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REDUCTION OF FAN NOISE IN AN ANECHOIC CHAMBER BY REDUCING CHAMBER WALL INDUCED INLET FLOW DISTURBANCES

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ABSTRACT

The difference between the flight and ground static noise of turbofan engines has been identified as a significant problem in engine noise testing. The additional noise for static testing has been attributed to inlet flow disturbances or turbulence interacting with the fan rotor. In an attempt to determine a possible source of inflow disturbances entering fans tested in the Lewis Research Center anechoic chamber the inflow field was studied using potential flow analysis. These potential flow calculations indicated that there was substantial flow over the wall directly behind the fan inlet that could produce significant inflow disturbances. Fan noise tests were run with various extensions added to the fan inlet to move the inlet away from this backwall and thereby reduce the inlet flow disturbances. Significant noise reductions were observed with increased inlet length. Over 5 dB reduction of the blade passage tone sound power level was observed between the shortest and longest inlets at 90% fan speed and the first overtone was reduced 9 dB. High frequency broadband noise was also reduced.

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INTRODUCTION

The difference between flight and ground static noise data in fan jet engine noise testing has been identified in the past few years as a significant problem (ref. 1). The primary difference occurs at the blade passage frequency for "cutoff" fans. The flight tone is almost nonexistent while the ground static tone is very prominent. This additional tone noise for static testing has been attributed to some inlet flow disturbance creating noise as it interacts with the fan rotor. Many possible disturbances exist ranging from fixed inlet flow distortions to elongated turbulence (refs. 2 and 3). Fan tests conducted in anechoic chambers also show additional blade passage tone noise.

In an attempt to determine the source of possible inflow disturbances entering a fan tested in the Lewis Research Center anechoic chamber, the inflow field was studied using a two-dimensional potential flow analysis. The potential flow analysis showed that significant flow velocities could occur over the wall behind the fan inlet. It was postulated that this flow could produce significant flow disturbances. The inlet length of the fan was increased by the use of extension pieces to move the inlet away from this back wall. The noise data obtained with these longer, cleaner inlets are compared with the noise data obtained with the standard and shorter inlets.

The able assistance of D. H. Dittmar during the initial experimental portion of this program is gratefully acknowledged.

STAR Category 71

POTENTIAL FLOW ANALYSIS

A two-dimensional potential flow analysis was undertaken to identify possible sources of inlet disturbances entering the inlet of fans tested in the Lewis Research Center anechoic chamber. Figure 1(a) is a picture of the anechoic chamber showing a fan with the standard length bellmouth inlet. Figure 1(b) is a plan view of the chamber showing the fan inlet and the geometry of the room. Figure 1(c) is an elevation view of the room. In order to represent the chamber in two dimensions a cross section was taken to pass through the center of the fan inlet in a horizontal plane which is similar to the plan view of figure 1(b). This horizontal cut was taken since the side wall of the chamber was closer to the fan inlet than was the floor and lateral symmetry about the fan centerline was used in the calculations.

Figure 2(a) shows the potential flow solution obtained with the inlet extending one half of a fan diameter into the room, which is approximately the standard test configuration. For ease of viewing only part of the horizontal plane is shown. The fan centerline is shown on the left and only a portion of the backwall is shown. This figure does not extend to the sidewall or to the silencer wall which were included in the calculations (see fig. 1(b)). The solid lines on the figure represent 5% increments in the streamlines and the dotted lines, where they are shown, indicate 2.5% increments. Since this diagram only shows one half of the fan inlet the other side has the other 50% of the flow.

As can be seen in figure 2(a) a significant portion of the inlet flow passes along the back wall, over the wedges, along the outside surface of the inlet duct and then into the fan inlet. This flow may be contaminated by wakes being trailed from either the anechoic wedges or the "sunburst" arrangement of anechoic wedges around the inlet, instrumentation attached to the outside of the fan inlet duct, and any bolting or flanges for attaching the inlet pieces. In addition a vortex attached to the back wall might enter the fan inlet. Any of these possible situations could create an inlet flow disturbance that would generate extraneous blade passage tone noise.

A number of potential flow calculations were performed with the fan inlet at several distances from the back wall. These longer distances into the room would reduce the influence of the back wall. Figure 2(b) is the potential flow solution when the fan is moved 2 fan diameters into the room. By comparing the two stream line patterns (figs. 2(a) and (b)) the advantages with the fan further into the room can be observed.

The distance of the 45% streamline from the back wall is an indication of the velocity in this region. The smaller the distance between the streamline and the wall the larger the velocity becomes. As can be seen the velocity decreases when the fan inlet is moved into the room. It is expected that moving the fan away from the wall would decrease the wakes from the anechoic wedges, etc. because of the lower velocity. As can be observed the 47.5% streamline is not as affected by the wall wedges when the fan inlet is moved into the room as it was with the standard length and thus less of the fan flow is disturbed. Any disturbance created on this back wall would also have more distance to disperse when the fan protrudes further into the room.

In addition to the potential flow study some crude water table experiments were performed. These tests indicated that wakes trailed from the wedges were likely to enter the fan inlet in the standard length version but were greatly diminished when the fan was moved further into the room.

EXPERIMENTAL APPROACH

The most definitive experiment to assess the possible "back-wall-induced disturbance" concept is to move the fan stage into the room while maintaining a fixed inlet length. However, the practical problems associated with moving the fan, such as increasing shaft lengths, made this approach unfeasible. The approach chosen for this study was to move the fan inlet into the room by using various inlet duct extensions while the fan remained in a fixed position. The longer inlets move the fan intake away from the back wall, which is desired, but increased inlet lengths may have additional effects which would not be seen if the fan itself were moved. The long inlet lengths could (1) increase boundary layer thickness at the fan which might alter the noise, (2) alter the propagation of sound in the duct, and (3) increase the decay of other possible disturbances such as inlet lip separation. Although such additional effects of long inlets may occur it was still felt that the primary noise reduction would be the results of the reduction of the back wall-induced disturbances. Therefore experimentation with various inlet lengths was undertaken as the most feasible method of testing the concept.

APPARATUS AND PROCEDURE

Facility Description

Anechoic chamber. - The results presented herein were obtained in the NASA-Lewis Anechoic Chamber. A detailed description of this facility can be found in reference 4. Figure 1(a) presents a photograph of the chamber and figures 1(b) and (c) present plan and elevation views.

Research fan. - The research fan stage used in this study had a 1.5 pressure ratio, a 337 m/sec (1107 ft/sec) tip speed and contained 53 rotor blades and 112 stator vanes. This fan was designed with a 3.5 rotor chord spacing between rotor and stator and with the blade to vane ratio chosen to satisfy the Tyler-Sofrin cutoff criteria (ref. 5) for the fundamental tone. A detailed description of this fan can be found in reference 6.

Acoustic data. - Far field acoustic data were obtained using 0.64 cm (0.25 in.) microphones on a 7.6 m (25 ft) arc from the fan inlet. The microphones were space in ten degree increments from 0° to 90°. The microphone arc was moved with each inlet extension so that the 7.6 m (25 ft) radius was always centered on the inlet face. The signals from the microphones were analyzed on a one-third-octave band analyzer and recorded on magnetic tape. Data reduction was performed using the computer programs described in reference 7.

