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COMPUTER SIMULATION OF AUDITORIUM ACOUSTICS

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SUMMARY

The acoustic simulation of an auditorium using a computer is described, which allows the designer to listen to the sound of the proposed auditorium and to control its main acoustical parameters.

Other methods and further developments of these techniques are discussed.

INTRODUCTION

The acoustics of rooms as presently understood is not an exact science. It is not possible to predict reliably the properties of concert halls, recording studios, or multiple purpose auditoria from theoretical considerations. There are two identifiable reasons for this inability. The first is the complexity of the acoustic phenomena present within closed spaces, currently unresolveable by available mathematical methods. The second relates to the subjective aspects of auditory perception, which are often inexact with regard to specification of perceptual requirements.

The inability to use exact calculation methods makes it necessary to rely upon modeling techniques, if one wishes to avoid the possibility of significant errors in a design. This is particularly true when architectural and other requirements do not allow for the reproduction of existing acoustically successful solutions.

A large number of simulation procedures have been used to aid in the acoustical design of a hall. These range from simulations that allow partial understanding of certain limitted phenomena, such as ripple tanks and optical models in two dimensions, to more global procedures, such as three dimensional acoustic models and computer programs.

We aren't going to discuss the acoustic models which are well-known today, but only to discuss the use of the computer for simulation purpose in auditorium acoustics.

GEOMETRICAL ROOM ACOUSTICS AND COMPUTER PROGRAMS

Although three dimensional acoustical models are still often used on new important auditoria, more and more people are turning increasingly to computer programs, beacause of their many possibilities.

It is well known that there are currently two principal approaches in the computer modelling of acoustical phenomena in rooms, which are both based on the geometrical acoustics assumptions, the method of acoustical images and the method of sound rays. These two methods are very different from those trying to solve the wave equation with given boundary conditions. They are probably less accurate but they are much more easy to use than the others.

The source image method

The source image method is known to lead to a solution which converges toward the exact solution of the wave equation in the case of rigid boundaries.

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In ordinary conditions, this method is considered to allow for a valid approximation of the sound pressure within an enclosure, but rapidly encounters difficulties when the geometry becomes a little complicate. If "m" is the maximum order of the image sources taken in account and "p" is the numbers of walls, the total number of images to compute is given by

$$N = 1 + p\,\frac{(p-1)^m - 1}{(p-2)}$$

Amoung these sources, some of them cannot contribute to the acoustical pressure on a given point, so it is necessary to use very complex algorithms to test if the sources are to be kept or not.

For these reasons, the use of this method is in general restricted to rooms with simple forms.

The method of sound rays is in contrast, easily adapted to all sort of geometries, but due to the need of a source with a finite number of radiation directions and large microphone volumes', it cannot account for the wave aspects of acoustical phenomena.

The method allows for the prediction of an echogram provided that the energy content of each ray can be considered as uncorrelated. Most of the energy based criteria may be derived from this method,and the accuracy is strongly dependent on the number of rays, the sampling time interval for the echograms, the size of the microphones, the distance between source and microphone etc... On the other hand, it is not possible to derive impulse responses because of the strong approximations of the method, which forbid mainly to use a sampling time interval sufficiently small.

Neverthelєss, this method is widely used because of its simplicity and its advantages compare to the traditional rays drawing by hand.

THE METHOD OF CONES AND THE PROGRAM EPIDAURE

In order to improve the performance of computer room simulation, a new method has been developed at the acoustical department of the C.S.T.B., which derives from both the method of sound rays and the method of images. This method is in fact an image source method in which the really contributing sources are calculated according to a ray scanning of the volume, without any limitation in the maximum order of the source taken in account.

Each sound ray emitted by the source, represents the axis of a very directional source radiating energy in a cone of circular section associated with the ray, for which the vector propagation and reflections by the walls of the room are calculated. When a cone intercepts a point microphone, one can calculate the amplitude and phase of the contribution of the cone to the acoustic pressure at the microphone. It is also possible to take into account diffusive surfaces as well as the dependence upon frequency and angle of incidence for absorption coefficients of surfaces. For each microphone and each octave band considered, one can therefore calculate the equivalent of the impulse response with a temporal resolution of 25 to 100 μs for a duration of 200 to 800 ms. By digital filtering and processing of the impulse responses calculated for different frequency bands, one obtains the impulse response for each microphone position over an height octave frequency band, compatible with the temporal resolution chosen.

When the axis of a cone hits a diffusive surface, its energy content is partly geometrically reflected and partly diffused, according to the diffusion coefficient. The diffused part is supposed to be radiated by a virtual source, located at the impact point, with a cosine law for the directivity and a time history derived from the reverberant characteristics of the hall.

