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SOME RESULTS OF RECENT RESEARCH ON FAN AND JET NOISE AT LEWIS RESEARCH CENTER

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JET NOISE AT LEWIS RESEARCH CENTER

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ABSTRACT

A six-foot-diameter low-speed fan designed for low-noise production was tested to provide data on noise generation, suppression effects of acoustic treatment, and exhaust jet noise. Preliminary results showed that the overall noise varied with the 5.5 power of the fan speed but was independent of blade loading obtained by varying back pressure at constant speed. The low-velocity jet from the fan produced noise that followed the eighth power law and was lower than predicted by extrapolation of the SAE curve. Modifying the SAE method to eliminate the effects of jet density greatly improved the agreement between prediction and data.

INTRODUCTION

This paper discusses some results of recent research on fan and jet noise at the Lewis Research Center of the NASA. These results were obtained from on-going programs which are not yet complete. As a consequence, this paper will not give complete stories or final conclusions. Rather, this paper is an intermediate progress report on selected portions of the program. Specifically, the topics to be covered are: the generation of noise by large, low-speed fans; the suppression of fan noise by acoustic treatment; and the production of noise by the discharge jet from a large, low-pressure-ratio fan.

FAN NOISE GENERATION

The facility used for conducting research with full-scale fans is shown in figure 1. The fan is mounted in a boiler-plate nacelle whose proportions can be adjusted to accommodate various fan arrangements, various duct lengths, and acoustic treatment. The fan is driven by a drive shaft which is connected through gears to the drive motors of a large wind tunnel. The nacelle is mounted on a tall concrete pylon and the surrounding ground is paved to promote reproducibility of acoustic measurements.

The particular fan that produced the data to be discussed here is shown in figure 2. Salient characteristics of the fan are listed in figure 3. The low tip speed of 1107 feet per second was chosen for low-noise production. Rotor and stator blade numbers were chosen to minimize the production of sound in the rotating modes. The stator was spaced 3.7 rotor chord lengths behind the rotor to reduce interaction noise.

Listeners report three types of noises from the fan: a broadband random noise; discrete tones; and buzzsaw or multiple pure tones. Narrow-band spectra illustrating these three noises are shown in figure 4. The microphone was located in front of the inlet and ten degrees off the axis; the analyzer bandwidth was 10 Hz. Spectra are shown for the fan with three different discharge nozzle areas corresponding to three different blade loadings as obtained by varying back pressure at 90 percent speed. Discrete spectral spikes are seen rising above the random broadband noise; these peaks are at the fundamental and harmonics of the blade passing frequency. With the intermediate-sized nozzle, a jumble of spectral lines is evident toward the low-frequency end of the spectrum; these make up the multiple pure tone or "buzzsaw" noise. It is interesting to note that the multiple pure tones are most prominent at an intermediate nozzle size and are less evident with the larger or smaller nozzles. It is clear, therefore, that the relative importance of the three noises depend upon the operating conditions of the fan.

The acoustic power in the three classes of broadband, blade passing tones, and multiple pure tones can be determined by inspection and integration of spectra such as those shown in figure 4. The polar distribution of blade passing tones and broadband noise are shown in figure 5. The blade passing tones are dominant ahead of the fan and the broadband noise is dominant behind the fan. At the conditions of this test the multiple pure tones were very low.

The total acoustic power can be obtained by integrating the sound field around the fan. Results of such an integration are shown in figure 6 which shows the total acoustic power as a function of discharge nozzle area at 90 percent design speed. The variation of nozzle area causes a variation of stage operating point, large area corresponds to light blade loading and small area corresponds to heavy blade loading. The broadband acoustic power is almost independent of operating point in these tests. The acoustic power in the blade passing tones are weakly dependent on operating-point blade loading and have a poorly defined minimum at the intermediate nozzle size. The acoustic power in the multiple pure tones is extremely sensitive to operating-point blade loading and nearly reaches the value of the blade passing tones at the intermediate nozzle size. The overall noise power is nearly independent of operating-point blade loading because the broadband noise is dominant. This conclusion might not apply to high-speed, close-spaced, or multistage fans.

The effects of fan rotative speed on fan noise are shown in figure 7. The broadband sound power rises rapidly with fan speed; approximately as the 4.5 power of the speed. The blade passing tone noises also rises rapidly with speed, but passes through a maximum and falls slightly at the highest speed tested. The multiple pure tones are very low at low fan speeds but rise at an extremely rapid rate as the tip speed approaches the speed of sound, and exceeds the blade passing tones at the highest speed. The overall noise is dominated by the broadband noise at the lower speeds, and varies approximately with the 5.5 power of the fan speed. This conclusion may not hold for higher speed fans or for fans of different design.

