ARCHITECTURAL ACOUSTICS WORKBOOK

M. David Egan

New Acoustics Workbook (200 pages). Supported by Newman Fund.

Intended to be a self-study aid for students and teachers. For 17 sample pages, including Table of Contents, refer to Paper Copying Service (Golden Gavel I).

1. Acoustics Demos

    - Ripple tank on overhead projector (Kellogg & Ceraldi)
    - Full-scale pulpit canopy by Clemson students (evaluated by RASTI)
    - Noise box (Oregon tribute)
    - Examples from Rossing et al

2. Hands-on and Ears-on Self-Study Exercises

    - Acoustical diary using low-cost sound-level meters
    - AI word lists
    - Ray diagraming
    - Optical models (several case study drawings)
    - Fill-in blanks problems and tables (see sample pages)

3. Directed Self-Study Projects

    - Noise impact assessments by walk-talk method (Schultz for HUD)
    - Listening to buildings using evaluation guide (several case study drawings)
    - Electronic sound systems identification guide (Shade)

4. Learning Resources

    - Books (from publishers, ASA, INCE, NSCA)
    - Videos, CD-ROMs, manufacturers booklets (Wenger examples)
    - Grants (Newman Fund's Schultz grant, AIA's Fellows grant)

5. Ethics in Acoustics (part of section on acoustical design projects)

    - To quote H. G. Rickover (1974): "Any system of education which does not inculcate moral values simply furnishes the intellectual equipment whereby men and women can better satisfy their pride, greed, and lust."
    - Need moral courage to *not* tolerate: trimming, cooking, forging, and plagiarizing.

ARCHITECTURAL ACOUSTICS WORKBOOK

M. David Egan, Hon. AIA

Consultant in Acoustics
and
Professor Emeritus
Clemson University

Charles W. Tilley, AIA

Production Editor

Supported in part by a grant from
The Robert Bradford Newman Student Award Fund
Lincoln, Massachusetts

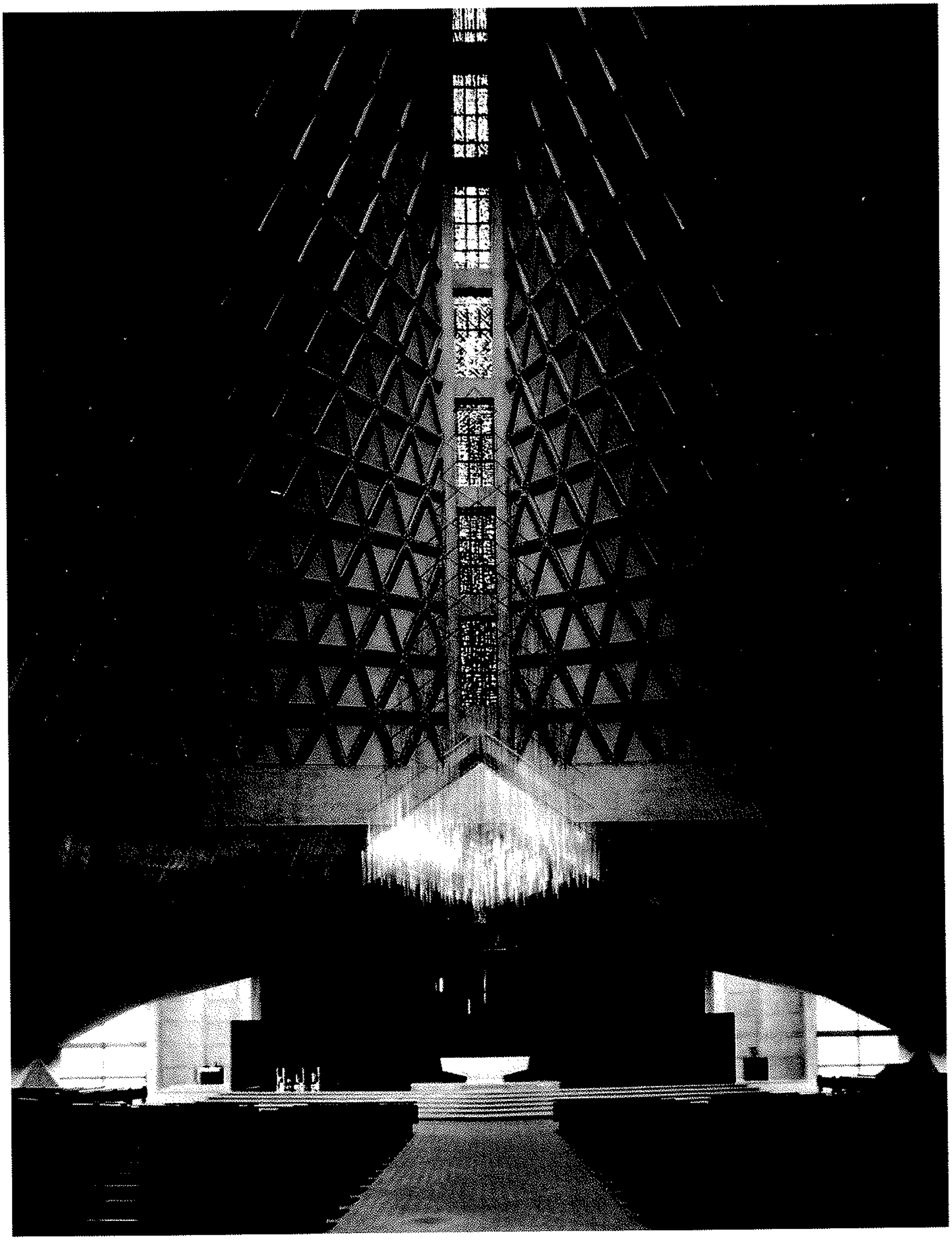
2000

Front Cover

A photo of Professor Wallace Clement Sabine is inset on the front cover. The background image is a view of Boston Symphony Hall as seen from the stage. This world-renowned concert hall was Professor Sabine's first major performing arts consulting project. Architects were McKim, Mead & White of New York City. The hall opened in 1900 to mixed acoustical reviews from the Boston, Mass. music critics, but today is acknowledged to be one of the finest halls for music in the world. For background on Sabine's contributions to the science of architectural acoustics, see J. W. Kopec, *The Sabines at Riverbank*, Acoustical Society of America, Woodbury, NY, 1997.

Facing Page

The photograph on the facing page shows the worship space of Cathedral of St. Mary of the Assumption, San Francisco, California. Architects McSweeney, Ryan & Lee, in collaboration with consulting architects Professor Pietro Belluschi (MIT) and Pier-Luigi Nervi, designed the Cathedral in the late 1960s. To control reverberance in the 2.2 million cubic foot volume, acoustical consultants D. Fitzroy and A. Raes recommended using sound-absorbing board by USG in the vaulted ceiling coffers. The measured reverberation time for fully-occupied conditions is 2.4 sec at mid-frequencies. The Ruffatti organ (4842 pipes), supported on a concrete pedestal in the central volume, has acoustical line-of-sight to the congregation. Photograph courtesy of USG Corporation.



"The technology of noise control both inside and outside buildings is well developed today. The problem is that it is too seldom used. Architects continue to "hope" that a row of trees or bushes will solve the problem of noise intrusion from the nearby highway, or perhaps that someone will invent an air curtain that will stop the transmission of sound between two parts of a room! But, there are no miracles—there are simply some hard physical facts."

Robert B. Newman, 1972

PREFACE

The goal of this workbook is to reinforce one's common sense in the study of architectural acoustics through a variety of learning materials. Using principles and examples from the book *Architectural Acoustics*, the workbook includes demonstration examples, listening exercises, case studies, design projects, and other resources. Many of the project assignments and problem exercises can be used for self study if cited references are carefully read. Answers to the problem exercises are given at the end of the workbook.

Thanks are due to colleagues who provided suggestions and materials (current or former affiliations follows): Ed Allen and Bob Apfel (Yale University), Leo Beranek (MIT), Bill Cavanaugh (RISD), Ted Ceraldi (Syracuse University), Bob Coffeen (University of Kansas), Howard Heemstra (Iowa State University), Chris Jaffe (RPI), Dick Kellogg (University of Arkansas), Peter Lee (Clemson University), Jerry Marshall (Marshall/KMK), John Reynolds (University of Oregon), Tom Rossing (Northern Illinois University), Neil Shade (American University), Gary Siebein (University of Florida), Emily Thompson (University of Pennsylvania), Ted Uzzle (NSCA), Barry Wasserman (Cal Poly Pomona), and Red Wetherill (UBC).

Thanks also to Rose Tardao (1992 Newman Medalist, Clemson University) and Kimberley Murray (1993 Newman Medalist, Clemson University) for their research on optical modeling of first sound reflections and to Walter Nurmi (1987 Newman Medalist, Clemson University) who prepared drawings for the acoustical design projects. Special thanks are due Charles Tilley (1994 Newman Medalist, Clemson University) for his dedication to graphic communications and his editorial efforts to produce this workbook. Tilley is a three-time recipient of the prestigious "Alice L. Sunday Prize" given by the James River Chapter (VA) of the AIA for excellence in architectural graphics and presentations.

Thanks also to Mrs. Mary Shaw Newman and her Robert B. Newman Fund Advisory Board volunteers for nearly two decades of support to students and faculty worldwide in the field of architectural acoustics. Section 10 explains the Newman Fund: its *raison d'être*, bio-sketch of Robert Newman, roster of participating schools, and form for instructors to nominate a Medalist from their school.

M. David Egan, Fellow ASA, INCE Bd Cert, Hon. AIA
Anderson, South Carolina
2000

NOTE: Material in this workbook has been reproduced and adapted from M. David Egan, *Architectural Acoustics*, McGraw-Hill, New York, 1988 [ISBN 0-07-019111-5] with permission of the publisher, the McGraw-Hill Book Company, 1221 Avenue of the Americas, New York, NY 10020-1095.

CONTENTS

1.0 INTRODUCTION

The Sound Environment: Teaching Architectural Acoustics

EWART A. WETHERILL
Paoletti Associates Inc.
WILLIAM J. CAVANAUGH
Rhode Island School of Design
M. DAVID EGAN
Clemson University

WHY THE NEED FOR ACOUSTICS INFORMATION

The need for some basic technical background in architectural acoustics, as in any of the other contributing environmental disciplines, will remain as long as buildings are designed to be lived in. The creative output of the designer will be judged good or bad, depending on his/her understanding of the discipline and its relevance to the particular project. At the most fundamental level, the design must fulfill its essential programmed functions. In terms of detailed design and construction, the designer must be able to usher each special requirement through the collaborative process and reconcile the inevitably conflicting requirements of other disciplines to attain a satisfactory result. The completed building will demonstrate at best the professional competence of the designer in satisfying the myriad aesthetic, technical and economic requirements of the project or, at worst, the failure to meet the owner's basic needs and the possibility of a lawsuit. Of the need for awareness of each design discipline there is no doubt, but whether it should be acquired in school or in practice remains a difficult question.

The battle over course status has been fought in schools of architecture for many years, each discipline receiving a larger or smaller share of the pie depending on its standing in the teaching hierarchy. On the one hand, even a five-year architectural program can only include a limited number of purely technical courses if a strong design curriculum is to be maintained. On the other, it is common to find that graduates who are unfamiliar with the basic principles or terminology of a given subject do not easily acquire such information when working in an architectural practice. The precise reasons for this may vary, but it is clearly a disadvantage not to have even a basic understanding of the tangible results of one's design. For the graduate who elects to teach instead of going into architectural practice, the long-term results may be even more profound because this person may totally neglect a subject in which he/she cannot speak with assurance. Thus, at least a basic literacy in the technical areas affected by architectural design is an absolute minimum.

LEVEL OF INFORMATION NEEDED

The minimum level of information required in any subject is that which allows the designer to recognize when that particular discipline must be considered. For acoustics, this level is surprisingly modest and essentially conceptual, but the understanding of how it can or should be applied will broaden with experience. The designer must know at least enough in analyzing the program to ascertain the potential uses of each space or complex of spaces. In an era of increasing technical sophistication in construction and increasingly specialized user requirements, it is essential to look beyond a simplified description of each activity to fully appreciate its level of importance. This acquired information must then be carefully integrated with an understanding of the acoustical design implications of the building configuration, structural system and ventilation system, etc. that have been selected by the designer for this particular commission.

Figures I and II represent the authors' experience in what is considered a minimum level of exposure to the fundamentals of architectural acoustics and their application to building design. Acoustics problems can be classified in three basic groups, 1) sound outdoors, or in outdoor-like spaces 2) sound in fully-enclosed spaces, and 3) sound transmitted from room to room through some intervening structure. Figure I enumerates in each of these categories a few of the reasons why an architect should know a little about sound behavior in and around buildings. The student must have a glimpse of the significance of this discipline to the design process before he or she can be motivated to explore the technical details. Most students quickly appreciate that acoustics is more than just the design of concert halls or broadcast studios. The acoustical environment of a particular site may determine the placement of the building, the planning and arrangement of spaces within the building, the exterior construction, and even the choice of the site itself.

For each space in the building, the sound field is influenced by its volume, shaping, surface finishes and furnishings - all factors that are under the direct control of the designer. An understanding of the relatively few concepts that are summarized in Figure II enables the designer to solve most acoustical problems in advance. The equations in this figure for each of the three basic groups define essentially all the information needed to make intelligent design decisions. For example, the decrease in sound level outdoors as one moves away from a sound source is fundamentally dependent on distance. But this is a logarithmic relationship and is thus governed by the law of diminishing returns. Similarly, where the sound field indoors is influenced by the absorption of sound at the boundary surfaces, there are practical limits to how much quieting can be achieved by acoustical materials. These principles must be taught early by simple examples and reinforced consistently in subsequent design projects.

PREREQUISITES

What is *not* required to understand architectural acoustics is an intensive background in physics or mathematics. An elementary understanding of algebra, geometry and the physics of sound, which should in fact be part of any high school curriculum, provides the background on how sound behaves in buildings. This should reinforce rather than compete with the lessons of acoustics learned in everyday life, making architectural acoustics tangible rather than just a paper exercise. Which child of 8 or 10 years old, for example, has not learned that it is difficult to hear conversation over a loud radio program (the concept of acoustical masking), or has not experienced the joy of shouting in a reverberant room - or of singing in a tiled shower (the concepts of reverberation and resonance)?

An excellent starting point to formally introduce the student to building acoustics is to examine the individual's own hearing ability and sensitivity to the sounds of the everyday environment. An audiometric test - which should be available at no cost on most campuses - and a listening test in one's home are always well-received by a beginning class. Example: Listen to the sounds of your home (a) by day (b) by night. Which sounds are pleasing and which are not? Where do they originate? Are they within your power to control?

TEACHING PROCESS AND RELATIONSHIP TO OTHER COURSES

From these simple beginnings, followed by the more developed concepts of Figures I and II, a series of easy steps can be integrated into the curriculum so that acoustics can be seen as part of the overall design process. An appreciation of the basic difference between spaces for communication and spaces for non-communication, coupled with the appropriateness of common building materials for specific functions - and reinforced by the experience of first-hand examples - will build a lasting and practical foundation for any designer. It is by this natural process of discovery and experience that what we like to call intuition enters the design process. The ultimate test will arise when the designer [be it student or practitioner] must decide whether a previously untried building form or structure is appropriate in a situation with particular sensitivity to acoustics or vibration.

In a well-integrated design program, there should be no need for a course labelled "acoustics" just as there should be no need for such titles as structures, mechanical systems, etc. However, regardless of the formal organization, at each stage of the program the student must be introduced to specific acoustical concepts, must experience their physical effects in actual buildings, and must learn how to analyze and - above all - to discuss their implications with other members of a design team. In actual building design, the ability of the design coordinator to assess and to make accommodation for each contributing discipline will determine the success or failure of that particular building, regardless of the competence of each specialist. In a visual discipline such as architecture, the very invisibility of sound makes it imperative to accord special attention to acoustics. The words of a leading architect from an earlier time, "We'll make it so beautiful that they won't care how it sounds" still echo with profound irony.

In acoustics, probably more than any other discipline, it is essential to experience and analyze existing buildings. The auditory effects of reverberation, or of a particular ceiling shape, can be demonstrated on paper, given a receptive viewer. However, the experience of actually hearing how reverberation affects intelligibility of speech, or how an acoustically-bad lecture room can be made entirely satisfactory by the proper application of a few sheets of plywood and several square yards of building insulation, is profound to anyone. Such a demonstration requires neither mathematics nor training in computer use, and yet it will be remembered for a lifetime. Similarly, listening in a lecture room whose ventilation system is loud enough to obscure the instructor's voice is a prime learning example to a student whose interest in the acoustical environment has been stimulated.

Every university campus is a treasure trove of examples of both good and bad acoustics. At any level, the student is capable of selecting a familiar building, identifying an acoustical problem, and proposing a solution. The chosen subject may be more complex than the student's level of understanding, making it ideal for those who are interested in reaching farther than absolutely necessary. A seminar in which the students then discuss individual examples adds to the learning process and encourages the application of this experience to subsequent design studies.

CONCLUSIONS

The past decade or so has seen a steady increase in the number of architectural schools with strong acoustics courses. However, the preponderance of new buildings with acoustical deficiencies makes it clear that a much greater teaching commitment - including engineering and trade schools as well as architecture schools - is still needed.

Around 40 years ago, Robert B. Newman began teach-

FIGURE I - Reasons for knowing a little about sound

OUTDOORS	INDOORS	ROOM TO ROOM
Select quiet site	Design quiet spaces	Design for isolation
Meet local codes	Design for speech	Acoustical privacy
Location on site	Music performance	Locate critical spaces
Define noise sources	Multi-use spaces	Detail construction
Design noise barriers	Expandable spaces	Design door systems
Locate sensitive spaces	Athletic facilities	Avoid cross talk
Design walls & windows	Control mechanical noise	Inspect construction

FIGURE II - Quantifying Sound

	OUTDOORS	INDOORS	ROOM TO ROOM
Sound Intensity I	$I = \frac{W}{4\pi d^2}$	$I = \frac{W}{A}$	$I^1 = \frac{W^1}{A}$
Sound Intensity Ratios	$\frac{I^1}{I_2} = \frac{d_2^2}{d_1^2}$	$\frac{I_1}{I_2} = \frac{A_2}{A_1}$	$\frac{I_1}{I_2} = \frac{A_2}{TS}$
Sound Level Reduction R	$R = 20 \log \frac{d_2}{d_1}$	$R = 10 \log \frac{A_2}{A_1}$	$R = TL + 10 \log \frac{A_2}{S}$
Reverberation Time T	$T = 0$	$T = 0.05 \frac{V}{A}$ (English) or $T = 0.16 \frac{V}{A}$ (metric)	

FIGURE III - Schools where Newman Medals have been awarded (1986-91)

Boston Architectural Center
Cal Poly, San Luis Obispo
Clemson University
Cornell University
Georgia Institute of Technology
Harvard Graduate School of Design
Iowa State University
Kent State University
Massachusetts Institute of Technology
Oklahoma State University
Pennsylvania State University
Princeton University
Rhode Island School of Design
Ricardo Palma University, Lima, Peru
Roger Williams College
Southern California Institute of Architecture
University of Arizona
University of Auckland, New Zealand
University of California at Los Angeles
University of Florida
University of Illinois, Urbana
University of Maryland
University of North Carolina, Charlotte
University of Western Australia, Perth
Virginia Polytechnic Institute

ing architectural acoustics courses at Harvard and MIT, chiefly in the graduate programs, where they remained a staple item until his death in the early 1980's. Through these courses, lectures that Newman gave on other campuses, and courses given by his former students, the teaching of a carefully integrated course in architectural acoustics has become a feature in architectural schools throughout the world. A few of the students who have taken such courses, including the authors, have become deeply involved in the profession of acoustics. However, as a result of this exposure, many practicing architects have learned to consciously incorporate acoustics as a design parameter in their work, with a resulting improvement in the general quality of building acoustics and, indeed, of building design itself.

Since Newman's death, many of his colleagues and former students have contributed to a foundation which promotes the teaching of architectural acoustics and recognizes both outstanding student work and outstanding teaching. Every accredited school of architecture is eligible for participation in this program, and the results to date - both in recognition of student/teacher ability and in the growth of the program - have been gratifying. At the present time some 25 schools of architecture participate in the program, as noted on Figure III, and 53 Robert Bradford Newman medals have been awarded to students for merit in the study of acoustics and its application to architectural design projects. More recently, the Theodore J. Schultz Award has been established by the foundation to honor excellence in teaching acoustics.

However, the ultimate success of any specialized discipline depends entirely on the acceptance and support of other faculty members and on the allocation of teaching resources to support it, regardless of budget fluctuations. If this support is forthcoming, the recognition of "minor" courses such as acoustics by design faculties, and thus in time by the profession at large, will be assured. The trend toward better acoustical environments is encouraging. It rests with the educational institutions of the profession - the schools of architecture - to expand and encourage this trend.

REFERENCES

F.H. Bosworth and R.C. Jones, *A Study of Architectural Schools*, published by ACSA, 1932

W.J. Cavanaugh, *Acoustics: Basic Principles*, Encyclopedia of Architecture, Wiley, NY, 1989

M.D. Egan, *Architectural Acoustics*, McGraw Hill, NY, 1988

M.D. Egan and P. R. Lee, *Acoustics, Architecture and Speech: A Student Inquiry*, AIA 1990

F.P. Rose, *Owner's Viewpoint in Residential Acoustical Control*, Acoustical Society of America, 1964

D.M. Scott and E.A. Wetherill, *Education in Architectural Acoustics*, Acoustical Society of America, 1975

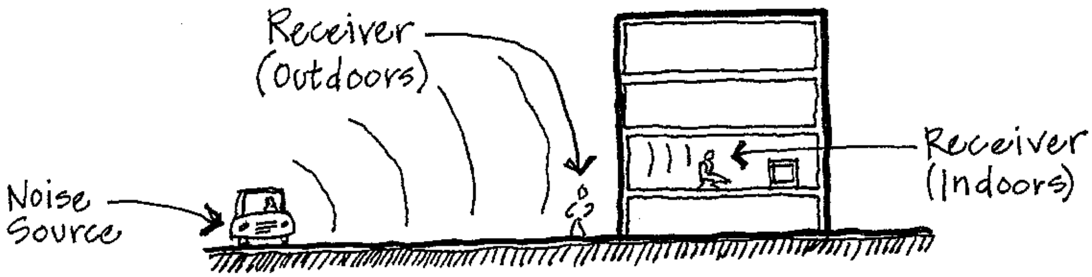
E.A. Wetherill, *A Technological Basis for Design*, ACSA National Convention, 1982

E.A. Wetherill, *Architectural Acoustics: The Forgotten Dimension*, Audio Engineering Society, 1990

NOTE: "The Sound Environment: Teaching Architectural Acoustics" is reproduced from C. B. Hess (ed), *Proceedings of 10th Annual ACSA Technology Conference*, Association of Collegiate Schools of Architecture, Washington, DC, 1992, pp. 44-47 with permission of ACSA.

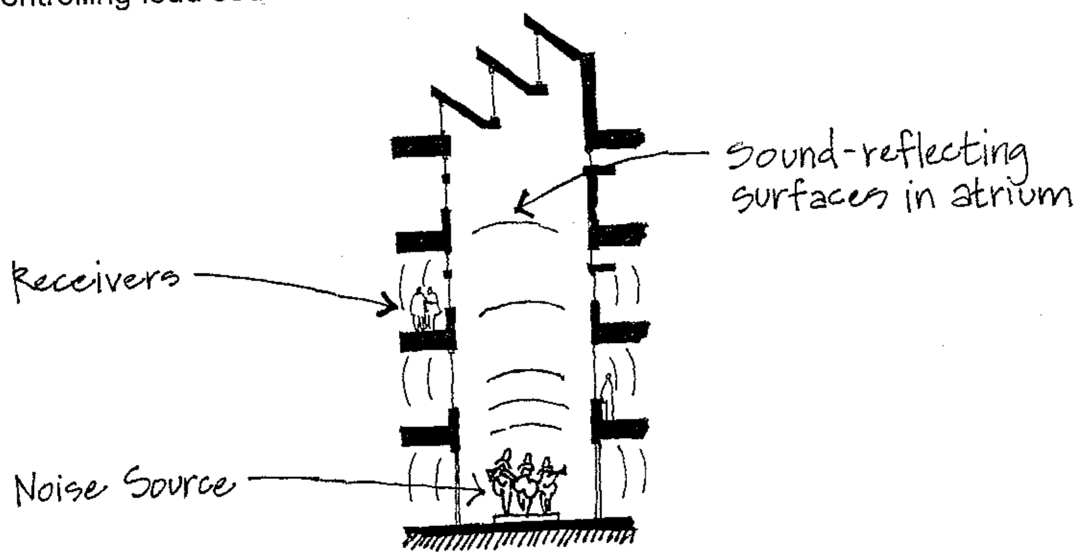
THREE COMMON PROBLEMS IN ARCHITECTURAL ACOUSTICS

1. Protecting *outdoor* or *indoor* spaces from environmental noise.



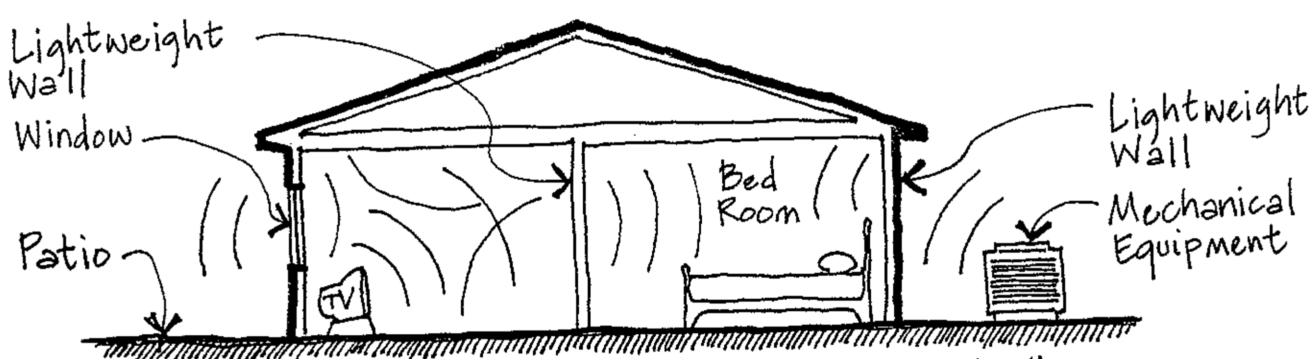
Sound in *free field* conditions outdoors.

2. Controlling loud sound within enclosed spaces.



Sound in *reverberant field* conditions indoors.