Aerodynamic instrumentation. - Aerodynamic data were taken primarily to establish fan operating conditions. The fan operating point was controlled by downstream valves at the collector exit and was monitored on line.

Test Configurations

Inlet lengths. - In the course of the study five lengths were tested. The shortest length tested was with the inlet bellmouth directly coupled to the fan casing and is shown in figure 3(a). This configuration has the bellmouth lip approximately coplanar with the surrounding "sunburst" wedges and is referred to as the $L/D = 0$ length. In this notation L is the length of extension into the room and D is the fan diameter. The next longest length tested ($L/D = 0.6$) was with a 30.5 cm (12 in.) piece between the bellmouth and the casing. A photograph of this inlet length is shown in figure 3(b). This length is the one typically used in the chamber. Two additional inlet pieces were manufactured for this testing, they were 91.4 cm (3 ft), and 1.52 m (5 ft) in length. The various combinations of these pieces and the standard length resulted in inlets of $L/D = 2.4$, $L/D = 3.6$, and $L/D = 5.4$. These inlets are shown in figures 3(c) through (e).

The first four lengths were installed by cantilevering the inlet pieces from the fan casing. The longest configuration required some additional support and a band was attached to the inlet at the junction between the 91.4 cm (3 ft) and 1.52 m (5 ft) pieces. The band was supported from the ceiling by use of a 0.635 cm (1/4 in.) diameter steel cable which is marginally visible in figure 3(e).

Test points. - The data points for each inlet length were taken along the standard operating line at 60, 70, 75, 85, 90, and 95% of design speed. Three data points were taken at each test condition and the results were averaged. The data presented were taken with the room in an open configuration where the airflow enters through the silencer and the aspirating areas on the chamber floor and walls are closed (see figs. 1(b) and (c)).

RESULTS AND DISCUSSION

Sound Power Level

One-third-octave sound power level spectra for the five inlet lengths at 60, 70, 75, 85, 90, and 95% speed are shown in figures 4(a) through (f), respectively. These spectra have been corrected to "lossless spectra" by the addition of 7.6 m (25 ft) worth of excess atmospheric attenuation. These excess atmospheric attenuations were computed using the information in reference 8. Any excess atmospheric attenuation which might occur inside the various lengths of inlet is not accounted for in these spectra. These sound power spectra were calculated for angles from 0° to 80° from the inlet because the 90° microphone was not useable at all inlet lengths. The spectra presented in figure 4 cover the frequency range from 200 to 40 000 Hz.

Blade passage and higher frequencies. - The largest differences in the spectra for the different inlet lengths are at the high frequencies. At 40 000 Hz the trend is the same at all speeds with a consistent noise reduction with progressively longer inlets. The difference between the shortest length (L/D = 0) and the longest length (L/D = 5.4) is as large as 12 dB at 40 000 Hz (95% speed, fig. 4(f)). The trend of the longer inlet being quieter extends from 40 000 Hz down to the blade passage frequency of the fan at all speeds. The difference in blade passage tone powers from the longest to the shortest inlet length is as great as 5 dB (90% speed, fig. 4(e)) and the first overtone difference is as great as 9 dB (90% speed, fig. 4(e)).

The large differences observed in sound power level indicate that the long inlets may be removing some of the inlet flow disturbance and thereby reducing the generated noise. The blade passage tone from rotor-stator interaction should not be present in the spectra because this tone is cutoff. The presence of this tone even at the longest inlet length indicates that some inlet flow disturbance is still present. However, the progressive noise reduction with longer and longer inlets points to the possibility that more and more distortion is being removed and that further inlet flow cleanup might result in even less noise.

The first overtone (2 X BPF) from rotor-stator interaction is not cutoff in this particular fan. The large reductions in this tone with increased inlet length indicate that the inflow disturbances were controlling this tone also. The reductions in the overtone with flight have not been as large as the blade passage tone reductions so this controlling of the overtone by the inflow disturbances may be somewhat unique to this facility. However, the small amount of remaining overtone with the L/D = 5.4 inlet has some significance itself. The remaining tone with the L/D = 5.4 inlet at 90% speed is only a few decibels above the broadband noise. Even if all of this remaining tone were attributed to rotor-stator interaction, and none from residual distortion, the indication would be that the rotor-stator interaction is a small tone noise source for this fan. The apparent unimportance of the rotor-stator interaction in this fan stage may be the result of the large, 3.5 rotor chord, rotor to stator spacing.

The reduction in noise with the long inlets grows as the frequency increases. Figure 5 shows the amount of reduction between the L/D = 0 and the L/D = 5.4 inlets as the frequency is increased. The 70% and 90% speed data are shown on this figure and the solid symbols indicate one-third octave bands which contain harmonics of the blade passage frequency. The trend of the reductions with increasing frequency is almost linear on this plot and the broadband reductions fall roughly on the same line as the tone reductions. These ever increasing reductions with frequency, particularly the broadband, have not been shown in static to flight comparisons (ref. 1), in wind tunnel tests (ref. 9), or with a honeycomb and screen flow control device (ref. 10). This phenomena may be a result unique to this fan, to the anechoic chamber or to the long inlet testing method and it cannot be fully explained at this time.

Frequencies below blade passage. - At frequencies below that of the blade passage tone the trend with inlet length is not consistent. A number of regions are of interest however. For speeds from 60 through 85% (figs. 4(a) through (d)), and in the region from about 3150 Hz to the blade passage frequencies the four longer inlet lengths gave nearly equal sound power levels. The shortest length (L/D = 0) was a few decibels noisier than the others which may be the result of even more distortion. The 90 and 95% speed points (figs. 4(e) and (f)) exhibit multiple pure tones in the region between 3150 Hz and the blade passage tone. Here in this multiple pure tone region no consistent trend with length was observed.

An interesting effect of inlet length appears in the range from about 800 to 2000 Hz. Here the trend of shorter inlets being noisier was somewhat reversed with the longer inlets being noisier. A possible explanation for this lies in the buildup of wall boundary layer with increasing length. It is possible that this increased boundary layer thickness causes more low frequency noise as it interacts with the fan blades. Noise reductions have been observed with reduction in boundary layer thickness (ref. 11).

Sound Pressure Level

Directivity. - In order to further investigate the tone noise reductions with the longer inlets, some sound pressure directivities of these tones are shown in figure 6. Figure 6(a) is a plot of sound pressure level in the one-third-octave band containing the blade passage tone at 90% speed. The general trend in this plot is for the shorter inlets to be noisier but because of some directivity changes this may not be true at any given angle. The L/D = 2.4 and the L/D = 3.6 curves are very close to each other. The directivities of the first overtone (2 X BPF) are plotted in figure 6(b) for the same 90% speed point. Here the difference in sound pressure levels between the lengths is greater so the curves tend to separate with the longer lengths being quieter. Again the L/D = 2.4 and L/D = 3.6 curves are almost on top of each other possibly indicating that they were the result of the same distortion level.

