FITTING ROUND PEGS INTO SQUARE BOXES - using planar surfaces in computer models of auditoria

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1. INTRODUCTION

Computer model predictions are increasingly being required for sound system designs in auditoria, and being used by consultants at the design stage. Choosing the correct level of geometric modelling is a difficult balance between accuracy and detail on one hand and manageability and cost of preparation on the other. This paper discusses the factors affecting the use of plane surfaces, particularly when modelling curved shapes and complex surfaces.

2. MODEL TYPES.

2.1 Statistical model

The simplest scientific model [1] is a statistical model based on a rectangular room with a completely diffuse sound field and this model is still an everyday tool for many acousticians. Various attempts have been made to improve the model [2],[3],[4] but these are still based on an approximation of a rectangular box. This is not surprising, as in a completely diffuse sound field the actual geometry will not be important, many rooms are roughly a rectangular box, and it is easy to model. It is also useful as there is a good body of data on diffuse field absorption co-efficients. However, the diffuse field model is not suitable for predicting early reflections or for predicting response differences at particular seat locations. Sound systems are often required to meet minimum RASTI figures for all seats and RASTI is closely correlated with the Clarity indicators C50 or C80 [5], which requires accurate prediction of the early reflections and therefore more detailed modelling.

2.2 Geometric model

Geometric acoustics treats sound as rays, which is valid if the dimensions of the geometry are an order of magnitude greater than the wavelength of the sound under consideration [6]

$$b > 10\,\lambda = 10\,c/f \qquad (1)$$

(λ = 0.68m for 500Hz, used in RASTI calculations [7]).

Overall room dimensions will usually meet this requirement, and geometric acoustics allows different room geometries to be considered and individual locations within a room to be studied, either on paper, in a three dimensional physical model or by a computer model. The latter case is discussed here.

2.3 Computer models

Computer models based on image source and ray tracing methods [8], [9], [10], offer the prospect of providing detailed analysis of individual reflections from surfaces or individual seat positions for any shape of room. However, the models are based on geometric assumptions (see above) and the room geometry must be a series of plane surfaces, which is rarely the case in practice.

Early modelling programs were limited in the number of planes that could be processed within reasonable timescales and in the presentation of complex room shapes. Improvements in processing power and graphics handling mean that very detailed visual representations may now be obtained (and are often expected) but this paper looks at the acoustical representation of real rooms with plane surface models. Two factors will mainly be discussed; the planar approximation of curved and irregular surfaces and the reflections form those surfaces.

3. PLANE SURFACE MODELLING

3.1 Plane Size.

The larger the individual planes used to model an auditorium the quicker the model can be prepared, the quicker prediction results can be obtained, and the more likely are the geometric conditions to be valid. Even if the basic geometry is a single plane, it may be necessary to divide the plane to allow for different surface materials or the plane may be broken by a smaller detail, such as a pillar or a fitting. Balcony and terrace fronts, especially when punctuated by stairs, can easily have dimensions of the order of, or less than, 0.6m (the wavelength of 500Hz).

At the early design stage a large plane model will probably be sufficient to allow the general room properties to be predicted, but to predict a required RASTI performance for a new or existing building[11], [12] the acoustician will need to be confident that the surfaces near each seat are modelled with reasonable accuracy for both 2kHz and 500Hz.

3.2 Concave Surfaces

Concave surfaces may be modelled by a series of planes, usually tangentially touching the curve. Kuttruff [13] considered a polyhedral approximation of an infinite concave cylindrical section, and suggested that for coherent sources (image modelling) the plane width should be:

$$b2 = (ca/2f) \qquad (2)$$

where

b = width of the planes
a = radius of cylindrical surface
c= speed of sound
f = frequency

Note that this is an equality, not minimum or maximum sizes, so ideally different planes should be used for each frequency. Although this is quite easily done with the plane creation tools in EASE 3.0 [8] the geometric requirements must still be met, so substituting for b from (2) into (1)

$$b2= (ca/2f) > (10c /f)2 \quad (3)$$

or

$$a > 200c/f \quad (4)$$

which gives minimum radii of 136m at 500Hz and 34m at 2kHz, although smaller radii are often encountered in auditoria. Furthermore, at 500Hz a small element (such as the vertical plane of a balcony front) may end up only requiring a single plane, implying that the model would no show the curved effect at all! Actually, if a much less rigorous limit on the geometric assumption is allowed (e.g. $b>2\lambda$) smaller radii could be accommodated, but in real auditoria curves are rarely infinite cylindrical sections, and for short sections the plane approximation may still not be valid.