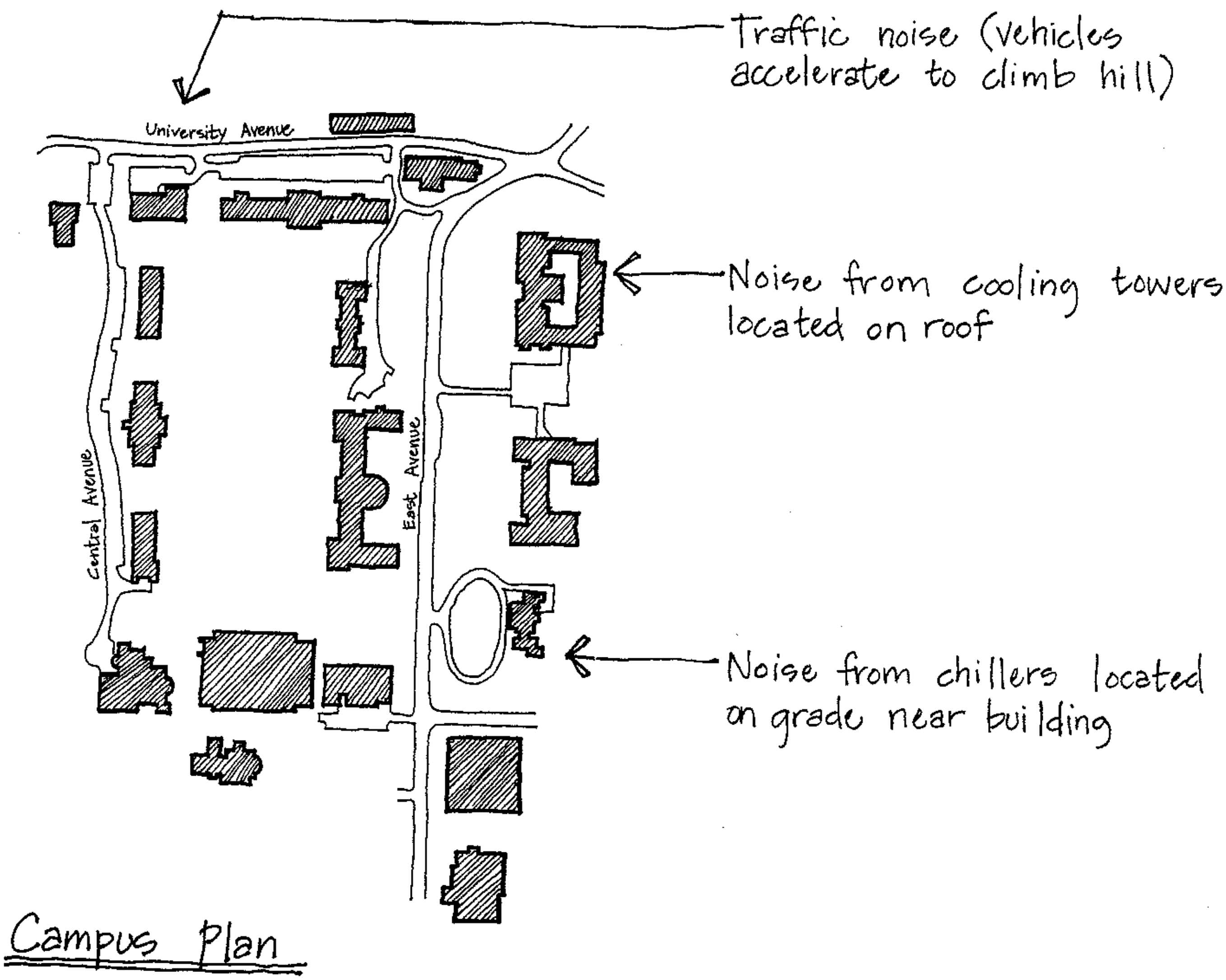
3. Reducing sound transmission between rooms (or from or to outdoors).



Sound easily transmitted through stiff, lightweight constructions.

ACOUSTICAL DIARY

To increase awareness of sound and noise, students should use the table on the following page to record their observations of the acoustical environments encountered during a typical 24-hour period. Activities occur that may vary from pleasant or restful to annoying or distracting. Place an X mark in the table to identify the type of activity; also include a brief description of the activity and location. Identify the source of sound or noise and record: level in dBA, pitch or *frequency* (low, mid-range, high), and duration in minutes. Describe possible architectural solutions for any noise problems encountered.



Note to Instructor: This acoustics exercise is similar to the "24-hour Lighting Log" used by William Lam for many years in his technology courses at MIT and Harvard GSD. Lam believed this kind of assignment would be a valuable self-education exercise for design professionals so he included it on pages 443 and 444 in W. M. C. Lam, *Sunlighting as Formgiver for Architecture*, McGraw-Hill, New York, 1986.

	Activity and Space				Sonic Environment				
	Work	Recreation	Relaxation	Description of Activity & Space	Sound or Noise Sources	Peak Level (dBA)[1]	Frequency (Hz)[2]	Duration (min)	Potential Architectural Solutions
Morning 7 8 9 10 11 12									
Afternoon 1 2 3 4 5 6									
Evening 7 8 9 10 11 12									

Notes:

1. Use *A-weighting* scale on sound level meter available from: Quest (Model 208L), Radio Shack (Cat. No. 23-553), Rion (Model NA-26), TES (Model 1350A), or equal.

2. Estimate sound frequency to be neutral (broadband) or predominantly high (> 2000 Hz), mid-range, or low (< 250 Hz). High frequency sounds *screech* or *squeal;* low frequency sounds *rumble.*

2.0 ACOUSTIC DEMONSTRATIONS

ACOUSTICAL DESIGN GOALS AND THE PHYSICS OF SOUND;

A TEACHING METHOD FOR ARCHITECTURAL DESIGN CLASSES

On my campus there is a large lecture room in which lectures are difficult to hear. Ironically the room is in the relatively new "Communications" building. The room is square in plan, with a low ceiling. All surfaces are reflective *except* the deeply coffered ceiling, which is sprayed on all surfaces with acoustically *absorptive* material!

Acousticians and many architects will immediately identify the design flaws responsible for poor hearing conditions in the above example. All of us can recall similar rooms we have encountered in otherwise well-designed buildings. Many new hotels have meeting rooms with relatively low, absorptive ceilings, whose expanse is only broken by overhead return-air grilles which emit loud masking fan noise from the roof-mounted AC units. So there's a built-in PA system........it often doesn't work, so the speaker cannot be heard well. Even if it does work, questions from the audience must be repeated by the speaker (if she is thoughtful) so the rest of the audience can follow.

Why do such spaces get built? Why do not architects display more knowledge about acoustical needs and design principles?

My conjecture is that they have not organized the various goals of architectural acoustics into a clear conceptual framework, based on hearing needs and sound behavior. They do not have a clear understanding of the acoustical design goals, and thus have little basis on which to make correct design and specification decisions. They tend to merely "treat" the room for acoustics----like a doctor telling a patient to "take two aspirins" (and don't call him in the morning!)

This article will describe a lecture/demonstration I present to architectural design students in an attempt to help them clarify the goals and methods of acoustical design while linking the achievement of those goals to facts about the physical behavior of sound in a graphic and realistic manner. I will not here attempt to go into detail about the specific acoustic points, but will describe the lecture, and give some details on the method used in the demonstrations.

The lecture

First, using transparencies on an overhead projector, I emphasize the three major goals of acoustical design in architecture:

- **sound distribution** *within* spaces designed for hearing music or speech,
- **sound isolation** *between* spaces where privacy or quiet are needed,
- **noise control** *within* spaces.

Many of the mistakes we encounter, I point out, likely result from the designer having confused these goals, along with the (sometimes conflicting) methods of achieving them. The lecture and meeting rooms described above provide fair noise control and sound isolation, but consequently poor sound distribution; the wrong goals were pursued.

My next point is that two aspects of sound behavior;

- **slow** speed of propagation, and
- propagation by **waves,** dictate most of the strategies for achieving these goals.

Referring to the transparencies, I then identify slow speed and wave behavior as positive or negative factors in relation to each goal. For instance, wave action is a plus for distribution because waves reflect and diffract, but also a minus because waves allow sound to focus from concave walls, or be absorbed when too much absorptive material is present. Or, slow speed of propogation can ruin good distribution because of echos or excessive reverberation time. I also cover certain aspects of wave behavior, pointing out ways in which reflection, absorption, transmission, and diffraction each act to benefit or create problems for the designer. Refraction is important only in outdoor situations.

The demonstrations

The key to making these points about wave phenomena clear is the demonstrations which accompany the lecture. I place on the overhead projector a clear acrylic molded picture frame about 16" by 20" by 1.5" deep (available at most art and hobby stores.) It is raised above the projector face by about 1/2" on shims of modelling clay so that transparencies can be inserted under the tray. The tray is filled with about 1/2" of clear water. (Fig 1.)

Waves created in the water are projected onto the screen as as they propagate and reflect. Experimentation with the focus is needed to get the best contrast between waves and troughs on the screen, because the screen images are not mere shadows; they are images formed by refractioin. (For this reason, no benefit is gained from staining the water.)

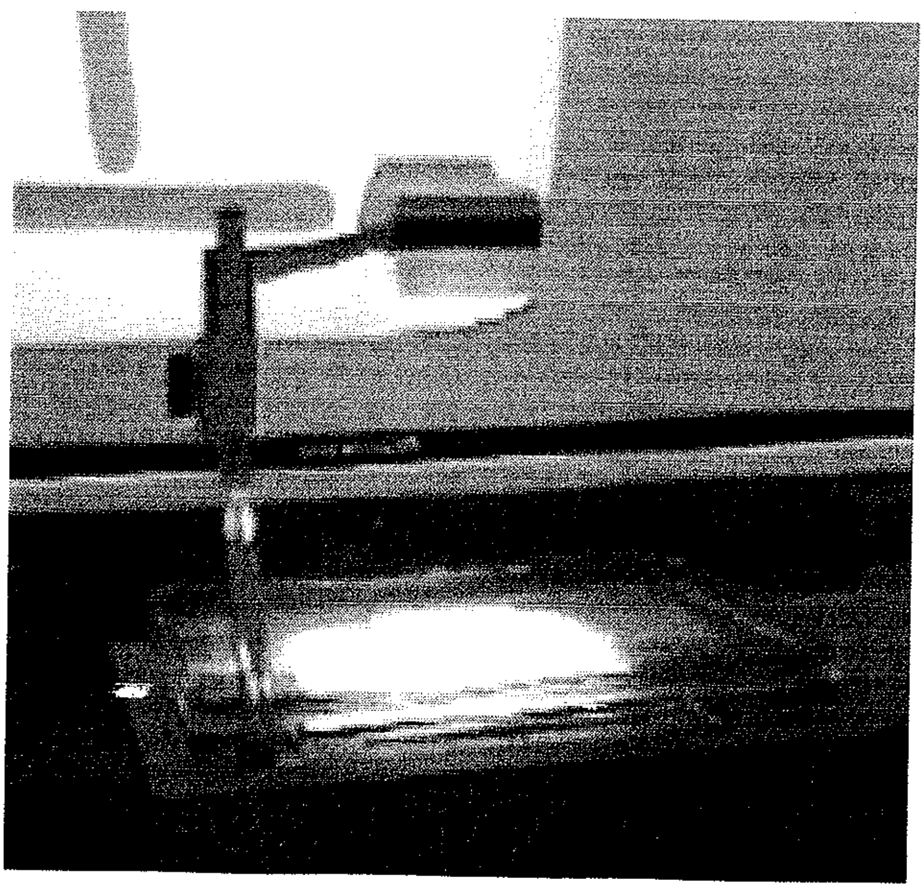


Fig. 1 The projector and water tray setup for wave demonstrations

Waves are initiated in the water by tapping with a small ball of clay on the end of a wire or letting a drop of water fall from an eye-dropper at the appropriate sound source location. I have found that using a short burst of waves is more effective than a vibrating source which produces continuous waves. The course of the wave bundle can be followed more clearly, and time-related effects such as echo and reverberation are more obvious.

Reflective surfaces are represented by strips of (oil-based) modelling clay placed in the tray of water.* For certain demonstrations I insert below the tray a piece of opaque paper with a cutout which shows a room plan or section on a transparent plastic sheet. Reflective boundaries are represented on the plan or section by a dark line and a clay strip in the water; absorptive boundaries by a halftone gray boundary and no clay strip. The tray should be large enough to effectively dissipate these "absorbed" waves before they reflect from the tray boundaries. A sloped rough-textured "beach" made of Styrofoam helps to limit reflections from the tray edge by dissipating the wave energy.

Since the water waves are essentially fixed in wavelength, certain sound wave phenomena related to different reflective or refractive behavior at different wavelengths cannot be properly demonstrated. These points must be made by other means, such as diagrams.

There are, however, numerous acoustical wave phenomena which can be demonstrated with this setup. I will describe one here and list some of the others with a few illustrations. You are encouraged to experiment using the described setup and develop others.

Diffraction of waves through a crack under a door:

Arrange a clay strip for a floor and a door, leaving a crack beneath the door. Produce a wave pulse on one side of the door. If the crack is wide enough, waves will be seen emanating from it on the opposite side of the door (Fig. 2) as if from a new source, illustrating a common problem in achieving sound isolation.

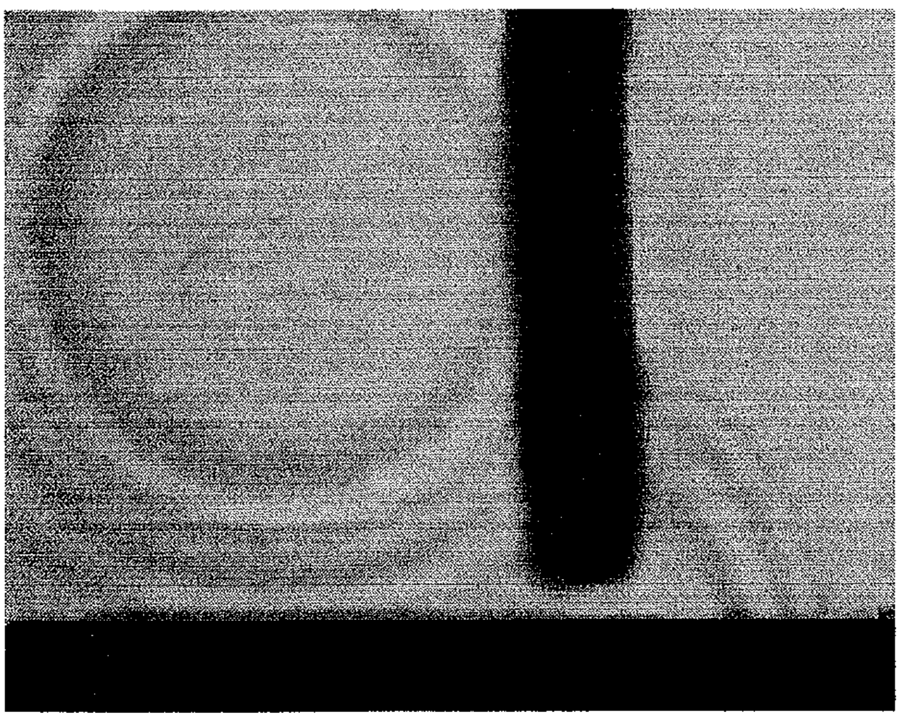


Fig. 2 Diffraction under a door

**Capillary repulsion between the water and the oily clay causes the water surface at the juncture to curve, distorting the projected image along that edge. To make the image clearer, I line the clay strips with blotting paper, which, when wet, eliminates the capillary action and the curved water edge.*

Other demonstrations

- reflection and echo from a straight wall (slow speed of sound is clear here.)
- scattered reflection from an irregular wall if the facets are longer than the water wavelength.
- undistorted reflection from an irregular wall if the facets are somewhat shorter than the water wavelength.
- focusing of reflections from a concave wall.
- corner reflections from a right angle room or ceiling corner (reflections always return to emission source.)
- flutter between parallel walls (Fig.3), and elimination of flutter by a small deviation from parallel.
- reverberation within a closed boundary (Fig. 4) Show good diffusion vs. poor by making boundary irregular vs. rectangular or by including gaps to simulate absorptive patches.
- diffraction around a short wall or at any edge, (Fig. 5) or through small openings (such as back-to- back electrical outlets.)
- transmission through a thin wall (use thin plastic strips for the "sheetrock," held in place by clay strips at the ends.)
- how a "whispering gallery" works (such as along the curved wall of the drum under a dome as in St. Peter's Cathedral.)
- why hearing is so good in a Greek theater in spite of no rear reflecting wall (the orchestra--literally "dancing area"-- is important as a reflecting surface, and audience seating area must be steep.)
- demonstrations of some recommended room plans and sections, using transparencies placed under the water tray.(Figs. 6, 7, & 8)

Some demonstrations illustrated

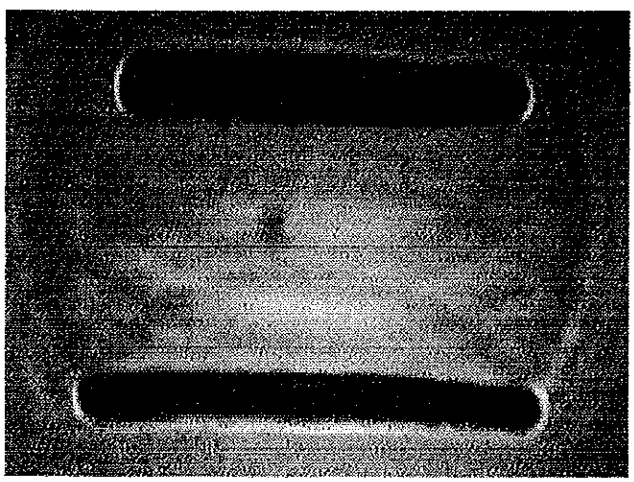


Fig. 3 Flutter between parallel walls. Waves continue back and forth for some time.

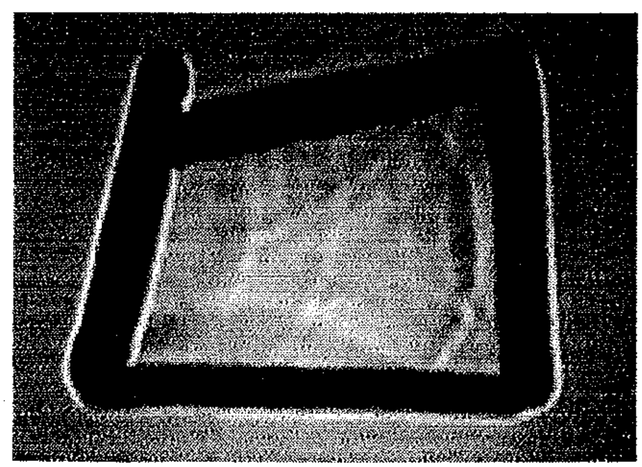
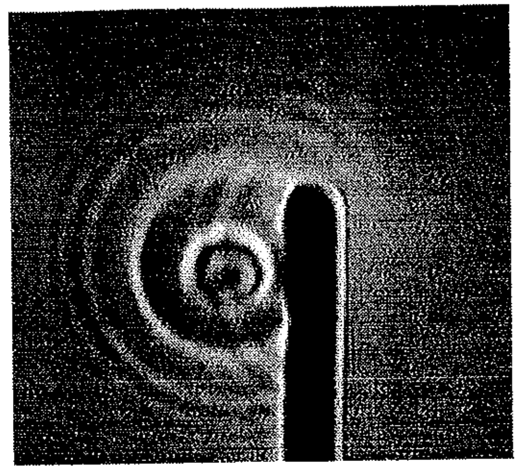
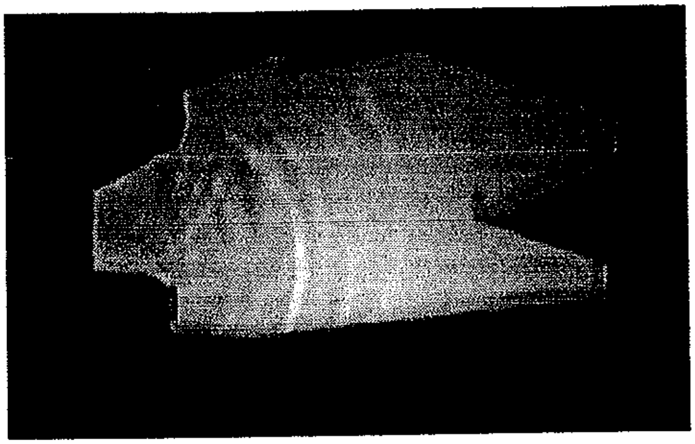


Fig. 4 Reverberation in an irregular room. Waves travel in all directions, continuing for a relatively long time.

Fig. 5 Diffraction over a wall; note the reflection toward the left, and the bending of waves over the wall and downward to the right.





Figs. 6 A good auditorium section; note the reinforcing reflections from stage rear wall and ceiling, plus the strength of waves at the seats caused by reflection from these surfaces and the main ceiling.

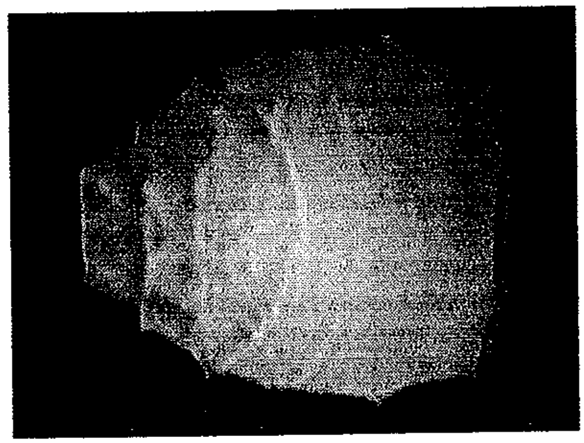


Fig.7 A good auditorium plan; note the good diffusion of the waves into the audience.

Conclusions

Please remember that this presentation method is aimed at clarifying the goals of acoustical design and some of the phenomena of sound behavior. I have found immediate improvement in students' design proposals after they have been sensitized by the presentation, but I wish to emphasize that the points must be continually stressed in design class and should be followed by a more detailed course about sound behavior and measurement.

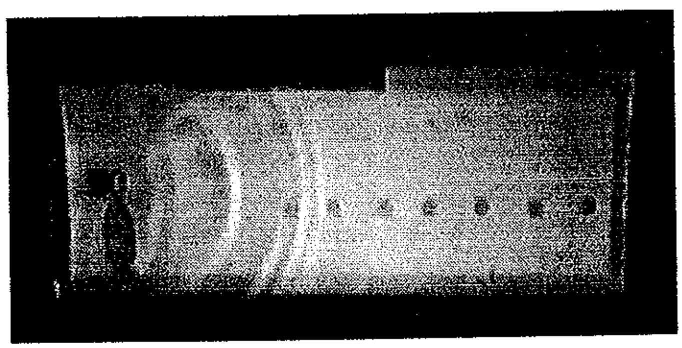


Fig. 8 A good classroom section; note the reflections from the frontwall and reflective forward section of the ceiling. Floor, rear part of ceiling, and rear wall are absorptive.

If good acoustical performance is to become the norm in buildings, architects must understand the acoustical design goals and why certain design details and forms work to reach those goals, (or others work against achieving them.) Knowledgeable architects will also bring in acoustical consultants at an earlier stage of design, rather than later stage when they might be asked to "treat" the building, often when it is too late to do any real good.

Richard Kellogg,
Professor Emeritus of Architecture
University of Arkansas

NOTE: The following eighteen slide images are from Prof. Kellogg's lectures.

ACOUSTICS
THE ARCHITECTURAL DESIGN GOALS

1. SOUND DISTRIBUTION

• TO HEAR VOICE AND MUSIC AT ALL POINTS IN A ROOM

2. SOUND ISOLATION

• TO **NOT** HEAR UNWANTED SOUND BETWEEN ROOMS OR OUTSIDE TO INSIDE

3. NOISE CONTROL

• TO REDUCE OR CONTROL SOUND LEVEL WITHIN A ROOM

EACH GOAL HAS ITS OWN SET OF SOLUTIONS

IMPORTANT SOUND CHARACTERISTICS

S L O W
S P E E D

WAVES)))))))

SLOW

1130 FEET PER SECOND

340 METERS PER SECOND

DISTRIBUTION: —

ISOLATION:

NOISE CONTROL: —

WAVES

λ = .7" or 1.8 cm @ 20,000 HZ
λ = 1.4" or 3.6 cm @ 10,000 HZ
λ = 1.1' or 34 cm @ 1,000 HZ
λ = 11.3' or 3.4 m @ 100 HZ

DISTRIBUTION: + —

ISOLATION: —

NOISE CONTROL: +

WAVES CAN BE:

REFLECTED	*by hard surfaces*
ABSORBED	*by "fuzzy" materials*
DIFFRACTED	*through cracks, around corners, at smooth/fuzzy edges*
TRANSMITTED	*through thin, light walls*
REFRACTED	*(mostly outdoors)*

REFLECTION

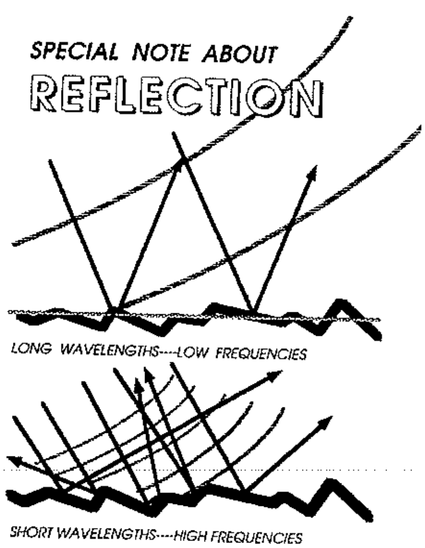
BENEFITS +

- *HIGHER SOUND LEVEL*
- *REVERBERATION*

PROBLEMS —

- *ECHO*
- *FLUTTER*
- *FOCUSING*
- *RESONANCE*
- *EXCESSIVE REVERBERATION*

SPECIAL NOTE ABOUT REFLECTION



ABSORPTION

BENEFITS +

- *ELIMINATE UNWANTED REFLECTIONS*
- *IMPROVE DISTRIBUTION BY SCATTERING*

PROBLEMS —

- *HEARING POSSIBLY POOR*
- *TRANSMISSION NOT CONTROLLED*
- *MUSIC SPACES POSSIBLY TOO "DEAD"*

DIFFRACTION

BENEFITS +

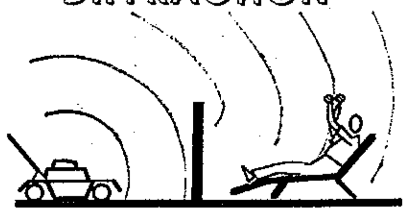
- *HELPS DISTRIBUTION*

PROBLEMS —

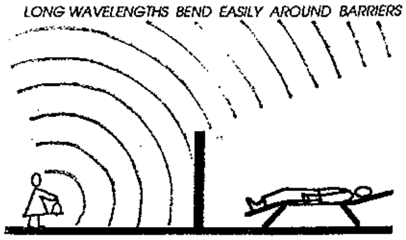
- *MAKES SOUND :*
  - *LEAK THROUGH CRACKS*
  - *BEND OVER AND AROUND BARRIERS*
- *REDUCES ISOLATION*

