EFFECT OF CONICAL HORNS ON THE INTENSITY OF SOUND EMITTED BY AN ORGAN PIPE

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ABSTRACT

Effect of conical horn on the intensity of sound emitted by an open organ pipe.—In a room lined with hair felt one inch thick to reduce resonance effects, readings taken with a Webster phonometer showed that while the horn (50 cm long, 6° flare) doubled the intensity, it acted merely as a resonator and did not concentrate the energy in front to any measurable extent. Outdoor experiments gave the same result except that the intensity was increased by only one half.

Webster phonometer with a disk supported by wires under tension, is a convenient portable instrument, as sensitive as the ear to the pitch to which it is tuned, but it shows a very sharp resonance to the natural frequency of the disk and this selectivity limits its usefulness.

Rayleigh disk phonometer is described. It may be used to measure the absolute energy density of sound.

THE commonly accepted explanation of conical megaphones is that sound waves are reflected by the walls of the tube and thus sent out in some definite direction. Similarly, conical mouth pieces of telephones are supposed to concentrate the waves upon the diaphragm. However, photographs taken by Dr Foley, of sound waves entering conical tubes show that the waves are reflected so as to be sent back out of the horn at the end where they entered. This indicates that the so-called "condensing power" of horns having a large angle of flare may be partly imaginary.

It was thought desirable, therfore, to investigate the effect of a conical horn on the sound emitted by an organ pipe, both as to the intensification of the sound and as to the directing action.

The source of sound was an ordinary organ pipe 52.6 cm long, blown at constant pressure. The receiving apparatus was a Webster phonometer, except for some experiments for which a Rayleigh disk phonometer was used.

The Webster phonometer[1] has a mica disk supported by means of three symmetrically placed wires in a vertical plane. Attached to the center of this disk is a brass pin ground to a point, which presses against a flexible steel strip which carries a minute concave mirror and is supported

[1] Webster, Boltzmen Memorial Volume 1904; King, Phil. Trans. **218** (1919)

in a vertical position by means of a separate frame. The circular metal frame supporting the mica disk forms one end of the ordinary cylindrical resonator, whose length may be varied by drawing out the inner telescoping tube. The image of a lamp filament is focused by the concave mirror on the scale of the eye-piece by which readings are taken. When a train of sound waves of suitable frequency falls upon the resonator the motion of the mica disk is transmitted to the mirror and the filament image, otherwise sharp, widens out into a broad band of light whose width may be read from the scale. It may be of interest to note that when an ordinary small siren was used as a source, the broadened band showed a number of flutings, doubtless due to overtones.

The phonometer showed sharp resonance to the natural frequency of the disk, regardless of the position of the resonator. For instance when a Stearn's variometer was sounded continuously nearby and the pitch gradually changed, readings such as the following were obtained:

Pitch:	160	202	210	221	225	226	227	300
Reading:	0.1	2.5	4.0	10	>10	10	6.0	0.1

By changing the tension in the wires supporting the mica disk, the pitch to which the phonometer reponds most vigorously could be varied from about 150 to 320. As might be expected, change in temperature alters the tension and therefore the pitch to which the phonometer is most sensitive.

Effect of the conical horn. For the indoor readings, an attempt was made to minimize reflection and the resulting interference effects by covering the floor, walls and ceiling of a room 12 by 18 feet with hair felt one inch thick.

The organ pipe was clamped in a horizontal position in the center of the room and phonometer readings were taken at points A, B, C, and D, 45° apart on the circumference of a circle drawn with the mouth of the organ pipe as center. Sets of readings were taken at various distances from the source and with various air pressures. One set is given in Table I. A is directly in front of the horn, C directly behind it. The results show that the amplification ratio for this particular horn is about 2, and that this ratio is practically the same behind the horn as in front of it.

TABLE I

Effect of a conical horn; indoor results

Position	With horn	Without horn	Ratio
A (front)	4.0	2.1	1.9
B	4.1	2.0	2.0
C (back)	4.0	2.0	2.0
D	5.2	2.1	2.5

It appears, therefore, that for continuous sounds of this type the horn does not concentrate the sound energy in front of the horn by reflecting the waves from the conical walls, but acts as a resonator to the source, increasing the amplitude of the wave and hence the loudness of the sound in all parts of the room.

By means of a rubber hose, air was conducted to a point on the campus 200 feet from any building and the experiments with the horn repeated. The readings were more nearly uniform on the athletic field away from trees and buildings but owing to a lack of air pressure there, the readings were inconveniently small. An increase in loudness and a change in the quality of the note could be detected by the ear when the horn was inserted but readings taken directly in front of the horn were only slightly greater than those taken at the same distance but at one side or behind the horn. Table II is a sample of many sets of readings.

TABLE II

Effect of a conical horn; outdoor results

Distance	Front	Side	No horn	Distance	Front	Side	No horn
5 ft	7.2	7.0	5.1	150 ft	.4	.3	.3
10	4.5	4.5	3.0	200	.4	.4	.2
30	1.8	2.0	1.0	300	.3	.3	.0
60	1.2	1.1	.6	400	.2	.1	.0
100	.6	.6	.3	500	.1	.1	.0

The effect again seems to be one of resonance rather than concentration of energy in front of the horn. In the same way that the box on the violin and the sounding board on the piano enable those instruments to emit stronger waves than would be sent out by the strings alone, so here the horn increases the amplitude of the wave produced by the pipe.

