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LOW-SPEED JET NOISE FROM A 1.83-METER (6-FT) FAN FOR TURBOFAN ENGINES

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16. Abstract

The jet noise from a large fan model has been determined for two simulated nacelle configurations. These were a hard-wall nacelle and one having acoustic liners on the walls and on inlet splitter rings. The jet velocity range of the data was from 137 to 223 meters per second (450 to 730 ft/sec). The data show that internally generated low-frequency noise is effectively removed by the acoustic liners. Data from the lined configurations show the classical eighth-power dependence on jet velocity. Data from the hard wall configurations were higher in value and had a weaker velocity dependence due to the noise from internal sources. Several comparisons of the data were made with correlations of jet noise data from the literature.

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SUMMARY

The jet noise contribution to the far-field sound from a 1.83-meter- (6-ft-) diameter fan has been determined for two simulated nacelle configurations. One nacelle had hard walls, while the other had acoustic liners on the wall and on inlet splitter rings. The jet velocities, typical of high-bypass-ratio fan engines, varied from 137 to 223 meters per second (450 to 730 ft/sec). The results of the study show that the acoustic liners effectively eliminate low-frequency noise from internal sources. Data from the lined configurations were found to be in good agreement with the eighth-power dependence on jet velocity. Data from the hard-wall configurations, because of the influence of internally generated noise, show higher noise levels and a weaker velocity dependence. The data are also about 6 decibels less than predicted by extrapolation of the SAE curve to the velocities present. This result may be due to the contribution of jet density in the SAE correlation, where jet density appears to the second power. The data were in better agreement with a correlation obtained for unheated jets. The shape of the measured spectra agreed well with the spectra published by the SAE when annulus height of the nozzle was used as the characteristic dimension in the Strouhal number.

INTRODUCTION

For high-bypass-ratio fan engines operating at subsonic fan exhaust velocities, there has been considerable interest in the level of jet noise and its dependence on velocity. Theoretical studies of jet noise show that it should follow an eighth-power dependence on velocity (e.g., refs. 1 and 2). This result is supported by experimental studies at high velocities in general and also at low velocities with simple nozzles where the flows are relatively free from upstream turbulence and flow noise (refs. 1 and 3); however, engine data at low velocities generally show higher noise levels and a weaker velocity dependence than these nozzle experiments (refs. 3 and 4). This behavior has been attributed to the emergence of other noise sources at low exhaust velocities (ref. 5). In reference 5, it has been shown that increasing the turbulence level of the flow through a nozzle results in a significant increase in the noise, coupled with a decrease in its velocity dependence from eighth power to sixth or even fourth power. Since noise floors for an engine are generally assumed to be set by the jet noise level, it becomes important to know how to estimate the jet noise. This is especially true when one considers the weight and size penalties associated with engines designed for low exhaust velocities.

In the present report, far-field sound data from a 1.83-meter-diameter (6-ft-) diameter fan have been analyzed for jet noise content for two nacelle configurations. One of the nacelles had hard walls, while the other had acoustic liners on the walls and on inlet splitter rings. The exhaust velocity of the fan jet was varied from 137 to 223 meters per second (450 to 730 ft/sec). The experimental results are presented in several forms and are compared with correlations from the literature. The fan design details may be found in reference 6, while complete acoustic and aerodynamic data are given in references 7 and 8 for the hard-wall and acoustically lined nacelle configurations, respectively.

SYMBOLS

A	nozzle area, m^2; ft^2
c_o	atmospheric speed of sound, m/sec; ft/sec
$OASPL_m$	maximum sideline overall sound pressure level (referenced to 2×10^{-5} N/m^2), dB
$OASPL_{m,p}$	maximum polar overall sound pressure level (referenced to 2×10^{-5} N/m^2), dB
P	sound power, W
R	radial distance, m; ft
T_{isa}	international standard atmospheric temperature, ^oK; ^oR
T_o	atmospheric temperature, ^oK; ^oR
V	velocity, m/sec; ft/sec
ρ	jet density, kg/m^3; lb/ft^3
ρ_{isa}	international standard atmospheric density, kg/m^3; lb/ft^3
ρ_o	atmospheric density, kg/m^3; lb/ft^3

APPARATUS AND PROCEDURE

The data used here were obtained during testing of a full-scale fan at the Lewis Research Center. The design of the fan and facility are described in reference 6. The fan tests included both hard-wall nacelles and nacelle configurations with inlet and exhaust ducts that had been acoustically treated to absorb a portion of the internally generated noise. These two nacelle treatments, hard and lined, and the corresponding data are described in references 7 and 8, respectively. Two nozzle areas were also tested. A summary of the nacelle and nozzle arrangements is given in table I. The test facility consisted of the fan with a 1.83-meter- (6-ft-) diameter inlet duct mounted in a simulated engine cowl on a concrete pedestal. The fan centerline was 5.79 meters (19 ft) above ground level. The fan nozzle had an annular cross section with a conical centerbody extending approximately 1.52 meters (60 in.) beyond the end of the outer wall as shown in figure 1. The design area of the nozzle was 1.26 square meters (13.56 ft^2).

