Low-frequency models for room acoustic prediction

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This paper studies some recent methods for the calculation of room impulse responses: a 3D waveguide method and a method based on edge diffraction. A simple model of an auditorium is used to study wavefront propagation with these methods and it is shown that they can both predict the correct wave front propagation at low frequencies.

INTRODUCTION

Computer simulations have been used for room acoustics prediction for a long time. Most commercially available software is based on geometrical acoustics (GA). Recently, their performance was evaluated in an international round robin and demonstrated that the accuracy is good for mid to high frequencies but worse for the lowest octave band, 125 Hz [1]. This is clearly because methods based on GA can not correctly handle wave phenomena, such as effects of finite surfaces and complex surface impedance. In an earlier attempt to improve performance, a GA method was complemented with the accurate boundary element method for low frequencies [2].

The purpose of the current paper is to compare recent time-domain methods that are accurate in the low-frequency region. A very simple model of a concert hall, shown in Fig. 1, is chosen as a test case.

METHOD

For rooms with rigid surfaces, the exact sound wave solution can be written as a sum of the GA solution,

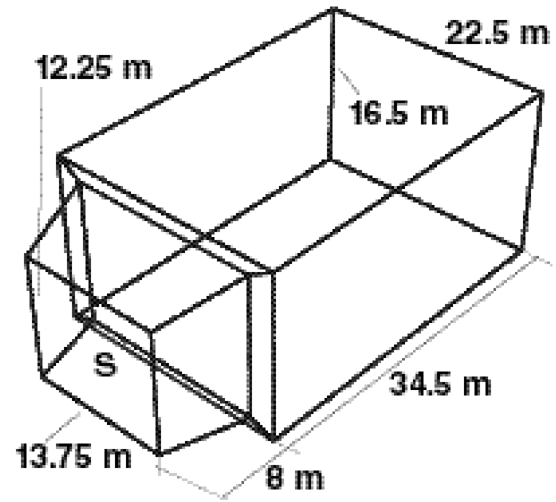

FIGURE 1. Illustration of the model of the concert hall used as an example. Some key dimensions, as well as the source position, are indicated.

i.e., direct sound and specular reflections, and edge diffraction (ED) components. The latter represent the effects of the finite sizes of surfaces. A new formulation based on the exact Biot-Tolstoy solution is used here [3]. For this formulation, all edges of the room are subdivided into small edge elements that act as secondary sources. These sources generate higher-order diffraction and combinations of reflections and diffraction. This method has no inherent approximations and the entire frequency band of interest can be covered as long as enough reflection/diffraction combinations are included. In addition, as an add-on to existing methods based on GA, the ED method is very straightforward. However, a notable limitation is that no formulation has been developed for general complex impedances yet.

Two related time-domain methods that can handle arbitrary surface impedances are the wave-guide (WG) method [4] and the transmission-line (TL) model [5]. Both are based on a subdivision of the air volume into equally-sized cubical elements. The wave equation is solved by step-wise propagating a sound wave, one element per time step. For both methods the propagation will be dispersive, with different propagation speeds in different directions. For the WG method, non-cubical elements and time-domain interpolation have been shown to minimize these problems.

The ED method is efficient with large planes and few edges, whereas the WG and TL methods are more advantageous for complex geometries. The WG and TL methods also automatically give the response at many receiver points while the calculation time for the ED method basically is proportional to the number of receiver points.

NUMERICAL EXAMPLES

The sound pressure was calculated across the hall in Fig. 1 after the single source, 1.25 m above the stage floor, emitted a pulse band-pass filtered in the 125 Hz octave band. Receivers were placed in the regular grid of the WG model, with 25cm spacing in a plane 1.5m above the audience floor, or 0.25m above the stage floor. Fig. 2 shows snap shots after, (a), 100 and, (b), 150 time steps using a sampling frequency of 2.4 kHz and the WG, the ED, and the GA methods. The stage house shape is visible at the top of the plots. Fig. 2 shows that the GA method gives truncated wave forms, which clearly are unphysical. The WG and ED methods show similar results with continuous wave fronts, and waves apparently emanating from the edges around the stages. Some differences between the two methods are due to a lack of higher-order diffraction components for the ED method.

