Acoustical Design Methods for Concert Halls in Dallas, Texas (USA) and Birmingham, England.

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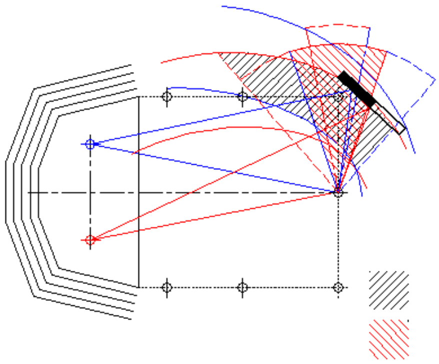
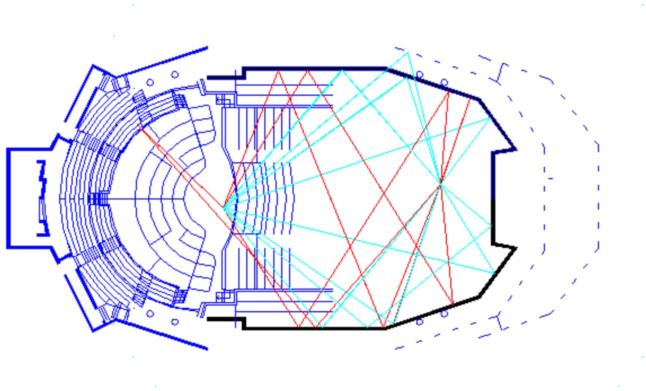




Meyerson – Second order reverse fan room shaping

Symphony Hall – Third order reverse fan shaping

The Morton H. Meyerson Symphony Center in Dallas, Texas and Symphony Hall, Birmingham are among the first concert halls with room shaping designed specifically to produce strong early lateral sound energy in the audience areas. This paper concerns the some of the methods employed in the acoustical design of these halls.

Many authors including Barron [1], Schroeder [2], Gottlob [3], and Ando [4] have contributed to knowledge concerning relationships between listener preferences and the temporal and spatial distributions of energy in the sound field. This work shows that sound fields with strong early sound energy and particularly with strong early lateral sound, are preferred.

Despite such general agreement little has been written concerning how such characteristics of the sound field can be achieved in practical designs for the architecture of concert halls. The concert halls in Dallas and Birmingham have room shaping which is designed to promote strong early lateral sound. At first inspection, these halls may appear to be traditional "shoebox" designs; it is necessary to look a little deeper to see how the room shapes promote strong early lateral sound.

The approach in Dallas and in Birmingham evolved from earlier concert hall designs such as the one in Nottingham, England.

In the Nottingham hall, the upper wall and ceiling surfaces are tilted so as to reflect sound into the audience area. Such an approach utilises the architectural surfaces of the room to direct first order reflections into specific seating areas,

One effect of this approach is to impose a highly visible "acoustical" form on the architecture of the concert hall.

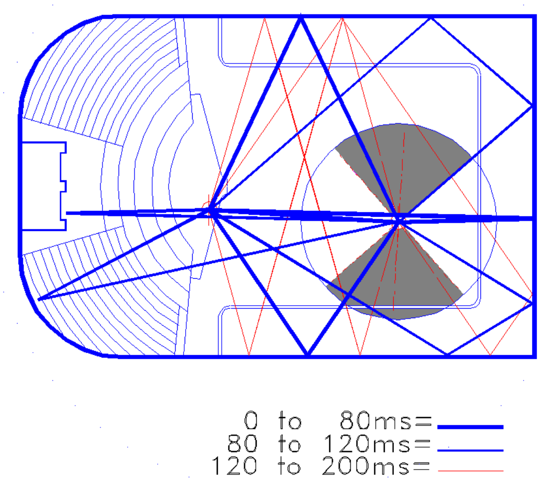
A simple design method we employed to develop the Nottingham room shaping based on first-order reflections, was to build a scale model with mirrors applied to the acoustically reflective surfaces and to utilise a light source to simulate the sound source. This technique is effective for revealing where first-order reflections are directed.

However, the brightness of the first-order reflections masks the visibility of the second and higher order reflections, and we found this limitation significantly impeded design development.

