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TECHNICAL NOTE 4217

EFFECT OF JET TEMPERATURE ON JET-NOISE GENERATION

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SUMMARY

An experimental investigation was conducted in order to determine the effect of jet temperature on jet-noise generation. Jet pressure ratios from 1.3 to 1.9 and temperatures from 80° to 1000° F were used. Results showed that sound power can be adequately predicted by the Lighthill parameter based on ambient temperature over the range of temperatures investigated. The dimensionless frequency spectra of the jet was shown to be affected by temperature; increasing jet temperature resulted in a shift of acoustic energy from high to low Strouhal numbers. Shifts in the jet spectra were explained on the basis of the effect of temperature on the spreading characteristics of the jet, and a method of correcting the spectra for jet temperature was presented.

INTRODUCTION

The far-field noise of jets and jet engines has received considerable attention in recent years (refs. 1 to 9). A survey of the literature indicates that the effect of temperature is not as immediately evident as the effect of jet velocity. The temperature effect may be significant because the temperature range of interest is quite large. It would be desirable to know, for instance, whether cold-model-jet tests will correctly simulate turbojet and rocket noise.

Reference 4 indicates that jet temperature has a negligible effect on sound pressure at a single point in the sound field. Early experiments with various gases (ref. 5) showed that sound pressure varies linearly with jet density. Since jet density varies inversely with temperature, sound power would be expected to vary inversely with the square of the temperature. For a first approximation one might expect that the variation of jet density either by the use of temperature variation or by the use of gases of various molecular weights should give similar results. However, the experiments of reference 3 indicate that data from both full-scale tests with jet engines and small cold-air jets can be correlated on a total-sound-power basis and that no significant effect of jet temperature was observed.

Theoretical treatments of the effect of jet temperature also show a considerable diversity of conclusions. Such a treatment by Lighthill (ref. 6) indicates that sound power varies inversely as the square of the jet temperature; whereas the analytical treatment of reference 7 indicates that a large effect is possible, that is, that sound power varies as the reciprocal of temperature to the 6.6 power.

In view of the considerable divergence of experimental and theoretical results, a study of the temperature effect on sound-power generation of jets was considered necessary. This report covers an investigation of the sound power generated by a small jet over a range of Mach numbers up to 1.00 and jet temperatures from 80° to 1000° F. This work was conducted at the NACA Lewis laboratory as part of a program of study on jet noise and methods of suppression. 4465

APPARATUS AND PROCEDURE

A schematic diagram of the test setup is shown in figure 1(a). In order to eliminate the possibility of combustion noise that could propagate out through the nozzle and contribute to the jet noise, the air was heated indirectly by means of a heat exchanger. Hot gas was supplied to the hot side of the counterflow exchanger by means of a propane combustor. Mufflers were used upstream of both the hot-gas and air sides of the heat exchanger to minimize piping and valve noise. The exhaust gas from the exchanger was ducted for a considerable distance away from the jet to eliminate any contribution of exhaust noise to the measurements of the jet noise.

Jet total temperature and pressure were measured in the large section upstream of the nozzle. By using the arrangement shown, the jet total pressure could be held to ±0.1 inch of mercury and the jet total temperature to ±5°. Tests were conducted over a range of nozzle total pressures from 9 to 27 inches of mercury above atmospheric pressure (pressure ratios from 1.3 to 1.9) in 3-inch increments. For each pressure ratio the jet total temperature was varied from 200° to 1000° F in 200° F increments. One set of data was also taken with cold air at approximately 80° F.

Figure 1(b) shows a photograph of the test apparatus. The nozzle was located 7 feet above the ground plane. All acoustic measurements were made in a plane parallel to the ground at the jet centerline. A small (5/8-in. diam.) condenser microphone was mounted on a rotating survey arm as shown. Acoustic measurements were made on either side of the jet axis in 15° increments for 105°. All measurements were taken at a radius of 7 feet from the jet exit with the microphone face in the horizontal plane. Sound-pressure spectra data were obtained with an automatic frequency analyzer and recorder. At each microphone location sound

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pressures were obtained in 1/3-octave bands for midfrequencies from 40 to 16,000 cycles per second. Several additional runs were made with a modified frequency analyzer and recorder that extended the range to 31,500 cycles per second. The sensitivity of the measurement system was standardized at 400 cycles with a small loudspeaker-type calibration and transitor oscillator.

A calibration of the microphone used in the investigation is shown in figure 2. All the spectrum data presented herein have been corrected for microphone characteristics. The over-all sound-pressure levels were obtained from a summation of the corrected spectrum data.