SPECIAL NOTE ABOUT

DIFFRACTION



LONG WAVELENGTHS BEND EASILY AROUND BARRIERS



SHORT WAVELENGHTS DO NOT BEND AS EASILY

TRANSMISSION

BENEFITS +

- *ALLOWS EAVESDROPPING....?*

PROBLEMS —

- *REDUCES PRIVACY*
- *REDUCES NOISE ISOLATION*

SOME RECOMMENDATIONS

DISTRIBUTION

IN ROOMS FOR MUSIC AND SPEECH

1. PROPER SHAPE

- *IRREGULAR IS BEST*
- *NO CONCAVE SHAPES*

2. PROPER LOCATION OF ABSORPTIVE AND REFLECTIVE SURFACES

- *TO DIRECT SOUND TO AUDIENCE*
- *TO ELIMINATE DEFECTS*

ISOLATION

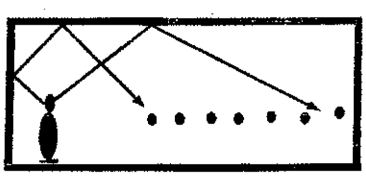
1. BETWEEN SPACES

- *SOLID, DENSE WALLS*
- *SPECIAL CONSTRUCTION*
- *NO AIR PATHS*
- *NO WEAK SPOTS*
- *NO STRUCTURE PATHS*

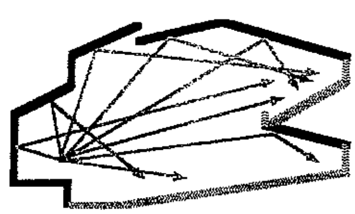
2. WITHIN ROOM

- *LOW, ABSORPTIVE CEILING*
- *CARPET ON FLOOR*
- *ABSORPTIVE "BOOTHS" AT SOURCES*
- *RESILIENT MACHINE MOUNTS*
- *"WHITE" BACKGROUND NOISE*

OFFICE



CLASSROOM



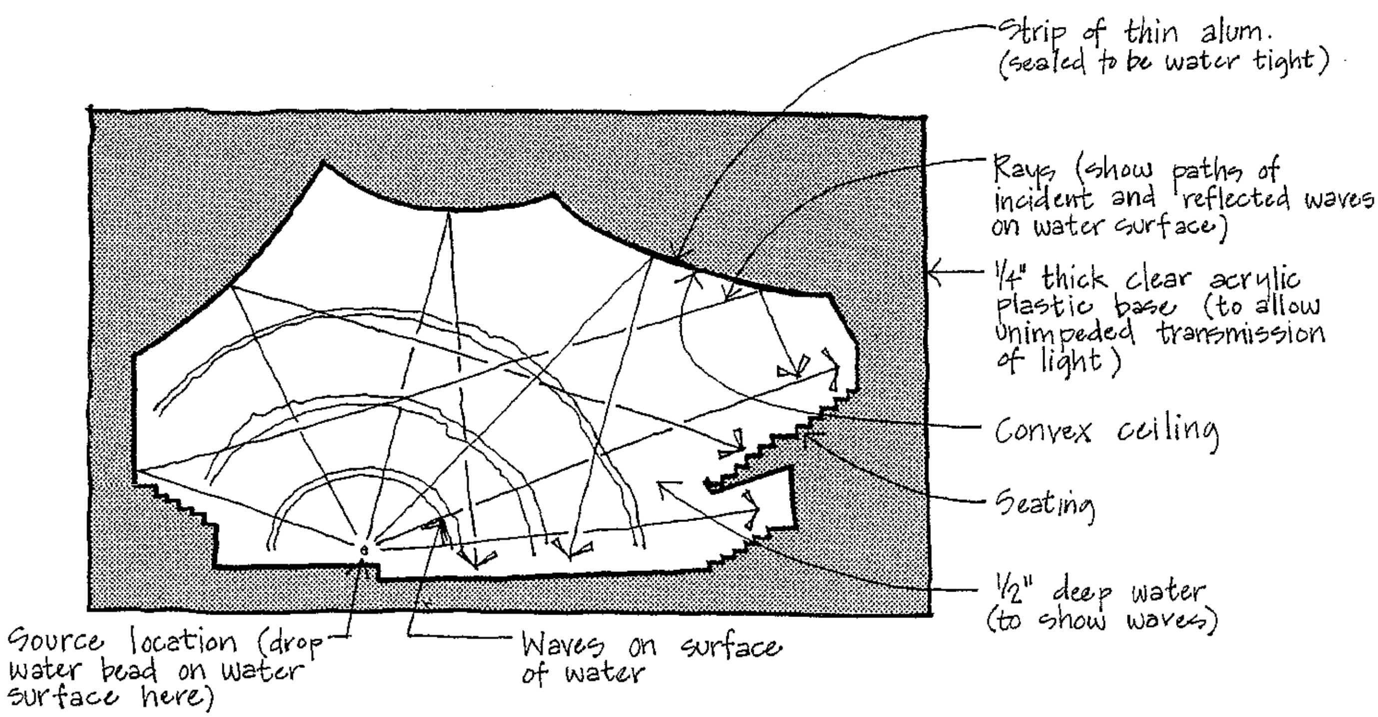
AUDITORIUM

NOISE CONTROL

PLENTY OF ABSORPTIVE MATERIAL !

EXAMPLE STUDIES BY STUDENTS AT SYRACUSE UNIVERSITY

- To study acoustical attributes of concert halls, students modeled well-known halls such as: Musikvereinssaal, Vienna (1870); Philharmonie, Berlin (1963); Opéra Garnier, Paris (1875); Carnegie Hall, New York (1891); and Symphony Hall, Boston (1900).
- The Kellogg method was used to evaluate reflected sound waves. Longitudinal sections of the halls were constructed from thin aluminum and then bonded by silicone sealant to a clear acrylic plastic base. The models were placed on an overhead projector and filled with ½" of water. Waves initiated by drops of water were observed on the projected image.
- The water surface models helped students to understand basic principles of room acoustics. In addition to the classic halls, students tested and refined their own designs to achieve even distribution of sound and to avoid hot spots and echoes.



Analysis of Student Design Project

Project By:
A. Chow, Syracuse University
1998 Newman Medallist

Acoustics, Architecture, and Speech: A Student Inquiry

Peter R. Lee, AIA
M. David Egan, Hon. AIA
Clemson University

Abstract

A hands-on student project aimed at identifying an acoustics problem and correcting it was undertaken during a special two-day period set aside by the College of Architecture to encourage innovative learning methods. The exercise combined acoustics theory and problem definition with architectural design response and testing of the solution.

The pastor of a local church was concerned that worshipers had difficulty hearing his sermons. Examination of the sanctuary space revealed that speech intelligibility was being degraded by an excessive amount of reflected sound. In-situ experimentation led to the conclusion that a canopy could control sound emanating from the pulpit and effectively direct it toward the congregation. Following the exploration of alternate designs, a final canopy model was constructed at full scale and placed over the pulpit for testing purposes.

Before and after measurements with a portable meter measuring speech intelligibility revealed that listening conditions in the church improved significantly with the installation of the canopy. Similar findings emerged from surveys of church members conducted during the period of time the canopy remained in place.

Place In Curriculum

For two days during the spring semester of 1988, all design studio and supporting lecture classes in the College of Architecture were canceled in order that students could take part in special learning programs. Five undergraduate architecture students joined in the acoustics design exercise conducted by a teaching team from design studies and building technology, assisted in turn by two graduate students. The work performed over the two-day period by this student group forms the basis of this innovative instructional program.

Educational Purpose

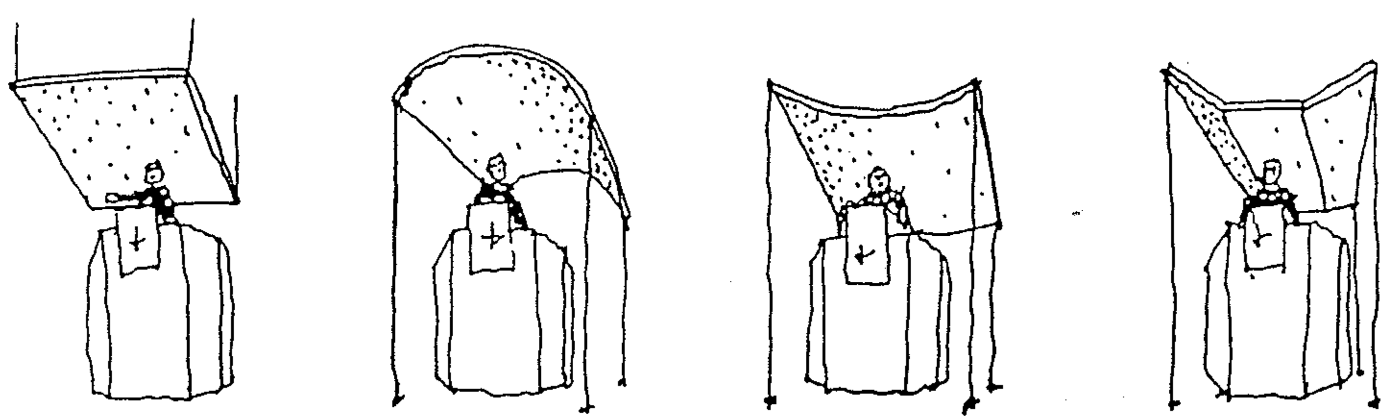
The fundamental goal of the exercise was to demonstrate that acoustical design and architectural design can be integrally linked. The specific objectives consisted of the following:

1. To learn to identify acoustics problems in spaces for listening such as churches and auditoriums.
2. To determine how to correct faults such as echoes and excessive reverberation of sound.
3. To explore the design of architectural elements that successfully enhance good hearing conditions.

Teaching Strategies

A local church, where speech intelligibility had been a problem since its construction in the early 1960s, was selected as a subject for the study. The following procedure was employed:

1. The students gathered the first morning for an introductory seminar on basics of room acoustics design, accompanied by familiarization with the use of the B & K portable meter in measuring the



Canopy design evolution

rapid speech transmission index [RASTI]. This meter, which permits very rapid measurement of speech intelligibility throughout listening spaces, was loaned to the school by Bruel and Kjaer of Marlborough, Massachusetts, specifically for this exercise. A workbook of critical acoustical data prepared by the two graduate students was also issued to the participants at this time.

2. That afternoon, the group moved to the church, where the students used phonetically balanced word lists to determine the articulation index [AI] within the sanctuary space, took measurements with B & K's meter to measure RASTI, and drew ray diagram tracings on plan and section drawings to indicate patterns of reflected sound. These analyses led to the conclusion that natural sound emanating from the pulpit was being poorly distributed and was causing excessive reverberation within the high-ceilinged worship space.

3. Later in the day, empirical testing of an improvised covering above the pulpit indicated that such a device would direct more sound toward the congregation and, as a consequence, result in less reverberation, higher signal-to-noise ratios, and overall better hearing conditions. The students subsequently explored design ideas for such a pulpit canopy by means of sketches, small-scale study models, and partial mock-ups. Following a critique of the various proposals, agreement was reached on the best design approach, and construction of a full-scale prototype canopy was begun.

4. Work on the project continued throughout the night and into the following morning. The canopy was constructed of 3/4" thick polystyrene panels joined by thin ribs of the same material. This assemblage in turn was supported by columns made of large diameter commercial carpet rolls donated by a local store. The three panels of the canopy, which formed a convex shape, were intended to be symbolic of the trinity, with the extended ribs alluding to the crown of thorns. The column supports in turn represented the four corners of the universe, while a green ribbon entwining one recalled a snake and the fall from grace in Eden.

5. Installation of the canopy over the pulpit required that the columns be cut to different lengths to adjust to floor level changes at the pulpit area, after which they were set into bases and stabilized with sand-filled polyethylene bag inserts. With the canopy now in place, the original speech intelligibility tests were repeated, with the results indicating that the introduction of the canopy caused significant improvement in listening conditions as indicated in the accompanying AI gradients and contours.

6. The pulpit canopy remained in place for two successive weeks of Sunday services. Several of the students took this opportunity to observe its effect on speech intelligibility within the sanctuary. Taking into account they had not attended the church previously and therefore lacked a long-term basis of comparison, they reported listening conditions to be favorable and none indicated any difficulty in hearing the pastor during his sermon. Equally important to this informal evaluation of the canopy's effectiveness was the sense of accomplishment afforded these students in being able to see their work being put to real use.

Means of Assessment

The exercise was assessed both on the basis of individual learning achievements by the participating students and its overall success in focusing collective student learning toward an achievable product. In the former case, students were evaluated on the basis of

1. The degree of active participation in all aspects of the undertaking, and the demonstration of an inquiring attitude and healthy work ethic. While overall interest in the exercise initially appeared modest as its theoretical foundation was being established, a show of enthusiasm emerged as the students were able to see the application of this knowledge to an actual problem, and particularly as they observed the canopy itself take physical shape.

2. The quality of performance during pre-design documentation, design exploration, and the construction phase. Since the participating students were from different year levels, it was not unexpected that their proficiency as designers would vary. However, in both the pre-design documentation phase and the canopy construction work, ability appeared more equally distributed and each student proved able to make a significant contribution to the exercise.

The success of the students in directing their efforts toward an achievable product was evaluated on the basis of

3. The results of the exercise as compared with other innovative learning programs, and its application to further studies. In a comprehensive slide documentation of the collective efforts of the two-day College event, it was evident that among the approximately two dozen undertakings, this exercise uniquely directed critical inquiry toward an achievable end. In a broader framework, the exercise has spurred interest in further integration of acoustic science and studio design, and the increased use of hands-on activities in technology studies.

4. The responsiveness of the proposal both to the auditory needs and the visual character of the church sanctuary. Survey forms developed by the church building committee were distributed to the congregation to secure their opinions on the effectiveness of the canopy in improving listening conditions within the sanctuary, as well as to its visual qualities. A current move to develop a permanent canopy of similar design is indicative of a positive response in each of these areas.

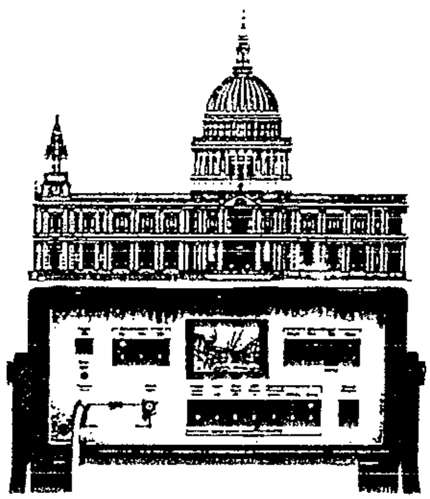
Jury Comments

"It is well executed, design sensitive, and a solid course that is transferable to lighting, HVAC, etc."

"This has an intensity of experience that the students from the whole school will never forget. From analysis through execution in a short time it provides a full rounding of experience. The sense of satisfaction at the end must have been phenomenal. It not only represents the complete cycle for analysis through execution, it links the top and bottom of the school and offers a balance between service and learning, which is not a casual by-product."

"What may be innovative here is the idea of the Community Design Centers applied to technologies rather than design."

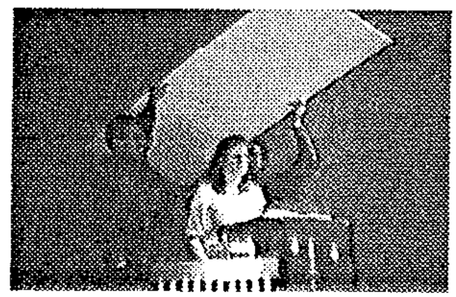
NOTE: Kay Moore Mason and Arnold McClure (1988 Newman Medalists, Clemson University) prepared materials for the introductory seminar on acoustics. They also served as facilitators for the RASTI measurements and during design, construction, and installation phases of the working canopy.



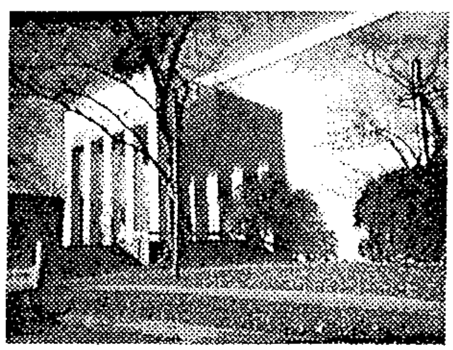
SPRING EVENT · ACOUSTICS AND DESIGN · SPRING EVENT

This Bruel and Kjaer speech transmission meter was used to study speech intelligibility in London's St. Paul Cathedral. Similar equipment will be used during spring week by a group of students exploring the listening conditions within a local church. The students will analyze the sounds of worship in voice and music, evaluate them for clarity and quality, and develop proposals for their improvement. Full scale mock ups of architectural elements may be employed for this purpose. On site studies will be complemented by seminars and discussion sessions by university faculty and other acoustic specialists.

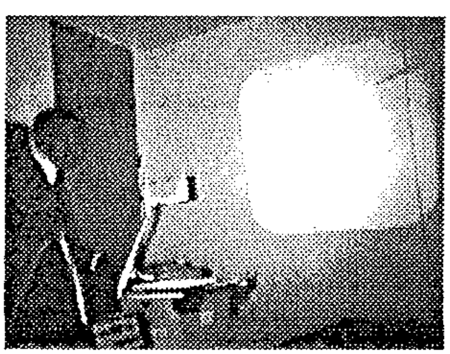
Student measuring RASTI



Testing improvised covering



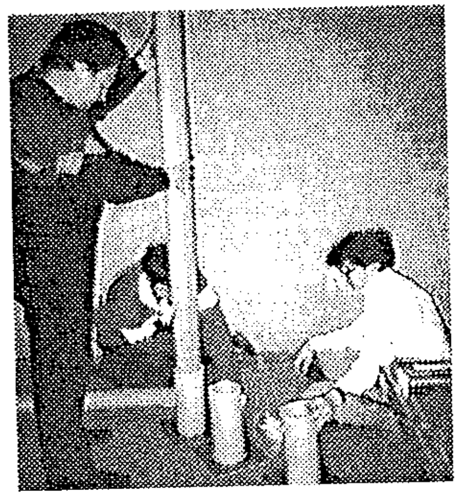
Exterior view of church



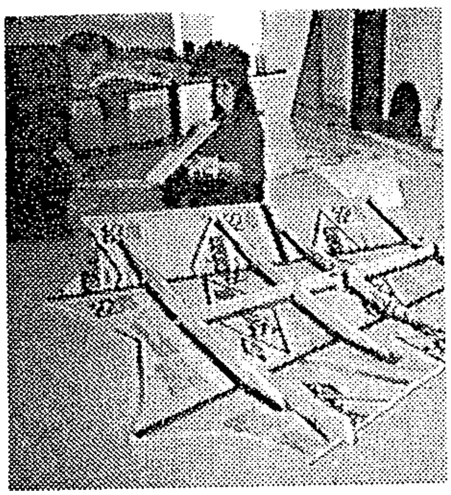
Seminar on acoustics

Exploring design alternatives

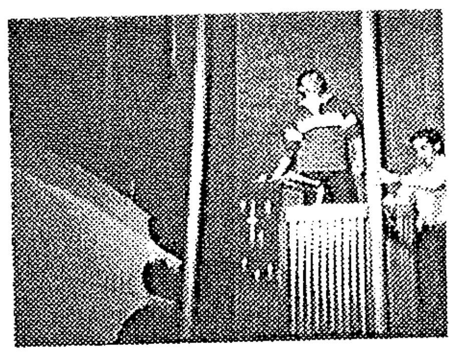
Group design critique



Securing column bases

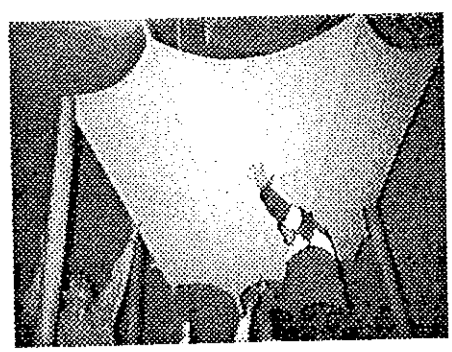


Canopy under construction

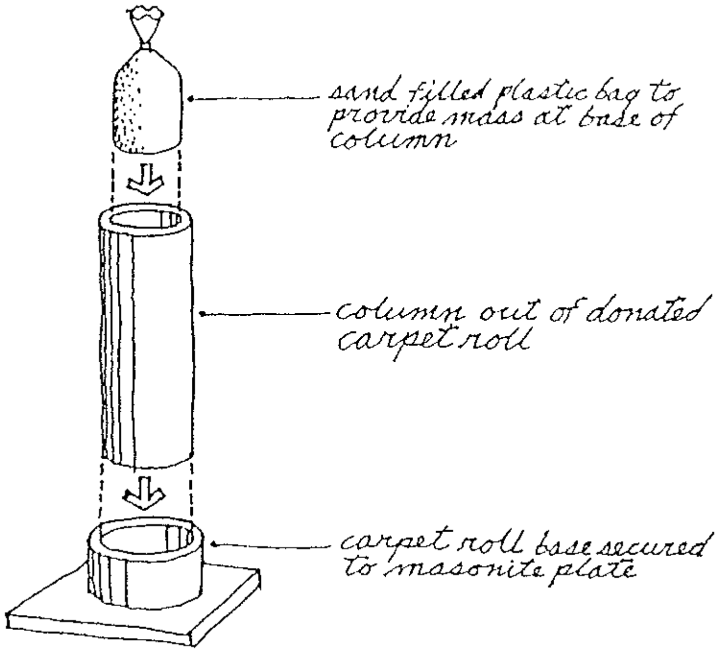


Setting the columns

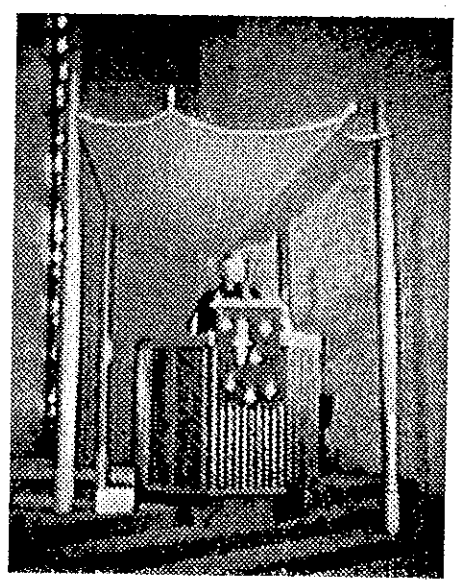
On to the church



Attaching the canopy



Column base detail



Conclusion

TIPS FOR DESIGN OF REFLECTORS FOR SPEECH

1. In general, the larger the reflector and the closer it is to the speaker's location, the better. Minimum dimension of length, width, or diameter should be at least 4 ft.

2. Use tilted *flat* surfaces or moderately *convex* surface (radius of curvature about 20 ft) to reflect sound toward listeners at middle to rear of seating areas.

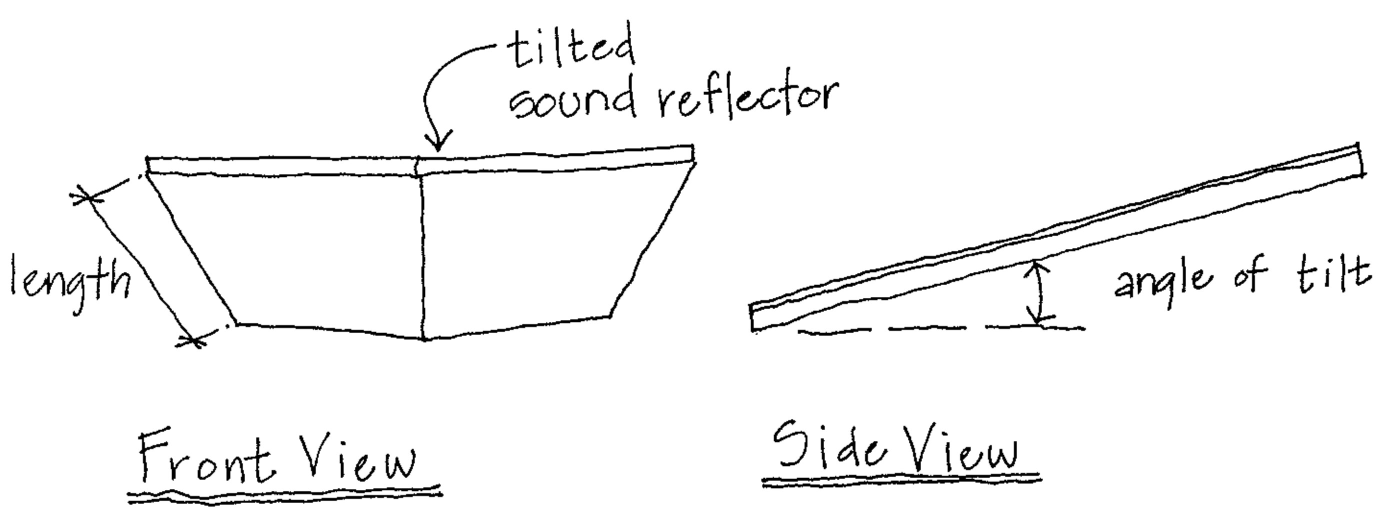
3. Avoid concave shapes because they focus sound rather than evenly distributing it.

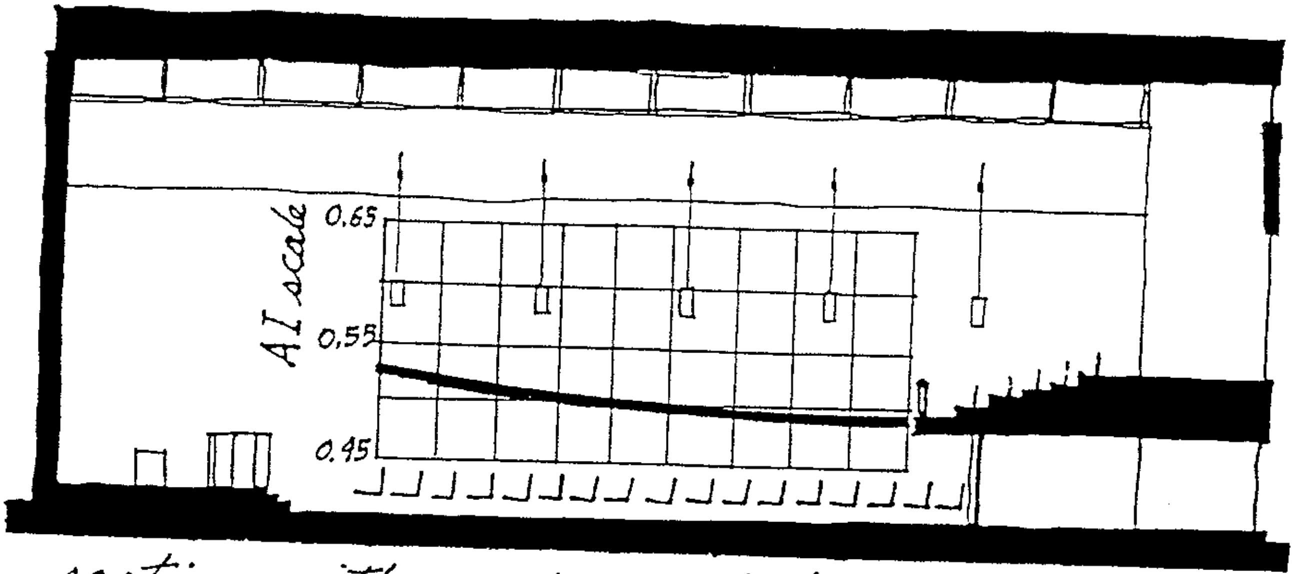
4. Use ray diagrams on section drawings to find optimum position and orientation for reflector. Be sure reflector extends forward of the speaker's location.

5. Construct reflector from materials such as wood, gypsum board, laminated-glass, or acrylic plastic that have sound absorption coefficients less than 0.10 at 2000 Hz. Reflector should be well braced to be rigid.

