NASA TECHNICAL MEMORANDUM

NASA TM X-3538

NASA TM X-3538

NOISE OF FAN DESIGNED TO REDUCE STATOR LIFT FLUCTUATIONS

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • MAY 1977

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM X-3538		

4. Title and Subtitle
NOISE OF FAN DESIGNED TO REDUCE STATOR LIFT FLUCTUATIONS

5. Report Date
May 1977

6. Performing Organization Code

7. Author(s)
James H. Dittmar, Richard P. Woodward, and Edward G. Stakolich

8. Performing Organization Report No.
E-8986

10. Work Unit No.
505-03

9. Performing Organization Name and Address
Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio 44135

11. Contract or Grant No.

13. Type of Report and Period Covered
Technical Memorandum

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, D.C. 20546

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract
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17. Key Words (Suggested by Author(s))	18. Distribution Statement
Fan noise Noise Turbofan	Unclassified - unlimited STAR Category 07

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	45	A03

* For sale by the National Technical Information Service, Springfield, Virginia 22161

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SUMMARY

An existing fan stage was redesigned to reduce stator lift fluctuations and was acoustically tested for reduced noise generation. The lift fluctuations on the stator were reduced by increasing the stator chord, adjusting incidence angles, and adjusting the rotor velocity diagrams. Tests were performed to make comparisons between the original and redesigned fans at four speeds and with three nozzle areas.

The experiments showed significantly reduced broadband noise levels in the middle to high frequencies. Despite a predicted reduction in the blade passage tone, no total sound power reduction was observed. Reductions in the blade passage tone were observed in the front hemisphere but increases were observed in the rear. Decreases in the sound power level of the blade passage tone harmonics were observed. In addition, aerodynamic improvements in both performance and efficiency were obtained.

INTRODUCTION

One of the noise generation mechanisms in a fan stage for turbofan engines is the interaction of the rotor blade wakes with the downstream stator vanes. These incoming wakes create lift fluctuations on the stator vanes and they, in turn, produce noise. A number of researchers have formulated analytical models to predict the noise from this mechanism by calculating the fluctuating lift on the stator vanes as they intercept the rotating pattern of rotor wakes. Elements of these analyses were used in a previous report (ref. 1) to obtain an expression for the magnitude of the stator lift fluctuation. Results presented in reference 1 indicated that the fluctuating lift, and therefore the noise of a fan stage, could be reduced by increasing the chord of the stator vanes and by adjusting the fan aerodynamic design to provide a minimization of the total stator response.

An existing fan stage, referred to as QF-2 (ref. 2), was redesigned using the methods of reference 1 to reduce the fluctuating lift, and therefore the noise of the fan, while maintaining a relatively constant aerodynamic design performance. The redesigned fan, designated QF-11, was tested at the Lewis full-scale fan noise facility (fig. 1) in the same manner as the previously tested QF-2 fan. Acoustic and aerodynamic data taken with the redesigned fan are compared with the data for the original fan stage.

THEORETICAL BACKGROUND

This section presents the theoretical background for the redesigned fan for both tone and broadband noise. The fluctuating lift model that was used as the theoretical basis to reduce the rotor wake - stator interaction tone noise is examined, and the broadband noise effects are discussed.

Rotor-Stator Interaction Tone Noise

One purpose of the redesigned fan was to reduce the tone noise generated by rotor wake - stator interaction. A number of researchers have formulated analytical models to predict the noise from this mechanism by calculating the fluctuating lift on the stator vanes as they are struck by the rotor wakes. Examples of these analyses are given by Kemp and Sears (ref. 3) and Horlock (ref. 4). Portions of some of these analyses were used in a previous report (ref. 1). The expression used in the redesign for the magnitude of the stator fluctuating lift, taken from reference 1 (p. 14), is repeated here:

$$|\Delta L_N| = \left| \pi\rho \frac{1.6\sqrt{C_D}}{\left(\frac{X}{C_R} + 0.025\right)^{1/2}} U_3 V_1 \sin(\bar{\beta}_3 + \beta_3) \times \Big[|S(\omega)| - \alpha \cot(\bar{\beta}_3 + \beta_3) |T(\omega)| \Big] \right| \quad (1)$$

where

ΔL_N fluctuating lift, force/area

ρ fluid density, mass/(length)^3

C_D rotor profile drag coefficient

C_R rotor chord

X distance from trailing edge of rotor to leading edge of stator

U_3 absolute velocity at stator inlet, length/time

V_1 relative velocity at rotor inlet, length/time

β_3 relative flow angle from rotor after translation to stator inlet, deg

$\bar{\beta}_3$	absolute flow angle at stator inlet, deg
α	angle of attack of stators relative to flow, radians
$\lvert S(\omega)\rvert$	magnitude of transverse response function
$\lvert T(\omega)\rvert$	magnitude of longitudinal response function
ω	reduced frequency ($\pi C_S/l$)
C_S	stator chord
l	disturbance wavelength

Two general techniques suggested by this expression to reduce the magnitude of the stator lift fluctuations were investigated. These techniques were (1) to reduce the magnitude of the stator response funccion terms $|S(\omega)|$ and $|T(\omega)|$ and (2) to enhance the cancellation of the two response terms (minimize the enclosed expression in eq. (1)) by adjusting $\alpha \cot(\bar{\beta}_3 + \beta_3)$. The base fan (QF-2) was first investigated to determine where improvements could be made; then, a new fan (QF-11) was designed to incorporate as many of these improvements as possible.

Base fan. - The base fan stage (QF-2) had 53 rotor blades, 112 stator vanes, and an overall pressure ratio of 1.5. The rotor chord was 13.97 centimeters (5.5 in.), and the stator chord was 6.78 centimeters (2.67 in.). Since each spanwise section of the blade acts differently, 11 sections (tip to hub) were chosen for the analysis. The valves of the aerodynamic design parameters used in the evaluation of the base fan are included in table I. When the analysis was applied to the base fan, the lift pressure fluctuations presented in table II were obtained. The magnitude of the average life pressure fluctuation for the blade was calculated as 7659.2 newtons per square meter (159.9 lb/ft^2).

An examination of the spanwise variation of the lift fluctuation indicated that the hub was a large contributor. This particular fan has a constant hub to tip pressure ratio at the rotor outlet of 1.541. This required pressure ratio at all spanwise stations results in large amounts of rotor turning, in this case up to 60° at the rotor hub. The large amount of rotor turning gives rise to a larger wake defect which would, in turn, result in more stator lift fluctuation.

No attempt was made in the design of the base fan to minimize the bracketed term ($[|S(\omega) - \alpha \cot(\bar{\beta}_3 + \beta_3)|T(\omega)|]$) in equation (1). A reduction in this term was thought possible. The stator blade angles of incidence could be adjusted at each section to help minimize the expression. In addition, a reduction in rotor turning near the hub would improve the flow angles into the stators. As the turning is lowered, the term $\alpha \cot(\bar{\beta}_3 + \beta_3)$ would come closer to providing a cancellation between the response functions.

The magnitudes of both the response functions $|S(\omega)|$ and $|T(\omega)|$ decrease with increasing values of the reduced frequency ω. Since $\omega = \pi C_S/l$, where C_S is the stator chord and l is the disturbance wavelength, a reduction in the lift response could be achieved by increasing the stator chord and decreasing the incoming gust wavelength.

Redesigned fan. - A new fan (QF-11), which attempted to improve the base fan (QF-2) by incorporating these ideas, was then designed. Some of the design goals of the new fan were that it have the same overall stage pressure ratio and mass flow as the base fan and that the rotor-stator spacing be approximately the same number of rotor chord lengths.

The first step in reducing the noise was to reduce the hub rotor turning. This was accomplished by trailing off the pressure ratio near the hub and, at the same time, slightly increasing the rotor tip speed from approximately 335 meters per second (1100 ft/sec) to 347 meters per second (1140 ft/sec). The pressure ratio across the rotor was slightly increased at the tip to 1.556 and reduced at the hub to 1.375. A table comparing the rotor pressure ratios of the two fans is found in table III. Both the base fan and the redesigned fan had overall design fan stage pressure ratios of 1.5.

The angle of attack of the stators was varied on the redesigned fan to assist in minimizing the bracketed expression in equation (1). The incidence angle to the suction surface of the stator blades on the redesigned fan varied from 3° at the tip to a slightly negative value at the hub as is shown in table IV.

In order to increase the reduced frequency parameter ω, the number of rotor blades was increased from 53 to 58 and the stator chord was approximately doubled to 12.45 centimeters (4.9 in.). The result of all of these changes is indicated in table V, which shows the design parameters for the QF-11 fan. The resultant lift pressure fluctuations are found in table VI. The average lift pressure fluctuation for the new stators was 3554.6 newtons per square meter (74.2 lb/ft^2).

The predicted blade passage tone reduction is based on the total lift fluctuation of each stage. The new fan (QF-11) has 17 percent more stator area than the base fan, and this was included in the calculation. The calculation yielded a predicted blade passage tone reduction of approximately 5 decibels for the redesigned fan. The reduction in the second harmonic of the blade passage tone was also predicted to be about 5 decibels.

A more complete discussion of the fan redesign process and the application of this method is found in the example in reference 1. The base fan discussed in this report (QF-2) is the same as the base fan in the example of reference 1. The "improved fan" in reference 1 is the fan that was to have been built as the redesigned fan for this testing; however, some aeroelastic considerations, namely flutter, forced the reduction of rotor blades from the 60 of reference 1 to the 58 tested. The fan casing configuration in the test facility necessitated that an even number of stator vanes be used. The number was reduced to 70 from the 71 specified in reference 1. The predicted reductions in tone levels were based on the fan design aerodynamics at the 100 percent design speed point of the fan.

Broadband Noise

The internally generated broadband noise comes from many sources. These include turbulence interacting with the fan blading, shed vorticity from a blade, and scrubbing of the flow over blade surfaces to name a few. Broadband noise generated by turbulence and rotor wake irregularities interacting with the stator blades are of specific interest in this study. Such broadband noise should be reduced because of the increased ω of the redesigned fan. Lieppman (ref. 5) and Goldstein, et al. (ref. 6) have shown that the broadband acoustic power generated in a turbulent flow is directly related to the Sear's function $S(\omega)$ mentioned previously. Here again, the reduced frequency $\omega = \pi C_S/l$ depends on the blade chord and the wavelength of the incoming gust of turbulence. The increase in the stator chord should result in a broadband noise reduction. The amount of the reduction achieved by the increased chord should depend on the properties of the incoming turbulence. Since no measurement of the turbulence striking the stator has been made, a prediction of the reduction is not undertaken. Observations of broadband noise reduction from increased stator chord have been made previously in reference 7. These previous reductions were significant, in some cases more than 5 decibels, and occurred in the 1000 to 20 000 hertz frequency range. It was therefore expected that a broadband noise reduction over this general frequency range would be observed as a result of the redesign of the fan stator vanes.

APPARATUS AND PROCEDURE

Fan Stages

Both the original (QF-2) and redesigned fan (QF-11) stages compared in this study are full-scale 1.83-meter- (6-ft-) diameter fans with a design pressure ratio of 1.5. The aerodynamic design features of the QF-2 and QF-11 stages are given in table VII. The redesigned fan featured an increase in rotor blade number from 53 to 58 and a decrease in stator vane number from 112 to 70. The stator vane number decrease was to accommodate the increase in stator chord from 6.83 centimeters (2.69 in.) to 12.45 centimeters (4.9 in.). Redesign also included changes in stator incidence angles and changes in rotor pressure ratio distribution as given in tables III and IV. Photographs of the two fan stages are found in figure 2.

Aerodynamic and acoustic data for the original (QF-2) fan, to be used for comparative purposes, were obtained in a previous study and were reported in reference 2. The data were acquired at the same facility and reduced by the same procedures as those to be described for the redesigned fan.

Test Facility and Configurations

The experiments reported herein were conducted at the full-scale fan test facility at the Lewis Research Center. Figure 1(a) shows the test site and figure 1(b) shows a plan view of the test facility. Acoustic data were obtained by 1.27-centimeter (0.5-in.) condenser microphones located at 10° increments from 10° to 160° from the fan inlet centerline (fig. 1(b)). The microphones were level with the fan centerline, 5.79 meters (19 ft) above the asphalt surface on a 30.48-meter (100-ft) radius. A complete description of the acoustic instrumentation and the data acquisition techniques are given in references 8 and 9.

Three samples of acoustic data were taken at each test condition and averaged to obtain the spectra which are presented. The data were recorded on magnetic tape, and one-third-octave band and some narrow band analyses were performed.

To determine fan mass flows, aerodynamic data were taken by instrumentation located in front of the fan; to determine performance and efficiency, data were obtained by instrumentation located downstream of the stator vanes. The upstream instrumentation consisted of wall static pressure taps and bellmouth temperature elements. Downstream instrumentation consisted of four aerodynamic rakes just downstream of the stator vanes and three aerodynamic rakes at the nozzle discharge station. Static pressure taps were also included downstream of the stator vanes. A more complete description of the fan aerodynamic instrumentation can be found in reference 10.

A description of the redesigned fan (QF-11) configurations tested can be found in table VIII. Data were taken at 60, 70, 80, and 90 percent of design speed with each of three nozzle settings corresponding to 100, 110, and 120 percent of design nozzle area. A test point was also run at 85 percent speed with the 110 percent nozzle. These 13 test conditions corresponded to conditions tested previously for the base fan (QF-2). In addition to these test points, five points were run at conditions where no comparable base fan (QF-2) data existed. Four of these points were along the 80 percent speed line and corresponded to 104, 108, 114, and 117.5 percent of design nozzle area. The fifth test point was at 95 percent design speed with the 110 percent design nozzle area. No higher speeds or other nozzles were tested since a strain gage failure precluded safe operation.

RESULTS AND DISCUSSION

Acoustic Data

As mentioned previously in the THEORETICAL BACKGROUND section, an existing fan stage was redesigned to reduce the rotor wake - stator interaction noise. The sound power noise reductions achieved with this redesigned fan can be seen in the one-third-octave spectra of figures 3, 4, and 5 for 100, 110, and 120 percent design nozzle area, respectively. In each of these figures the spectra for both the base and redesigned fans are plotted; parts (a) to (d) are for 60, 70, 80, and 90 percent speed, respectively. One-third-octave sound pressure levels (SPL's) are tabulated for all of the configurations tested in tables IX to XV.

Blade passage tone noise and harmonics. - Although theory indicated that the blade passage tone generated by rotor wake - stator interaction should have been reduced with the redesign, no reduction in the sound power at the blade passage frequency is observed in the data of figures 3 to 5. In fact, at some speeds with the larger nozzles (fig. 5(a), e.g.), the blade passage tone appears to be increased. A possible explanation for this lack of reduction is that an inlet flow distortion interacting with the rotor blades produces noise which controls the sound power level of the blade passage tone. This distortion control of blade passage frequency noise was observed in reference 2 for tests in the same facility; its ability to control the tone was shown in reference 7. Another possibility is that a counterbalancing effect is being observed. In the redesigned stage, the propagation of the fundamental tone is not "cut off" in the duct; in the original stage, the proper number of rotor and stator blades existed to provide "cutoff." (The redesigned fan had a reduced number of stator vanes to maintain the same stator solidity.) The reductions achieved by reducing the fluctuating stator forces may, in this stage, be counterbalanced by removing the cutoff criterion.

Although no reductions in the sound power level at the blade passage tone were observed, changes in the directivity of the tone were noted. (Significant reductions in the broadband noise were also observed and are discussed in the next section.) Figure 6 is a plot of the design nozzle SPL in the one-third-octave band containing the blade passage tone at the 60 percent design speed test point. The 60 percent speed case is chosen for illustration since both the original and the redesigned fan have their blade passage tone contained in the same one-third-octave band (2000 Hz center frequency). As seen in figure 6, the blade passage tone has typically been reduced in front of the fan (10° to 70°) with the redesigned fan, but toward the rear it has been increased (90° to 140°). The inlet reduction may be an indication that the two fan rotors have a different response to the same inlet flow distortion or possibly that the reduced stator lift fluctuations have reduced the inlet noise. The increase in the aft noise is possibly a result of the cutoff violation in the redesigned fan. Heidmann (ref. 11) has indicated for this test facility that cutoff may be effective in reducing the fundamental tone propagation from the aft duct. The violation of cutoff for the redesigned fan may then be responsible for the increased aft noise and, thus, may provide some support for the counterbalancing effect mentioned previously. If this is the case, then this method of minimizing stator fluctuating lift should be applied only up to a point short of violating cutoff.

Reductions in the harmonics of the blade passage tone, which are also indicated by the theory, are shown in the data of figures 3 to 5. As observed in previous papers (refs. 2 and 7), the second harmonic was not as greatly affected by the inflow distortion known to be present in this test facility. In addition, since the harmonics are not cutoff in either fan, no counterbalancing effect is expected. Although the noise reductions achieved at the harmonics are not as great as those predicted by the rotor wake - stator interaction theory, they are significant.

An interesting effect may be observed in the variation of the second harmonic reduction with percent of design speed as shown in figure 7. This figure indicates a growing reduction as the speed is increased with a maximum reduction around 80 percent speed. The reductions then tend to level off or decrease slightly at 90 percent speed. As indicated in the THEORETICAL BACKGROUND section, the predicted reduction of around 5 decibels was based on the design point aerodynamic calculations (100 percent speed). The falloff of the reduction toward the low speed points may be a result of reduced cancellation between the response functions, since the velocity diagrams at these low speed points are not the same as the design values used in the calculations. As the speed is increased, the velocity diagrams should more closely match the design numbers used in the noise calculations, and the data may thus approach the expected reduction in noise.

In the redesigned fan stage, as well as the original stage, the perceived noise level (PNL) was controlled by the blade passage tone, and little reduction in PNL was observed due to the harmonic reductions. However, the reduction in such harmonics may be important for STOL-type fans with low numbers of rotor blades and low tip speeds where the harmonics are the largest contributors to the PNL. In this case, the reduction in the harmonics could result in a comparable perceived noise reduction.

Broadband. - As shown by figures 3 to 5, significant broadband reductions were also achieved with the redesigned fan stage. The broadband noise generated by turbulence, rotor wake irregularities, etc., interacting with the stator vanes was expected to be reduced with the reduction of the stator lift response functions. This reduction was observed over a large frequency range at all speed points and amounted to as much as 5 decibels at some frequencies. The reductions in the broadband noise appear to be relatively uniform with angle as can be seen in figure 8. Figure 8 is a plot of the broadband SPL for the one-third-octave band centered at 5000 hertz for the design nozzle 60 percent speed point as a function of angle. The redesigned fan exhibited a consistent reduction in broadband noise over a large frequency range at all polar angles. This result is particularly significant because the reduction was obtained without the weight or performance penalty usually associated with acoustic suppression.

Multiple pure tones. - The redesigned fan (QF-11) exhibited more multiple pure tone (MPT) activity at the 90 percent speed point than did the original fan (QF-2). This can be seen slightly in figure 3(d) with the design nozzle and figure 5(d) with the 120 percent nozzle and strongly in figure 4(d) with the 110 percent nozzle. The trend with nozzle size for the two fans is shown in figure 9. This is a plot of the sound power level at 90 percent speed in the 1600 hertz center frequency one-third-octave band. The 1600 hertz band is chosen since it appears to be the peak MPT area. As can be observed in figure 9 the original fan had its largest MPT noise with the design nozzle whereas the redesigned fan had its peak with the 110 percent nozzle. The redesigned fan has a larger MPT noise peak than the original fan by about 3 dB. The larger MPT noise from the redesigned fan may be explained because it has a slightly higher tip speed (350.1 m/sec (1140 ft/sec) as opposed to 337.4 m/sec (1107 ft/sec)) which would give stronger shock patterns. The different behavior of the two fans with nozzle size is not understood at this time.