An interesting facet of these sound pressure level plots is the change in directivity with the different inlets. Figure 7 is a polar plot of some of the data from figure 6(a) to elaborate on the directivity shift. Shown here are the sound pressure levels at the blade passage tone for the L/D = 0.6, L/D = 3.6, and L/D = 5.4 inlet lengths. In going from the standard inlet length L/D = 0.6 to L/D = 3.6, the character of the directivity plot changes significantly. The lobe in the L/D = 0.6 pattern at 60° to 70° does not appear in the L/D = 3.6 inlet length data. This would appear to indicate that the inlet flow disturbance was significantly changed in character, and possibly that one of the inlet flow disturbances was eliminated. However in going from the L/D = 3.6 to L/D = 5.4 length inlet the directivity patterns are very similar with only a reduction in sound pressure level. This may indicate that the same disturbances are present in the L/D = 3.6 and L/D = 5.4 case but have just been reduced in level with the longer inlet. The net result of this may be that the L/D = 3.6 inlet results in the removal of an inlet disturbance while the longer inlet L/D = 5.4 then results in a reduction in the strength of the remaining disturbances.

Narrow band data. - Some selected narrow band data analyses were undertaken to provide a more detailed examination of the character of the sound pressure level spectra. These narrow band spectra are not corrected for atmospheric attenuation. For illustrative purposes the 90% speed, 60° angle narrow band spectra are shown in figure 8 for the base case (L/D = 0.6) and the longest inlet L/D = 5.4.

As with the one-third-octave data the largest reductions are at the high frequencies. The reduction of the blade passage tone with the long inlet is particularly significant along with the near removal of the overtone from the spectra. The reduction of the multiple pure tones just higher in frequency than the blade passage tone was not observed in the one-third-octave data because of a lack of resolution and the observed noise decreases were just thought to be a reduction in the broadband noise. The slight increase in the broadband skirt of the blade passage tone was not obvious in the one-third-octave data. The broadband increase in the 800 to 2000 Hz region is possibly the result of boundary layer buildup in the long duct and was observed with the one-third-octave band data. In general the narrow band data showed in more detail what was already observed from the one-third-octave data.

CONCLUDING REMARKS

Potential flow calculations for the Lewis anechoic chamber indicated that there was substantial flow over the wall directly behind the fan inlet. This flow near the wall anechoic wedges could produce significant inflow disturbances that would then interact with the fan and create extraneous fan noise. Fan noise tests were run with various fan inlet lengths to move the inlet away from this backwall and thereby reduce the inlet flow disturbances. Five inlet lengths were run. These inlets included the standard inlet length (L/D = 0.6), one shorter than standard (L/D = 0) and three longer than the standard (L/D = 2.4, 3.6, and 5.4). The results of this testing are as follows:

a. Significant reductions in noise were obtained with increased inlet length for the blade passage and higher frequencies. These reductions were both in the broadband noise and at the tones. Over 5 dB reduction of the blade passage tone sound power level was observed between the shortest and longest inlet at 90% fan speed while the overtone was reduced 9 dB. The reductions in both tone and broadband noise increased linearly with frequency above the blade passage frequency. Although broadband and tone noise reductions have been previously observed, this linear increase of the reduction with frequency has not been observed and cannot be fully explained at this time.

b. As well as a reduction in the blade passage tone a significant change in tone directivity was observed in going from the standard to the next to the longest inlet (L/D = 3.6). In going to the longest inlet (L/D = 5.4) the pattern stayed the same as the L/D = 3.6 length but was just reduced in level. The change in directivity in going to the

L/D = 3.6 inlet may indicate the removal of a disturbance source while the reduction with the L/D = 5.4 inlet may indicate a reduction in the remaining inlet disturbance. It should be noted that even with the longest inlet some blade passage tone was present for this fan which had the rotor-stator interaction blade passage tone cutoff.

c. Some increases in broadband noise were observed with the longer inlets at low frequency (800 to 2000 Hz). These increases are possibly a result of increased boundary layer on the duct walls interacting with the rotor blade tips.

The reduction in noise with increasing inlet length indicates that significant inlet flow disturbances may be created by flow over the back wall in the Lewis anechoic chamber. As the general inlet proximity to the back wall is present in a number of fan noise testing facilities, the flow over this back wall should be considered as a possible cause of extraneous noise in these facilities.

REFERENCES

1. C. E. Feiler, and J. E. Merriman, "Effects of Forward Velocity and Acoustic Treatment on Inlet Fan Noise," AIAA Paper 74-946, (Aug. 1974).

2. F. P. Povinelli, J. H. Dittmar, and R. P. Woodward, "Effects of Installation Caused Flow Distortion on Noise from a Fan Designed for Turbofan Engines," NASA TN D-7076, (1972).

3. D. B. Hanson, "Spectrum of Rotor Noise Caused by Atmospheric Turbulence," J. Acoust. Soc. Am. 56, 110-126 (1974).

4. J. A. Wazyniak, L. M. Shaw, and J. D. Essary, "Characteristics of an Anechoic Chamber for Fan Noise Testing," NASA TM X-73555, (1977).

5. J. M. Tyler, and T. G. Sofrin, "Axial Flow Compressor Noise Studies," SAE Trans., 70, 309-322 (1962).

6. T. F. Gelder, and G. W. Lewis, Jr., "Aerodynamic Performance of 0.5-Meter-Diameter, 337-Meter-Per-Second Tip Speed, 1.5-Pressure-Ratio, Single-Stage Fan Designed for Low Noise Aircraft Engines," NASA TN D-7836 (1974).

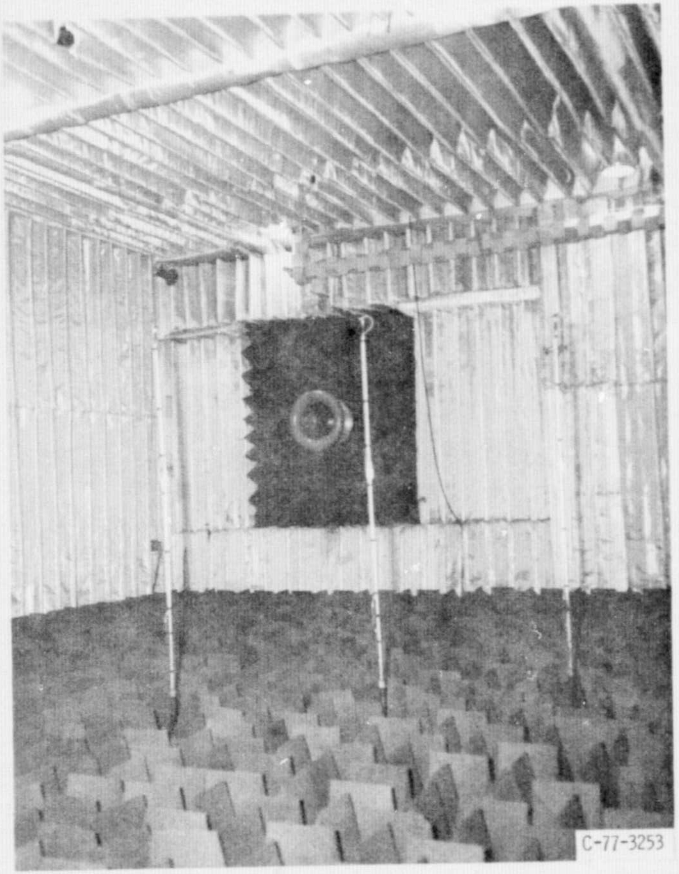
7. F. J. Montegani, "Some Propulsion System Noise Data Handling Conventions and Computer Programs used at the Lewis Research Center," NASA TM X-3013, (1974).