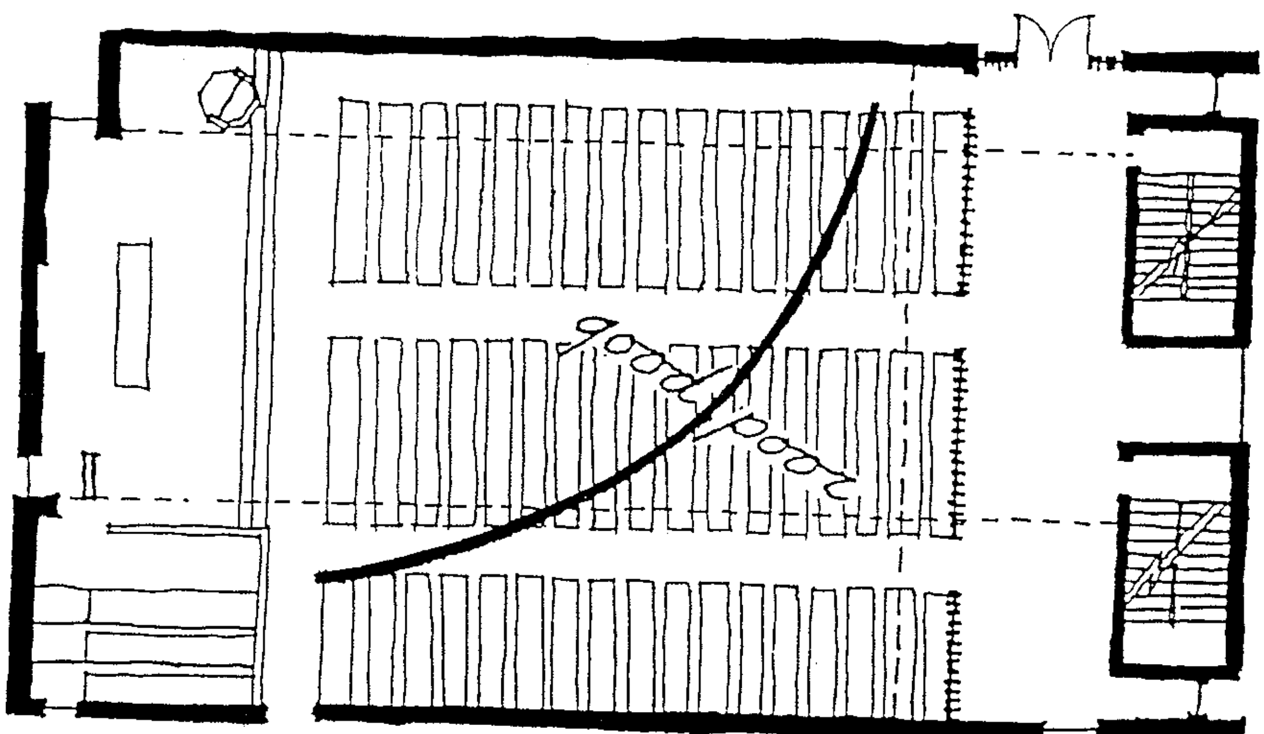
6. Be sure sound-reflecting surface is smooth and does not have any sound-diffusing elements or significant surface modulations. Depth of ribs or other surface relief should not exceed ½ inch.

7. To adjust reflector *in situ* (or temporary full-scale mock-up of thick molded polystyrene or foam-core board), cover bottom surface with high light-reflectance membrane such as aluminum foil, silvered mylar, or *glossy* polyethylene. Then with room darkened, use narrow-beam theater followspot positioned at speaker's location to evaluate pattern of reflected light into seating areas. Adjust tilt until desired even coverage is achieved.





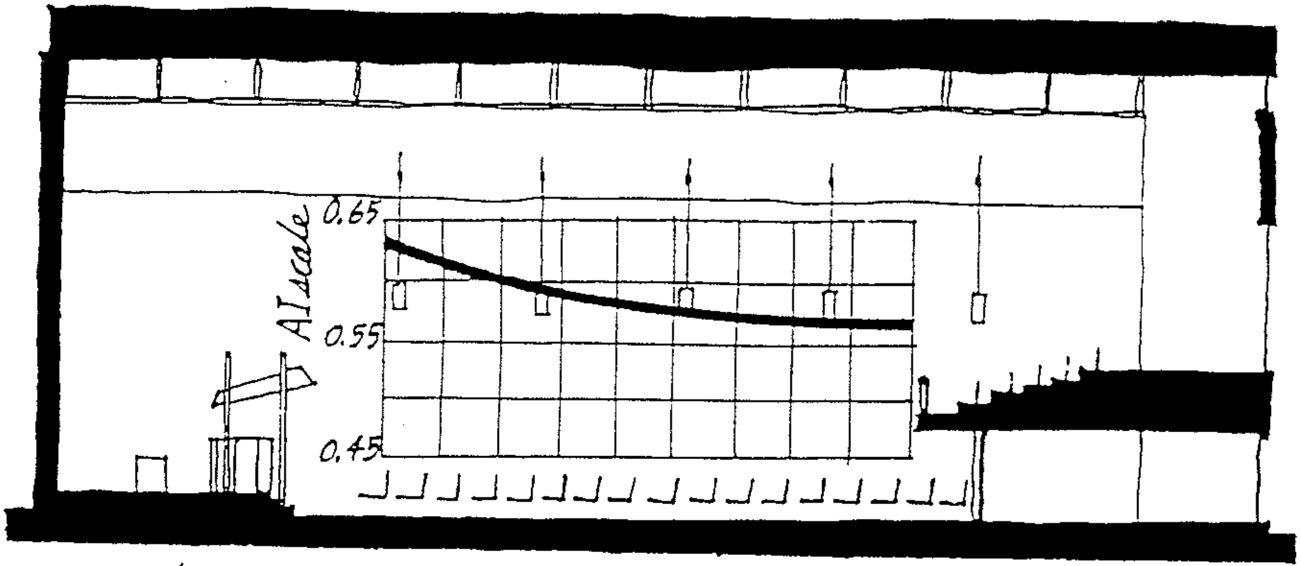
section with overlay grid of AI vs. distance



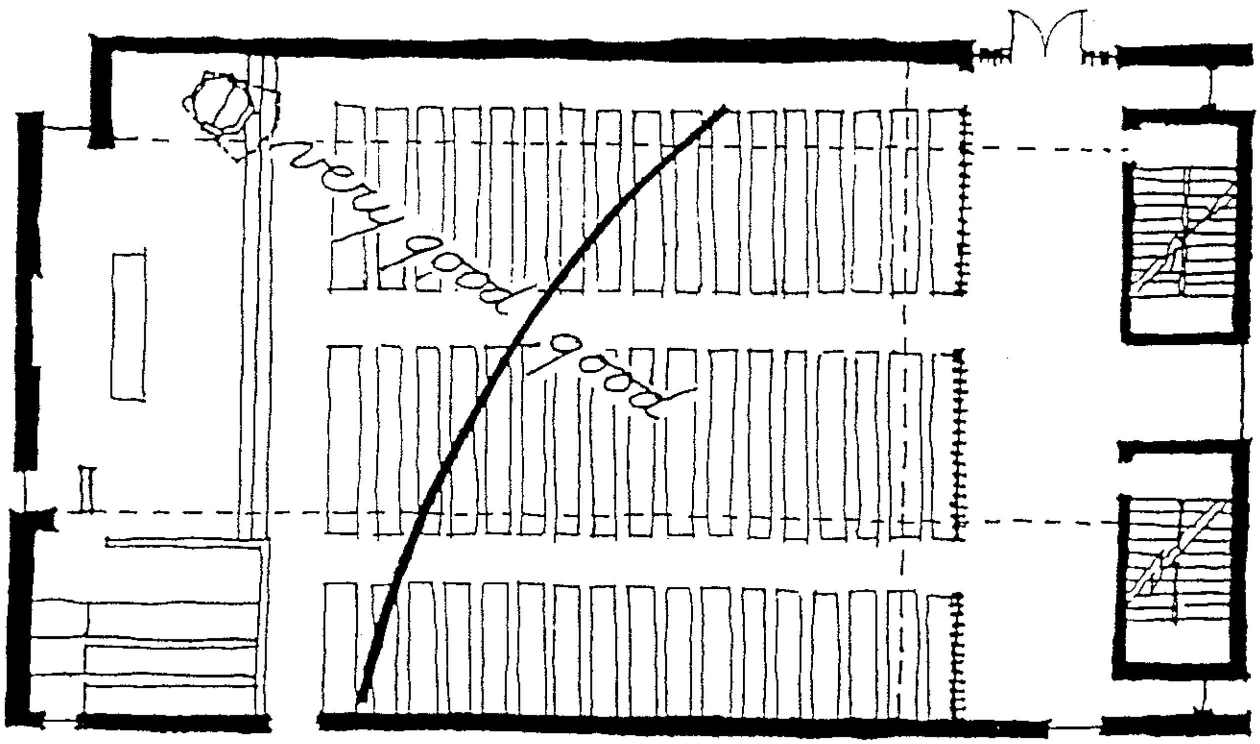
plan showing zones of listening conditions

0 4 8 16

AI gradients **before** canopy installation



section with overlay grid of AI vs. distance



plan showing zones of listening conditions

0 4 8 16

AI gradients **after** canopy installation

SOURCES FOR CLASSROOM DEMONSTRATIONS

Most of the acoustics experiments presented in these books and videos can be performed with inexpensive equipment. Although some of the books are out-of-print, they should be available in most university libraries. Classroom demonstrations can help demystify acoustical principles and leave a lasting impression.

Books

D. R. Carpenter and R. B. Minnix, *The Dick and Rae Physics Demo Notebook*, Dick and Rae, Inc., Lexington, VA, 1993.

R. D. Edge, *String and Sticky Tape Experiments*, American Association of Physics Teachers (AAPT), College Park, MD, 1987.

Exploratorium Cookbook, Exploratorium, San Francisco, CA, Vol. I [1975], Vol. II [1980], Vol. III [1987].

G. D. Freier and F. J. Anderson, *Demonstration Handbook for Physics*, American Association of Physics Teachers (AAPT), College Park, MD, 1981.

T. D. Rossing, *Acoustics Laboratory Experiments*, Northern Illinois University, DeKalb, IL,1982.

R. M. Sutton, *Demonstration Experiments in Physics*, McGraw-Hill, New York, 1938.

C. Taylor, *The Art and Science of Lecture Demonstrations*, Institute of Physics (IOP), 1988. Available from Adam Hilger, Philadelphia, PA. [Taylor's book discusses the art and science of classroom demonstrations, including advice on how to achieve well-executed, memorable demos.]

J. Walker, *The Flying Circus of Physics*, John Wiley, New York, 1974.

Videos (VHS format)

"Simple Waves" [Order from: Central Scientific Co., 11222 Melrose Ave., Franklin Park, IL 60131].

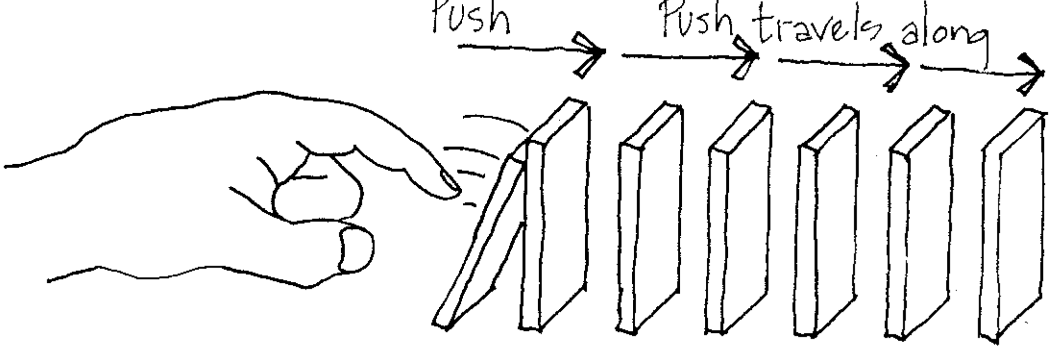
"What is a Wave?" [Order from: Science Kit and Boreal Laboratories, Tonawanda, NY 14150].

"World of Sound" [Order from: Science Kit and Boreal Laboratories, Tonawanda, NY 14150].

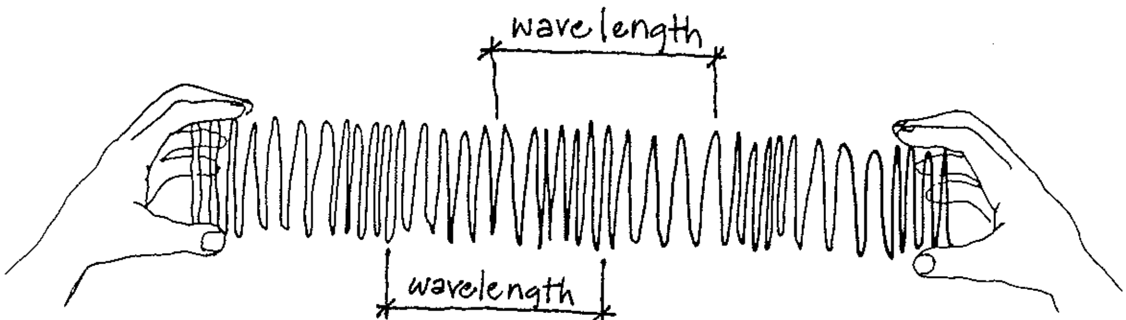
"The Puzzle of the Tacoma Narrows Bridge Collapse" [Order from: AAPT, 5112 Berwyn Road, College Park, MD 20740].

EXAMPLE TABLE-TOP DEMOS

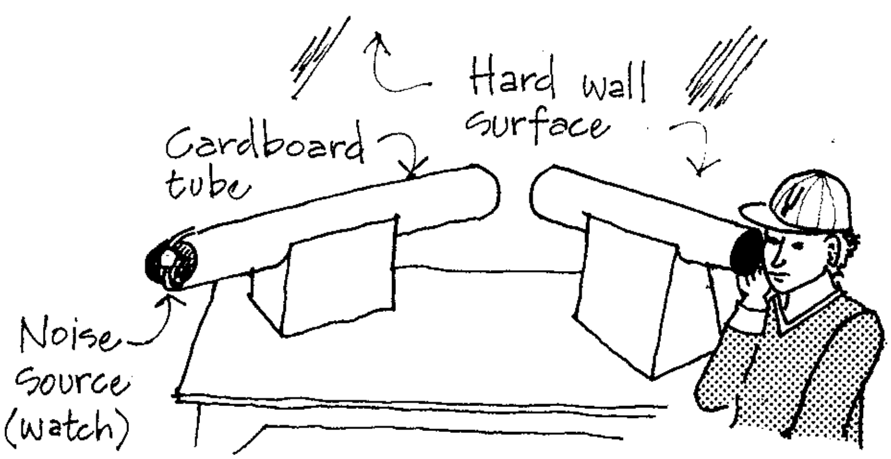
To demonstrate how molecules bump each other and *propagate sound energy*, set up a row of dominoes. By pushing the first domino, the chain reaction passes energy to the other end.



Use a slinky toy to show *wave propagation*. Suspending the toy between both hands, shake one end. Observe the dynamic pattern produced by tightly spaced coils and widely spaced coils. The distance between adjacent concentrated coils, or between adjacent widely spaced coils, is the *wavelength*.



A tube for mailing architect's drawings can be used to demonstrate *specular reflection* of sound. Cut the tube in two, set each half on a pile of books, and tape a noise source to the end of one of the tubes. With that tube at an angle to the wall, adjust the opposite tube until the sound is loudest. This should be when the angle of incidence (∠i) equals the angle of reflection (∠r).



Reference

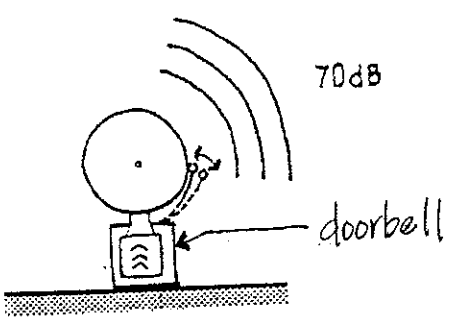
J. J. Wellington, *Sounds*, Stanley Thornes, Cheltenham, England, 1984.

SOUND ISOLATION DEMONSTRATION

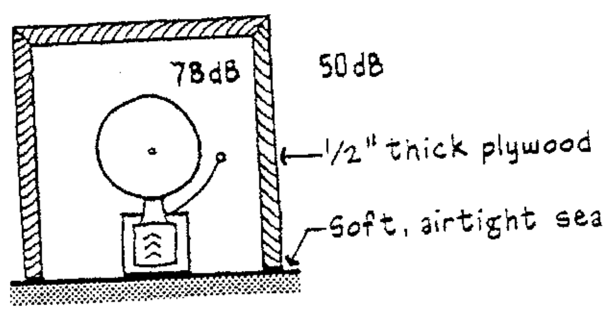
A doorbell can be used to demonstrate the basic principles of sound isolation. With no isolation, the doorbell produces 70 dB at a few inches away. When the doorbell is surrounded by a 3/4-in-thick enclosure of low-density, porous glass fiber (called "fuzz"), the transmitted noise is reduced by only 3 dB. Porous sound absorbers are very poor isolators because air molecules can readily pass through them. By themselves they act as sponges; they absorb sound but do not prevent its transmission.

When the doorbell is surrounded by a 1/2-in-thick plywood enclosure with a soft, airtight seal around its edges, the noise level is reduced from 78 dB within the enclosure to 50 dB outside. This significant reduction in noise level would be perceived by most observers to be about one-fourth as loud as the unenclosed bell. The plywood enclosure is an effective barrier because it is solid, has sufficient mass, and is sealed airtight at the gaps around its edges. The seal is essential because even a very small opening can noticeably increase the transmitted sound.

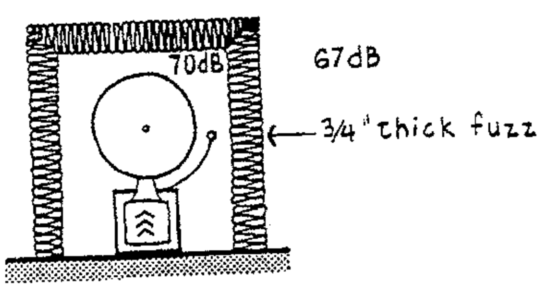
When the doorbell is surrounded by a 1/2-in-thick plywood enclosure fully lined with 3/4-in-thick sound-absorbing material, the buildup of reflected sound energy within the enclosure is reduced by 6 dB. The noise level outside the enclosure now is reduced to 43 dB.



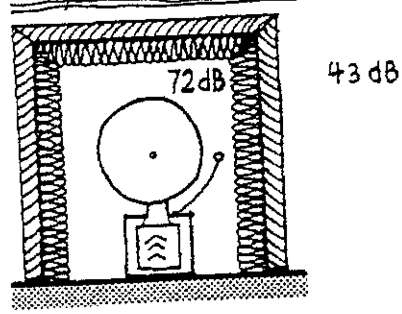
No Enclosure



Plywood Enclosure



Fuzz Enclosure



Plywood Enclosure (fuzz-lined)

NOISE BOX LECTURE DEMO

In the article below, "Homage to Bob Newman," Connector, Spring 1998, Professor John Reynolds tells how he uses a noise box demo to teach acoustics to architecture students at the University of Oregon. The Connector, edited by Ed Allen, is a biannual newsletter for teachers of technology at schools of architecture. It focuses on examples of how to teach technology and provides a forum for information exchanges by faculty. To request a subscription, write to: 129 Eliot Street, South Natick, MA 01760.

Homage to Bob Newman

Consider the following in homage to Bob Newman, from whom I took this idea. It made such an impression on me in his class 31 years ago that I promptly copied it and have used it every year since.

We begin our discussion of sound isolation in acoustics by the "noise box demonstration". Our class is about 110 undergrad-grads mixed. I have rigged up a small annoying buzzer and an equally annoying bell, sounding together. I plug this contraption in, and manage to make myself heard above the din. Holding up in one hand a small wooden box capable of covering this noisemaker, and in the other a thick hat-like creation made of carpet underlayment fabric, also capable of covering the noisemaker (and just small enough to fit inside the wooden box, later on). I shout, "which will reduce the noise more, the box or the hat"? Then I unplug the noise, and ask them if, before they vote, have they any more questions? Typical questions: "How thick?" and "what exactly is the material?" Less frequently, "how much does each weigh?" The class then holds up hands; typically, two-thirds favor the "hat", one-third the "box", and one or two people vote "the same". (I'm quite sure I voted for the hat myself once upon a time.) Then I plug the thing back in again, cover it first with the hat, then the box. The result, of course, is dramatic. They tend to remember (at least thru the Midterm Exam...) that noise absorbing materials do NOT, by themselves, isolate. The box-hat combination can then be used to show how absorbing materials within the box reduce noise still further (a nice accompaniment to PWL and SPL, for which we use Egan's graph), and, by pressing down on the box cover, how "caulking" of cracks can further reduce noise transmission.

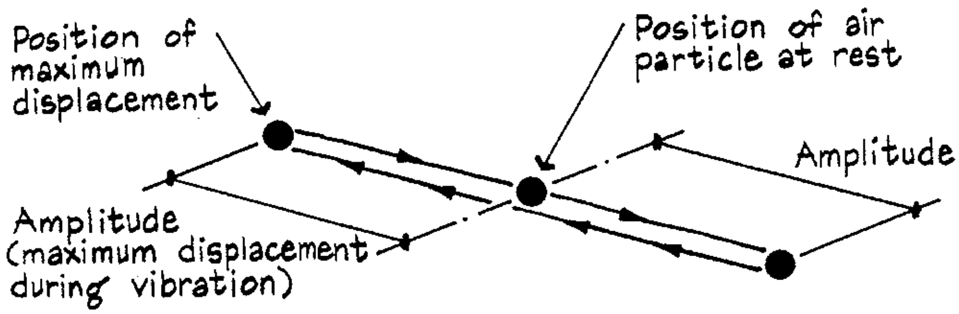
So, thanks, Bob, for the demo idea; you were tops.

3.0 BASIC THEORY

BASICS OF SOUND

Sound and Vibration

Sound is a vibration in an elastic medium such as air, water, most building materials, and the earth. Noise is unwanted sound (annoying sound made by other people or loud sound which may cause hearing loss). Sound energy progresses rapidly, producing extremely small changes in atmospheric pressure, and can travel great distances. However, each vibrating particle moves only an infinitesimal amount to either side of its normal position. It *bumps* adjacent particles and imparts most of its motion and energy to them.



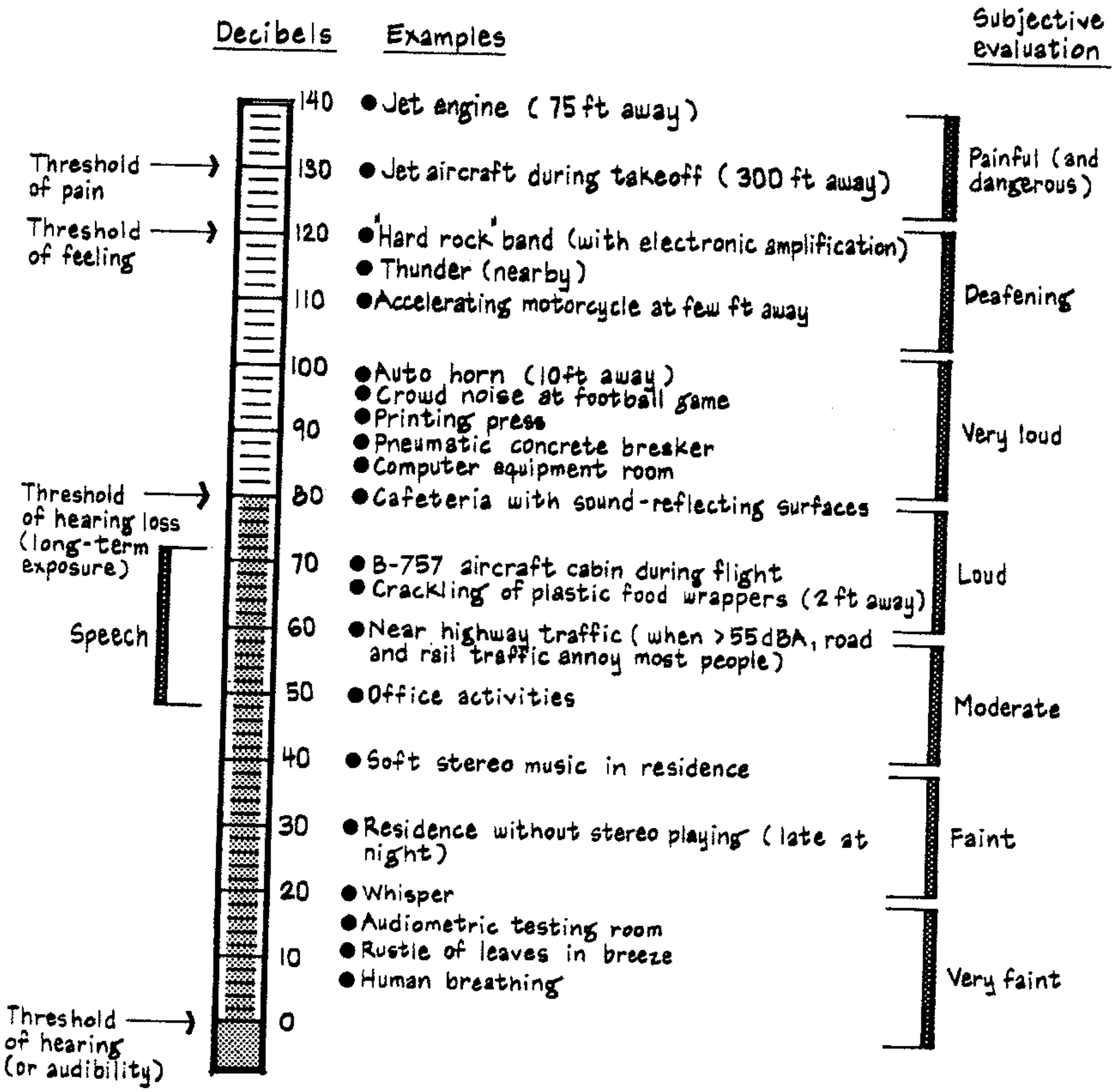
Frequency of Sound

A full circuit by a displaced particle is called a cycle. The number of complete cycles per second is the frequency of vibration. Frequency is measured in cycles per second, the unit for which is called the hertz (abbreviated Hz). It is more difficult to isolate low-frequency sound energy (<250 Hz) than energy at high frequency (>2000 Hz).

Decibels

Ernst Weber and Gustav Fechner (nineteenth-century German scientists) discovered that nearly all human sensations are proportional to the logarithm of the intensity of the stimulus. In acoustics, the bel unit (named in honor of Alexander Graham Bell) was first used to relate the intensity of sound to an intensity level corresponding to the human hearing sensation.

Some common, easily recognized, example sound levels in decibels (abbreviated dB) are shown in the figure below. The human hearing range from the threshold of audibility at 0 dB to the threshold of pain at 130 dB represents a tremendous intensity ratio of 1 to 10 trillion.



