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Effect of Temperature on Surface Noise

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Introduction

It has generally been assumed (e.g., Refs. 1 and 2) that the noise from large scale surfaces immersed in a hot turbulent flow can be accurately determined from a simple scale-up of cold flow model data, where the model is geometrically and aerodynamically similar. With such a simple scale-up of data, the effect of temperature on surface noise is considered to be small. This assumption may be in error for two reasons. First, it is well known that temperature and temperature fluctuations have a measureable effect upon jet noise.[3] Second, turbulence measurements[4] have shown that the intensity of the temperature fluctuations in a jet are of the same order of magnitude as the velocity fluctuations; and velocity fluctuations near the edge of a surface are the source of surface noise at ambient temperature.[5,6] Therefore, temperature fluctuations may also be a source of additional surface noise.

Apparently, the effect of temperature on surface noise has not been investigated either by careful experiment or by analysis. The object of the experimental work discussed in this Note was to obtain data that show the effect of temperature and temperature fluctuations on surface noise. This was accomplished experimentally by immersing a small chord airfoil in the turbulent airstream of a hot jet. This experiment was an extension of the experiment reported in Ref. 6, where the fundamental theory of Ref. 5 was shown to be in almost perfect agreement with the data. The theory and experiment discussed in Ref. 6 were limited to ambient temperature jets; nevertheless, they provided a guide for designing and validating the hot jet experiment and for interpreting the data.

Apparatus and Procedure

The apparatus, instrumentation, and data reduction system were essentially the same as those described in Ref. 6, except for changes required for the hot jet. The flow system consisted of, in order: a flow control valve, a muffler, a combustor, a hot flow muffler, and a nozzle. The mufflers removed valve and combustor noise down to a velocity of about 100 m/s, as evidenced by the excellent agreement between the jet noise data of this experiment and published hot jet data.[7]

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Figure 1 is a schematic showing the airfoil in the center of the mixing region of the jet. The thin airfoil was made of stainless steel; it was 1-m long, and had a chord of 2.54 cm. The airfoil was attached to a rigid structure; the bottom end of the airfoil was weighted and permitted unobstructed spanwise thermal expansion to avoid buckling. To establish the desired impingement velocity V_i and temperature T_i the nozzle was calibrated to the corresponding nozzle stagnation conditions P_N, T_N. This was accomplished with a temperature and pressure rake attached to the airfoil. The rake was then removed for the acoustic data run, where the nozzle stagnation conditions corresponding to the desired impingement conditions were set.

The noise emission was measured with eleven 0.63-cm diameter microphones at different angles θ_i on a horizontal semicircle of 4.57-m radius. Panels of open-pore urethane foam were placed on the ground in the test area. This arrangement resulted in far-field data that were not subject to ground reflections (i.e., were free field) above about 250 Hz. Furthermore, neither the nozzle nor the airfoil supports caused measureable reflections or shielding.

The noise signals were analyzed by an automated spectrum analyzer which yielded1/3 octave band sound pressure levels (SPL) at each microphone. These data were corrected subsequently to remove the small losses due to atmospheric attenuation of the sound. Jet noise, which was measured separately with only the airfoil support in place, also was removed subsequently so that the data reported, SPL_c, are corrected and represent pure surface noise. None of the data reported required more than a 2-dB correction. These corrected data were summed spectrally to produce the overall sound pressure level, $OASPL_c$.

Discussion of Existing Theory

There is no theory for the effects of temperature, temperature gradients, or temperature fluctuations on surface noise. However, there is a theory for a small chord airfoil immersed in an ambient temperature turbulent airstream that is small and surrounded by a uniform environment at rest. The noise emission is described by Eq. (1) of Ref. 5. This equation is rewritten here in a summary form that shows only the terms that are appropriate for this study.

$$SPL_c = 10\log_{10}\left\{\left[\left(\frac{bc}{R^2}\right)\left(\frac{\rho_0}{c_0}\right)^2 V_i^6\left(\frac{\bar{v}}{V_i}\right)^2\right](\sin^2\theta_i)\right.$$
$$\left.(\text{shape of spectrum, defined in Ref. 6})\right\} + K \qquad (1)$$

The experimental data in Ref. 6 showed that this equation was very accurate.

Equation (1) involves three factors and a term K that is constant for a given spanwise distribution of the turbulent flow. The first factor is the relative amplitude of the noise at $\theta_i = 90$ deg; it is a function of the airfoil chord c, scrubbed span b, microphone arc radius R, the peak impingement velocity V_i, transverse turbulence intensity $\bar{v}/V_i$, the ambient

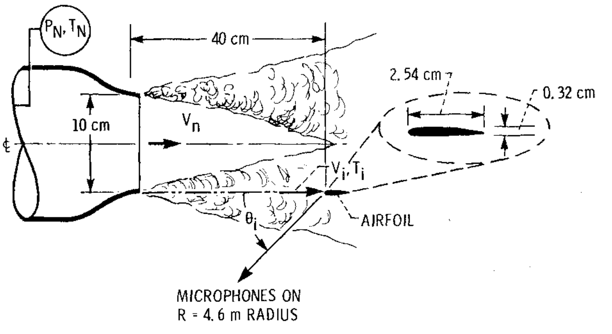

Fig. 1 Schematic of the nozzle and airfoil, top view.

