CHURCH ACOUSTICS.*

An examination of several church auditoriums was made recently with a view to determine whether any general principles could be discovered, appertaining to the acoustic qualities of a hall for public speaking, and also any special acoustic features that might reveal themselves in the particular rooms examined.

It was assumed that for a hall of good acoustic qualities:

(*a*) A low sound from the speaker should be audible in every part of the room.

(*b*) A sound from any part of the room should not be readily heard at the speaker's desk.

(*c*) The sound that is readily re-enforced by the resonance of the room should be as nearly as possible the pitch of the speaker's voice when used without effort.

(*d*) There should not be such effect of resonance or of echoes as to render rapid speaking indistinct or confused.

Five churches in Brooklyn were examined, and in each case the tests were made with reference to the four points named.

These tests were necessarily made when the rooms were unoccupied, and in consequence they did not perfectly represent the conditions met with when occupied by an audience, but some additional observations were made during church services in regard to the third and fourth points. As all the rooms were examined under similar conditions, the results justified a comparison of the five among themselves. Probably the greatest acoustic difference between a well filled auditorium and an empty one is in the echoes and the related effects of resonance.

To make the test of the effort required to produce a sound at one point which should be of a definite intensity at another point, the lowest sound that could be perceived plainly by a listener was the standard to be reached.

To a small trumpet, a reed instrument, of the key of F, which was near the note in each case to which the rooms resounded readily, was affixed a siphon manometer, which indicated the pressure of the air producing the sound of the instrument. It was shown by theory that the intensity of the sound at the instrument would be proportional to the pressure thus indicated, and preliminary experiments were made with the apparatus, which proved the practice to be fairly in accord with the theory. The force required, then, to make a sound just audible at various points, with the trumpet at a given station, was read off by the experimenter, from the scale of the gauge, in millimeters of the difference of level of water in the two arms of the U shaped gauge. The pressure requisite to make an audible sound with the listener close by the instrument was in each case first observed, and then the excess of pressure over this for other points was recorded.

The trumpet was then gently sounded at the pulpit, the pressure of the air being increased until the sound could be heard by the listener, in successive positions throughout the room. The location and distances of the points were recorded, as also the corresponding pressures requisite for each. These gave the data for the first point to be considered.

The listener, taking his place at the pulpit, while the trumpet was sounded at various places in the room, gave the data in the same manner for the second point.

A few trials with the voice determined the tone to which the room resounded forcibly, and the pitch as determined by a tuning fork was noted for comparison, later, with the tone of the preachers in conducting services.

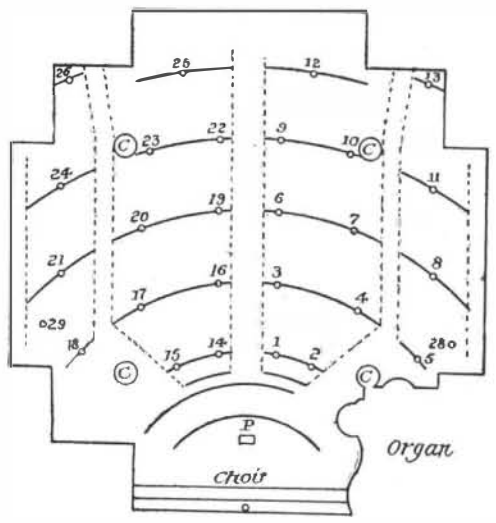
For the fourth point, the listener was stationed successively at various places, and the speaker at the pulpit read unfamiliar passages, in the resonance key as already determined, with various degrees of rapidity, and noted the rate of reading at which confusion was experienced by the listener.

The five auditoriums ranged in extreme dimensions from about 50 feet by 70 feet to 95 feet by 102 feet, and in seating capacity from 800 to 2,200, and were diverse in architectural style. Under the examination each readily displayed its own acoustic peculiarities.