Logarithm Basics

The first step to find the *logarithm* of a number is to express it as a digit from 1 to 9 multiplied by 10 to a power. A logarithm usually consists of two parts—the *characteristic*, which is the power of 10, and the *mantissa*, which is the decimal found in log tables (or from pocket calculators). In solving logarithms, remember that

$$
\begin{aligned}
10^5 &= 100{,}000 \\
10^4 &= 10{,}000 \\
10^3 &= 1000 \\
10^2 &= 100 \\
10^1 &= 10 \\
10^0 &\equiv 1 \quad (\equiv \text{ means } \textit{equal to} \text{ by definition}) \\
10^{-1} &= 0.1 \\
10^{-2} &= 0.01 \\
10^{-3} &= 0.001
\end{aligned}
$$

and when the decimal point is shifted to the left by *n* places, the number is to be multiplied by 10^n; when the decimal is shifted to the right by *n* places, the number is to be divided by 10^n. This may seem complicated at first, but after reviewing a few examples it should become routine.

$$4{,}820{,}000.0 = 4.82 \times 10^6 \simeq \boxed{5 \times 10^6} \quad (\simeq \text{ means } \textit{approximately equal to})$$

Numbers ending in 0.5 and greater should be rounded up as shown by the example above. If less than 0.5, the decimal should be dropped.

$$0.0000258 = 2.58 \times 10^{-5} \simeq \boxed{3 \times 10^{-5}}$$

$$8{,}400{,}000{,}000.0 = 8.4 \times 10^9 \simeq \boxed{8 \times 10^9}$$

The following shortened logarithm table can be used to quickly find the mantissa of numbers from 1 to 9.

A USEFUL LOG TABLE

Number	Mantissa
1	0
2	0.3
3	0.48
4	0.6
5	0.7
6	0.78
7	0.85
8	0.9
9	0.95

In almost all acoustical problems, it is not necessary to work with small fractions of decibels. Use either the log table above, or a four-place log table, and round the final answer to the nearest decibel. A pocket calculator that finds an entire logarithm in one step is very handy when working with decibels.

The following examples represent logs of very large and very small numbers. Remember, the first step is to arrange the number as a digit times 10 to a power.

$$\log(4{,}820{,}000.0) = \log(5 \times 10^6) = 6.7 = \boxed{6.7}$$

(enter number column to find)

$$\log(0.0000258) = \log(3 \times 10^{-5}) = -\log\left(\frac{1}{3} \times 10^5\right)$$

$$= -\log(0.33 \times 10^5) = -\log(3 \times 10^4) = \boxed{-4.48}$$

$$\log(8{,}400{,}000{,}000.0) = \log(8 \times 10^9) = \boxed{9.9}$$

Antilogarithms

The *antilogarithm* of a quantity, such as antilog (x), is the number for which the quantity x is the logarithm. For example,

$$\text{antilog}(6.7) = 5 \times 10^6 = \boxed{5 \times 10^6}$$

(enter mantissa column to find)

$$\text{antilog}(-4.48) = -3 \times 10^4 = \frac{1}{3} \times 10^{-4} = 0.33 \times 10^{-4} = \boxed{3 \times 10^{-5}}$$

When the mantissa of a log falls between values in the **shortened log table**, use the closest mantissa to find the corresponding number from 1 to 9.

Properties of Logs

1. $\log xy = \log x + \log y$
2. $\log \frac{x}{y} = \log x - \log y$
3. $\log x^n = n \log x$
4. $\log 1 = 0$*

*This property is important in acoustical analysis because openings in building elements have no resistance to sound flow which then can be expressed as 0 dB of isolation.

PRACTICE PROBLEMS

1. Using logarithms, compute the sound intensity levels (L) in decibels (dB) corresponding to following sound intensities (I) in watts per square meter. Round your answers to the nearest whole dB.

8.93×10^{-2} W/m^2 L = ________ dB

4.2×10^{-4} W/m^2 L = ________ dB

$8.48 \times 10^{+1}$ W/m^2 L = ________ dB

1.0×10^{-12} W/m^2 L = ________ dB

2. Find the corresponding sound intensities (I) in watts per square meter (W/m^2) from following sound intensity levels (L) in decibels (dB). Refer to page 22 in *Architectural Acoustics.*

125 dB $I =$ ________ W/m^2

29 dB $I =$ ________ W/m^2

73 dB $I =$ ________ W/m^2

0 dB $I =$ ________ W/m^2

POWERS OF 10 REVIEW

Remember, the symbol 10^3 is a shorthand notation for $10 \times 10 \times 10 = 1000$. Also, the product of two powers of the same number has an exponent equal to the sum of the exponents of the two powers:

$$10^2 \times 10^3 = (10 \times 10) \times (10 \times 10 \times 10) = \boxed{10^5}$$

or

$$10^2 \times 10^3 = 10^{(2+3)} = \boxed{10^5}$$

Additional examples follow:

$$10^7 \times 10^5 = 10^{(7+5)} = \boxed{10^{12}}$$

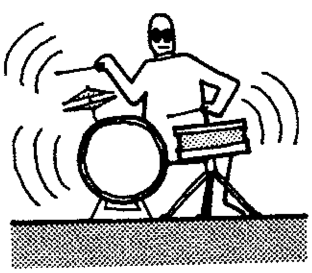
$$\frac{10^{-9}}{10^{-12}} = 10^{-9} \times 10^{+12} = 10^{(-9+12)} = \boxed{10^3}$$

When combining exponents, be careful of the signs. Dividing by a negative exponent such as 10^{-12} is equivalent to multiplying by its reciprocal, 10^{+12}.

$$\frac{10^{-3}}{10^{-12}} = 10^{-3} \times 10^{+12} = 10^{(-3+12)} = \boxed{10^9}$$

You have now learned to handle powers of 10 and logarithms, which are fundamental relationships needed to describe how humans perceive sound and how building materials affect sound energy.

Examples

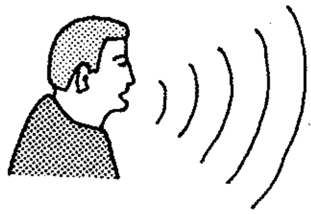


1. The intensity I of a rock music group is 8.93×10^{-2} W/m^2. Find the corresponding sound intensity level L_I.

$$L_I = 10 \log \frac{I}{10^{-12}}$$

$$= 10 \log \frac{8.93 \times 10^{-2}}{10^{-12}} = 10 \log (8.93 \times 10^{10})$$

$$L_I = 10\ (10.9509) = \boxed{110 \text{ dB}}$$



2. Loud speech, measured at 3 ft away, has a sound intensity level L_I of 73 dB. Find the corresponding intensity I.

$$L_I = 10 \log \frac{I}{10^{-12}}$$

$$73 = 10 \log \frac{I}{10^{-12}}$$

Next, divide both sides of the equation by 10.

$$7.3 = \log \frac{I}{10^{-12}}$$

The above expression states that the log of a ratio $(I/10^{-12})$ is equal to 7.3. When the number for which the log is 7.3 (i.e., antilog) is found, set it equal to the ratio.

$$\text{antilog}\,(7.3) = 1.995 \times 10^{7}$$

from mantissa table or pocket calculator

Therefore,

$$1.995 \times 10^{7} = \frac{I}{10^{-12}}$$

and by cross multiplication

$$I = 1.995 \times 10^{7} \times 10^{-12} = \boxed{1.995 \times 10^{-6}\ \text{W/m}^2}$$

PRACTICE PROBLEMS

1. Convert sound intensity (I) into corresponding sound intensity level (L).

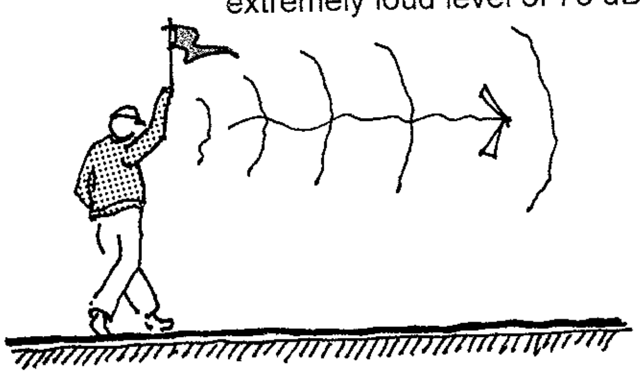
Given: Rock music at 5.4×10^{-2} W/m^2. Rock lacks two of the following defining elements of music: harmony, rhythm, and melody.

Warning: Prolonged exposure to noise exceeding 85 dBA can cause permanent hearing loss.

L = ________ dB

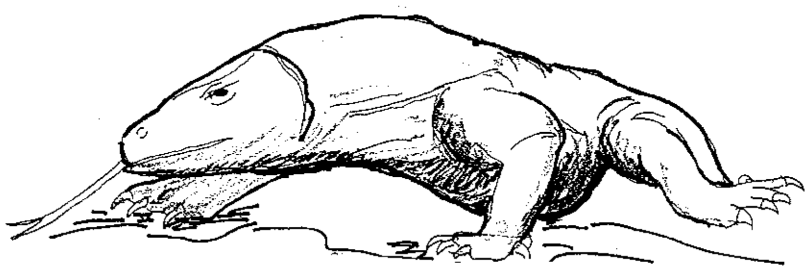
2. Convert sound intensity level (L) into corresponding sound intensity (I).

Given: Bruce from the University of Woolamaloo yells toward Sheila at an extremely loud level of 78 dB.



I = ________ W/m^2

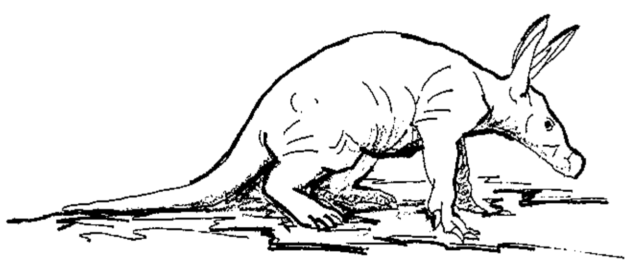
3. A Komodo Dragon angrily hisses at 82 dB. The corresponding intensity will be _________ W/m^2.



4. Sound at a wavelength of 2.5 ft will have a frequency of __________ Hz.

5. Three basketballs hitting a wooden floor are measured at sound levels of 63 dB, 64 dB, and 66 dB respectively. The combined sound level will be _________ dB. [HINT: Refer to pages 22 to 24 in *Architectural Acoustics*.]

6. An excited aardvark snorts at 50 dB. Find the combined sound level from seventeen snorting aardvarks clustered together during their nighttime journey over open terrain.



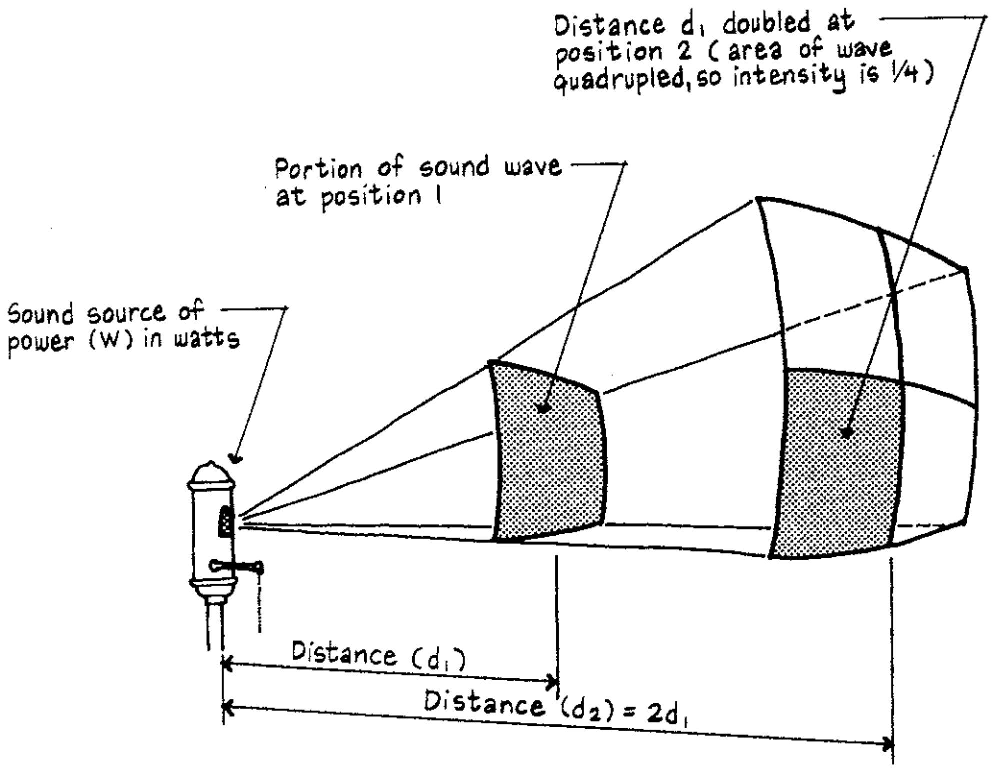
L = ________ dB

7. Pure tones stand out above adjacent frequencies. Will a 40 dB pure tone at 125 Hz be perceived as louder than a 40 dB pure tone at 4000 Hz? [HINT: Refer to graph of Fletcher-Munson's *equal-loudness contours*.]

Yes No

INVERSE-SQUARE LAW

Sound waves from a point source outdoors with no obstructions (called *free-field* conditions) are virtually spherical and expand outward from the source as shown below. A point source has physical dimensions of size that are far less than the distance an observer is away from the source.



Power is a basic quantity of energy flow. Although both acoustical and electric energies are measured in watts, they are different forms of energy and cause different responses. For instance, 10 watts (abbreviated W) of electric energy at an incandesent lamp produces a very dim light, whereas 10 W of acoustical energy at a loudspeaker can produce an extremely loud sound. Peak power for musical instruments can range from 0.05 W for a clarinet to 25 W for a bass drum.

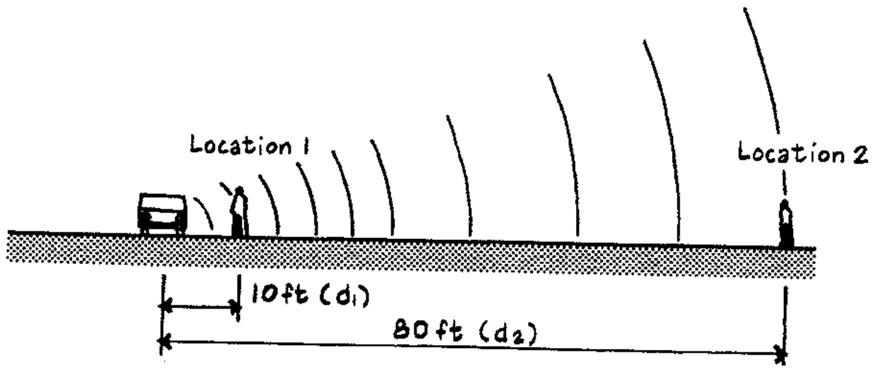
The intensity from a point source outdoors at a distance *d* away is the sound power of the source divided by the total spherical area $4\pi d^2$ of the sound wave at the distance of interest. This relationship can be expressed as:

$$I = \frac{W}{4\pi d^2}$$

where I = sound intensity (W/m^2)
W = sound power (W)
d = distance from sound source (m)

If the distance is measured in feet, multiply the result by 10.76, because 1 m^2 equals 10.76 ft^2.

EXAMPLE PROBLEM (INVERSE-SQUARE LAW)



1. A car horn outdoors produces a sound intensity level L_I of 90 dB at 10 ft away. To find the intensity I_1 at this first location, use

$$L_I = 10 \log \frac{I}{10^{-12}}$$

$$90 = 10 \log \frac{I_1}{10^{-12}}$$

$$9.0 = \log \frac{I_1}{10^{-12}}$$

$$\text{antilog } (9.0) = 1.0 \times 10^9$$

$$1.0 \times 10^9 = \frac{I_1}{10^{-12}}$$

$$I_1 = 1.0 \times 10^9 \times 10^{-12} = \boxed{10^{-3}\ \text{W/m}^2} \text{ at 10 ft away}$$

2. If the sound intensity I is known at a given distance in feet away from the source, sound power W can be found by the following formula.

$$I = \frac{W}{4\pi d^2} \times 10.76$$

By cross multiplication

$$W = 4\pi d^2 \times \frac{1}{10.76} \times I$$

Since $I_1 = 10^{-3}$ W/m² at 10 ft away

$$W = 4 \times 3.14 \times 10^2 \times \frac{1}{10.76} \times 10^{-3} = \boxed{0.12\ \text{W}}$$

3. The intensity level L_I at 80 ft away can be found by the inverse-square law. First, find the sound intensity I_2 at the location 80 ft away.

$$\frac{I_1}{I_2} = \left(\frac{d_2}{d_1}\right)^2$$

$$\frac{10^{-3}}{I_2} = \left(\frac{80}{10}\right)^2$$

$$\frac{10^{-3}}{I_2} = 64$$

$$64I_2 = 10^{-3}$$

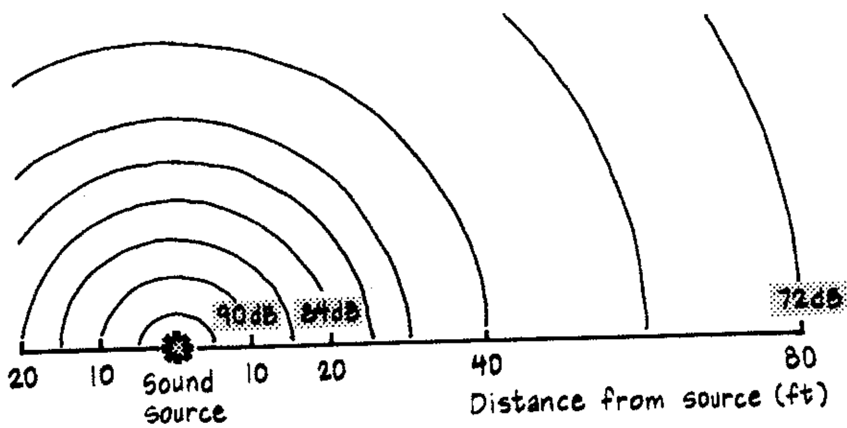
$$I_2 = \frac{1}{64} \times 10^{-3} = \boxed{1.56 \times 10^{-5}\ \text{W/m}^2} \text{ at 80 ft away}$$

Next, find L_I.

$$L_I = 10 \log \frac{I_2}{10^{-12}} = 10 \log \frac{1.56 \times 10^{-5}}{10^{-12}}$$

$$L_I = 10 \log (1.56 \times 10^{7}) = 10(7.1931) = \boxed{72\ \text{dB}} \text{ at 80 ft}$$

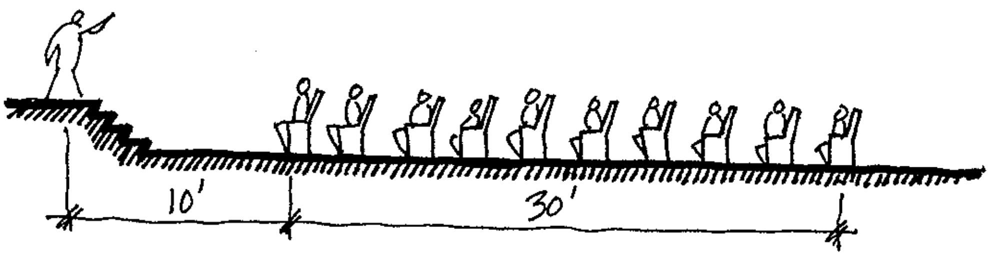
This means a listener moving from location 1 at 10 ft away to location 2 at 80 ft away would observe a change in intensity level of 18 dB (that is, 90 dB − 72 dB). This reduction would be judged by most listeners as "very much quieter". However, a car horn at 72 dB would still be considered "loud" by most people.



Note: From 10 to 80 ft away is three doublings of distance (i.e., 10 to 20 ft, 20 to 40 ft, and 40 to 80 ft). Therefore, three doublings × 6 dB/doubling = 18 dB reduction and $L_I = 90 - 18 = 72$ dB at 80 ft away.

PROBLEM EXERCISES

1. Convocations are held outdoors on a college campus where ambient background sound levels are 40 dB. Unamplified speech levels average 60 dB at the 1st row, located 10 ft from the raised platform. If audience attenuation is 1.5 dB per row, find the reduced speech level at the 10th row, located 40 ft from the platform.



Step 1. Speech level at 1st row. L_1 = ________dB

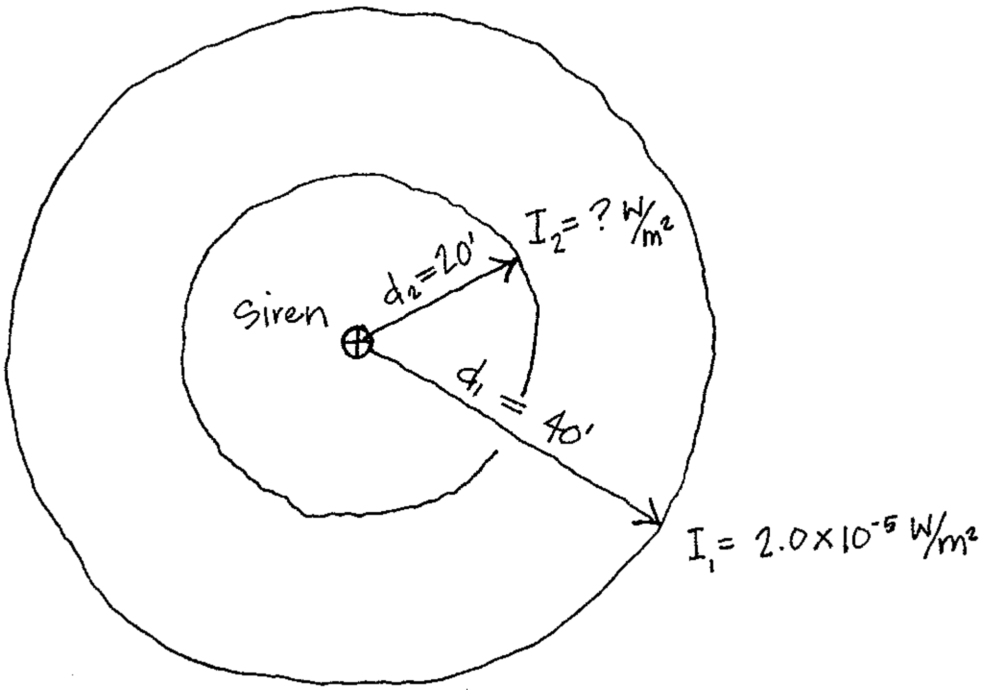
Step 2. Sound spreading loss to 10th row. Compute by inverse-square law. A = ________dB

Step 3. Audience attenuation. A = ________dB

Step 4. Speech level at 10th row. L_2 = ________dB

Step 5. Will speech levels be audible at 10th row? [Circle correct answer.] Yes No

2. A siren produces an intensity of 2.0×10^{-5} W/m^2 outdoors at a distance of 40 ft away. What would be the intensity at 20 ft away?



I_2 = ________W/m^2 at 20 ft away

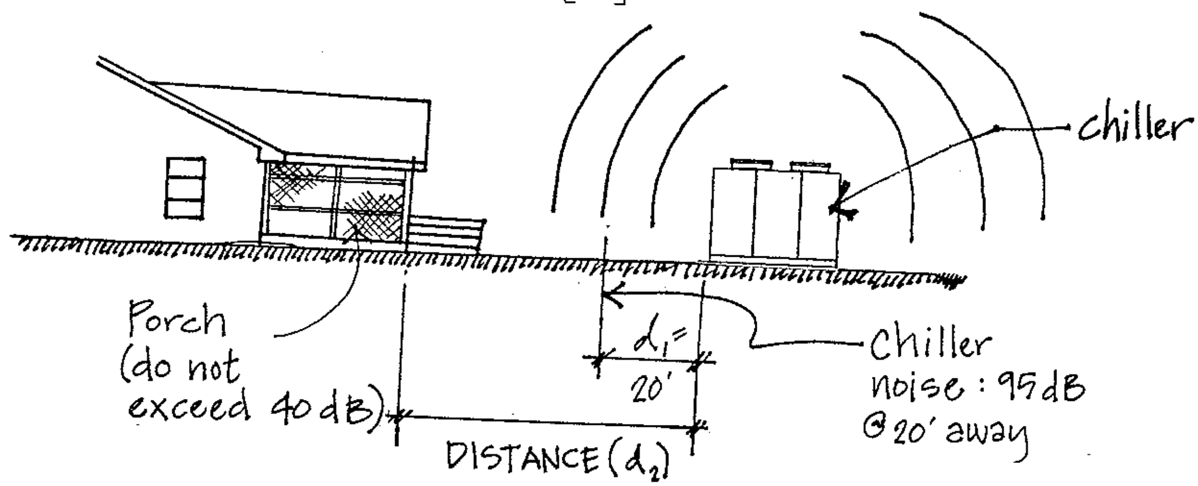
3. At 25 ft away, cicadas produce a sound level of ________ dB at 2000 Hz. Find the sound level from these cicadas at 100 ft away. [HINT: Refer to table on page 34 in *Architectural Acoustics*.]

L_2 = ________dB at 100 ft away

4. Find how far a noisy rotary-screw chiller should be away from a screened outdoor porch. The noise level on the porch should *not* exceed 40 dB.

Given: 1. Chiller noise is 95 dB at 20 ft away outdoors. Consider chiller to be a point source.

2. Inverse-square law is $\frac{I_1}{I_2} = \left[\frac{d_2}{d_1}\right]^2$.



Step 1. Find intensity (I_1) at 20 ft from chiller.

I_1 = ________ W/m^2

Step 2. Find intensity (I_2) corresponding to 40 dB, *not* to be exceeded at porch.

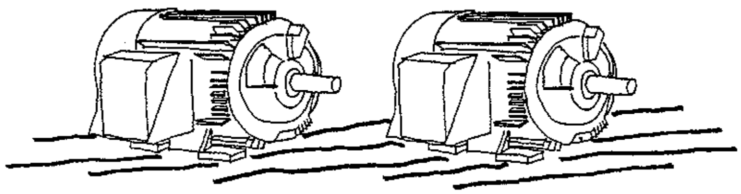
I_2 = ________ W/m^2

Step 3. Use inverse-square law to find distance (d_2) chiller must be away from porch.

d_2 = ________ ft

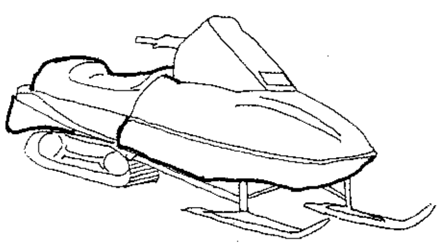
NOTE: You can check your answer using formula for noise reduction outdoors: NR = 20 log (d_2/d_1), where NR will be 95-40 = 55 dB and d_1 = 20 ft. Solve for d_2.

5. Two electric motors are side-by-side in an open area outdoors. When operating alone, one motor measures 80 dBA at 5 ft away, the other 78 dBA at 10 ft away. Find the combined noise level at 40 ft away when both motors are operating simultaneously. [HINT: For a method to quickly combine decibels, refer to pages 23 and 24 in *Architectural Acoustics*.]