In addition to the data which are comparable between the original and redesigned fans, two additional points were taken with the redesigned fan at 110 percent design nozzle area. These points were at 85 and 95 percent of design speed. The incorporation of these data with the 90 percent data enables some comparison of the MPT activity with speed. Figure 10 shows the one-third-octave sound power spectra for the three percent speeds (85, 90, and 95) with the 110 percent nozzle. As is observed, a large increase in MPT activity is noted in going from 85 to 90 percent speed. Little change in MPT activity is noted in going to 95 percent speed. This leveling off of the MPT activity has been observed previously for "shock swallowing" blades and it may be that some of this effect is being observed here.

Loading. - To more closely examine the change with various nozzle sizes four additional nozzle areas were run at the 80 percent speed point. The four areas were 104, 108, 114 and 117.5 percent of design nozzle area. The sound power level spectra for these nozzle areas and the 100, 110, and 120 percent nozzle areas at 80 percent speed are found in figure 11. The scale has been increased so that the data points are distinguishable. As can be seen from these figures, the data follow a fairly orderly decrease in noise from the design nozzle to the 120 percent design nozzle (figs. 11(a), (b), and (c)). This indicates that the decrease in noise with reduced loading is fairly uniform across the majority of this constant percent speed line. Most of the noise differences from nozzle to nozzle are very small, maybe even within the repeatability of the data. However, the progression from nozzle to nozzle is consistent and logical. The largest difference between any two successive nozzle settings is between the design and design + 4 percent nozzles (fig. 11(a)). (These differences are as much as 3 dB at some frequencies and are not within the repeatability range of the data.) In fact, the difference between design and design + 4 percent is larger than the total spread of the other nozzle areas. This additional noise at the design nozzle area is primarily broadband in nature occurring at frequencies below the blade passage frequency. The noise increase with the design nozzle may be an indication of some poor aerodynamic condition. This is only speculation and all that can be said is that the fan with the design nozzle made more noise than would be expected from an extrapolation of the other nozzle area data.

Aerodynamic Results

As mentioned previously, the redesigned fan stage was designed to have the same design pressure ratio and mass flow as the original fan stage at 100 percent design speed. Neither fan was run at 100 percent design speed so no comparisons are made at the design point. It was discovered during testing that the redesigned fan performed better than the original fan at the part speed points that were tested. This is seen in figure 12(a) which is a plot of pressure ratio as a function of mass flow for the two fans. The design point pressure ratio and mass flow are also indicated on the figure. As can be observed, the new fan exhibited larger pressure ratios and mass flows than did the original fan at all part speed points tested.

Aerodynamic efficiency data obtained on this outdoor noise test facility are somewhat compromised by not enough temperature sensors, and comparisons with efficiencies taken on a specially instrumented quarter scale test facility have historically been only fair. The efficiency data taken on the outdoor noise facility, however, indicate that the redesigned fan did perform better than the original fan. This can be seen in figure 12(b) where the stage adiabatic efficiency is plotted against percentage of fan design speed. The redesigned fan is more efficient than the original fan at all tested speed points. Although the improvement in aerodynamic performance shown by this redesigned fan stage does not prove that designing for reduced lift fluctuation will give better aerodynamics, at least it indicates that reduced noise through lift fluctuation reduction and improved aerodynamics are compatible.

SUMMARY OF RESULTS

An existing fan stage was redesigned to reduce the rotor wake - stator interaction noise. The redesigned fan had an increased stator chord, an increased number of rotor blades, altered rotor velocity diagrams, and altered stator incidence angles. The ultimate goal of these changes was to reduce the fluctuating lift on the stators and therefore reduce the generated noise. In comparing the redesigned fan with the original fan the following were determined:

1. Despite a predicted reduction in the blade passage tone, no total sound power reduction was observed. Reductions in the blade passage tone were observed in the front hemisphere, but increases were observed in the rear. The lack of the predicted blade passage tone power reduction is possibly the result of an inlet flow distortion controlling the tone noise or a counterbalancing effect as a result of a violation of the "cutoff" ratio of rotor blades and stator vanes in the redesigned fan.

2. Reductions in the harmonics of the blade passage tone were observed. This result provides some evidence for tone reduction by reducing stator lift fluctuations even

though the reductions observed were not as great as those predicted by theory. Such harmonic reduction could be effective for a low tip speed - low blade number fan stage where the harmonic reduction could result directly in perceived noise level reductions.

3. The broadband noise output of the fan was significantly reduced by the reduced lift fluctuation design. This reduction occurred over a large frequency range, at all speed points, and amounted to as much as 5 decibels at some frequencies.

4. An increase in the multiple pure tone activity was observed with the redesigned fan probably as a result of the slightly higher tip speed. This multiple pure tone activity increased from 85 to 90 percent speed but then leveled off at 95 percent speed.

5. Aerodynamic data showed that the redesigned fan had better performance and higher efficiency than the original fan.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, January 19, 1977,
505-03.

REFERENCES

1. Dittmar, James H.: Methods for Reducing Blade Passing Frequency Noise Generated by Rotor-Wake-Stator Interaction. NASA TM X-2669, 1972.

2. Povinelli, Frederick P.; Dittmar, James H.; and Woodward, Richard P.: Effects of Installation Caused Flow Distortion on Noise from a Fan Designed for Turbofan Engines. NASA TN D-7076, 1972.

3. Kemp, Nelson H.; and Sears, W. R.: The Unsteady Forces Due to Viscous Wakes in Turbomachines. J. Aeron. Sci., vol. 22, no. 7, July 1955, pp. 478-483.

4. Horlock, J. H.: Fluctuating Life Forces on Aerofoils Moving Through Transverse and Chordwise Gusts. J. Basic Eng., vol. 90, no. 4, Dec. 1968, pp. 494-500.

5. Lieppmann, H. W.: On the Application of Statistical Concepts to the Buffeting Problem. J. Aeron. Sci., vol. 19, no. 12, Dec. 1952, pp. 793-800.

6. Goldstein, Arthur W.; Glaser, Frederick W.; and Coats, James W.: Effect of Casing Boundary-Layer Removal on Noise of a Turbofan Rotor. NASA TN D-6763, 1972.

7. Dittmar, James H.; et al.: Effects of Long-Chord Acoustically Treated Stator Vanes on Fan Noise. I - Effect of Long-Chord (Taped Stator). NASA TN D-8062, 1975.

8. Leonard, Bruce R., et al.: Acoustic and Aerodynamic Performance of a 6-Foot-Diameter Fan for Turbofan Engines. I - Design of Facility and QF-1 Fan. NASA TN D-5877, 1970.

9. Montegani, Francis J.: Some Propulsion System Noise Data Handling Conventions and Computer Programs Used at the Lewis Research Center. NASA TM X-3013, 1974.

10. Woodward, Richard P.; and Lucas, James G.: Acoustic and Aerodynamic Performance of a 1.83-Meter (6-Ft) Diameter 1.25-Pressure-Ratio Fan (QF-8). NASA TN D-8130, 1976.

11. Heidmann, Marcus F.: An Observation on Tone Cut-Off in Static Test Data from Jet Engine Fans. NASA TM X-3296, 1975.

TABLE I. - DESIGN PARAMETERS FOR BASE FAN (QF-2)

Blade section	Fluid density, ρ		Absolute velocity at stator inlet, U_3		Relative velocity at rotor inlet, V_1		Relative flow angle from rotor after translation to stator inlet, β_3, deg	Absolute flow angle at stator inlet, $\overline{\beta_3}$, deg	Stator setting angle (angle between chord line and axial direction), λ, deg	Profile loss coefficient, $\overline{\omega_p}$	Rotor solidity, σ	Magnitude of transverse response function $S(\omega)$	Magnitude of longitudinal response function $T(\omega)$
	kg/m^3	lbm/ft^3	m/sec	ft/sec	m/sec	ft/sec							
1 (tip)	1.262	0.0788	251.2	824	374.9	1230	40.71	37.89	8.03	0.1884	1.343	0.24	0.72
2	1.275	.0796	251.5	825	369.1	1211	41.39	34.31	7.53	.1063	1.372	↓	↓
3	1.277	.0797	253.9	833	362.4	1189	40.04	33.06	7.41	.0576	1.414	↓	↓
4	1.269	.0792	257.3	844	354.2	1162	38.09	33.31	7.74	.0472	1.466	↓	↓
5	1.256	.0784	260.3	854	345.0	1132	33.92	33.98	8.26	.0486	1.531	↓	↓
6	1.245	.0777	264.3	864	334.4	1097	31.79	35.31	8.87	.0527	1.611	↓	↓
7	1.229	.0767	269.1	883	332.5	1058	27.13	37.27	9.62	.0609	1.707	↓	↓
8	1.213	.0757	274.0	899	309.4	1015	21.01	39.49	10.56	.0751	1.827	↓	↓
9	1.197	.0747	279.2	916	295.4	969	13.17	42.23	11.84	.0976	1.982	↓	↓
10	1.181	.0737	285.9	938	279.8	918	1.26	46.54	13.68	.1323	2.1906	↓	↓
11 (hub)	1.160	.0724	296.6	973	264.3	867	-16.86	53.06	13.55	.1929	2.4915	↓	↓

TABLE II. - LIFT PRESSURE FLUCTUATION FOR BASE FAN (QF-2)

Blade section	Lift-pressure fluctuation	
	N-m^2	lb-ft^2
1 (tip)	17 301.1	361.2
2	11 688.2	244.0
3	7 619.2	159.1
4	6 201.5	129.5
5	4 946.0	103.3
6	4 596.2	96.0
7	3 484.0	72.7
8	1 681.1	35.1
9	1 256.7	26.2
10	7 081.6	147.8
11 (hub)	18 395.7	384.0
Total	84 251.3	1758.9
Average	7 659.2	159.9

TABLE III. - PRESSURE RATIO AT ROTOR EXIT

Blade section	Pressure ratio	
	Base fan	Improved fan
1 (tip)	1.541	1.556
2		
3		
4		
5		
6		
7		
8		
9		
10		1.485
11 (hub)		1.375

TABLE IV. - ANGLE OF INCIDENCE TO SUCTION SURFACE OF STATOR BLADE

Blade section	Incidence angle, deg	
	Base fan	Improved fan
1 (tip)	0	3.0
2		
3		
4		
5		
6		
7		2.9
8		2.6
9		2.1
10		1.2
11 (hub)		-0.7

TABLE V. - DESIGN PARAMETERS FOR REDESIGNED FAN (QF-11)

Blade section	Fluid density, ρ		Absolute velocity at stator inlet, U_3		Relative velocity at rotor inlet, V_1		Relative flow angle from rotor after translation to stator inlet, β_3, deg	Absolute flow angle at stator inlet, $\overline{\beta_3}$, deg	Stator setting angle (angle between chord line and axial direction), λ, deg	Profile loss coefficient, $\overline{\omega_p}$	Rotor solidity, σ	Magnitude of transverse response function $S(\omega)$	Magnitude of longitudinal response function $T(\omega)$
	kg/m^3	lbm/ft^3	m/sec	ft/sec	m/sec	ft/sec							
1 (tip)	1.270	0.07912	252.4	828	385.6	1265	41.56	37.69	8.72	0.1991	1.4500	0.15	0.45
2	1.285	.08007	252.7	829	379.8	1246	40.52	33.94	7.90	.1095	1.5096	.16	.46
3	1.287	.0802	254.5	835	373.1	1224	38.78	32.67	7.77	.0657	1.5731		
4	1.283	.0799	257.6	845	364.9	1197	36.25	32.89	8.31	.0535	1.6431		
5	1.275	.0794	260.3	854	354.8	1164	33.40	33.55	8.99	.0467	1.7223		
6	1.265	.0788	264.0	866	343.5	1127	29.82	34.89	9.93	.0530	1.8139		
7	1.250	.0779	268.2	880	331.0	1086	25.26	36.93	11.19	.0716	1.9223		
8	1.238	.0771	272.2	893	317.0	1040	19.86	39.31	12.68	.0889	2.0542	↓	↓
9	1.230	.0766	275.5	904	301.8	990	13.06	42.59	14.64	.1072	2.2201	.15	.45
10	1.215	.0757	262.4	861	284.7	934	9.62	44.77	16.04	.1419	2.4396	.15	.44
11 (hub)	1.207	.0752	235.6	773	267.3	877	7.15	47.78	18.57	.1908	2.7533	.13	.40

TABLE VI. - LIFT PRESSURE FLUCTUATIONS FOR REDESIGNED FAN (QF-11)

Blade section	Lift-pressure fluctuation	
	N/m^2	lb/ft^2
1 (tip)	11 630.5	242.81
2	7 394.4	154.37
3	4 998.4	104.35
4	3 988.8	83.27
5	3 193.5	66.67
6	2 787.1	58.19
7	2 354.4	49.15
8	1 484.1	30.98
9	77.1	1.61
10	727.6	15.19
11 (hub)	464.5	9.69
Total	39 100.5	816.2
Average	3 554.6	74.2

TABLE VII. - DESIGN VALUES

	Base fan (QF-2)	Redesigned fan (QF-11)
Rotor tip diameter, m (in.)	1.824 (71.81)	1.824 (71.81)
Stator tip diameter, m (in.)	1.726 (67.94)	1.726 (67.94)
Rotor tip speed (cruise design value, corrected), m/sec (ft/sec)	337.4 (1107)	350.1 (1149)
Design stagnation pressure ratio	1.5	1.5
Design weight flow (corrected), kg/sec (lbm/sec)	396 (873)	396 (873)
Rotor hub to tip radius ratio (inflow face)	0.50	0.50
Stator hub to tip radius ratio	0.59	0.59
Rotor-stator spacing (rotor trailing edge to stator leading edge at the hub), cm (in.)	50.8 (20)	50.8 (20)
Number of rotor blades	53	58
Number of stator blades	112	70
Rotor chord length, cm (in.)	13.97 (5.5)	13.70 (5.4)
Stator chord length, cm (in.)	6.83 (2.69)	12.45 (4.9)

TABLE VIII. - CONFIGURATIONS

Configuration	Percent speed tested	Nozzle, percent of design
412	60, 70, 80, 90	120
413	60, 70, 80, 85, 90, 95	110
414	60, 70, 80, 90	100
422	80	117.5
423	80	114
424	80	108
425	80	104

TABLE IX. - TABULATION OF ONE-THIRD-OCTAVE DATA (QF-11) WITH A DESIGN NOZZLE

[Data adjusted to standard day of 25^{o} C and 70 percent relative humidity; SPL referenced to 2×10^{-5} Pa; PWL referenced to 0.1 pW.]

(a) 60 Percent speed; fan physical speed, 2187 rpm

FREQUENCY	ANGLE, DEG															
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160
	1/3-OCTAVE BAND SOUND PRESSURE LEVELS (SPL) ON 45.7 METER RADIUS															
50	67.3	65.1	66.3	66.1	65.6	67.0	67.3	67.8	67.6	68.3	69.8	70.6	73.1	74.0	76.3	76.9
63	64.7	67.3	64.0	64.8	65.5	66.0	66.2	65.8	66.2	67.7	69.8	70.9	73.3	75.2	77.8	78.6
80	68.2	67.1	63.2	62.6	66.1	67.2	66.4	65.6	68.6	69.7	71.7	73.8	76.7	77.7	80.4	81.3
100	67.5	67.0	66.0	67.4	66.2	66.7	67.9	70.2	71.4	73.9	75.4	76.5	78.7	79.4	81.2	81.9
125	70.0	70.2	70.3	70.8	69.8	70.0	70.8	72.2	73.2	74.0	75.2	76.3	76.8	77.8	78.7	77.9
160	72.4	72.9	72.4	71.2	71.0	70.5	71.7	71.9	72.0	72.7	72.7	73.3	73.9	74.9	76.5	75.9
200	72.6	72.7	71.1	70.4	70.7	69.6	69.2	70.1	69.6	70.4	72.4	73.3	75.7	76.7	77.9	77.0
250	73.0	73.0	71.0	70.5	70.2	68.7	69.0	70.2	71.3	72.3	73.8	74.9	75.7	76.0	76.0	74.9
315	74.0	74.3	73.3	72.6	71.8	71.3	71.5	71.6	71.6	72.1	72.8	74.2	75.6	75.8	75.8	74.7
400	75.8	75.9	74.3	72.9	72.1	70.9	70.3	70.3	71.4	72.3	73.6	75.0	75.9	75.9	75.6	74.2
500	77.9	78.4	77.4	76.2	73.7	72.0	71.2	71.5	72.2	73.2	74.2	75.6	77.0	76.5	75.0	73.9
630	78.4	79.6	78.8	77.1	74.8	72.9	72.4	72.3	72.9	74.8	75.4	76.5	77.4	77.3	75.3	73.3
800	80.0	81.1	80.5	79.8	77.6	75.8	74.6	74.8	75.3	76.8	78.1	78.4	79.5	78.8	76.1	74.2
1000	82.6	83.2	82.1	80.2	78.2	76.2	75.4	76.2	76.6	77.9	79.7	79.5	81.6	80.4	76.5	74.6
1250	84.5	86.2	85.0	82.2	80.5	78.0	76.2	77.2	78.7	80.2	81.4	81.5	83.2	81.9	77.7	75.8
1600	87.0	88.8	88.0	85.6	82.8	80.8	79.0	80.1	82.3	83.3	84.6	84.6	86.0	84.1	79.5	77.7
2000	91.5	94.4	93.7	91.2	89.0	86.7	84.5	86.0	86.9	93.0	91.7	93.3	95.9	93.2	85.4	84.3
2500	89.2	90.9	90.0	88.2	85.4	83.0	80.7	82.9	84.9	86.8	87.0	88.0	89.9	87.9	82.0	79.9
3150	89.1	90.1	90.1	88.8	86.4	83.1	80.3	82.1	84.4	86.1	88.1	89.0	89.9	87.9	82.6	79.7
4000	89.2	91.7	92.7	90.4	89.9	85.5	81.1	81.1	83.9	87.4	90.2	90.2	91.1	88.9	84.7	80.8
5000	85.8	88.7	89.0	88.0	85.3	83.7	77.2	77.8	79.5	81.5	84.4	86.6	87.2	85.0	80.2	78.1
6300	87.2	88.8	87.1	88.7	86.2	84.3	78.0	77.1	80.7	81.5	83.8	85.6	86.6	85.2	80.0	77.6
8000	83.9	85.8	83.9	86.0	82.8	81.8	75.3	74.8	77.8	79.8	82.5	83.3	83.4	82.7	76.9	75.2
10000	81.2	82.2	80.7	83.9	79.0	79.0	72.2	70.6	73.8	75.1	78.8	79.9	79.8	79.9	73.2	72.6
12500	78.6	80.4	77.6	81.7	76.6	76.6	69.7	66.8	70.5	71.8	75.2	77.3	76.7	76.3	70.8	70.7
16000	74.1	76.6	72.9	76.2	72.2	72.1	64.3	60.8	63.9	65.9	70.5	73.1	72.7	71.7	66.4	65.9
20000	69.0	70.0	66.0	71.1	66.2	64.7	56.5	53.0	57.0	58.4	62.5	66.3	65.6	65.5	60.5	59.9
OVERALL	98.2	100.2	99.8	98.4	96.2	93.8	90.5	91.5	93.2	96.5	97.3	98.3	99.9	98.0	93.4	92.1

TABLE IX. - Continued.