The acoustic liners (configurations 10 to 13, table I) consisted of aluminum honeycomb panels faced with perforated aluminum sheets. The inlet liners were placed on the outer wall and on both sides of three splitter rings. Figure 1 shows this geometry and the liner parameters. As shown in table I, two inlet lengths were tested to vary the length of acoustic treatment. In the exhaust duct, the centerbody and outer wall were lined.

For each nacelle configuration aerodynamic and far-field acoustic data were taken in 5-percent speed increments between 60 and 90 percent of the sea-level standard-day fan design speed. The standard-day conditions were 282.2 K (518.7° R), 1.013×10^5 newtons per square meter (2116.2 lb/ft^2), and 70 percent relative humidity. At each speed, three independent data samples were taken and subsequently averaged.

Aerodynamic data consisted of rake measurements of total temperature, total pressure, and static pressure. These data were used to compute velocity and density profiles in the nozzle exit plane. Acoustic data consisted of microphone measurements of sound pressure level at 10° intervals in the horizontal plane through the fan axis. The microphone locations are shown in figure 2. The microphone outputs were analyzed with standard 1/3-octave band filters with center frequencies from 50 to 10^4 hertz. Sound pressure levels were also "corrected" to the standard-day conditions. The random error in sound pressure level was estimated in reference 7 to be 1.7 decibels.

ANALYSIS OF DATA

Aerodynamic Data

Typical velocity profiles in the nozzle exit plane are shown in figure 3(a) for the hard-wall configuration. Similar profiles are shown in figure 3(b) for a lined configuration. From these figures it is evident that the profiles for the two cases are similar and that the peak velocities are within 8 percent of the mass-averaged velocities obtained by integration over the annulus area. The mass-averaged values were used in correlating the jet noise.

Determination of Jet Noise

The far-field sound measured by the microphones comes from inside the fan nacelle and from the jet mixing region. Examination of typical sound pressure level spectral and directivity distributions gave the basis for separation of the jet noise from the total measured sound.

As indicated by the SAE curve correlating jet noise spectra (ref. 9), the maximum sound pressure level due to jet noise should occur at about 100 hertz for jets of the size and speed of the present case. By contrast, the internally generated noise associated with the fan occurs predominantly at higher frequencies in the range of the blade passing tone. For the present fan, this frequency varies from about 2000 to 3000 hertz depending on the fan speed. Figure 4 shows typical sound pressure spectra for several fan speeds at an angular microphone position of 160°. The two sound level maxima described can be seen, separated by a relative minimum. The location of the minimum varies somewhat with fan speed; however, it generally occurs at 1000 hertz. Therefore, the noise below 1000 hertz was attributed to the jet, and that above was attributed to sources inside the fan nacelle. For noise following the SAE spectrum mentioned earlier, the contribution of the sound pressures outside of ±3 octaves from the peak value to the overall sound pressure level is less than 1/2 decibel. The selected upper frequency of 1000 hertz is more than 3 octaves above the peak and therefore should include nearly all the jet noise.

Although the jet noise radiates in all directions, a dominant portion of its power radiates through a limited range of angles. In order to determine this range, polar distributions of the sound pressure at the frequency associated with the peak value of jet noise were examined on a 30.5-meter (100-ft) radius. These data are shown in figure 5, where the sound pressure level at 100 hertz is plotted against angular position for both hard and lined configurations. The curves are characterized by high levels at large angles and by relative minima at approximately 70°. Thus total sound power for the jet was calculated over the angular positions from 70° to 160°. Because of the much higher sound pressure levels at larger angles, the precise selection of 70° did not have a critical effect on the calculated value of jet sound power. The noise from 0° to 70° is associated with the inlet.

RESULTS AND DISCUSSION

The criteria used to separate jet noise from the total noise measured were described in the previous section. In this section the results are presented and compared with other results from the literature. The data of sound power are presented first, followed by a comparison of the measured spectra with the spectra given by the SAE. Finally, peak values of overall sound pressure level are presented and compared with correlations from the literature.