This design method leads to very distinctive architectural forms such as in Nottingham, in Christchurch, New Zealand (see Marshall [5]) and Artec's Colorado Springs, Colorado.

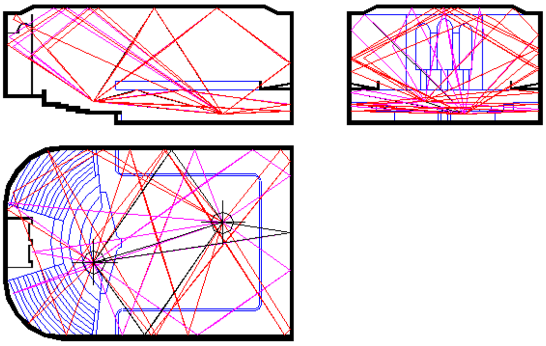
Colorado Springs – First order room shaping

Concergebouw, Amsterdam – less obvious acoustical shaping



It is perhaps not obvious that the traditional "shoebox" concert hall has a shape that promotes early lateral sound, but in fact it does.

Concertgebouw Plan ±45deg overlay shows early lateral reflections

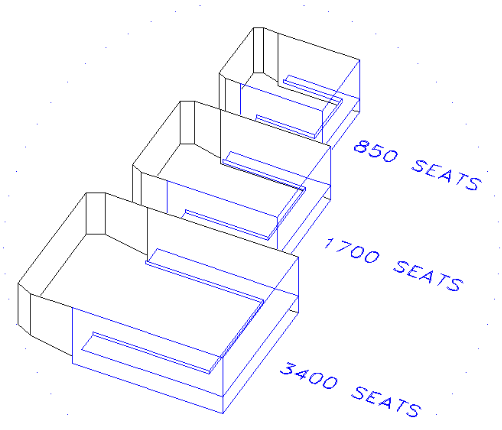


The rectangular concert hall shape produces early reflections in the seating areas principally through <u>second-order</u> reflections from the side walls and soffits of the side balconies.

Concertgebouw, showing Side Balcony second order

The traditional shoebox hall shape can provide strong early lateral reflections -- making it as relevant a model for acoustical design today as it was over one hundred years ago. In fact, many modern concert halls in the United States such as Avery Fisher Hall, New York, J.F. Kennedy Hall, Washington, and Singer Hall in Calgary, Alberta are based on this traditional model.

Jack Singer Concert Hall, Calgary

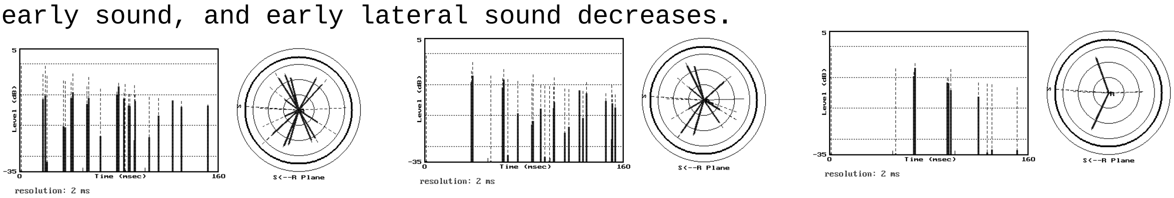


850, 1700, and 3400 Shoeboxes

The shoebox design is perhaps best applied in smaller halls of 1700 or fewer seats. (The Concertgebouw would seat only 1700 at modern standards for seat spacing).

If the shoebox shape is simply enlarged so as to accommodate 3400 seats, the amount of early sound is dramatically reduced. In halls with seat counts larger than 1700 and where acoustical excellence is desired, such as the Dallas hall with 2000 seats or the Birmingham hall with 2200, the shoebox approach would have been less than satisfactory.