[Data adjusted to standard day of 25° C and 70 percent relative humidity; SPL referenced to 2×10^{-5} Pa; PWL referenced to 0.1 pW.]

(b) 70 Percent speed; fan physical speed, 2549 rpm

FREQUENCY	ANGLE, DEG															
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160
	1/3-OCTAVE BAND SOUND PRESSURE LEVELS (SPL) ON 45.7 METER RADIUS															
50	72.2	69.8	71.7	70.7	71.3	72.3	73.0	73.7	72.0	73.5	74.7	76.1	77.5	79.5	81.5	83.6
63	68.1	71.0	69.0	69.3	68.8	69.8	70.3	70.6	71.0	72.5	74.1	75.6	78.5	81.5	83.8	85.7
80	69.8	71.2	67.8	67.5	68.5	69.5	70.0	69.7	72.2	74.0	77.0	78.9	81.3	83.7	86.3	87.4
100	71.7	70.8	71.2	70.8	69.8	71.3	73.5	74.2	76.2	78.2	80.3	81.8	84.2	85.2	87.2	88.2
125	74.5	77.0	77.3	74.3	75.0	75.5	76.3	77.3	78.2	79.8	80.8	82.4	83.2	83.7	84.7	85.2
160	77.0	77.7	76.7	75.2	74.9	77.4	76.7	77.5	77.5	77.9	79.0	79.8	80.0	81.4	82.5	82.6
200	77.4	77.1	74.7	74.4	74.6	74.6	74.4	74.1	74.4	76.1	78.1	79.8	81.7	82.7	83.9	83.3
250	76.5	77.0	74.8	74.3	73.6	73.3	73.6	74.6	76.3	77.6	79.5	80.6	81.0	81.5	82.3	81.5
315	77.8	79.1	77.1	76.5	75.3	74.8	75.6	76.3	76.3	77.1	78.5	79.5	81.0	81.8	81.6	80.5
400	78.8	79.4	78.3	77.1	76.3	74.9	74.6	75.4	75.9	77.4	78.8	80.0	80.8	81.6	80.9	79.7
500	80.9	81.3	80.1	80.4	81.7	78.1	77.3	77.1	77.8	77.9	79.1	80.0	81.1	81.1	80.3	78.8
630	81.7	82.7	80.9	80.2	80.2	78.9	77.4	77.1	77.1	78.2	79.6	80.5	81.4	81.1	79.7	78.3
800	82.7	83.7	82.9	83.1	81.7	79.7	78.2	78.7	79.1	80.4	81.6	81.8	82.7	82.1	79.9	78.3
1000	85.0	85.5	84.9	83.9	82.7	80.7	79.9	80.5	80.7	81.7	83.0	83.5	85.2	83.5	80.0	78.1
1250	86.0	87.9	86.9	85.0	83.9	81.9	81.2	81.7	82.7	83.4	84.7	84.5	86.4	84.2	80.9	78.6
1600	89.1	91.1	90.3	88.1	86.5	84.0	82.8	84.1	85.3	85.8	87.3	87.4	88.3	86.1	82.1	80.7
2000	90.0	92.0	92.2	90.2	89.0	86.2	85.0	86.9	88.0	88.9	89.9	90.5	90.7	88.0	83.2	81.6
2500	94.8	97.8	97.3	97.3	96.8	94.5	91.7	91.5	92.2	93.0	96.2	98.3	100.0	93.7	89.2	86.6
3150	91.1	93.0	92.3	91.3	90.5	87.8	85.3	87.5	88.8	90.3	92.3	93.2	93.8	90.6	85.8	83.6
4000	91.1	92.5	93.7	91.9	91.5	87.7	84.4	85.4	87.3	89.6	92.9	93.1	93.9	90.4	86.1	83.2
5000	90.3	93.5	94.2	93.5	92.2	91.9	85.5	85.5	85.5	87.0	90.0	93.1	92.0	90.0	84.7	82.8
6300	88.9	91.1	89.6	91.3	89.8	88.3	83.1	82.4	85.1	85.1	87.8	89.4	90.3	87.3	82.3	80.4
8000	87.5	89.5	88.2	90.4	88.2	88.0	82.7	81.5	83.2	85.0	88.2	89.0	88.2	86.2	81.0	79.2
10000	84.8	85.9	84.6	87.8	83.6	84.6	78.8	77.0	79.4	79.5	84.3	85.1	84.3	83.3	77.1	76.5
12500	82.2	84.1	81.4	85.6	81.6	82.1	76.6	73.3	76.1	76.7	81.0	83.1	81.7	80.4	74.7	74.7
16000	78.1	80.4	76.8	80.8	77.9	77.8	71.3	67.5	69.8	71.3	76.3	79.2	77.6	76.1	70.6	70.4
20000	72.8	73.6	70.1	75.7	72.3	70.9	64.1	60.2	63.4	64.0	68.7	72.6	70.5	70.1	65.1	64.7
OVERALL	100.8	103.0	102.7	102.3	101.3	99.5	96.2	96.6	97.6	98.8	101.3	102.7	103.6	100.3	97.5	96.9

TABLE IX. - Continued.

[Data adjusted to standard day of 25° C and 70 percent relative humidity; SPL referenced to 2×10^{-5} Pa; PWL referenced to 0.1 pW.]

(c) 80 Percent speed; fan physical speed, 2925 rpm

FREQUENCY	ANGLE, DEG															
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160
	1/3-OCTAVE BAND SOUND PRESSURE LEVELS (SPL) ON 45.7 METER RADIUS															
50	79.3	75.8	77.7	79.3	78.0	80.2	80.7	81.3	78.5	78.5	79.3	80.7	82.5	84.7	86.7	88.7
63	73.2	74.5	73.3	73.3	74.0	74.3	74.5	75.0	75.3	77.0	79.2	80.8	84.0	85.7	89.5	90.6
80	74.8	74.0	71.1	71.8	72.0	73.1	73.3	74.6	76.3	79.5	81.5	83.9	87.0	88.8	91.8	93.0
100	78.8	76.2	78.0	78.2	75.7	78.2	81.0	80.2	82.0	84.2	86.0	87.7	89.5	91.3	93.0	93.6
125	80.8	80.2	79.7	79.2	78.8	79.8	80.7	82.0	82.8	84.5	85.7	86.9	87.7	88.7	90.7	90.7
160	80.3	81.8	81.1	80.0	79.8	80.6	81.1	82.1	82.8	82.6	83.5	85.2	85.3	86.6	88.1	88.5
200	83.9	88.2	86.4	82.7	82.4	81.5	80.9	79.9	79.9	81.0	83.0	84.6	86.7	89.0	89.7	88.8
250	81.9	82.5	82.0	86.9	86.6	83.4	81.7	81.5	81.4	83.7	85.0	86.1	86.9	87.4	87.4	86.8
315	83.2	83.4	81.5	81.0	80.5	80.7	80.5	81.9	81.5	82.2	83.5	85.3	86.2	87.2	87.4	85.8
400	82.7	83.2	82.7	81.5	80.4	79.7	79.4	80.2	80.9	82.5	83.7	85.3	85.9	86.5	86.4	84.4
500	83.9	84.6	83.4	82.8	81.4	80.6	80.3	80.4	81.3	82.4	83.6	85.0	86.3	86.1	85.1	83.7
630	84.7	86.0	85.2	85.2	83.9	82.4	82.2	81.4	81.9	82.9	83.5	85.3	86.2	85.9	84.9	82.6
800	85.2	86.4	86.2	86.0	85.4	83.5	82.7	83.0	82.7	84.0	85.2	86.1	87.0	85.7	84.0	81.9
1000	86.9	87.9	88.1	87.8	86.4	84.1	83.8	84.4	84.6	85.3	86.6	86.7	88.3	86.1	83.9	82.0
1250	88.0	89.9	89.2	88.9	87.7	85.4	85.2	85.7	86.5	87.0	88.2	88.1	89.2	86.5	84.4	81.8
1600	91.5	94.1	93.6	92.1	90.3	88.3	86.6	88.0	88.6	88.8	89.8	89.7	90.8	88.0	84.8	82.9
2000	93.8	95.5	95.5	93.3	91.8	89.5	87.6	89.6	90.3	91.0	92.8	93.1	94.3	90.3	86.3	84.4
2500	94.2	97.2	98.5	99.2	98.8	97.8	94.3	94.2	94.0	94.7	96.5	99.1	98.2	94.3	89.2	87.3
3150	95.7	98.6	99.9	100.9	100.4	99.4	95.9	95.2	94.6	95.7	98.1	101.2	100.9	96.6	91.9	90.2
4000	92.8	95.2	96.0	93.5	93.3	90.0	88.2	89.0	90.5	92.7	96.0	96.0	96.7	92.3	88.3	85.4
5000	91.6	94.6	95.2	94.2	92.9	91.7	87.9	88.6	88.4	89.9	92.9	95.3	94.2	90.9	86.2	84.3
6300	92.4	94.7	93.4	95.6	94.4	92.7	88.6	88.0	89.4	89.7	92.1	94.3	94.5	91.0	86.0	84.5
8000	89.7	91.7	90.8	93.2	90.7	90.3	86.5	85.7	86.8	88.7	91.8	92.3	91.4	88.8	83.7	82.0
10000	86.7	88.4	87.6	90.4	86.4	87.1	82.7	81.7	83.7	84.1	88.2	89.4	88.2	86.2	80.4	79.9
12500	84.7	86.7	84.7	88.5	84.7	85.2	81.0	78.7	80.6	81.8	85.2	87.2	85.7	83.5	77.7	78.1
16000	80.2	83.3	80.2	83.9	81.1	81.4	75.8	73.3	75.0	76.3	80.9	83.5	81.7	79.6	74.1	74.1
20000	74.5	76.3	73.3	78.5	75.9	74.6	68.8	65.7	68.1	69.5	73.7	77.1	75.1	74.0	68.7	68.3
OVERALL	103.1	105.4	105.8	106.1	105.2	104.0	101.0	101.0	101.2	102.2	104.5	106.4	106.3	103.6	101.9	101.5

TABLE IX. - Concluded.

[Data adjusted to standard day of 25° C and 70 percent relative humidity; SPL referenced to 2×10^{-5} Pa; PWL referenced to 0.1 pW.]

(d) 90 Percent speed; fan physical speed, 3284 rpm

FREQUENCY	ANGLE, DEG															
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160
	1/3-OCTAVE BAND SOUND PRESSURE LEVELS (SPL) ON 45.7 METER RADIUS															
50	84.2	77.0	79.7	79.0	79.2	80.7	81.0	80.2	80.7	81.8	82.3	86.3	87.2	89.0	91.8	94.6
63	79.3	78.5	77.8	77.6	78.0	78.1	78.5	78.6	79.1	81.0	82.8	86.0	88.3	90.3	93.0	95.9
80	77.5	78.0	75.6	75.3	75.6	76.5	77.1	78.6	80.5	83.3	86.1	87.9	90.6	93.0	96.1	98.2
100	84.2	85.3	85.3	83.3	80.7	83.0	82.5	85.7	86.8	88.3	90.5	92.4	94.3	96.0	98.0	98.6
125	84.8	83.7	84.7	83.7	83.0	84.5	84.7	86.5	87.2	88.5	89.8	90.9	92.2	93.3	95.3	95.2
160	84.5	85.2	84.3	84.8	86.5	86.3	85.3	86.8	86.5	86.3	87.7	89.1	89.8	91.3	93.3	93.7
200	85.9	87.1	83.9	84.1	85.1	84.2	83.6	83.6	84.1	85.1	87.2	89.2	91.6	93.2	94.9	93.5
250	85.5	86.6	84.5	85.5	84.0	83.5	83.0	83.6	86.1	87.0	88.6	90.2	90.8	91.8	93.0	91.9
315	85.6	85.1	88.2	88.9	85.1	84.2	84.6	85.4	85.2	86.4	87.4	89.5	90.7	92.2	92.7	90.6
400	84.8	86.1	85.5	85.1	84.8	84.1	84.0	84.5	85.6	86.3	87.8	89.6	90.6	91.5	91.5	89.7
500	86.1	86.9	85.9	86.1	85.3	85.1	84.1	84.4	85.3	86.4	87.4	88.9	90.3	90.6	90.4	88.3
630	86.2	87.2	86.9	87.4	87.5	85.5	85.0	84.7	85.4	86.4	87.2	88.8	89.5	90.2	89.2	87.4
800	86.7	88.5	88.4	88.5	87.9	86.7	86.7	86.4	86.5	87.2	88.0	89.1	89.5	89.5	88.7	86.8
1000	88.1	89.8	90.0	90.5	89.3	90.3	89.0	88.3	88.6	88.1	89.1	89.4	90.5	89.1	88.3	85.5
1250	90.3	92.2	92.7	94.2	95.6	94.0	91.2	90.5	91.3	90.3	91.3	90.9	91.2	89.7	88.0	86.2
1600	92.9	95.7	96.4	96.9	98.0	96.9	93.1	93.5	93.0	92.0	92.7	92.3	92.9	90.5	88.5	87.1
2000	94.1	96.0	96.5	95.3	96.1	95.0	91.0	92.6	92.8	92.7	94.2	94.3	94.9	91.5	89.0	86.7
2500	93.0	95.1	95.5	94.6	94.8	93.1	91.6	93.0	94.0	95.1	96.5	95.7	96.0	92.6	88.8	86.5
3150	98.8	101.1	103.4	104.1	103.4	100.9	97.3	97.8	98.4	100.4	102.4	103.2	102.8	98.4	94.8	92.2
4000	93.6	96.4	97.4	95.6	95.9	93.6	91.9	91.9	93.2	95.6	98.6	97.5	97.6	94.1	90.7	87.8
5000	92.1	95.1	96.6	95.1	93.9	93.6	89.3	90.9	90.9	92.6	95.6	97.1	95.1	91.6	87.8	86.2
6300	92.7	95.2	94.0	96.2	94.4	93.4	90.0	90.5	92.2	92.9	95.4	96.7	96.0	92.5	88.5	86.7
8000	90.3	92.0	91.1	92.9	90.5	90.9	87.3	88.3	89.8	92.0	94.6	94.8	92.6	90.1	86.3	84.6
10000	87.5	89.1	88.4	91.4	87.0	87.7	84.5	84.9	87.4	88.4	92.0	92.6	90.4	89.4	83.5	82.9
12500	84.9	87.6	85.3	88.7	84.5	85.4	82.2	81.8	84.5	85.7	89.2	90.9	87.7	86.0	80.7	81.1
16000	80.5	83.9	80.7	84.2	81.5	81.9	77.5	76.9	79.1	80.8	85.5	87.8	84.4	82.5	78.1	77.5
20000	74.7	77.2	73.8	79.5	76.0	75.2	71.0	69.7	73.0	74.0	78.5	81.7	78.7	77.0	72.7	72.1
OVERALL	104.4	106.5	107.5	107.8	107.4	105.8	102.9	103.5	104.2	105.4	107.5	108.1	108.0	106.3	106.0	106.0

TABLE X. - TABULATION OF ONE-THIRD-OCTAVE DATA (QF-11) WITH DESIGN PLUS 10 PERCENT NOZZLE

[Data adjusted to standard day of 25° C and 70 percent relative humidity; SPL referenced to 2×10^{-5} Pa; PWL referenced to 0.1 pW.]

(a) 60 Percent speed; fan physical speed, 2189 rpm

FREQUENCY	ANGLE, DEG															
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160
	1/3-OCTAVE BAND SOUND PRESSURE LEVELS (SPL) ON 45.7 METER RADIUS															
50	68.2	64.7	66.2	66.8	66.8	67.3	67.8	67.8	68.3	68.7	69.5	70.1	72.5	73.8	76.2	77.9
63	64.3	66.0	64.6	65.3	65.1	65.8	65.8	66.0	66.5	68.1	68.8	70.5	72.8	74.8	78.1	78.2
80	66.5	66.8	63.6	63.8	65.8	68.0	67.6	65.8	67.5	69.6	71.1	73.7	75.0	77.3	80.0	80.9
100	67.4	67.5	65.8	67.5	67.9	67.2	68.9	69.2	71.7	73.7	75.0	76.9	77.7	78.9	80.5	80.4
125	69.3	69.7	69.3	69.8	69.8	70.0	70.7	71.7	72.8	74.0	75.5	76.1	76.5	77.2	78.0	77.9
160	72.5	71.5	70.2	70.3	70.8	71.5	71.8	71.8	72.3	72.3	72.1	73.9	73.5	74.6	75.8	76.2
200	72.5	71.5	71.3	71.0	70.0	69.8	69.3	69.3	69.2	70.5	71.8	73.4	75.3	76.2	77.0	76.2
250	72.2	72.5	70.1	68.6	69.1	69.0	68.9	69.7	70.9	72.0	73.4	74.3	74.7	75.0	75.7	74.4
315	72.6	72.6	72.9	70.1	70.9	70.4	70.2	70.9	70.7	71.6	71.9	73.8	74.6	75.1	75.2	74.1
400	73.5	73.6	72.7	71.8	71.5	70.0	69.1	69.8	70.6	71.5	72.5	73.9	74.6	75.5	74.3	73.2
500	74.9	74.9	73.9	72.4	72.1	70.3	69.6	70.1	70.8	71.8	73.1	74.0	74.9	75.1	73.6	72.3
630	75.4	76.2	74.9	74.5	73.2	70.9	70.2	70.4	71.0	72.4	73.4	74.6	74.7	75.3	73.0	71.8
800	77.2	78.0	78.2	78.3	76.7	73.8	72.5	72.8	72.3	74.0	75.3	75.9	76.8	76.5	73.7	72.2
1000	79.3	80.3	79.8	77.5	76.5	74.2	72.7	73.0	73.7	74.8	76.2	76.9	77.8	77.0	73.7	71.7
1250	81.7	82.5	81.5	79.0	77.7	75.2	73.2	74.2	75.5	76.8	78.3	78.4	79.5	78.2	74.5	72.2
1600	84.0	85.8	85.5	82.5	80.5	78.3	76.0	77.5	79.0	80.1	81.7	81.5	82.9	81.0	76.5	74.2
2000	91.3	93.5	94.7	92.2	90.7	88.5	85.8	86.0	88.3	92.5	93.0	92.8	96.8	91.5	86.8	84.9
2500	87.5	89.3	89.3	87.1	85.5	83.1	80.0	81.8	83.6	85.5	86.8	87.1	89.5	86.6	82.0	79.0
3150	86.6	88.1	87.9	86.1	84.4	81.7	78.7	81.1	83.1	85.2	86.7	87.4	88.4	86.1	80.9	77.7
4000	87.9	90.6	92.1	89.6	90.1	86.0	81.1	81.1	83.6	87.1	89.6	89.0	90.2	88.2	83.7	79.5
5000	84.1	86.9	87.9	85.9	84.1	83.1	76.7	77.6	78.9	81.2	83.7	86.0	86.4	84.2	79.6	76.7
6300	85.4	87.4	85.6	86.9	85.3	83.4	77.8	76.9	80.1	80.6	83.3	84.7	86.3	84.1	79.1	76.9
8000	82.2	83.7	82.4	84.0	81.7	81.3	75.1	74.6	77.2	79.5	82.0	82.8	82.7	81.6	76.6	74.1
10000	78.8	80.3	78.4	81.8	77.6	78.4	71.6	70.2	73.4	74.3	78.1	79.4	78.9	78.9	72.4	71.5
12500	75.9	77.6	75.2	78.7	74.8	75.4	69.1	66.2	69.5	71.2	75.0	76.8	75.6	75.4	69.4	69.0
16000	70.8	73.3	70.0	73.1	70.6	70.7	63.2	60.0	63.2	64.9	69.5	72.3	70.9	70.6	65.3	64.3
20000	65.6	66.2	62.6	67.9	64.4	62.9	55.3	52.1	55.9	57.1	61.1	64.8	63.6	63.7	59.0	57.8
OVERALL	96.6	98.6	99.1	97.3	96.1	93.8	90.2	90.8	92.8	95.7	97.1	97.3	99.7	96.5	93.0	91.4

TABLE X. - Continued.