Distribution in intensity around an organ pipe source. For these experiments a *Rayleigh disk phonometer* was used. This instrument had a Rayleigh disk, a silvered cover glass 15 mm in diameter, suspended in the throat of a compound resonator made of two cylindrical metal chambers, 12.5 and 3.2 cm long respectively, and each 4.8 cm in diameter, connected by a tube 8 cm long and 2.8 cm in diameter (see Fig. 1). The opening at the outer end of the large chamber could be varied by means of an iris diaphragm which was surrounded by a flange extending 20 cm beyond the tube.

When the disk is set at 45°, its most sensitive position, the deflection φ, if small, is directly proportional to the energy per unit volume of the vibrating medium of the resonator.

$$\varphi = C(\tfrac{1}{2}\rho v^2) \qquad (1)$$

The absolute value of the energy may be computed if C is known. C was determined by measuring the period of the disk and fiber with and without a short cylinder whose moment of inertia was known. Then to pass from the energy density in the resonator to that outside we use the Helmholtz factor $2R^3/\pi^2S$.

To eliminate reflection and interference effects, measurements were made outdoors. A level tract of land covered with grass was selected, with neither buildings nor trees near. It was found impossible to obtain trustworthy readings when a strong wind was blowing, but on the calmest days the zero reading of the spot of light on the scale was fairly constant and readings could be repeated within about 5 per cent. The whole apparatus was protected from the wind by means of a light frame covered with cheese cloth, and four thicknesses of the same material

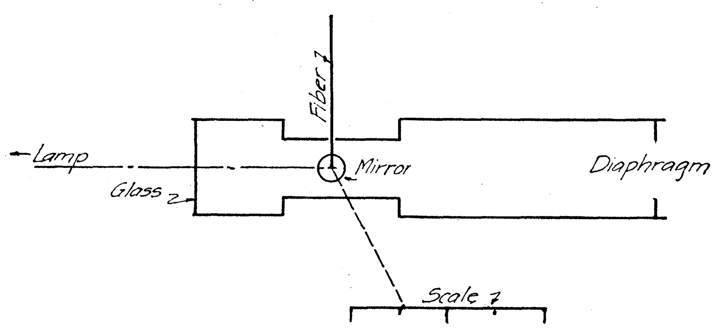

Fig. 1. Rayleigh Disk Apparatus

were loosely placed over the mouth of the resonator and held in position by means of rubber bands. These layers of cheese cloth did not appreciably diminish the response of the resonator.

With a radius of ten feet, a circle was drawn with the resonator as center. The circumference was divided into arcs of 45° each, the points of division being lettered A, B, C, D, E, F, G and H, beginning directly in front of the resonator. Readings were taken when the pipe was blown at A, B, C, and so on in succession around the circle. The radius of the circle was then increased to 20, 30, 40 and 50 feet in succession. This was done several times and the average readings are recorded in Table III.

Variation of intensity of sound with distance over flat ground. Tables II and III show that the intensity does not decrease as fast as the inverse square but more nearly as the inverse first power of the distance. The exact law depends, of course, in the reflecting power of the ground and on the elevation of the source and receiver.

Absolute efficiency of an organ pipe. By evaluating the constant C in Eq. (1) and measuring the volume and pressure of the air used to blow the organ pipe, the efficiency of this source at a distance of 40 feet was calculated isothermally and found to be only .005 per cent. Of course the energy in the upper partials was not measured.

Interference effects in a closed room. In a room 12 by 16 feet with a 12 foot ceiling, the resonator was placed in a fixed position and the organ pipe moved around it. Positions were found in which the pipe produced almost no effect upon the resonator, due to interference. Similar results were obtained in a larger room with the Webster phonometer, only in this case the phonometer was carried around. As many

TABLE III

Distribution of intensity around an organ pipe

Radius in feet	Scale deflection in cm								
	A	B	C	D	E	F	G	H	Mean
10	28	28	26	25	25	26	25	28	26.4
20	12.5	12	12	10	10	10	11	12	11.2
30	7.5	7	6	6	6	6	6	7	6.4
40	4	4	3	3	3	3	4	4	3.5
50	2	2	1	1	1	1	1	1	1.2

as thirty minima or regions of silence were located and marked on the floor of the room. They showed considerable regularity, resembling the interference patterns seen on the surface of a liquid produced by reflection from the walls of the vessel. The average distance between these points of silence was about 80 cm, just half the length of the wave produced at that temperature. These points of minima and maxima could be distinguished with the unaided ear. A long step ladder was placed in the room by which the phonometer could be carried step by step from floor to ceiling, and minima and maxima were again located, showing the presence of three-dimensional nodes and loops in satisfactory agreement with Sabine.[2]

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[2] Sabine, Collected Papers on Acoustics, pp. 166 and 233