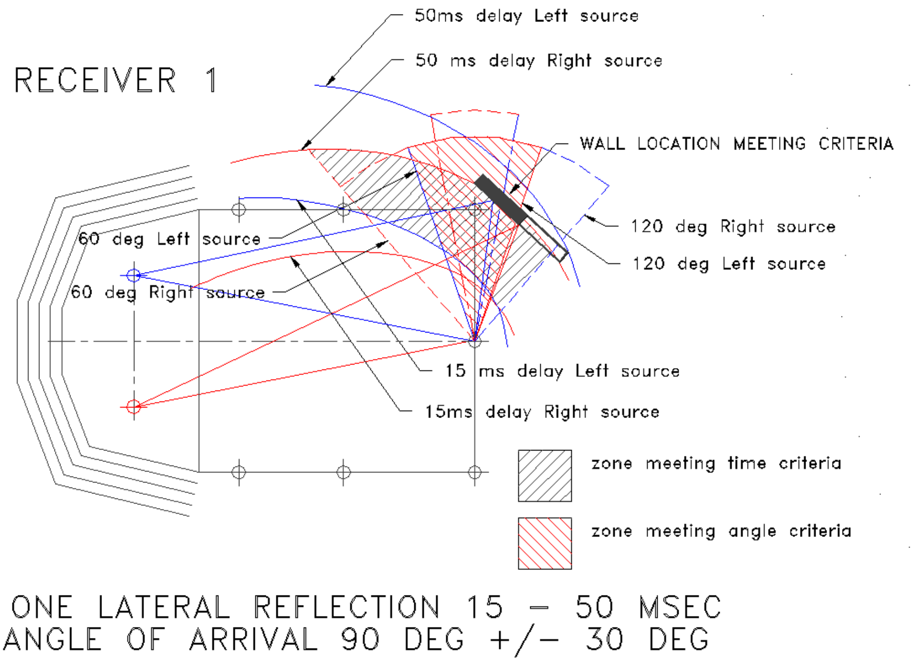
As the size of a shoebox hall increases, it is inevitable that the amount of early sound, and early lateral sound decreases.



Small, Medium, Large
Shoeboxes Echograms(to 160ms) and Soundroses

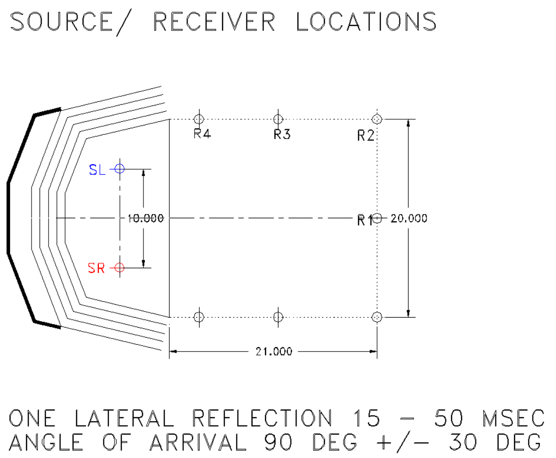
One of the goals of the designs for Dallas and Birmingham, with their seat counts well in excess of 1700, is to compensate for the reduced number and intensity of reflections arriving in the first 80 ms by making the early sound field more lateral, whilst retaining other desirable acoustical qualities of the shoebox (such as reverberance). In other words, as the hall gets larger, the acoustical design must be more efficient, and directing the reflected sound in the hall becomes a more critical part of the design. Every possible surface must be utilised.

There are many other options for directing sound than the obvious one of tilting wall/ceiling panels to direct the first order reflections. In the design for Dallas the sound is directed with second order wall/soffit reflections, through rotating the plan angle of the walls. The shaping was derived by simple geometric studies to determine locations of wall segments that fitted the following criteria:



