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LOW-FREQUENCY REAR QUADRANT NOISE OF A TURBOJET ENGINE WITH EXHAUST DUCT MUFFLING

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16. Abstract

A J-65 engine was run with a tuned sound-absorbing exhaust duct to study the internal and jet components of rear quadrant noise. Full muffler, half muffler, hard wall duct, and regular production engine configurations were tested. The jet exhaust velocities were subsonic. The use of the exhaust muffler extended the relation between the jet noise and the eighth power of the jet velocity to lower velocities than for the hard wall duct.

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SUMMARY

A J-65 turbojet engine was fitted with a tuned sound-absorbing exhaust duct to study the internal and jet components of rear quadrant noise. This duct removed a portion of the internally generated noise, verifying that there is removable internal noise in the frequency range of interest for jet noise. The jet exhaust velocities were subsonic, ranging from about 135 to 478 meters per second (445 to 1569 ft/sec). The muffler was tuned to remove internally generated noise in the engine spectrum, nominally at 250 and 1000 hertz. Full muffler, half muffler, hard wall duct, and regular production engine configurations were tested. The use of the exhaust muffler extended the relation between jet noise and the eighth power of the jet velocity to lower velocities. The sound power level PWL attenuation observed with the muffled exhaust agree favorably with those theoretically predicted. Comparisons were made with some jet noise predictions appearing in the literature.

INTRODUCTION

There has been considerable interest in the relation of jet noise to the jet velocity. M. J. Lighthill (ref. 1) predicted that the jet noise should be proportional to the eighth power of the jet velocity. Data at high subsonic velocities in general, and at low velocities for simple nozzles where the flows are relatively free of upstream turbulence and flow noise, have supported this theory. However, the applicability of this relation for turbojet engine jet noise is not so well established at low exhaust velocities. The noise levels under such conditions have been greater than a simple extension of the eighth power velocity relation would predict. In addition to having higher levels, the engine data varied approximately as the fifth or sixth powers of velocity. This sixth-power relation between the noise level and the jet velocity was experimentally determined by

Gordon and Maidanik (ref. 2) for flow from a pipe with internal noise-generating obstructions. It was shown in results (ref. 3) of jet noise from the NASA quiet fan facility that the internally generated noise becomes more important as jet velocity is reduced and that this internal noise could be reduced by internal noise suppressors, thus exposing the jet noise for study. This behavior is sketched in figure 1.

As present-day fan and jet noise sources are reduced, the internally generated core engine noise will become more important in the overall noise problem. Acoustic treatment of the exhaust duct should reduce this internal noise contribution, and a sufficient amount of acoustic treatment would reduce the internal noise to the jet noise level.

To eliminate a portion of the internally generated noise and thus allow a study of noise due to the jet, a standard J-65 engine was fitted with an exhaust muffling duct with sound absorbing sections tuned for peak attenuations at 250 and 1000 hertz, which are in the range of interest for jet noise. It was of considerable interest to know whether an acoustic liner could be made to function at such low frequencies and high-temperature flow conditions. The rear quadrant noise sound power for this arrangement was correlated with the Lighthill parameter. Also, the maximum overall sound pressure levels along a 61-meter (200-ft) sideline were considered as a function of the jet velocities measured, as in the SAE AIR 876 (ref. 4) jet noise correlation. The performance of the exhaust muffler was compared with predicted values. The engine nozzle velocities were varied from about 137 to 503 meters per second (450 to 1650 ft/sec). This range corresponds to operation at 50 to 98 percent of the design compressor speed of the J-65 engine.

SYMBOLS

A_j	exit area of jet nozzle, m^2; ft^2
C_o	ambient speed of sound, m/sec; ft/sec
OAPWL	overall sound power level
$OASPL_m$	maximum overall sound pressure level
PWL	sound power level, dB
V_j	jet exit velocity, m/sec; ft/sec
ρ	density of gas in jet, kg/m^3; lbm/ft^3
ρ_o	density of ambient air, kg/m^3; lbm/ft^3

APPARATUS AND PROCEDURES

Turbojet Engine

A standard J-65 engine was used for the acoustic tests as being representative of a typical turbojet engine. A view of this engine showing the exhaust muffling duct in place is presented in figure 2.

The published specifications for the J-65 engine are for the engine with a 0.48-meter (19-in.) diameter nozzle rather than the 0.53-meter (21-in.) diameter nozzle used in this study. With the 0.48-meter nozzle the following design conditions are given for sea level operation:

Thrust, N; lbf	32 116; 7220
Rated airflow, kg/sec; lbm/sec	53.5; 118
Rated exhaust pressure ratio	2.3

A more detailed listing of the J-65 engine parameters appears in reference 5.

An existing inlet bellmouth and noise suppressor duct were used for all tests to reduce the inlet noise contribution. Figure 3 shows this inlet suppressor in place on the test engine. The characteristics of a similar suppressor are discussed in reference 6.

Muffler Duct Design

The exhaust muffler duct was designed with two axial sections nominally tuned to 250 hertz and two tuned to 1000 hertz. Allowing for muffler bandwidth, appreciable muffling should occur in the frequency range of interest for jet noise. Each muffler section consisted of concentric inner and outer bodies with an annular flow channel. A schematic cross section of the muffler duct is shown in figure 4. A half-lined, half-hard configuration was achieved by covering the treated surfaces of one 250-hertz and one 1000-hertz muffler component with 1.60-millimeter (0.063-in.) thick stainless steel. Similarly, for the hard duct case this covering was extended over all the treated surfaces. The engine was also run without the exhaust mufflers in place. This is designated as the "regular engine." A standard 0.53-meter (21 in.) diameter exhaust nozzle was used for all tests.

The presence of the exhaust duct imposed some loss in the engine performance at low speeds. For example, at 50 percent of the engine design compressor speed, the duct reduced the exhaust velocity to 135 meters per second from 149 meters per second for the regular engine. Likewise, at 60 percent speed the exhaust velocity was reduced to 172 from 180 meters per second. At higher engine speeds the hard-duct case produced a higher exit velocity than the treated or regular engine cases. This unexpected result at high engine speeds remains unexplained.

