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Modeling chairs and occupants to closely approximate the sound absorption of occupied full scale theatre chairs

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ABSTRACT

The present work reports on the process of modeling chairs and occupants to closely approximate the sound absorption of occupied full scale theatre chairs and explains how the best form of model listener was determined. Modifying the form of the model listeners to have shorter upper legs and narrower lower legs, led to improved agreement between model and full scale occupied chairs at all frequencies including at 125 Hz. The measured absorption coefficients of single blocks of model chairs with or without model listeners agreed well with the measured values for both full scale types E and G chairs. However, the estimated values for larger sample blocks of model chairs with $P/A = 0.5\ m^{-1}$ showed better agreement with the measured values for full scale type G chairs than type E chairs due to the different slopes of the regression lines versus P/A. The present results demonstrate that the model chair and listener accurately simulate the sound absorption characteristics of a particular type of quite absorptive full scale occupied chairs for all sample sizes of the full scale chairs.

1. Introduction

The successful modeling of chairs and occupants in scale models is particularly important because the audience is usually the largest single component of absorption in an auditorium. Some previous studies [1–6] have demonstrated the development of model listeners for adding the sound absorption of an audience, seated on chairs, in model lecture rooms or auditoria. The model listeners have varied in form from egg cartons [1] to the simplified human forms [2,3,5]. Table 1 summarizes the details of model listeners developed in some earlier studies.

Day [2] developed 1/10 scale model listeners with a simplified human form to investigate the effect of the degree of occupancy on the audience absorption in a model lecture room. The model listener consisted of smoothed softwood body and hardwood head. A single layer of surgical gauze was used for simulating human clothing. Hegvold [3] investigated the effects of the amount of clothing worn by a person on the absorption of a group of people and developed 1/8 scale model listeners to simulate the sound absorption of a typically dressed Sydney audience. The model listeners were constructed with a rigid polyurethane foam body and a sanded pine head. Hegvold adopted Day's simplified human form to model the sound absorption of model Sydney listeners.

Cremer et al. [4] used cardboard egg cartons to simulate the sound absorption of the audience in a 1/16 scale model of a multi-purpose hall and found that the cardboard egg cartons were capable of simulating the partially diffuse reflections from the audience. In a recent study, Tahara et al. [5,6] developed 1/16 scale model listeners to simulate the audience absorption in a model auditorium. The model listeners consisted of a wooden head with a single layer of 1 mm felt simulating human hair and a wooden torso. Their model listeners were more similar to a head and torso simulator rather than the simplified more complete human form of model listeners developed by Day and Hegvold. Similar types of head and torso forms of model listeners were used in other recently reported scale model predictions [7]. The absorption coefficients of the simple forms of model listener were obtained from the measurements of single blocks of model chairs, and therefore the results were never justified to closely approximate the absorption characteristics of occupied full scale chairs for all sample sizes of the chairs.

Some earlier studies demonstrated the value of using model tests to better understand the sound absorption of theatre chairs [3,8,9]. Reverberation chamber tests of both model and full scale chairs showed that the sound absorption characteristics of smaller blocks of chairs are not representative of those found for the larger blocks of chairs in an auditorium because the measured absorption coefficients vary with the dimensions of the sample and larger samples tend to have lower absorption coefficients due to edge effects [3,8–10]. The edge absorption may be reduced by using screens around the seating blocks, but diffraction effects are not eliminated by this method and the absorption coefficients of the seating blocks would still vary with the sample perimeter-to-area

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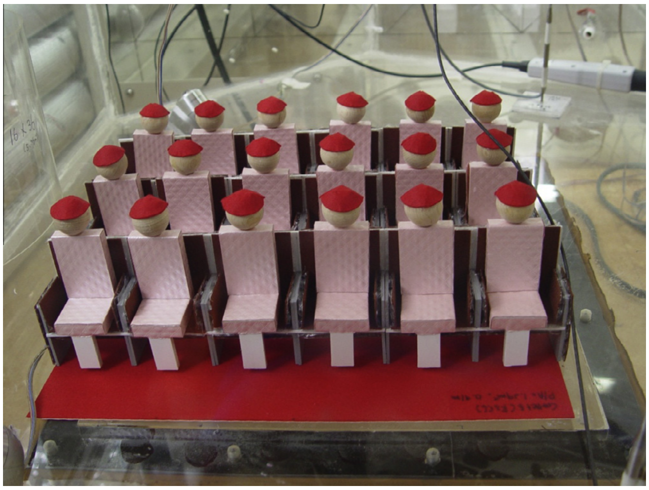

Fig. 1. A photo of high absorption model chairs occupied with model listeners in the model reverberation chamber.