Correlation of Jet Sound Power

Jet sound power in watts is shown as a function of the Lighthill parameter $\rho_o AV^8/c_o^5$, also in watts, in figure 6. Data from both hard and lined configurations are shown. It is evident that there are two distinct patterns of behavior displayed by the two sets of data. A least squares fit of the data from the lined configurations gave

$$P = 2.3\times10^{-5}\left(\frac{\rho_o AV^8}{c_o^5}\right)^{1.0} \qquad (1)$$

The data from the lined configurations thus correlate well with the Lighthill parameter. The coefficient in equation (1) is also in reasonable agreement with the literature value that is given as 3×10^{-5} in reference 2.

The data from the hard-wall configurations, in contrast, lie above the lined configuration data and have a weaker dependence on the Lighthill parameter. A possible explanation for this result is that there is low-frequency noise generated within the fan nacelle and that this noise is effectively removed by the acoustic liner. The possibility that low-velocity jet noise may be dominated by internally generated noise has been suggested previously, for example, in references 3 and 5. In reference 5, it is shown that the velocity dependence of the internal noise sources is less than the usual eighth-power dependence found for free jets. Thus, as the velocity is decreased, other sources having a lower velocity dependence become more important contributors to the sound power. This effect could cause the larger sound power and weaker velocity dependence observed for the hard-wall data.

Correlation of Jet Noise Spectra

In figure 7, experimental octave spectra are compared with spectra predicted by the SAE correlation of reference 9. Data are shown from a microphone at the 150° position for a lined nacelle for several fan speeds. The SAE correlation is based on a dimensionless Strouhal number. In converting the Strouhal number to frequency, the annulus height of the fan exhaust nozzle was used as the characteristic dimension rather than the equivalent diameter of the annulus. This procedure gave improved agreement between the measured and predicted spectra and suggests that annulus height is the better of the two choices for the present data. The level of each predicted spectrum was determined such that its overall sound pressure level was equal to that of the measured spectrum. As shown in the figure, the shapes of the predicted and measured spectra agree reasonably well. The largest differences occur at the higher frequencies and at the lower fan speeds. This is probably due to the increasing influence of the fan-dominated portion of the spectrum that does not decrease as rapidly with decreasing fan speed as does the jet noise.

Correlation of Maximum Overall Sound Pressure Levels of Jet Noise

The maximum values of overall sound pressure level, $OASPL_m$, have been computed both on a 30.5-meter (100-ft) sideline and on a 30.5-meter (100-ft) radius. In general, the angular position at which the sideline maximum was observed was 140° from the fan inlet. The polar maximum was observed at 150° and 160° for the hard and lined configurations, respectively. The sideline data are compared with an extrapolated curve from the SAE correlation, and the polar data are compared with the correlation obtained in reference 3.

In figure 8, the sideline data from both hard and lined configurations are plotted in terms of the SAE correlation parameter $OASPL_m - 10 \log (\rho^2 A)$ as a function of jet velocity. As was true of the sound power data, the hard-wall results are above the lined results and have a weaker velocity dependence. The same explanation applies here also, namely, that internal noise present in the far field of the hard-wall configurations is effectively removed when the acoustic liners are installed. A least squares curve is shown through the lined configuration data. The velocity exponent found for this curve fit was 8.3.

The SAE correlation curve does not extend to velocities less than 304.8 meters per second (1000 ft/sec). The curve shown in figure 8 and attributed to the SAE was obtained by linear extrapolation on the log plot of the SAE curve from the velocity range of 304.8 to 609.6 meters per second (1000 to 2000 ft/sec). As shown in the figure, essentially all of the present data lie below the extrapolated SAE curve. The curve describing the present lined configuration data is approximately 6 decibels below the SAE curve. This difference is most probably related to the density function appearing in the SAE correlation. Other investigators have found a weaker dependence of $OASPL_m$ on jet density than the squared dependence given by the SAE correlation. In references 3 and 10, for example, the first-power dependence was found, while in reference 11, the total radiated power was found to be independent of jet density. In the present data, the jet was essentially at atmospheric density; thus, the present density was probably of the order of 2 to 2.5 times that of the hot jets from the engines used to obtain the SAE correlation. If the atmospheric density were used in the calculation rather than jet density, the SAE curve of figure 8 would be lowered by 6 to 8 decibels and would then agree more closely with the present data.