L = __________ dBA at 40 ft away

6. Find the A-weighted decibel (dBA) for a snowmobile. At 50 ft away, the measured octave-band sound levels are: 82 dB at 125 Hz, 84 dB at 250 Hz, 75 dB at 500 Hz, 78 dB at 1000 Hz, and 77 dB at 2000 Hz. [HINT: For the weighting decibels and examples, refer to pages 31 and 32 in *Architectural Acoustics*.]



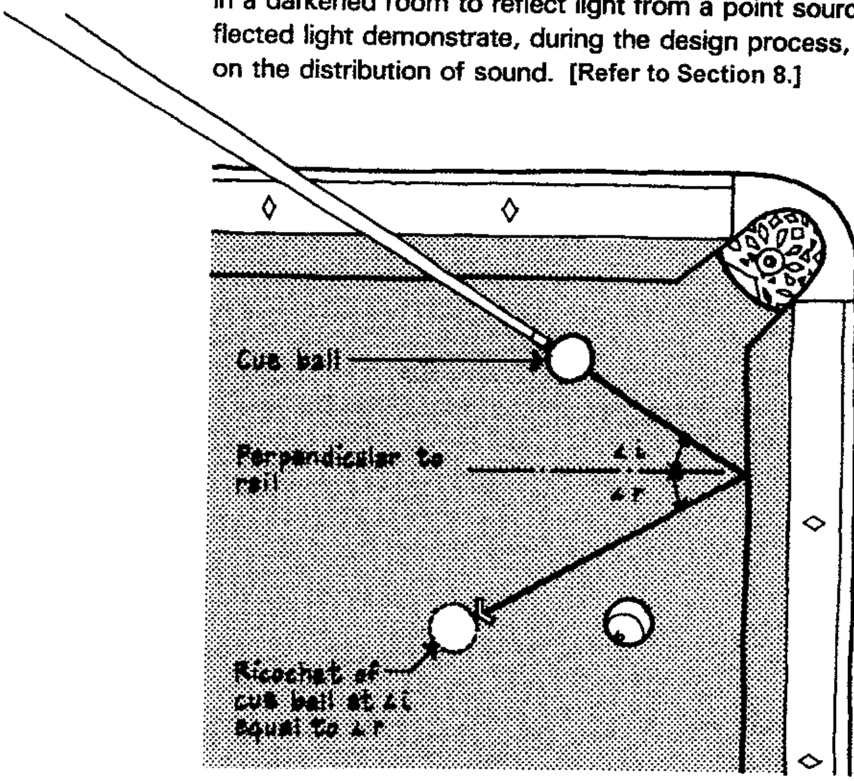
L = __________ dBA

7. The Irish Tenors™ (Tynan, Kearns, and McDermott) sing "Galway Bay" outdoors at 80 dB each. How many additional tenors would be needed to reach 97 dB?

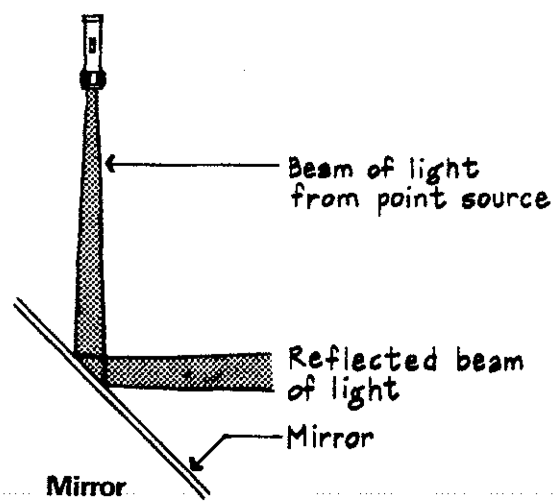
N = __________ Irish Tenors

RAY DIAGRAMS

Ray-diagram analyses can be used to study the effect of room shape on the distribution of sound and to identify surfaces which may produce echoes. A ray diagram is an acoustical analogy to the *specular* reflection of light where the angle of incidence $\angle i$ of an impinging sound wave equals the angle of reflection $\angle r$, with angles measured from the perpendicular to the surface. That is, sound waves are reflected from surfaces in the same way a billiard ball, without spin, rebounds from a cushion. Because of this, small mirrors or silvered paper can be used with architectural drawings (or small-scale models) in a darkened room to reflect light from a point source. The patterns of reflected light demonstrate, during the design process, the effect of room shape on the distribution of sound. [Refer to Section 8.]



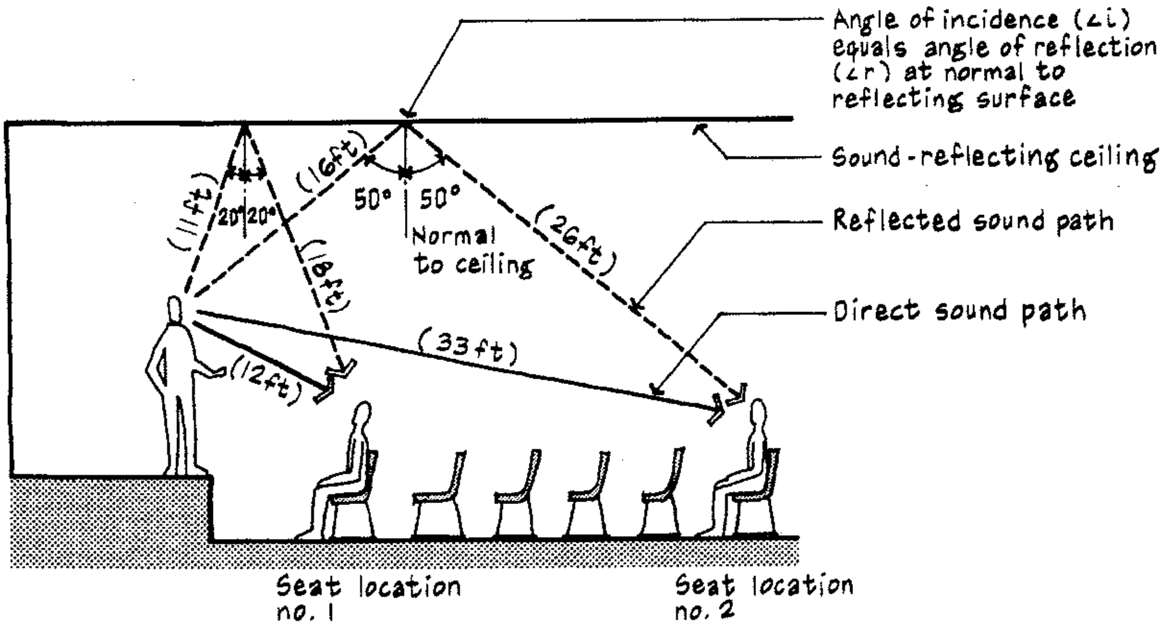
Billiard Table



Mirror

An inexpensive protractor to measure angles, a pencil, scale, and paper are all the equipment required for ray-diagram calculations. Shown below is an auditorium section with sound path differences calculated to front and middle-rear audience locations from a typical source location.

Path difference = reflected path − direct path



Example Ray-Diagram Measurements (Distances are shown in parentheses on above drawing)

Front location no. 1:

Path difference = (11 + 18) − (12) = 17 ft

Excellent for speech and music because path difference is less than 23 ft.

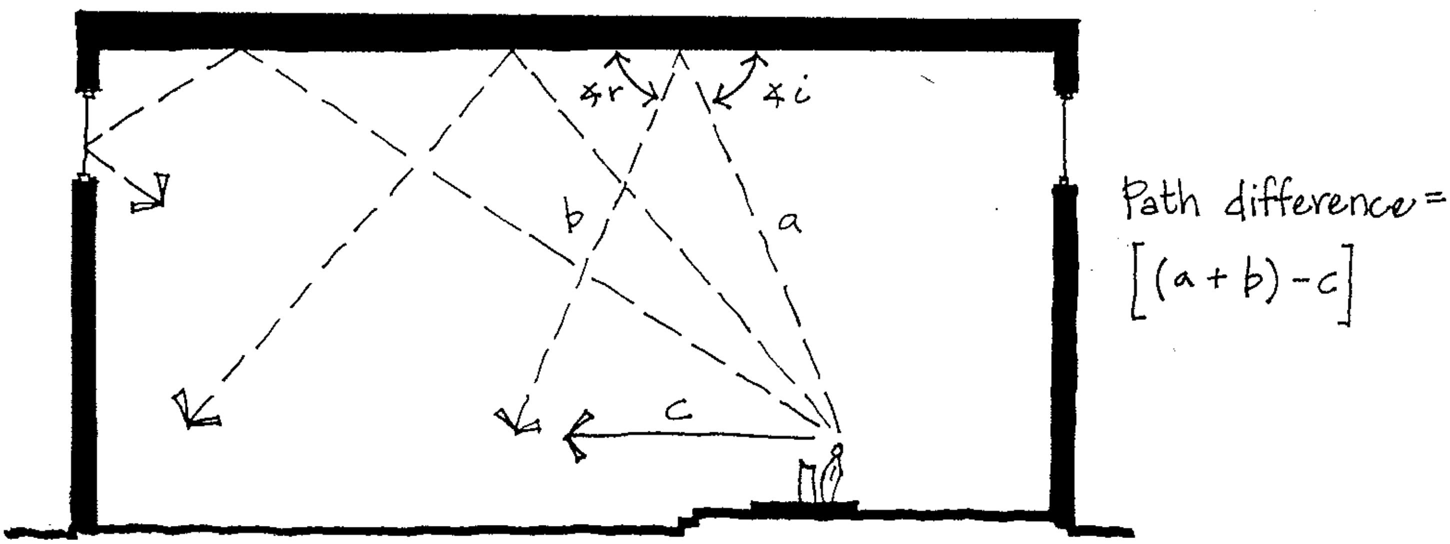
Middle location no. 2:

Path difference = (16 + 26) − (33) = 9 ft

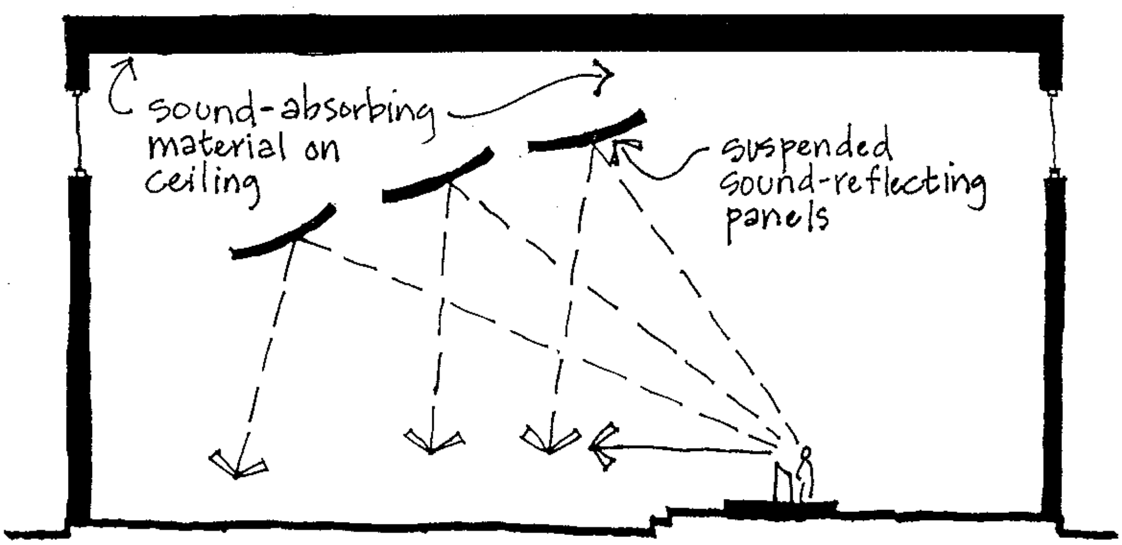
Excellent for speech and music because path difference is less than 23 ft.

EXAMPLE RAY DIAGRAMS (Adaptive Reuse Design)

According to L. L. Beranek, "Concert Hall Acoustics," JASA, July 1992, p. 36, *intimacy* is the most important subjective attribute in a hall. Intimacy correlates well with short path differences and the corresponding ITDG (<20 msec).



Before Modifications (Poor distribution of reflected sound.)



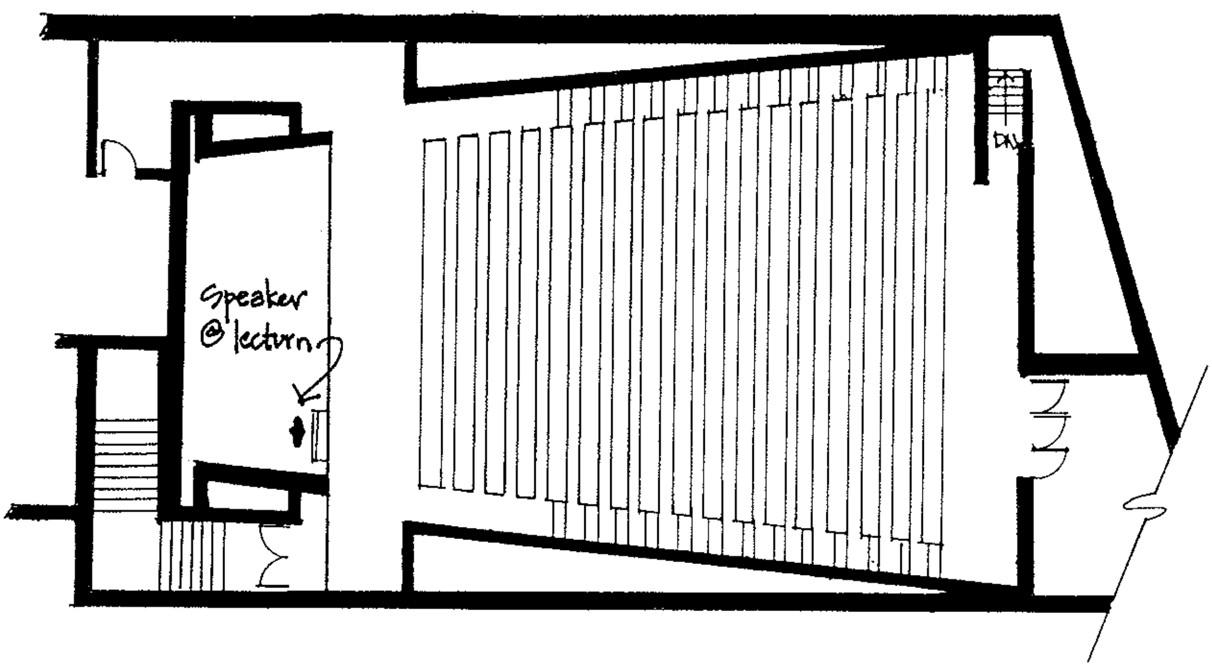
After Modifications (Better distribution & shorter ITDG's.)

PROBLEM EXERCISES

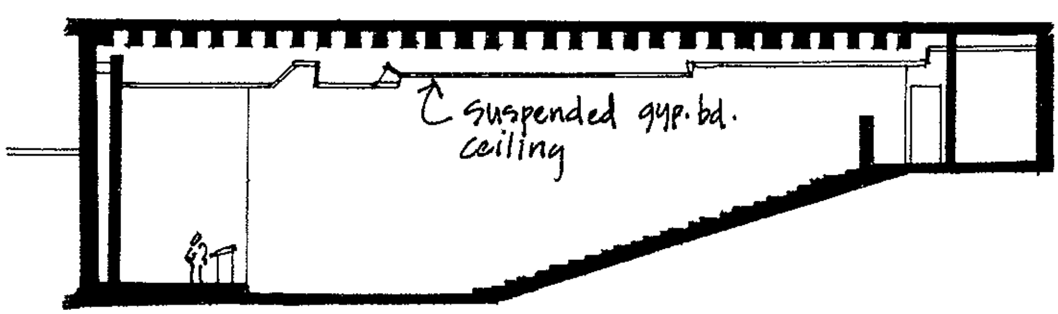
1. Use the lecture hall plan and section drawings below to practice ray diagramming. Sound should be evenly distributed to seating area.

    - Show how sound is reflected off the front half of ceiling and front half of side walls.

    - Find initial time delay gap (ITDG). To convert path difference (in ft) to ITDG (in msec), multiply path difference by 0.9. Refer to page 105 in *Architectural Acoustics*.



Plan

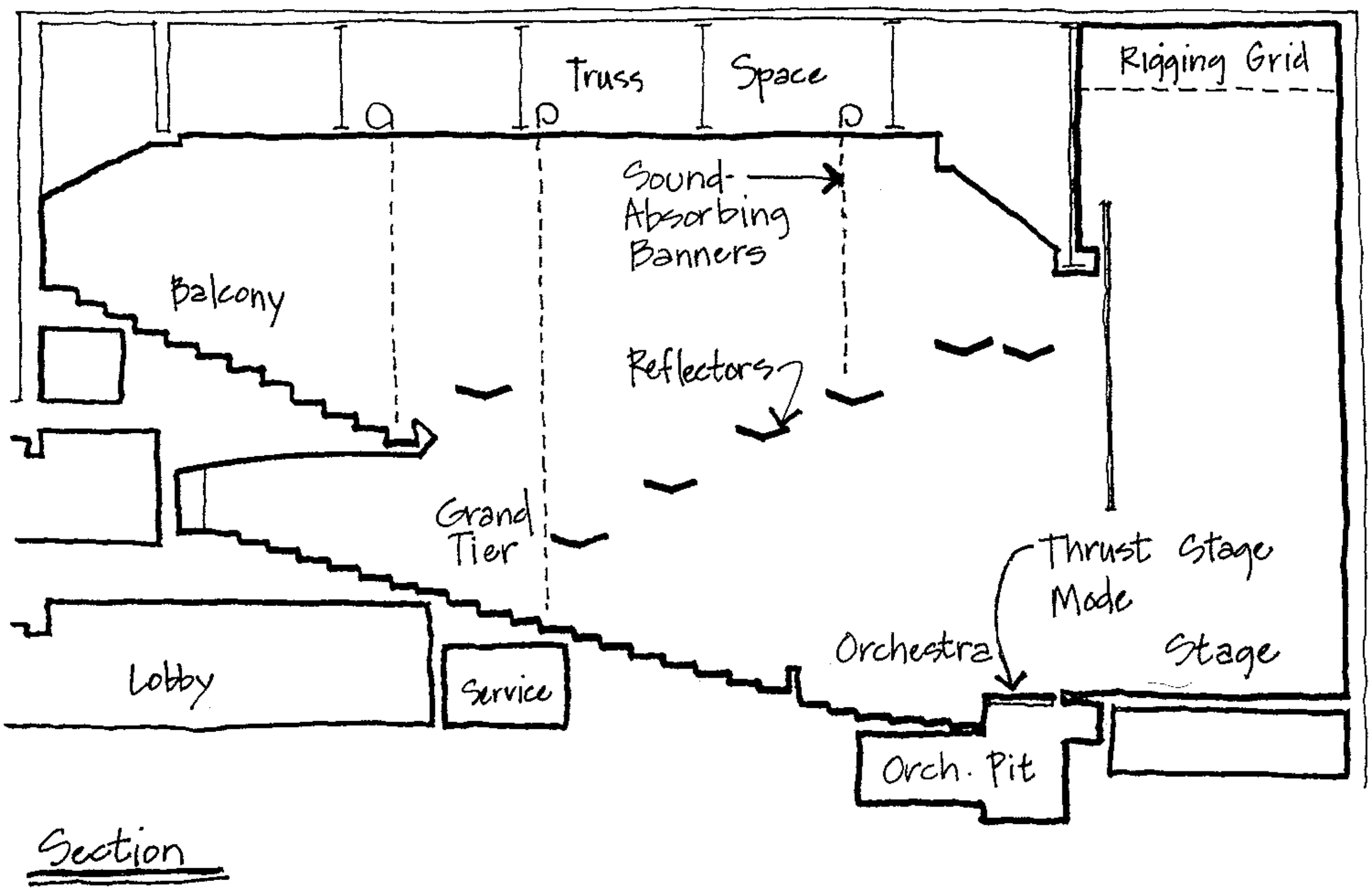


Section

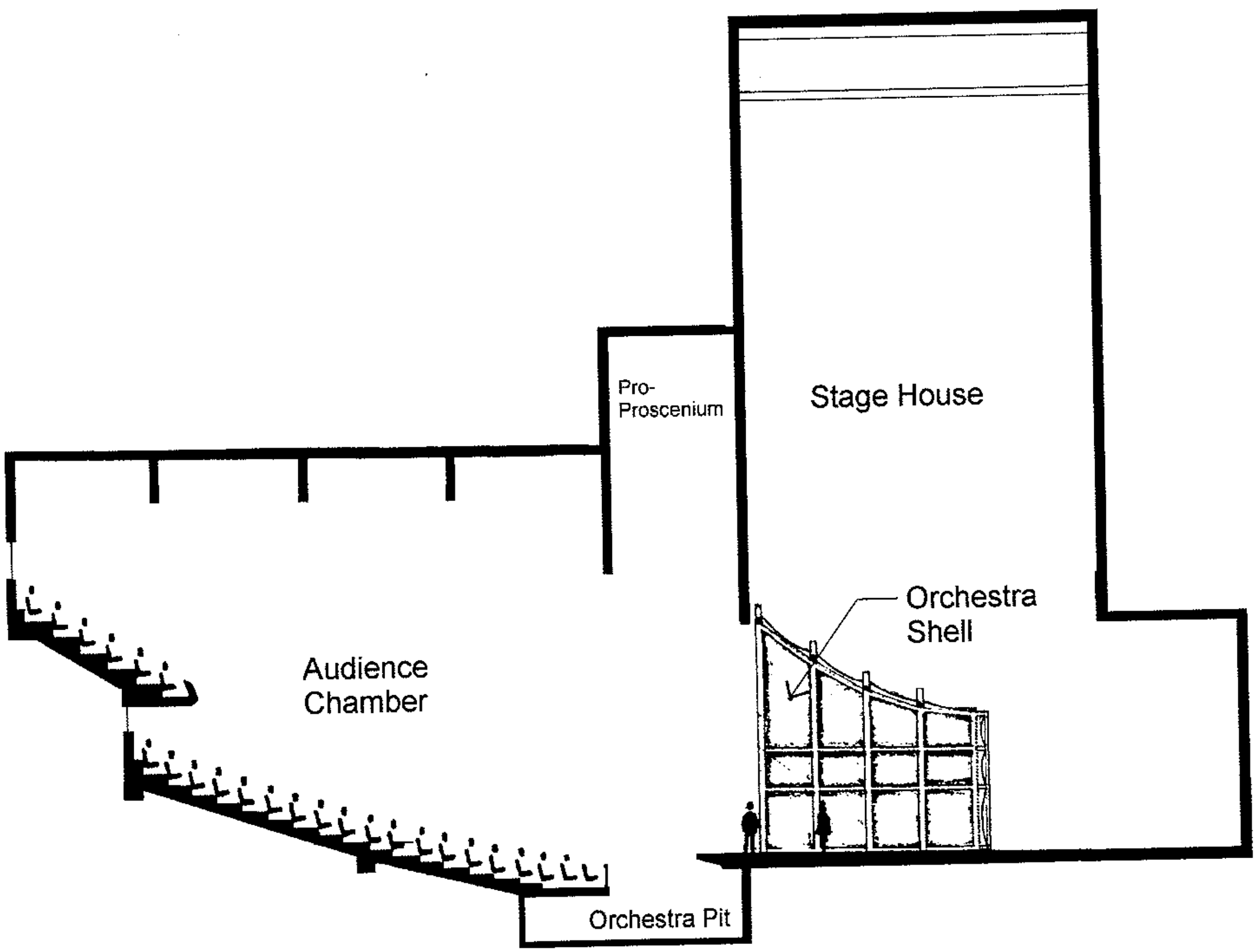
2. Use auditorium section drawing to show how sound is reflected off suspended reflectors in the lowered position and when raised to be flush with ceiling. Sound should be evenly distributed from stage to audience on all levels. Two conditions are:

   - Intimate theater mode (suspended reflectors in lowest position as shown below).

   - Concert hall mode (suspended reflectors flush with ceiling and sound-absorbing banners retracted into truss space).

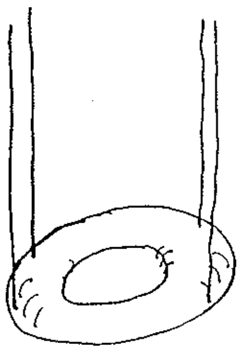


3. Lay out a suspended array of panels to acoustically couple the cubic volume of the orchestra shell to the audience chamber. Use ray diagrams to show distribution of reflected sound. Indicate thickness, size, and shape of your panels. *Note to Instructor:* For a review of geometric principles for designing sound reflectors, see pages 105 to 118 in L. Cremer and H. A. Müller, *Principles and Applications of Room Acoustics,* Vol. 1, Applied Science Publishers, Barking, England, 1978.

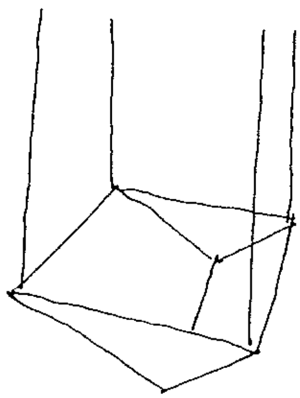


Section

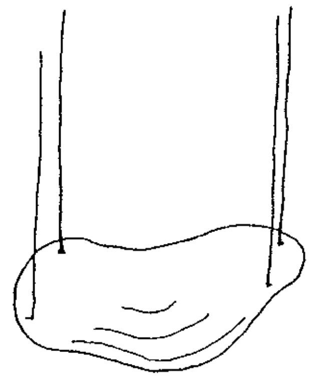
4. Match the sound reflectors shown below to the prominent concert halls in the cities listed below. For photos and drawings of seventy-six halls, refer to L. L. Beranek, *Concert and Opera Halls,* Acoustical Society of America, Woodbury, NY, 1996. If you finish before time is called, you may check your work on this section only.



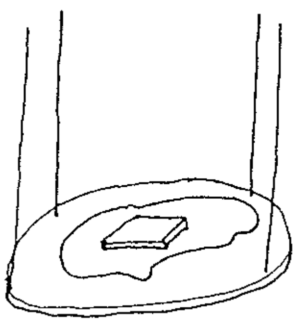
A. "THE BAGEL" or "DOUGHNUT"



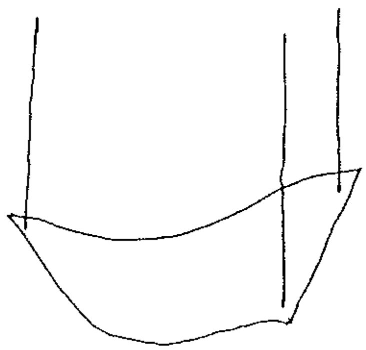
B. "THE ICE CUBE"



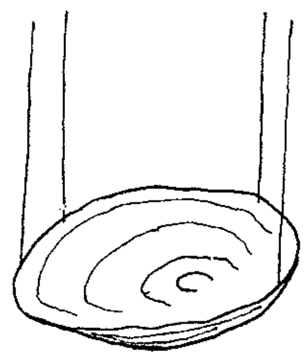
C. "THE PRINGLE"



D. "THE PANCAKE"



E. "THE DORITO"



F. "THE CRYSTAL SALAD BOWL"

Baltimore, Maryland___B___
Berlin, Germany___E___
Caracas, Venezuela___C___
Christchurch, New Zealand___E___

Dallas, Texas___D___
Minneapolis, Minnesota___B___
San Francisco, California___E___
Toronto, Canada___F___

4.0 STUDENT COLLABORATIVE EXERCISES

GOOD HEARING IN ROOMS

Students are to evaluate the speech intelligibility in one of the spaces listed below. The report should contain sketches, diagrams, graphs, and charts as needed to effectively convey information.