The sound power radiated from the nozzle was calculated from the sound-pressure levels by the general method described in reference 8. Because the nozzle size was small (9/16-in. diam.), wind direction and velocity had a considerable effect on the jet and resulted in distorted sound fields. Tests made on different days showed that local sound-pressure-level variations might be as high as ±3 decibels. However, the sound-power levels varied less than ±1 decibel. The sound power should have less variation, since it results from an integration over the whole sound field. No data were taken when wind velocities exceeded 10 miles per hour. Data taken directly downstream of the nozzle were not used in the calculations because of errors resulting from the effects of jet impingement on the microphone.

RESULTS AND DISCUSSION

The results of tests with subsonic cold-air jets (refs. 2 and 9) have indicated that sound power can be correlated by means of the Lighthill parameter $\rho_0 AV^8/a_0^5$ where ρ is density, A is the exit area of nozzle, V is jet velocity, and a is the speed of sound. The subscript 0 refers to ambient conditions of the medium into which the jet is discharging. The tests of references 2 and 10 were conducted with jet total temperatures very close to ambient and, since the jets were subsonic, the static pressure in the jet must be the same as ambient. The sound powers for all jet temperatures and pressure ratios were calculated and plotted against the Lighthill parameter (fig. 3). The correlation appears to be excellent, and no effect of jet temperature is evident.

Moreover, the agreement between the present data and the results of reference 3, shown by the curve, indicates that the relation between sound power and the Lighthill parameter $\rho_0 AV^8/a_0^5$ holds for a wide range of jets from very small jets, both hot and cold, up through several sizes of jet engines.

It should not be assumed from this, however, that jet density has no effect on jet-noise generation, since such an effect is shown in references 5 and 6. Rather, the temperature, while reducing jet density, must be assumed to somehow increase noise generation in a manner that almost exactly counteracts the decrease in jet density associated with temperature.

The spectral distribution of sound power for several conditions covering the whole range of the data is shown in figure 4, where corrected power level is plotted as a function of the dimensionless parameter, Strouhal number (frequency times diameter divided by jet velocity). The use of Strouhal number for the comparison of spectra is well recognized (refs. 3 and 11). The shape of the spectra in figure 4 appears to be independent of Mach number (pressure ratio) but to vary slightly with temperature. The high-temperature (1000° F) spectra peak at a slightly lower Strouhal number than the low-temperature spectra and fall off more rapidly at high Strouhal numbers.

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The negligible effect of Mach number on the shape of the spectrum is shown in figure 5(a), where the curves for the minimum (1.3) and maximum (1.9) pressure ratios coincide.

The shift in energy from high to low Strouhal number with increasing temperature is clearly illustrated in figure 5(b), where data of figure 4 are replotted as cumulative sound power (power below a given frequency) as a function of Strouhal number.

A comparison of the cold-air spectra with those of reference 3 shows excellent agreement. The nozzle sizes of the two sets of data are vastly different; but the flows are geometrically similar, and hence the dimensionless spectra are similar. The data at the two temperatures, 90° and 1000° F, yield two separate curves. The intermediate temperature data fell between the two curves, but temperature differences less than 400° F were not recognizable because of data scatter. The results of figure 5(b) clearly show that the Strouhal number corresponding to the 50-percent power point shifts from approximately 0.24 to 0.18 as the temperature increases from 90° to 1000° F. The shift in energy from high to low Strouhal number may possibly be the result of increased spreading rate of hot jets as compared with cold jets. Corrsin and Uberoi (ref. 10) have shown that, at 15 diameters downstream from the nozzle, a 1000° F jet has a spread of momentum 1.3 times the spread of a 90° F jet (ref. 10, fig. 15). The ratio of the Strouhal numbers at 50-percent cumulative acoustic power (fig. 5(b)) for hot and cold jets was also approximately 1.3. This result indicates that the change in spectrum can be estimated from the change in spreading rates.

The previous discussion of the correlation of sound power against the Lighthill parameter $\rho_0 AV^8/a_0^5$ mentioned that the good correlation probably results from some effect of temperature on the jet mixing characteristics that tends to counteract the effect of temperature on jet density. Reference 6 suggests that data for a hot jet might correlate by using the parameter $\rho_j^2 AV^8/\rho_0 a_0^5$. The increase in effective diameter at any position downstream of the exit represents just such an effect, since the characteristic length, that is, diameter, in the Lighthill parameter is increased while the density is decreased. An estimate of this effect can be made from the results of reference 10 and, for the range of temperatures of current interest, the compensating effect of temperature on diameter would appear to almost cancel out the effect of decreasing density with increasing temperature. This result appears qualitatively correct, but it cannot be verified without detailed turbulence measurements in a hot jet.