The preceeding results showing small effects of operating-point blade loading and large effects of fan speed on noise discourage somewhat the prospects of trading low-blade loading for high-fan speed to obtain low noise. The results presented here are preliminary and further research now in progress may give different results.

Perceived noise levels were computed from spectral data and adjusted for distance to corresponding positions along a sideline 1000 feet from and parallel to the fan axis. Results are shown in figure 8. The noise levels are very low, and if 6 PNdB were added to correspond to a four-engine transport, the values are below the FAA ceiling of 108 PNdB.

ACOUSTIC TREATMENT

Even lower noise levels can be reached by adding acoustic absorption at the fan inlet and outlet. Successful reductions of the noise of two-stage fan engines were demonstrated by McDonnell-Douglas and Boeing under contracts with NASA.[1] Zero to modest performance and weight penalties were incurred. The Lewis Research Center conducted further tests with the single-stage, low-pressure-ratio fan and test facility described earlier to determine the affectiveness of acoustic treatment in the inlet and discharge. Figure 9 shows the inlet treatment which consists of honeycomb-backed perforated plates covering the walls of the inlet duct and all surfaces of the three splitter rings. Figure 10 gives details of the treatments of the inlet and discharge ducts.

Spectra of the noises at peak angle at take-off speed (90 percent design) from the front and rear of the fan are shown with and without treatment in figure 11. Large reductions in the blade-passing noise and the broadband noises were obtained. The inlet noise was reduced 15 PNdB and the discharge noise was reduced 12 PNdB.

JET NOISE

A fan discharges a large, low-velocity, cold jet. The mixing of this jet with the surrounding atmosphere generates noise external to the nacelle. This noise can be higher than fan noise radiated from truly quiet fan installations. Thus, the jet noise represents a practical floor below which it is extremely difficult to go. In many V/STOL airplane designs, this noise floor

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[1] NASA Acoustically Treated Nacelle Program, NASA SP-220, October, 1969.

is greater than the desired noise level. Accurate estimates of the low-velocity jet noise floor are important in these cases. The full-scale fan experiments described earlier provide new data on low-velocity jet noise.

A spectrum of noise measured behind the fan with acoustic treatment in the nacelle is shown in figure 12. An estimated spectrum of jet noise[2] has been adjusted to the level of the data and plotted in the figure. The observed spectrum falls above the adjusted jet spectrum at frequencies above 1000 Hz. It was assumed that the noise below 1000 Hz is jet noise and the higher frequency noise is broadband noise from the fan.

The low-frequency sound intensities in the rear hemisphere were integrated to obtain total jet sound power in watts. This power is plotted as a function of the Lighthill parameter in figure 13. The Lighthill parameter is proportional to the density of the surrounding air, ρ_0; the area of the jet, A; the velocity of the jet, V; and inversely proportional to the speed of sound in the surrounding air, a_0. A straight line with a slope of unity fits the data very well indicating that the eighth power law holds.

This result is contrary to some widely known experiences with complete jet engines. At idle power settings, the jet velocities are low and the observed noises are higher than would be expected from an eighth power extrapolation of noise at high jet velocities. The measured engine noises at low jet velocities may be higher than the jet noise because of other noises such as the fan noise discussed earlier, turbine noises, combustion noises, and tailpipe obstruction noises. For the present data, the acoustic treat-

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[2]Jet Noise Prediction, SAE AIR 876, 1965.

ment probably reduced the internally generated noise so that the results shown are representative of jet noise only.

Another discrepancy may be the effects of jet temperature on noise. The SAE prediction formula assumes that the jet noise is proportional to the jet density squared. This assumption is open to doubt as can be seen by comparing data between cold jets and hot engines in figure 14. This slide, which is 15 years old, shows total acoustic power in watts as a function of the Lighthill parameter.

Data from small cold air jets at low velocities correlate well with the data from nonafterburning turbojet engines when plotted this way. The slope of the correlating line is unity indicating that the eighth power law represents the data. Also the density and speed of sound in the surrounding medium were used to obtain this correlation.

The SAE correlation curve[2] was modified in figure 15 assuming that noise power is proportional to atmospheric density. The SAE curve was obtained from data on hot engines. We guess that this temperature averaged 2.5 times the atmospheric temperature. This change lowers the SAE curve 8 decibels. The extrapolation of the SAE curve now fits the data that were previously shown in figure 13.

The foregoing analysis and data seem to reaffirm the 15-year-old conclusion that low-velocity jet noise is proportional to eighth power of the jet velocity; directly proportional to the density of the surrounding atmosphere, and independent of the jet temperature.