CONCLUSIONS

It has been demonstrated that two quite different time-domain methods give similar results in the low-frequency range for a concert hall case. For mid- to higher frequencies the time-domain methods can be combined with a GA based method in a relatively straightforward manner. Simple geometries with rigid surfaces are efficiently modelled with ED methods whereas more complex cases need WG or TL methods.

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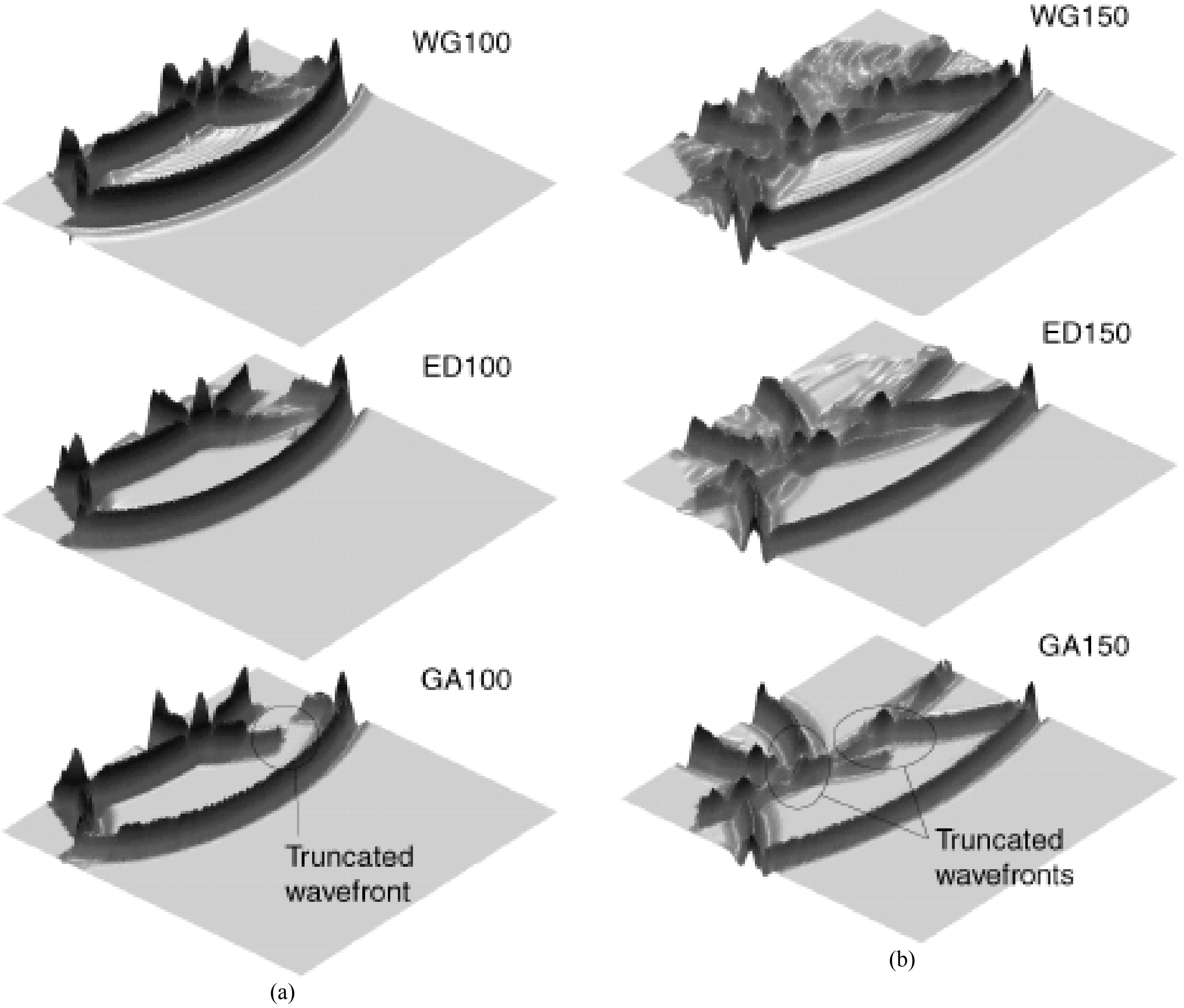

FIGURE 2. Snapshots of the wave field aross the hall in Fig. 1 after (a) 100 and (b) 150 time steps for the WG method, the ED method, and the GA method. The stage is in the upper left part of each diagram.