8. F. D. Shields, and H. E. Bass, "Atmospheric Absorption of High Frequency Noise and Application to Fractional-Octave Bands," NASA CR-2760, (1977).

9. M. F. Heidmann, and D. A. Dietrich, "Simulation of Flight-Type Engine Fan Noise in the NASA-Lewis 9x15 Anechoic Wind Tunnel," NASA TM X-73540, (1976).

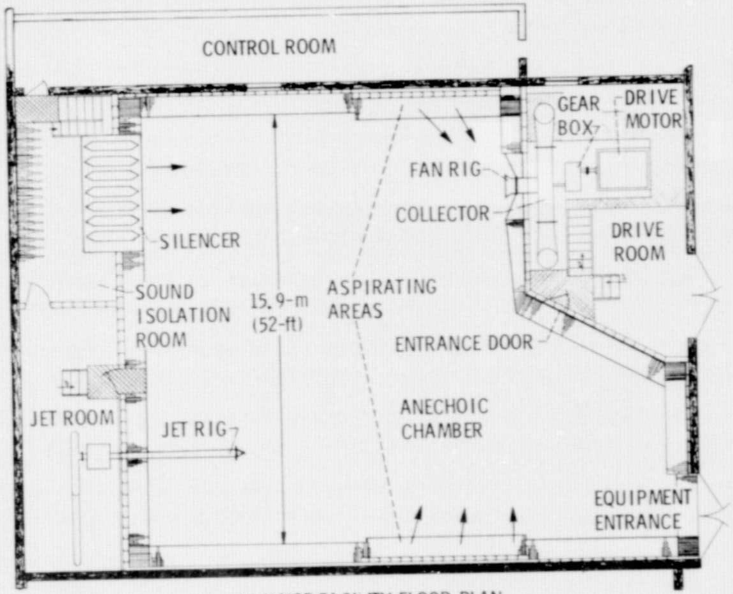
10. R. P. Woodward, J. A. Wazyniak, L. M. Shaw, and M. J. MacKinnon, "Effectiveness of an Inlet Flow Turbulence Control Device to Simulate Flight Fan Noise in an Anechoic Chamber," NASA TM X-73855, (1977).

11. A. W. Goldstein, F. W. Glaser, and J. W. Coats, "Effect of Casing Boundary-Layer Removal on Noise of a Turbofan Rotor," NASA TN D-6763, (1972).

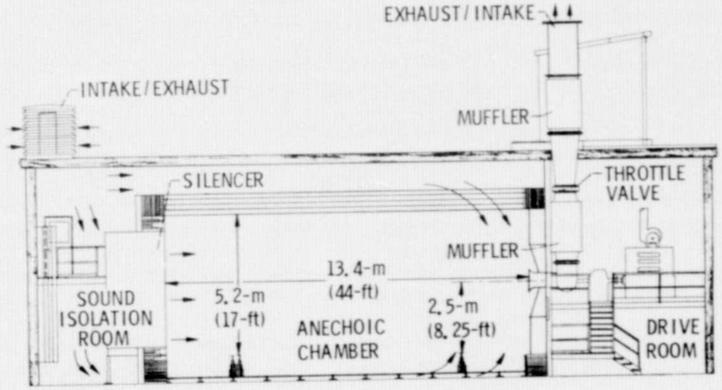


(a) FAN INLET.

Figure 1. - Anechoic chamber.

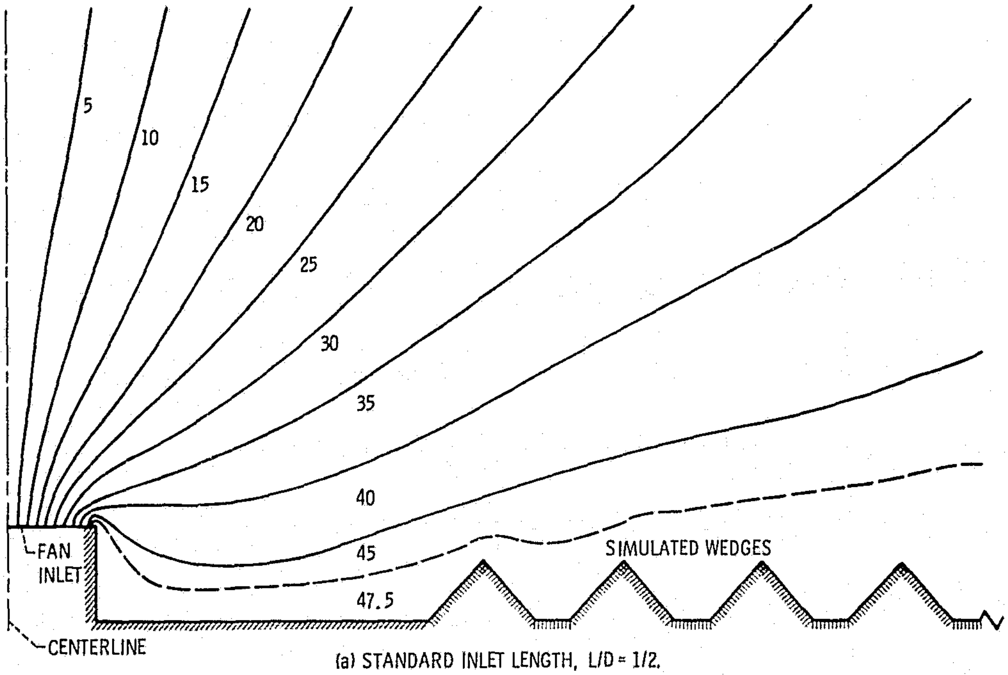


(b) NOISE FACILITY FLOOR PLAN.