Clearly, a difference in the jet velocities at a given engine speed has an effect on the exhaust jet noise level. Again, using the 50 percent speed data the expected velocity difference effect on the jet noise is $10 \log_{10}(149/135)^8$ or 3.4 decibels.

The design of the muffler sections followed the procedure developed in reference 7. Given a desired center frequency for the muffler attenuation and the expected flow conditions in the muffler duct, four fundamental parameters are manipulated to construct a practical muffler:

Open area ratio (orifice area to wall area), σ

Perforated sheet thickness, t

Perforated sheet hole diameter, d

Backing depth of liner resonators, b

For the 250-hertz muffler sections, the design called for an unacceptably large perforated sheet thickness. This problem was solved with the use of short open-ended tubes welded to the flow surface to simulate this thickness. Details of the muffler design appear in figure 5. A photograph of a portion of the muffler duct centerbody appears as figure 6. These mufflers were designed for the flow conditions expected with the engine running at 60 to 65 percent of its design speed, since there was particular interest in the engine noise at lower engine speeds. These flow conditions are given in table I.

DATA PROCEDURE

The far-field noise data were taken at 10° increments in the rear quadrant as shown in the plan view of figure 7. For each test the 30.5-meter (100-ft) radius microphone circle was centered at the exit of the exhaust nozzle with the microphones at the engine centerline elevation of 1.2 meters (4 ft). The test area had an asphalt surface. The noise data were recorded on magnetic tape for later analysis. The data were not corrected for ground reflection.

A horizontally traversing total temperature and pressure probe was installed just downstream of the nozzle exit to determine the exit velocity profile. The entire nozzle diameter was surveyed. The total pressure was read through a transducer and plotted continuously through the survey, with the total temperature being recorded at selected locations in the traverse. From these values an area-weighted, average exit jet velocity was determined.

A typical exit velocity profile appears in figure 8 for the full muffler case at 98 percent of engine speed. The lower velocity near the center of the profile is due to the presence of the muffler duct centerbody.

Tests were made with the engine running at 50, 55, 60, 65, 70, 80, 90, and 98 percent of its compressor design speed, with more points taken at the lower speeds where the effect of the exhaust muffler is most pronounced. The engine speed range corresponds to an approximate jet exit velocity range of 135 to 478 meters per second (445 to 1569 ft/sec).

ANALYSIS OF DATA

Correlation of Jet Sound Power

A comparison of the sound power level spectra for varying amounts of acoustic liner is presented in figure 9 for each of the engine speeds. In figure 9(a), with the engine at 50 percent of its design speed, the peak attenuation measured for the 250-hertz liner occurred reasonably near the predicted frequency; the high-frequency muffler produced its peak attenuation at a lower frequency than its nominal design value. This frequency relation does not change as the engine speed increases to 70 percent as in figure 9(c). At higher engine speeds (figs. 9(d) and (e)) the effect of the muffler is not sufficiently pronounced to make a maximum attenuation frequency determination. The measured peak attenuation was at the 800-hertz one-third-octave band for the 1000-hertz design. Because noises from other sources, such as the jet, become controlling after the internal noise is reduced, the observed attenuations were not expected to reach the peak predicted values.

The measured overall sound power level was correlated with the Lighthill parameter for the jet for the portion of the spectrum that was felt to be jet noise, that is, up to a cutoff frequency of approximately 2000 hertz (depending on the percent of engine design speed). For the overall sound power level calculations, the high-frequency cutoff (the highest frequency used in the power level calculation) was determined by comparing the data with the SAE jet spectrum. In figure 10 this comparison is shown for the full-treatment configuration. A significant high-frequency deviation of the data from the SAE spectrum was considered to arise from internal sources. Therefore, high-frequency data that showed this deviation from the SAE spectrum were not included in the calculation. The portion of the spectrum that was included in the calibration is indicated by darkened symbols.

The OAPWL results are plotted in figure 11. The results compare favorably with the straight line, which shows a V^8 dependence except at the low values of the parameter where internal noises are probably still contributing to the overall noise level. Based on the fully treated exhaust muffler case, the fit of the data had a proportionality constant equal to 5.5×10^{-5} for the relation between the sound power and the Lighthill parameter. This value compares well with Lighthill's value of 5×10^{-5} for the coefficient.

CORRELATION OF MAXIMUM OVERALL SOUND PRESSURE LEVEL

The SAE noise parameter, $OASPL_m - 10 \log(\rho^2 A)$, along a 61-meter (200-ft) sideline was correlated with the jet exit velocity as shown in figure 12. A faired curve fit of the data for the fully lined duct at jet velocities above 275 meters per second (900 ft/sec) has the same slope and is 3 decibels above the extrapolated SAE curve. At the lower jet velocities the data deviate from the faired curve; however, this deviation occurs at a lower velocity for the fully lined case than for the all-hard duct and regular engine cases. If the internally generated noise could be further reduced, the data would be expected to follow the extrapolated SAE curve down to a lower jet velocity.

COMPARISON OF PREDICTED TO ACTUAL MUFFLER PERFORMANCE

The predicted muffler performance is compared with the data in figure 13 for 50 percent maximum engine speed. The performance of the muffler duct was predicted using the theory developed in references 8 and 9. The frequency of maximum attenuation for the low-frequency muffler agreed well with the predicted value of 250 hertz. The high-frequency section was predicted to yield maximum attenuation of 1000 hertz, somewhat above the observed 800-hertz maximum.

In all cases the predicted maximum levels of attenuation were considerably above those observed. At high engine speeds the jet noise level is high, thus obscuring the amount of attenuation of internal noise. Figure 14 shows the decreasing observed attenuation with increasing engine speed, an effect that is also apparent in figure 9 in which the noise spectra for several engine speeds is compared.

The attenuation predictions were based on the fully treated case, with the predicted level of attenuation being approximately linear with the length of treatment - all other factors being held constant. In the data a small increase in attenuation was observed in the fully treated case over the half-treated case. This observation may imply that the relation between treatment length and attenuation is not linear; however, at least at high speeds, the apparent nonlinearity is more likely caused by the proximity of the jet noise floor.

