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Polycylindrical Diffusers in Room Acoustic Design*

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INTRODUCTION

EXPERIENCE in rooms with wood-paneling and sound-diffusing surfaces indicates that the manner in which the reverberant and other aftersounds in a room are distributed has possibly as much to do with the acoustical excellence of a room as the actual time of decay in the room, and from time to time we have heard discussions on the diffusion of sound in rooms not only in regard to fulfilling the assumptions in the Sabine reverberation formula, but in regard to its subjective effect.

Before presenting data on the convexed wood panels or diffusers described in this paper, let us briefly discuss some general observations on the action of sound in rooms and halls known for their acoustic excellence, a fuller discussion of which may be found in the literature.[1] In many of these rooms, as, for example, the Philadelphia Academy of Music, which has several tiers of boxes, and wood paneling throughout the auditorium, the projecting surfaces which are comparable in dimensions to the wave-length of sound tend to disperse the reflections and give a more diffuse distribution of sound. The important point regarding sound diffusion is that it does not lessen the total energy in the room, but rather it increases the number of reflections per unit time and hence lessens the intensity level of the individual reflections. This factor is of practical importance in the placement of microphones in that it lessens the effect of interferences between the direct sound and the first reflections. The small increments of energy and random phases of the diffused sound also produce a smoother decay curve in the enclosure. Since a smooth decay curve[2] presupposes the absence of echoes, rooms with sound diffusers apparently can tolerate a slightly greater reverberation time and thereby effect a better compromise between the optimum conditions for speech and music. This increased reverberation time coupled with the effects of panel resonance may account for rooms treated with polycylindrical diffusers sounding somewhat larger than ordinary rooms.

A second factor of importance in the acoustics of the Philadelphia Academy of Music is that the wood paneling also helps to give a diffuse distribution of sound by virtue of the fact that the energy incident on its surface which is not absorbed is reradiated.[3] This reradiated energy does not follow the regular law of equal angle of incidence and reflection, but due to panel vibration acts more like a loudspeaker diaphragm and,

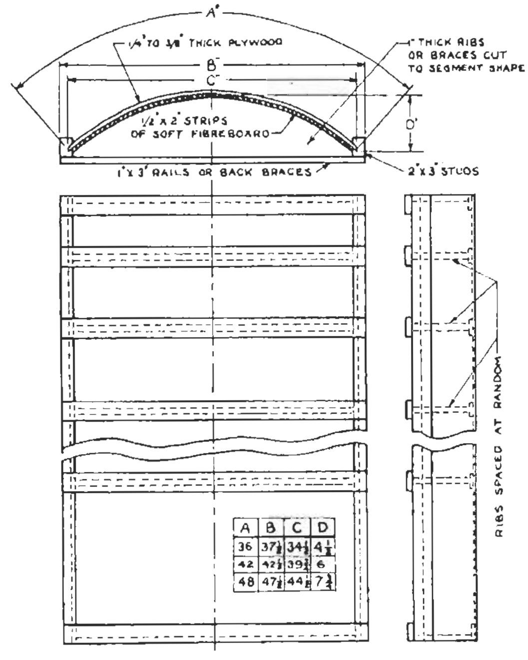

FIG. 1. Convex plywood panel.

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[1] F. R. Watson, *Acoustics of Buildings* (John Wiley and Sons, New York, 1930), second edition; H. Bagenal and A. Wood, *Planning for Good Acoustics* (Methuen and Co., 1930); V. O. Knudsen, *Architectural Acoustics* (John Wiley and Sons, New York, 1932); P. E. Sabine, *Acoustics and Architecture* (McGraw-Hill, 1932).

[2] See C. C. Potwin and J. P. Maxfield, "A modern concept of acoustical design," J. Acous. Soc. Am. **11**, 48 (1939), for interesting comments on modulation effects in the decay curve due to shifting interference patterns. Also R. L. Hanson, "Liveness of rooms," J. Acous. Soc. Am. **3**, 318 (1932).

[3] Hope Bagenal and Alex. Wood, *Planning for Good Acoustics* (Methuen and Co., 1931), p. 10.