[Data adjusted to standard day of 25^{o} C and 70 percent relative humidity; SPL referenced to 2×10^{-5} Pa; PWL referenced to 0.1 pW.]

(b) 70 Percent speed, fan physical speed, 2549 rpm

FREQUENCY	ANGLE, DEG															
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160
	1/3-OCTAVE BAND SOUND PRESSURE LEVELS (SPL) ON 45.7 METER RADIUS															
50	72.3	69.6	71.9	71.3	71.1	72.6	73.8	73.3	72.9	73.4	74.4	76.0	77.4	79.3	82.4	83.7
63	68.2	70.3	69.2	68.8	69.5	70.2	71.0	70.0	71.2	71.8	74.2	76.1	78.3	80.8	83.3	85.2
80	69.3	72.3	68.7	67.8	69.0	70.2	70.0	70.0	72.7	74.8	77.3	78.4	81.2	83.8	85.2	86.9
100	70.3	69.3	70.6	69.8	69.5	71.3	73.1	74.5	76.1	77.8	79.8	81.4	83.1	85.1	86.6	87.5
125	74.2	75.2	74.5	73.0	74.5	75.4	75.9	76.9	77.7	78.7	80.5	81.4	82.0	83.4	84.0	84.8
160	75.2	74.5	75.7	74.2	75.4	76.2	76.5	76.4	77.5	77.2	78.4	79.3	79.4	80.7	82.2	82.3
200	76.8	75.6	74.1	74.5	73.6	74.0	74.6	74.0	73.8	74.6	77.1	78.9	81.0	82.0	82.8	82.5
250	75.6	76.7	75.6	73.2	72.1	71.9	72.7	73.4	75.7	77.6	79.2	80.2	80.4	81.1	81.7	80.6
315	76.1	78.1	76.2	75.4	74.2	74.6	75.1	75.7	76.1	76.4	77.9	79.2	80.2	80.9	81.4	80.1
400	75.9	77.1	76.9	75.4	74.2	74.1	73.7	74.7	75.7	76.7	78.1	79.3	79.9	80.4	80.2	78.6
500	77.1	78.3	78.0	77.1	78.1	77.1	76.6	75.6	76.0	76.5	77.8	78.9	79.8	80.0	79.5	78.0
630	77.9	79.2	79.2	78.1	77.9	77.9	75.9	75.1	75.2	76.7	77.6	78.7	79.4	79.2	78.7	77.1
800	79.4	80.4	80.7	79.4	77.6	75.9	75.7	75.7	76.2	77.6	78.4	79.2	80.1	79.9	78.4	76.5
1000	80.7	82.3	82.0	80.5	79.3	77.3	76.8	76.8	77.3	78.3	79.3	80.1	81.3	80.0	78.0	75.9
1250	82.7	84.2	83.7	82.2	80.5	78.5	78.0	78.0	79.2	80.2	81.9	81.1	82.5	80.7	78.4	75.8
1600	84.5	86.5	85.8	84.0	82.3	80.5	78.8	80.1	81.0	81.8	83.8	83.2	84.3	82.3	78.6	76.7
2000	86.8	89.1	89.5	87.6	85.8	83.8	82.5	83.8	85.5	86.3	88.6	88.2	89.0	85.3	80.8	78.6
2500	92.5	96.3	96.3	97.0	94.7	93.2	91.2	90.0	92.8	92.0	98.3	97.4	100.7	93.8	89.0	86.6
3150	88.4	90.0	90.2	89.2	87.9	85.5	83.7	85.5	86.7	88.7	90.0	91.0	91.9	89.2	84.0	81.1
4000	87.3	90.0	90.8	88.3	88.0	85.1	82.8	83.9	85.7	88.6	90.9	90.9	92.1	89.1	84.2	80.6
5000	88.6	92.1	93.2	91.6	89.7	89.2	84.9	84.9	84.9	88.1	89.6	92.0	91.4	88.7	83.7	81.7
6300	86.3	88.6	87.2	88.6	87.1	85.3	81.6	81.4	83.6	84.6	87.3	88.7	89.3	86.4	81.6	79.6
8000	85.9	87.9	86.2	88.7	86.4	86.4	81.9	80.7	82.2	84.7	87.2	87.9	87.2	84.9	80.0	78.4
10000	82.0	83.8	82.3	85.5	81.6	82.6	78.1	76.0	78.3	79.5	83.5	84.1	83.6	82.6	76.3	75.8
12500	79.0	81.7	78.9	82.7	78.7	79.9	75.2	72.3	75.1	76.8	80.4	82.1	80.7	79.4	73.5	73.5
16000	74.4	77.4	73.5	77.4	74.8	75.4	69.8	66.6	68.8	70.8	75.5	77.4	76.6	74.9	69.3	69.2
20000	68.5	70.2	66.3	72.0	69.0	68.2	62.4	58.7	61.8	63.2	66.9	70.2	69.1	68.5	63.5	63.1
OVERALL	98.0	100.8	100.8	100.6	98.7	97.4	95.1	94.9	96.7	97.6	101.3	101.3	103.2	99.3	96.6	96.0

TABLE X. - Continued.

[Data adjusted to standard day of 25° C and 70 percent relative humidity; SPL referenced to 2×10^{-5} Pa; PWL referenced to 0.1 pW.]

(c) 80 Percent speed; fan physical speed, 2913 rpm

FREQUENCY	ANGLE, DEG															
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160
	1/3-OCTAVE BAND SOUND PRESSURE LEVELS (SPL) ON 45.7 METER RADIUS															
50	80.0	76.3	77.8	78.6	78.6	81.1	80.6	81.5	77.5	77.5	79.3	80.4	82.3	85.1	87.1	89.9
63	72.2	74.6	72.9	73.4	73.7	74.4	75.1	74.7	74.6	76.7	78.2	80.8	83.4	86.4	88.1	91.1
80	73.9	73.4	71.4	72.6	72.4	72.9	73.6	74.9	76.6	79.1	82.1	84.2	86.9	89.2	91.2	92.6
100	79.3	77.1	75.8	76.3	77.3	76.8	79.1	80.1	81.3	84.1	85.6	86.7	88.8	90.6	92.3	93.2
125	79.0	78.2	79.0	78.2	79.2	80.0	80.7	82.0	83.0	84.2	85.3	86.2	86.8	88.7	89.7	90.1
160	79.3	80.8	80.0	79.6	80.0	80.5	81.6	82.3	83.3	82.8	82.8	83.5	85.0	86.3	87.8	88.4
200	81.6	81.1	79.9	79.7	80.2	79.2	80.2	78.9	79.7	80.9	82.4	84.3	86.4	67.4	88.7	88.1
250	79.4	81.7	81.4	79.7	78.4	78.4	78.1	80.1	80.7	82.1	83.6	85.2	86.1	86.9	87.7	85.8
315	79.9	80.1	80.4	79.4	79.7	79.4	80.4	81.1	81.1	81.7	82.6	84.3	85.4	86.9	87.1	86.0
400	79.5	80.0	81.0	79.9	80.2	79.2	78.5	79.5	80.5	81.5	82.7	84.1	85.2	86.4	85.7	84.6
500	80.6	81.1	80.6	80.1	79.9	78.9	79.2	79.6	80.1	80.9	82.2	83.8	84.7	85.1	84.9	83.1
630	80.9	81.6	82.1	82.1	81.3	80.3	79.3	79.9	80.3	81.3	82.1	83.5	84.4	84.3	83.9	82.3
800	81.4	82.9	83.4	84.0	82.5	82.0	81.7	81.2	81.2	82.0	82.7	83.5	84.4	84.4	83.0	81.8
1000	82.9	83.6	84.6	84.3	83.8	82.9	82.3	81.6	82.1	82.3	83.1	83.5	84.6	83.8	82.6	80.8
1250	84.8	86.2	87.3	87.5	86.8	84.8	84.2	83.3	83.3	84.0	84.8	84.8	85.5	84.0	82.3	80.7
1600	85.9	87.9	88.6	89.3	88.9	85.9	84.1	84.9	84.4	85.3	86.3	85.9	86.6	84.9	82.4	80.7
2000	86.8	88.6	89.1	88.8	88.8	86.3	85.1	86.6	87.1	87.8	88.8	87.9	88.3	86.1	82.6	81.0
2500	92.3	94.8	96.3	97.7	97.7	96.3	92.7	93.2	93.0	95.5	97.2	98.1	97.7	94.2	88.5	88.1
3150	93.4	96.2	97.5	98.9	98.9	97.7	93.7	94.4	93.9	95.5	97.9	99.0	99.0	96.4	91.4	90.3
4000	88.0	90.6	92.1	90.6	91.1	87.8	87.3	88.0	89.0	91.3	93.8	93.2	94.1	90.5	86.3	83.2
5000	87.7	91.2	91.5	91.7	90.4	89.0	85.9	87.3	87.5	89.3	91.3	94.0	93.0	89.4	84.5	83.3
6300	88.7	91.0	90.0	92.7	91.7	89.9	86.7	86.9	88.0	89.0	91.2	93.3	93.7	89.7	85.2	83.7
8000	85.9	88.2	87.3	89.7	87.3	87.4	84.4	84.7	86.1	88.2	90.6	91.2	90.0	87.7	82.7	81.2
10000	83.0	84.5	83.9	86.7	83.4	83.9	81.0	80.7	82.7	83.7	87.5	88.0	86.7	85.4	79.5	79.3
12500	80.4	83.1	80.7	84.8	81.4	81.9	79.1	77.9	80.0	81.2	84.4	86.1	84.1	82.2	76.9	77.2
16000	75.6	78.9	76.0	79.6	77.9	78.1	73.3	72.3	74.0	76.1	80.2	82.2	80.2	78.4	73.3	73.2
20000	69.9	71.6	68.4	74.2	71.7	70.9	66.1	64.4	67.5	68.9	72.4	75.8	73.5	73.0	67.5	67.5
OVERALL	99.6	101.9	102.7	103.7	103.4	102.0	99.2	99.8	99.9	101.6	103.6	104.6	104.6	102.8	101.1	101.2

TABLE X. - Continued.

[Data adjusted to standard day of 25° C and 70 percent relative humidity; SPL referenced to 2×10^{-5} Pa; PWL referenced to 0.1 pW.]

(d) 85 Percent speed, fan physical speed, 3135 rpm

FREQUENCY	ANGLE, DEG 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160
	1/3-OCTAVE BAND SOUND PRESSURE LEVELS (SPL) ON 45.7 METER RADIUS															
50	78.4	76.1	79.9	77.7	79.7	82.6	81.2	82.6	80.7	80.2	79.9	83.3	85.1	87.1	89.1	91.8
63	73.6	75.8	75.0	75.0	75.8	76.1	76.0	77.3	77.3	78.3	79.6	82.2	84.3	87.6	90.6	93.0
80	75.7	74.7	73.3	73.5	74.3	74.2	74.7	76.0	78.8	81.0	82.7	85.7	87.5	90.5	92.5	94.7
100	86.2	77.3	79.8	81.0	79.0	80.0	80.7	80.3	84.5	86.0	86.8	88.9	90.7	92.2	94.3	95.1
125	80.1	78.9	80.2	79.2	79.7	80.7	82.1	83.1	84.7	85.6	86.7	87.3	88.9	90.2	91.6	91.5
160	82.6	82.2	80.6	80.9	81.6	85.1	82.6	83.1	85.6	84.4	85.6	87.1	87.9	87.9	89.9	90.0
200	81.9	81.7	83.9	80.9	81.2	81.2	80.7	80.7	82.7	83.0	83.9	85.6	88.4	89.5	90.5	89.8
250	81.3	81.7	80.0	80.0	80.2	79.7	79.7	80.5	82.7	83.7	85.0	86.4	87.7	88.2	88.8	88.1
315	81.0	80.8	81.3	81.3	80.8	81.0	81.5	82.3	82.8	83.5	84.2	85.9	87.3	88.5	88.2	87.4
400	81.6	82.6	82.0	81.0	80.8	80.8	80.5	81.0	82.3	83.1	84.1	85.9	86.8	87.8	87.1	85.9
500	82.0	82.1	81.5	81.6	82.0	80.8	80.6	81.0	82.5	82.5	84.0	85.6	86.5	87.1	86.1	84.9
630	81.6	82.4	83.1	82.8	82.3	81.3	80.8	81.6	82.1	82.4	83.6	85.0	85.6	85.9	85.4	83.5
800	81.6	83.0	83.8	84.8	85.0	83.6	82.8	82.0	82.8	83.1	83.8	85.2	85.6	86.1	84.3	83.0
1000	84.2	85.3	86.3	86.7	86.3	85.8	83.8	83.5	83.8	84.0	84.7	85.4	86.2	85.3	83.8	82.4
1250	86.1	87.8	89.4	89.4	90.6	88.6	87.1	85.9	85.8	85.4	86.3	86.0	86.8	85.6	83.6	82.7
1600	88.6	90.6	92.9	92.9	94.2	91.2	88.7	89.2	89.2	87.2	87.9	88.0	88.7	86.4	84.2	83.5
2000	87.7	89.7	90.7	91.0	91.0	89.7	87.5	87.7	88.4	88.7	89.4	89.5	89.4	86.4	83.7	82.6
2500	88.6	91.4	92.4	91.9	91.9	90.9	88.7	90.2	91.2	94.2	93.9	95.3	94.4	89.7	85.4	84.8
3150	95.3	99.8	101.8	102.5	103.1	100.6	97.6	97.1	97.5	99.3	99.8	103.2	104.8	98.0	93.1	91.9
4000	89.0	91.4	93.1	91.4	92.3	90.3	88.6	89.3	90.9	92.8	96.0	94.7	95.3	91.6	87.3	85.5
5000	87.3	90.8	92.1	90.9	89.8	89.8	86.8	87.9	88.2	90.9	94.6	94.5	93.1	89.9	85.2	83.7
6300	89.1	93.0	91.8	94.3	92.3	91.1	88.6	88.5	90.1	91.3	92.6	94.9	95.0	91.1	86.5	84.6
8000	86.0	88.8	87.8	90.1	87.9	88.3	85.6	86.2	87.5	90.5	92.2	91.8	90.9	88.4	84.0	82.2
10000	83.4	86.2	85.1	87.6	84.7	85.7	82.0	82.7	85.4	86.3	88.9	90.4	88.7	87.1	81.2	80.1
12500	80.6	84.1	81.5	84.1	82.1	83.4	78.9	79.8	82.2	82.5	86.3	88.0	86.3	83.9	78.8	77.8
16000	76.0	80.2	76.6	80.4	78.7	79.0	74.2	74.7	77.1	77.7	81.2	83.5	82.2	80.2	75.9	73.3
20000	69.9	73.0	69.0	75.7	72.4	72.1	67.7	67.3	70.6	71.8	74.7	77.5	76.1	74.6	70.6	67.4
OVERALL	100.4	103.3	104.7	105.1	105.4	103.5	101.0	101.1	101.9	103.4	104.7	106.4	107.3	103.8	102.6	102.8

TABLE X. - Continued.

[Data adjusted to standard day of 25° C and 70 percent relative humidity; SPL referenced to 2×10^{-5} Pa; PWL referenced to 0.1 pW.]

(e) 90 Percent speed; fan physical speed, 3281 rpm

FREQUENCY	ANGLE, DEG															
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160
	1/3-OCTAVE BAND SOUND PRESSURE LEVELS (SPL) ON 45.7 METER RADIUS															
50	83.7	77.0	79.3	78.3	81.0	80.8	81.8	81.2	80.5	82.3	82.3	85.9	86.3	88.7	91.3	93.9
63	78.7	78.4	77.4	76.9	78.4	77.9	79.1	78.4	79.6	80.7	82.4	85.3	87.7	90.1	92.4	95.5
80	77.3	76.0	75.3	75.8	75.5	76.5	77.7	78.3	80.3	82.7	85.7	87.9	90.0	92.8	95.3	96.9
100	82.4	86.9	84.2	83.7	86.4	81.7	87.4	85.2	85.9	89.7	90.4	92.8	93.4	94.7	96.7	97.4
125	82.8	83.5	82.7	82.2	83.0	83.0	84.7	85.7	86.7	88.3	89.2	90.9	91.3	92.8	94.7	94.4
160	83.1	83.4	83.1	83.2	82.9	84.2	84.7	85.2	85.7	86.2	86.9	87.8	88.7	90.9	92.1	92.8
200	84.6	83.4	83.6	83.4	83.3	83.1	83.3	83.3	83.6	85.1	86.9	88.7	90.8	92.6	93.6	92.7
250	82.6	84.1	82.6	81.3	80.6	80.6	81.1	83.1	85.1	86.4	87.8	89.5	89.8	91.3	91.6	90.8
315	83.0	83.5	85.8	85.8	82.6	82.6	83.5	84.5	85.0	86.1	87.0	89.1	90.0	91.1	91.8	89.9
400	83.0	84.9	83.0	83.0	83.4	82.9	82.5	83.4	84.4	85.7	86.9	88.8	89.5	90.5	90.4	88.6
500	83.0	83.7	84.8	83.5	84.5	84.2	83.2	83.3	84.2	85.3	86.8	87.9	89.0	89.8	89.5	87.4
630	83.6	84.2	84.9	84.9	83.4	82.9	83.2	83.7	84.2	85.2	86.2	87.8	88.6	88.9	87.9	86.3
800	83.4	86.4	85.9	87.1	87.1	83.9	84.9	85.2	84.6	85.4	86.4	87.7	88.1	88.2	87.4	85.5
1000	84.2	86.5	86.4	87.2	87.5	86.0	85.7	86.2	84.7	86.0	86.5	87.3	88.0	87.7	86.3	84.3
1250	88.3	91.8	93.2	94.2	94.8	93.5	90.6	90.4	89.4	88.4	88.3	88.9	88.9	88.3	86.8	84.7
1600	94.4	96.9	98.7	100.2	101.9	100.2	96.4	95.4	93.7	90.9	91.5	91.8	91.5	89.4	88.7	86.6
2000	89.6	92.8	94.1	95.1	96.0	95.3	92.5	91.3	90.8	90.2	90.9	90.3	90.5	88.2	86.3	84.2
2500	88.7	91.4	91.7	91.9	92.9	92.3	92.0	91.9	92.9	95.7	97.2	95.6	93.4	90.4	86.4	84.3
3150	95.6	99.1	100.0	99.5	99.6	96.8	96.0	95.8	96.6	99.1	103.1	103.6	103.6	98.0	93.6	91.2
4000	88.9	91.7	93.2	92.6	93.1	90.7	90.1	90.4	91.4	93.9	96.6	95.9	96.4	92.9	89.2	86.7
5000	87.6	91.1	92.3	91.8	90.3	90.6	87.9	89.4	89.8	91.8	94.3	96.1	94.1	90.4	86.4	85.0
6300	88.9	91.1	89.6	91.9	90.6	89.8	87.6	88.8	91.0	92.0	94.3	95.2	95.1	91.8	86.9	85.1
8000	86.5	88.1	87.2	89.2	87.3	88.2	85.7	87.5	88.9	91.4	93.9	93.5	91.9	89.4	85.0	83.5
10000	83.8	84.9	84.1	86.9	83.3	84.8	82.6	83.6	86.6	87.4	91.1	91.3	89.1	87.6	81.8	81.6
12500	81.3	83.0	80.6	84.8	80.8	82.1	80.5	80.3	83.4	84.6	88.1	89.7	86.5	84.8	79.7	80.1
16000	76.0	79.1	76.0	79.9	77.1	78.0	75.3	75.5	78.3	79.8	83.9	86.0	83.1	81.6	76.4	76.6
20000	70.3	71.8	68.8	74.3	70.9	70.8	68.4	68.3	71.7	72.7	76.9	79.9	76.8	75.8	70.9	71.0
OVERALL	101.6	104.2	105.1	105.6	106.2	104.7	102.8	102.6	103.0	104.5	107.0	107.5	107.4	105.4	104.9	105.0

TABLE X. - Concluded.

