XVII. PHYSICAL ACOUSTICS*

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RESEARCH OBJECTIVES

In general terms, our research objectives concern the physical problems involved in the generation, propagation, and absorption of sound and vibrations in matter. Specifically, our program of study includes:

1. Acoustics of moving media.
2. Acoustical studies of molecular structure of liquids.
3. Generation of very high frequency sound waves ("hypersonics").
4. Nonlinear acoustics.

U. Ingard

A. PROPERTIES OF A MOVING ACOUSTIC RESONATOR

The acoustic properties of a resonator cavity at rest are determined by the resonator geometry and by internal viscous and heat-conduction losses. However, when the

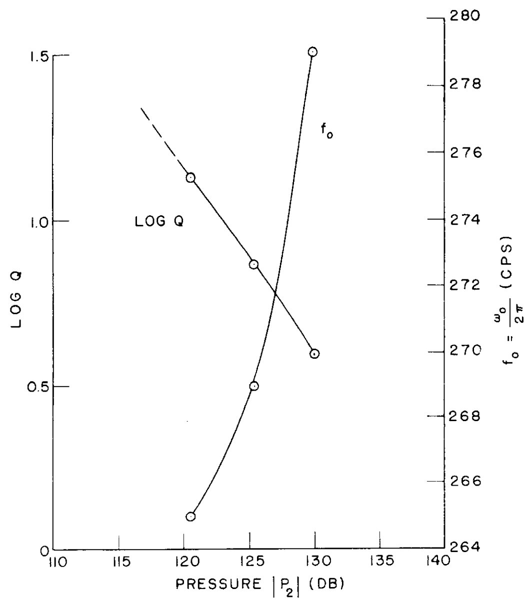

Fig. XVII-1. Cavity Q and resonant frequency as functions of sound pressure in cavity.

resonator is set in motion the turbulence produced about the cavity is expected to influence the acoustic behavior of the resonator. In this report we present some preliminary

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Table XVII-1.

Speed (cm/sec)	Sound Pressure in Cavity (db) $\theta = 0°$	$\theta = 90°$
490	—	126
980	130	117
1960	129	108
2930	132	102

data on an investigation of this problem.

The resonators used in these experiments were hollow copper spheres, 4 inches in diameter, with a 0.5-inch hole drilled in each one. They were set in motion at speeds as high as 2900 cm/sec – a Mach number of approximately 0.09. The sound level in the resonator was measured as a function of frequency for various speeds and various orientations of the mouth with respect to the direction of motion. The resonator was also excited by a loud-speaker placed in the vicinity. Details of the experimental arrangement were published previously (1).

For a cavity at rest, the Q and the resonant frequency, f_o, are plotted as functions of the sound pressure level in the cavity, $|P_2|$, in Fig. XVII-1. When the cavity is in motion, the cavity radius, which is drawn to the center of the mouth, intersects the velocity vector at an angle θ. When $\theta = 0°$, for instance, the mouth is in the forward position. We find that for $\theta = 0°$ or $\theta = 180°$, motion of the cavity does not change the value of Q. However, when $\theta = 90°$, motion changes the value of Q drastically. In Table XVII-1 the sound pressure in the cavity at resonance is tabulated for several speeds at $\theta = 0°$ and $\theta = 90°$. The cavity is driven by a wave of constant amplitude. When $\theta = 0°$, the pressure in the cavity is nearly independent of speed; but when $\theta = 90°$,

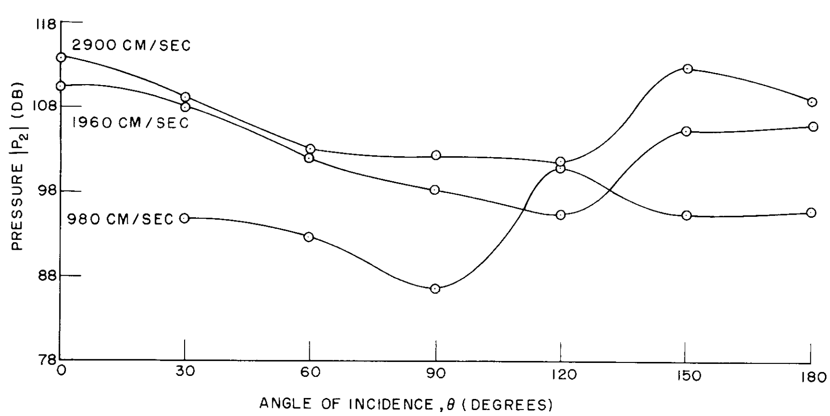

Fig. XVII-2. Noise in cavity at 100 cps for three cavity speeds.

