Concert-hall acoustics: meeting place of science and art

Concert Hall Acoustics

Yoichi Ando
151 pp. Springer-Verlag, New York, 1985. $41.50

Reviewed by Leo L. Beranek

This book joins the handful written since 1900 on the science of concert-hall acoustics. It should be on the shelf of every acoustician interested both in practice and in research. The substantial use of mathematics throughout the text will make it difficult for "architects and musicians alike" to read, contrary to what is suggested in the foreword. The author, Yoichi Ando, promises much—"the precise qualities necessary for attaining excellent results"—and in the foreword Manfred Schroeder writes that present research "has finally elevated the art of concert hall acoustics to the level of a reliable science." Wallace C. Sabine promised much the same in 1900 (see PHYSICS TODAY, February 1985, page 44), and other writers since have evinced similar confidence. We hope that history bears out the level of assurance expressed in this book.

Certainly, no other acoustician has written a text like this. It contains seven chapters packed with physical acoustics, the behavior of the physical hearing system, the response of the nervous system, the formation of psychoacoustic judgments, the composition of a sound field in a hall, prediction of subjective preferences in halls based on the sound field, and design studies for concert halls. The whole now awaits the test of time, especially since the book makes no reference to concert halls of different shapes as "musical instruments" that can lend different textures to the same music, with resulting differences in levels of acceptance by musicians and critics.

Ando specifies the acoustic characteristics of a hall in terms of a sound-pressure transfer function, which yields the music at the two ears in terms of a number of reflected sound components and the reverberation that follows after the first few reflected components. He then states that all independent objective parameters of acoustic information arriving at the basilar membranes of the two ears may be reduced to

- the autocorrelation function of the source
- a set of transfer functions that represent the effects of reflections and reverberation
- the interaural cross-correlation between the signals that arrive at the two basilar membranes.

From this last "spatial-binaural criterion" Ando concludes that the direction of arrival of early reflections in a hall must be taken into consideration. Ando has determined the preferred values of these parameters, using 19 Japanese listeners exposed to electronically generated sounds in an anechoic chamber.

Ando next describes a laboratory setup for simulating the acoustics of a hall. From his tests, Ando obtained four subjective preference parameters, which he is satisfied are independent of one another. For each parameter, Ando develops a linear scale of values; he then combines these to yield a "total value of preference" for the acoustics of a concert hall. Finally, he tests this total criterion on the plans for one hall, Boston Symphony Hall,

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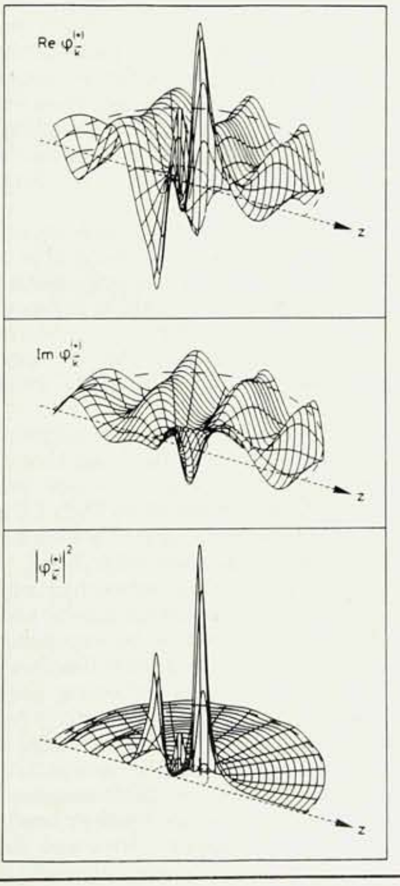

Scattering of a plane wave incident from the left along the *z* axis by an attractive potential confined in the region indicated by the small semicircle. This computer-generated figure shows the real part, the imaginary part and the absolute square of the resonant wavefunction. The figure is reprinted from *The Picture Book of Quantum Mechanics*, by Siegmund Brandt and Hans Dieter Dahmen (Wiley, New York, 1986, $29.95). The book consists of an exposition of the principal ideas of wave mechanics supplemented by a large number of computer-drawn figures produced with a program developed especially for the book. Brandt and Dahmen write in the preface that computer drawings are very helpful for developing in the student "an intuition of how the concepts of classical mechanics are altered and supplemented by the arguments of optics in order to acquire a roughly correct picture of quantum mechanics." The book contains more than a hundred problems, many of them designed to help students extract the physics from the figures. (Illustration reprinted with permission of the publisher.)

with good results.