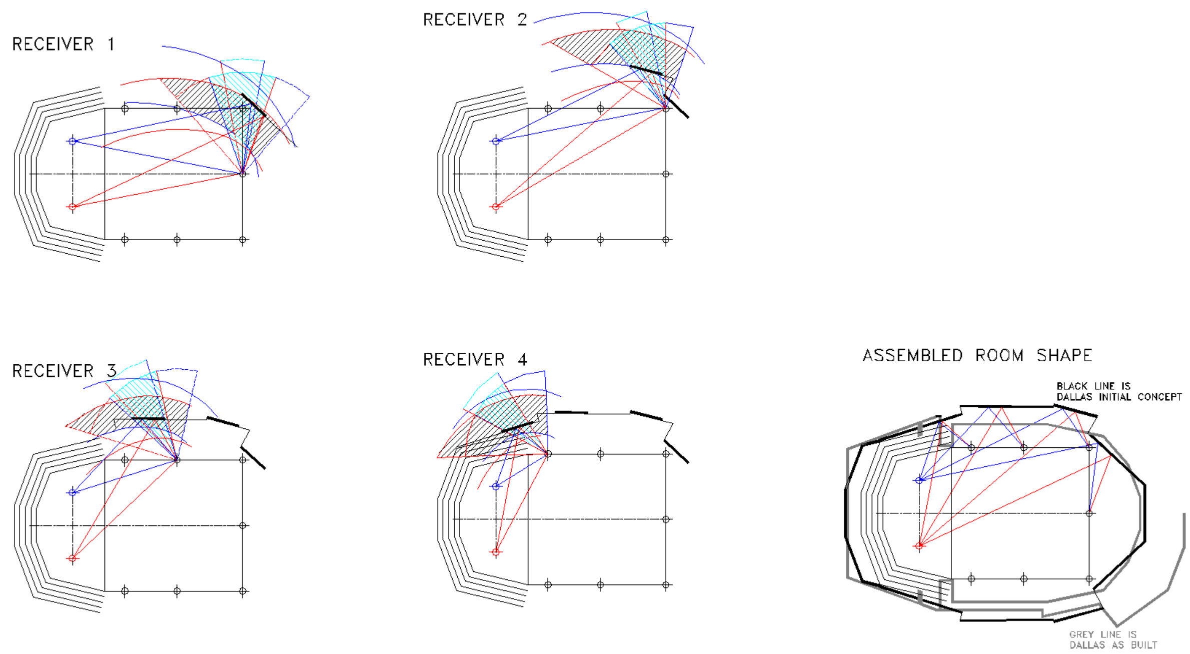
-reflected sound delay between 15ms and 50ms for both left and right sources
-reflected sound azimuth angle 90 degrees ± 30 degrees for both sources

These criteria were applied to a set of receiver listener positions distributed about an imaginary audience area. Two source positions representing the orchestra, and five receiver positions representing the audience on the main floor level were chosen.



SET OF SOUND SOURCE AND RECEIVER LOCATIONS

Using these simple geometric criteria for the set of receiver points, and potential locations for the walls were determined, and the initial concept for the room shape was assembled.



Listener locations 1,2,3,4 and all

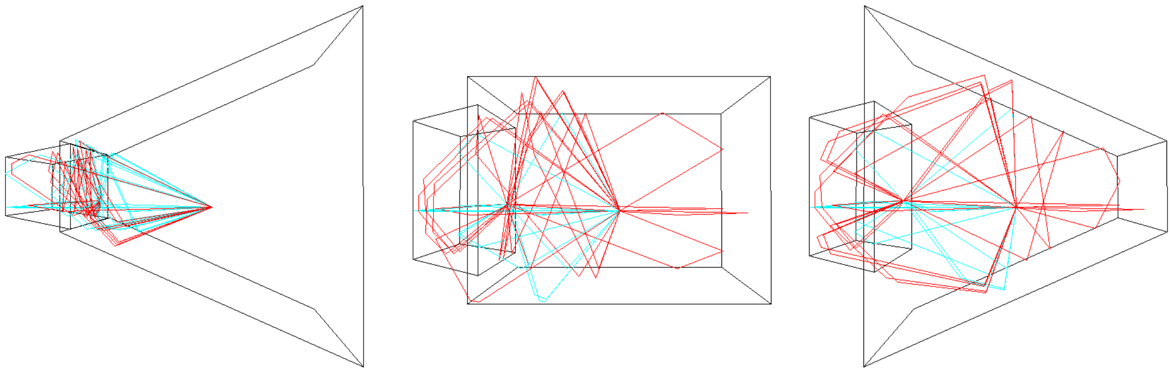
This conceptual shaping of the room has some relation to the shoebox, but is significantly different. The plan angle of the walls at the rear of the hall runs counter to the familiar fan-shaping of halls. I have called this shaping "reverse fan". Interestingly, there are few historical precedents for such shaping in concert halls.