[Data adjusted to standard day of 25° C and 70 percent relative humidity; SPL referenced to 2×10^{-5} Pa; PWL referenced to 0.1 pW.]

(f) 95 Percent speed; fan physical speed, 3503 rpm

FREQUENCY	ANGLE, DEG 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160
	1/3-OCTAVE BAND SOUND PRESSURE LEVELS (SPL) ON 45.7 METER RADIUS															
50	82.0	77.9	78.7	79.5	79.5	79.5	81.2	81.7	82.7	82.4	84.0	86.0	87.2	90.0	93.0	95.3
63	86.0	80.5	78.3	83.0	79.3	81.2	80.8	79.8	82.5	82.3	85.0	88.1	89.5	91.2	95.0	97.2
80	78.7	78.9	76.9	77.4	77.5	78.2	78.0	79.0	81.9	83.7	86.4	88.9	92.0	95.2	98.2	98.8
100	86.9	85.4	82.9	84.2	83.2	81.4	83.0	84.0	87.5	88.0	90.0	92.6	94.2	96.4	99.4	98.9
125	93.9	92.4	88.9	90.0	90.2	85.5	87.9	86.7	90.5	90.4	91.9	94.1	94.5	96.2	97.2	96.6
160	84.0	85.2	85.0	84.0	84.0	85.4	86.4	86.2	87.2	87.5	88.0	89.0	90.5	92.2	94.0	94.6
200	84.2	84.6	84.2	84.2	83.4	84.1	84.6	83.7	84.7	86.1	88.1	90.5	92.1	93.9	95.1	94.3
250	84.0	86.5	84.3	82.7	81.8	82.2	82.8	84.3	86.8	88.3	89.7	91.1	91.7	92.8	93.5	92.4
315	87.3	84.5	85.0	85.8	84.8	85.0	86.1	86.5	87.6	87.5	88.1	90.5	91.3	92.6	93.0	91.9
400	83.8	83.3	84.6	84.0	83.8	84.3	85.1	85.1	86.5	87.1	88.3	90.1	91.0	91.6	91.6	90.5
500	83.2	84.0	83.5	84.5	86.9	85.0	86.7	85.8	86.7	87.0	87.8	90.4	90.3	91.2	90.8	89.3
630	83.7	84.2	86.6	88.6	92.4	89.1	87.2	86.6	86.7	86.6	87.6	89.8	90.1	90.1	89.6	88.0
800	84.1	87.6	87.3	87.9	88.4	87.8	86.3	86.4	87.1	87.3	88.1	89.7	90.1	90.1	88.8	87.4
1000	85.0	86.7	86.5	88.0	87.5	86.7	86.8	86.2	86.7	87.2	87.7	88.8	89.7	89.3	88.3	86.3
1250	88.7	90.6	90.2	92.4	94.4	91.5	90.5	88.7	88.1	90.7	88.9	90.3	91.1	89.6	88.1	88.1
1600	93.4	96.0	95.0	96.0	98.1	100.1	98.6	93.4	93.7	91.9	92.5	92.3	91.9	90.0	89.0	87.8
2000	89.9	93.2	94.0	93.7	98.9	97.9	97.7	96.2	93.2	92.3	91.6	92.4	91.4	89.0	87.4	85.8
2500	88.8	91.9	92.4	93.6	94.9	96.1	94.1	93.9	93.1	94.3	94.8	94.9	92.6	89.8	86.9	86.2
3150	96.8	99.8	100.8	99.8	98.7	97.3	96.0	96.7	97.5	101.5	104.2	106.3	101.8	97.3	92.8	91.8
4000	91.1	93.9	95.4	93.9	94.1	92.1	91.7	91.9	93.2	95.9	99.1	99.5	98.7	95.2	91.6	89.8
5000	87.2	90.4	91.5	90.9	89.9	90.4	88.7	90.0	90.2	92.5	95.9	96.2	93.7	90.5	86.4	85.5
6300	88.6	91.3	89.9	92.0	90.8	89.9	89.1	90.0	92.0	93.8	94.8	96.4	95.6	92.3	88.1	85.9
8000	86.5	89.0	87.5	89.1	87.4	88.3	87.0	88.3	90.2	92.8	94.2	93.8	92.3	89.7	86.2	84.5
10000	84.0	85.8	84.7	85.8	83.8	85.2	83.3	85.5	87.8	89.0	91.7	92.7	90.4	88.7	83.0	82.0
12500	81.3	84.0	81.6	83.3	81.3	82.7	80.8	82.5	85.3	85.7	89.3	91.2	88.2	85.8	81.4	80.4
16000	76.8	80.0	75.9	79.2	77.3	78.7	76.2	77.8	79.8	80.7	84.5	87.1	84.9	82.5	78.2	76.5
20000	70.6	72.9	68.5	74.2	70.9	71.3	69.7	70.5	74.4	75.4	78.2	81.2	78.6	76.9	73.2	70.4
OVERALL	102.8	104.8	105.0	105.0	105.9	105.6	104.7	103.7	104.1	106.0	108.0	109.5	107.6	106.5	106.8	106.7

TABLE XI. - TABULATION OF ONE-THIRD-OCTAVE DATA (QF-11) WITH DESIGN PLUS 20 PERCENT NOZZLE

[Data adjusted to standard day of 25^{o} C and 70 percent relative humidity; SPL referenced to 2×10^{-5} Pa; PWL referenced to 0.1 pW.]

(a) 60 Percent speed; fan physical speed, 2189 rpm

FREQUENCY	ANGLE, DEG															
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160
	1/3-OCTAVE BAND SOUND PRESSURE LEVELS (SPL) ON 30.5 METER RADIUS															
50	72.0	67.7	68.7	69.3	69.3	71.0	70.8	70.8	71.8	72.3	72.8	74.4	75.3	76.8	79.0	80.6
63	67.0	70.7	68.0	68.3	68.7	69.7	68.8	69.2	69.5	71.3	72.0	74.4	76.2	78.2	79.7	82.4
80	69.8	70.2	66.3	65.8	70.0	70.5	69.7	68.5	71.3	72.3	74.3	76.3	78.7	80.5	82.3	84.1
100	70.9	72.7	70.7	71.9	70.9	71.9	73.2	73.0	74.5	77.0	77.4	79.3	80.7	82.4	83.2	83.8
125	75.0	75.7	73.8	73.7	73.8	73.8	74.3	75.0	75.8	77.0	78.2	79.3	79.7	80.2	80.8	80.9
160	79.5	77.9	75.2	76.0	73.0	75.2	74.4	75.0	75.2	75.4	75.4	77.0	76.4	77.9	78.7	78.8
200	75.7	76.0	74.4	73.2	73.7	73.2	73.0	72.7	72.5	73.2	74.9	76.5	78.4	78.9	79.5	78.8
250	76.1	76.8	75.3	76.3	74.9	73.9	73.1	73.3	74.1	75.3	76.8	77.5	77.6	78.4	78.4	77.7
315	77.4	77.5	75.2	75.0	74.9	74.4	74.2	73.9	74.7	74.7	75.5	76.8	77.7	78.7	78.0	77.1
400	77.9	79.0	76.2	75.5	75.2	73.7	73.2	72.9	74.4	75.0	76.2	77.5	77.7	78.9	77.2	75.9
500	78.8	79.0	76.8	76.7	75.5	74.3	74.0	73.7	74.3	75.0	76.0	76.3	77.7	78.5	76.5	75.4
630	78.0	79.3	78.0	77.6	77.0	74.8	74.0	74.1	75.0	75.3	76.6	76.5	77.8	78.6	76.0	74.5
800	79.6	81.1	80.2	81.2	80.7	77.4	76.7	75.7	76.1	76.9	78.1	78.8	79.4	79.9	76.6	75.3
1000	81.1	82.6	81.1	80.3	79.3	76.4	76.3	75.9	76.6	77.4	78.8	79.3	80.3	79.9	75.9	74.2
1250	83.6	84.5	83.1	81.5	80.6	77.3	76.3	76.8	78.1	79.1	80.3	80.7	81.6	81.1	76.5	74.5
1600	86.0	88.3	87.3	84.6	83.6	81.0	79.1	79.5	81.3	82.3	84.3	84.2	85.5	83.6	78.3	76.2
2000	96.2	98.2	98.4	96.2	95.4	93.0	91.5	91.2	93.9	96.4	98.2	98.5	100.7	95.5	90.0	86.8
2500	90.8	93.2	92.3	90.3	89.2	86.7	84.8	85.3	87.5	89.0	90.7	90.8	93.3	89.8	84.7	81.7
3150	89.1	90.6	90.5	88.5	88.0	85.0	82.5	84.1	86.5	88.1	89.5	89.6	91.3	89.0	83.1	80.2
4000	92.1	94.8	96.0	93.3	93.8	89.1	85.5	84.8	88.0	91.0	93.0	92.6	93.8	91.8	86.5	83.1
5000	87.7	90.5	91.1	89.2	88.4	86.3	81.0	81.5	83.3	85.1	87.8	89.8	90.2	88.0	83.0	81.0
6300	89.3	91.2	89.0	90.5	89.7	87.3	82.3	81.0	84.1	84.8	87.3	88.9	90.7	88.3	83.0	80.7
8000	85.8	87.1	85.9	87.1	85.3	84.8	79.4	78.9	81.3	83.3	86.3	87.1	86.9	85.6	80.3	78.3
10000	82.6	83.8	82.1	85.0	81.6	81.3	76.3	74.3	78.3	78.6	82.6	83.8	83.5	83.3	76.3	76.3
12500	80.1	81.5	78.7	82.6	79.0	78.7	73.9	70.9	74.7	76.1	79.8	81.5	80.9	80.2	73.8	74.4
16000	75.3	77.3	74.5	77.5	75.2	75.0	68.3	65.3	68.6	70.1	74.8	77.4	76.6	75.5	70.0	70.0
20000	69.6	71.0	67.4	72.2	69.6	67.7	61.2	57.7	61.9	63.1	67.2	70.4	69.6	69.8	64.5	64.2
OVERALL	100.5	102.5	102.5	100.8	100.1	97.5	95.0	94.8	97.3	99.4	101.3	101.7	103.4	100.2	95.8	94.4

TABLE XI. - Continued.

[Data adjusted to standard day of 25° C and 70 percent relative humidity; SPL referenced to 2×10^{-5} Pa; PWL referenced to 0.1 pW.]

(b) 70 Percent speed; fan physical speed, 2549 rpm

FREQUENCY	ANGLE, DEG															
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160
	1/3-OCTAVE BAND SOUND PRESSURE LEVELS (SPL) ON 45.7 METER RADIUS															
50	71.7	70.1	71.4	71.2	71.1	71.6	73.6	73.7	72.4	73.1	73.7	75.5	77.7	78.9	81.7	83.6
63	66.8	70.2	68.2	68.8	68.2	69.8	70.2	69.2	70.0	72.0	73.5	75.1	78.3	80.5	82.8	84.2
80	70.0	71.8	68.0	67.2	68.5	68.7	69.2	69.0	72.3	74.0	75.7	78.8	80.5	83.0	85.2	86.4
100	70.0	69.3	69.8	69.7	69.5	70.5	72.0	73.5	75.7	77.7	79.7	81.4	82.8	83.7	85.8	86.9
125	73.7	74.5	74.9	73.2	74.0	75.4	75.4	77.4	77.4	79.2	79.9	80.8	81.2	82.2	83.4	84.3
160	75.5	76.3	75.5	73.8	74.3	76.7	75.8	75.7	77.2	76.3	77.2	79.8	79.0	80.3	80.7	81.4
200	76.0	75.5	73.7	73.8	73.2	73.7	73.5	73.5	73.7	75.0	76.3	78.6	80.7	81.2	82.3	81.6
250	75.0	76.6	74.5	73.6	72.0	71.8	71.3	73.3	75.3	77.0	78.1	79.2	79.3	80.5	80.5	80.0
315	75.3	75.8	74.8	73.8	73.2	73.2	74.0	75.2	75.2	76.0	77.2	78.4	79.5	80.2	80.3	79.2
400	74.8	76.6	75.4	74.1	73.8	72.9	72.9	73.8	74.3	75.8	77.1	78.4	79.1	79.6	79.3	78.3
500	76.0	77.2	76.0	76.2	79.4	76.2	75.4	74.7	75.2	75.5	76.7	78.1	79.2	79.5	78.5	77.1
630	76.8	77.9	77.4	77.3	79.4	79.1	75.4	74.3	74.1	75.4	76.8	77.7	78.8	78.8	77.4	76.0
800	78.1	79.6	78.4	77.4	76.2	74.9	74.2	74.7	75.7	76.7	77.1	78.2	79.1	78.6	77.4	76.1
1000	79.5	81.0	80.3	78.7	78.0	76.2	75.0	75.8	76.2	76.8	78.2	78.4	79.8	78.7	76.8	75.1
1250	81.6	82.9	82.1	80.6	79.7	77.4	76.1	77.1	77.6	78.7	79.7	79.7	80.9	79.2	76.9	74.8
1600	82.5	84.9	84.2	81.9	81.2	79.0	77.2	78.4	79.2	80.2	82.2	82.0	82.7	80.5	76.9	75.1
2000	85.2	87.5	87.7	85.9	85.4	83.0	81.4	82.4	83.9	85.7	87.4	87.6	87.2	84.5	79.7	77.6
2500	92.9	96.5	96.2	95.4	95.5	92.7	89.5	90.4	90.2	95.5	95.4	98.8	98.2	95.5	88.9	88.4
3150	87.6	89.2	88.7	87.2	87.2	84.4	82.1	84.4	85.2	87.6	89.4	90.0	90.6	88.2	82.6	80.2
4000	86.0	88.9	89.7	86.9	87.1	84.1	81.9	83.0	85.0	87.6	90.4	90.0	91.0	87.9	83.0	79.5
5000	87.8	91.8	92.7	90.9	89.7	89.9	84.5	84.5	85.0	87.0	89.5	91.8	90.8	88.7	83.3	81.3
6300	85.0	87.2	86.0	87.4	86.2	84.9	81.2	81.2	83.2	84.7	86.9	88.5	89.2	86.2	81.2	79.2
8000	84.9	87.2	85.9	87.4	86.2	86.1	81.6	80.4	81.9	84.7	87.3	87.6	87.1	85.1	80.2	78.1
10000	81.2	83.0	81.6	83.8	80.9	81.8	77.3	76.1	78.2	79.6	83.2	84.2	83.3	82.5	76.2	75.4
12500	77.6	80.6	77.8	81.0	78.0	78.5	74.7	72.3	75.0	76.5	80.2	82.1	80.4	79.0	73.0	73.1
16000	72.3	76.0	72.3	75.8	73.9	74.4	69.0	66.5	68.7	70.8	75.0	77.5	75.8	74.4	69.1	68.8
20000	66.4	68.1	64.8	69.9	67.6	67.0	61.5	58.5	61.5	62.8	66.6	70.1	68.7	68.3	63.1	62.5
OVERALL	97.4	100.3	100.1	99.2	98.8	97.1	93.9	94.5	95.2	98.5	99.7	101.7	101.5	99.4	96.0	95.7

TABLE XI. - Continued.

[Data adjusted to standard day of 25° C and 70 percent relative humidity; SPL referenced to 2×10^{-5} Pa; PWL referenced to 0.1 pW.]

(c) 80 Percent speed; fan physical speed, 2913 rpm

FREQUENCY	ANGLE, DEG															
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160
	1/3-OCTAVE BAND SOUND PRESSURE LEVELS (SPL) ON 45.7 METER RADIUS															
50	80.2	75.2	76.7	77.9	79.1	80.9	80.2	81.9	77.6	78.7	78.9	80.5	81.7	84.1	86.9	88.6
63	72.3	74.1	73.0	72.6	73.1	73.6	74.0	74.3	75.0	76.3	78.0	79.7	82.8	85.3	87.6	90.3
80	74.1	73.6	71.7	72.1	72.2	72.6	72.7	73.4	75.7	77.6	80.6	82.7	85.6	87.6	90.1	92.0
100	83.2	83.9	80.7	82.1	80.7	77.1	78.2	79.1	80.6	84.4	84.2	86.5	88.4	89.7	91.6	92.1
125	77.1	77.6	77.4	76.8	77.3	78.8	79.3	80.9	81.8	83.1	83.9	85.7	86.1	87.1	88.9	89.7
160	79.8	79.9	79.6	78.8	79.6	80.3	80.4	80.9	81.8	81.8	82.1	83.5	83.9	85.3	86.6	87.5
200	79.9	81.3	78.9	78.8	79.1	79.3	79.4	79.9	79.8	79.9	82.1	83.5	85.3	87.3	88.1	87.0
250	78.7	80.5	81.5	78.2	77.5	77.5	77.0	78.3	79.8	81.8	83.0	84.1	84.7	85.7	86.5	85.4
315	80.0	79.6	78.6	77.6	78.1	78.1	79.6	80.0	80.0	81.0	82.1	83.2	84.6	85.5	86.3	84.9
400	78.4	80.1	79.6	78.9	78.7	78.6	77.7	78.4	79.2	80.9	81.9	83.0	83.9	84.9	84.7	83.5
500	79.5	81.5	80.2	79.5	79.0	77.8	77.5	78.7	79.2	80.2	81.3	82.6	83.3	84.0	83.7	82.2
630	78.9	82.1	80.6	81.1	80.6	79.8	77.9	78.4	79.4	80.3	80.8	82.3	83.1	83.1	82.8	81.3
800	80.2	83.3	82.0	82.5	81.7	80.5	80.5	80.2	80.2	81.0	81.5	82.4	83.2	82.8	82.5	80.6
1000	81.8	84.3	83.6	83.6	83.3	83.3	80.9	80.4	80.8	81.8	81.9	82.5	83.3	82.8	81.3	80.0
1250	84.8	87.6	87.6	88.3	87.8	86.3	83.8	82.9	82.1	83.1	83.6	83.5	84.2	82.7	81.4	79.8
1600	85.1	88.6	88.8	89.1	89.3	86.8	83.9	84.1	83.9	83.9	85.6	84.9	85.8	83.3	81.6	79.3
2000	85.1	87.8	88.1	87.6	87.6	86.3	84.0	84.7	85.8	87.0	87.5	87.3	86.8	84.2	81.3	79.7
2500	91.5	95.1	95.6	95.3	96.0	95.1	91.8	92.5	94.3	97.1	99.3	101.1	99.8	92.5	88.1	87.2
3150	92.7	96.3	96.7	96.5	97.2	96.2	93.0	93.5	95.3	97.3	99.5	102.1	101.2	95.5	91.2	89.8
4000	86.3	90.3	91.0	89.8	90.7	88.2	86.7	86.7	88.0	90.7	93.5	92.6	92.8	89.3	85.5	82.4
5000	86.1	89.8	90.3	89.6	88.6	88.4	84.9	86.3	86.9	88.8	91.1	93.4	92.1	88.4	84.1	82.5
6300	87.2	90.0	88.8	90.5	89.7	88.8	85.9	86.0	88.0	89.2	90.9	92.8	93.0	89.5	85.2	83.3
8000	84.6	87.1	86.2	87.4	86.2	86.3	83.4	84.3	85.8	88.3	90.8	91.1	89.9	87.8	82.6	81.3
10000	81.3	83.2	82.0	84.5	82.0	83.0	79.8	80.2	82.7	83.5	87.0	88.0	86.5	85.2	79.5	78.6
12500	78.7	81.9	79.1	82.1	80.1	80.6	77.6	77.2	79.8	81.4	84.2	86.1	83.9	82.2	76.8	76.7
16000	73.8	77.4	73.9	77.0	75.7	76.5	72.1	71.4	73.7	75.8	79.8	81.8	79.5	78.0	72.7	72.7
20000	67.7	70.1	66.8	71.7	69.7	69.2	65.0	63.7	67.0	68.6	72.4	75.1	72.8	72.0	67.2	66.8
OVERALL	98.7	101.8	101.9	101.8	102.0	101.1	98.4	98.9	100.3	102.3	104.4	106.2	105.5	101.7	100.4	100.4

TABLE XI. - Concluded.