CONCLUSIONS

An experimental investigation to determine the effect of jet temperature on jet-noise generation was conducted for a range of jet pressure ratios from 1.3 to 1.9 and temperatures from 80° to 1000° F, and the following results were obtained:

1. The sound power can be adequately predicted by the Lighthill parameter based on ambient temperature over the range of temperatures investigated.

2. The dimensionless frequency spectra of the jet was affected by temperature. Increasing jet temperature resulted in a shift of acoustic energy from high to low Strouhal numbers.

3. Shifts on the jet spectra were explainable on the basis of the effect of temperature on the spreading characteristics of the jet, and a method of correcting the spectra for jet temperature was shown.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, December 6, 1957

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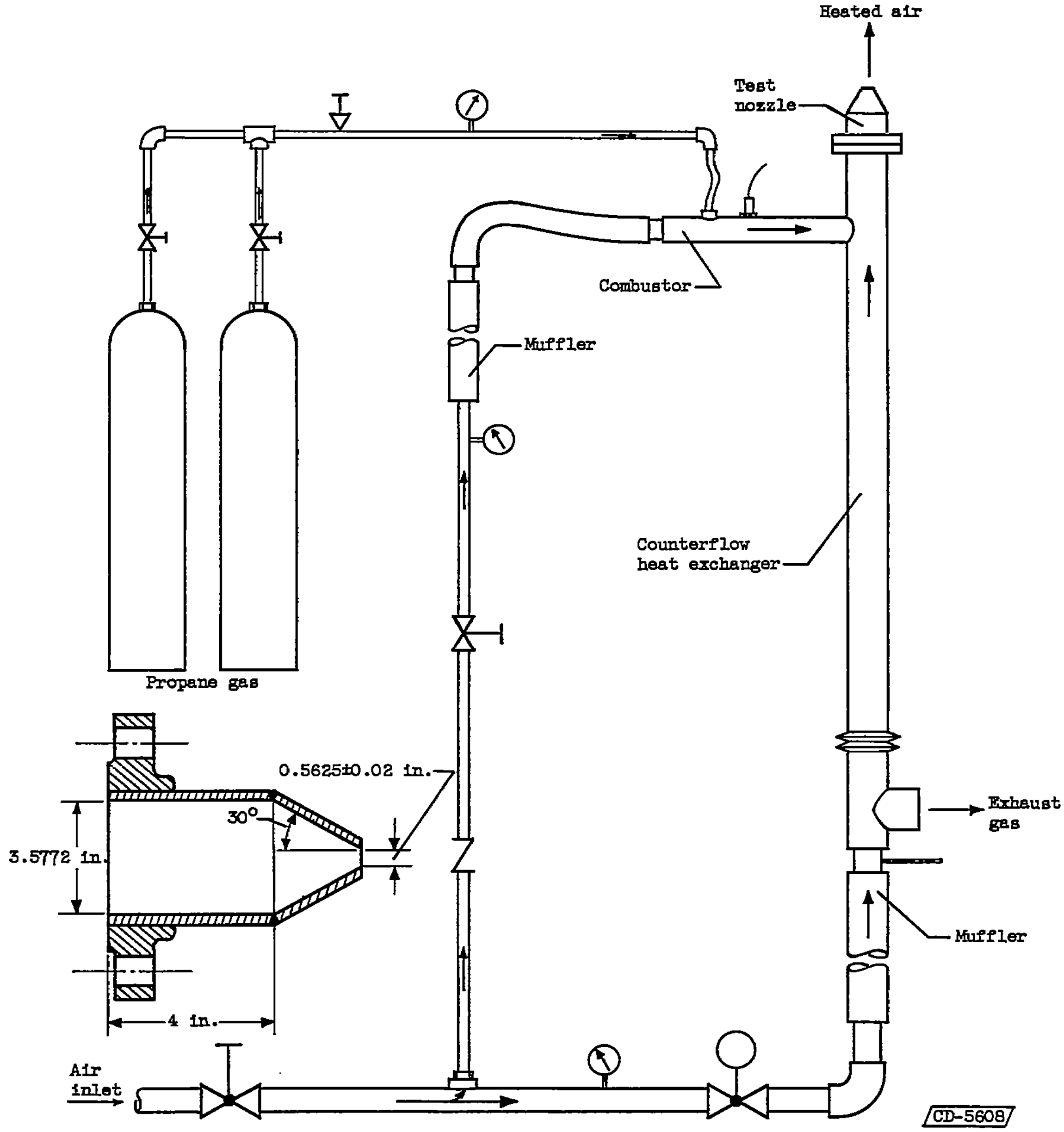
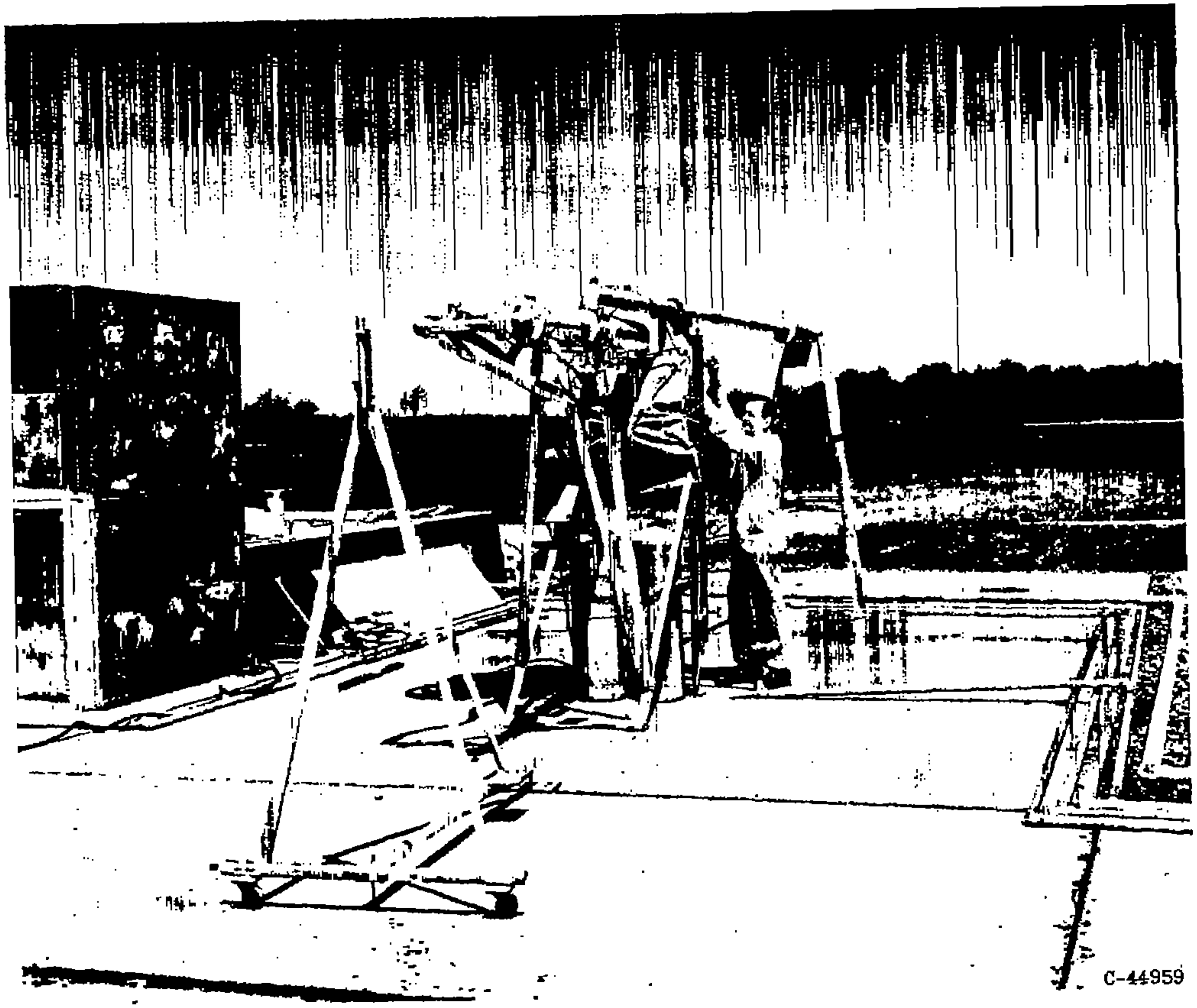