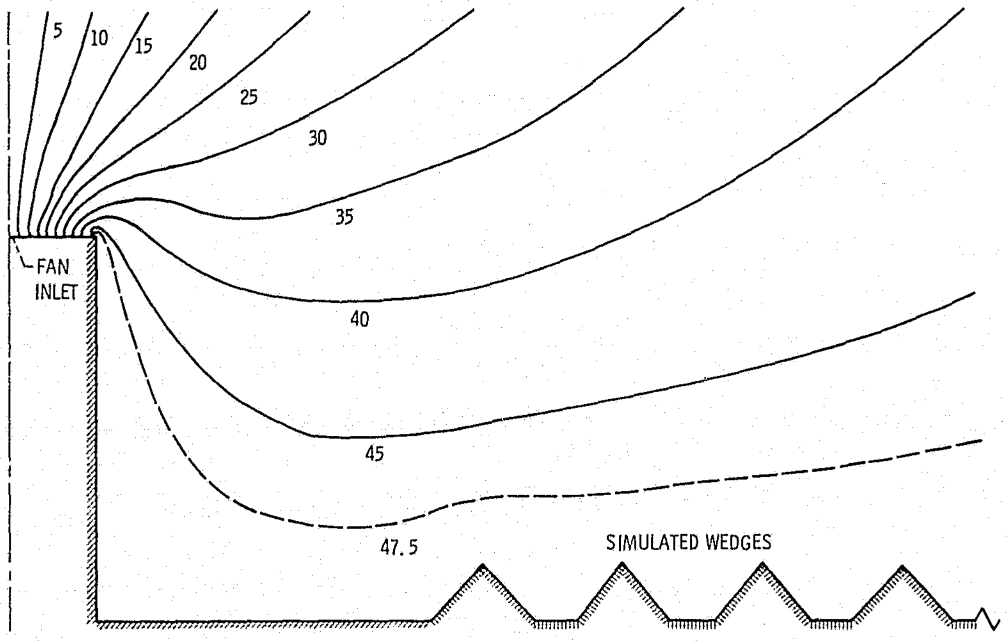


(c) NOISE FACILITY ELEVATION VIEW.

Figure 1. - Concluded.

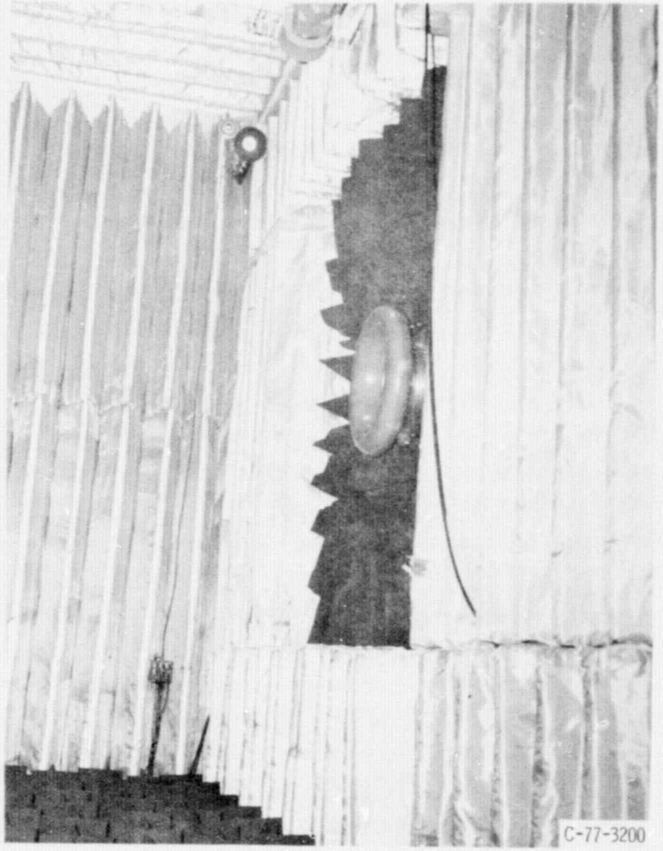


(a) STANDARD INLET LENGTH, L/D = 1/2.



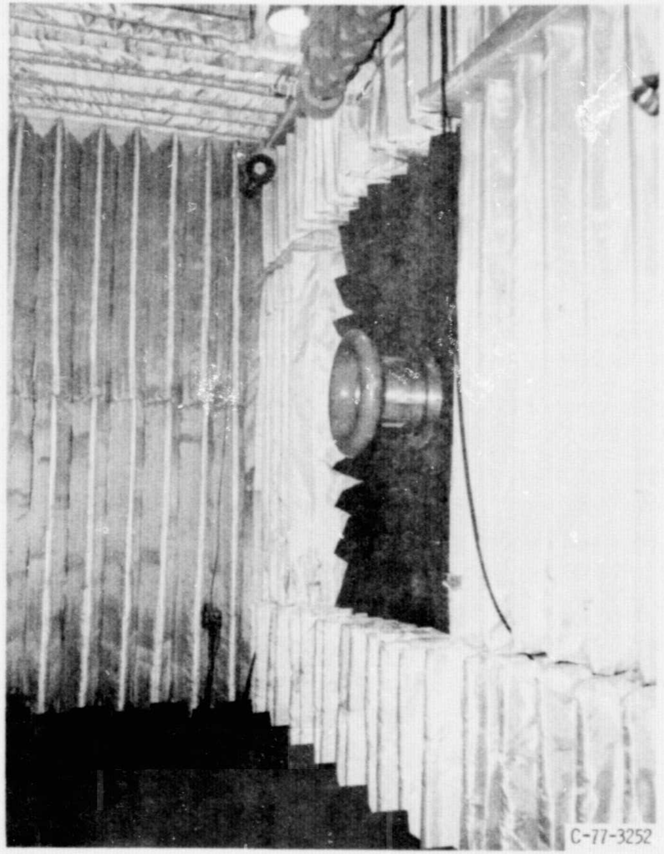
(b) LONG INLET, L/D = 2.

Figure 2. - Potential flow in room for two inlet length to diameter ratios (L/D).



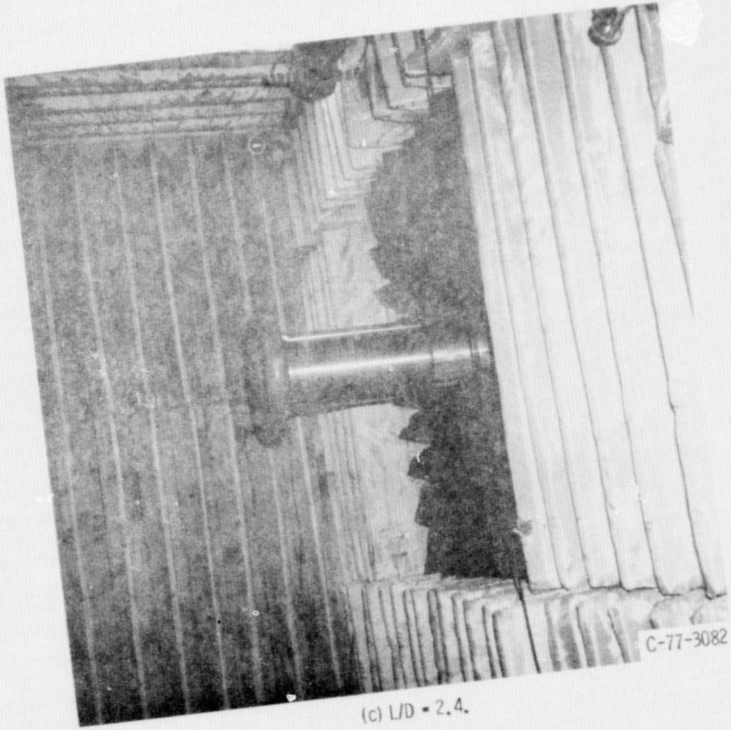
(a) L/D = 0.

Figure 3. - Inlet lengths tested with several length to diameter ratios (40).