The reconstruction of a spherical source with a given directivity is achieved by using a small angle between rays (usually 1 degree) overlapping the cone with a directivity fonction in cosine square and weighting the amplitude in each cone.

Before analysis of the results, the impulse responses are lengthened by extrapolation using a random process, having the same frequency and statistical characteristics as the reverberant part of the response. Next one calculates frequently used indices such as E.D.T., clarity, speech intelligibility as derived from M.T.F. and others. By digital convolution with an anechoic sound segment, one calculates the sound that one could hear in the hall under study. This simulation is of particular interest since it allows direct subjective evaluation of the acoustics of the room.

The program EPIDAURE which used this method coresponds in fact to a set of programs allowing :

- to define the geometry of the hall using only plane surfaces up to more than 200, the acoustical characteristics of the materials, and some computing parameters
- to display axonometric or perspective views of the hall from inside or outside
- to calculate an estimate of the reverberation time
- to calculate the impulse responses in height octave bands and in wide band
- to calculate the convolution process, after lengthening of the response, to obtain the sound that one could hear in the hall
- to analyse the main reflections and to display the acoustical paths corresponding to given components of the impulse response
- to draw maps of acoustical indices over the audience, such as sound level (dB(A) or octave band), clarity, definition, speech intelligibility, or lateral efficiency.

The table 1 gives an overview of the main feature of the program.

A part from the effect of the scanning process used to find the image sources, which are very small because of the large number of rays, this method is based on the same assumptions as the image sources method. Due to the high order of the source taken in account, its accuracy is better and its use is much more flexible.

To test the validity of this method, we have done a lot of comparisons with theoretical situations and actual halls. As an example, the figure 1 shows the amplitude of the acoustical pressure on the median plan of a rectangular box, in which four sources in the corners are adjusted to excite the normal mode 2-1-2.

TABLE 1 : EPIDAURE PROGRAM MAIN FEATURES		
	NUMBER	COMMENTS
Source	1	– Adjustable directivity and spectrum – Uniform distribution of rays associated with cones – Any number of rays depends on the angular resolution
Surfaces	≤ 128	– Must be plane surfaces – May be defined as reflective, transparent, diffusing or receiving
Absorption		– May depend on angle of incidence or not – Defined in octave band by a coefficient
Diffusion		– Defined in octave band by a coefficient – Cosine law and time scattering
Receivers	9 2 000	– Dot microphones for impulse response – Dot microphones with spherical and cosine directivity for receiving surfaces
Frequency	16 kHz or 32 kHz	– Sampling frequency - may be changed
Impulse response	9 for each microphone 8 192 points 512 ms or 256 ms	– One for each 8 octave bands plus one for wide band (32 Hz to 4 kHz or 63 Hz to 8 kHz) – Length of the time window depending on the frequency

The results obtained with this method for several existing auditoria show a good agreement with the measured impulse responses. Reverberation times, early decay time, clarity are predicted with an accuracy of about 10 %. The resultant simulation of the sound of these rooms offers, though not yet a perfect simularity, a really similar impression. The differences between the calculated sound and the sound directly recorded in the actual rooms are nearly the same as those you can hear, when you switch from one loudspeaker to another.

The figures 2 to 5 show some outputs of the program EPIDAURE.

To improve the performance of the system, the stereophonic prediction of the impulse response is going to be introduced in the program. In addition to stereophonic listening, this development will allow the calculation of parameters relevant to lateral reflections and spatial impression.

An effort to simplify and speed up the calculation is currently being done, as well as extended validity tests of the program, on auditoria of different size and shape.

CONCLUSION

The new developments in computer simulation of room acoustic that we have just described, the experience of acousticians already using this calculation program, as well as the more recent ideas for improvement of the method, suggest that the computer as a design tool for the prediction of room acoustics will continue to grow in importance in coming years. Similarly, it is possible to anticipate the development of programs written for non-specialists that allow for computer assisted design (C.A.D.) in room acoustics, particularly for the resolution of many minor acoustical problems encountered by designers.

