

XI. PHYSICAL ACOUSTICS

Academic Research Staff

Prof. Uno Ingard

Graduate Students

Vijay K. Singhal

A. REFLECTION OF SOUND FROM A SIDE-BRANCH CAVITY IN A DUCT IN THE PRESENCE OF FLOW

U. S. Navy Office of Naval Research (Contract N00014-67-A-0204-0019)

Uno Ingard, Vijay K. Singhal

As one problem in our study of the interaction of sound with flow in ducts, we are considering the absorption, reflection, and transmission of sound at a side-branch cavity in a duct with flow. In the experiments a sound pulse is produced in the duct from a

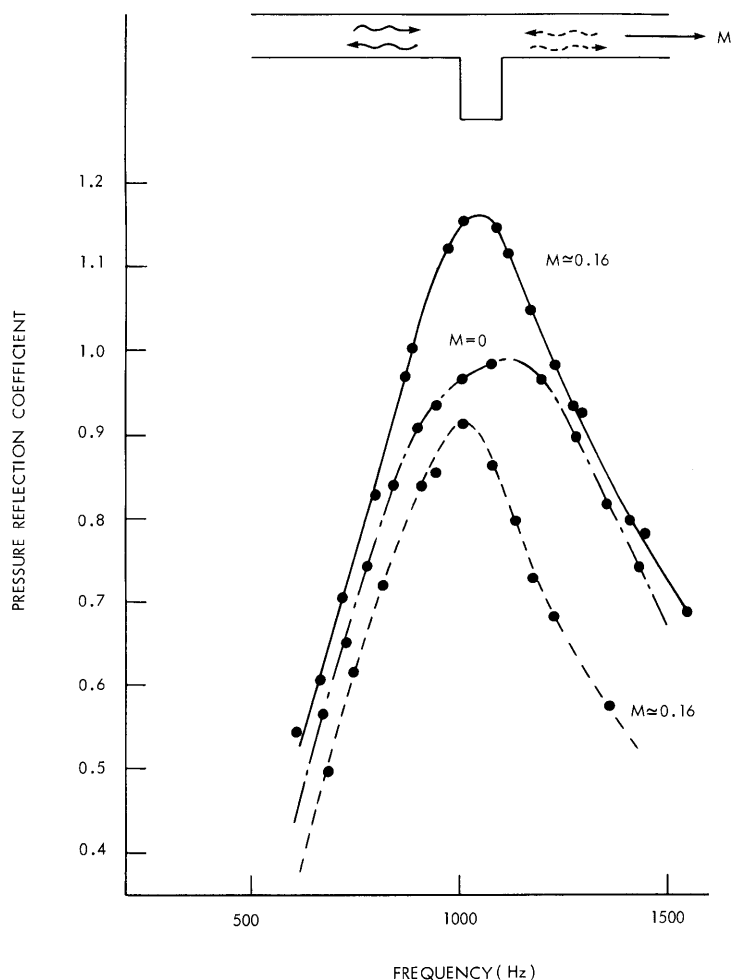


Fig. XI-1.

The reflection coefficient as a function of frequency. Cavity depth, 3 in; cavity cross section, $3/4 \times 3/4$ in; pipe cross section, $3/4 \times 3/4$ in. For $M \approx 0.16$, the upper curve is obtained when the speaker and the microphones are upstream of the cavity, and the lower curve when the speaker and the microphones are downstream of the cavity. The middle curve is for no flow.

(XI. PHYSICAL ACOUSTICS)

sound source that can be either on the upstream or the downstream side of the cavity. In either case the incident and reflected sound from the cavity is measured by means of microphones mounted in the side wall of the duct, and the frequency dependence of the pressure reflection coefficient is determined for different values of the flow Mach number in the duct and for different values of the amplitude of the sound wave.

The result at zero flow is shown in Fig. XI-1, which shows a typical resonance curve, with the peak corresponding to a wavelength approximately equal to four times the depth of the side-branch cavity, as expected. The width of the curve is an expression of the acoustic losses in the vicinity of the cavity. In the presence of flow the results depend on whether the sound is reflected upstream or downstream. In the upstream direction the pressure reflection coefficient can be larger than unity, as indicated in Fig. XI-1. Also, note that the peak of the curve is now shifted downward and the width of the curve has decreased. The corresponding curve when the sound is reflected in the downstream direction is also shown in Fig. XI-1.

A detailed theoretical explanation for this behavior is still not available. Considered qualitatively, the reason for the increased sharpness of the resonance curve is probably that the cavity is excited into self-oscillation by the flow, in which case the total internal resistance is reduced. Similarly, the reason for a pressure reflection coefficient larger than unity in the upstream direction is probably the same as that given in our previous paper on upstream and downstream radiation into a duct with flow.¹ A theoretical analysis of this problem is under way, which we hope to report in a subsequent quarterly report.