CONCLUDING REMARKS

Experiments with a large, low-speed fan designed for low-noise production showed that the broadband noise dominated the sound field at most speeds. This broadband noise, and the overall noise were nearly independent of blade loading as obtained by varying operating point at fixed speed. The overall noise varied with approximately the 5.5 power of the fan speed. The noise level of the fan is lower than the FAA requirements for large airplanes, and acoustic treatment produced further large reductions in noise levels. The low-velocity jet from the fan produced noise according to the eighth power law, and is lower than would be predicted by extrapolation of the SAE prediction curve. Modifying the SAE method by eliminating the effects of jet density greatly improved the agreement between the prediction and the data.

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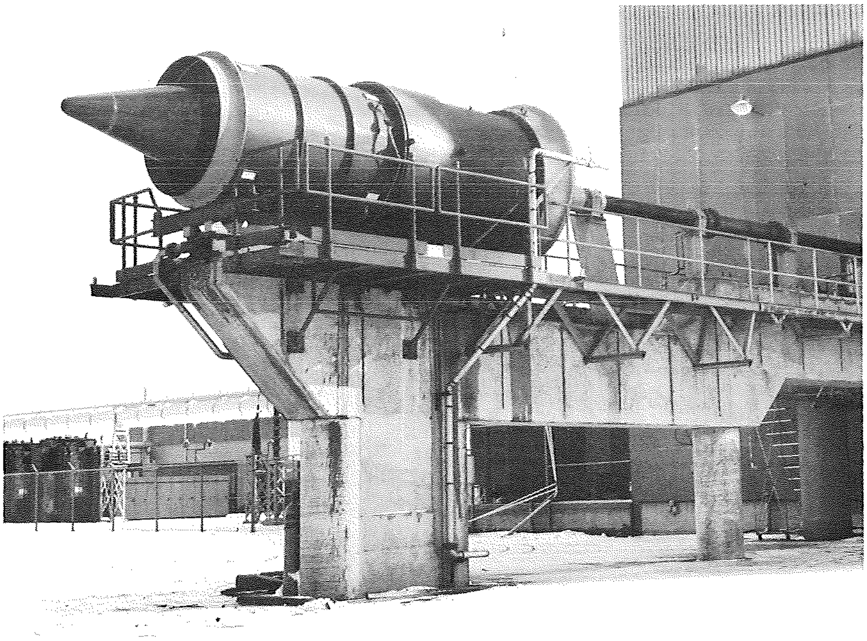
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Figure 1. - Fan assembly installed in test facility.

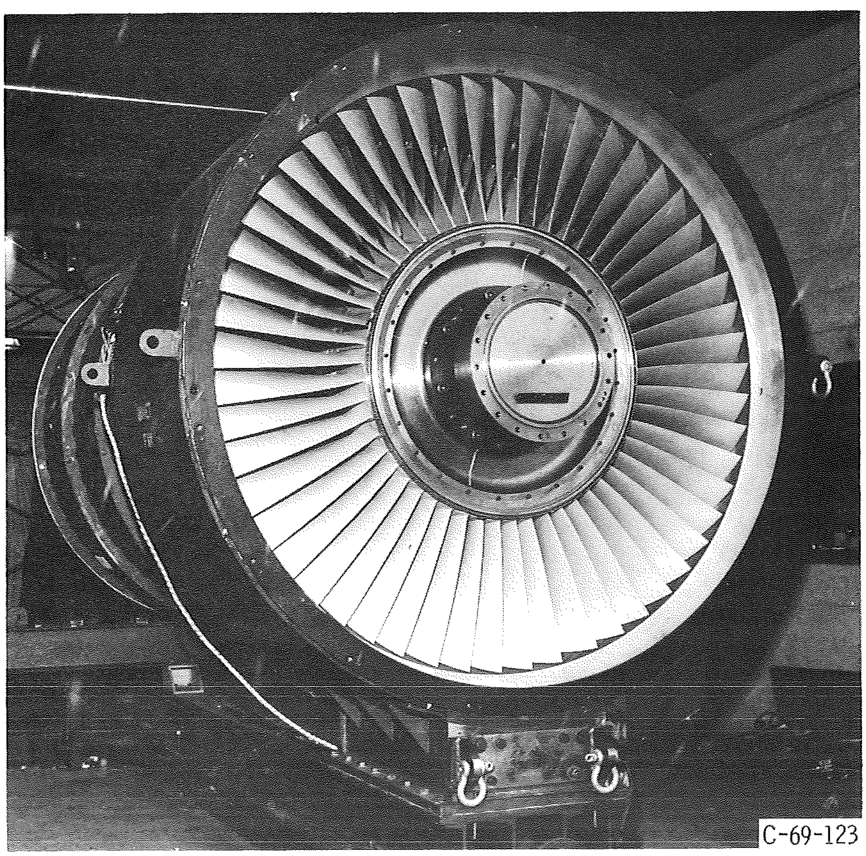
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Figure 2. - Inlet face of rotor in fan assembly.