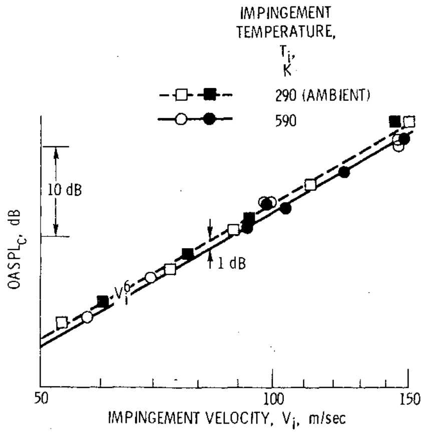

Fig. 2 Dependence of OASPL on velocity at constant impingement temperature: polar angle, 90 deg. airfoil chord, 2.54 cm.

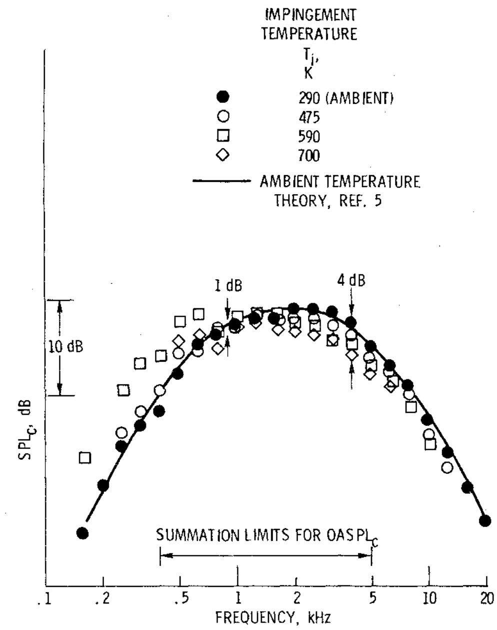

Fig. 3 Effect of impingement temperature on the acoustic spectrum at constant impingement velocity of 90 m/s. Polar angle, 90 deg; airfoil chord, 2.54 cm; thickness, 0.32 cm; free-field lossless data.

density ρ_0, and speed of sound c_0. The quantities bc/R^2 and $(\rho_0/c_0)^2$ are each constant for this experiment. Data for the turbulence intensity at high temperatures and velocities[8] indicate that $\tilde{v}/V_i$ is effectively constant for this experiment. The second factor describes the shape of radiation pattern (i.e., how the SPL at a given frequency varies with angle); it is only a function of angle. The third factor is a complicated one that describes the shape of the acoustic spectra. The spectrum shape is not a function of angle or impingement velocity; therefore, the overall SPL differs from the peak SPL by a constant.

Results and Discussion

If the effect of temperature is small, then Eq. (1) suggests several ways to validate the experimental technique. First, the overall sound pressure from the small airfoil shown in Fig. 1 should follow a V_i^6 law independently of the jet impingement temperature. Indeed, Fig. 2 shows that the overall sound pressure does follow the V_i^6 law very closely at ambient temperature and also at an elevated temperature (590 K). Data for a repeat experiment also fall on these lines. These results also show that the effect of temperature on the absolute value of the overall SPL is small. Therefore, the main assumption of the experiment is verified; namely, that noise from a full scale surface, immersed in a hot turbulent flow, can be adequately estimated from a simple scale-up of cold flow data.

A second validation argument comes from the radiation pattern. The data (not shown) agree very well with the theoretical pattern ($\sin^2\theta_i$), except for large angles and at high frequency where the effect of refraction (not included in the theory) becomes important.

In order to establish additional confidence in the experiment and in the ambient temperature theory, the ambient temperature spectrum for $\theta_i = 90$ deg and $V_i = 90$ m/s, are compared with the theory in Fig. 3. The theory, described by the solid curve, agrees exactly with the ambient temperature data. The agreement shown here is as good as that shown in Ref. 6; furthermore, the absolute level of the data (not shown) repeats within 1 dB.

The effect of temperature upon the spectra at $\theta_i = 90$ deg is also shown on Fig. 3. The temperature of the airstream impinging on the airfoil varies from 290 K (ambient) to 700 K, while the impingement velocity is held constant at $V_i = 90$ m/s. The data show that the spectra at elevated temperatures are slightly different from the spectrum at ambient temperature. The sound levels at the highest temperature of 700 K are generally lower than the levels at ambient temperature. A maximum decrease of 4 dB occurred at about 4kHz; therefore, the SPL varied inversely as the first power of the impingement temperature. At low frequency there is a slight increase in the sound levels. A similar but larger spectral shift with temperature occurs with subsonic jet noise.[7]

The reader is cautioned that the results of this paper are for a surface immersed in a hot finite turbulent flow, e.g., a jet. If the airfoil were immersed in the hot turbulent airstream within a long duct, then the environment would be the duct; in this cube the ambient variables in Eq. (1), $(\rho_0/c_0)^2$, indicate that the noise would vary inversely as the cube of the temperature.

Conclusions

This experiment investigated the effect of the temperature of a finite turbulent jet on the noise produced by a surface immersed in that jet. The experimental data showed that increased temperature caused a small decrease in the sound levels; at the same time it also caused a shift in the spectra that was smaller but similar to the shift observed with subsonic hot jet noise.

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