BEAM-TRACING MODEL FOR PREDICTION OF IMPULSE RESPONSES, AND EFFECTS OF SURFACE-REACTION MODELING AND EDGE DIFFRACTION IN ROOMS

Behrooz Yousefzadeh and Murray Hodgson
Acoustics and Noise Research Group, University of British Columbia,
3rd floor, 2206 East Mall, Vancouver, BC, V6T 1Z3, Canada

1. INTRODUCTION

This paper presents the development of a wave-based, triangular-beam-tracing model for predicting the transient response of rooms. The model is based on the one developed by Wareing and Hodgson [1] for studying the steady-state response of empty rooms with specularly-reflecting, extended-reaction surfaces. Room surfaces are modeled as multiple layers of elastic solid, fluid or poroelastic materials, and their acoustical properties are calculated using a transfer-matrix approach. The new model can predict the pressure impulse response between a source and a receiver, required for deriving room-acoustical parameters that correlate with the subjective perception of sound. Energy-based prediction (including diffuse surface reflection) has been implemented in the new model, and both wave- and energy-based modeling have been validated against theory for the case of sound propagation above a specularly- or diffusely-reflecting rigid plane.

The model has been further improved to include sound diffraction around wedges, based on the theory developed by Svensson *et al.* [2]. This improves the application of the model to configurations with more realistic features, such as sound propagation in fitted rooms or in long enclosures with bends, and the evaluation of screen barriers in open-plan offices. The application of the beam-tracing model is not limited to rooms; provided that the proper boundary conditions are used, it can be applied to other environments such as ventilation ducts and outdoor environments where the medium is unbounded in one or more directions.

2. TEST CONFIGURATIONS

The new beam-tracing model was used to compare the effects of different surface-reaction models on the transient response and derived room-acoustical parameters. In addition to investigating the significance of modeling room surfaces as of extended or local reaction, effects of phase change due to surface reflections have been studied by considering real and complex reflection coefficients. Moreover, wave-based energy impulse responses and room-acoustical parameters have been compared with those obtained from energy-based modeling.

Following the previous investigation of the effects of extended- and local-reaction surfaces on steady-state sound levels in rooms [3], three room geometries were studied: Room 1: a small office (3*3*3 m^3); Room 2: a corridor (10*3*3 m^3); and Room 3: a workshop (10*10*3 m^3). In each room one or more of the surfaces were modeled as multilayer walls. The configurations were as follows: a single glass panel as a large window in all three rooms (configurations G1, G2, G3); the previous configurations, but with double glass panels, (DG1, DG2, DG3); four walls modeled with double drywall panels in Rooms 1 and 2 (D1, D2); double steel panels as the walls in Room 3 (SW3); carpet on a hard backing as the floor in Rooms 1 and 2 (C1, C2); suspended acoustical ceiling modeled as a fiberglass with air backing in Rooms 1 and 2 (SAC, SAC2); double-steel panel as the ceiling in Room 3 (SC3); and fiberglass with a rigid backing as the floor for Room 3 (FG3). In all cases, other room surfaces had an angularly-invariant average diffuse-field absorption coefficient of 0.1.

3. APPLICATION OF THE MODEL

In each room configuration, predictions were made using both the energy and phase models. The energy model is the same as the phase model except that, instead of complex values of sound pressure (magnitude and phase), squared absolute values of pressure are calculated. Moreover, the effects of phase changes due to reflections have been studied by considering both complex and real reflection coefficients. The following room-acoustical parameters were calculated for each configuration, in octave bands from 63 to 4000 Hz: EDT, T20, T30, Ts, C80 and C50.

All predictions in this work have been made with 4500 beams traced for 80 reflections. The acoustical properties of the multilayer surfaces were pre-calculated in order to make runtimes reasonable. The impedance of each surface was calculated for angles of incidence from 0 to 90 degrees, with 1-degree increments. The reflection coefficients of the extended-reaction surfaces were then calculated accordingly. For local-reaction surfaces, the impedance value at normal incidence was used for all angles of incidence [3].