[Data adjusted to standard day of 25° C and 70 percent relative humidity; SPL referenced to 2×10^{-5} Pa; PWL referenced to 0.1 pW.]

(d) 90 Percent speed; fan physical speed, 3278 rpm

FREQUENCY	ANGLE, DEG															
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160
	1/3-OCTAVE BAND SOUND PRESSURE LEVELS (SPL) ON 45.7 METER RADIUS															
50	84.7	76.5	77.9	78.9	80.5	82.5	80.4	80.4	80.5	81.2	82.5	86.3	86.7	87.9	90.5	93.6
63	79.1	77.4	77.1	76.2	77.4	79.1	78.2	78.1	77.9	80.1	82.1	84.6	87.1	89.4	92.4	95.5
80	76.7	76.5	74.9	75.4	75.4	75.7	76.5	77.4	79.9	82.2	84.7	86.9	89.7	92.0	95.0	96.9
100	91.1	94.4	87.3	88.8	83.3	83.6	86.1	84.9	85.9	88.6	90.6	92.0	93.4	94.9	97.1	97.0
125	84.9	86.9	83.0	83.5	81.7	82.4	84.7	85.2	86.2	87.7	88.9	90.0	90.7	92.2	93.5	93.4
160	82.1	82.9	82.8	81.8	82.8	83.9	84.3	84.8	85.1	85.8	85.8	87.4	88.3	89.8	91.4	91.5
200	83.9	86.4	83.9	83.4	83.3	83.3	83.1	82.6	83.3	84.9	86.1	87.7	89.9	91.1	92.4	91.5
250	82.2	84.5	81.2	81.0	80.2	81.2	80.7	82.2	84.2	85.7	87.0	88.0	89.0	90.0	91.0	89.6
315	82.2	83.9	84.4	82.7	81.5	82.2	82.7	83.5	83.9	85.0	86.2	87.8	88.9	89.7	90.2	88.9
400	80.6	83.8	83.3	82.6	82.8	82.5	82.1	83.1	83.3	84.8	86.3	87.6	88.5	89.1	89.3	87.7
500	81.2	82.5	83.5	83.2	81.7	81.9	82.2	82.9	83.2	84.2	85.7	87.3	87.7	88.5	88.0	86.1
630	80.9	81.9	83.3	83.8	82.4	82.4	82.1	82.6	83.1	83.9	85.4	86.7	86.9	87.6	87.1	85.5
800	82.3	83.9	85.1	86.6	84.9	84.9	83.8	83.3	83.3	84.4	85.6	86.5	86.8	87.3	86.3	84.3
1000	83.6	85.1	86.2	87.7	88.1	87.6	85.7	85.6	84.9	85.6	85.9	86.7	87.1	86.4	85.6	83.5
1250	86.6	88.4	90.8	91.8	91.6	90.8	89.8	88.3	87.1	86.9	87.6	88.2	88.1	87.1	85.7	83.5
1600	89.7	91.6	94.4	95.9	96.4	95.6	93.2	92.7	89.2	88.7	89.6	90.7	89.4	87.2	86.2	83.8
2000	87.5	89.5	91.6	92.3	92.6	92.6	91.1	89.8	89.0	88.9	90.4	90.1	89.0	86.7	84.6	82.9
2500	88.1	90.7	91.2	91.2	91.4	91.4	89.9	90.5	91.2	94.6	95.9	95.3	92.1	89.6	86.1	83.5
3150	97.0	100.2	101.3	101.0	100.3	99.7	97.3	96.7	98.2	100.7	102.8	105.1	103.5	98.0	94.2	91.3
4000	87.4	90.4	92.9	91.6	91.2	90.7	89.4	89.6	90.7	93.2	96.2	96.0	95.4	91.9	88.9	85.8
5000	85.5	88.5	90.7	89.9	89.0	89.5	87.4	89.0	89.0	90.9	93.5	95.7	92.7	89.9	85.7	84.1
6300	88.3	90.8	89.8	91.8	91.2	89.8	88.0	89.2	90.8	92.3	94.7	96.3	95.3	92.2	87.7	85.5
8000	84.5	86.7	86.4	88.1	86.3	87.4	85.6	87.1	88.4	90.4	93.1	93.6	91.5	89.4	85.1	83.1
10000	82.7	83.9	83.2	86.2	82.7	83.9	82.7	84.2	86.5	87.4	90.9	91.9	89.5	88.5	82.7	82.3
12500	79.3	81.9	79.6	83.4	80.0	81.5	80.4	80.8	83.4	85.0	87.9	89.9	86.4	85.2	79.5	80.0
16000	74.7	77.8	74.6	78.2	75.8	77.3	74.9	75.8	77.9	79.8	84.0	86.5	82.9	81.2	76.2	76.5
20000	68.3	70.7	67.3	72.8	69.4	69.7	68.1	68.3	71.3	72.8	76.8	80.6	76.3	75.6	70.8	70.6
OVERALL	101.2	103.8	104.5	104.7	104.2	103.8	102.1	101.9	102.5	104.5	106.6	108.1	106.9	104.8	104.5	104.5

TABLE XII. - TABULATION OF ONE-THIRD-OCTAVE DATA (QF-11) WITH DESIGN PLUS 4 PERCENT NOZZLE

[Data adjusted to standard day of 25° C and 70 percent relative humidity; SPL referenced to 2×10^{-5} Pa; PWL referenced to 0.1 pW; 80 percent speed; fan physical speed, 2947 rpm.]

FREQUENCY	ANGLE, DEG															
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160
	1/3-OCTAVE BAND SOUND PRESSURE LEVELS (SPL) ON 45.7 METER RADIUS															
50	81.1	73.4	79.4	79.1	80.6	82.2	79.6	80.9	77.9	78.1	78.9	81.5	82.1	84.6	86.6	88.6
63	72.0	73.6	73.1	73.3	73.0	73.8	74.1	74.5	75.3	76.1	78.0	79.9	82.6	85.8	87.8	90.5
80	74.0	73.2	71.7	72.0	71.8	72.8	73.0	74.0	76.3	78.5	80.8	83.3	85.7	87.7	90.5	92.6
100	76.9	74.9	76.8	78.7	74.6	77.2	80.7	79.2	82.2	83.4	85.1	86.6	88.9	90.7	92.2	93.5
125	79.2	78.2	77.7	77.9	77.7	78.9	79.5	80.9	82.2	83.4	85.0	86.3	87.2	87.9	89.4	89.9
160	79.0	79.9	80.2	78.9	79.2	80.4	80.7	81.4	82.7	82.4	82.7	83.6	84.2	85.7	87.5	87.4
200	81.2	85.7	82.7	79.5	79.5	80.0	79.7	78.7	79.3	80.2	82.0	83.8	86.2	88.0	88.3	87.4
250	81.1	80.9	79.9	85.4	84.3	84.1	79.9	79.4	80.8	82.4	83.9	85.2	86.1	86.4	87.1	86.3
315	80.6	80.4	79.6	79.6	79.8	79.8	79.6	80.8	81.3	81.9	82.6	84.0	85.3	86.1	86.3	85.2
400	80.0	80.7	79.8	79.3	79.5	78.2	78.0	79.3	80.2	81.5	82.5	84.3	85.0	85.8	85.5	84.1
500	81.1	82.3	81.1	80.1	79.9	79.1	78.9	79.4	80.1	81.1	82.3	83.5	84.8	85.1	84.4	82.8
630	81.5	82.7	82.0	82.0	81.2	80.5	79.2	79.5	80.5	81.2	82.2	83.3	84.5	84.5	83.5	81.9
800	82.1	83.5	83.0	83.1	84.3	82.8	80.8	81.3	81.3	82.5	83.3	84.2	84.6	84.5	83.1	81.2
1000	84.2	84.9	84.9	83.5	83.0	81.9	81.2	81.9	82.7	83.2	83.9	84.5	85.7	84.2	82.5	80.8
1250	85.9	87.2	86.6	85.4	84.6	82.7	82.4	83.2	84.1	84.9	86.1	86.2	86.2	84.7	82.4	80.7
1600	87.7	89.7	89.1	87.9	86.9	85.2	83.7	84.9	86.4	86.4	87.6	87.7	88.6	85.7	82.9	81.5
2000	90.6	92.3	91.6	89.9	88.9	86.3	85.6	87.3	89.4	89.6	90.8	90.5	90.9	87.4	84.1	83.0
2500	91.7	94.9	94.9	96.4	96.7	94.4	90.9	91.7	92.1	94.7	97.2	100.5	98.7	92.2	87.6	87.3
3150	94.1	97.5	97.6	99.8	100.0	97.5	94.3	94.0	93.8	96.5	99.1	103.4	102.5	96.6	91.0	91.4
4000	91.3	93.3	93.6	91.3	90.9	87.6	86.6	87.6	90.3	92.6	95.1	94.7	94.9	91.3	86.8	84.5
5000	90.0	93.0	93.5	93.4	91.0	90.0	86.0	86.9	88.0	90.2	93.9	94.6	93.5	90.0	85.2	83.3
6300	90.3	93.8	92.3	95.6	93.8	91.8	87.9	86.9	88.9	89.8	91.4	93.7	94.6	90.6	86.1	83.6
8000	88.1	90.2	88.9	92.1	89.4	88.7	85.4	85.0	87.0	89.8	91.0	91.4	90.4	87.8	83.2	81.4
10000	84.8	87.2	85.8	88.7	85.3	85.5	81.3	81.2	83.5	85.1	87.2	89.0	87.5	85.8	80.0	78.7
12500	82.8	85.8	83.3	86.3	84.3	84.3	79.3	78.6	80.9	81.4	85.1	87.1	85.3	83.1	78.1	77.0
16000	78.5	81.9	78.1	82.5	80.4	80.2	74.7	72.9	75.3	76.1	80.1	82.4	81.7	79.2	75.0	72.3
20000	72.5	75.4	70.8	77.8	74.4	73.5	67.7	66.0	69.2	70.2	73.7	76.3	75.2	73.9	69.9	66.4
OVERALL	100.9	103.5	103.2	104.4	103.9	101.9	99.0	99.3	100.3	102.1	104.4	107.0	106.3	102.7	100.9	101.1

TABLE XIII. - TABULATION OF ONE-THIRD-OCTAVE DATA (QF-11) WITH DESIGN PLUS 8 PERCENT NOZZLE

[Data adjusted to standard day of 25^{o} C and 70 percent relative humidity; SPL referenced to 2×10^{-5} Pa; PWL referenced to 0.1 pW; 80 percent speed; fan physical speed, 2950 rpm.]

FREQUENCY	ANGLE, DEG															
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160
	1/3-OCTAVE BAND SOUND PRESSURE LEVELS (SPL) ON 45.7 METER RADIUS															
50	81.1	73.1	79.1	79.1	80.6	83.0	79.5	81.6	77.3	78.3	79.5	82.1	82.3	84.5	87.0	89.0
63	71.9	73.7	73.0	72.9	73.2	74.0	74.5	74.4	75.5	76.5	78.2	79.8	83.0	85.5	88.2	90.1
80	72.7	72.7	71.7	71.7	71.9	73.2	73.1	73.6	76.2	78.9	81.2	83.1	85.9	88.2	90.1	91.6
100	75.0	75.9	74.7	76.0	76.0	76.0	78.7	79.4	81.2	83.2	85.9	87.1	89.2	90.5	92.2	92.8
125	78.9	77.6	77.1	77.8	77.6	78.4	79.6	81.4	82.8	83.8	84.9	86.0	86.8	87.9	89.1	90.3
160	78.4	79.1	79.7	78.9	79.9	80.2	80.6	81.7	82.6	81.9	82.4	83.5	84.2	86.1	87.6	87.8
200	80.3	82.5	80.8	79.1	80.3	79.0	79.1	78.8	79.6	80.3	82.3	83.9	86.1	87.8	88.8	87.9
250	80.9	81.1	79.2	84.2	84.6	83.1	79.7	79.7	81.2	82.4	83.6	84.5	85.9	87.1	87.2	86.1
315	79.7	79.4	79.7	79.4	79.0	79.4	79.9	80.4	81.4	81.7	82.5	84.1	85.2	86.4	86.9	85.3
400	79.3	80.2	79.5	79.0	79.7	78.3	78.3	79.2	80.5	81.5	82.5	83.8	84.8	85.8	85.5	83.9
500	80.0	81.0	80.5	80.2	79.7	78.9	78.9	79.0	80.4	81.0	82.2	83.6	84.4	85.2	84.9	82.9
630	80.4	81.5	81.9	82.4	81.7	80.7	79.5	79.9	80.5	81.4	82.2	83.4	83.9	84.5	83.9	81.8
800	81.0	82.5	82.7	82.9	83.4	83.5	81.2	80.7	81.2	81.7	82.7	83.5	84.0	84.0	82.9	81.3
1000	82.8	83.9	84.6	83.9	82.6	81.9	81.1	81.6	81.9	82.4	83.3	84.0	84.6	83.6	82.3	80.7
1250	85.0	86.0	86.3	86.3	85.2	84.2	82.2	83.2	83.7	84.2	85.3	85.3	85.2	84.2	82.3	80.9
1600	86.1	87.6	88.0	88.0	87.6	86.8	83.6	84.3	85.0	85.6	86.6	86.9	87.1	85.0	82.5	80.9
2000	88.3	89.6	90.3	89.5	88.3	86.6	84.5	86.1	87.8	88.1	89.5	89.7	89.3	86.3	83.0	82.1
2500	91.0	94.2	95.0	98.2	96.2	95.5	91.0	91.7	91.7	94.7	95.7	98.4	97.0	91.7	87.3	87.4
3150	93.5	97.0	97.5	102.0	99.7	99.4	94.0	94.0	93.7	95.9	96.2	101.0	101.2	95.9	91.5	91.3
4000	89.8	91.8	92.7	91.0	90.2	87.8	86.2	87.3	89.7	91.7	94.8	93.9	94.3	90.8	86.2	84.1
5000	88.8	92.5	92.6	92.8	90.0	89.3	85.5	86.8	87.6	89.8	93.8	94.8	93.0	89.3	85.0	83.1
6300	89.2	93.4	91.7	95.1	92.1	90.9	87.6	87.1	88.6	89.9	91.4	93.7	93.9	90.2	85.6	83.8
8000	87.1	89.3	88.3	91.2	88.2	88.2	84.5	84.8	86.2	89.2	90.9	91.2	90.2	87.6	83.1	81.5
10000	83.9	86.4	85.1	88.3	84.1	84.9	80.3	80.9	83.6	84.7	87.1	88.8	86.9	85.6	80.1	78.6
12500	81.8	85.0	82.3	86.0	83.0	83.8	78.5	78.3	80.5	80.9	85.0	86.8	85.0	82.1	77.8	76.3
16000	77.2	80.7	77.0	81.7	79.4	79.6	73.5	73.1	74.8	75.5	79.6	82.3	81.1	78.7	74.2	72.0
20000	71.1	73.6	69.8	77.4	72.9	72.5	66.4	65.7	68.4	69.8	73.3	76.0	74.8	72.8	69.0	65.8
OVERALL	99.9	102.6	102.7	105.4	103.3	102.8	98.7	99.2	99.8	101.7	103.3	105.5	105.3	102.3	100.9	100.9

TABLE XIV. - TABULATION OF ONE-THIRD-OCTAVE DATA (QF-11) WITH DESIGN PLUS 14 PERCENT NOZZLE

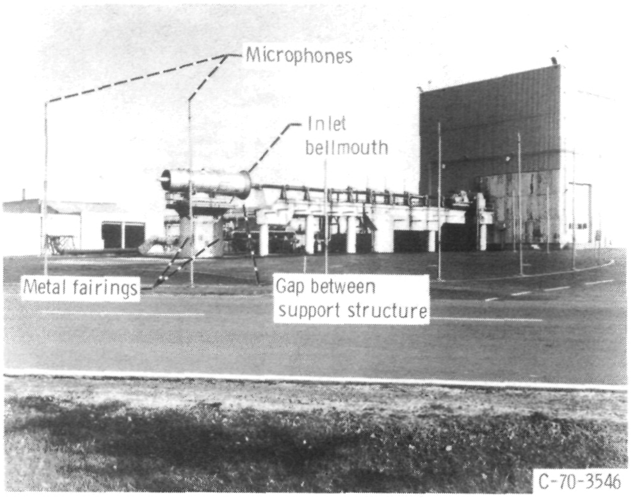
[Data adjusted to standard day of 25° C and 70 percent relative humidity; SPL referenced to 2×10^{-5} Pa; PWL referenced to 0.1 pW; 80 percent speed; fan physical speed, 2950 rpm.]