Let's examine the data shown in figure 12. A curve faired through the data (at speeds above 275 m/sec) of the fully lined configuration lies parallel to the SAE curve but is shifted upward by 3 decibels. This difference is unexplained, but it seems reasonable to assume that this faired line represents the jet noise for the present experiment. Extrapolating the faired curve to lower velocities and using this extrapolated curve to predict the jet noise results in an under-prediction of the measured low-velocity data.

It would seem that there is additional internal noise that could be removed by an additional suppressor. Such a suppressor would attempt to remove internal noise at different frequencies, since little further reduction of overall level can be accomplished by further reductions of internal noise at the design frequencies of the present liner; that is, the noise at some other frequencies now control the level.

SUMMARY OF RESULTS

A J-65 engine was fitted with a component exhaust muffler duct in order to study the jet noise behavior of a turbojet engine at low exhaust speeds. The muffler was designed to allow testing of full-suppression, half-suppression, and hard-duct configurations, in addition to the regular engine without the duct. A standard 0.53-meter (21-in.) diameter nozzle was used for all tests. Inlet noise was reduced with a previously tested suppressor which was used for all tests.

The results may be summarized as follows:

1. The use of the exhaust muffler extended the relation between jet noise and the eighth power of the jet velocity to lower velocities by eliminating part of the internally generated noise component. Based on the fully suppressed case, the experimental constant of proportionality between noise power and the Lighthill parameter was 5.5×10^{-5}. This compared well with Lighthill's value for the coefficient of 5×10^{-5}.

2. The maximum value of the overall sound pressure level along a 61-meter (200-ft) sideline was considered as a function of the jet velocity and was compared with the SAE AIR-876 jet noise correlation curve. A curve drawn through the fully suppressed case data at jet velocities above 275 meters per second has the same slope but is 3 decibels above the extrapolated SAE curve. Below this jet velocity the trend of the data deviates from the SAE curve because of the contribution of internally generated noise which dominates the jet noise at low velocities. The extent of this deviation was dependent on the amount of treatment in the exhaust duct.

3. The general behavior of the muffler performance was reasonably well predicted by the theory at 50 percent of engine design speed. The observed attenuations of internal noise at high engine speeds were small because jet noise controlled the measured noise levels at these speeds.

With respect to the frequency of maximum attenuation, the prediction was accurate at the 250-hertz one-third-octave band. The maximum attenuation for the high-frequency section was predicted for the 1000-hertz, rather than the observed 800-hertz, one-third-octave band.

With respect to the magnitude of the maximum attenuation, the predictions were considerably above the actual attenuations. However, because the data for the fully lined case showed only a small additional attenuation over the half-lined case, it may be reasonable to assume that a floor was approached and that, in the absence of this floor, the predicted attenuation may be quite reasonable.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, November 7, 1972,
501-04.

REFERENCES

1. Lighthill, M. J.: Jet Noise. AIAA J., vol. 1, no. 7, July 1963, pp. 1507-1517.
2. Gordon, Colin G.; and Maidanik, Gideon: Influence of Upstream Flow Discontinuities on the Acoustic Power Radiated by a Model Air Jet. NASA CR-679, 1967.
3. Minner, Gene L.; and Feiler, Charles E.: Low-Speed Jet Noise from a 1.83-Meter (6-ft) Fan for Turbofan Engines. NASA TN D-6314, 1971.
4. Anon.: Jet Noise Prediction. AIR-876, SAE, July 1965.
5. Fenn, D. B.; and Jones, William L.: Over-All Performance of J65-B3 Turbojet Engine for Reynolds Number Indices From 0.8 to 0.2. NACA RM SE55C08, 1955.
6. Groeneweg, John F.; Feiler, Charles E.; and Acker, Loren W.: Inlet Noise Suppressor Performance with a Turbojet Engine as the Noise Source. NASA TN D-6395, 1971.
7. Rice, Edward J.; Feiler, Charles E.; and Acker, Loren W.: Acoustic and Aerodynamic Performance of a 6-Foot-Diameter Fan for Turbofan Engines. III - Performance with Noise Suppressors. NASA TN D-6178, 1971.
8. Groeneweg, John F.: Current Understanding of Helmholtz Resonator Arrays as Duct Boundary Conditions. Basic Aerodynamic Noise Research. NASA SP-307, 1969, pp. 357-368.
9. Rice, Edward J.: Propagation of Waves in an Acoustically Lined Duct with a Mean Flow. Basic Aerodynamic Noise Research. NASA SP-207, 1969, pp. 345-355.

GENERAL REFERENCE

1. Howes, Walton L.: Similarity of Far Noise Fields of Jets. NASA TR R-52, 1959.

2. Marshall, D. A. A.: Sources of Noise in Aero-Engines. Presented at the 1st International Symposium on Air Breathing Engines, Rolls-Royce (1971) Limited, Derby, England, 1972.

TABLE I. - OPERATING CONDITIONS[a]

[Muffler design point conditions[b]: duct gas velocity, 91.4 m/sec (300 ft/sec); gas temperature, 811 K (1460° R); pressure ratio in duct, 1.05.]

Percent speed	Total temperature, T_t		Total pressure		Jet velocity		Duct velocity	
	K	°R	N/m²	psia	m/sec	ft/sec	m/sec	ft/sec
50	713	1284	555	15.05	135.6	445	71.3	234
55	699	1259	563	15.26	153.6	503	79.9	262
60	672	1211	573	15.54	171.9	564	88.7	291
65	658	1184	586	15.89	192.6	632	98.1	322
70	639	1151	600	16.25	210.0	689	105.8	347
80	631	1136	657	17.80	274.0	899	130.8	429
90	708	1275	752	20.39	368.5	1209	160.3	526
98	837	1507	880	23.85	478.2	1569	186.2	611

[a]Based on hard duct case.

[b]These conditions approximate the 60 to 65 percent engine speed point.