(P/A) ratio both in full scale [9–11] and in model tests [3,9]. This would also be true for the approach of putting absorbing samples in a well in the floor of the reverberation chamber [12]. This latter method is also not very practical for objects as large as chairs. The sound absorption coefficients of blocks of theatre chars have been shown to be linearly related to the sample P/A ratio [10]. One can predict the expected absorption coefficients of the larger blocks of chairs found in auditoria using linear regression fits to the measured values obtained from 5 or more sample blocks of chairs with varied P/A ratio in a reverberation chamber. This method is referred to as the P/A method. This method can more completely characterize particular types of chairs than one sound absorption test of a single sample block of chairs in the reverberation chamber. The method has been shown to accurately predict the absorption coefficients of chairs measured in an auditorium both in full scale [10,11] and in model tests [9,13].

Many have previously used scale model chairs and listeners, but previous efforts to create scale model chairs and occupants have not always been very thorough. There are a range of absorption characteristics for occupied and unoccupied theatre chairs and the absorption characteristics vary with P/A and the form of this variation varies with chair type [13]. It is not enough to compare single samples in reverberation chamber tests. One should validate model chairs and occupants to confirm that the variation of absorption coefficients with P/A for the model chairs and listeners are similar to those for common types of full scale chairs with occupants. This would ensure that absorption coefficients of the model chairs would be similar to the corresponding full scale chairs for all sample sizes of the chairs.

This process could enhance the credibility of future studies using these model chairs and occupants such as for investigation of the incremental effects of occupants in chairs or carpet under chairs on the absorption coefficients of each combination. It is important to better understand such interactive effects rather than to depend on measurements of every new situation. The goal of this work is to develop model chairs and occupants as closely representative as possible of common types of full scale theatre chairs with audiences. The present work reports on the process of modeling chairs and occupants to closely approximate the sound absorption of occupied full scale theatre chairs and describes how the best form of model listeners was determined. This paper was also intended to give some useful guidelines on constructing model occupants by investigating how the form and dimensions of model listeners affect to the measured sound absorption characteristics of occupied theatre chairs.

2. Measurement procedures

2.1. Model chair construction

The main purpose of developing various types of model theatre chairs and listeners was to accurately simulate their sound absorption characteristics and to better understand how they affect to the acoustical conditions in real auditoria. The model chairs and occupants were developed to have similar absorption characteristics, as a function of P/A, to typical more highly absorbing full scale chairs and occupants. The previously reported results for full scale types E and G chairs [10,11] were used as design goals for the model chairs and occupants.

The type E chairs were considered very highly absorptive chairs and the type G chairs more typically highly absorptive. These high absorption full scale theatre chairs had thicker absorbing material and included thick absorbing pads on the chair backs. The type E chairs also had absorptive padding on the rear of the seat backs as well as on the arm rests and sides of the chairs. They also had quite thick and absorptive seat cushions and perforated seat pans over glass fiber material. Chair type G had cloth covered metal of the rears of the seat backs. The slopes and intercept values of the regression lines for both unoccupied and occupied types E and G chairs were included in Ref. [13]. Beranek and Hidaka's [14] estimates of the average absorption coefficients of the most absorptive group of chairs (their Group 1) were less absorptive than the values calculated from the measured types E and G full scale occupied chairs with $P/A = 0.5\ m^{-1}$.

A variety of 1/10 scale model chairs were systematically tested to develop a model chair with absorption characteristics similar to those for full scale high absorption chairs. Model chairs having a width of 0.6 m (full scale) were constructed as connected seats with arm rests and underpasses as shown in Fig. 1. The height of

Table 1
Summary of the model listeners developed in previous studies. The symbol "Ø" indicates the diameter of the model listener's head measured in mm.

Researcher (year)	Materials	Scale	Size (width × length × depth), mm
Brebek et al. [1]	Egg cartons	1/10	–
Cremer et al. [4]		1/16	
Day [2]	Head: softwood Body: hardwood Cloth: surgical gauze adding on the body	1/10	Head: Ø25 Torso: 35 × 75 × 18 Hips: 35 × 45 × 18 Legs: 35 × 47 × 18
Hegvold [3]	Head: sanded pine Body: polyurethane foam Cloth: no cloth	1/8	Head: 22.2 (depth) × 31.7 (length) Torso: 54.6 × 73.6 × 22.2 Hips: 54.6 × 57.2 × 22.2 Legs: 54.6 × 58.4 × 22.2
Tahara et al. [5]	Head: wood Torso: wood Cloth: felt 1 mm adding on the torso and head	1/16	Head: Ø10 Torso: 24 × 38 × 12