The accompanying diagram and tables of the room No. 3 will serve as an example. In addition to the floor plan, it is necessary to understand the form of the ceiling in order to interpret the results. CCCC are columns four feet in diameter, from which, at a height of about twelve feet, rise circular arches, forming a transverse arch across the front and rear portions of the auditorium and a corresponding one along each side, with smaller arches at the corners. Above the central part of the room rise from the columns the four corners of a square dome or lantern, with a flat top at a considerable height above the crowns of the four arches. In the center hangs a large chandelier. It is the fourth column in each of the tables that is significant, as it shows the additional pressure upon the reed of the trumpet requisite to make a sound audible at various points in the room, as compared with that close at hand. It shows whatever of irregularity exists in any one hall, as well as the actual pressure required in the different cases. In No. 3 the pressure is seen to be irregular, ranging from 0 to 6 mm. of water, with an average value of 3·7 mm. It is not, however, so important that these numbers should be small as that they should be uniform.

In No. 1 they ranged from	0	to	1,	with an average of	0·2 mm.
In No. 2 " "	0	to	2,	" " "	1·1 "
In No. 3 " "	0	to	6,	" " "	3·7 "
In No. 4 " "	0	to	4,	" " "	2·5 "
In No. 5 " "	0	to	4,	" " "	2·2 "

Rererring again to the first table of No. 3, the effect at 7, 8, and 21 is in striking contrast to that at 6, 19, and



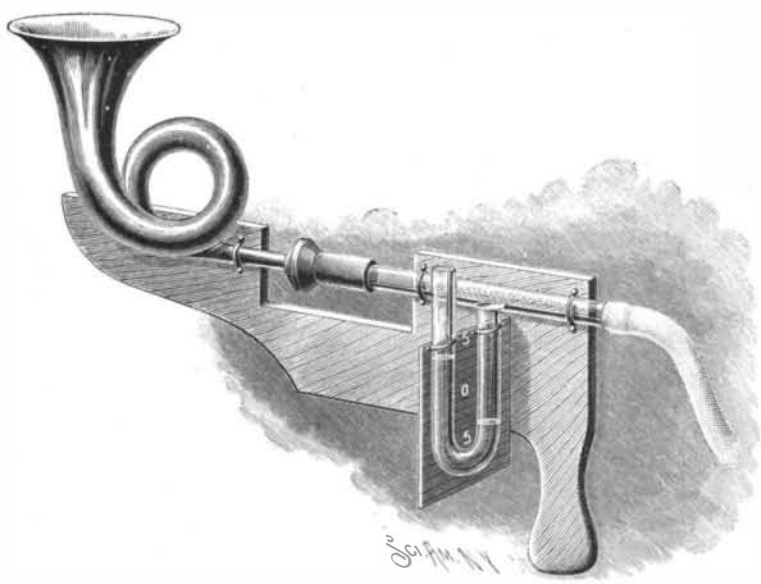
ROOM No. 3.

20, as shown by column 4. Positions 8 and 21 are under the arches whose axis is transverse to the church, and slightly forward of the axis; 19 and 6 are at the same distance from the pulpit, but are under the lantern.

Looking at the table of the "reverse series," it is seen that in most of the positions a less force is needed to produce a sound that would be audible at the pulpit than in the direct order. This peculiarity showed itself in every one of the rooms, and in a marked degree.

In No. 2, however, when the trumpet was sounded at the organ, which was to the rear and above the preacher, no increase of pressure could be detected, to be heard at the center of the room and at the farthest position, a distance of seventy-five feet.

The most difficult feature to deal with, in the acoustics of an auditorium, is the so-called echo. It is questionable whether all cases of such effects are genuine echoes. Still, the effect, if detrimental to distinctness, is objectionable by whatever name it may be known.



HERING'S PHONOMETER.