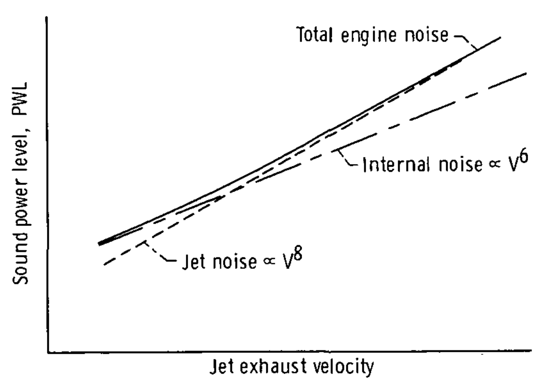


Figure 1. - Components of turbojet engine noise.

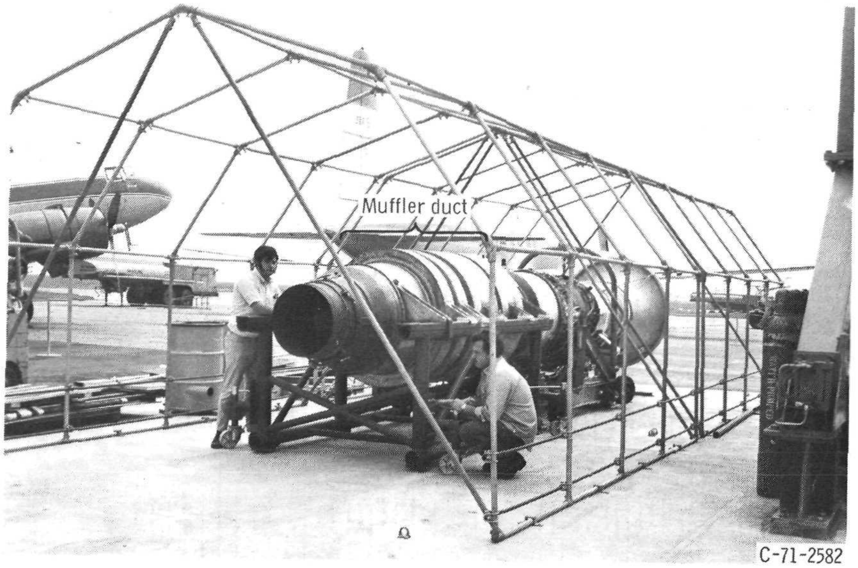


Figure 2. - Rear view of J-65 installation showing full exhaust muffler.

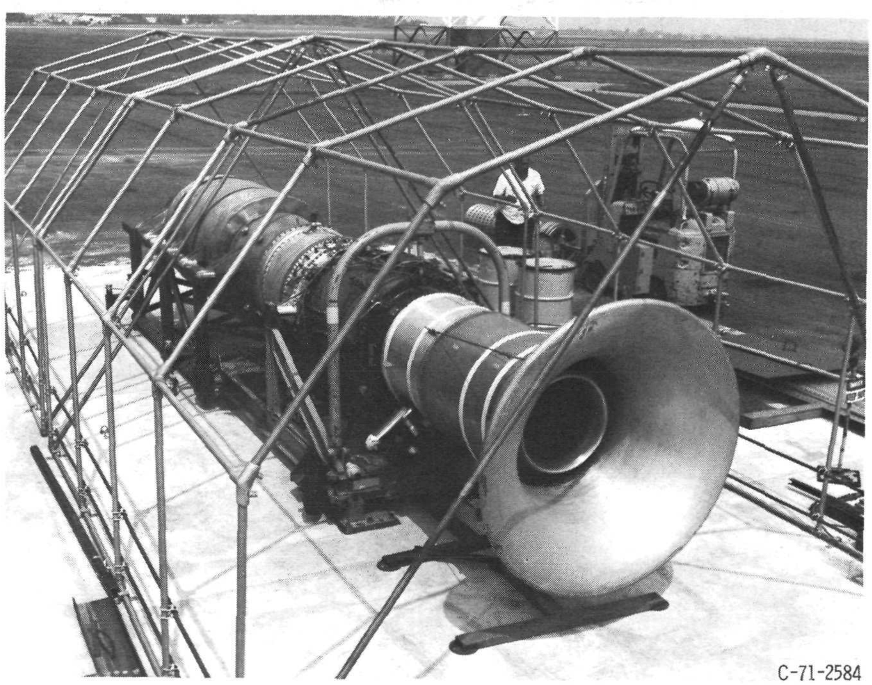


Figure 3. - Front view of J-65 installation showing inlet suppressor in place.