FREQUENCY	ANGLE, DEG															
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160
	1/3-OCTAVE BAND SOUND PRESSURE LEVELS (SPL) ON 45.7 METER RADIUS															
50	81.6	74.0	78.8	79.1	79.3	83.5	78.3	80.8	77.6	78.1	78.5	81.2	82.8	85.0	86.1	88.5
63	71.8	74.4	73.1	72.1	73.1	73.6	73.9	74.4	74.4	75.8	78.1	79.8	83.8	85.8	87.8	90.3
80	74.1	73.8	71.9	72.1	72.1	72.4	72.4	74.4	75.8	78.8	80.9	83.0	86.1	88.1	90.4	92.2
100	82.1	83.0	79.1	82.1	81.0	76.6	78.1	80.3	81.1	85.5	85.6	87.7	90.5	90.6	91.6	92.5
125	77.1	76.1	77.6	77.5	77.5	78.1	79.6	80.8	82.3	83.5	84.8	85.7	86.8	88.0	88.8	89.2
160	78.3	79.1	78.1	78.5	79.5	79.1	80.5	81.3	81.8	81.6	82.0	82.9	83.8	85.6	87.1	87.0
200	80.4	79.8	78.3	78.8	79.3	78.8	79.3	78.9	79.8	80.8	81.8	83.7	85.9	87.3	87.9	87.0
250	82.2	81.0	78.7	82.0	82.3	81.3	77.8	79.2	80.2	81.8	83.0	84.1	85.2	85.8	86.3	85.7
315	79.2	79.5	78.7	78.7	78.5	78.2	79.5	80.0	81.0	81.0	82.2	83.2	84.8	86.0	85.8	84.6
400	78.4	79.4	78.9	78.7	78.2	78.0	78.0	78.9	79.9	80.9	81.9	83.6	83.9	85.0	84.9	83.4
500	79.7	80.7	80.0	80.9	79.5	79.5	78.4	79.0	79.7	80.4	81.5	83.0	84.0	84.2	83.5	82.3
630	79.4	81.2	81.2	82.2	81.7	79.9	78.9	79.2	79.7	80.5	81.5	82.4	83.2	83.7	82.7	81.1
800	80.3	82.1	82.3	85.0	84.3	83.1	81.5	81.3	80.6	81.3	81.8	82.7	83.6	83.1	82.3	80.4
1000	82.5	84.0	82.7	83.8	84.3	82.3	81.0	82.1	82.5	82.0	82.6	83.4	83.8	82.5	81.5	80.2
1250	84.3	86.5	86.8	87.5	87.1	84.6	83.0	83.0	85.0	83.3	84.1	83.9	84.3	83.0	81.1	80.1
1600	85.1	87.4	87.9	87.7	88.4	86.4	84.1	83.7	84.9	84.4	85.4	86.0	85.7	83.4	81.2	80.0
2000	87.9	88.3	88.4	88.3	88.3	86.8	83.8	85.8	86.9	87.1	88.4	88.4	87.6	84.8	81.8	80.5
2500	90.6	95.1	96.1	95.8	95.8	94.4	90.8	91.8	92.1	93.8	95.3	100.0	97.1	91.6	87.3	86.5
3150	93.7	98.7	99.5	98.9	99.5	98.0	94.0	94.4	93.9	96.4	97.0	103.1	101.0	95.9	91.9	90.8
4000	87.8	90.8	91.6	90.4	90.3	88.4	86.6	86.9	89.1	91.1	94.0	93.1	93.3	89.6	85.4	83.4
5000	87.2	91.0	91.2	91.2	88.7	88.8	85.2	86.7	87.2	89.3	92.8	94.3	92.3	89.0	84.3	82.9
6300	87.7	92.4	90.4	93.4	90.9	90.6	86.9	87.1	88.4	89.4	90.9	93.7	93.6	89.9	85.2	83.5
8000	85.8	88.7	87.2	89.9	87.2	87.7	84.4	84.7	86.4	89.3	90.6	91.1	89.7	87.6	82.6	80.7
10000	82.1	85.2	83.9	86.6	83.2	84.2	79.7	80.7	83.2	84.3	86.7	88.6	86.7	85.2	79.6	78.4
12500	80.1	84.0	81.3	84.0	81.6	82.5	77.6	78.0	80.8	80.5	84.6	86.8	84.5	82.5	77.5	76.2
16000	75.2	79.8	75.6	79.9	77.3	78.3	72.6	72.8	74.7	74.8	79.1	81.7	80.5	78.7	74.2	71.8
20000	69.1	72.8	68.0	74.8	71.1	71.3	65.9	65.2	68.1	68.8	72.4	75.6	73.9	72.4	68.6	65.5
OVERALL	99.3	102.9	103.2	103.3	103.0	101.9	98.6	99.2	99.8	101.5	102.9	106.5	105.0	102.0	100.4	100.5

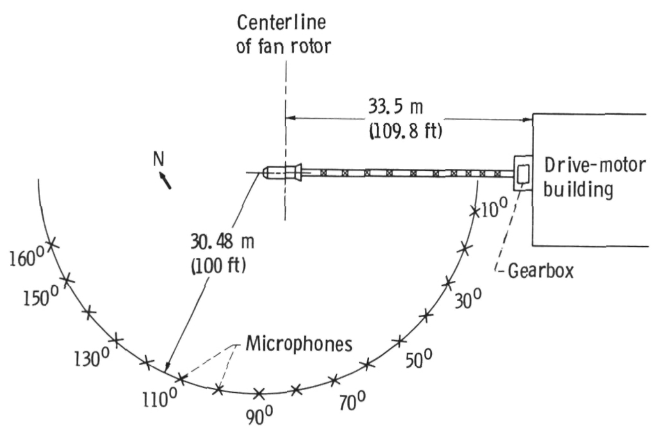
TABLE XV. - TABULATION OF ONE-THIRD-OCTAVE DATA (QF-11) WITH DESIGN PLUS 17.5 PERCENT NOZZLE

[Data adjusted to standard day of 25° C and 70 percent relative humidity; SPL referenced to 2×10^{-5} Pa; PWL referenced to 0.1 pW; 80 percent speed; fan physical speed, 2950 rpm.]

FREQUENCY	ANGLE, DEG															
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160
	1/3-OCTAVE BAND SOUND PRESSURE LEVELS (SPL) ON 45.7 METER RADIUS															
50	81.5	74.1	78.5	78.3	79.0	82.1	78.3	80.6	77.6	77.8	77.5	80.2	82.0	83.1	86.6	88.5
63	71.7	74.2	72.5	72.5	73.0	73.2	73.7	73.9	74.7	76.0	77.0	80.0	82.5	85.0	87.5	89.8
80	73.4	72.9	71.2	70.9	71.5	72.2	72.2	72.9	76.2	77.9	80.0	82.8	85.2	87.5	89.9	91.6
100	83.0	83.5	79.7	78.7	79.3	75.5	77.8	79.5	80.5	83.8	85.0	86.7	88.5	89.8	91.2	90.9
125	77.0	76.2	77.8	76.5	77.2	77.8	78.5	80.3	81.5	83.0	83.5	84.6	86.0	87.0	88.7	89.1
160	78.4	79.0	78.2	79.0	78.5	79.0	79.7	80.9	81.2	81.5	81.5	82.5	83.5	84.5	86.4	86.6
200	79.6	79.6	78.4	78.6	79.1	78.7	78.7	79.4	79.2	79.9	81.4	82.7	85.4	86.4	87.7	86.3
250	80.9	80.4	78.8	81.4	81.8	80.4	76.9	78.1	79.8	81.3	82.6	83.8	84.8	85.4	85.9	85.0
315	78.8	79.1	77.9	77.8	77.4	77.8	79.1	79.8	80.4	80.6	81.6	83.0	83.8	85.4	85.6	84.5
400	77.6	79.1	78.8	78.0	78.0	77.1	77.6	78.0	79.1	80.1	81.6	82.7	83.6	84.1	84.3	83.0
500	79.5	80.5	79.5	79.5	79.3	78.8	78.1	79.0	79.1	80.0	81.1	82.7	83.6	84.0	83.5	81.9
630	78.8	79.9	81.4	81.6	81.3	78.9	77.9	78.8	79.1	79.9	80.9	82.0	82.9	82.9	82.6	80.7
800	79.7	81.2	81.9	82.5	83.4	82.0	81.0	79.2	80.4	80.5	81.2	82.1	83.0	82.5	81.7	80.0
1000	81.8	82.8	83.3	82.8	83.6	81.5	81.1	80.6	80.8	81.0	81.6	82.6	82.8	82.3	81.1	79.4
1250	83.7	85.4	86.4	86.5	85.9	83.5	83.0	82.0	81.9	82.4	83.5	83.5	84.2	82.4	80.9	79.6
1600	84.5	86.7	87.3	87.7	88.0	86.3	83.8	83.2	83.5	84.0	85.2	85.4	85.5	83.2	81.2	79.6
2000	87.1	87.2	87.7	87.1	87.8	86.1	83.6	84.9	85.8	86.8	87.9	87.5	87.1	84.1	81.6	80.2
2500	89.9	92.9	94.1	94.8	95.4	93.9	89.8	91.3	91.8	94.4	96.1	98.9	97.1	91.6	87.4	86.2
3150	93.3	96.1	97.6	98.4	98.9	97.3	93.4	93.6	94.1	95.6	97.1	101.6	101.5	96.0	91.8	90.4
4000	87.2	89.5	90.7	89.7	90.0	87.4	86.0	86.5	88.4	90.5	93.4	92.5	92.7	89.5	85.4	82.8
5000	86.2	89.4	90.2	90.4	88.2	87.9	84.9	86.1	86.7	88.9	92.4	93.2	91.9	88.4	84.2	82.2
6300	87.1	90.4	89.6	92.2	90.7	89.1	86.6	86.6	87.7	88.9	90.2	93.2	93.6	89.9	85.4	83.0
8000	84.8	87.4	86.2	88.7	86.7	86.6	84.1	84.5	86.1	88.8	90.1	90.1	89.5	87.3	82.6	80.8
10000	81.7	84.4	82.9	85.4	82.9	83.7	79.7	80.5	82.9	84.1	86.2	88.0	86.7	85.5	79.5	78.2
12500	79.4	82.6	80.0	82.5	80.9	81.7	77.4	78.0	80.1	80.4	84.2	85.9	84.5	82.5	77.4	75.9
16000	74.5	78.5	74.7	79.0	77.1	77.3	72.4	72.5	74.2	74.7	79.0	81.3	80.5	78.3	74.0	71.2
20000	68.0	70.7	67.2	73.7	70.7	70.1	65.3	64.9	67.8	68.7	71.8	75.1	73.7	72.2	68.5	64.9
OVERALL	98.7	101.0	101.8	102.5	102.5	101.1	98.0	98.6	99.3	101.1	102.8	105.4	105.0	101.7	100.2	99.9

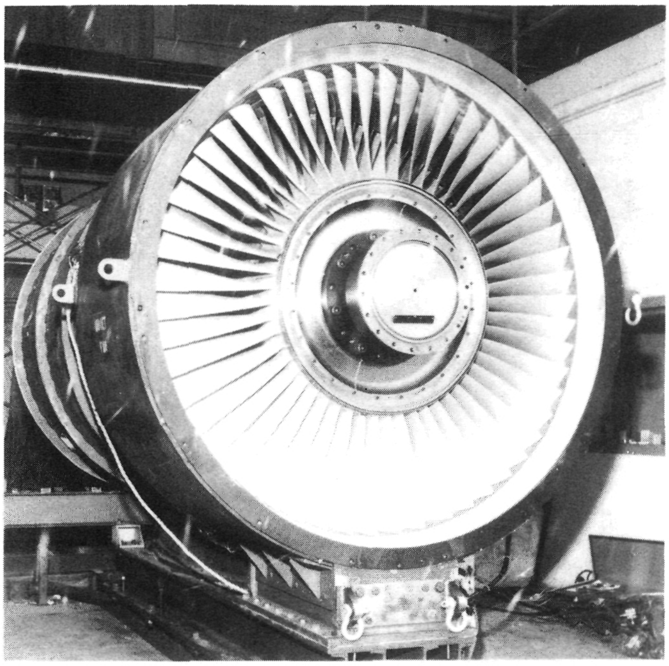


(a) Test site.

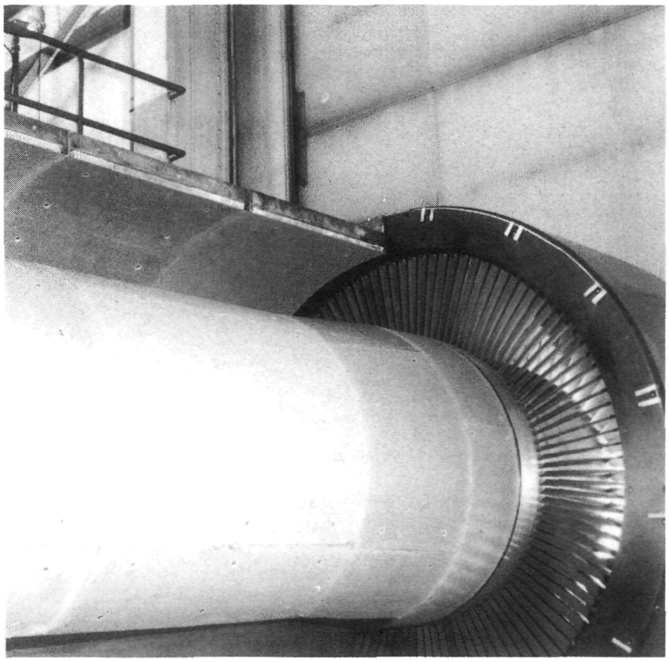


(b) Plan view of test site.

Figure 1. - Full-scale fan test facility.

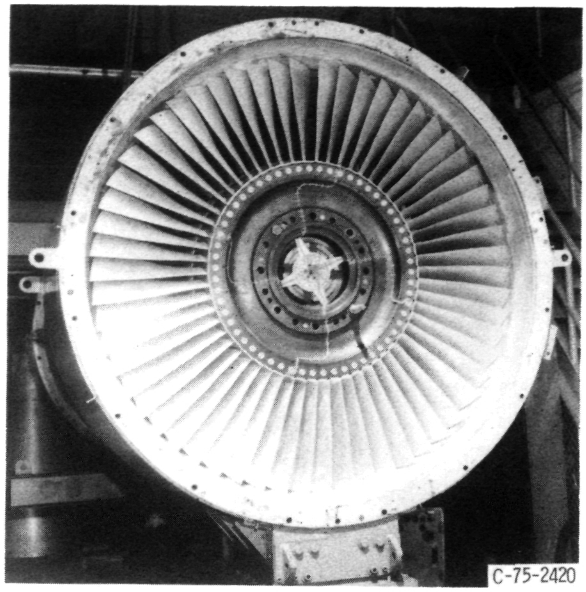


(a) Original QF-2 rotor.

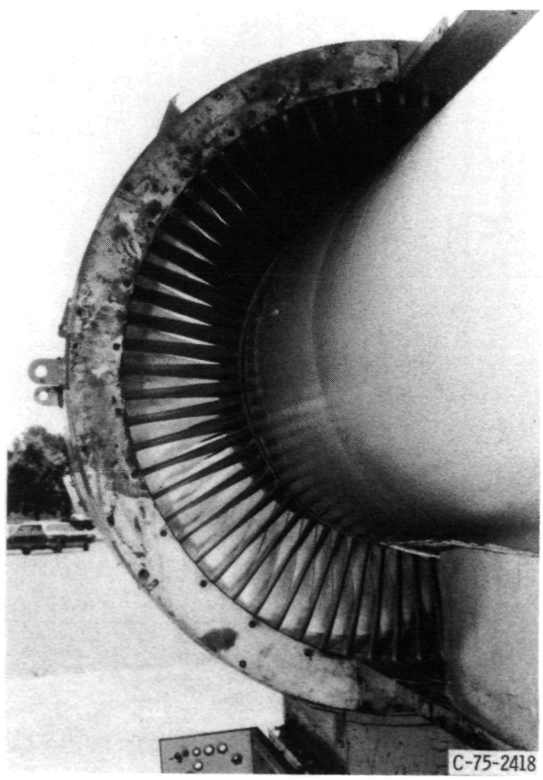


(b) Original QF-2 stator.

Figure 2. - Fan stages.



(c) Redesigned QF-11 rotor.



(d) Redesigned QF-11 stator.

Figure 2. - Concluded.

