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ERRORS IN THE ESTIMATION OF SURFACE VELOCITY BY USE OF THE TWO-MICROPHONE TECHNIQUE

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INTRODUCTION

During the past several years, the two-microphone technique has proved to be a very useful and versatile measurement method. The use of this method now includes the determination of in-duct acoustic properties, acoustic intensity, acoustic velocity and estimation of surface velocity and radiation efficiency.

Previously reported work by the authors [1,2] showed an overestimate of the measured surface velocity obtained with a two-microphone probe near the surface of a homogeneous aluminum panel. In this paper a simple theory is developed to explain this phenomenon.

THEORETICAL WORK

Consider an infinitely extended plate in transverse motion, radiating sound waves into a 2-D plane, as shown in Fig. 1. Let the transverse surface velocity of the plate be given by [3]

$$v(x) = v_o \exp(-jk_B x) \qquad (1)$$

where v_o is the amplitude and the plate wavenumber

$$k_B = 2\pi[f/1.8\ tc_\ell]^{1/2}. \qquad (2)$$

Here f is the frequency, t is the plate thickness and c_ℓ is the longitudinal wave speed. The pressure field near the panel due to the panel motion is [3]

$$p(x,z) = \frac{v_o \rho c}{[1-(k_B/k)^2]^{1/2}} \exp(-jk_B x)\cdot\exp\left[-j(k^2-k_B^2)^{1/2} z\right] \qquad (3)$$

where ρ is the density, c is the speed of sound and k ($= 2\pi f/c$) is the acoustic wavenumber.

The auto power spectral density (APSD) estimated by an accelerometer mounted on the surface is ideally

$$G_{uu} = G_{uu}^{AM} = \frac{2}{T} V^* V = \frac{2}{T} v_o^2 \qquad (4)$$

where V is the finite Fourier transform of the plate velocity and T is the total record length [4]. In the case of a two-microphone system, the APSD is [2]

$$G_{uu} = G_{uu}^{2M} = \frac{1}{(\rho\ \Delta r\ \omega)^2} \left[G_{11} + G_{22} - 2\mathrm{Re}(G_{12}) \right] \qquad (5)$$

where G_{11} and G_{22} are the APSD's of microphones 1 and 2, respectively and $\mathrm{Re}(G_{12})$ is the real part of the cross spectral density between these signals. In practice, instrumentation distorts the pressure signals both in magnitude and phase, and accurate velocity measurements therefore require careful calibration. This is discussed in reference [2].

The difference in the velocity levels, the error level, is defined as

$$L_\varepsilon = 10\ \mathrm{Log} \left[G_{uu}^{AM} / G_{uu}^{2M} \right] \qquad (6)$$

If the sound pressure at each microphone position is finite Fourier transformed, and these transforms are used to compute G_{uu}^{2M} from equation (5), it can be shown that the resulting expression for G_{uu}^{2M} together with equations (4) and (6) lead to the following error levels:

I. $k<k_B$ (below coincidence)

$$L_\varepsilon = -10\ \mathrm{Log} \left\{ \frac{1}{(\Delta r)^2 (k_B^2 - k^2)} \left[\exp\left[-2z_1 (k_B^2 - k^2)^{1/2}\right] + \exp\left[-2z_2 (k_B^2 - k^2)^{1/2}\right] - 2\cos\left[k_B(x_1 - x_2)\right] \cdot \exp\left[-(z_1 + z_2)(k_B^2 - k^2)^{1/2}\right] \right] \right\} \qquad (7)$$

II. $k>k_B$ (above coincidence)

$$L_\varepsilon = -10\ \mathrm{Log} \left\{ \frac{2}{(\Delta r)^2 (k^2 - k_B^2)} \left[1 - \cos\left[k_B(x_1 - x_2)\right] \cos\left[(k^2 - k_B^2)^{1/2}(z_1 - z_2)\right] + \sin\left[k_B(x_1 - x_2)\right] \sin\left[(k^2 - k_B^2)^{1/2}(z_1 - z_2)\right] \right] \right\} \qquad (8)$$

where (see Figure 1)

$$x_2 = x_1 + \Delta r \sin \phi \tag{9}$$

$$z_2 = z_1 + \Delta r \cos \phi \tag{10}$$

It is seen that the error level is a rather complex algebraic function of the two-microphone probe orientation and distance to the surface, the acoustic and plate wavenumber, and the microphone spacing.

EXPERIMENTAL WORK

The error levels computed from Eqs. (7) and (8) are compared with the corresponding measured levels [2] using BK 4165 one-half inch microphones in Figs. 2 and 3. The same trend is seen to be well predicted in both these figures: a rising error level in the subcritical region to about one octave below the panel critical frequency. This is followed by a sharp dip at this frequency. It is seen that even a small probe misalignment can result in a significant overestimate of the surface velocity by the two-microphone probe. This alignment was never measured during experiments and it is likely that the alignment was in error by a few degrees in the one point measurement, perhaps even more so in the surface scan (Fig. 3).

CONCLUSIONS

A two-microphone probe can be used at low subcritical frequencies to estimate the normal surface velocity of thin panels. At midrange subcritical frequencies an underestimate of this velocity is caused by a combined effect of the microphone spacing, probe misalignment, probe distance to the panel surface, and acoustic and panel wavenumbers. In the coincidence region an overestimate of this velocity appears to be most affected by probe misalignment.

REFERENCES

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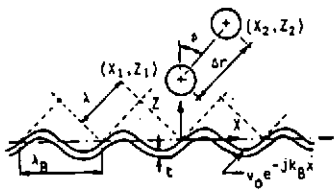

FIG. 1 LOCATION OF A TWO MICROPHONE PROBE NEAR AN INFINITELY EXTENDED PLATE IN TRANSVERSE MOTION.

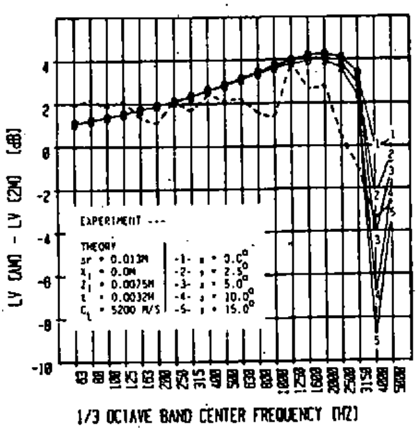

FIG. 2 PREDICTED AND MEASURED (2) DIFFERENCE BETWEEN SURFACE VELOCITY LEVELS, ESTIMATED BY AN ACCELEROMETER, LV (AM), AND A TWO MICROPHONE PROBE, LV (2M), AT ONE POINT ON AN ALUMINUM PANEL (3.2 MM THICK).

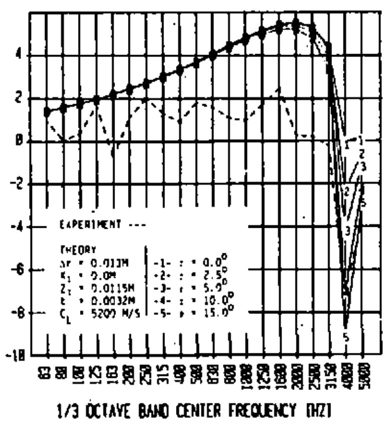

FIG. 3 PREDICTED (AT ONE POINT) AND MEASURED (SURFACE AVERAGED) (2) DIFFERENCE BETWEEN SURFACE VELOCITY LEVELS, ESTIMATED BY AN ACCELEROMETER, LV (AM), AND A TWO MICROPHONE PROBE, LV (2M), ON AN ALUMINUM PANEL (3.2 MM THICK).