An echo is the repetition of a sound by reflection, to a hearer, after an interval of time long enough to permit him to distinguish the second sound from the first. The usual limit of time allowed for thus distinguishing two articulate expressions is one tenth of a second, and in this length of time a sound will travel 110 to 115 feet. Unless, therefore, the reflected sound has traveled 110 feet further than the direct sound, it will cause no confusion to the hearer. Whether it will prove objectionable depends also upon its intensity, when it does reach him. The intensity decreases with increase of distance, and also with the number of reflections the sound has undergone. But, if the rate of speaking is less than ten syllables to a second, which may be taken as a maximum, then the difference of distances for a direct and a reflected sound must be more than 110 feet, for interference. In a forward and back line of transmission, the hall would have to be 55 feet long to produce an echo, and if the rate of speaking were so deliberate as to permit one-fifth of a second interval between articulate sounds, no interference by reason of an echo from the front or back would occur, unless the hall were at least 110 feet long. In the five instances here presented, the lengths ranged from 70 feet to 102 feet, and in each it was possible to produce confusion by an echo, but the echo was subject to modifying influences that in several instances could be clearly recognized. A hearer may be so placed that the direct sound is greatly obstructed while the reflected has a clear pathway, and so may be the stronger. This was especially noticeable in room No. 3, at the positions numbered 28 and 29.

The key to which a hall readily resounds, by reason of its size and proportions, is the pitch at which the sound of least intensity can be heard throughout the room. It is also just the tone in which the echo is likely to be annoying. Hence it is in this tone that the orator has least propriety in speaking loudly. Thus in the room No. 4, which was nearly square, and with a flat ceiling broken in surface by girders running both longitudinally and transversely, the echo became perceptible only with words nearly in the keynote of the church. It was noticeable that in each auditorium, with a congregation present, the prevailing note of the speaker's voice was from a half to a whole tone lower than the resonance key of the room when empty.

In room No. 4, the galleries extending along each side and across the end, with their columns and rising tiers of occupants, together with the organ behind the speaker, destroy the forms of the sound waves, both incident and reflected, and defeat the echo. In No. 5, the organ, with its corrugated front, and gallery at the entrance, and the forest of columns about the pulpit at the end of the hall accomplish the same for the medial portion, and the pendent lamps probably assist laterally. A placing of the organ in Nos. 1 and 2 as in No. 4 is doubtless beneficial. In No. 3 there is nothing but one chandelier to do good, while the speaker has an elastic glass partition behind him to heighten instead of defeat the second reflection.

Plainly, little generalization is possible from so few instances. So far as they do show anything in common, we might say that a position near a wall is likely to be a better place for hearing than the center of the room; that in all the instances here presented, the place occupied by the preacher was superior for hearing sounds throughout the room to nearly every place in the room for listening to sounds from the pulpit. Also, that any arrangement of ceiling or wall that tends to focus the sounds by reflection excites thereby inequalities in the acoustic merits of the auditorium. Such are especially spherical domes, and arched ceilings *across* the room. This was exemplified in No. 2, No. 3 and No. 5.

TRUMPET AT P.

Distance.	Listener.	Press.	Difference.
0	At hand.	10 mm.	0
15′	1	14	4
15′	2	12	2
15′	14	14	4
15′	15	13	3
30′	3	14	4
30′	4	13	3
30′	5	13	3
30′	16	13	3
30′	17	14	4
30′	18	16	6
45′	6	14	4
45′	7	12	2
45′	8	13	3
45′	19	16	6
45′	20	15	5
45′	21	13	3
60′	9	14	4
60′	10	14	4
60′	11	14	4
60′	22	15	5
60′	23	14·5	4·5
60′	24	14	4
75′	12	13	3
75′	13	13	3
75′	25	14	4
75′	26	14	4
13′	27	12	2

TESTS ON ROOM NO. 3.

REVERSE SERIES, LISTENER AT P.

Distance.	Trumpet.	Press.	Difference.
0	At hand.	10 mm.	0
30′	3-16	14	4
30′	5	12	2
30′	18	12	2
45′	6-19	13	3
45′	7-8	13	3
45′	21	13	3
60′	9-22	13	3
60′	11	14	4
60′	24	12	2
75′	12-25	13	3
75′	13	13	3
75′	26	12	2
13′	27	11	1

*Abstract of a paper read before the Department of Physics in the Brooklyn Institute, January 29, 1891. By Prof. D. W. Hering.