A correlation similar to that of the SAE is given in reference 3 for both engine data and cold model jets. The correlation parameter, based on the maximum polar value of overall sound pressure level, is $OASPL_{m,p} - 10 \log\left(\rho_o \rho T_o^2 A\right)\Big/\left(\rho_{isa}^2 T_{isa}^2 R^2\right)$. In figure 9 data from the hard and lined configurations are plotted in this form as a function of jet velocity. From the figure, it can be seen that the data from the lined configurations are in good agreement with curve A. Curve A was obtained in reference 3 from nozzle experiments in which considerable effort was expended to eliminate upstream turbulence and flow noise. Data from the hard-wall configurations are somewhat above curve B from reference 3. Curve B was obtained from tests of a simulated engine-nozzle rig in which the combustor cans were removed from the upstream piping. The flow in this case was relatively "clean" or free of upstream turbulence or flow noise. From these comparisons it appears that the flow from the present fan nozzle is relatively "clean," even in the hard-wall configuration of the nacelle. Further, the acoustic liner was apparently successful in eliminating the effects of upstream or internal low-frequency noise, an effect not necessarily expected since the liner was designed for higher frequency sound attenuation.

Finally, figure 9 also shows curve C from reference 3. This curve represents data from a variety of engine and model rig tests. If these data include the contribution of noise from internal sources, it appears that acoustic liners might offer the possibility of attenuating this noise with the result that curve C could be moved toward curve A or B.

SUMMARY OF RESULTS

The contribution of jet noise to the total far-field noise from a full-scale fan model has been determined for two simulated fan nacelles. These were a hard-wall nacelle and one in which acoustic liners were placed on the walls and on inlet splitter rings. The data were obtained at the low velocities, 137 to 223 meters per second (450 to 730 ft/sec), typical of high-bypass-ratio fan engines. The results may be summarized as follows:

1. The acoustic liners effectively removed noise from internal sources so that the lined configuration data, either as sound power or as maximum overall sound pressure level, followed the classical eighth-power dependence on velocity.

2. Similar data from the hard-wall configurations had higher noise levels and displayed a weaker velocity dependence than did the data from lined configurations. This was due to a low-frequency contribution to the sound from sources inside the fan nacelle.

3. The overall sound pressure levels from the lined configurations were in good agreement with a correlation for unheated jets, but about 6 decibels less than would be predicted by extrapolation of the SAE correlation. It was observed that the discrepancy relative to the SAE correlation was probably related to the dependence of the predicted noise levels on the second power of jet density.

4. The shape of the sound pressure spectra agreed well with the correlation given by the SAE when annulus height of the nozzle was used as the characteristic dimension in the Strouhal number.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, January 25, 1971,
126-61.

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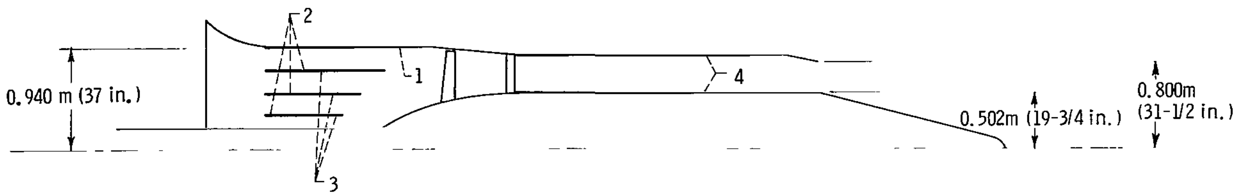
TABLE I. - NACELLE CONFIGURATIONS

Configuration		Inlet length	Nozzle area, percent design
Hard	Lined		
1	13	Short (1.524 m; 60 in.)	110
2	10	Short	97
3	11	Long (2.54 m; 100 in.)	97
4	12	Long	110



Acoustic liner characteristics

Surface	Open area ratio, percent	Hole diameter		Backing depth	
		in.	cm	in.	cm
1	2.5	0.032	0.082	0.88	2.24
2	2.5	.032	.082	.20	.51
3	2.5	.032	.082	.68	1.73
4	8.0	.050	.127	.88	2.24

Figure 1. - Cross-sectional sketch of acoustically treated inlet and exhaust ducts for large-scale fan. Plate thickness, 0.051 centimeter (0.020 in.); 0.953-centimeter (3/8-in.) hexagonal honeycomb.