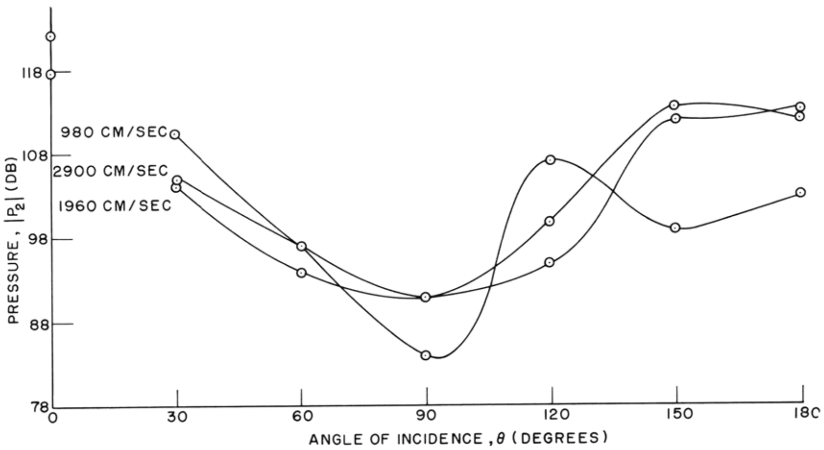

Fig. XVII-3. Noise in cavity at resonance ($f_o \approx 274$ cps) for three cavity speeds.

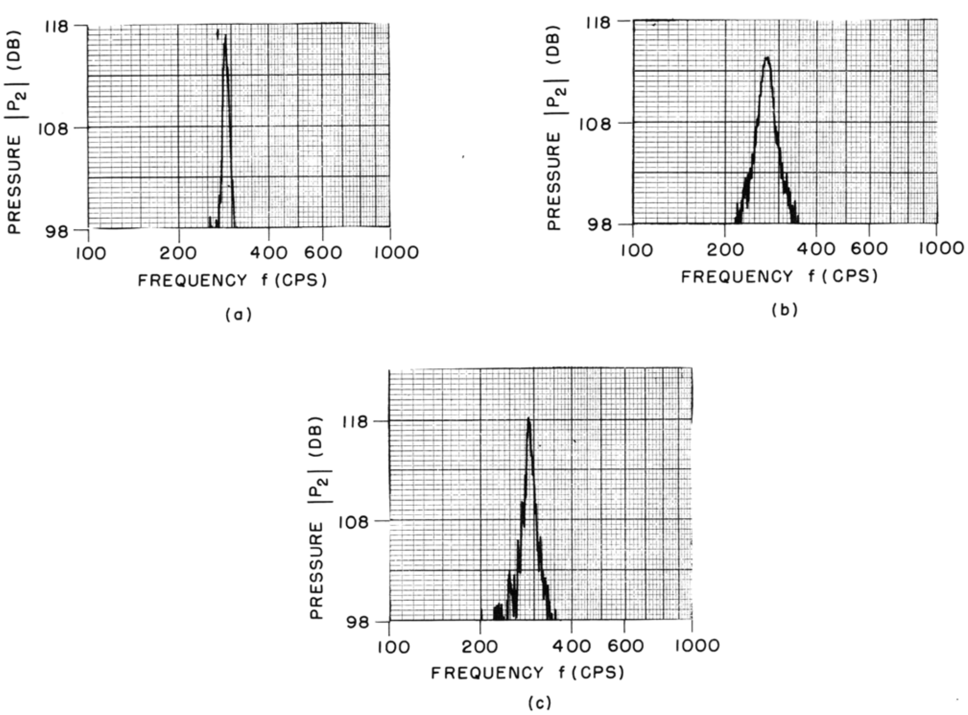

Fig. XVII-4. (a) Self-resonance in moving cavity. Speed is 590 cm/sec; θ = 60°. (b) Response of cavity at rest to incident wave pressure of 98 db. (c) Response of cavity with incident wave pressure of 98 db. Speed is 590 cm/sec; θ = 60°.

