VI. PHYSICAL ACOUSTICS*

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A. INTERACTION BETWEEN CONCENTRIC CYLINDRICAL SOUND WAVES

Because of nonlinear terms in the equations of motion and the equation of state of a fluid, it is to be expected that two sinusoidal sound waves, with frequencies f_1 and f_2, will interact in the fluid to produce waves with other frequencies. Unless linearity is grossly violated the major result of this interaction will be the generation of waves having the sum and difference frequencies $f_1 \pm f_2$.

Two sound waves that are geometrically identical interact much more strongly than two that are not. For example, two plane waves traveling in the same direction interact strongly, whereas plane waves traveling in different directions do not. The former case has been investigated theoretically[1] and has been verified experimentally.[2] The

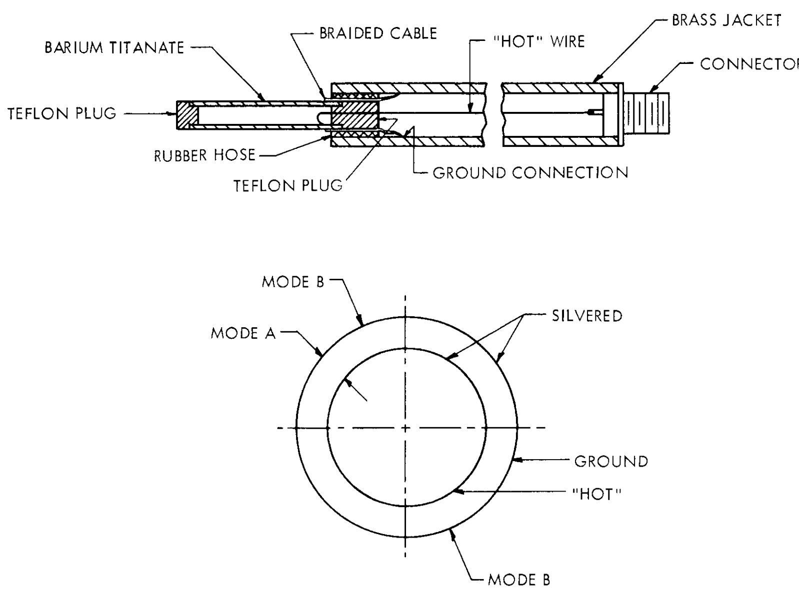

Fig. VI-1. The sound-producing apparatus (not to scale).

latter case is difficult both mathematically[3,4] and experimentally,[5,6] but the interaction is relatively weak.

The interaction between two concentric, cylindrical sound waves has been solved[6]

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and the solution indicates that the amplitudes of the waves generated by the interaction should not depend strongly on distance from the axis of the cylinder. When the receiver is in the far field, the amplitudes should be independent of distance from the axis.

The device for producing two concentric, cylindrical waves is shown in Fig. VI-1. The barium titanate cylinder is 6 cm long, 1 cm in outside diameter, and 2 mm in wall thickness. There are two resonant radial modes of oscillation. The thickness mode A

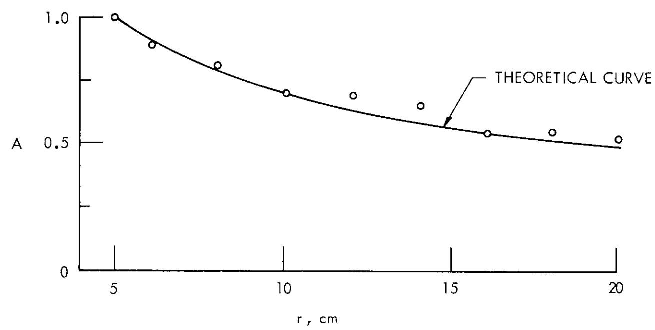

Fig. VI-2. Radial distribution of 987-kc primary wave.

has a resonant frequency of 987 kc and the radial mode B has a resonant frequency of 99 kc. The cylinder was driven at these two frequencies to generate the two primary sound waves. The angular distribution of sound in arbitrary units is shown in Tables VI-1 and VI-2. Plots of sound pressure as a function of radial distance are given in Figs. VI-2 and VI-3. The theoretical curve is the familiar $r^{-1/2}$ law.