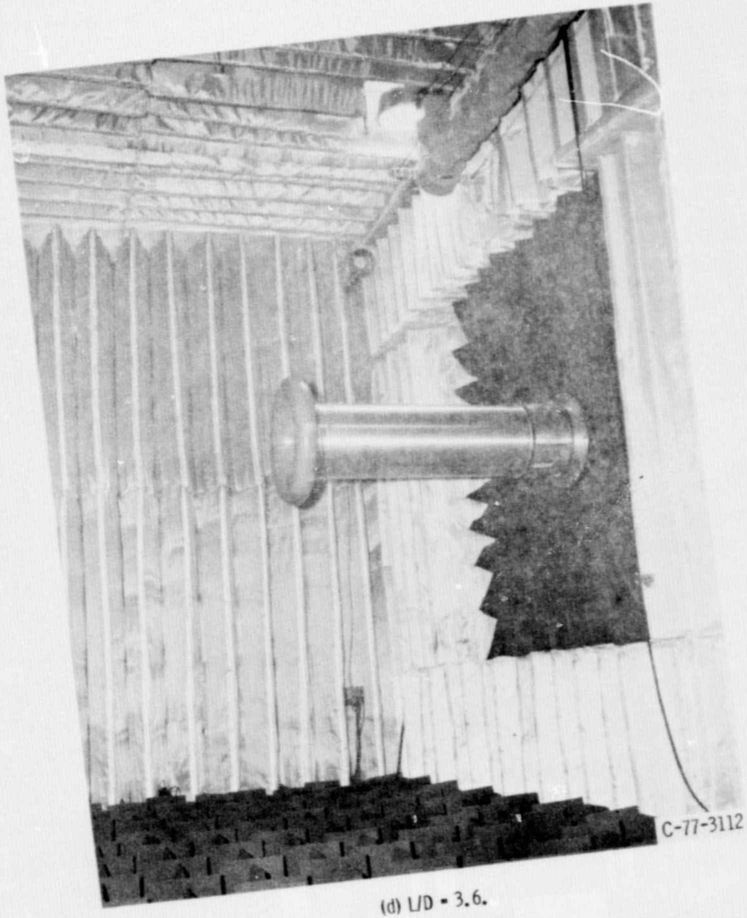
(b) L/D = 0.6.

Figure 3. - Continued.



(c) L/D = 2.4.

Figure 3. - Continued.



(d) L/D = 3.6.

Figure 3. - Continued.

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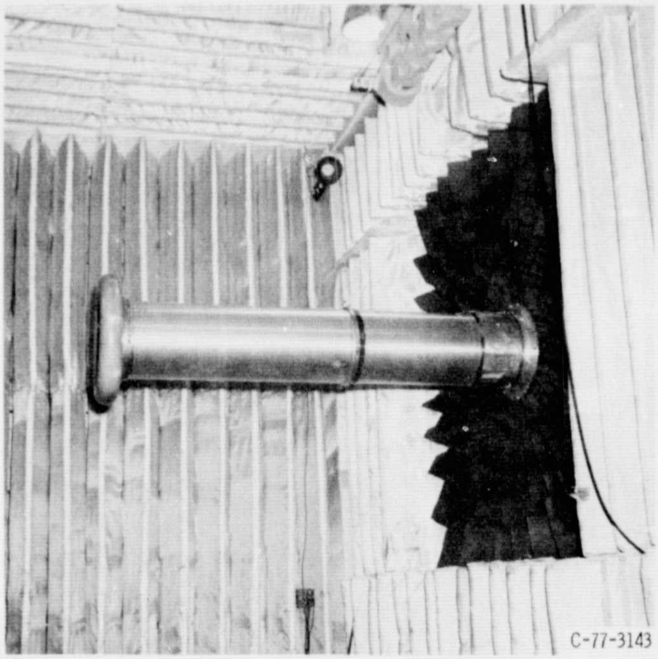
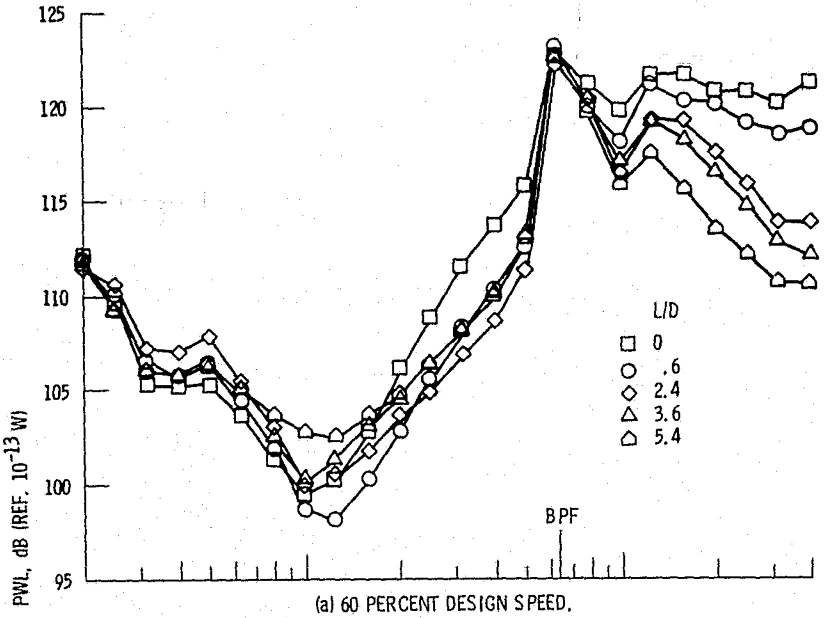
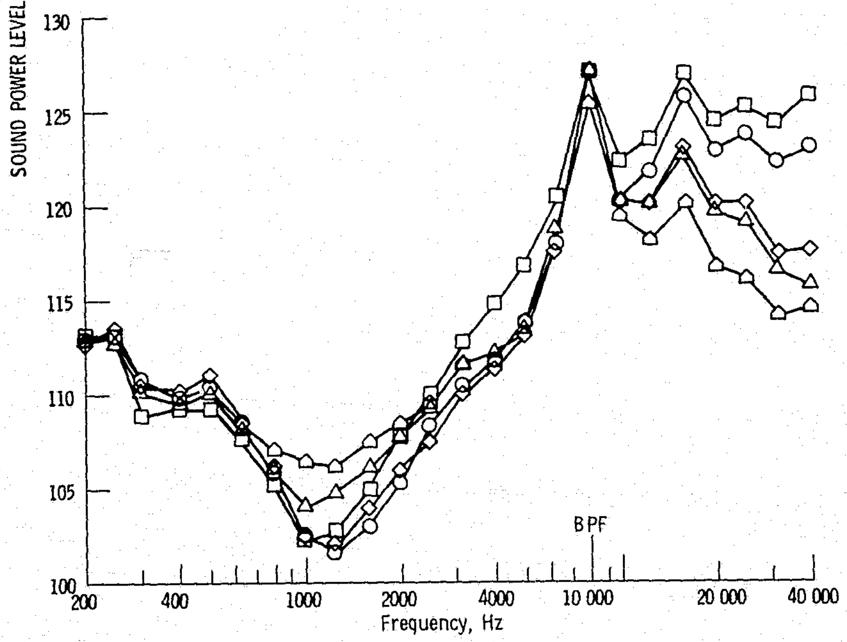


(e) L/D = 5.4.