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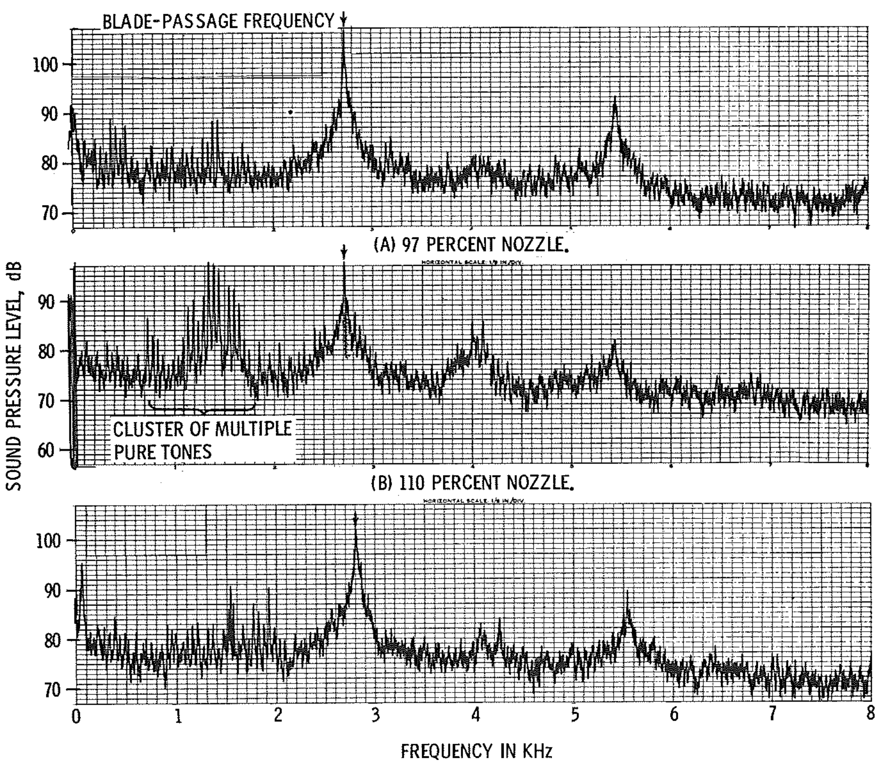
FAN PRESSURE RATIO	1.5
ROTOR TIP DIAMETER, IN.	72
NOMINAL THRUST, LB	24 000
ROTOR TIP SPEED, FT/SEC	1107
NUMBER OF ROTOR BLADES	53
NUMBER OF STATOR BLADES	112
ROTOR-STATOR SPACING IN ROTOR CHORDS	3.7

Figure 3. - Fan design characteristics.



(C) 124 PERCENT NOZZLE.

Figure 4. - Fan spectra at 90 percent speed.

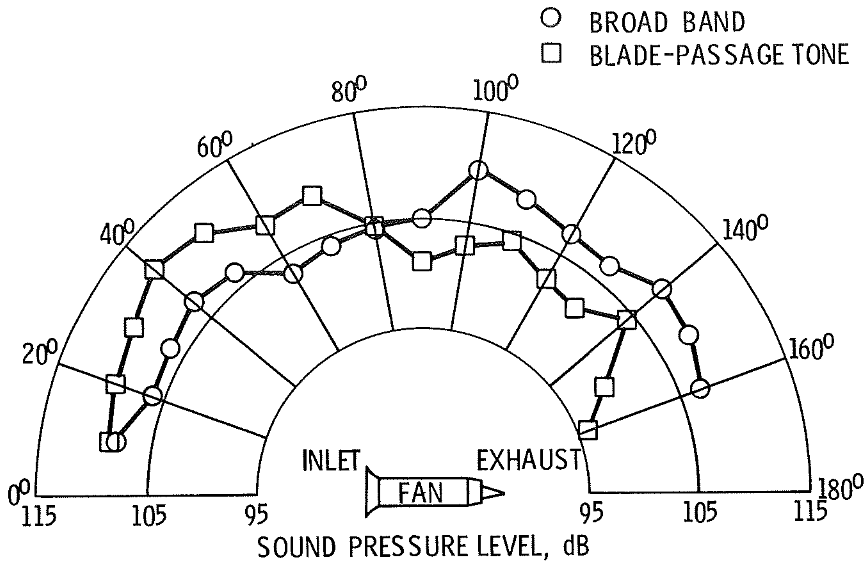


Figure 5. - Azimuthal distribution of sound pressure level at 90 percent speed for broad-band and blade-passage tone noises.