(a) Diagram of test setup.

Figure 1. - Model jet setup.



(b) Nozzle and survey rig.

Figure 1. - Concluded. Model jet setup.

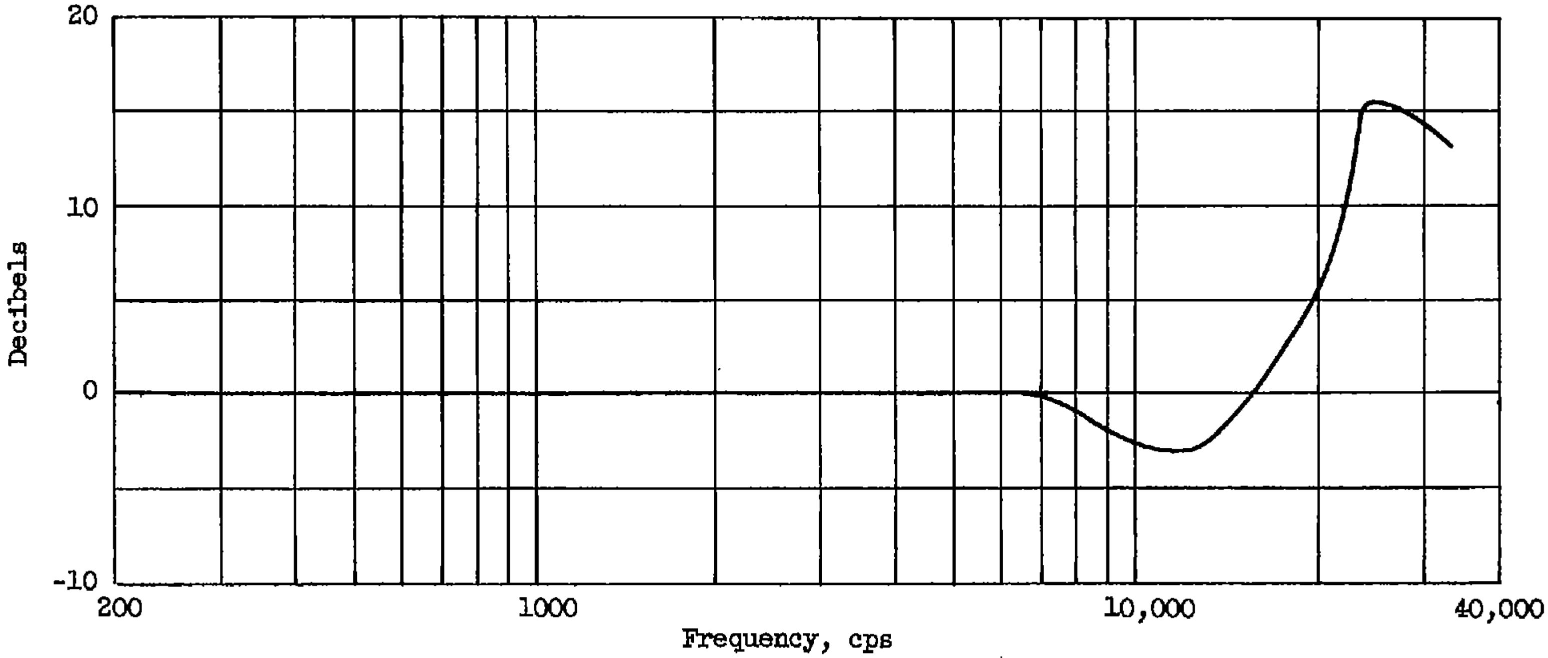


Figure 2. - Microphone correction curve.

