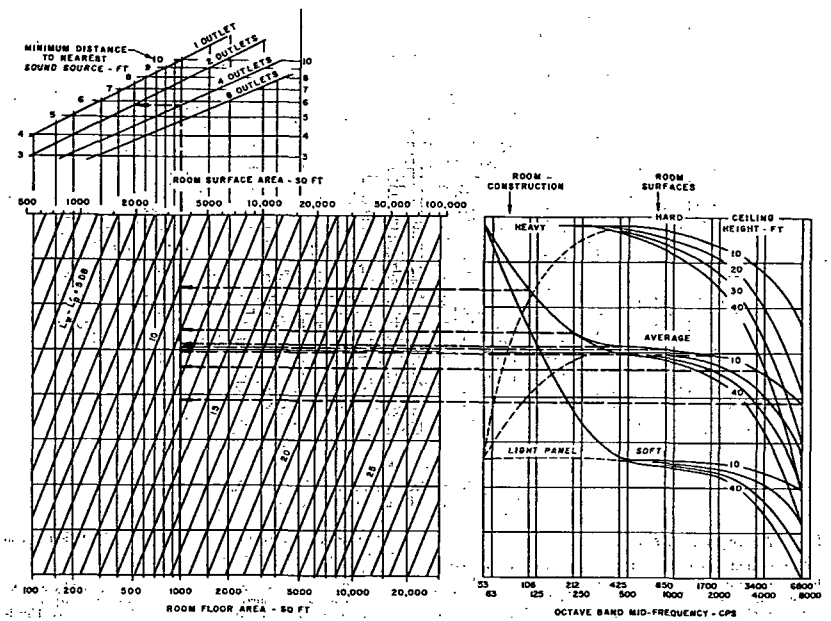

Fig. 6 .... Chart for Estimating $L_W - L_p$

necessary because the room absorption or the reverberation time of acoustically critical spaces can always be obtained from the architect.

Rapid Determination of $L_W - L_p$

In actual practice, the reverberant sound level in the room, expressed by the $4/R$ term of Equation 10, is usually dominant, but the direct sound radiation expressed by the terms involving r is not negligible. A rigorous solution involving all the terms is therefore too cumbersome for practical use, particularly when multiple sources are involved.[23]

Table 7 .... Typical Room Surface Absorption Ratings

Type of Room	*Rating for Use in Fig. 6*
Radio & TV Studios Theaters, Lecture Halls	Soft $a = 0.4$
Concert Halls Stores, Restaurants, Offices, Conference Rooms, Hotel Rooms, School Rooms, Hospitals, Private Homes, Libraries, Business Machine Rooms, Churches (Protestant)	Average $a = 0.2$
Large Churches (Catholic) Gymnasiums Factories	Hard $a = 0.1$

A detailed analysis of the practical ranges of all variables[24] has shown that it is possible to estimate $L_W - L_p$ within ± 1 or 2 db from Fig. 6 and Table 7. From the total sound power level so estimated for each octave band, the sound power level per source can be calculated by subtracting the values listed in Table 8. This procedure is illustrated by the following example and Table 9.

It should be noted that Fig. 6 is representative of floor areas of typical rooms. The surface area is of greater physical significance, so that use of this chart will be less accurate as room proportions depart greatly from the average.

Example 2: Calculate the permissible sound power level for a conference room of 1000 sq ft area, 10 ft ceiling height, with four air outlets on 8 ft centers located in wall, near the ceiling. The NC level from the air conditioning is not to exceed 30 db.

Solution: First check the distance to the acoustic center of the

Table 8....Allowance for Multiple Terminals

Number of Evenly Distributed Terminals of Equal Sound Power Rating	2	3	4	8	10	20	40	100
Decibels to be Subtracted from Total Sound Power Level in order to get Power Level per Terminal	3	5	6	9	10	13	16	20

Table 9 .... Sample Calculation of Permissible Sound Power Level for *Example 2*

1. Terminals: Number 4; Installed Height: 9 ft; Min. Distance from Listener (Fig. 4), r = 6.7 ft
2. Room Dimensions: ____ ft × ____ ft = 1000 sq ft Floor Area, 10 ft Ceiling Height
3. Room Construction: Heavy/Medium/Light Panels. Room Surfaces: Hard/Average/Soft (Table 7)

Line	Item	Reference	Octave Band Center, cps 106	212	425	850	1700	3400	6900
4.	Room Effect, $L_W - L_p$, db (Based on Floor Area (Line 2) or Distance (Line 1), whichever gives lower value).	Figure 6	10	11	11	11	12	12	13
5.	Sound Pressure Level for NC-30	Figure 2	51	43	37	32	30	28	27
6.	Total Permissible Sound Power Level	Line 4 + Line 5	61	54	48	43	42	40	40
7.	Allowance for 4 Terminals	Table 8	6	6	6	6	6	6	6
8.	Permissible Sound Power Level per Terminal	Line 6 − Line 7	55	48	42	37	36	34	34