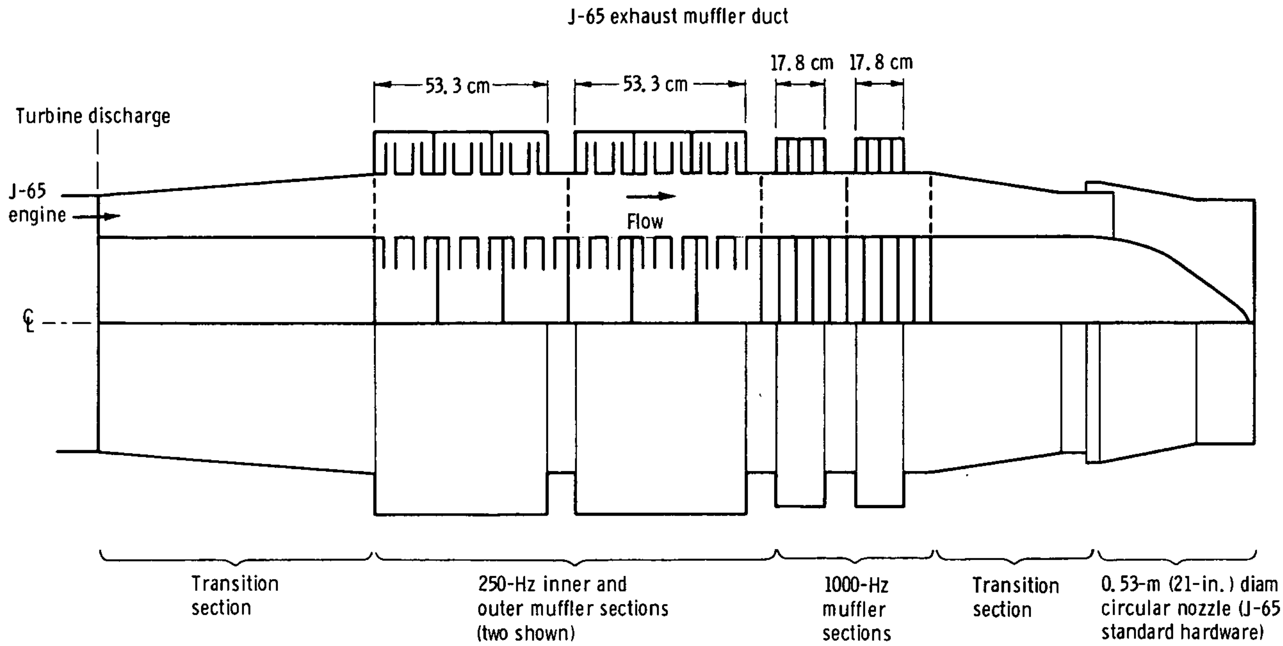
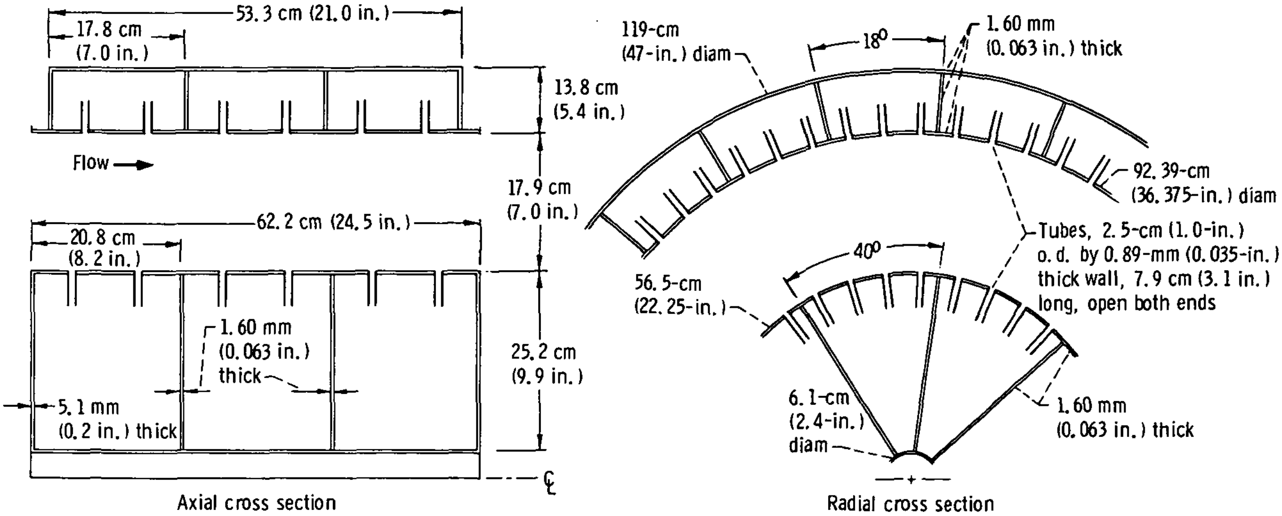
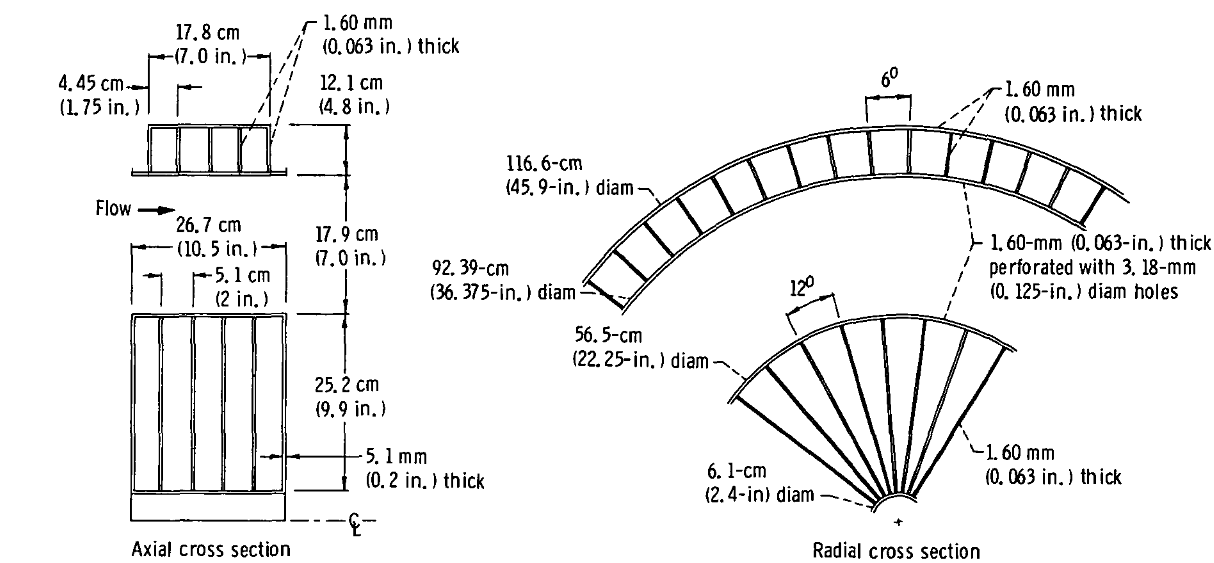


Figure 4. - Cross section of muffler duct.



(a) 250-Hertz section (two used); open area ratio, 8.8 percent for inner body and 10.3 percent for outer body.



(b) 1000-Hertz section (two used); open area ratio, 40 percent.

Figure 5. - Details of J-65 exhaust muffler sections.