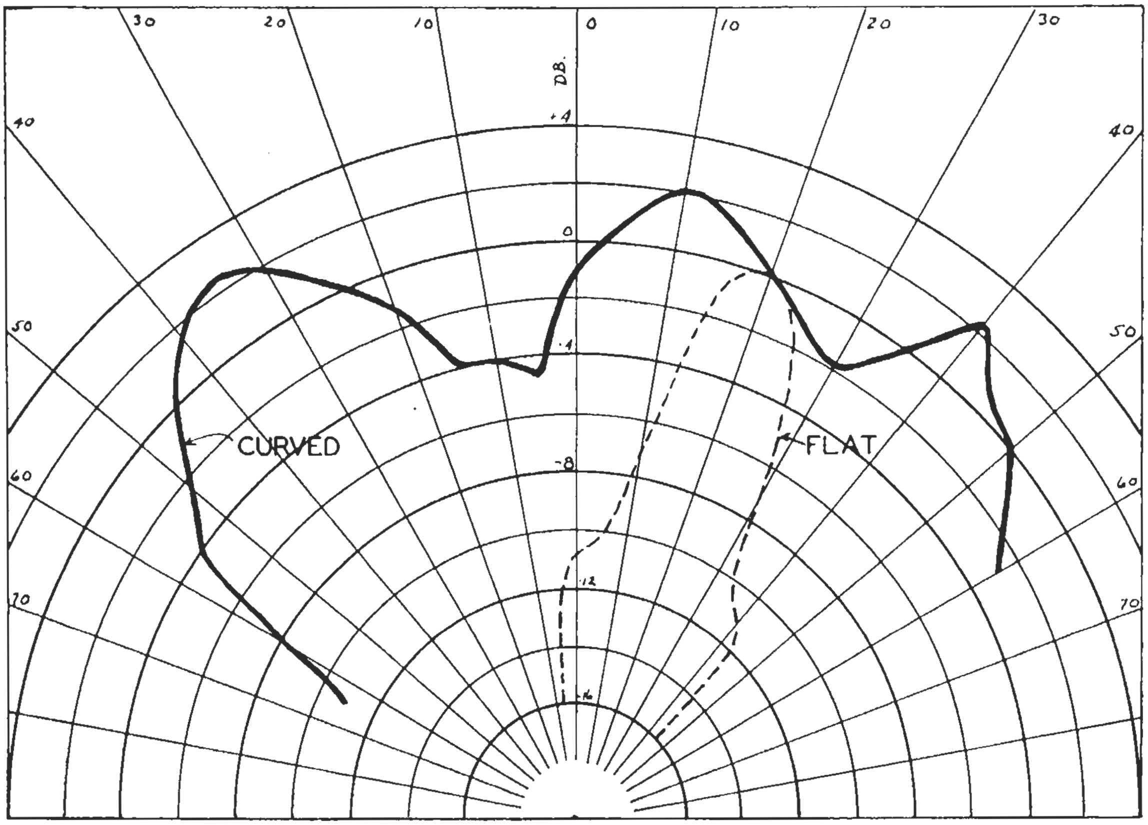

Fig. 2. Polar distribution characteristics of reflected wave for convex and flat panels.

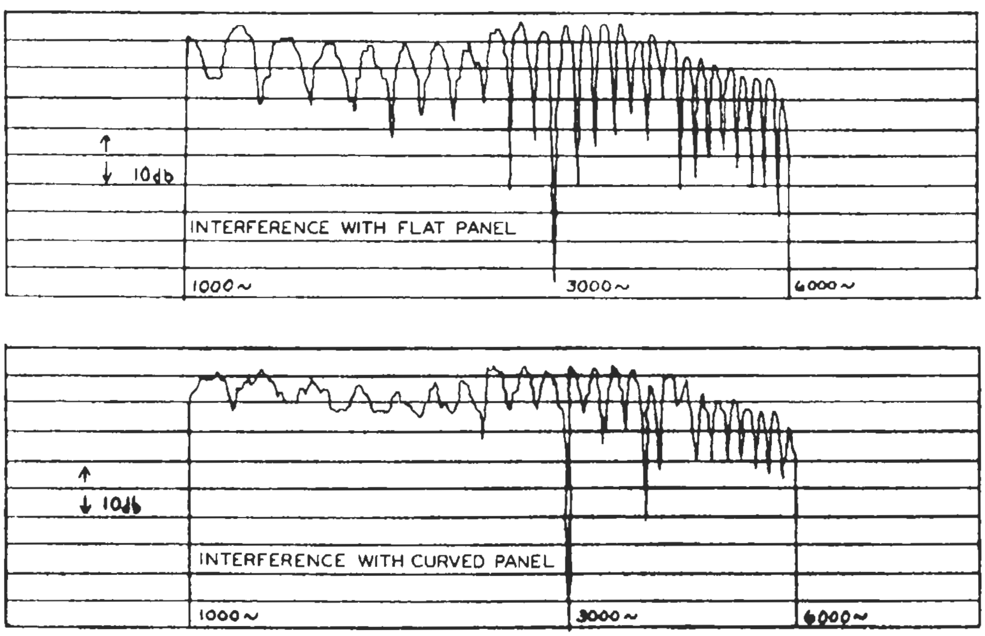

Fig. 3. Interference between direct and reflected waves for convex and flat panels.