- Church, Synagogue, Mosque, Temple
- Auditorium
- Performance Theater
- Large Classroom
- Cafetorium
- Atrium

Instructor should select space.

The above spaces are recommended, but do not limit report assignment to them.

Articulation Index

The articulation index (AI) is an objective measure of speech intelligibility, which can be calculated from the scores of a group of experienced listeners with normal hearing who write sentences, words, or syllables read to them from selected lists (see *"Egan's R-List"*). The graph on the following page relates AI to the percentage intelligibility of clearly spoken sentences or words that skilled listeners hear correctly. For example, if a speaker calls out 100 words and a listener correctly hears 90, the AI would be 0.7.

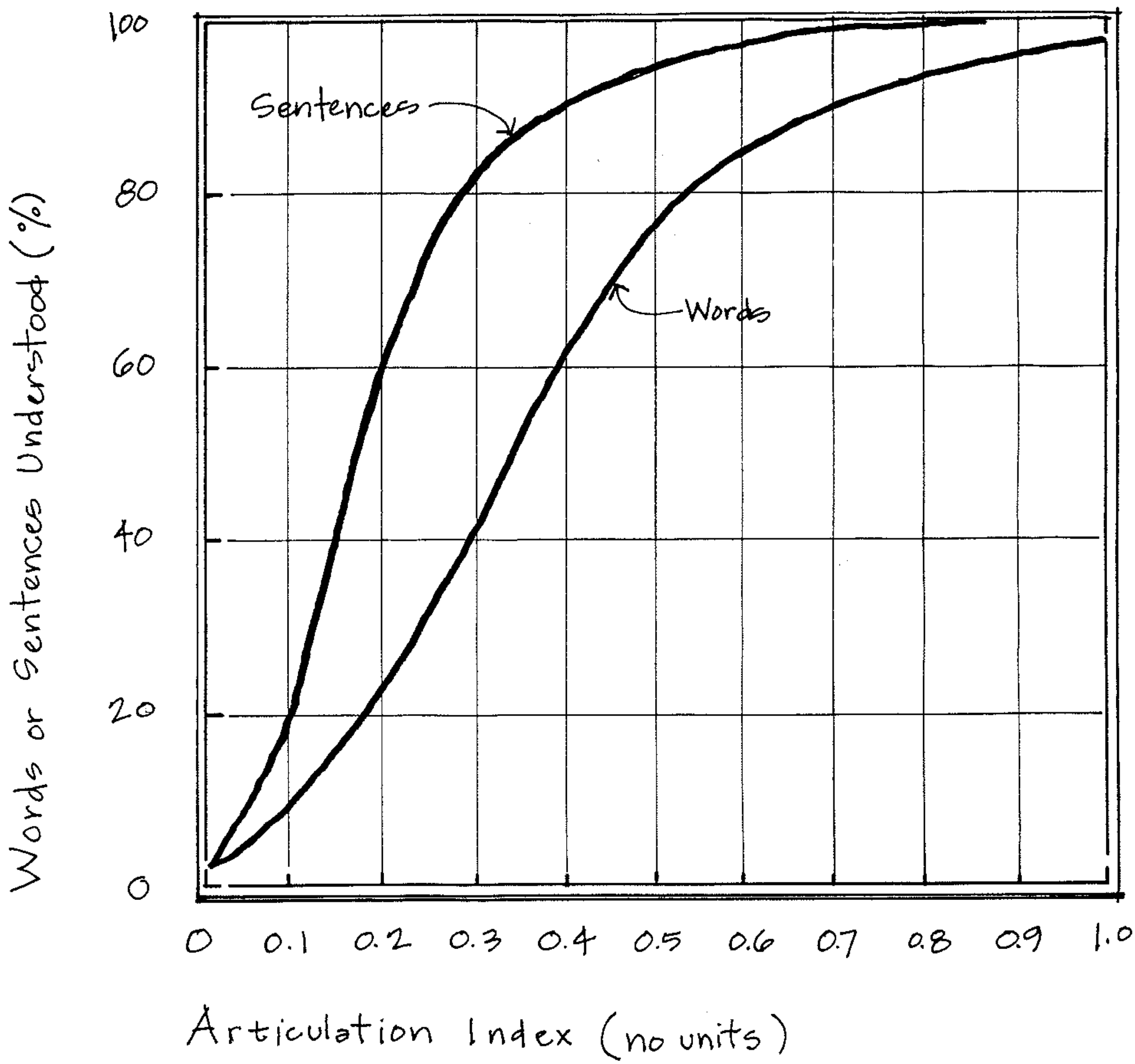
AI (words)	Speech Conditions
> 0.85	Excellent
0.7 to 0.85	Very Good
0.6 to < 0.7	Good

Evaluation Procedure

From a lectern, a speaker should read from the word lists in a *conversational* voice level. Listeners should be seated throughout the room. They should carefully listen and write down the words as they hear them. Do not allow guessing, but allow for spelling differences of words that sound the same such as: one or won and bare or bear (called *homophones*). Plot the AI results on plan drawings. Low AI can indicate excessive reverberation, poor distribution of reflected sound, or high noise levels. If possible, the room should be evaluated with and without the HVAC system operating.

Report Elements

Your report should include observations on AI results and recommendations to improve listening conditions. Provide outline lists and sketches to support your recommendations.


100
80
60
40
20
0
Sentences
Words
Words or Sentences Understood (%)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Articulation Index (no units)

EGAN'S R-LIST (100 SELECTED WORDS)

R LIST 1

1. Aisle
2. Barb
3. Barge
4. Bark
5. Baste
6. Bead
7. Beet
8. Beige
9. Boil
10. Choke
11. Chore
12. Cod
13. Coil
14. Coon
15. Coop
16. Cop
17. Couch
18. Could
19. Cow
20. Dale
21. Dame
22. Done
23. Dub
24. Feed
25. Feet
26. File
27. Five
28. Foil
29. Fume
30. Fuse
31. Get
32. Good
33. Guess
34. Hews
35. Hive
36. Hod
37. Hood
38. Hop
39. How
40. Huge
41. Jack
42. Jam
43. Law
44. Lawn
45. Lisle
46. Live
47. Loon
48. Loop
49. Mess
50. Met
51. Neat
52. Need
53. Oil
54. Ouch
55. Paw
56. Pawn
57. Pews
58. Poke
59. Pour
60. Pure
61. Rack
62. Ram
63. Ring
64. Rip
65. Rub
66. Run
67. Sale
68. Same
69. Shod
70. Shop
71. Should
72. Shrill
73. Sing
74. Sip
75. Skill
76. Soil
77. Soon
78. Soot
79. Soup
80. Spill
81. Still
82. Tale
83. Tame
84. Toil
85. Ton
86. Trill
87. Tub
88. Vouch
89. Vow
90. Whack
91. Wham
92. Woe
93. Woke
94. Would
95. Yaw
96. Yawn
97. Yes
98. Yet
99. Zing
100. Zip

R LIST 2

1. Ball
2. Bar
3. Bob
4. Bong
5. Book
6. Boot
7. Booth
8. Bout
9. Bowel
10. Boy
11. Boys
12. Brain
13. Bull
14. Crane
15. Cue
16. Curb
17. Curd
18. Curse
19. Curt
20. Cute
21. Dial
22. Dig
23. Dine
24. Ditch
25. Doubt
26. Dowel
27. Drain
28. Em
29. En
30. Fade
31. Far
32. Foam
33. Fob
34. Foe
35. Foot
36. Full
37. Gall
38. Gong
39. Grain
40. Hem
41. Hen
42. Huff
43. Hush
44. Jar
45. Job
46. Joy
47. Joys
48. Kirk
49. Leap
50. Leave
51. Made
52. Maize
53. Mew
54. Muff
55. Mush
56. Mute
57. New
58. Newt
59. Oh
60. Ohm
61. Peep
62. Peeve
63. Phase
64. Pull
65. Put
66. Raid
67. Raze
68. Rich
69. Rig
70. Ream
71. Roe
72. Root
73. Rough
74. Rush
75. Ruth
76. Sack
77. Sap
78. Slain
79. Tack
80. Tall
81. Tap
82. Them
83. Then
84. Title
85. Tine
86. Tong
87. Toot
88. Tooth
89. Tout
90. Towel
91. Toy
92. Toys
93. Weave
94. Weep
95. While
96. Whine
97. Wig
98. Witch
99. Yak
100. Yap

SITE NOISE EVALUATIONS

Students are to evaluate the overall noise level conditions at one of the outdoor sites listed below. The report should contain sketches, diagrams, graphs, and charts as needed to effectively convey information.

- Site One (near noisy highway)
- Site Two (near industrial plant)
- Site Three (near playground)
- Any other noisy location on or near campus

Instructor should select sites.

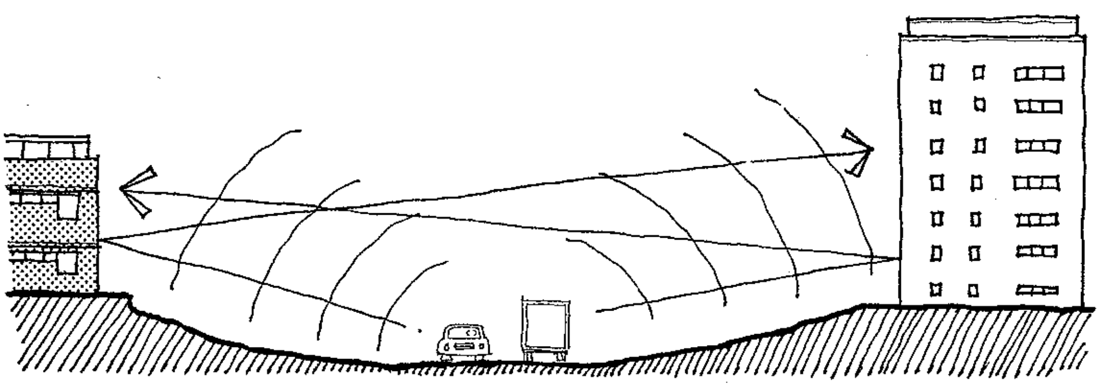
Evaluation Procedure

To assess site noise, follow the guidelines as recommended by the *walk-away* test described on the following page. Refer also to pages 268 to 271 in *Architectural Acoustics.*

Report Elements

Submit appropriate maps, location diagrams, calculations, and sketches as needed to convey your results. Comment on site noise and provide recommendations to mitigate noise so nearby buildings would not be adversely affected.

Note to Instructor: Preferred locations would be sites on which heavy vehicular traffic or other loud noise sources (such as industrial or commercial facility) and residential spaces are close together.

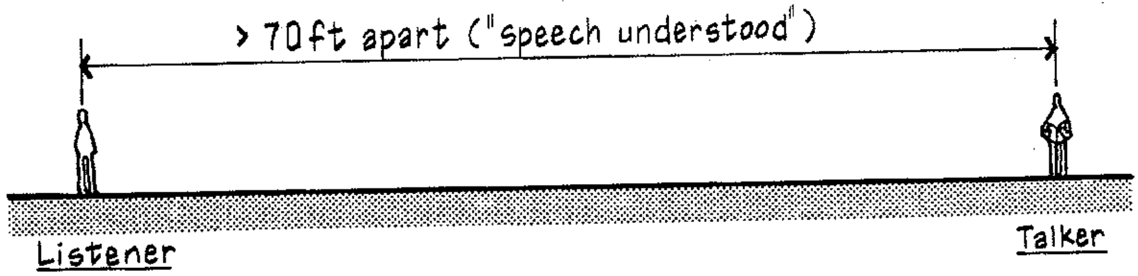


Noisy Site (sound waves reflect between buildings)

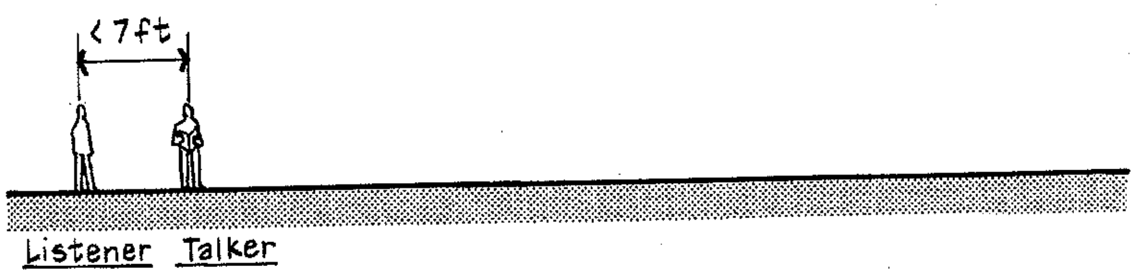
WALK-AWAY NOISE TEST

The *walk-away test* may be used to assess the noise level acceptability of a proposed building site for low-rise buildings. [However, to evaluate compliance with noise ordinances, measurements should be made only with precision sound level meters.] Two persons with normal hearing and average voices are required to perform the walk-away test. The speaker should stand at a fixed location and read unfamiliar text material in a conversational voice level normally used indoors. The listener should back slowly away until only a scattered word or two over a period of more than 10 s is understood. Measure the distance and evaluate conditions using the table below. Test during times when noise levels are highest (e.g., during peak morning and afternoon traffic) or most annoying (e.g., after 10 p.m. when people are trying to sleep). For best results, perform the test during several visits to the site and reverse the roles of speaker and listener.

Clearly Acceptable



Clearly Unacceptable



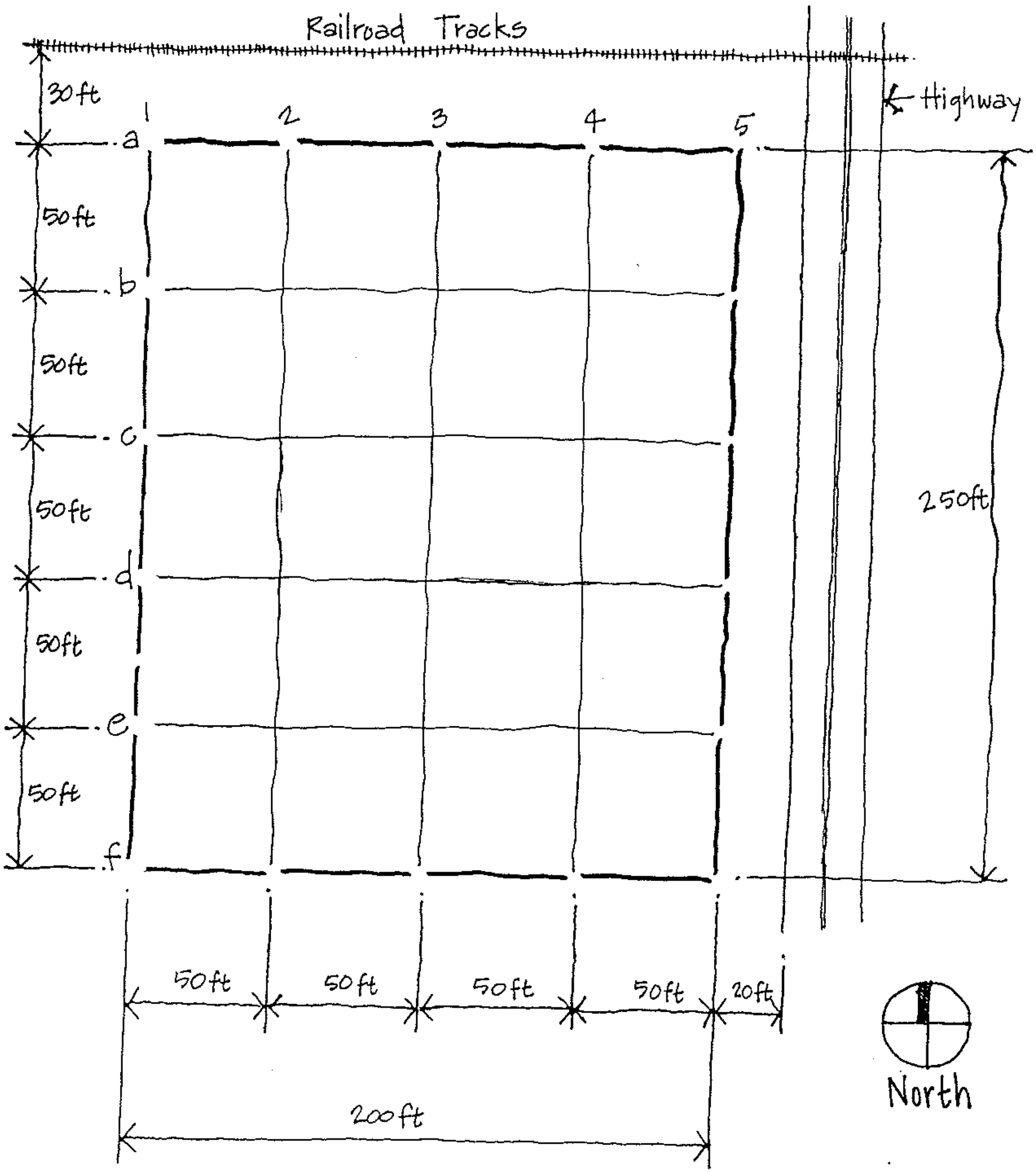
Distance from Which Male Speech is Understood (ft)	Noise Level Acceptability
>70	Clearly acceptable
26 to 70	Normally acceptable
7 to 25	Normally unacceptable
<7	Clearly unacceptable

Reference

T. J. Schultz and N. M. McMahon, *HUD Noise Assessment Guidelines*, U.S. Department of Housing and Urban Development, Washington, D.C., 1971.

OUTDOOR NOISE CONTOURS

Use a grid similar to the one below to record your estimated site noise levels. For example, the grid shows distances away from railroad tracks and highway. Refer to example transportation noise data on page 34 in *Architectural Acoustics.* Point sources drop off 6 dB per doubling of distance outdoors; line sources 3 dB per doubling of distance.



CHECKLIST FOR CONTROLLING OUTDOOR SOUND

1. Select the quietest site.

2. Locate buildings or exterior use areas far away from noisy streets and highways. In urban areas, roads should be designed so vehicle speeds will be slow and constant. Noise is loudest at hills, at intersections, and on rough road surfaces.

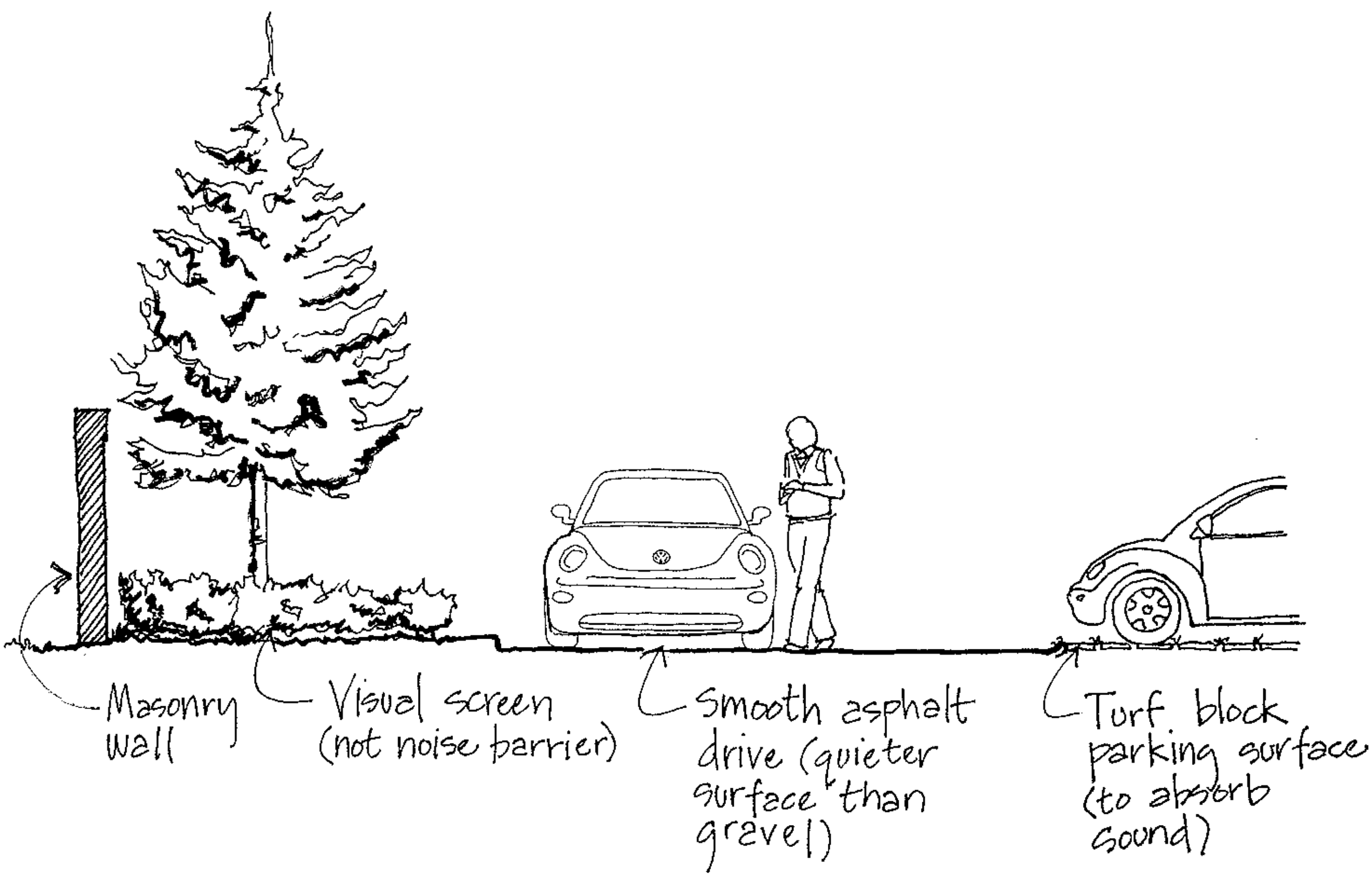
3. Take advantage of natural shielding of terrain and nearby buildings.

4. Use physical barriers such as earth berms, outdoor walls, and dense vegetation to reduce noise.

5. Face critical spaces toward quiet sides of site.

6. Use non-critical interior spaces as *buffers* to reduce transmitted noise.

7. Design *envelope* of building to reduce transmitted noise to be below ambient sound levels in rooms. Detail and specify sound-isolating construction elements: walls, roof, doors, windows, and the like. [Refer to Section 6 in *Workbook*.]



Listening to Buildings: Experiencing Concepts in Architectural Acoustics

Gary W. Siebein, FASA, *Associate Professor*
Richard P. Cervone, *Research Assistant and Adjunct Faculty*
College of Architecture, The University of Florida

Abstract

Acoustics is too beautiful, too intrinsically architectural, and too complex to be taught solely from a theoretical, abstract, or analytical perspective in the classroom. A series of listening experiences were arranged for students enrolled in a required environmental technology course. The listening experiences were designed to encourage students to view architecture from the perspective of their senses and to help them understand basic room acoustics principles in terms of their own listening judgments. A total of 26 rooms encompassing a wide variety of acoustical conditions were selected for the exercise. Students attended at least three speech intelligibility tests and two concert rehearsals in different rooms. At the concert rehearsals, an acoustics evaluation sheet was used as a vehicle for structuring the listening experiences. Each student prepared a typewritten paper relating what they heard in the rooms to the architectural characteristics of the rooms. They compared and contrasted the listening experiences, revealing many positive as well as negative architectural features and acoustical qualities in the process. The experience of visiting rooms and critically listening to sound in the rooms helped to bridge the gap that often exists between concepts discussed in lecture and tangible realities of buildings.

Place of Program in the Curriculum

The assignment was administered during the acoustics portion of an upper level course studying environmental technologies in architecture. This was a required course in the four-year Bachelor of Design curriculum leading to the professional Master of Architecture degree. Four class sections participated in the eight-week project involving approximately 180 third- and fourth-year students.

Educational Goals

There were several educational goals to this exercise. The assignment was intended to explore broad philosophical issues about architecture as well as specific principles of room acoustics simultaneously. The educational aims are listed below.

1. *To view architecture as an art that is experienced and understood in the realm of the senses.*

The idea that architecture is an art in which the participant is "submerged in the experience" was the philosophical ground for the project. Architecture is fundamentally different from arts such as painting, sculpture, film, etc., where one is exposed to a certain medium (Fitch, 1975). While we recognize the visual as a notable quality of buildings, light, temperature, and sound were also proposed as qualities of buildings. Students were able to understand the spatial and material decisions that shaped the rooms in terms of their senses (in this case hearing) by visiting buildings and critically listening to their acoustical qualities.

2. *To view human perception and technology within the context of architectural design.*

While the course was entitled *Environmental Technology*, lectures and assignments were not limited to or focused on technical material. On the contrary, the course sought to examine the essence of technology and its relations to experiential qualities of architecture. Emphasis was placed on integrating material typically taught in lecture format within the broader context of the curriculum. Human perception of sound was considered the "ultimate test of the acoustical performance of a space" (Siebein, 1986, p.1). Technology in architecture was viewed as the body of knowledge accumulated by people that considers the material and physical aspects of buildings as links between people and their environments. The size, shape, materials, and textures of a space determine to a large extent the physical behavior of sound waves within that space and therefore influence one's perception of acoustic quality.

3. *To realize the implications of architectural design on room acoustic quality.*

It was important that students understand that architectural design decisions—those influencing the size, shape, materials, and textures of a space—are the very decisions that determine the quality of sound in a space. Furthermore, it was important for students to understand the range of acoustical conditions possible in order for them to appreciate the magnitude of architectural design decisions.

4. *To understand the value (and shortcomings) of various theoretical techniques for predicting room acoustic quality.*

Physics of sound, room acoustics theory, and hearing perception theory were topics discussed in lecture. These topics were presented as methods to assist in the achievement of an artistic goal. It was emphasized that existing theoretical techniques are very useful in predicting the acoustical implications of architectural design decisions, but that they do not qualitatively describe the totality of the acoustical environment. Students experienced this firsthand by listening to the acoustical qualities of the rooms. They therefore could comprehend the strengths and weaknesses of current theories in terms of their own listening judgments.

5. *To enrich the general education of the students.*

For most, it was their first time listening to live symphonic or chamber music. Discussions with musicians, conductors, and theater/music directors occurred during the trips to the rehearsal performances and offered the students many insights into the beauty of these art forms and the difficulties involved in designing spaces for performance. The rehearsals generated a great deal of interest among the students as many attended more than the five required sessions and several brought tickets to actual performances.

Teaching Strategies

Teaching room acoustics thoroughly, accurately, and in terms useful to future architects is nearly impossible to do solely in the classroom. The reality and beauty of sound can only be appreciated sensually. Therefore, experiencing sound in actual rooms was essential to expose the students to the physical realities of acoustics. A detailed description of the teaching strategies is provided below.