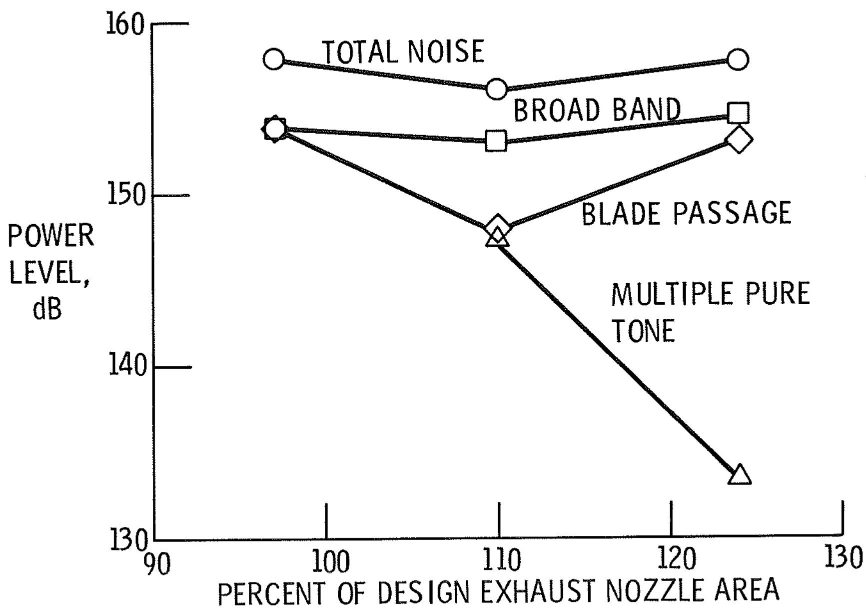


Figure 6. - Effect of loading on total noise at 90 percent of design speed.

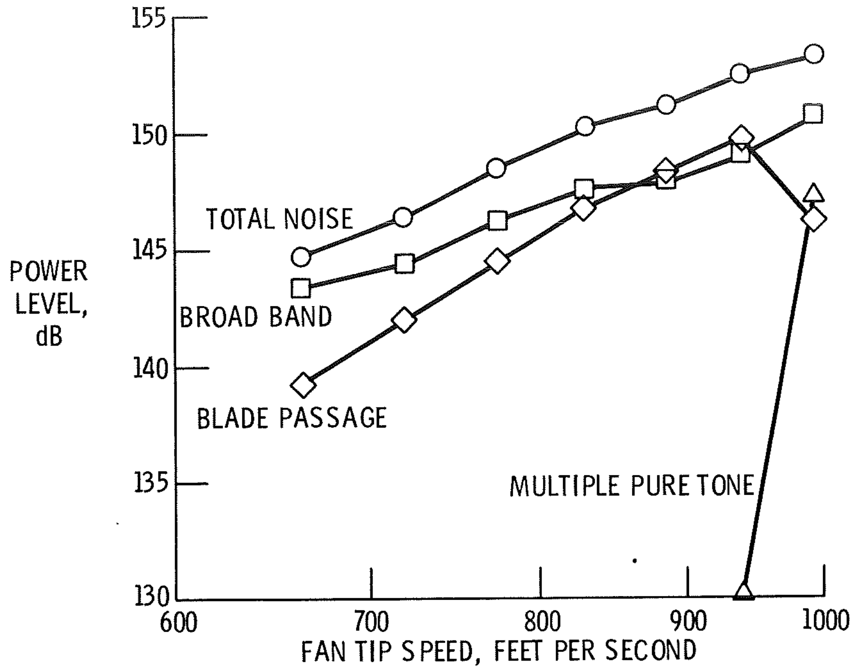


Figure 7. - Effect of speed on forward-radiated noise with 110 percent of design exhaust nozzle area.