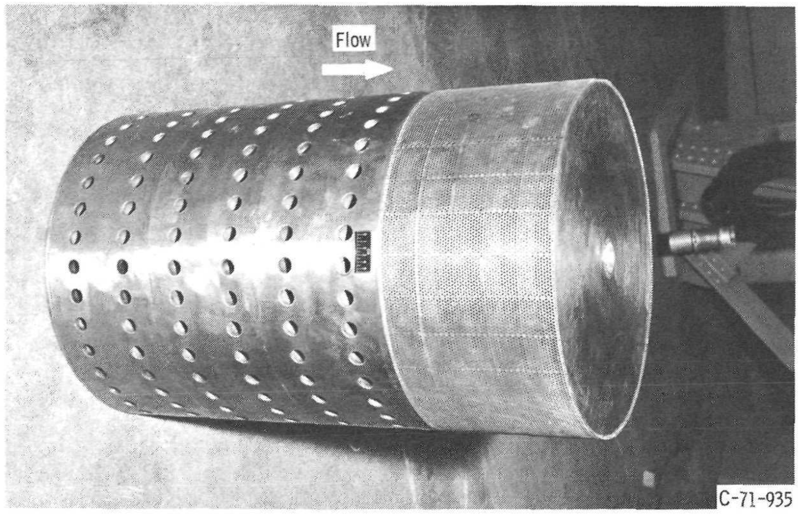


Figure 6. - Two inner muffler sections (250 and 1000 Hz).

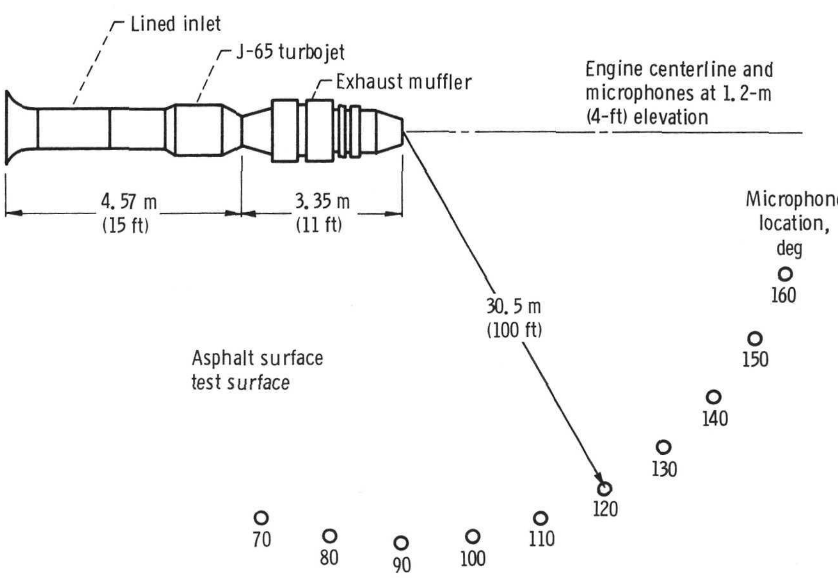


Figure 7. - Plan of test site.

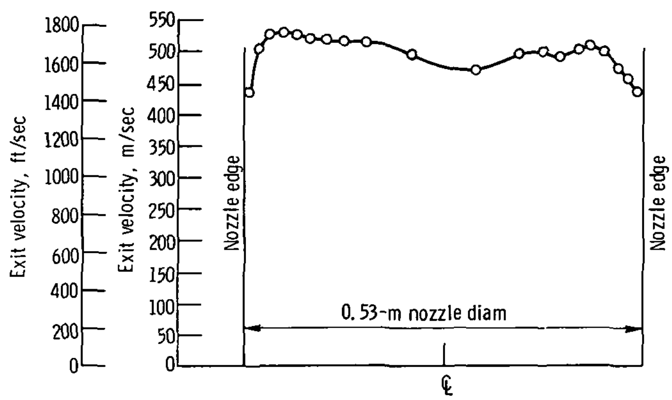


Figure 8. - Typical exit velocity profile. Full muffler case at 98 percent engine speed.