The last chapters of the book are devoted to an acoustic-design study based on the four preference scales and on acoustic test techniques for determining the four independent objective parameters in concert halls.

The overall study represents a prodigious effort that could lead to a new era of concert-hall design. Ando's conclusions will have to be tested in other types of simulation of concert halls, both by him and by other experimenters. Furthermore, halls of designs different from Boston Symphony Hall that satisfy his design criteria will have to be built and tested to learn if they meet the approval of musicians, music critics and concertgoers. History shows that this will require an architectural cycle of 30 to 50 years.

Ando makes a number of assumptions at various stages of the study that must be mentioned here:

▶ He rejects the use of reflecting panels ("acoustic clouds") in large or fan-shaped concert halls for obtaining sufficiently short initial-time-delay gaps (the time between arrivals of the direct sound and of its first reflection at a listener). He shows that a mathematical analysis of sound reflections from a single flat rectangular plate reveals "generally an absence of low-frequency reflected sound." He is correct. Indeed, as Schroeder mentions in the foreword, the acoustic clouds in New York's original Philharmonic Hall (now called Avery Fisher Hall) were widely considered unsatisfactory. However, highly satisfactory experiences with reflecting panels have been obtained in a variety of concert halls, notably the very large, fan-shaped Music Shed at Tanglewood in Lenox, Massachusetts.

▶ In applying the total scale value to Boston Symphony Hall, Ando does not consider reflections and scattering by balconies and floors. However, years of listening in that hall have convinced me that the balconies play an important part in establishing the initial-time-delay gap.

▶ In his tests Ando used young, mostly Japanese listeners. He found that the preferred reverberation times were fairly short—a little more than 1.5 sec for a Haydn symphony in a wide hall, for example. On the other hand, the Music Shed at Tanglewood has a full-occupancy reverberation time of about 2 sec, which is judged by experienced concertgoers as ideal for full-orchestra music. One wonders if young people from any nation, and particularly from a non-European culture, can judge the acceptability of musical acoustics for Western symphonic performances in the same way as do Western conductors, Western music critics and older Western concertgoers around the world.

▶ One of the most difficult facets of concert-hall acoustics that models or subjective laboratory tests must deal with is the fact that an orchestra consists of 105 musicians distributed over an area of about 200 m^2. Is a high rating obtained from each point on the stage by listening to the whole orchestra through a loudspeaker moved around equivalent to getting the same result for an orchestra with the different instruments located at different points all over the stage? This is one of many troublesome questions that will be resolved only by experience with new concert-hall design.

▶ And finally, Ando does not refer to the widely confirmed criterion that the reverberation time should be higher at low frequencies than it is at mid- and high frequencies.

I would like to conclude by responding to Schroeder's critical remarks in the foreword about the 1962 design of Philharmonic Hall, in which I was involved. First, I am certain that Schroeder would agree that the building of the first new concert hall in New York City since 1891 was an emotional event that closely involved the building committee representing the owner (Lincoln Center), the architect, the orchestra that would use the building, the acoustical consultant and the concertgoers who are represented by the music critics of the city's newspapers.

The original design was, as agreed, based on Boston's Symphony Hall, but with a longer reverberation time, 1.9–2.0 sec. To meet the acoustic preferences known at that time, the resulting design provided a seating capacity of 2400 persons; the small capacity was due to the large row-to-row seat spacing and seat width that the architect and owner demanded. Over my insistent objections, the balcony shapes and styles, rather than the chair size, were changed to accommodate 200 more people.

A number of other changes were made—without my approval—that affected the acoustics of the hall, some to cut costs, others to add features desired by the owner. For example, the architect was unable to incorporate a set of hung reflecting panels that resembled the ideal type used in Tanglewood. As a minimum, I had asked for the ceiling panels to be adjustable row by row and by individual tilt. To reduce costs, the row-by-row adjustability was eliminated and the adjustability of the tilt was restricted.

When the hall opened there was a deficiency of bass, which later laboratory tests showed could have been eliminated by realigning the panels and by bridging some of the spaces between them to produce varying sizes of panels. There was also an annoying echo,