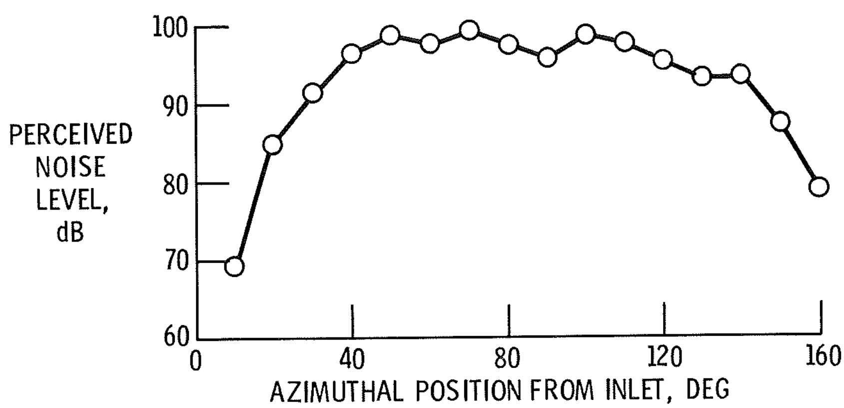


Figure 8. - Perceived noise at 90 percent speed on a parallel line 1000 feet from fan axis.

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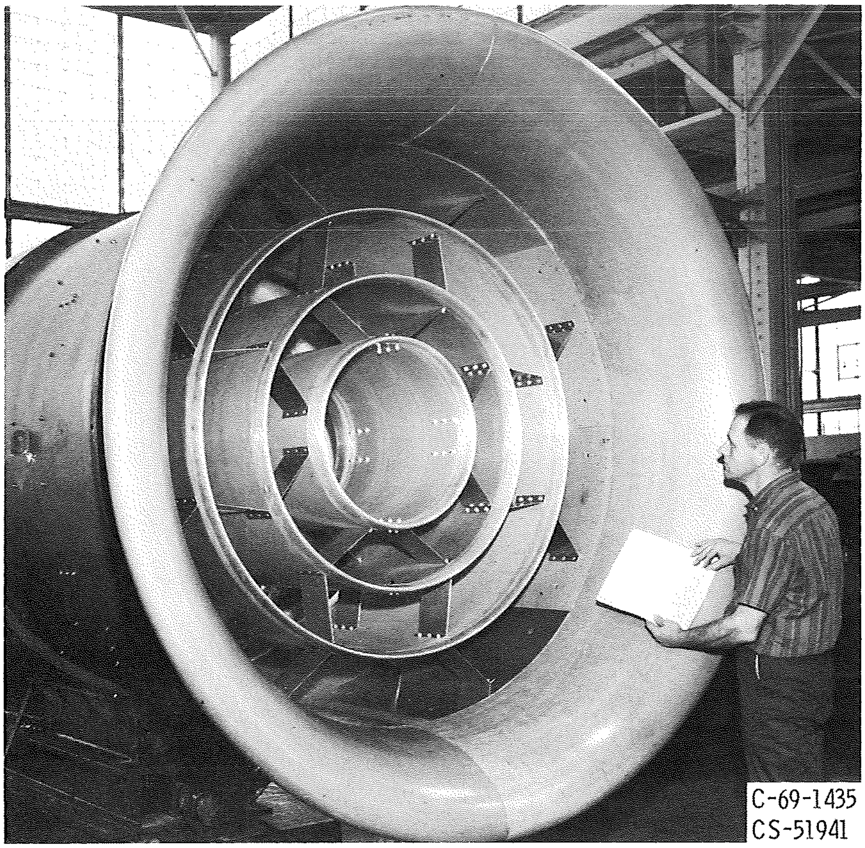
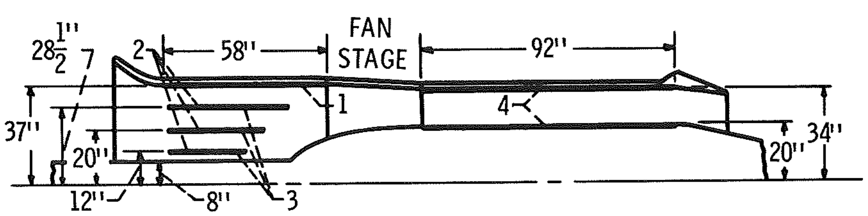


Figure 9. - Inlet duct with acoustic treatment.



	OPEN AREA RATIO, %	PLATE THICKNESS, IN.	HOLE DIAM, IN.	BACKING DEPTH, IN.	HONEYCOMB
1	2.5	0.020	0.032	0.88	3/8 IN. HEX
2	2.5	.020	.032	.20	3/8 IN. HEX
3	2.5	.020	.032	.68	3/8 IN. HEX
4	8.0	.020	.050	.88	3/8 IN. HEX

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Figure 10. - Details of treatment.