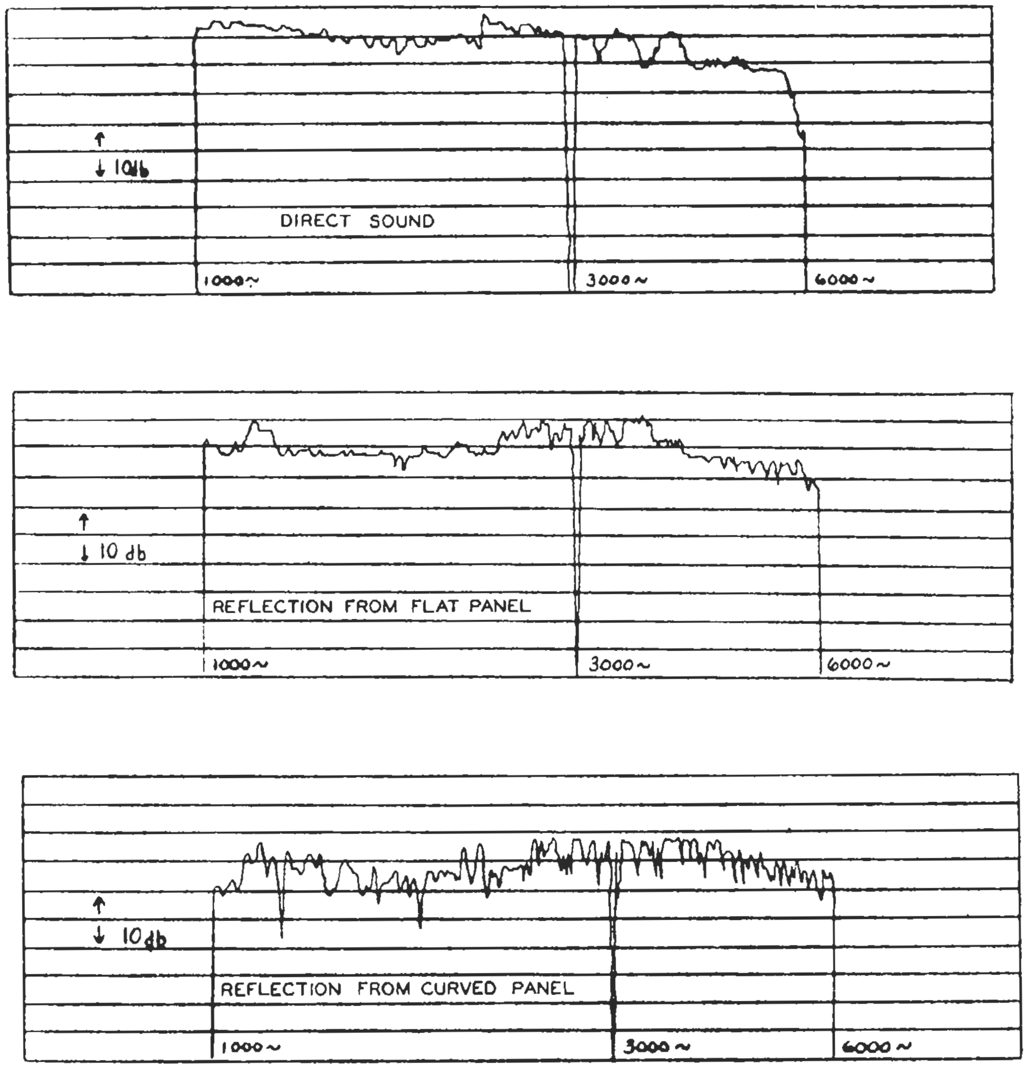

FIG. 4. Direct and reflected response of panels used in interference measurements.

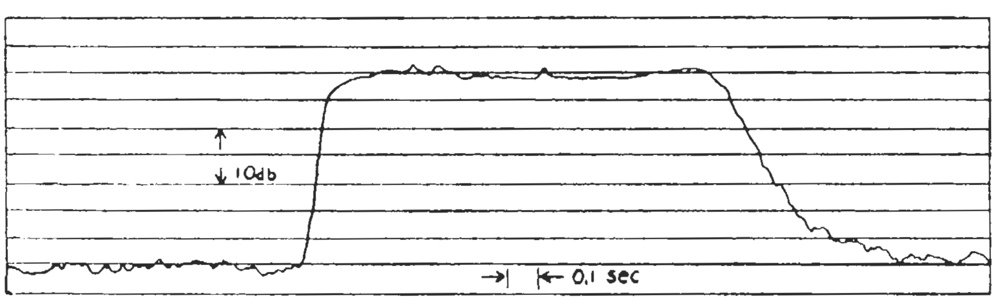

FIG. 5. Growth and decay curve of vibrating convex panel.