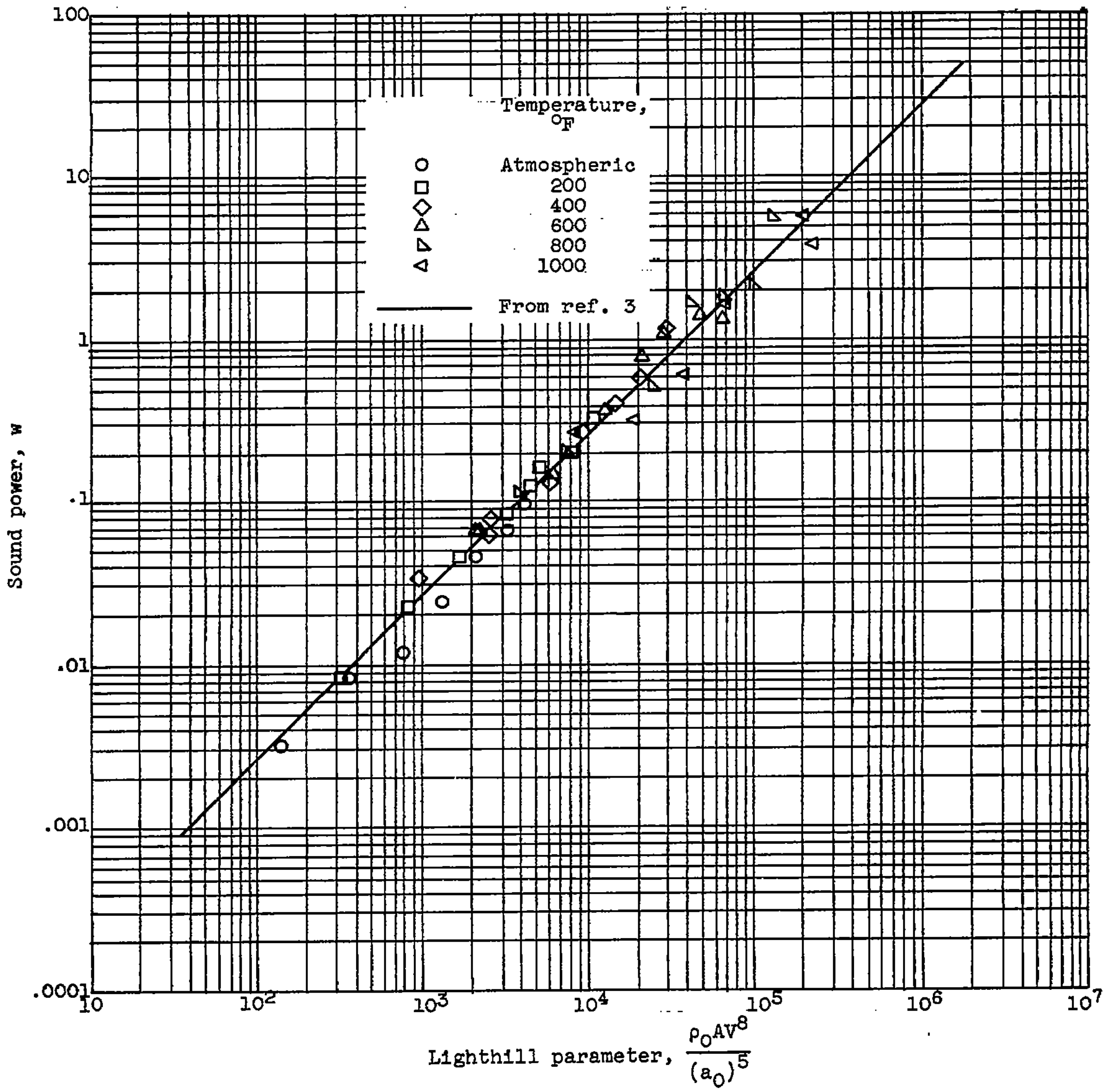


Figure 3. - Sound power as a function of Lighthill parameter.