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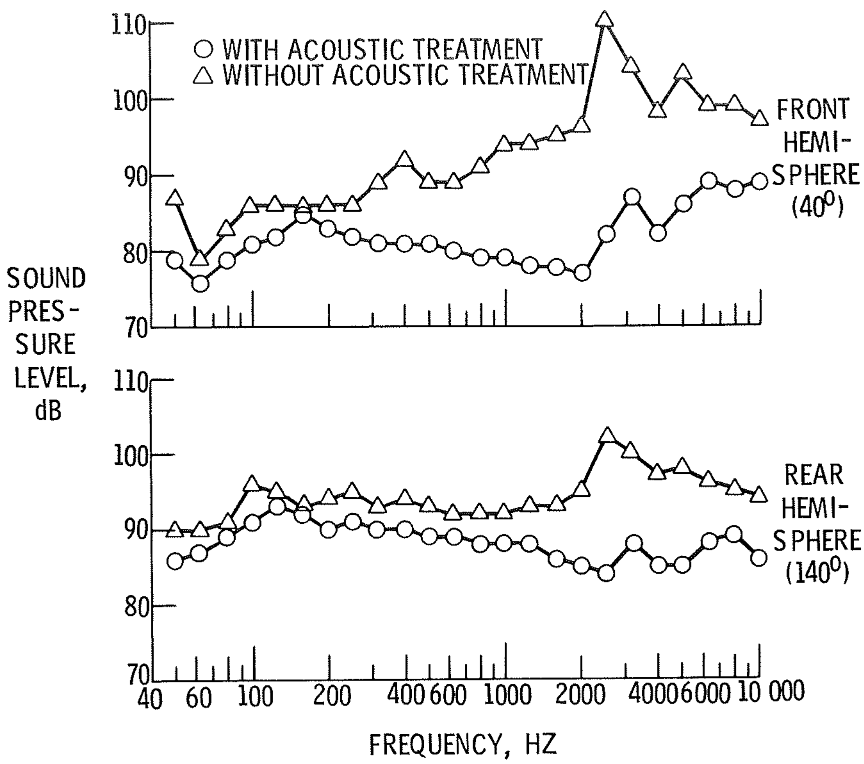

Figure 11. - Noise spectra at takeoff speed with and without acoustic treatment.

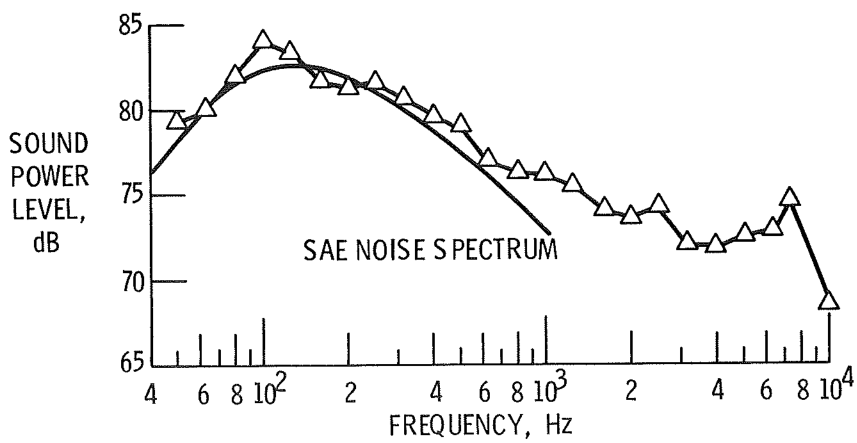

Figure 12. - Spectrum of fan discharge noise.

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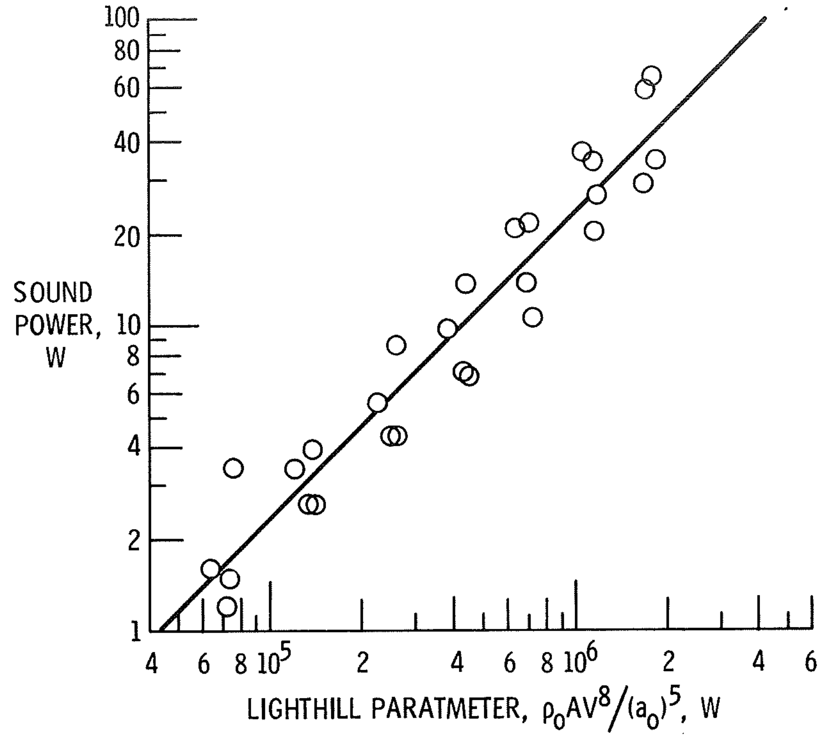