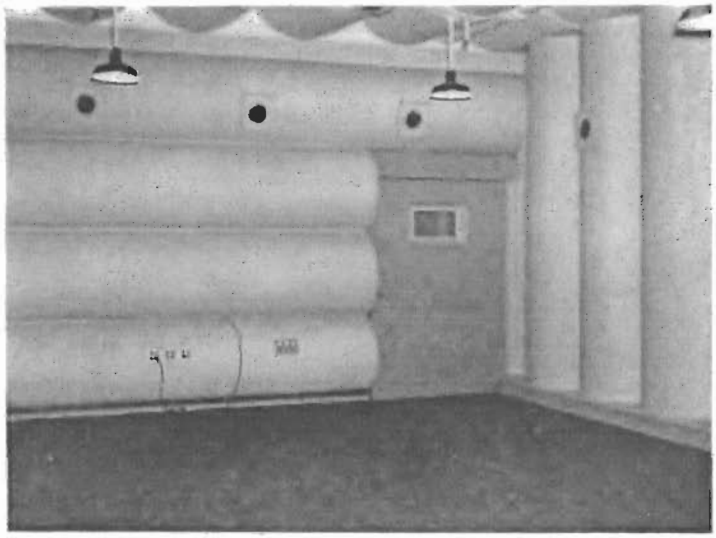

FIG. 6. Listening studio at RCA showing polycylindrical surfaces with axes mutually perpendicular.

therefore, for many frequencies either disperses the incident energy over a wide angle or changes its direction. Similar diffusion also occurs due to reradiation from cavity resonators formed by the boxes and other pockets in the tier balconies. A third important factor in the Academy acoustics is that the radiation from the wood paneling further occurs due to direct "telephonic" transmission from the original sound sources on the stage through the wood flooring and panel mounting structure. Since the panels in the Academy are more or less of different sizes and shapes the panel resonance frequencies are not selective. Two interesting factors to note here are that the panel radiators have a decay time of their own, and that the transmission time in wood is much shorter than in air.

This "diffuse" distribution of energy coming from many random directions and from a great number of small sources of sound in the room has, in addition to giving a more uniform distribution and decay of sound, the important psychological effect created by enveloping the audience with sound which gives a certain feeling of body or depth to the sound. The "feeling" effect of sound is further enhanced in the Academy by the transmission of sound through the wood floor to the seats and from other structures in the room.

Consideration of this diffuse aftersound in rooms known for their good acoustics has led to the following developments: (1) The use of convex curved surfaces, usually cylindrical wood paneling, in the acoustic design of rooms which forms the topic of the present paper. (2) The use of a multiplicity of "room" loudspeakers on sound reproducing systems for creating the feeling of depth or body through the spatial effect of enveloping the audience with sound. Such "room" loudspeakers have been used separately and in combination with "direct" loudspeakers for adding realism to reproduced reverberation.

CONVEX WOOD PANELS

Figure 1 shows a typical curved wood panel consisting of $4' \times 8'$ plywood formed over curved segment braces and fitted at the edges with $2'' \times 3''$ strips which have been routed and held together with $1'' \times 3''$ back braces. The segment braces which are spaced at random have strips of $\frac{1}{2}''$ Celotex or other soft fiber board placed between them and the paneling to prevent rattles. It is felt that convex cylindrical wood paneling is particularly suited to meet the aforementioned requirements of a good sound diffuser because it disperses sound energy not only by reflection from its curved surface but by radiation due to its resonance action or panel vibration which as already mentioned is set up by either direct transmission from the original sources of sound or by partial absorption and reradiation of the aerial sounds impinging on its surface.

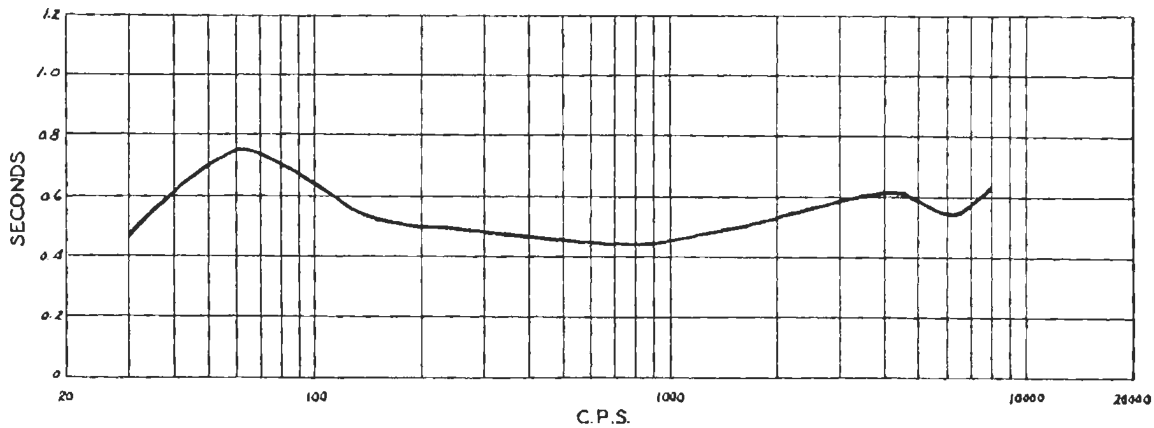

FIG. 7. Reverberation time of listening studio.