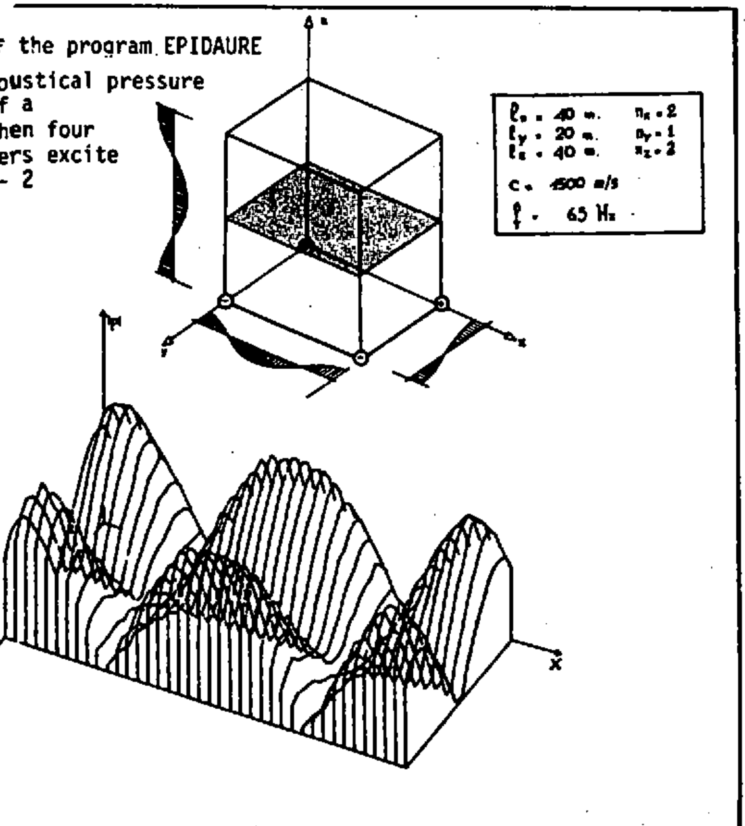


Figure 1 : Result of the program EPIDAURE

Amplitude of the acoustical pressure on the median plan of a rectangular room, when four sources in the corners excite the normal mode 2-1- 2

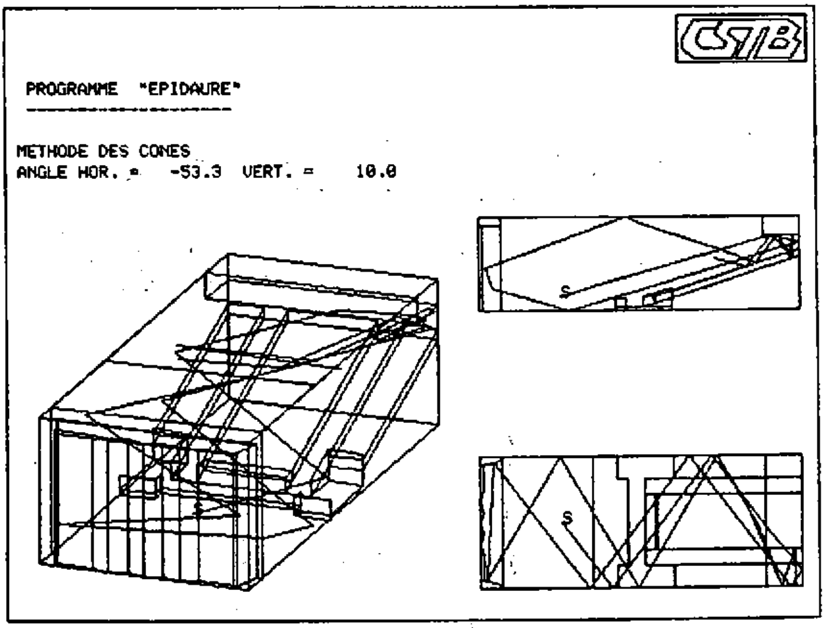


Figure 2 : A ray propagating in a concert hall (axonometric view of the numerical model, plane view and cross section).