Figure 13. - Low velocity jet noise.

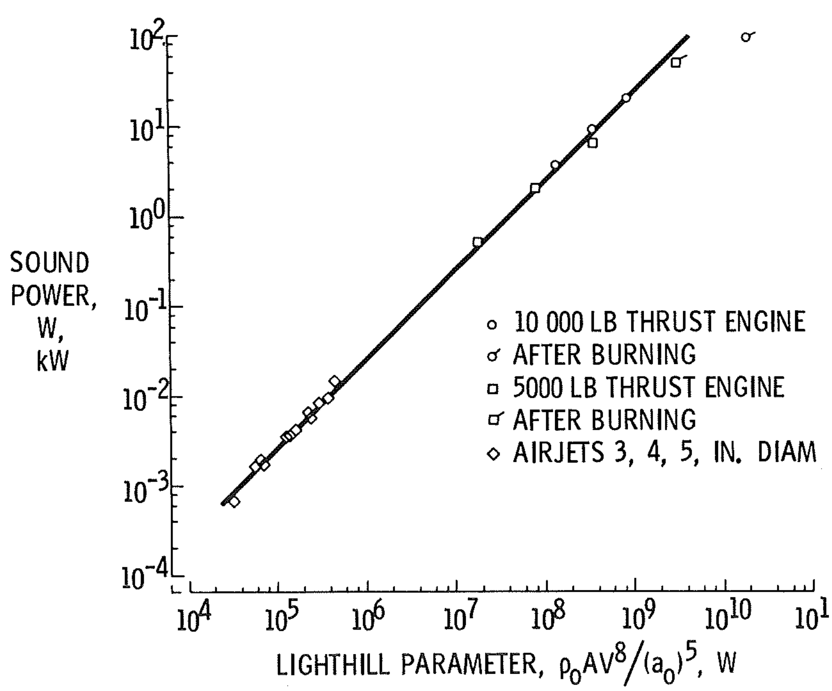

Figure 14. - Sound power as a function of Lighthill parameter.

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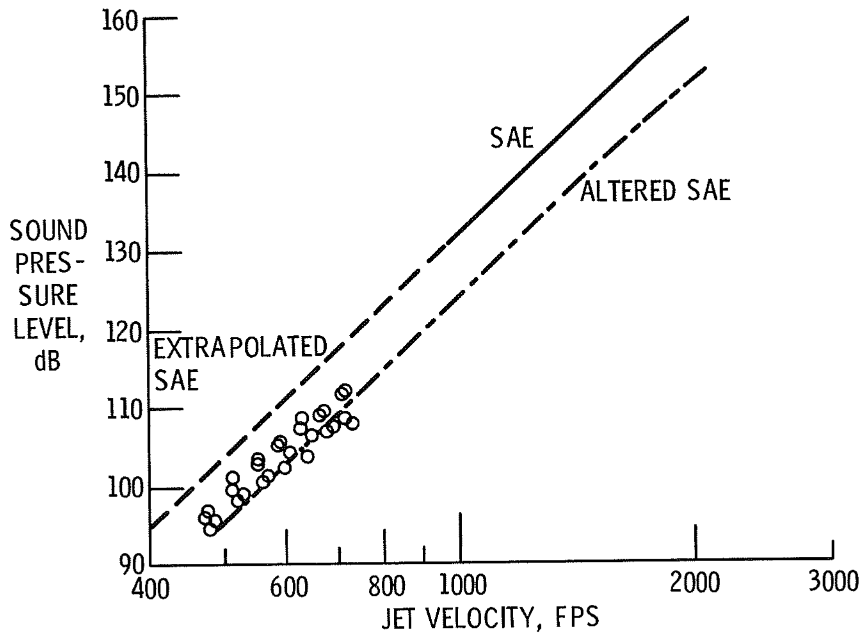

Figure 15. - Jet sound pressure level.

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