Dispersion by reflection depends on the size and curvature of the panel and their relation to the wave-length. Dispersion characteristics for a curved and flat panel plotted on polar coordinates are shown in Fig. 2. This shows clearly the diffusing action of convex curved surfaces and was obtained by rotating the panel about its long axis while keeping the source and directional pick-up constant. It should be noted here that the apparent source for convex reflectors is always behind the surface. The value of such surfaces in reducing the interference effect of first reflections as compared to flat surfaces is shown in Fig. 3. Note that the aiding effect at some frequencies and the cancelation at others is less for the convex panel. The relative intensity levels of the direct and reflected waves used in obtaining the interference curves are shown in Fig. 4. The reduction in interference effect is significant when we remember that the total energy content of the reflected wave from either surface remains the same. As mentioned earlier, the reduction of the interference effect of first reflections is important in studio microphone pick-up in allowing greater freedom of placement. For remote surfaces in large rooms a similar diffuse reflection may be obtained by means of concave reflectors providing the focus point or the apparent source of sound, which in this case is in front of the reflector, is not within or near the seating area or any other critical area.

Dispersion of sound by means of panel resonance depends on the modes of vibration set up. For areas of motion small compared to the wave-length radiated, the distribution will tend to be non-directional. For vibrations normal to the surface, a convex cylindrical panel would tend to set up a cylindrical wave front as compared to the plane wave front in the case of flat panels. The resonance frequencies and response of a panel depend on a great number of factors such as the damping coefficient of the material, thickness, spacing of braces, method of mounting of the entire panel, etc. It is interesting to note that due to the added stiffness introduced by bending, a smaller panel thickness may be employed for curved panels for the same frequency. The decay time or "resonance time" of a typical panel excited at one of its modes of vibration is shown in Fig. 5. In addition to the

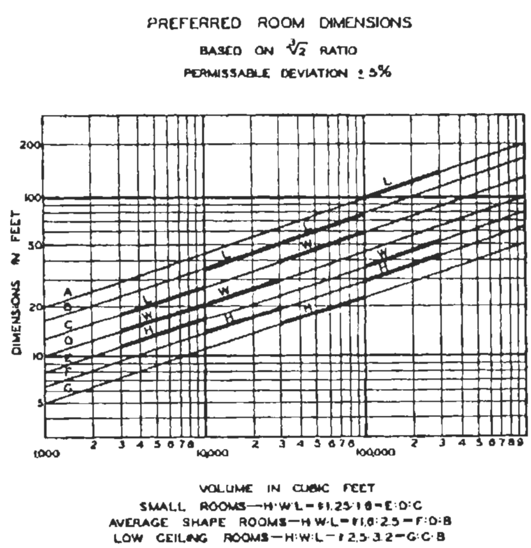

FIG. 8.

FIG. 9. Disk recording studio in South America.

FIG. 10. Disk recording studio in New York.

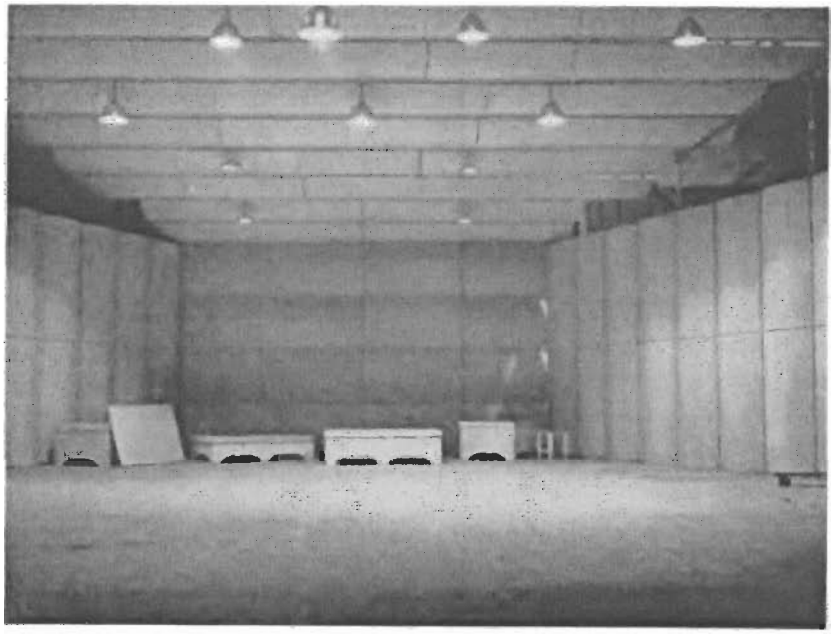

FIG. 11. Orchestra shell with polycylindrical plywood panels. (*Courtesy of Walt Disney Studios.*)

dispersion and radiation action, the vibration of the wood paneling aids the absorption efficiency over more rigid materials. Preliminary data indicates a coefficient of approximately 0.18 over a considerable band of frequencies, which checks data given by Bagenal & Wood on flat 3-plywood panels.