Figure 3. - Concluded.



(a) 60 PERCENT DESIGN SPEED.



(b) 70 PERCENT DESIGN SPEED.

Figure 4. - One-third octave sound power spectra. (BPF indicates the band which contains the blade passage frequency.)

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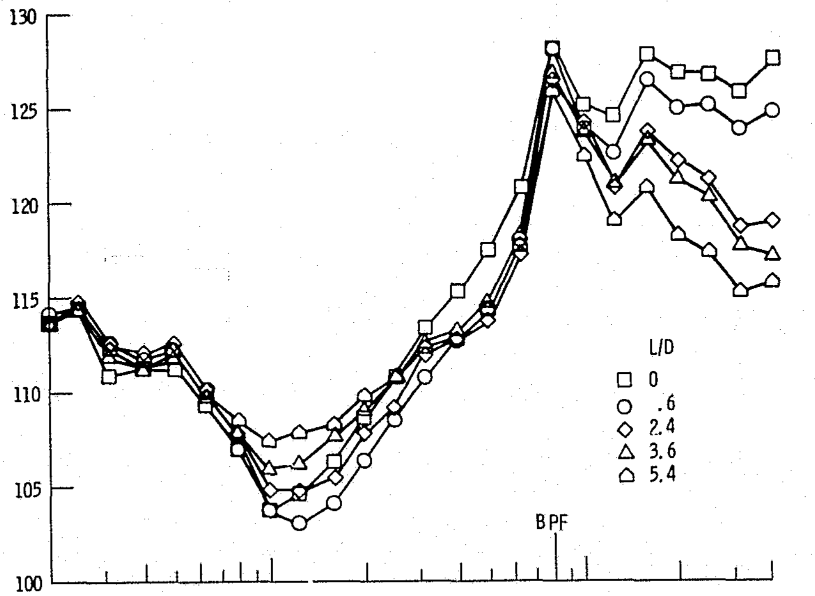
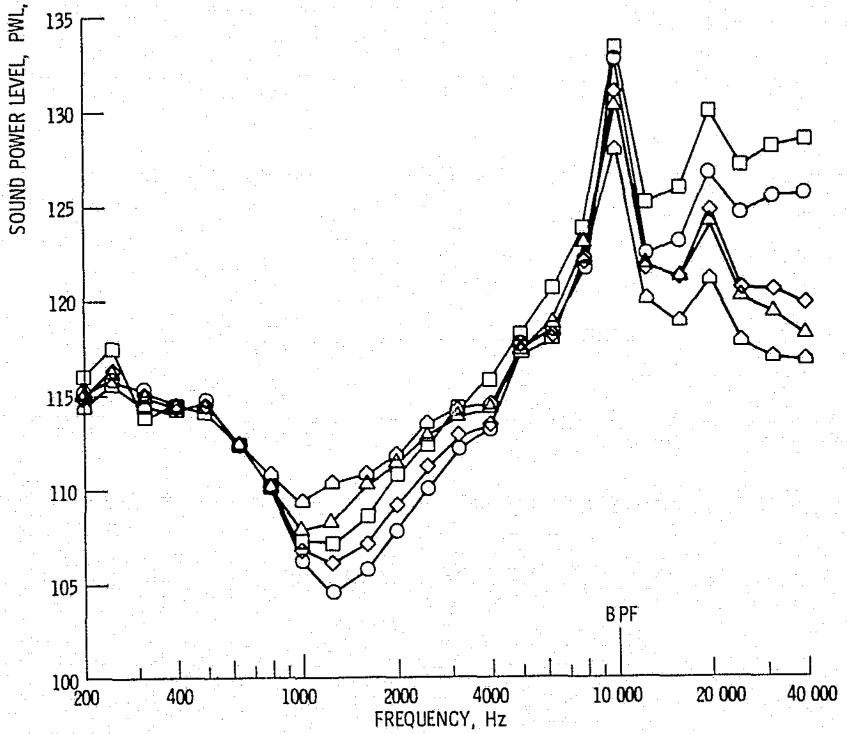
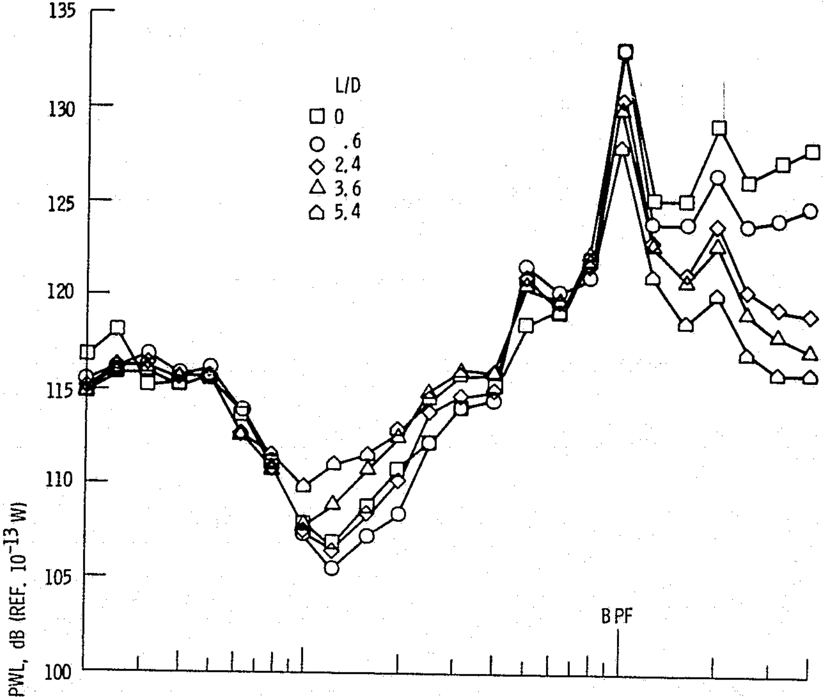


(c) 75 PERCENT DESIGN SPEED.