Pressure impulse responses were obtained in each configuration from the room transfer function via inverse Fourier transformation. Energy echograms were found by keeping track of the arrival times of beams, and their corresponding sound energies at the receiver positions. Sound-decay curves were then computed by backward integration of the squared impulse responses or the echogram, respectively, for the wave-based or energy-based models. Figure 1 shows octave-band sound-decay curves at 1000 Hz for configuration SAC2, the corridor with suspended acoustical ceiling.

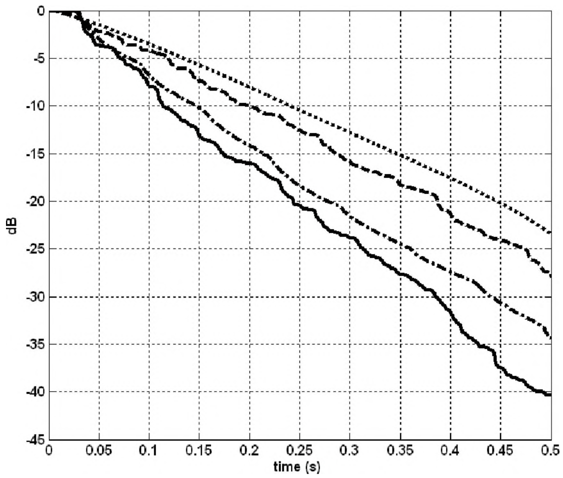

Figure 1. Octave-band sound-decay curves at 1000 Hz for configuration SAC2, the corridor with suspended acoustical ceiling. Solid line: extended reaction, wave-based; dash-dot line: extended reaction, energy-based; dashed line: local reaction, wave-based; dotted line: local reaction, energy-based.

4. SUMMARY OF THE RESULTS

Values obtained from wave-based modeling with extended-reaction surfaces are considered to be theoretically more accurate than other cases and therefore were chosen as reference values. Consequently, the standard deviation in the difference in values of the room-acoustical parameters with respect to the reference case was regarded as the comparison criteria.

The study results can be summarized as follows:

- The effects of changing between local- and extended-reaction modeling are in general smaller than the effects of changing between real and complex reflection coefficients, or changing between energy and phase models.

- Changing between local- and extended- reaction modeling is always least significant when using complex reflection coefficients with a phase model and is often most significant when using real reflection coefficients with a phase model.

- As expected, parameters obtained using a phase model with real-valued reflection coefficients are closer to reference values than those obtained using an energy model.

- When working with a phase model, extended-reaction surfaces often give results closer to reference values than local-reaction surfaces. Nevertheless, similar results were not observed for an energy model.

- Changing from complex to real reflection coefficients, and from a phase to an energy model, is, with a few exceptions, more significant in DG1, DG2 and DG3 than in G1, G2 and G3. This is due to the fact that the phase of the reflection coefficient of a double-glass panel is often larger than that of a single-glass panel.

- Changes in reverberation times (EDT, T20 and T30) follow the general trends mentioned above, except for SAC1 and SAC2 which have their most significant change in the case of local-reaction modeling with complex reflection coefficients in the phase model. Changing to real reflection coefficients and to the energy model is less significant. The suspended acoustical ceiling is the only multilayer surface in these rooms. Therefore, the large changes can be attributed to a large phase difference between the local- and extended-reaction reflection coefficients of the suspended acoustical ceiling for the incident angles of the early reflections from the ceiling.

- Similar results to the one above are observed for Ts, C80 and C50, but only for configuration SAC1. Since the dimensions of SAC1 and SAC2 are different, this can be attributed to bigger phase changes of the early reflections in SAC1.

- Changing from phase to energy modeling affects clarity indices - C80 and C50 - more than other parameters (these changes are more significant for C50). This indicates the significance of wave effects in the clarity of perceived sound. While changing from complex to real reflection coefficients makes non-negligible changes in both clarity indices, the changes are not always significant.

- Ts is the parameter which is least affected by a change of modeling conditions, with the most significant differences occurring for D1 and D2. While changing between local and extended reaction is overall not significant (*i.e.* below 10 ms), changing between phase and energy models is significant at all frequencies. Changing from complex to real reflection coefficients often makes the reverberant field stronger, and increases the center time. On the other hand, changing from phase to energy modeling often decreases the center time.

REFERENCES

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