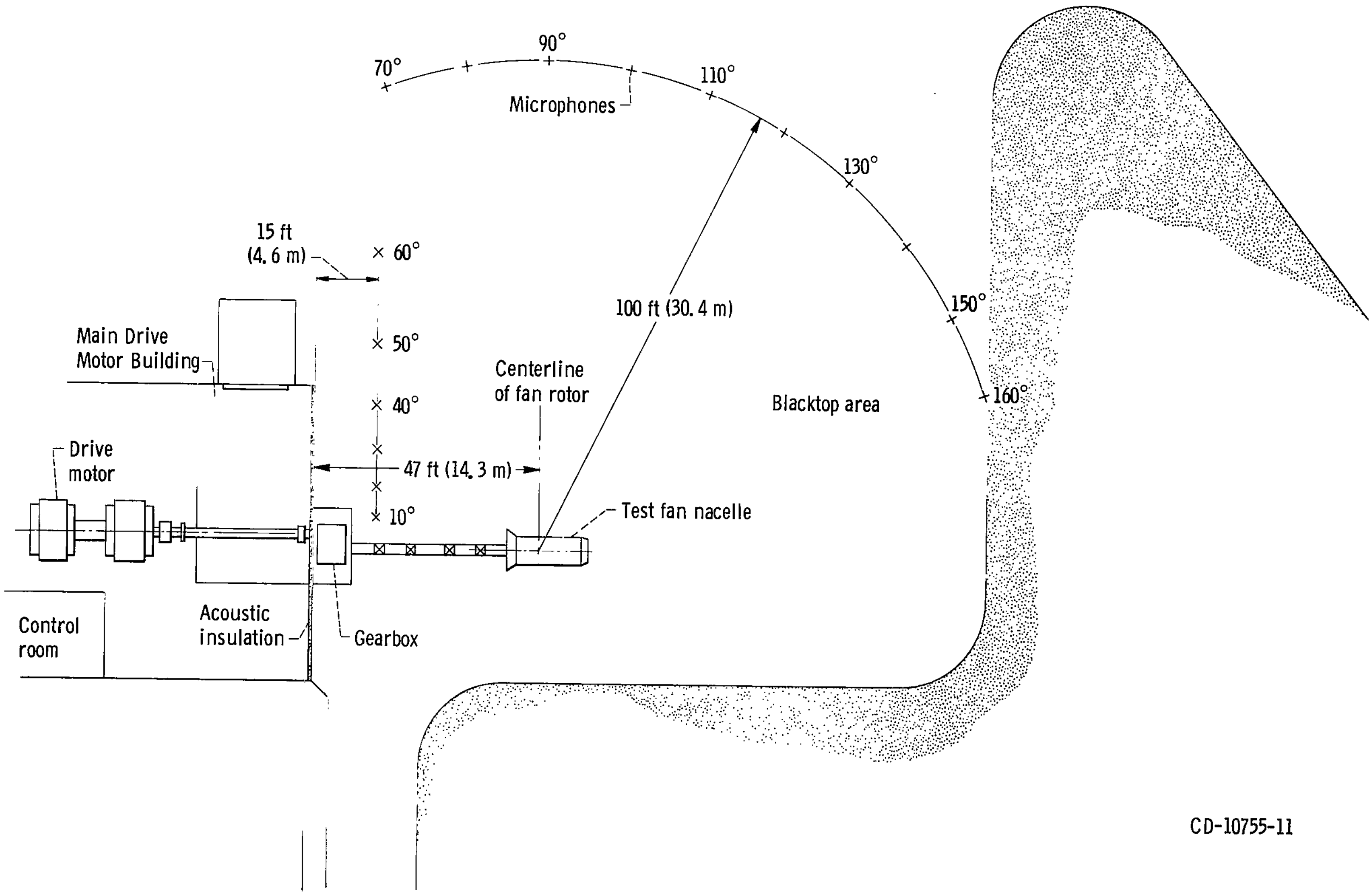
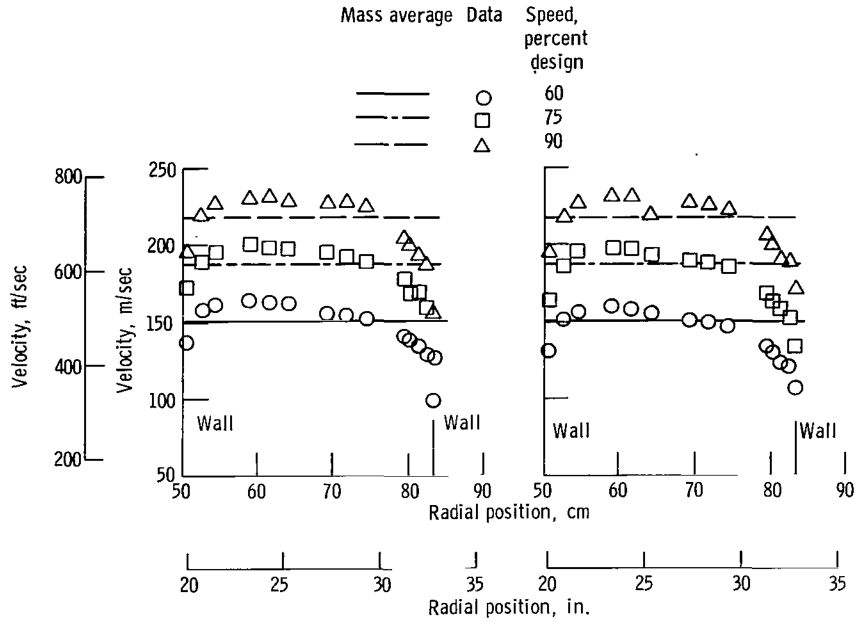


