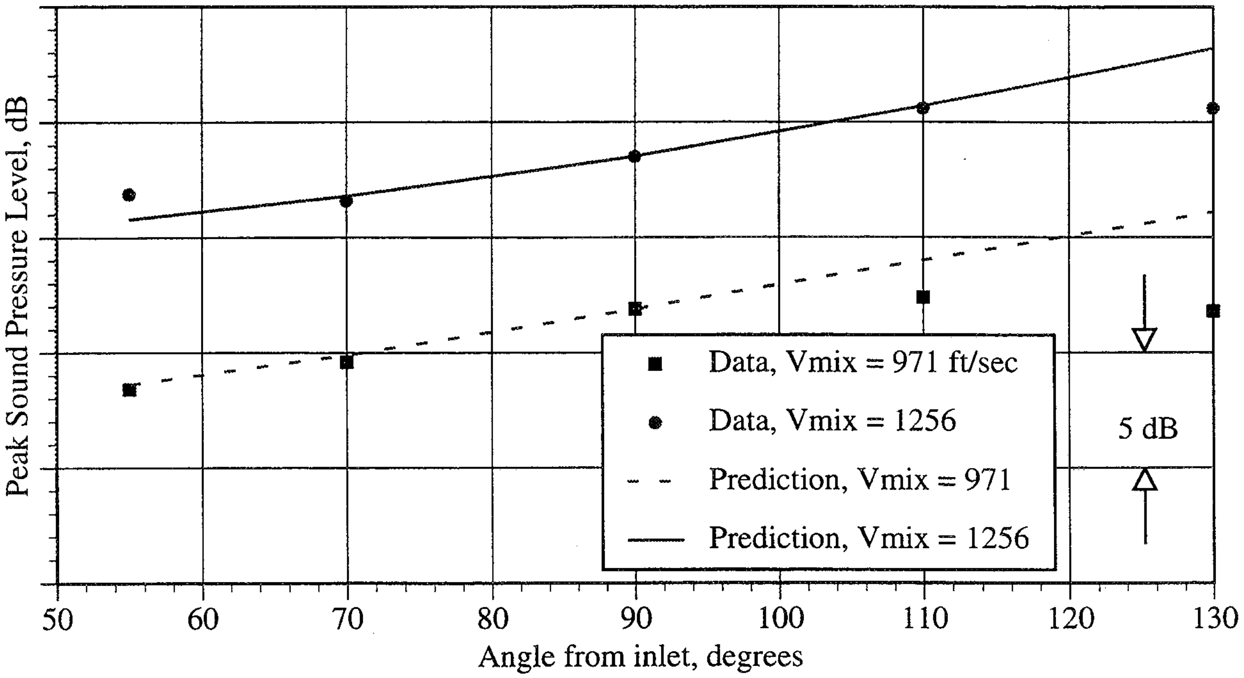
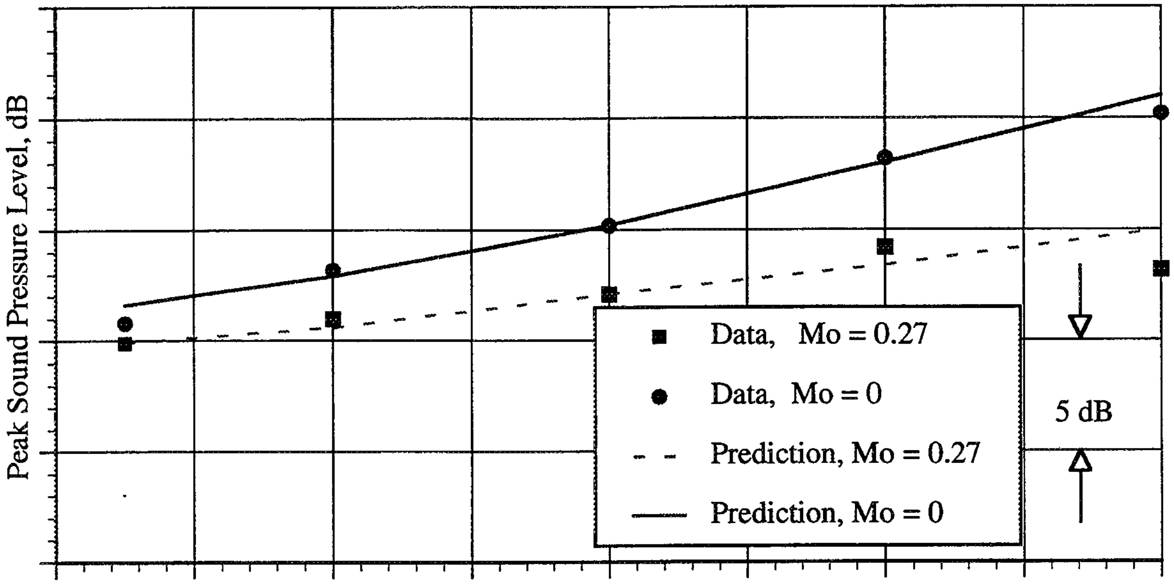