STUDIO WITH POLYCYLINDRICAL WOOD PANELS

Figure 6 is a photograph of one of the studios in the new RCA Sound Engineering Laboratories at Indianapolis, Indiana, used for listening purposes. In addition to the cylindrical wood diffusers already mentioned, these studios have several other features of interest in room acoustic design.

In order to obtain maximum diffusion in the three orthogonal planes the axes of the polycylindrical surfaces were placed mutually perpendicular to each other. Three different sized panels and curvatures were used further to obtain asymmetry in the pattern of diffused sound. The high degree of diffusion obtained in this type of room is evidenced in the smoothness of the decay curves. The reverberation curve for this studio is shown in Fig. 7, which conforms reasonably well with published optimal times.[4]

Another feature of the studio is the choice of the major dimensions (12.5 ft.×20 ft.×32 ft.) which progress in two-third octave steps in order to avoid the "piling up" of room resonances. This is especially important for small rooms where the frequency gap between fundamental and harmonic resonances is oftentimes great, and unless guarded against may lead to a room response with wide hollows in the audible range. In the present case this consideration was important because the use of large convex diffusers effective in the range below approximately 300 c.p.s. was not considered practical. In large rooms consideration should be given to the use of low frequency diffusers as well as for the mid range and high frequencies.

A chart giving preferred dimensions *versus* room size for various types of rooms is shown in Fig. 8. If a room is very small and nearly cubical in shape the direct ratio of the cube root of two would be preferred (see curves $C:D:E$). For average studio sizes the ratio should be near the

[4] Robert M. Morris and George M. Nixon, "NBC studio design," J. Acous. Soc. Am. **11**, 48 (1939).

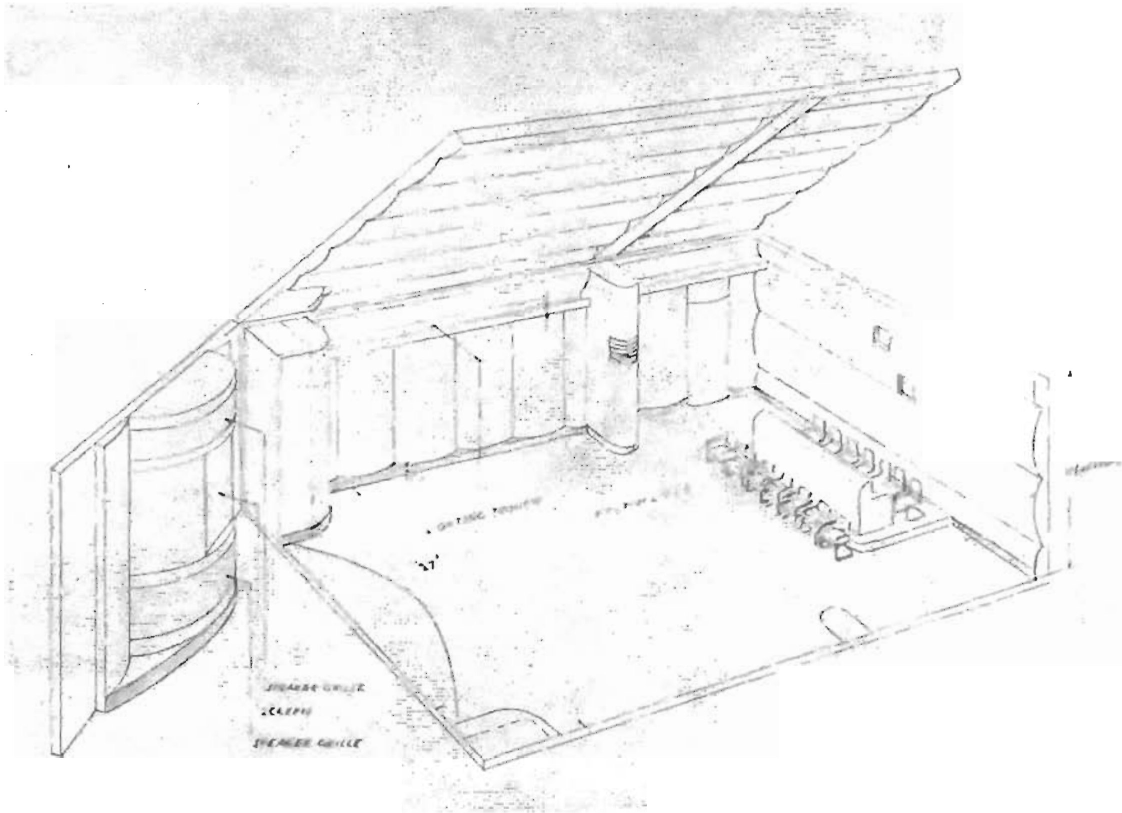

FIG. 12. Proposed design of a small film recording studio and review room.