Figure 2. - Plan view of quiet fan facility area with microphone locations. Microphones at fan shaft elevation, 19 feet (5.8 m) above ground. (Scale: 1 in. = 20 ft; 1 cm = 2.4 m).



(a) Hard wall. (b) Lined wall.

Figure 3. - Nozzle exit velocity profile.

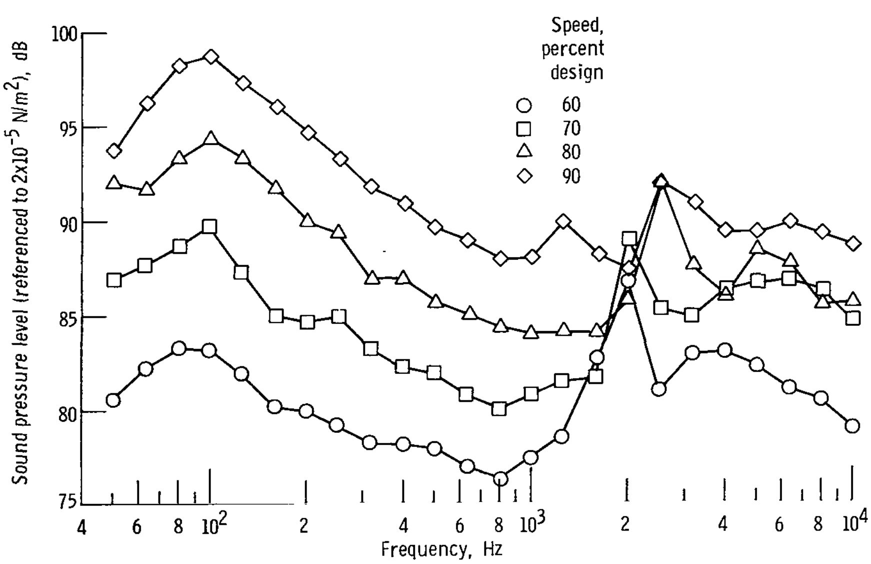


Figure 4. - Spectra of sound pressure level. Radius, 30.5 meters (100 ft), 160°; configuration: short inlet, 110-percent nozzle, hard wall.

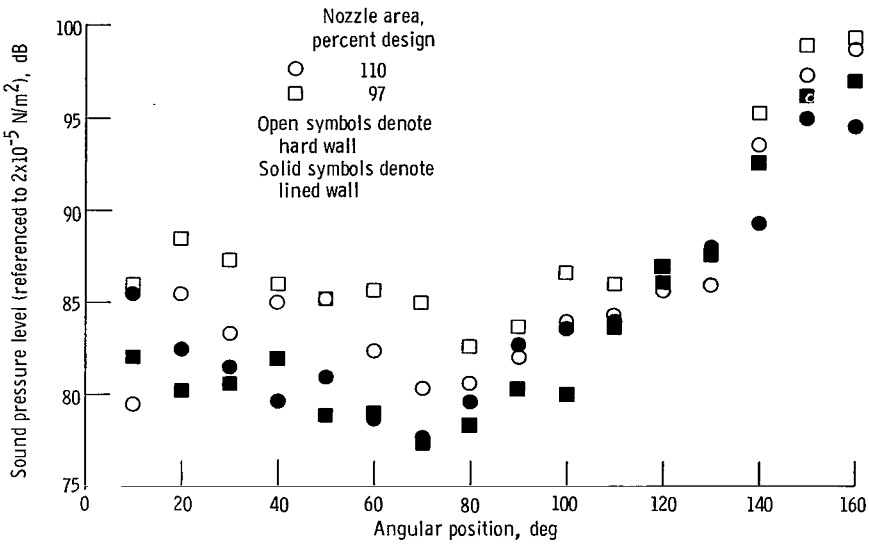


Figure 5. - Angular distribution of 1/3 octave sound pressure level for short-inlet configuration at 100 hertz. Radius, 30.5 meters (100 ft); speed, 90 percent design.