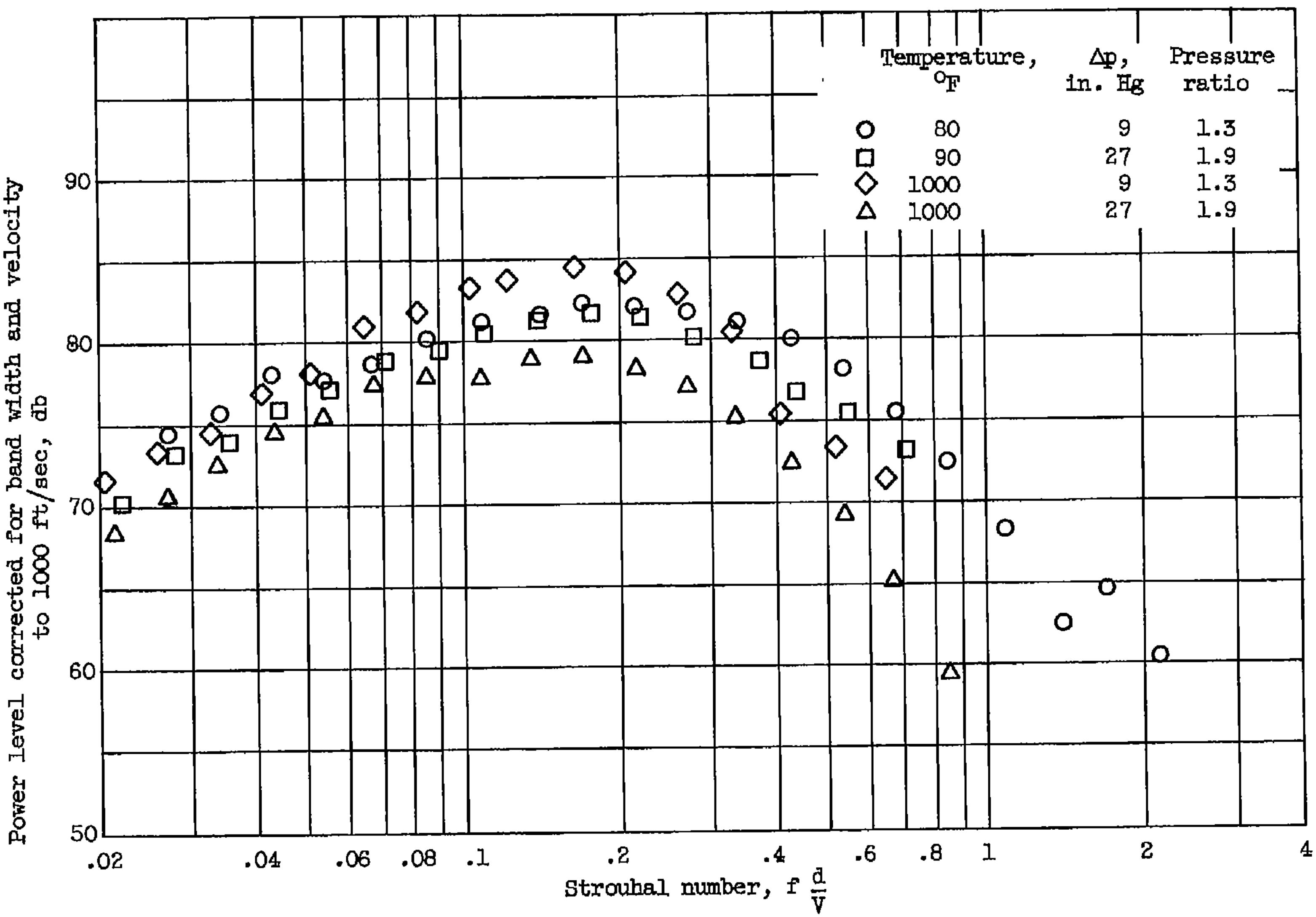
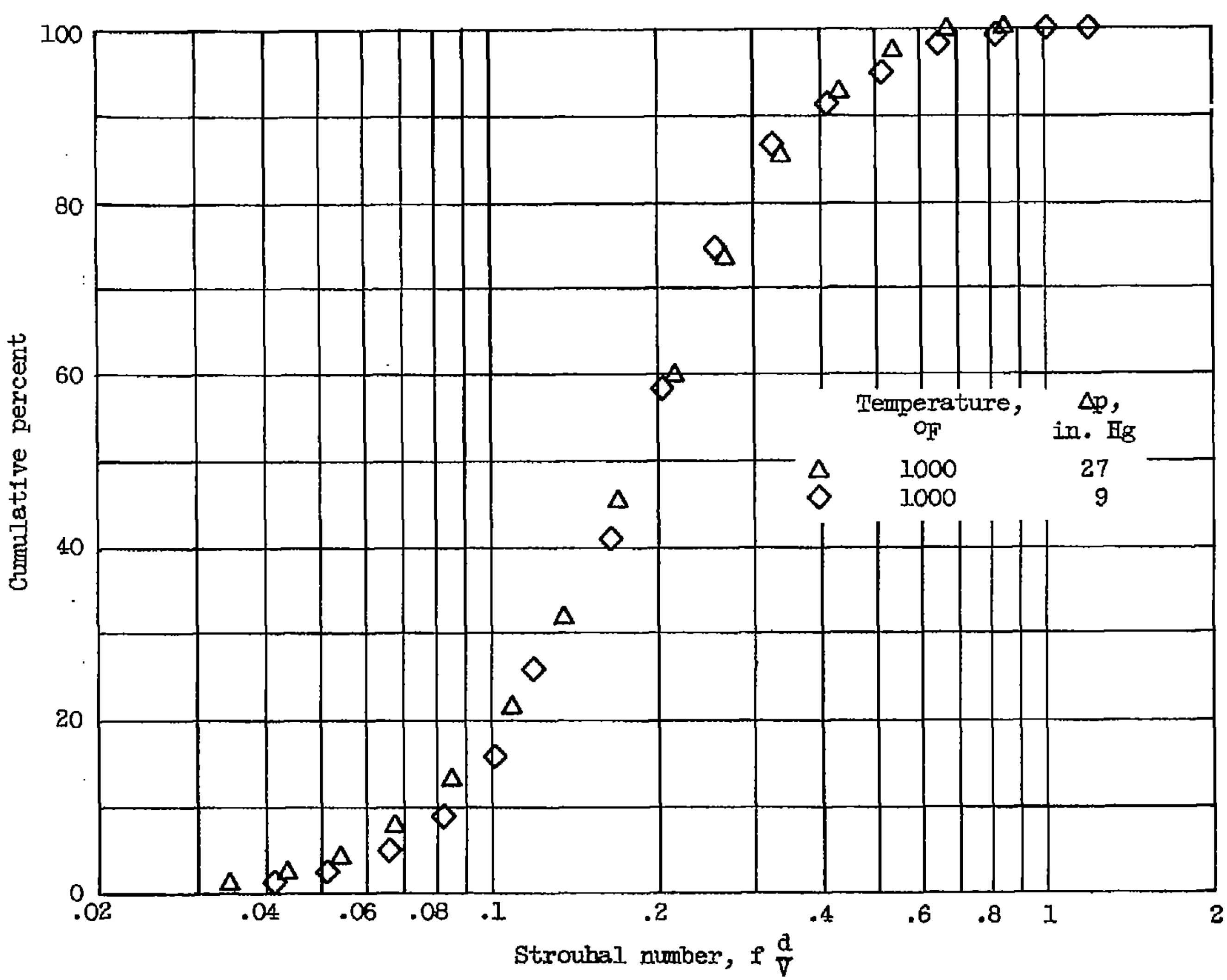
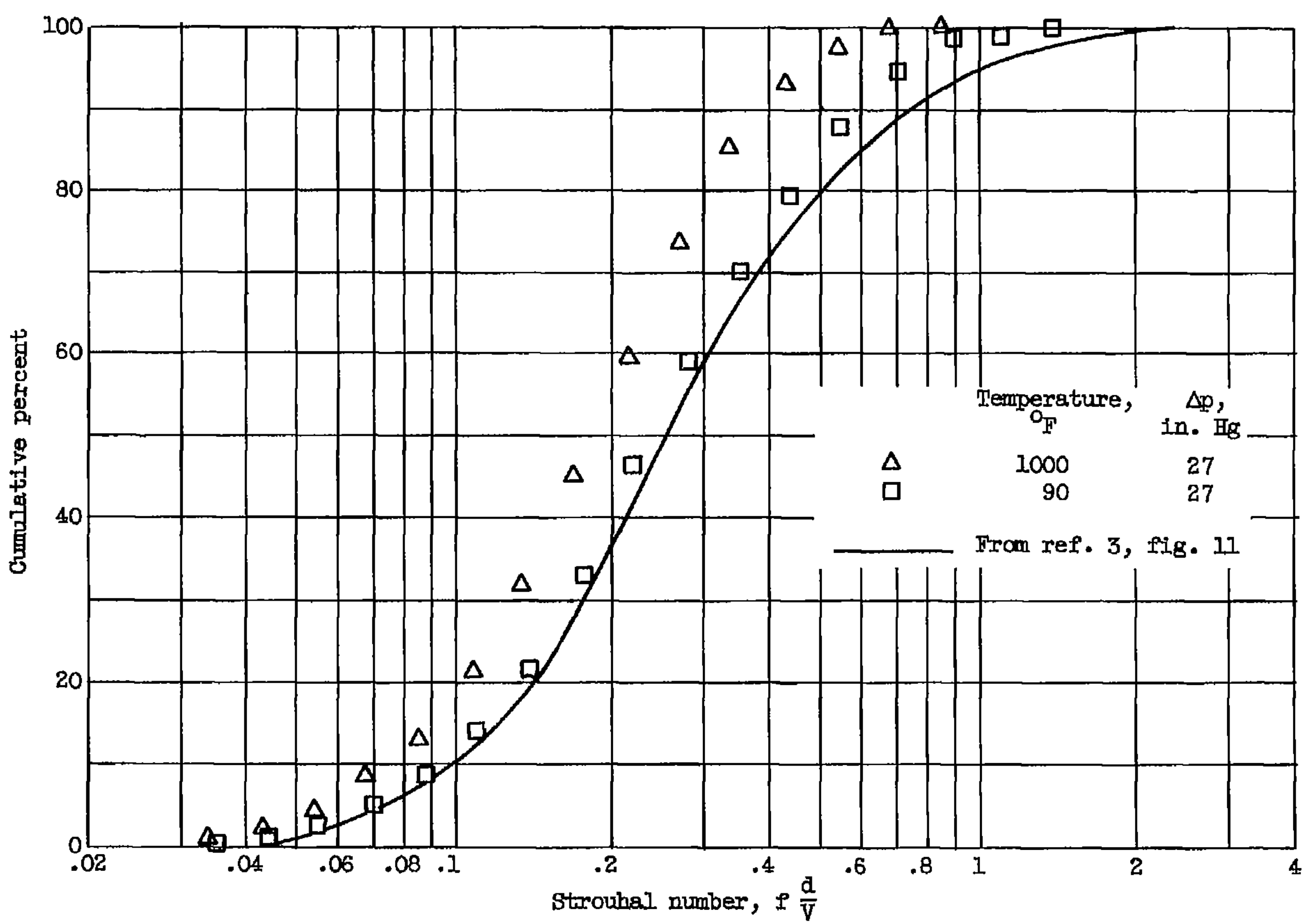


Figure 4. - Comparison of power level over range of Strouhal numbers.



(a) Constant temperature.

Figure 5. - Cumulative spectral distribution of sound power.



(b) Constant Mach number.

Figure 5. - Concluded. Cumulative spectral distribution of sound power.