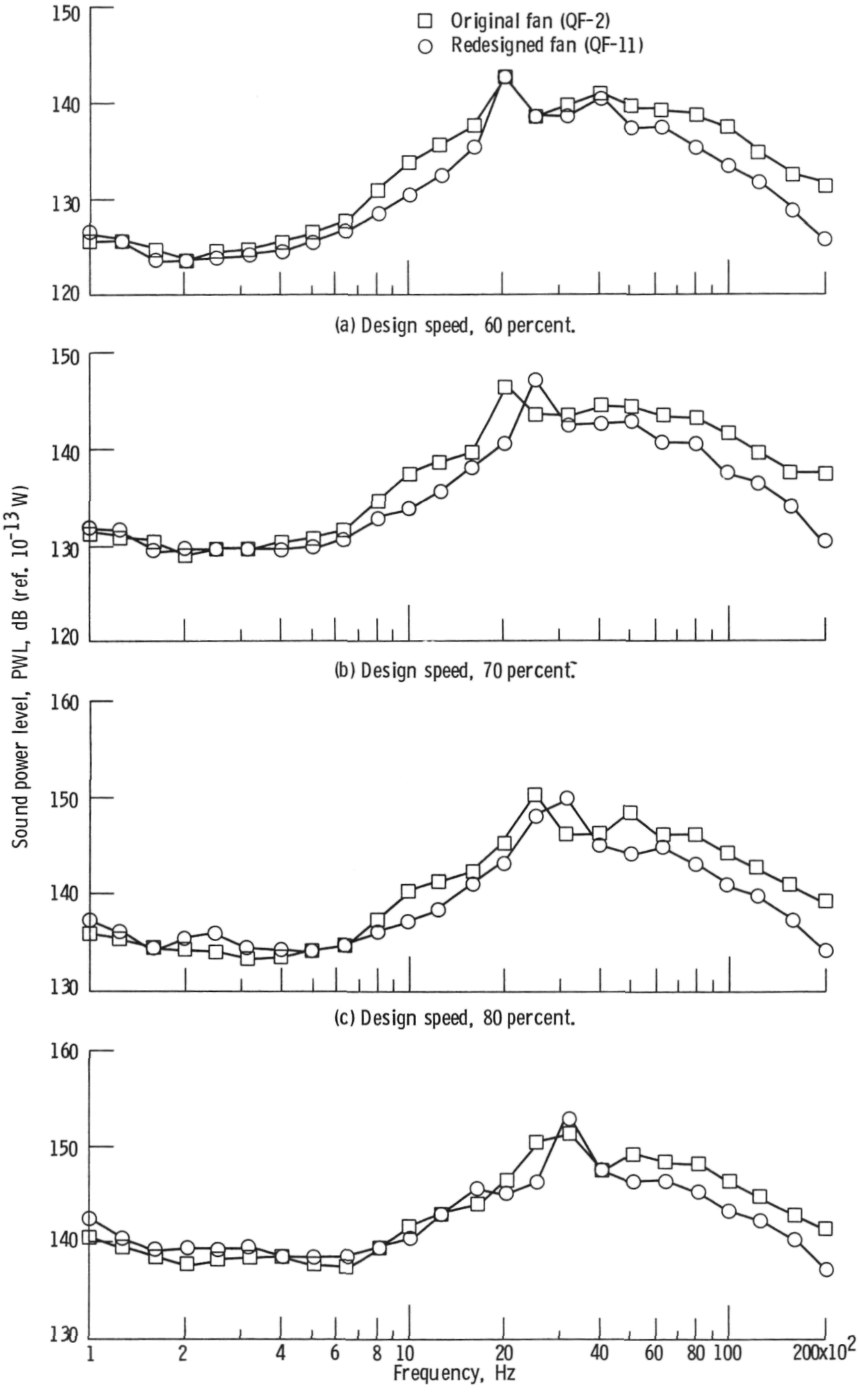
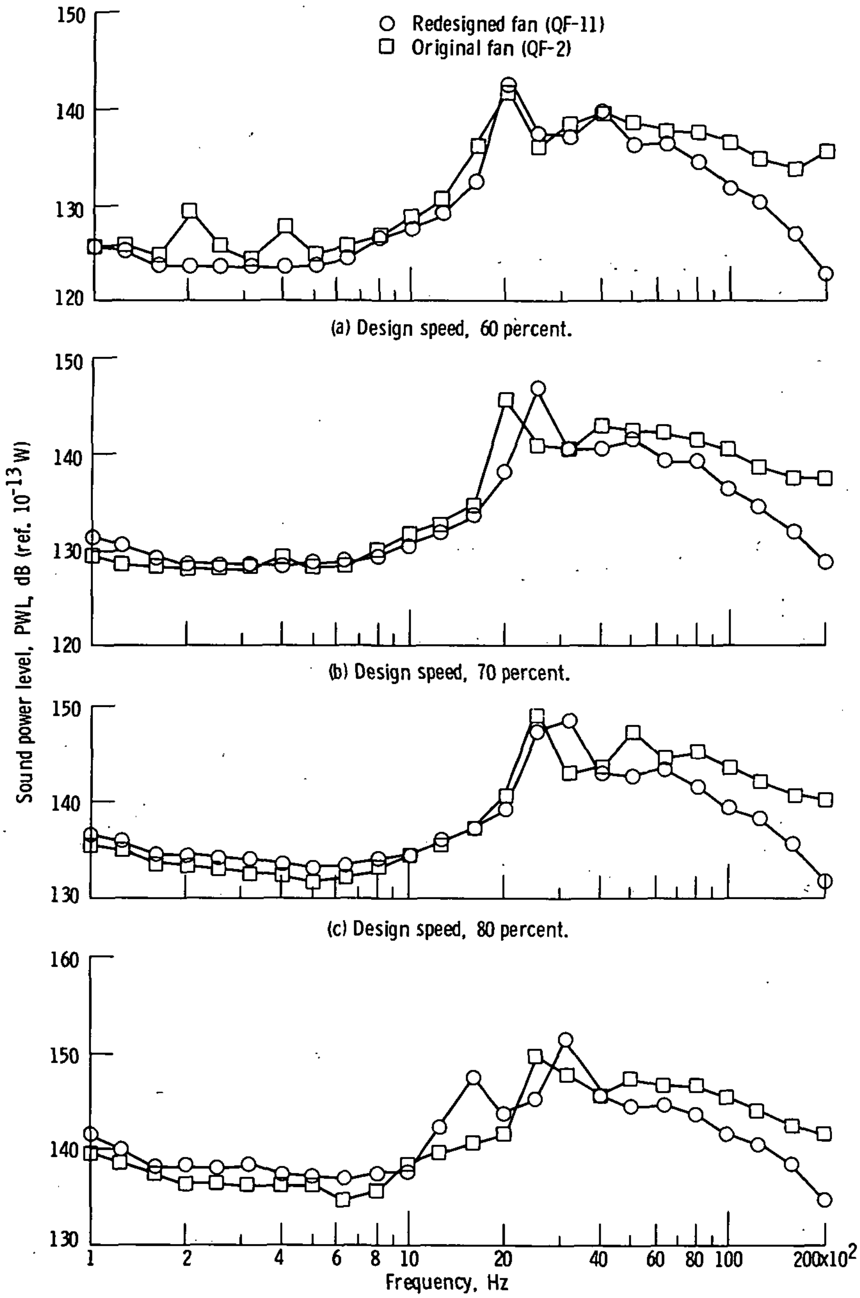
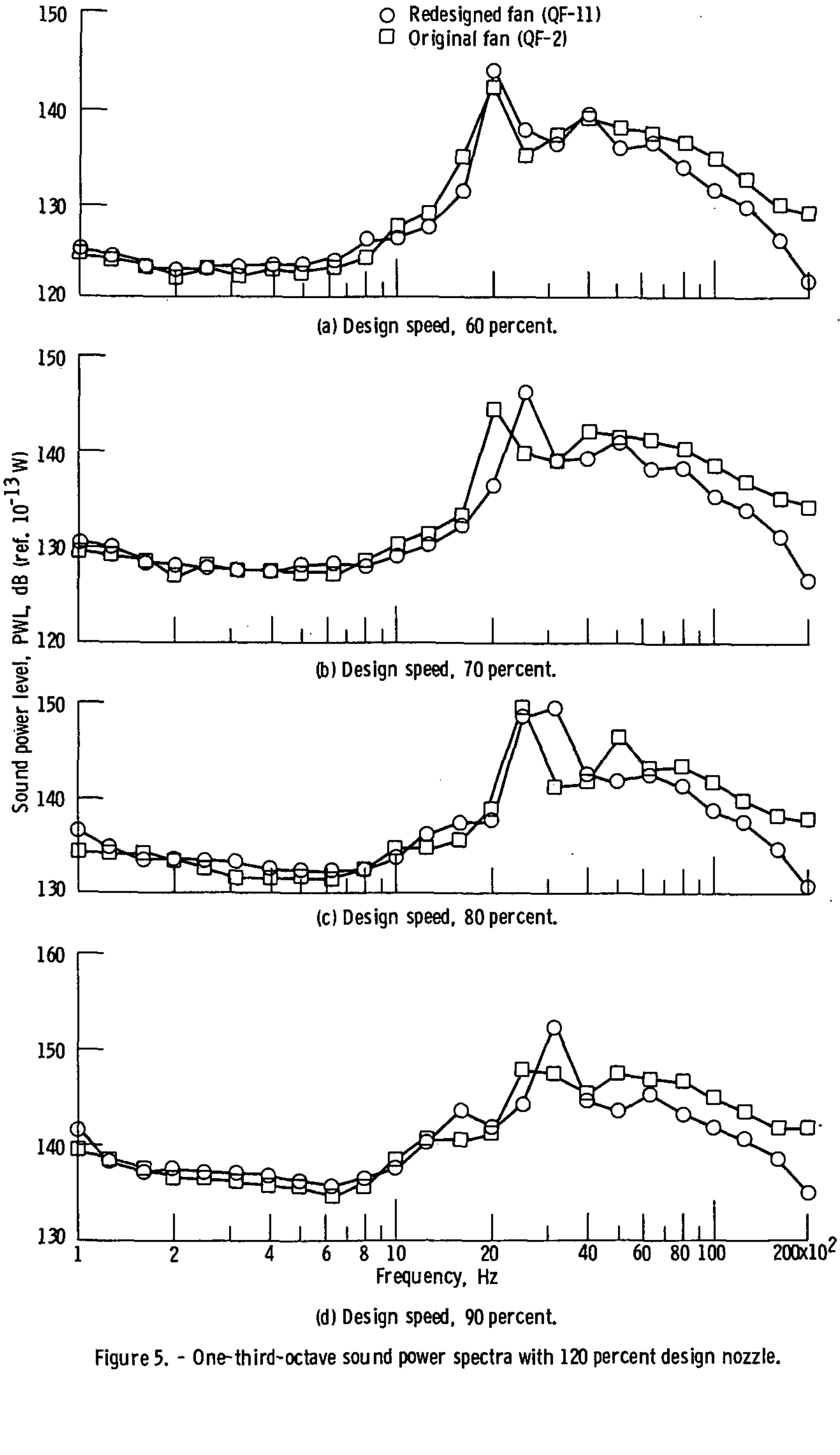


Figure 3. - One-third-octave sound power spectra with design nozzle.



(d) Design speed, 90 percent.

Figure 4. - One-third-octave sound power spectra with 110 percent design nozzle.



(d) Design speed, 90 percent.

Figure 5. - One-third-octave sound power spectra with 120 percent design nozzle.

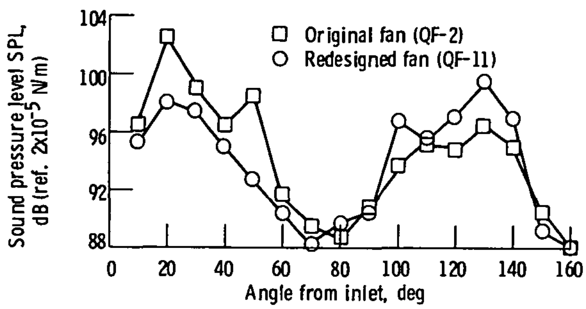


Figure 6. - Sound pressure level as function of angle in one-third octave band (2000 Hz center frequency) containing blade passage tone at 60 percent design speed.

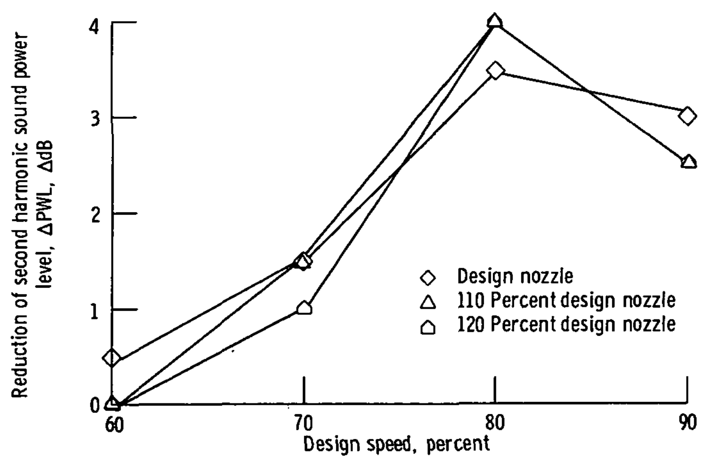


Figure 7. - Second harmonic reductions (one-third octave) as function of percent speed.

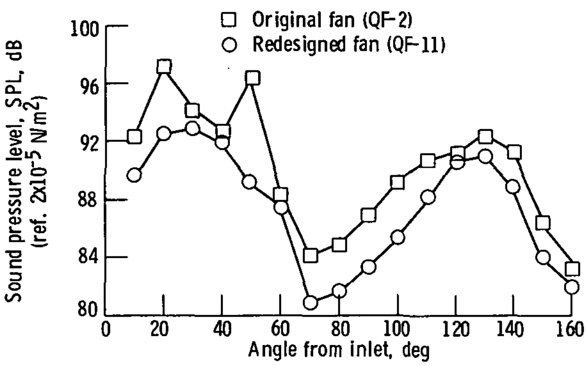


Figure 8. - Sound pressure level as function of angle for broadband noise in 5000 hertz center frequency one-third octave band at 60 percent design speed.

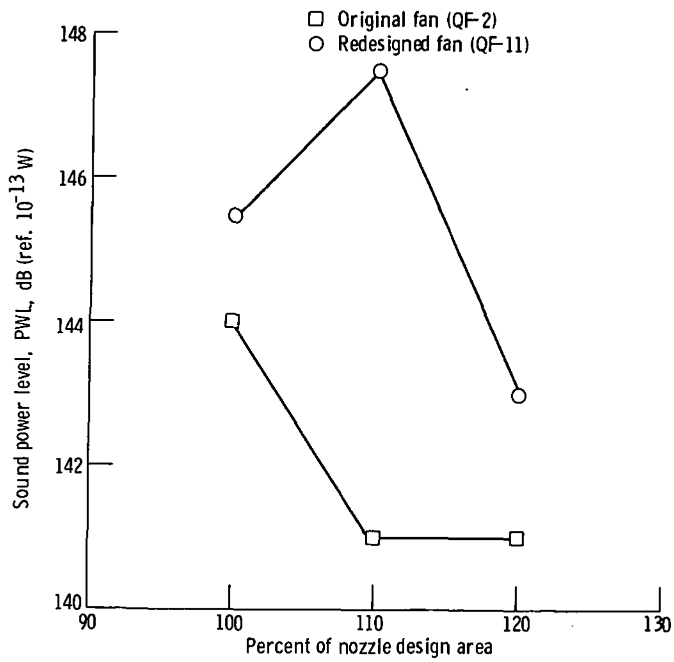


Figure 9. - Variation of multiple pure tone activity in 1600-hertz center frequency one-third-band with nozzle area. Design speed, 90 percent.

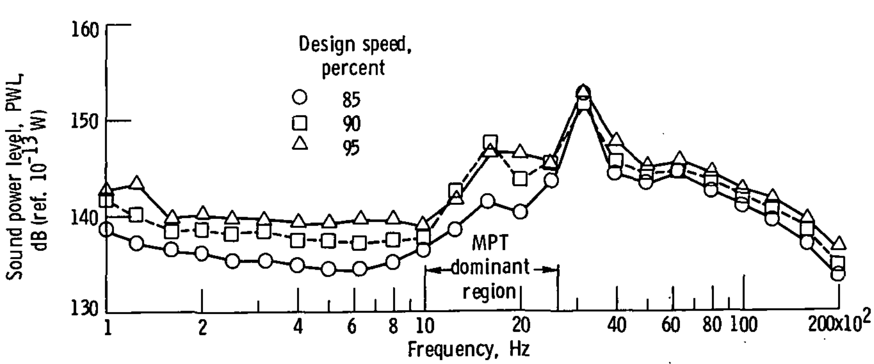
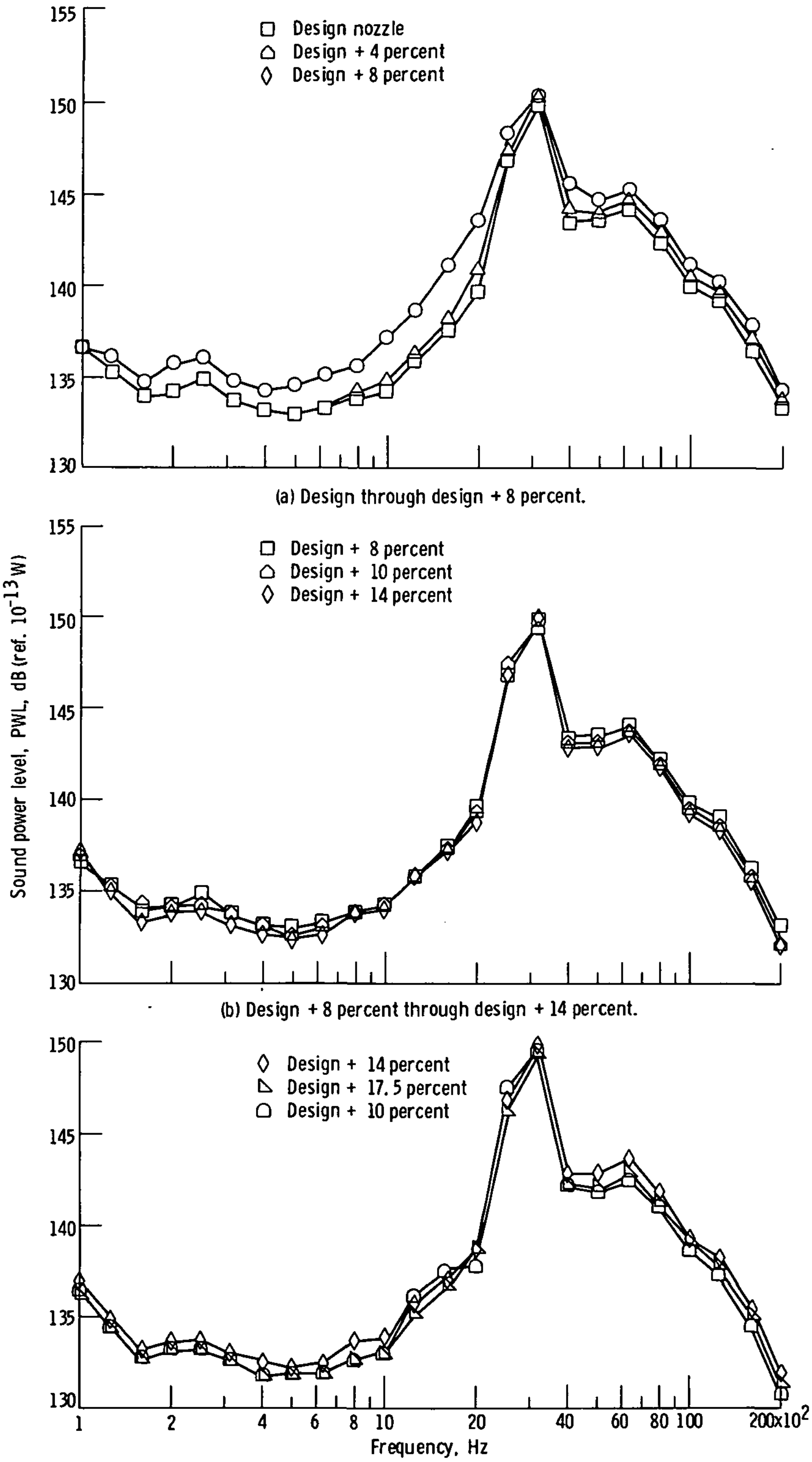
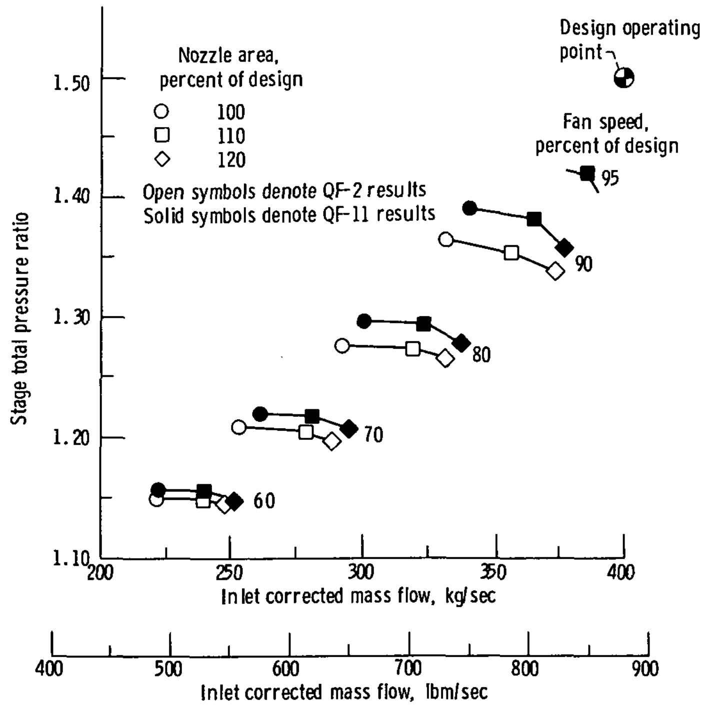


Figure 10. - One-third-octave sound power spectra with 110 percent design nozzle.

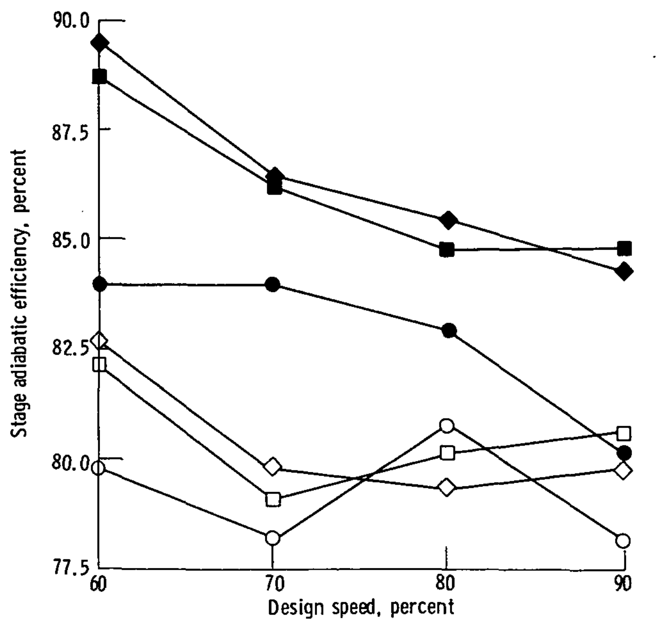


(c) Design + 14 percent through design + 20 percent.

Figure 11. - One-third-octave sound power spectra at 80 percent design speed.



(a) Fan operating map.



(b) Fan efficiency.

Figure 12. - Fan performance.

NASA-Langley, 1977 E-8986

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