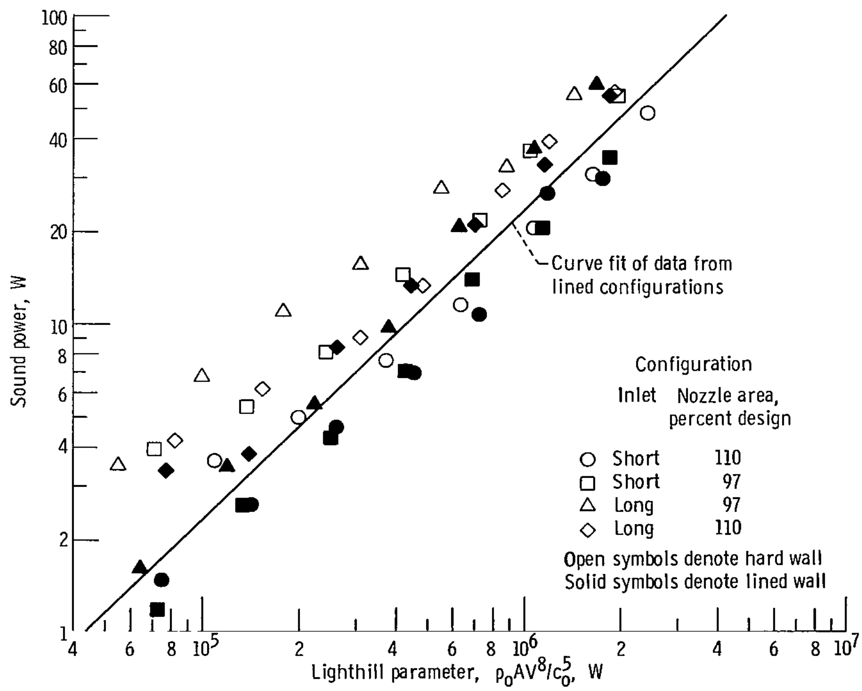


Figure 6. - Noise power as function of Lighthill parameter.

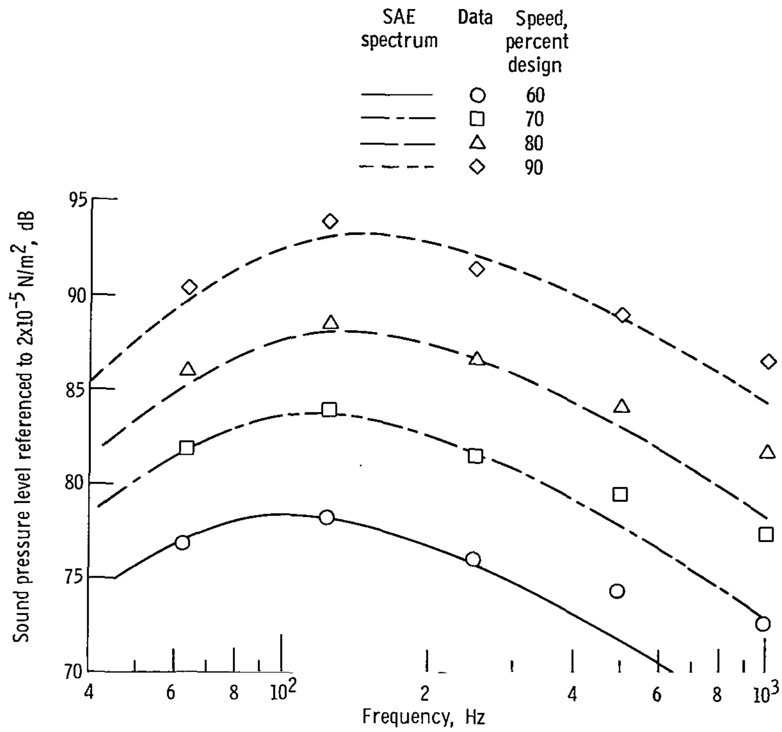


Figure 7. - Comparison between SAE standard spectrum and data of sound pressure level. Radius, 30.5 meters (100 feet), 150°; configuration: short inlet, 110 percent nozzle, lined wall.