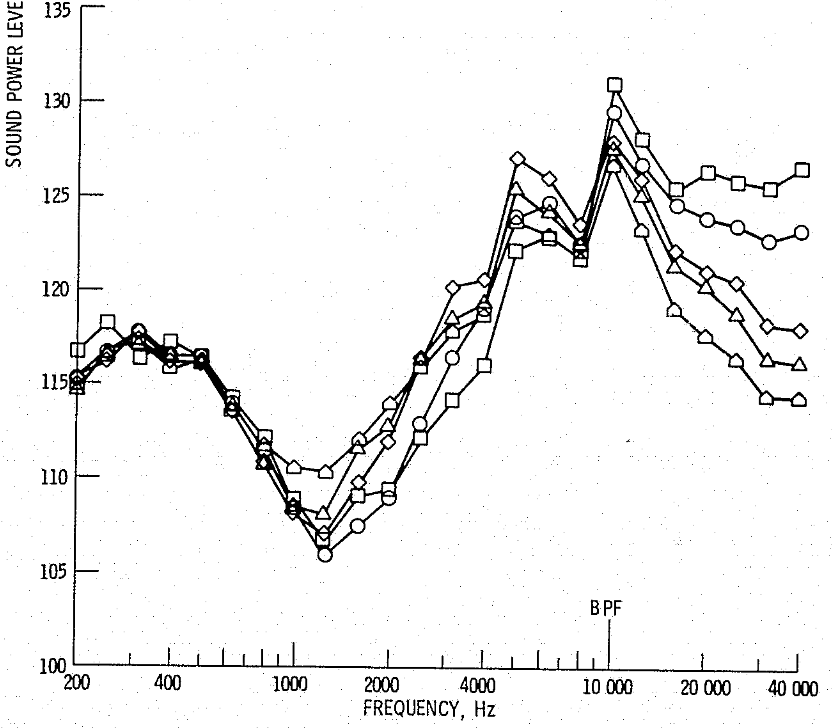


(d) 85 PERCENT DESIGN SPEED.

Figure 4. - Continued.



(e) 90 PERCENT DESIGN SPEED.



(f) 95 PERCENT DESIGN SPEED.

Figure 4. - Concluded.

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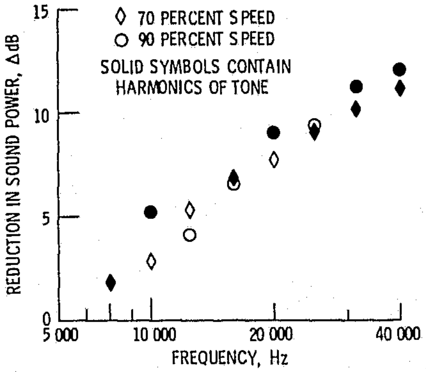
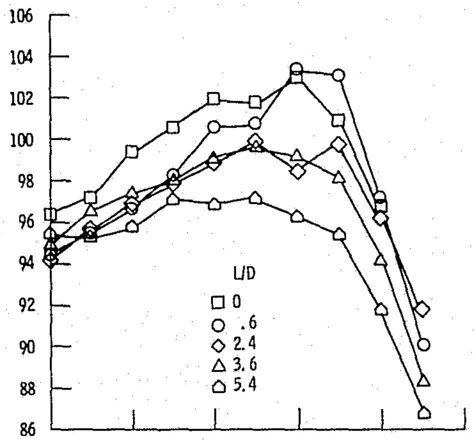
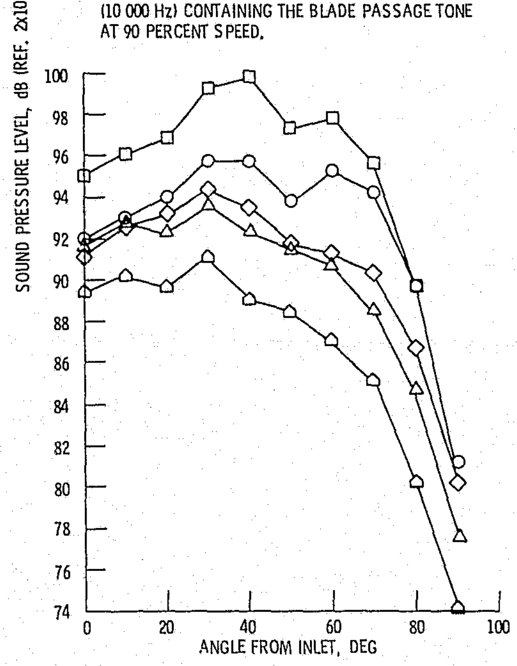


Figure 5. - The noise reduction in going from the L/D = 0 to the L/D = 5.4 inlet.



(a) SOUND PRESSURE IN THE ONE-THIRD OCTAVE BAND (10 000 Hz) CONTAINING THE BLADE PASSAGE TONE AT 90 PERCENT SPEED.



(b) SOUND PRESSURE IN THE ONE-THIRD OCTAVE BAND (20 000 Hz) CONTAINING THE OVER TONE (2 x BPF) AT 90 PERCENT SPEED.

Figure 6. - Sound pressure level directivity.

E-9580

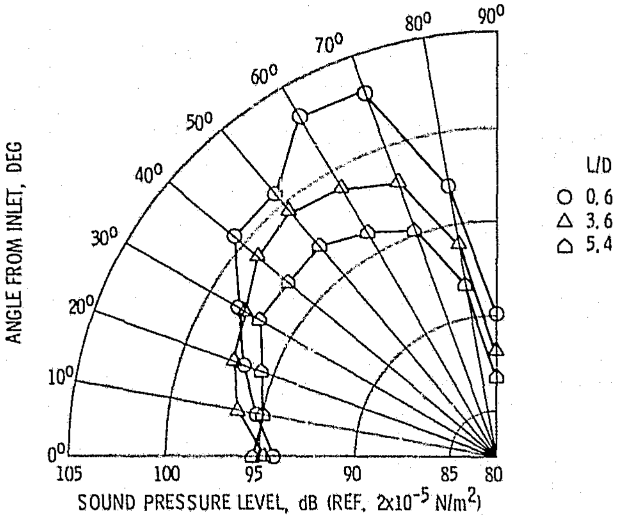


Figure 7. - Sound pressure level in the one-third octave band containing the blade passage tone at 90 percent speed.

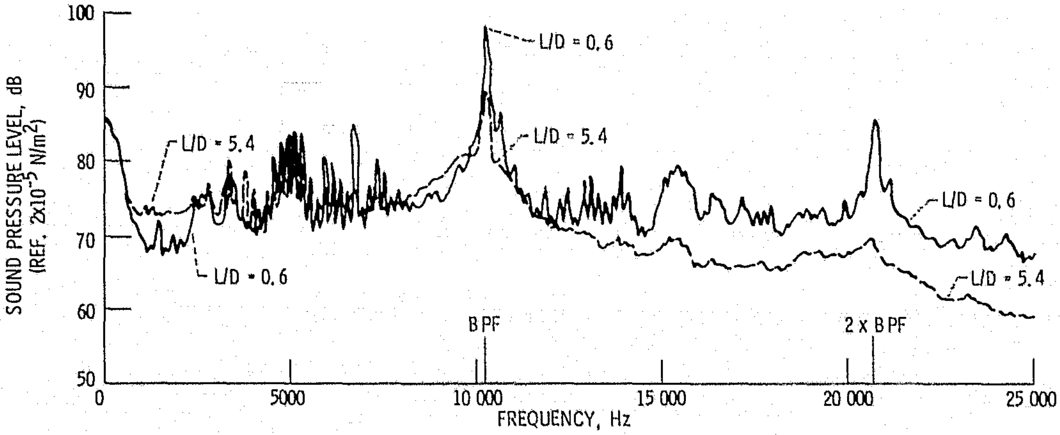


Figure 8. - Narrowband analysis of 60^0 microphone data at 90 percent design speed (approx. 50 Hz bandwidth).