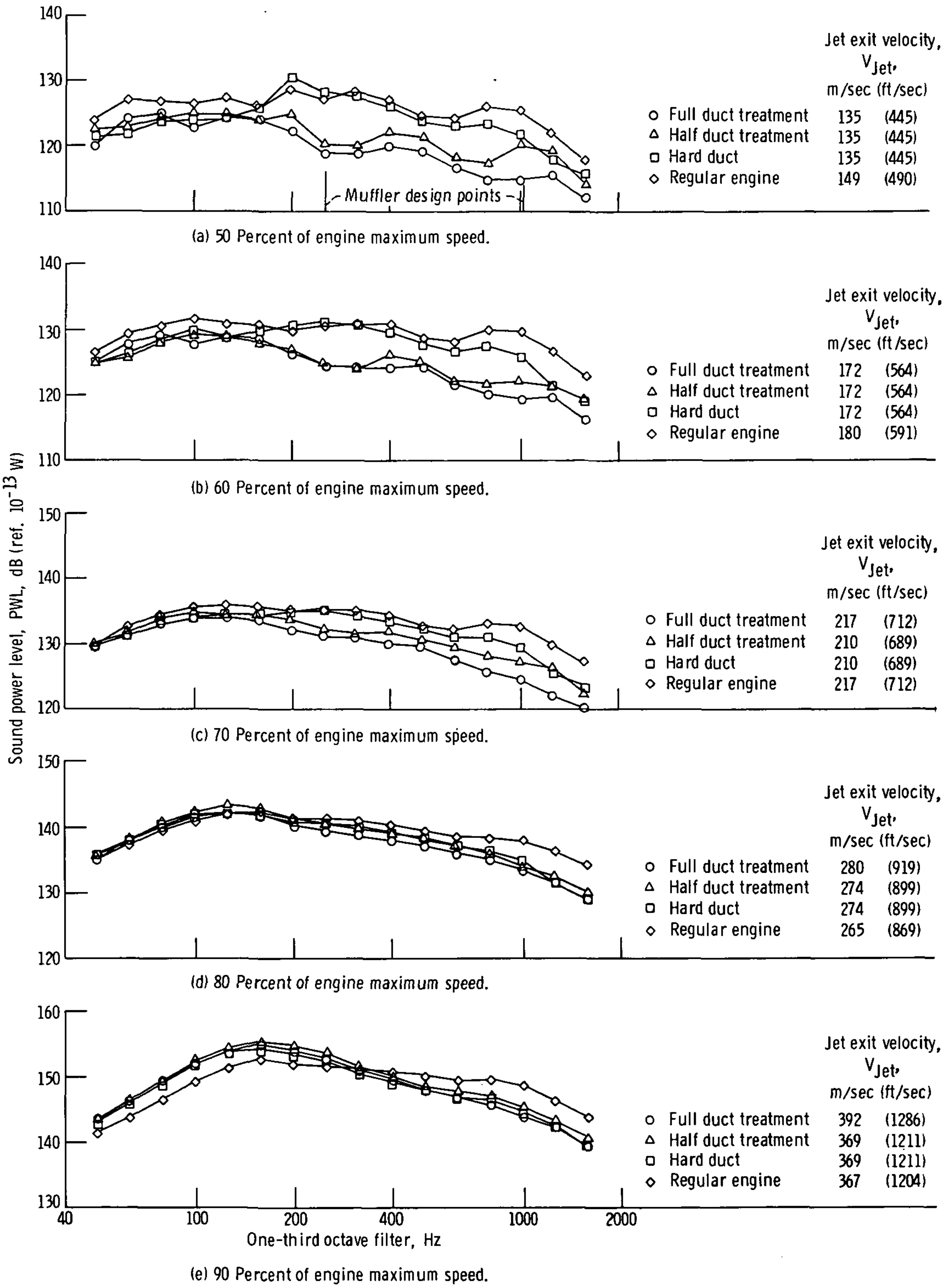


Figure 9. - Relative area quadrant sound power level.

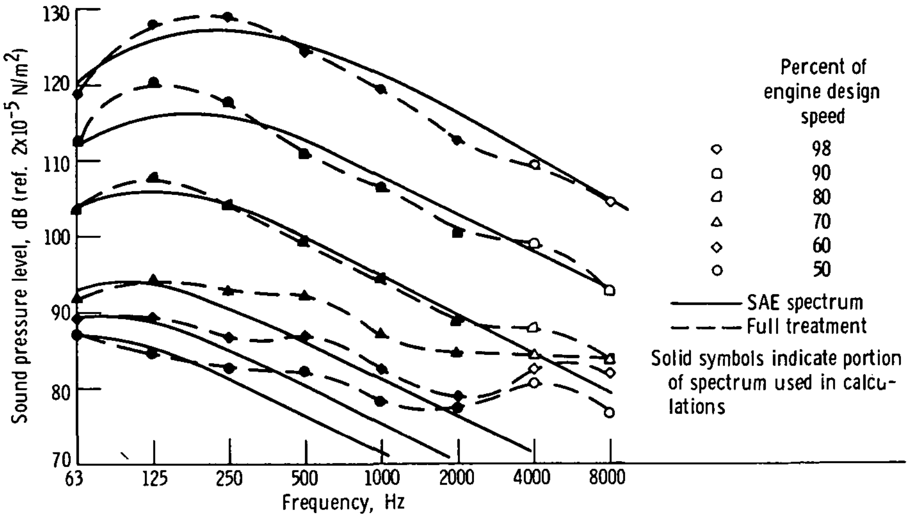


Figure 10. - Comparison of full treatment case with profile of predicted SAE pure jet spectrum.

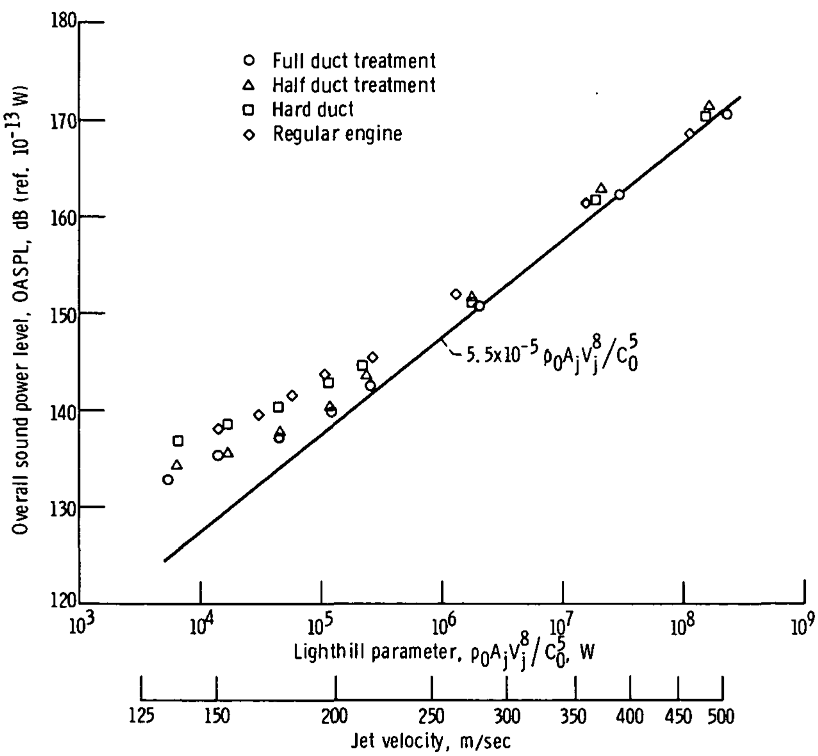


Figure 11. - Overall spectrum jet noise correlation.