The design method for Dallas was limited by the two dimensional (plan drawing) method illustrated. These limitations were recognized at the time, and provided the impetus for the development of three-dimensional methods for modelling sound fields in concert halls.

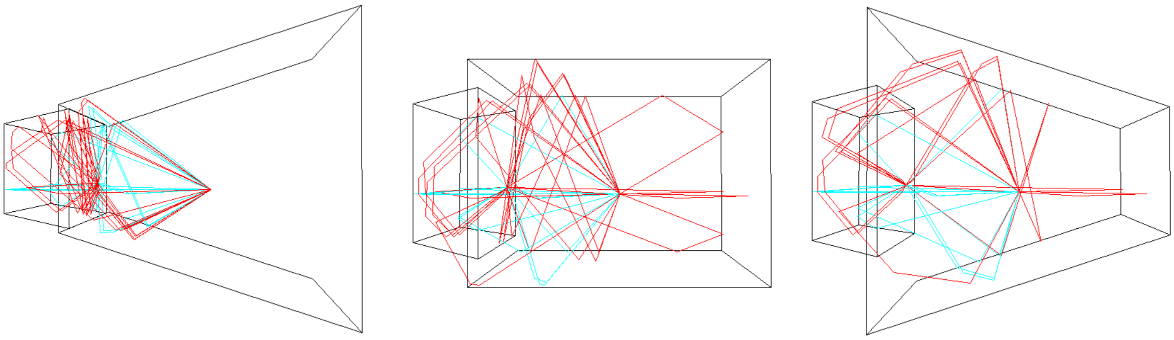
In 1983, Nicholas Edwards developed the IMAGES computer programme to examine sound paths in concert halls three-dimensionally. The IMAGES programme uses the straightforward geometric model where angle of incidence equals angle of reflection. No attempt is made to model diffraction, and we acknowledge this limitation. The IMAGES program handles arbitrarily shaped rooms and re-entrant forms (such as seating located on side and rear balconies)

Initially the program was of particular value in showing how a sound field is influenced by the angle between side walls in a very simple representation of a concert hall. This work was presented in Architectural Record magazine in 1984.

As the wall angle changes from fan to shoebox to reverse fan, the sound field becomes more lateral.

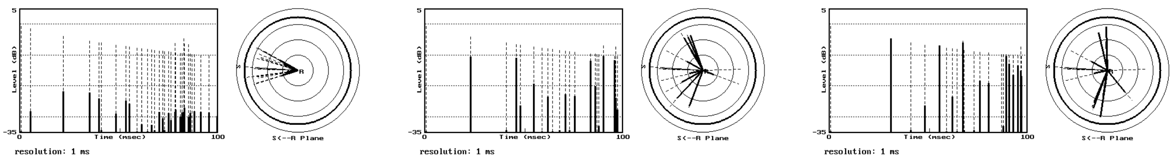


Fan and reverse fan rooms 24,0,-24 degrees



Fan and reverse fan rooms 18,0,-18 degrees

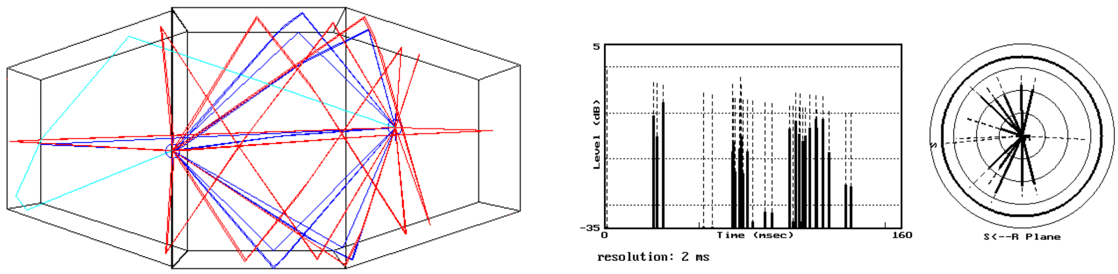
Another interesting trend that can be observed as the wall angle changes from fan to shoebox to reverse fan is that the sound field becomes more delayed.