References

1. U. Ingard and V. K. Singhal, J. Acoust. Soc. Am. 54, 1343-1346 (1973).

B. ACOUSTICALLY STIMULATED KARMAN VORTEX SHEDDING IN A TUBE

U. S. Navy Office of Naval Research (Contract N00014-67-A-0204-0019)

Uno Ingard, Vijay K. Singhal

In our continuing studies of sound propagation in ducts with flow, we are particularly interested in the interaction between sound and flow. One of the aspects of this interaction was discussed in Quarterly Progress Report No. 109 (pp. 39-47) which dealt with the attenuation of sound resulting from turbulence. We now describe an experiment dealing with an acoustically induced instability resulting from the interaction between the wake behind a cylinder and the first transverse acoustic mode in a pipe.

Thus far, we have considered only a circular pipe containing a cylinder transverse

to the axis of the pipe. As the flow speed in the duct is increased to a value where the Karman vortex shedding frequency is coincident with the first transverse mode, strong coupling between the wake and the sound field occurs, thereby resulting in self-sustained screech at a frequency equal to the cutoff frequency of the mode. This effect, which has been observed earlier in a rectangular tube,^{1,2} is poorly understood. The purpose of our studies is to determine the conditions under which screech is observed and to investigate the aeroacoustic coupling mechanism quantitatively.

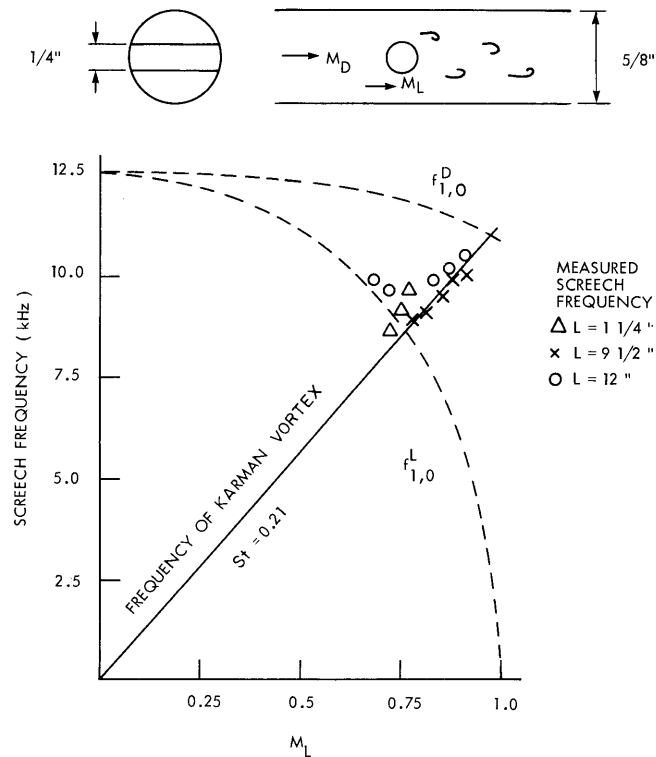


Fig. XI-2. Acoustic coupling between the wake behind a cylinder in a duct and the first transverse acoustic mode of the duct.

In Fig. XI-2 we have plotted the first cutoff frequency as a function of Mach number. We have presented two curves, one referring to the average Mach number in the duct and the other to the "local" Mach number in the vicinity of the cylinder. Also shown is the velocity dependence of the Karman vortex frequency, based on a Strouhal number of 0.21. The observed screech frequencies are found to be close to the intersection between the curves, that is, when the Karman vortex frequency coincides with the acoustic cutoff frequency. Actually, the observed data points lie somewhere between the cutoff frequency based on the local Mach number and the duct Mach number. Similar results have been obtained also for a cylinder 1/2 inch in diameter in a 1-inch pipe.

(XI. PHYSICAL ACOUSTICS)

The pure tone that is produced is very intense. We have measured levels as high as 115 dB outside the pipe, which is ~30 dB larger than the overall flow noise. Included in our continued studies of this effect is a theoretical analysis of the problem, as well as further experiments not only with rigid but also with acoustically "soft" cylinders.

References

1. K. U. Ingard and W. M. Manheimer, "Sound Emission from Karman Vortices," Quarterly Progress Report No. 70, Research Laboratory of Electronics, M.I.T., July 15, 1963, pp. 74-75.
2. Flow Induced Vibrations in Heat Exchangers (American Society of Mechanical Engineers, December 1970), p. 46.