Measurements were made on the difference-frequency wave generated in the volume

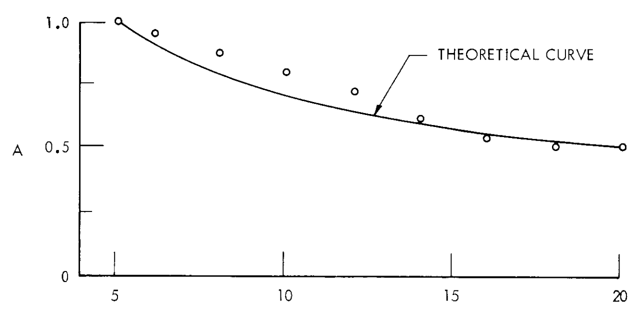

Fig. VI-3. Radial distribution of 99-kc primary wave.

surrounding the cylinder. The angular and radial pressure functions are shown in Table VI-3 and Fig. VI-4, respectively. The frequency is, of course, the difference

Table VI-1. Angular distribution of 987-kc primary wave.

Angle (degrees)	Pressure Amplitude (arbitrary units)
0	53
45	53
90	53
135	52
180	52
225	53
270	53
315	53

Table VI-2. Angular distribution of 99-kc primary wave.

Angle (degrees)	Pressure Amplitude (arbitrary units)
0	56
45	56
90	58
135	57
180	56
225	57
270	58
315	57

Table VI-3. Angular distribution of 888-kc wave.

Angle (degrees)	Pressure Amplitude (arbitrary units)
0	12
45	13
90	12
135	11
180	12
225	12
270	12
315	11

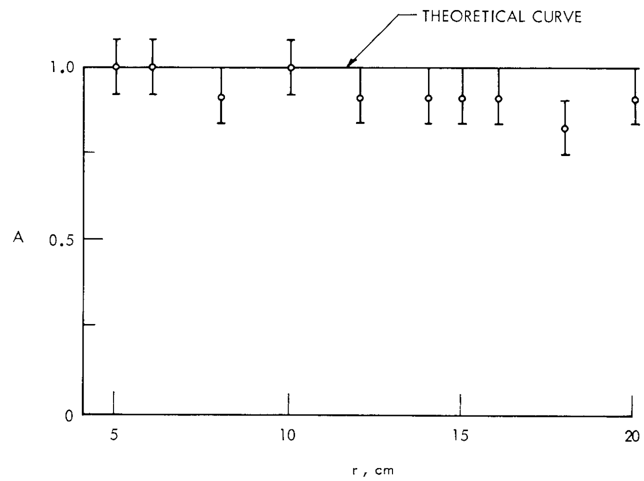

Fig. VI-4. Radial distribution of 888-kc wave.

between the primary frequencies, 888 kc. The theoretical curve represents the predicted independence on radius.

As the receiving transducer has not yet been calibrated, no attempt will be made to compare amplitudes. The independence of the difference-frequency wave on angle (which could be expected a priori) and radius, however, seem to be confirmed. The slight tendency of the difference-frequency signal to decrease in amplitude as the radius increases may be due to a radiation pressure component in the received signal. The radiation pressure is related to the energy density and should be inversely proportional to the radius.

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References

1. G. B. Airy, Sound and Atmospheric Vibrations (Macmillan, London, 1868), p. 47.

2. A. L. Thuras, R. T. Jenkins, and H. T. O'Neil, Extraneous frequencies generated in air carrying intense sound waves, J. Acoust. Soc. Am. 6, 173 (1935).