NOTE: This shortcut method assumes equal and evenly distributed terminals and gives values of permissible sound power level which are generally on the safe side. In critical cases, the actual sound pressure level at any point due to each source can be found by using Figs. 5 and 8 and totalled by using Table 2.

nearest outlet. For a person sitting 3 ft away from the wall in which the outlets are located (see Fig. 4), this is:

$$r = \sqrt{3^2 + (10 - 4)^2} = \sqrt{45} = 6.7 \text{ ft}$$

This distance is entered on Line 1 of Table 9. Since it is above the limit shown in the upper left-hand corner of Fig. 6 for four outlets and a floor area of 1000 sq ft, the distance does not have to be considered any further.

Next, locate the proper points in the right-hand part of Fig. 6 for each octave band. For the two center bands, this involves only the room surface absorption rating. According to Table 7, a conference room can be expected to have room surfaces with average sound absorption value. In the lower octave bands, the type of construction should also be considered because light panel walls will provide considerable sound absorption, but heavy walls will not. Assuming that a conference room is constructed with massive walls, floor, and ceiling to provide good sound isolation, the points are located on the curve connecting the *heavy construction* and *average surfaces* ratings. The higher the frequency, the greater the effect of air absorption, especially in high ceiling rooms. The points for the upper octave bands are therefore located according to ceiling height as well as room surface rating.

Finally, read the value of $L_W - L_p$ at the intersection of horizontal lines through these points, with the vertical line at 1000 sq ft floor area. These values are tabulated on Line 4 of Table 9. The rest of the calculations are identified on Lines 5 to 8.

The air outlets should be selected so that none of their octave band power levels exceeds the permissible levels calculated. To obtain the balanced sound spectrum implied in the NC criteria, the power level in the 600–1200 and 1200–2400 cps bands should not be more than 5 db *below* the calculated values.

Air outlets will not contribute significantly to the low frequency noise levels. For noise generated by fans, generally the second, third, and fourth octave bands are the most critical. Because of this difference in frequency range, an allowance for fan noise normally is not necessary in selecting air outlets (see Fig. 3).

The simplified determination of $L_W - L_p$ from Fig. 6 as illustrated in the above example, is applicable only so long as the distance from the listener to the nearest sound source is sufficiently great with respect to the room size. The range of this method can be extended to somewhat shorter distances by determining the maximum floor area corresponding to the distance to the nearest sound source as shown in Fig. 6, and by using this instead of the actual floor area in determining $L_W - L_p$.

If the distance to the nearest sound source is less than 80 percent of the one read from Fig. 6, a detailed analysis of the direct sound radiation and the directivity pattern should be carried out. This can be done by calculating, for each source, the actual sound pressure level at any given point, using $L_W - L_p$ values from Fig. 5, and then adding up the sound pressure level due to each source, by using Table 2.

Direct Sound and Directivity

In a space with very high room absorption, the reflected sound level is greatly reduced by absorption at the ceiling, walls, and furnishings. If, in such a space, the source is near the listener, direct sound will dominate because its intensity is inversely proportional to the square of distance.

Sound calculations in the region of dominating direct sound must include not only the distance, r, of a sound source, but also its directivity factor, Q.[18] This is a measure of the degree to which sound is concentrated in a certain direction rather than radiated evenly in a full spherical pattern. Directivity factors for typical radiation patterns are shown in Fig. 7.

Very low frequency sound with a wave length much larger than the dimensions of the sound source is always radiated uniformly. The directivity factor then depends only on the *location of the nearest walls.*

If the source is near the intersection of a wall with the ceiling or the floor, Q is approximately 4, because the sound can be radiated over only approximately ½ of a spherical pattern. A source near the center of a wall or ceiling, however, has a hemispherical radiation pattern, hence Q equals 2.

For the hypothetical case of a source in the center of a room with full spherical radiation, Q would be 1, and a source in the corner of the room near the ceiling would have a Q of 8, because the two walls and ceiling would limit its radiation pattern to ⅛ of a sphere.

At higher frequencies, when the half-wave length of the sound is equal to, or shorter than, the *smallest* dimension of the sound source (neck diameter or grille width), the sound is not radiated uniformly in all directions but rather *beamed* in a straight line. A listener standing directly in front of an outlet is in the center of the sound *beam.* Even at 45 deg from the center line of the source, the beam effect increases Q and hence adds to the level of the direct sound (see Fig. 8).

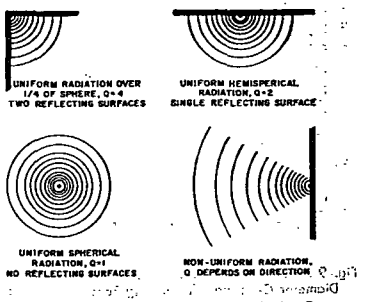

Fig. 7 .... Directivity Factors for Various Radiation Patterns