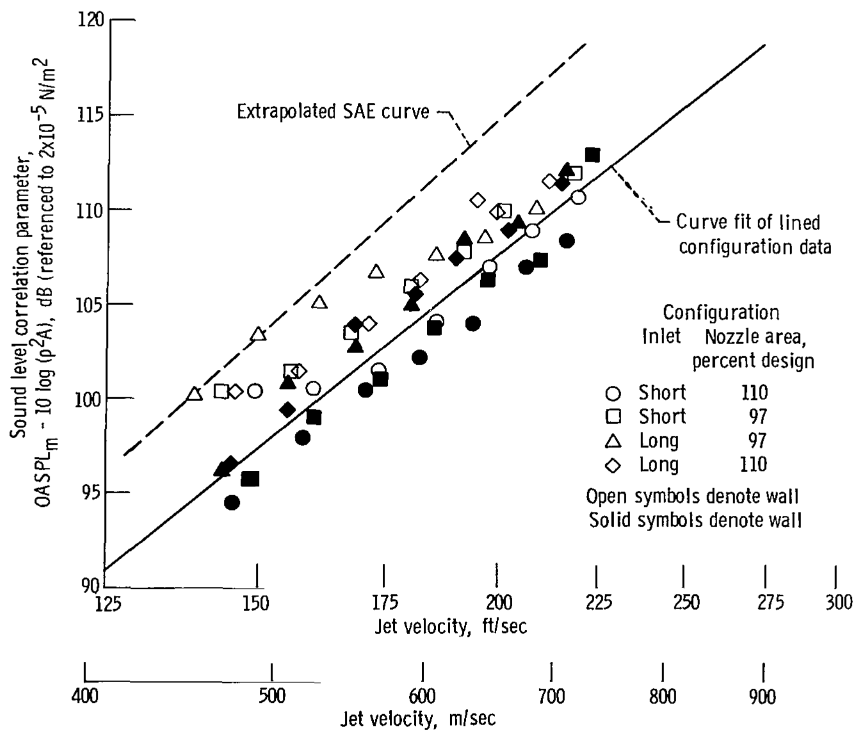


Figure 8. - Sound level as function of jet velocity. Radius 30.5 meters (100 feet).

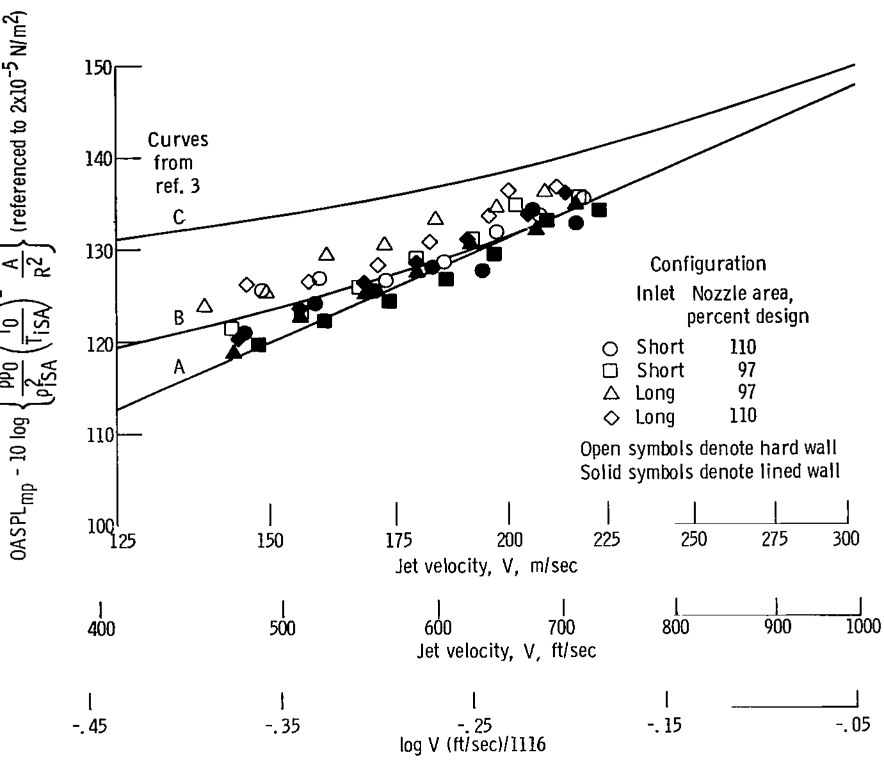


Figure 9. - Maximum polar sound level as function of jet velocity.

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