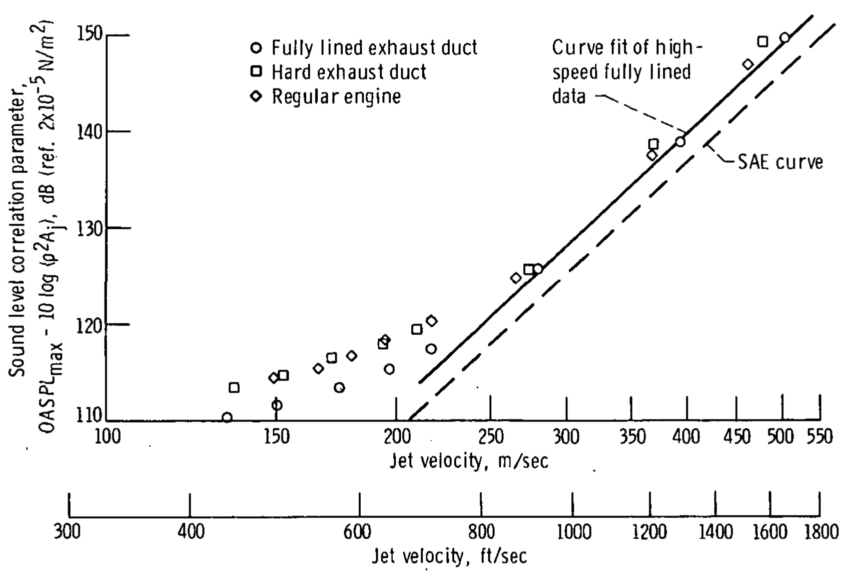


Figure 12. - Sound level as function of jet velocity. Sideline distance, 61 meters (200 ft).

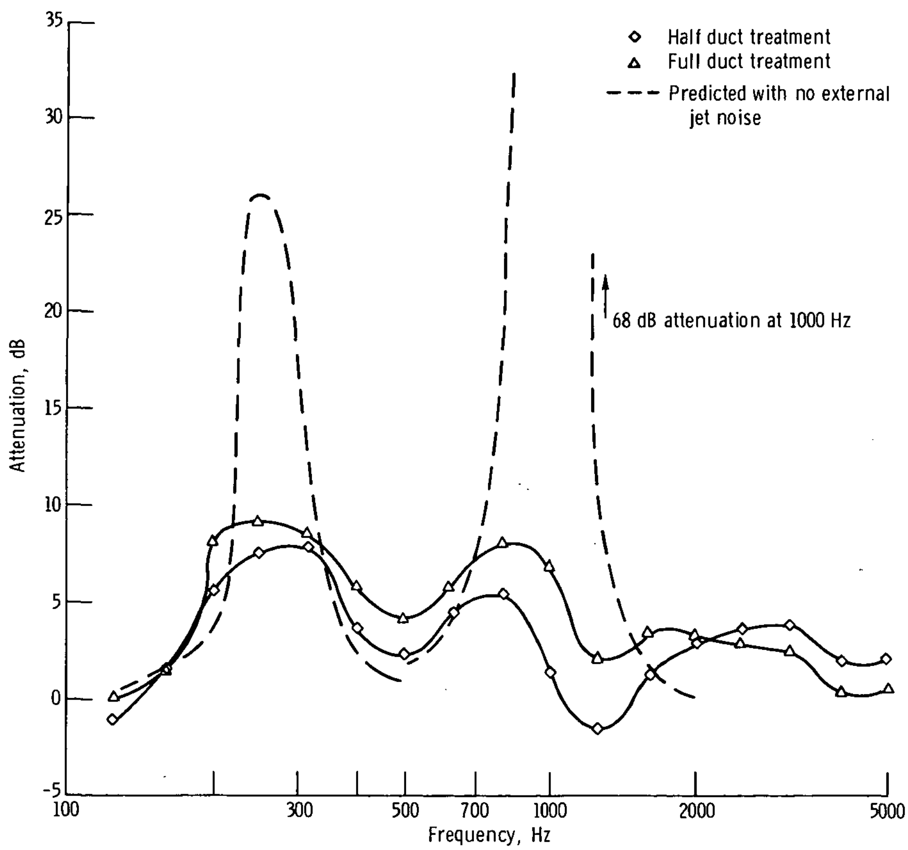


Figure 13. - Comparison of actual and predicted J-65 exhaust muffler attenuations. 50 Percent of maximum engine speed; jet exit velocity, 135 meters per second (445 ft sec).

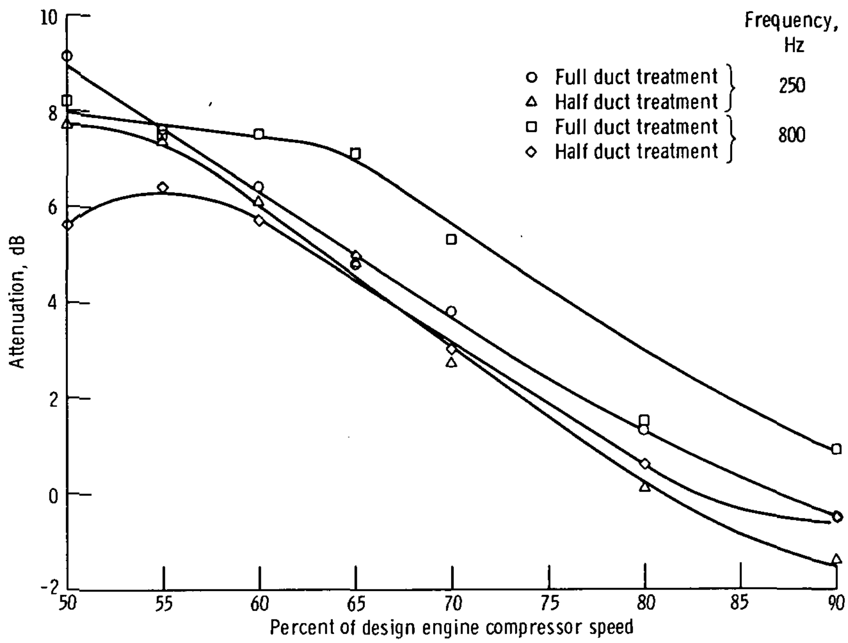


Figure 14. - Effect of engine speed on muffler performance. One-third octave data.

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