Figure 3 :
Wide band impulse response on a microphone

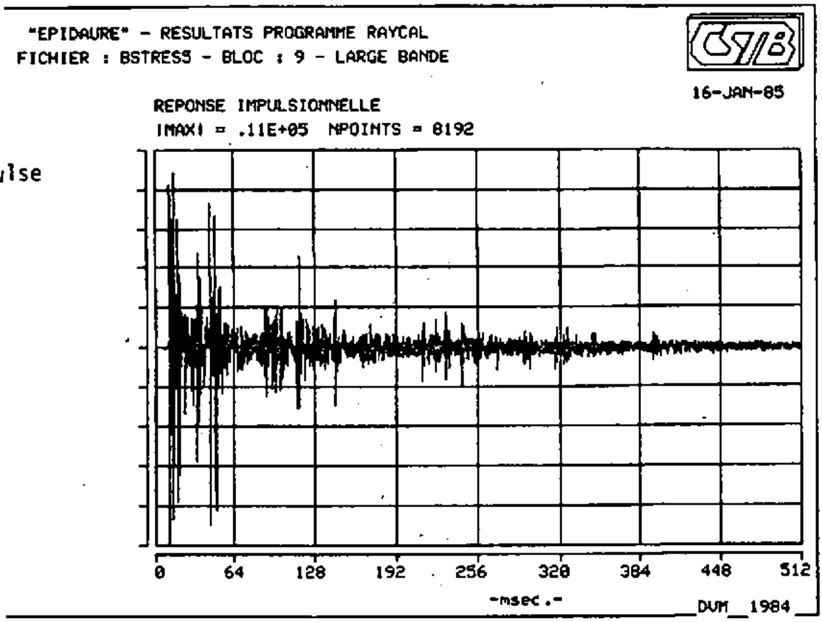
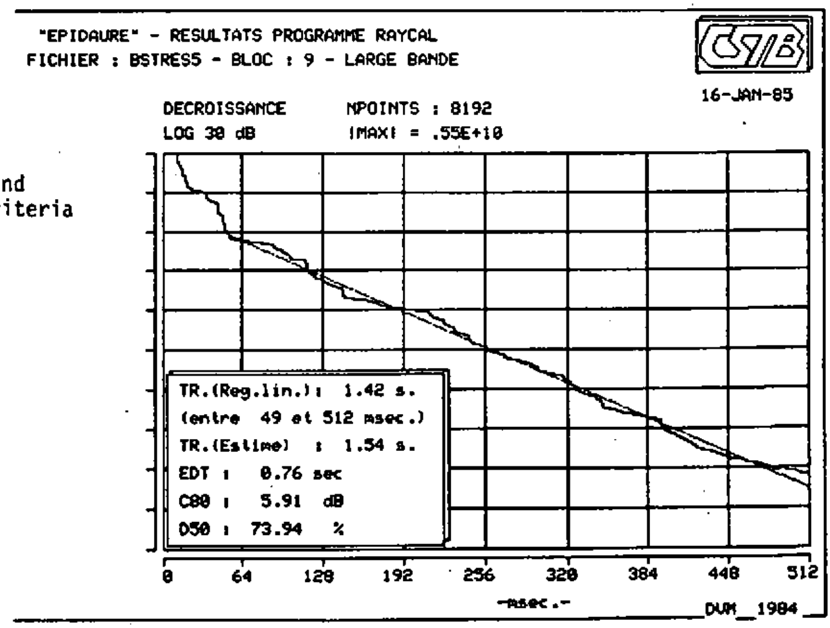


Figure 4 :
Decay curve and acoustical criteria derived from impulse response of Figure 3



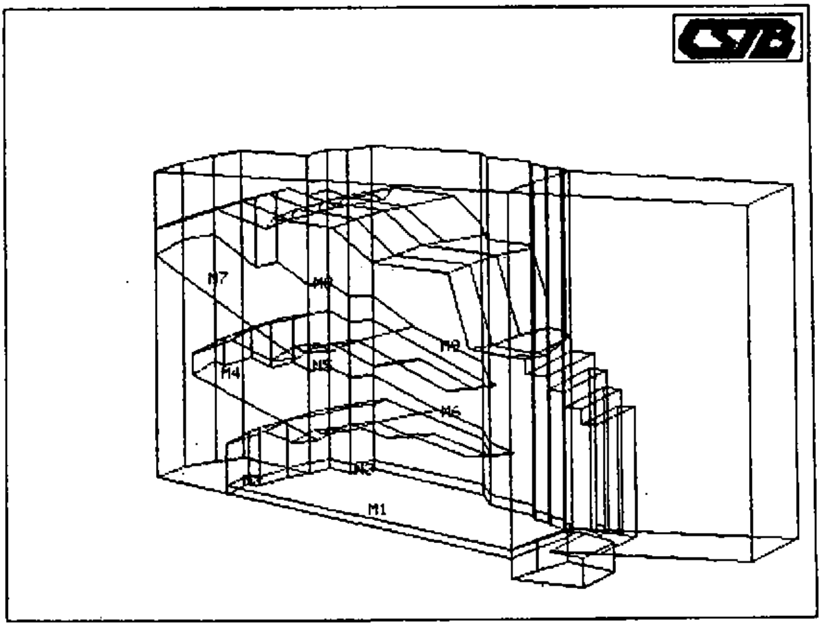


Figure 5 : Axonometric view of the numerical model of an Opera House