Figure 14. Comparison of measured and predicted directivities for excess noise (Mo = 0.27)

a. Vmix = 1020 ft/sec, 20-lobe mixer



b. Vmix = 1260 ft/sec, 20-lobe mixer

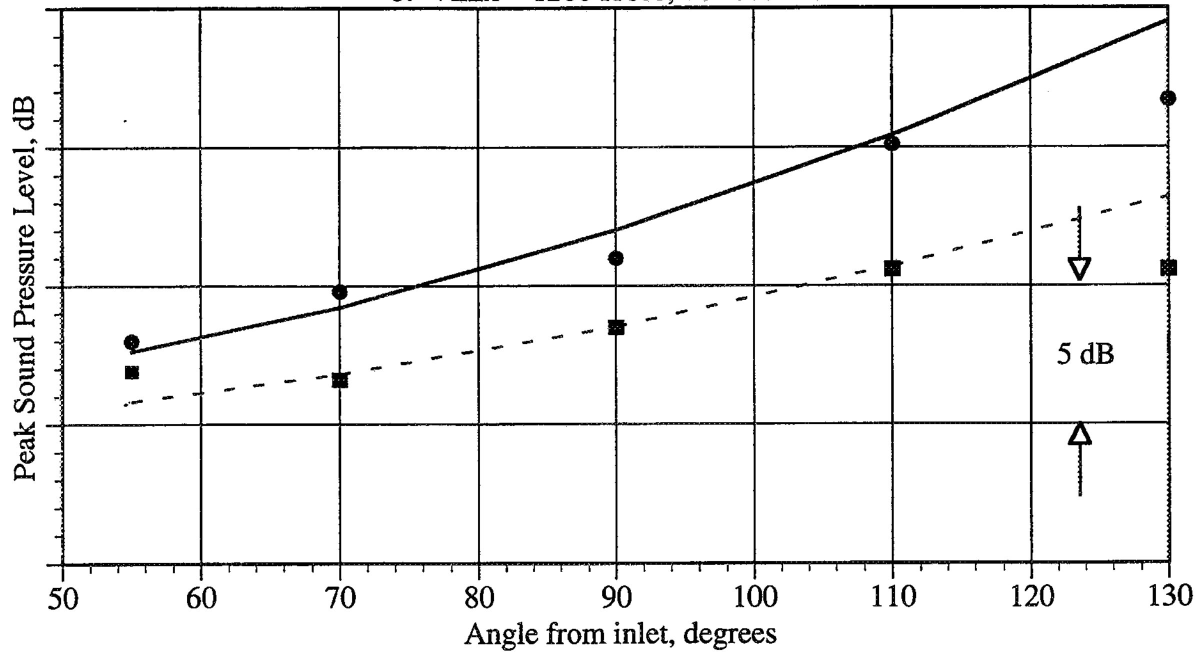


Figure 15. Comparison of measured and predicted effect of Mo on excess noise directivity

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13. ABSTRACT ***(Maximum 200 words)***

The jet mixing noise from two fan/core mixer nozzles is studied. Acoustic data from two fan/core mixer nozzles are analyzed to determine the properties of the noise signatures. It was assumed that there were three major contributors to the total noise signature: noise from mixing of the fan and core streams internal to the nozzle; noise from residual mixing of the fan and core streams external to the nozzle; and the noise associated with the fully mixed jet. In general, the low frequency portion of the noise spectra can be associated with the fully mixed jet and can be predicted using an empirical correlation for single round nozzle jet noise. The properties of the noise in excess of the fully mixed levels are studied.

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