3. P. J. Westervelt, Scattering of sound by sound, J. Acoust. Soc. Am. 29, 934 (1957).

4. V. Lauvstad and S. Tjøtta, Problem of sound scattered by sound, J. Acoust. Soc. Am. 34, 1045 (1962).

5. U. Ingard and D. C. Pridmore-Brown, Scattering of sound by sound, J. Acoust. Soc. Am. 28, 367 (1956).

6. L. W. Dean, Interactions between sound waves, J. Acoust. Soc. Am. 34, 1039 (1962).

B. SHOCK WAVE TRANSMISSION AND ATTENUATION

A tube has been constructed and instrumented that allows us to study some features of the propagation of large amplitude waves. The tube consists of two parts separated

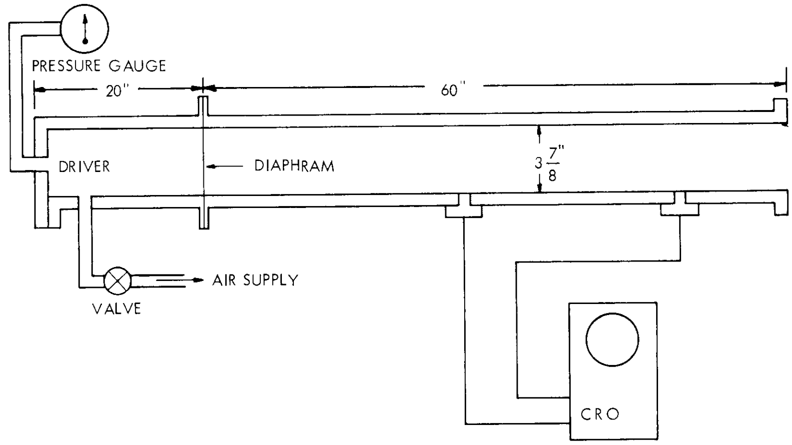

Fig. VI-5. Schematic diagram of the shock tube.

by a Mylar diaphragm. The driver section is pressurized until the membrane bursts, and the resulting flow quickly forms a shock wave that propagates down the remainder of the tube. The amplitude of the shock wave depends on the thickness of the diaphragm. The shock tube is shown schematically in Fig. VI-5.

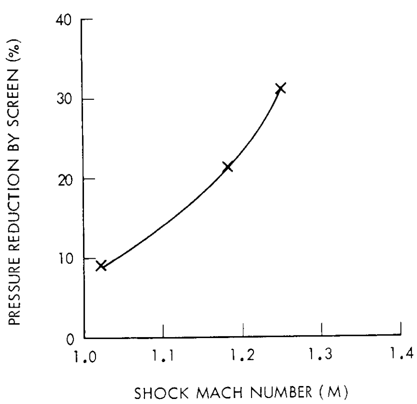

Fig. VI-6. Pressure distribution by a wire screen as a function of incident shock Mach number.

Columbia model 100-P pressure transducers are mounted either in the tube side-walls or in a rigid termination, and are connected directly to an oscilloscope. The transient pulses can then be photographed.

Some preliminary experimental data have been obtained:

1. Reflection from an open-end and closed-end tube.

The waveform of the pulse reflected from an open- and closed-end tube has been photographed for several shock Mach numbers. These will be compared with a theoretical analysis of the reflection of a pulse inside a tube.

2. Transmission through a thin screen.

Linear acoustic theory can be used to show that the pressure reduction $[p_i-p_t]/p_t$ is independent of the incident wave amplitude (where p_i is the amplitude of the incident wave and p_t is the amplitude of the transmitted wave). A thin screen was inserted in the shock tube in order to test this result for shock waves.

The dependence of the pressure reduction on incident shock Mach number is shown in Fig. VI-6. (The Mach number and shock pressure ratio are related by the Rankine-Hugoniot shock relations.) It can be seen that the pressure reduction caused by the screen is higher than that predicted on the basis of acoustic theory ($M \doteq 1$).

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