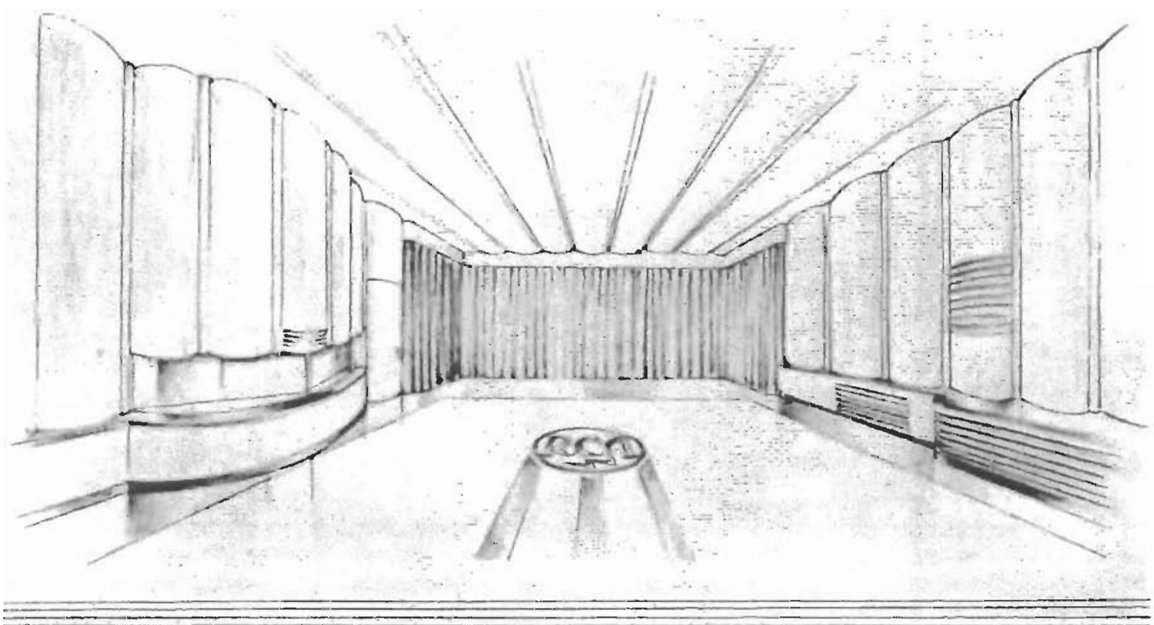

FIG. 13. Proposed design for RCA film scoring studio.