3.2 Convex Surfaces

A convex curved surface usually spreads sound energy and can be modelled by polyhedral planes, as concave surfaces, or as a single plane surface from which some of the sound is reflected and some diffused. This model is attractive as some curved surfaces are introduced for precisely this reason (e.g.:[14]). However, there are a number of models for treating diffusion in geometric acoustics [15], some of which may not be suitable for the modelling of individual diffuse reflections when considering early reflections.

Complex curves, such as a balcony and box fronts, which could for example be concave in the horizontal plane and convex in the vertical plane, may add to the difficulty of selecting the correct plane approximation.

3.3 Edges

The geometric assumption will not hold at the edge of a plane, except possibly for the highest frequencies, due to edge diffusion or diffraction, which is allowed for in the CATT-Acoustic computer model [9]. The planar model may also be inaccurate at the edges if a polyhedral approximation has been used for a curve, or if the join between two planes has any moulding, coving or other architectural feature. Finally a surface, moulding or fitting (e.g. a grille) may have a number of "sharp" edges which give rise to noticeable edge diffraction effects at high frequencies [16]. In auditoria the modelling of edges may also be important when considering the front seats of a balcony and especially box seats, which in some auditoria are premium seats.

3.4 Irregular Surfaces

A surface which is basically planar and reasonable size may contain irregular elements or surface treatments, such as mouldings or fittings. These elements may be too small to model individually within the geometric approximation and yet have a significant effect on specular reflections to specific seat locations. Individual and widely spaced features may be modelled as diffusing "bosses" but variations over the full surface are usually modelled by increasing the diffusion of the surface.

4. REFLECTIONS

The geometric model assumes "mirror" reflections, but the absorption coefficients used have usually been derived from diffuse field measurements and are a measure of the energy lost from the room, with the reflected component being a combination of specular and diffuse reflections, averaged over a large number of reflections [6]. This will be valid when considering reverberation or total energy, but may not be valid for single reflections. Many computer models now model the reflection with a portion of the reflected energy to be re-radiated as diffuse energy, by one of the models discussed in [15]. However, for an individual reflection, the diffuse energy may still have significant directional qualities [17]:

Consider the sound energy reaching a planar surface. Part of the incident energy will be absorbed, part of it will form a specular reflection and the remainder will be considered as diffuse energy, and by conservation of energy,

$$Ei = Ea + Er + Ed \qquad (5)$$

and normalising

$$1 = Ea/Ei + Er/Ei + Ed/Ei \qquad (6)$$

where

Ei = incident energy
Ea = absorbed energy
Er = specular reflected energy
Ed = diffuse energy,

Assuming that $\alpha = Ea/Ei$ then

$$Er/Ei + Ed/Ei = 1 - \alpha \qquad (7)$$

and as α is usually known, then only Er/Ei (reflection coefficient) or Ed/Ei (diffusion coefficient) need be determined. Although standard diffusion coefficients are being proposed [17] the emphasis is on the evenness of diffusion rather than allowing an accurate prediction of the energy at a given point from a given surface. For modelling reflections, a more logical approach would be to build up a database of reflection coefficients to complement the existing absorption coefficient database, and use a diffusion coefficient to guide the distribution of the remaining diffuse reflected energy. This may require directional data for both reflection and diffuse coefficients, but computer models already have algorithms for directivity modifiers, for natural and loudspeaker sources. This may appear to call for an alarming increase in computation time, but in practice only low order reflections arriving within the first 80ms or so would require this method as for later periods it is less important if the reflection is specular or diffuse so the statistical model may be used.

5. CONCLUSION

Improvements in computing power and graphic handling have improved visual representation of complex rooms but there are still practical limits on planar representations of auditoria, especially at 500Hz, which is important for RASTI predictions. The modelling of reflections as purely specular, purely diffuse or a simple combination of these two also has limits in low order reflections, which are important for both RASTI and Clarity predictions.

Using a small number of large planes to model auditoria leads to errors in geometry, errors in surface treatments and ignores fixtures but can produce general results . Using a large number of small planes leads to edge effect errors and the geometric assumption becomes less valid. There are a number of possible models for diffused reflections from surfaces and different models may be more appropriate for different planes.

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