Echograms and soundroses fan 24; fan 0; reverse fan24

Interpreting these qualities of the sound field (based on the general trends shown in the echograms and sound roses rather than any particular numerical evaluation), we selected 18 degrees as an optimum reverse fan angle. These simple fan and reverse fan shapes are not intended as real models for concert halls, but to facilitate our understanding of the effects of room shaping. To develop a practical concert hall design more complex room shapes are necessary.

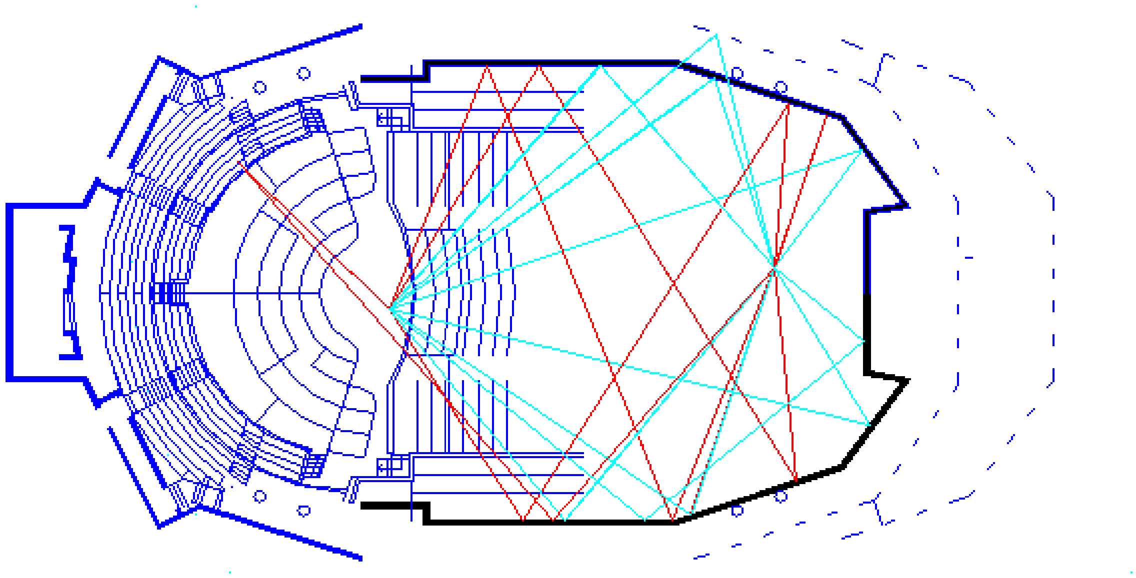
For the Birmingham design, we sought the acoustical advantages of both the shoebox and the 18 degree reverse fan shaping, and proposed a room with walls that are parallel sided nearer the front of the hall, and with the reverse fan shaping again at the rear.



18 degree reverse fan with parallel side walls

The echograms and sound roses indicate that this shaping combines some of best characteristics of the two room shapes: the reverse fan shaping gives strong lateral sound, and the parallel shaping ensures strong early sound and an even distribution of energy along the time axis of the echogram.

The 18 degree reverse-fan walls typically provide fully lateral sound with third order reflections, and these lateral reflections are not usually the first-arriving reflections. The IMAGES sound paths for the actual room shape illustrate this.



Symphony Hall Birmingham with sound paths

CONCLUSION

In the design for the Dallas and Birmingham concert halls we have used a "directed sound" approach but have employed second- and third-order reflections from walls/soffits rather than the first-order reflections from tilted and angled walls/ceilings. The design method for Dallas included two-dimensional graphical methods to achieve second-order, early lateral reflections.

The design method for Birmingham employed the IMAGES computer model to trace the paths of sound in three dimensions, and the room design generally relies on third-order reflections to provide early lateral sound.

It would be wrong to give the impression that lateral sound is the only or even the most important aspect of concert hall design. Lateral sound is just one of the many considerations that must be brought to bear in designing a concert hall. Its importance in design stems from its overriding influence on room shape.

The concert hall in Dallas opened in September 1989. The concert hall in Birmingham opens in April 1991.

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