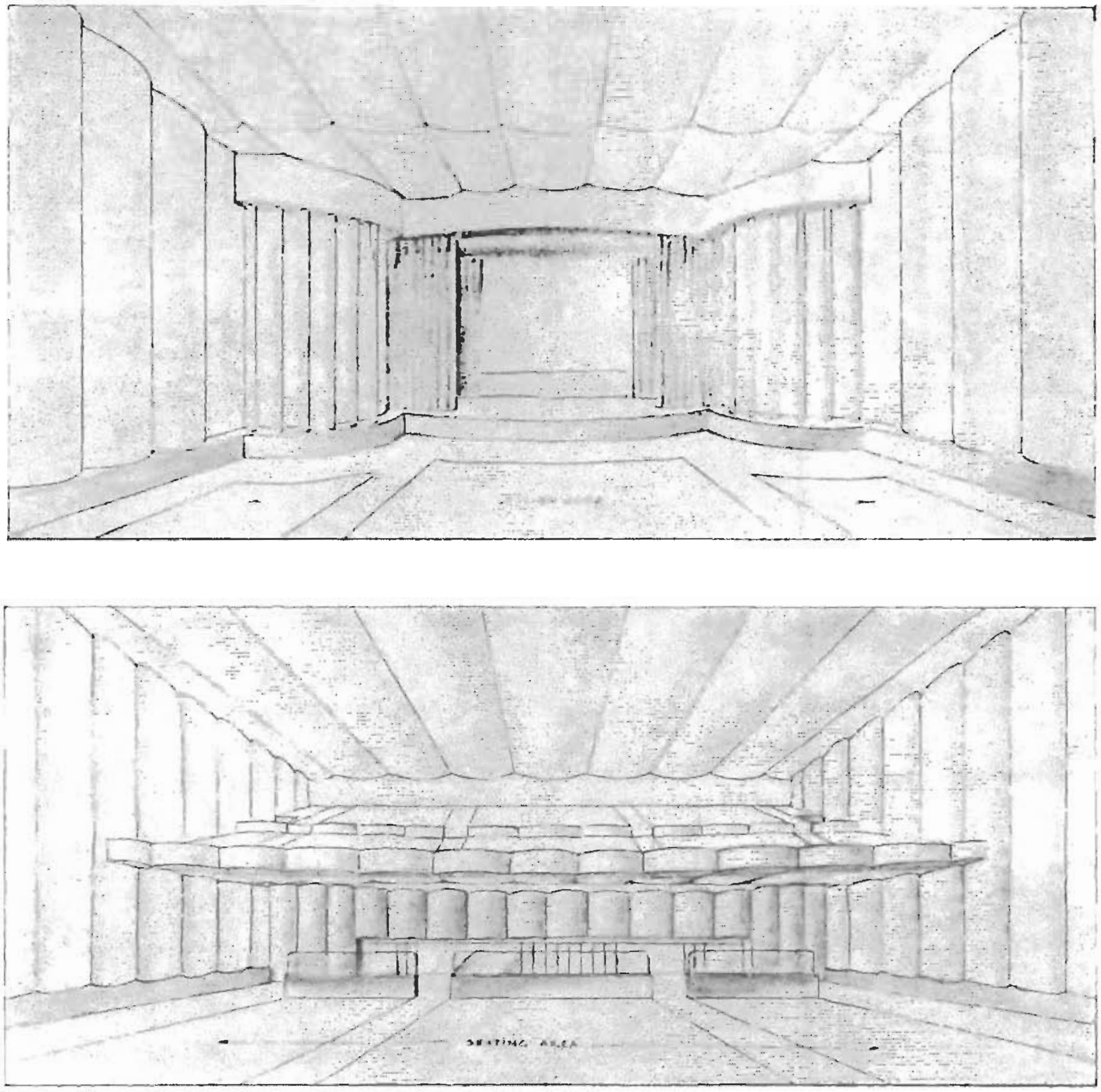

FIG. 14. Proposed design of a sound movie theater. Upper, stage of Cinema Encanto showing suggested acoustic treatment. Lower, view from stage.

cube root of four (see curves $B : D : F$). This approximates the frequent practice in the broadcast field of using a ratio of $2 : 3 : 5$. If a low ceiling is necessitated then the ratio given by curves $B : C : G$ would be preferred. In all cases the dimensions shown are derived from the ratio of the $\sqrt{2}$. Stating it another way the major dimensions should be separated ½ octave with respect to each other, or, other ratios derived from this fundamental ratio by shifting any or all of the dimensions by one or more integral octaves may be used.

Other Typical Applications of Convex Surfaces

The first application of the general principles outlined in this paper was in the RCA Recording Studio in South America which is shown in Fig. 9. This studio is approximately 38,000 cu. ft.

and has a calculated reverberation time of 0.9 sec. It has a wooden floor, 70 percent convex reflectors of 1″ plaster and 30 percent 1″ rockwool. A similar treatment, except that the polycylindrical diffusers were wood and less rockwool was used, is shown in Fig. 10 on the RCA disk recording Studio, New York, New York. This general type of design has also been applied to the WFAA Studios as mentioned in Dr. Boner's paper in collaboration with K. C. Morrical.

An application of polycylindrical design to an orchestra shell which was used last winter for a recording by Leopold Stokowski on the Walt Disney Live Action Stage and which is here reproduced through their courtesy, is shown in Fig. 11. The multiplicity of dispersing surfaces and resonant panels not only minimized the microphone placement problem, but gave a more pleasing reinforcement of sound to the conductor and musicians. The platforms were for elevating and reinforcing the bass instruments in the orchestra.

Functional styling in acoustics is receiving more and more recognition through a growing cooperation between architect and engineer. The styling sketches in Figs. 12 to 14 by Mr. Robert Holley on projects either under way or contemplated, show the adaptability of cylindrical surfaces to functional styling. Figure 12 is one of several studios now under construction in the east, while Fig. 13 shows the proposed design for the RCA Film Recording Studio in New York. Figure 14 shows the styling for a theater with side wall panels streamlined. Innumerable combinations of convexly curved surfaces will suggest themselves to the designer.

In conclusion it is gratifying to know that wherever this general type of polycylindrical wood diffusers has been used along with the necessary absorbents for optimum reverberation the results have been more than satisfactory. The author wishes to acknowledge the assistance received from his associates in the collection of data particularly from Dr. K. C. Morrical who carried through the design and tests on the RCA Disk Recording Studio, 24th Street, New York, New York. The author is also indebted to Dr. C. P. Boner for information and discussion in connection with his tests and application of convex panels to broadcast studios.