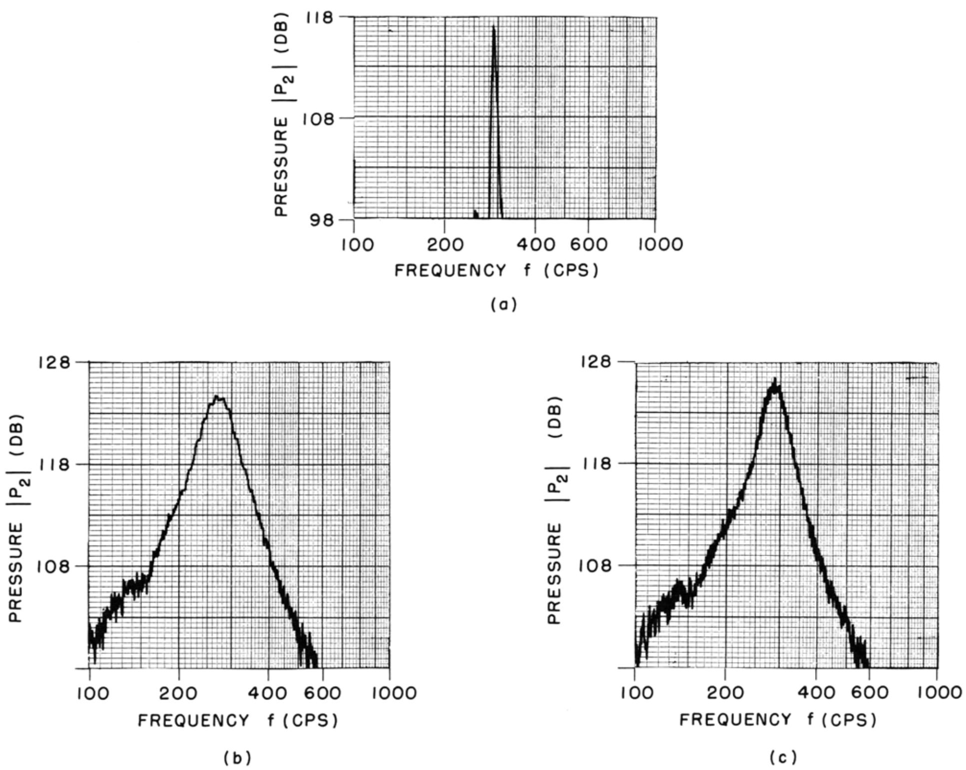

Fig. XVII-5. (a) Self-resonance in moving cavity. Speed is 590 cm/sec; θ = 60°.
(b) Response of cavity at rest to incident wave pressure of 118 db.
(c) Response of cavity with incident wave pressure of 118 db. Speed is 590 cm/sec; θ = 60°.

the pressure changes considerably. This indicates that the air moving past the cavity in the latter case either raises the radiation resistance, so that more energy is radiated, or increases the dissipation of sound energy, or both.

The noise in the cavity was measured in the absence of an external sound wave. Curves for these measurements are plotted in Figs. XVII-2 and XVII-3. This noise is the response of the cavity to driving forces arising from the motion of air past the cavity mouth. Again, at θ = 90° the response of the cavity is much lower than at θ = 0° or 180°; this difference indicates an increased radiation and/or dissipation of sound energy at this angle.

One of the most interesting features of a moving cavity is its ability to self-oscillate. When the angle of wind incidence on the mouth, θ, is between approximately 15° and 75° (the range varies from cavity to cavity) and the Strouhal frequency, $f \approx U/2d$, is equal to the resonant frequency of the cavity, the cavity may self-oscillate. Despite the violence of oscillation that may occur, the mechanism that converts the steady force of the air flow into the pulsating force driving the cavity has been found to be very sensitive to damping (2). For instance, if the Q of the cavity is reduced to approximately 10 it is difficult to excite these self-oscillations. Figures XVII-4 and XVII-5 show the effects of an external sound wave on such a self-oscillation. In Fig. XVII-4 the external sound wave is weaker than the self-oscillation; in Fig. XVII-5, it is stronger, in terms of the response recorded in the cavity. The weak sound wave has augmented the self-oscillation; compare the slightly higher and broader peak in Fig. XVII-4c with the peak of Fig. XVII-4a. However, the strong sound wave has almost entirely swamped the self-resonance mechanism, as indicated by the similarity of curves of Fig. XVII-5b and 5c.

Although it is difficult to draw definite conclusions about the mechanism of self-oscillation from these measurements, they provide additional evidence about the sensitivity of the mechanism. Moreover, they indicate that the damping mechanism that prevents self-oscillations from growing indefinitely might be the same as the damping mechanism that causes the Q to change for large amplitude responses. This mechanism is the generation of turbulence in the cavity mouth by the presence of large sound fields. For instance, the peak in Fig. XVII-4a is at 117 db. In Fig. XVII-1, this corresponds to a cavity Q of approximately 20. However, in Fig. XVII-5a the peak is at 126 db, which corresponds to a Q of approximately 4, and the self-oscillation effect has almost entirely vanished.

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References

1. U. Ingard, A. B. Lehman, and L. W. Dean, Sound Reception by a Moving Cavity, Final Report on Contract Nonr-1841(03), Part II, Research Laboratory of Electronics, M.I.T., June 30, 1960.

2. L. W. Dean III, Excitation of Acoustic Resonators by Wind, S.M. Thesis, Department of Electrical Engineering, M.I.T., May 20, 1957.

B. SCATTERING OF SOUND BY SOUND

It is possible that the failure of investigators to measure scattering of sound by sound for two beams intersecting at right angles may be caused by their use of beams of circular cross section. The intersection of two such beams looks something like a partly inflated football. The scattered wave must fit onto this shape, and therefore will not be a plane wave. However, if one uses beams of square cross section, the intersection will be a cube, and the scattered waves will be plane waves. Apparatus is now being completed to test this possibility.

L. W. Dean III

C. GENERATION OF SOUND BY PARALLEL JETS

Measurements have been made to determine the total power output and the power spectrum of a system of parallel jets. Ingard (1) has derived equations for the power spectra of a system of jets, based on Lighthill's equations and empirical data for jets whose orifice Mach number is 0.3 or greater. These equations predict that the total power output is proportional to the eighth power of the Mach number, while the power at peak frequency is proportional to the seventh power of the Mach number.

Data obtained thus far indicate that these equations are not valid for jets with an orifice Mach number less than 0.2. It appears that for $M < 0.2$ the total power is proportional to the first power of the Mach number. Measurements are being carried out to determine whether this deviation is due to interactions between the jets or to some other mechanism.

E. J. Martens, Jr.

References

1. U. Ingard, J. Acoust. Soc. Am. 31, 1202 (1959).