1. *To visit a* wide variety *of rooms with contrasting acoustical environments.*

The rooms included a large concrete fire stair, several concert halls and music recital spaces, three theaters, two churches, several classrooms and lecture halls, and an open field. The acoustical qualities of the rooms varied dramatically. Several of them were designed by nationally recognized acoustical consultants and many of them appeared to have had no acoustical considerations in their design. After one visited several of the rooms, it was very clear that the design of the rooms significantly affected the listening conditions. Students were deliberately exposed to a number of spatial conditions, seating arrangements, and building materials throughout the process.

2. *To evaluate the listening conditions* critically.

The rooms were divided into speech rooms and music rooms. Three speech intelligibility tests were given in each of the speech rooms. An acoustics evaluation sheet was completed in each of the music rooms during a rehearsal performance by a symphony orchestra or chamber orchestra. The sheet was composed of rating scales for several qualities widely accepted as important to music listening conditions. The intelligibility tests and evaluation sheets were used as vehicles to structure the listening experiences and establish a common vocabulary. It was important for the students to listen in the rooms for an ample length of time (usually about one hour) so that they could really hear the architecture. This was a very different experience than attending a field trip to a building and having an expert simply point out acoustical design features.

3. *To discuss the listening experience and the impact of the architecture on the listening conditions while in the room.*

After the speech intelligibility tests or concert rehearsals were finished, an open discussion took place. Students offered their comments on what they heard and how the architecture affected their listening. The instructors also offered their insights and posed questions to the students. In several of the music rooms, musicians and conductors became involved and generously offered their views as well! These discussions proved very valuable in order to articulate the benefits of the sessions.

4. *To document the listening experiences and offer suggestions for the improvement of less-than-satisfactory rooms.*

This portion of the assignment was in the form of a written paper. The students were given all of the results of the speech intelligibility tests and music evaluations. They were also given the background noise level and reverberation time of each room and asked to relate these quantitative indices to the qualitative observations they made during the listening sessions. In their papers, they were asked to discuss the relative benefits and drawbacks of the rooms they visited as rooms for listening. Furthermore, they were to compare and contrast the rooms and describe how the architecture affected the quality of sound in each of the rooms. Recommendations for improving rooms were included as well. Students were encouraged to revisit the rooms and carefully note their design features.

Means for Assessing Student Work

A very enthusiastic atmosphere prevailed in the course throughout the semester. Students became highly motivated to participate in class discussions as the listening experiences progressed. Each student was required to attend five listening sessions, yet many of them attended more and some attended as many as eight. Course evaluations completed by the students at the end of the semester displayed a high level of satisfaction. The student work was assessed by the criteria listed below.

1. *Attendance at the listening sessions.*

Attendance was taken at each of the sessions and contributed toward each student's grade for the project. Since the philosophical basis for the assignment was to understand architecture through the senses and by experience, participation was essential and therefore considered in student assessment.

2. *The preparation of a written paper demonstrating the student's ability to make connections between the architectural characteristics of the rooms and the listening conditions observed.*

As emphasized earlier, the exercise was intended to allow the students to develop a broad understanding of the consequences of architectural design. Therefore, it was critical that the students addressed this issue in their papers. This was viewed as meaningful to the education of architects.

The listening experiences gave the students the ability to understand the nature of the decisions that architects make regarding the size, shape, materials, textures, and ambient noise levels that affect the acoustical environment of buildings. The success of learning through experience led the instructors to develop a similar assignment for lighting during the remainder of the semester.

References

Fitch, James Marston. *American Building: The Environmental Forces That Shape It.* Schocken Books. New York, 1975.

Siebein, Gary W. "Project Design Phase Analysis Techniques for Predicting the Acoustical Qualities of Buildings." August 1986.

Excerpts From Student Papers

The statements and illustrations shown below are excerpted from the papers students wrote evaluating their experiences in the different rooms. Emphasis was placed on understanding acoustical qualities as intrinsically linked with architectural features of the rooms.

Jury Comments

This course hits at the heart of something we so often fail to do in coursework of this type and in our studios. It gets at the perceptual aspects of understanding qualities of space, buildings, and performance. We so often steer to abstract relationships, to planes and spaces, without fully understanding the implications of this aspect. Frankly, this building type often fails in our society. We really desperately need courses that convey all those cultural aspects of wonderful sounds of human voices and music. The ways in which they outlined their experiments and drawings were fascinating. Everything had been tuned to how to bring students' enthusiasm along. And how to take the problem of getting people out in real situations, away from the classroom, away from the abstractness of the classroom and getting them to notice things. ... It goes beyond technology to the human experience of buildings. ... this is where we put architecture back into the realm of the senses.... Students learned a lot about how acoustics actually work and the scientific definition of acoustical problems.... It also enriched their general education; many of them said that they bought tickets to musical events for the first time and actually began to see buildings enhanced by those events. ... I'm going to take it and show it to our high falutin' engineer acoustics man because I think that he is making a big mistake by not using this kind of approach. ... The fact that a human being is used as the instrument of evaluation, I thought, was really great.

The Architectural Acoustic Translation System

A musician, an acoustician and an architect have separate vocabularies to describe acoustic criteria. The language of each is correlated below:

MUSICAL VOCABULARY	*SCIENTIFIC VOCABULARY*	*ARCHITECTURAL VOCABULARY*
Running liveness, wetness, fullness, persistence of sound	Reverberation time throughout the frequency spectrum	Geometry of the hall Containment of volume Absorption in the room Distribution of volume Stiffness of boundary surfaces
Presence, brilliance definition, transparency	Arrival time of mid- and high frequency reflections	Geometry of the hall Audience to performer relationship Relationship of the audience to reflective surfaces Design of inner reflector systems
Warmth, low string balance	Arrival time of low frequency	Geometry of the hall Volume to seating area ratio Absorption in the hall Containment of volume Stiffness of boundary surfaces Coupled volumes near the source
Orchestral balance	Minimum masking of low power instruments	Geometry of the end of the room or the concert enclosure Musicians risers Audience seating rake Tunable inner reflector systems
On-stage hearing	Minimum masking of low power instruments Arrival time of mid- and high frequency reflections	Geometry of the end of the room or the concert enclosure Musicians risers Coupled stage volumes

Courtesy of Chris Jaffe (RPI)

ROOM ACOUSTICS EVALUATIONS OF EXISTING SPACES

1. Students are to select a listening space (such as a church, synagogue, mosque, auditorium, large meeting room, or lecture hall) seating 300 to 1500 persons.

2. By attendance at two or more functions with an audience, observe and evaluate listening conditions. If you can arrange it with the owners, try to listen from several seats during a given performance. Discuss listening conditions with the owners, performers, and/or experienced listeners. [Complete "Evaluation Guide" as described by the following pages.]

3. Your report should include the following important acoustical parameters.

   - Find cubic volume per person. Show all steps used to compute cubic volume. [For guidance, refer to pages 127 to 130 in *Architectural Acoustics*. Volume strongly affects reverberance and loudness.]

   - Compute the mid-frequency reverberation time (average of reverberation at 500 Hz and 1000 Hz) for fully-occupied conditions. [Use "Calculation Sheet" on facing page to organize your computations.]

   - Find bass ratio (BR). BR is the average of reverberation at 125 Hz and 250 Hz divided by mid-frequency reverberation. A room with sufficiently high BR sounds warm.

   - Prepare graph of reverberation in sec versus sound frequency in Hz.

   - By ray diagrams, show reflections off front half of ceiling and side walls. Also show how initial time delay gap (ITDG) was measured. [Refer to pages 95 to 99 in *Architectural Acoustics*. ITDG is related to attribute of intimacy.]

   - Identify any diffusing surfaces such as pilasters, deep reveals, or sound-diffusing wells. Sufficient diffusion prevents harsh, glaring sounds of music.

   - Listen for noise from HVAC system and any intruding noise from outdoors and nearby spaces. [Refer to Chapter 5 in *Architectural Acoustics*. Ambient sound must be low in listening spaces.]

   - Use word lists to find AI at several locations in the seating areas. [Refer to *Egan's R-Lists* in this section of *Workbook*. Clarity is important for speech.]

4. Finally, state your overall evaluations of the space and any recommendations to improve listening conditions. Include plan and section drawings as needed to communicate your findings.

CALCULATION SHEET

REVERBERATION TIME

PROJECT		ROOM
SEATING CAPACITY	ROOM VOLUME ft^3	RECOMMENDED REVERBERATION TIME AT 500 Hz sec

ROOM SURFACE	S (ft^2)	125 Hz		250 Hz		500 Hz		1000 Hz		2000 Hz		4000 Hz	
		α	a (ft^2)	α	a (ft^2)	α	a (ft^2)	α	a (ft^2)	α	a (ft^2)	α	a (ft^2)
TOTALS													

CALCULATIONS

EVALUATION GUIDE FOR MUSIC PERFORMANCE SPACES

How To Use Evaluation Guide

The scales on the evaluation guide can be used by listeners to record their subjective impressions of spaces for music performance (e.g., concert halls, churches, recital halls). Place a checkmark in the section of the scale which best represents your individual judgment of the specific attribute or condition. The primary purpose of the evaluation guide is to encourage users to become familiar with important acoustical properties of rooms where music is performed. The guide is *not* intended to be used to rank the best or worst spaces because there always will be a wide range of individual judgments, even among experienced listeners and performers. Recognize also that it is extremely difficult to separate judgment of a hall from either judgment of the quality of a particular musical performance, or from longstanding personal musical preferences.

Subjective Judgments of Music Performances

Subjective impressions can be recorded for the following conditions (see "evaluation guide").

Clarity (listen to beginnings of musical notes and observe degree to which individual notes are distinct or stand apart)

Reverberance (listen to persistence of sound at mid-frequencies)

Warmth (listen for strength or liveness of bass compared to mid- and treble frequencies)

Intimacy (listen to determine if music sounds as though played in a small room regardless of actual size)

Loudness (listen for direct sound and reverberant sound; evaluate during louder passages for comfort conditions and weaker passages for audibility)

Diffusion (listen for envelopment of terminal sounds or feeling of immersion in sound; compare conditions with eyes open and closed)

Balance (listen for relative strength and quality of various sections of orchestra, and between orchestra and soloist or chorus)

Sounds which interfere with perception of music performances may also be observed. The most common are the following:

Background noise (sounds other than music or from audience, heard during times solo instrumentalists play faintest notes, or when hall is empty)

Echoes (notice direction and strength of any long-delayed, discrete sound reflections)

Use a separate evaluation sheet for each seat where performance is to be evaluated. Absence of "dead spots," that is, locations where music is very weak, and minimum variations in listening conditions throughout space indicate good *uniformity*. Remember, there are no absolute or "correct" answers. Subjective impressions by individuals are the only evaluations that really matter.

Overall Impression

The box at the bottom of the guide should be used to record your overall impression of the musical performance at a given seat location. It is suggested that traditional academic ratings be used: A (for best ever, a most memorable listening experience) to F (for one of the worst, a truly bad listening experience), with C for average experience. Always keep in mind that this guide is intended to be used to develop an understanding of specific music performance conditions and, by careful observation, how they may be affected by architecture.

References

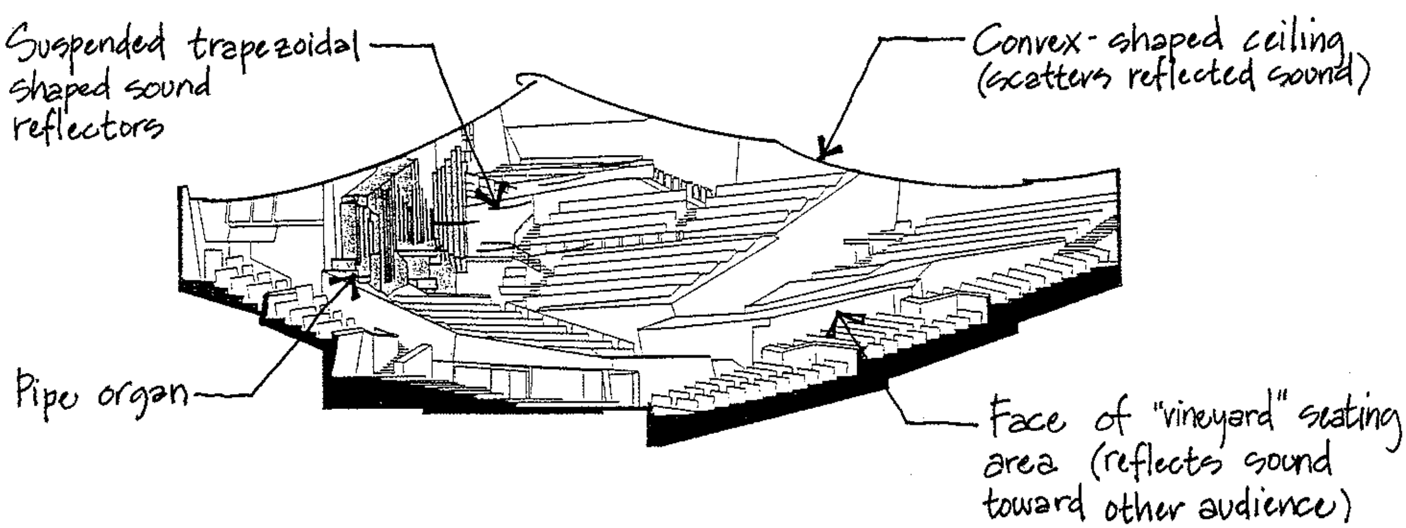
M. Barron, "Subjective Survey of British Concert Halls," *Proceedings Institute of Acoustics*, vol. 7, February 1985, pp. 41-46.

L. L. Beranek, *Music, Acoustics and Architecture*, Wiley, New York, 1962, pp. 471-480. (The pioneering, comprehensive rating system based on detailed study and analysis of 54 concert halls and opera houses.)

J. S. Bradley, "Experience with New Auditorium Acoustic Measurements," *Journal of the Acoustical Society of America*, June 1983, pp. 2051-2058. (Presents data from measurements in Canadian halls where several acoustical properties have been evaluated.)

P. H. Heringa, "Comparison of the Quality for Music of Different Halls," 11th International Congress on Acoustics, Paris, vol. 7, July 1983, pp. 101-104.

T. J. Schultz, "Concert Hall Tour of North America," Bolt Beranek and Newman Reverberation Time Data Report, BBN Labs., Cambridge, Mass., 1980.



Section (Berlin Philharmonie)

EVALUATION GUIDE

(Place mark on section of scale which best represents your impression of listening condition. Use separate sheet for each seat where performance is to be evaluated.)

CLEAR SOUND |____|____|____|____|____| BLURRED SOUND

(varies from clear or distinct to blurred or muddy)

LIVE REVERBERANCE |____|____|____|____|____| DEAD REVERBERANCE

(liveness or persistence of mid-frequency sounds)

WARM BASS |____|____|____|____|____| COLD BASS

(relative liveness of bass or longer duration of reverberance at bass compared to mid- and treble frequencies)

INTIMATE SOUND |____|____|____|____|____| REMOTE SOUND

(auditory impression of apparent closeness of orchestra)

SATISFACTORY LOUDNESS |____|____|____|____|____| UNSATISFACTORY LOUDNESS (too weak or too loud)

(indicate early or direct sound (symbol *D*) and reverberant sound (*R*) on scale)

RICH DIFFUSION (expansive sound) |____|____|____|____|____| POOR DIFFUSION (constricted sound)

(envelopment of sound which surrounds listener from many directions)

GOOD BALANCE |____|____|____|____|____| POOR BALANCE

(observe between musicians and soloist or chorus, among sections of orchestra)

SATISFACTORY BACKGROUND NOISE (very quiet) |____|____|____|____|____| UNSATISFACTORY BACKGROUND NOISE (very noisy)

(from HVAC system, or intruding noise from ancillary spaces or outdoors)

ECHOES |____| No |____| Yes Direction: ____________

(long-delayed reflections that are clearly heard)

Music Performance Space: ____________ Date: ________

Seating Capacity: ________ Cubic Volume: ________ ft^3

Orchestra/Conductor: ________ Composer/Work: ________

Seat Location: ____________ Seat No.: ______

(Use space at right to sketch floor plan, or cut and paste seating layout from program booklet.)

[ ] OVERALL IMPRESSION

(Refer to instructions on preceding pages.)

TIPS FOR EVALUATING MUSIC LISTENING SPACES

1. Request a copy of seating plan from ticket office so you can record locations where evaluations were made.

2. Before or after the performance, with the room empty, clap your hands together loudly to:

   - Listen to reverberation [persistence of sound].

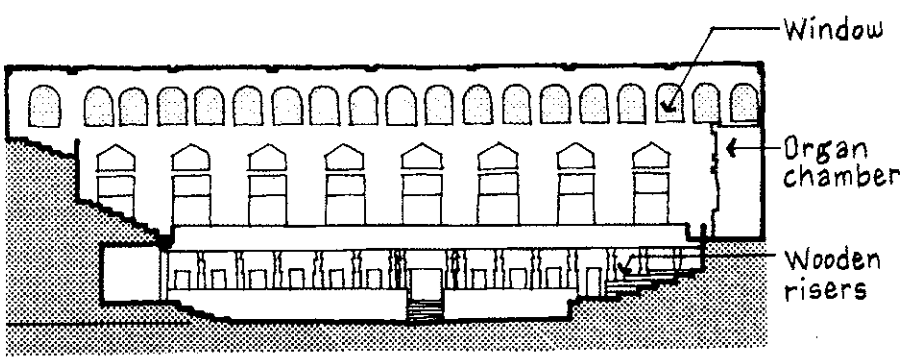
   - Observe echoes off large flat or concave surfaces, or other discrete sound reflections.

3. Identify any adverse effects on listening due to noise from HVAC system or from adjacent spaces.

4. During performance, cup both ears toward stage and again toward rear of hall. Try to determine if walls and/or suspended panels reflect sound toward sides of seated audience.

5. Listen to professional and amateur performances. Note the differences in loudness, clarity, and other qualities of sound.

6. If possible, listen to the same group performing the same music in different halls.



Section (Vienna)

EVALUATION GUIDE

(Place mark on section of scale which best represents your impression of listening condition. Use separate sheet for each seat where performance is to be evaluated.)

CLEAR SOUND |✓| | | | | BLURRED SOUND

(varies from clear or distinct to blurred or muddy)

LIVE REVERBERANCE |✓| | | | | DEAD REVERBERANCE

(liveness or persistence of mid-frequency sounds)

WARM BASS | |✓| | | | COLD BASS

(relative liveness of bass or longer duration of reverberance at bass compared to mid- and treble frequencies)

INTIMATE SOUND | | |✓| | | REMOTE SOUND

(auditory impression of apparent closeness of orchestra)

SATISFACTORY LOUDNESS |✓| | | | | UNSATISFACTORY LOUDNESS (too weak or too loud)

(indicate early or direct sound (symbol *D*) and reverberant sound (*R*) on scale)

RICH DIFFUSION (expansive sound) | |✓| | | | POOR DIFFUSION (constricted sound)

(envelopment of sound which surrounds listener from many directions)

GOOD BALANCE |✓| | | | | POOR BALANCE

(observe between musicians and soloist or chorus, among sections of orchestra)

SATISFACTORY BACKGROUND NOISE (very quiet) |✓| | | | | UNSATISFACTORY BACKGROUND NOISE (very noisy)

(from HVAC system, or intruding noise from ancillary spaces or outdoors)

ECHOES |✓| No | | Yes Direction: ____________

(long-delayed reflections that are clearly heard)

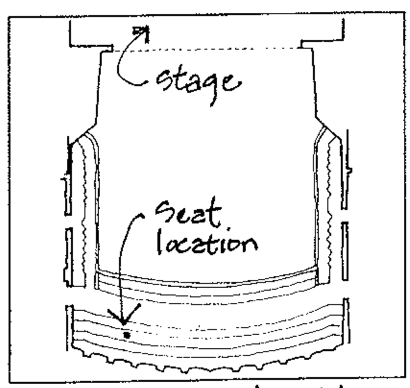
Music Performance Space: H.J. Hyde Theatre Date: 02/13/99

Seating Capacity: 1006 Cubic Volume: 240,000 (est.) ft³

Orchestra/Conductor: Lipsky Composer/Work: Music Man

Seat Location: Balcony Seat No.: E108

(Use space at right to sketch floor plan, or cut and paste seating layout from program booklet.)



Balcony Seating Plan

A⁻ OVERALL IMPRESSION

(Refer to instructions on preceding pages.)

WELL REGARDED CONCERT HALLS IN NORTH AMERICA AND EUROPE

Nearly all large cities have symphonic music performance spaces. Concert halls range from superb to the awful. A few years ago, Traveler's magazine singled out halls they believed had superior acoustics.

In Europe

Concertgebouw, Concertgebouwplein 2-6, Amsterdam, the Netherlands

Conservatory Hall, 13 Herzen Street, Moscow, Russia

Musikvereinssaal, Dumbastrasse 3, Vienna, Austria

Philharmonie, Matthäkirchstrasse 1, Berlin, Germany

Smetana Hall (Obecni dum), Republiky 5, Nové Mesto, Prague, Czechoslovakia

Symphony Hall, International Convention Centre, Broad Street, Birmingham, England

Théâtre des Champs-Elysées, 15, avenue Montaigne, Paris, France

Tonhalle, Zlaridenstrasse 7, Zurich, Switzerland

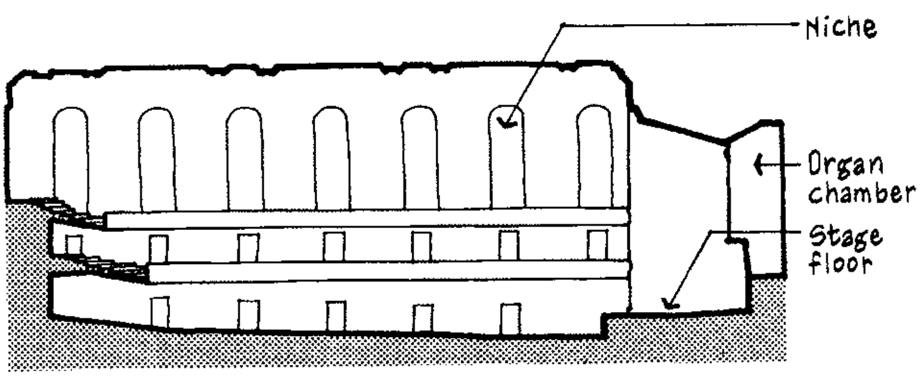
In North America

Jack Singer Concert Hall, Centre for Performing Arts, 205 Eighth Avenue S.E., Calgary, Alberta, Canada

Mechanics Hall, 321 Main Street, Worcester, Massachusetts

Morton H. Meyerson Symphony Center, 2301 Flora Street, Dallas, Texas

Symphony Hall, Huntington and Massachusetts Avenues, Boston, Massachusetts



Section (Boston)

TEN PRETTY GOOD RULES FOR AUDIENCES

According to a Spring 1997 issue of the Dallas Symphony Orchestra's Stagebill, "part of one's pact as an audience member is to take seriously the pleasure of other, a responsibility fulfilled by quiet, attentive (or silently inattentive) and self-contained behavior. After all, you can be as demonstrative as you want during bows and curtain calls." The DSO's ten *Golden Rules*, commonly observed at theatrical, opera, and symphonic performances throughout the world, are listed below.

1. Go easy with the atomizer; many people are highly allergic to perfume and cologne.

2. If you bring a child, make sure etiquette is part of the experience. Children love learning new things.

3. Unwrap all candies and cough drops before the curtain goes up or the concert begins.

4. Make sure beepers and watch alarms are **OFF**. And don't jangle the bangles.

5. The overture is part of the performance. Please cease talking at this point.

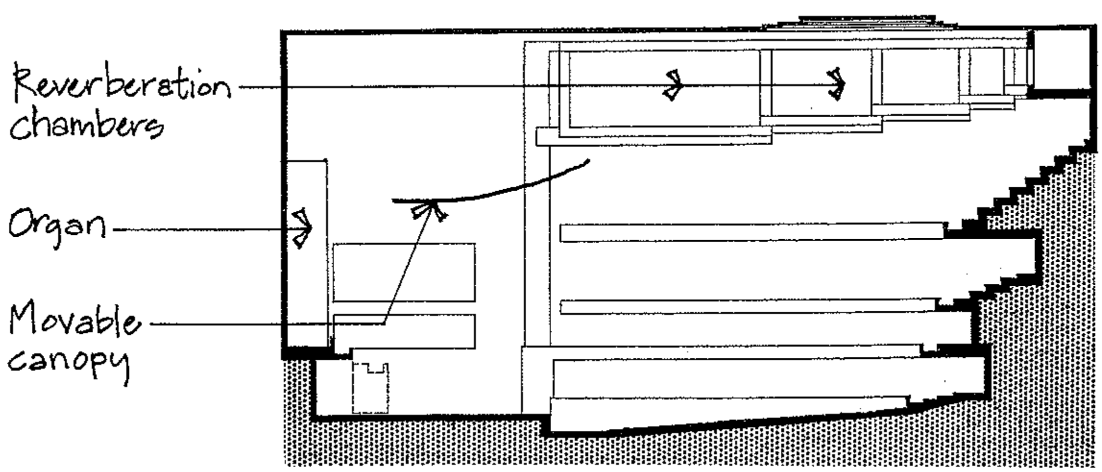
6. Note to lovebirds: when you lean your heads together, you block the view of the person behind you. Leaning forward also blocks the view.

7. **THOU SHALT NOT TALK**, or hum, or sing along, or beat time with a body part [sic].

8. Force yourself to wait for a pause or intermission before riffling through a purse, backpack, or shopping bag.

9. Yes, the parking lot gets busy and public transportation is tricky, but leaving while the show is in progress is discourteous.

10. The old standby: Do unto others as you would have them do unto you.



Section (Dallas)

MODERN ACOUSTICAL MEASUREMENTS FOR AUDITORIA

In the table below, students are to: define objective acoustical measurements, describe briefly how measurements are made (equipment and test setup), list criteria for auditoria, and identify architectural design features affecting sound. Some definitions, criteria, and essential design features are given for concert halls. For example, cubic volume to seat ratio (V/N) for concert halls should be 300 to 450 ft^3/seat. Most successful halls have low seating capacity (< 2000). [NOTE: Orchestras do not play best in half-filled halls.]

Attribute	Acoustical Measurement	Measurement Method	Acoustical Criteria	Architectural Feature
Reverberation (RT, EDT, BR)	RT is decay time from -5 to -35 dB x 2. EDT is decay time from 0 to -10 dB x 6. BR is		RT = 1.8 to 2.0 sec (occupied) and EDT = and BR = 1.10 to 1.45	
Clarity (C80, RASTI)			C80 = -1 to -4 dB per *ad vericordium* of orchestra conductors.	Cubic volume to seat ratio (V/N). and Seating area config. and
Loudness (G)	G is ratio of sound energy in room to sound energy 10 m away from same source in anechoic room.		4 to 6 dB	Height to width ratio (H/W) > 0.6. and Seating area (S_T). and
Spatial Impression (LF, IACC family)			LF > 0.15 and IACC (E) < 0.40 and IACC (L) <	Width (W) < 80 ft. and ITDG < 20 msec. and Multiple balconies and side wall boxes.
Diffusion (SDI)			0.8 to 1.0 per F. R. Fricke	Large and small irregularities on walls and ceiling.
Noise (NC, NCB)		Use ANSI Type 1 sound level meter at ear height through-out audience chamber.	NCB ≅ 15 and NC =	See Chapters 4 and 5 in *Architectural Acoustics.*

References

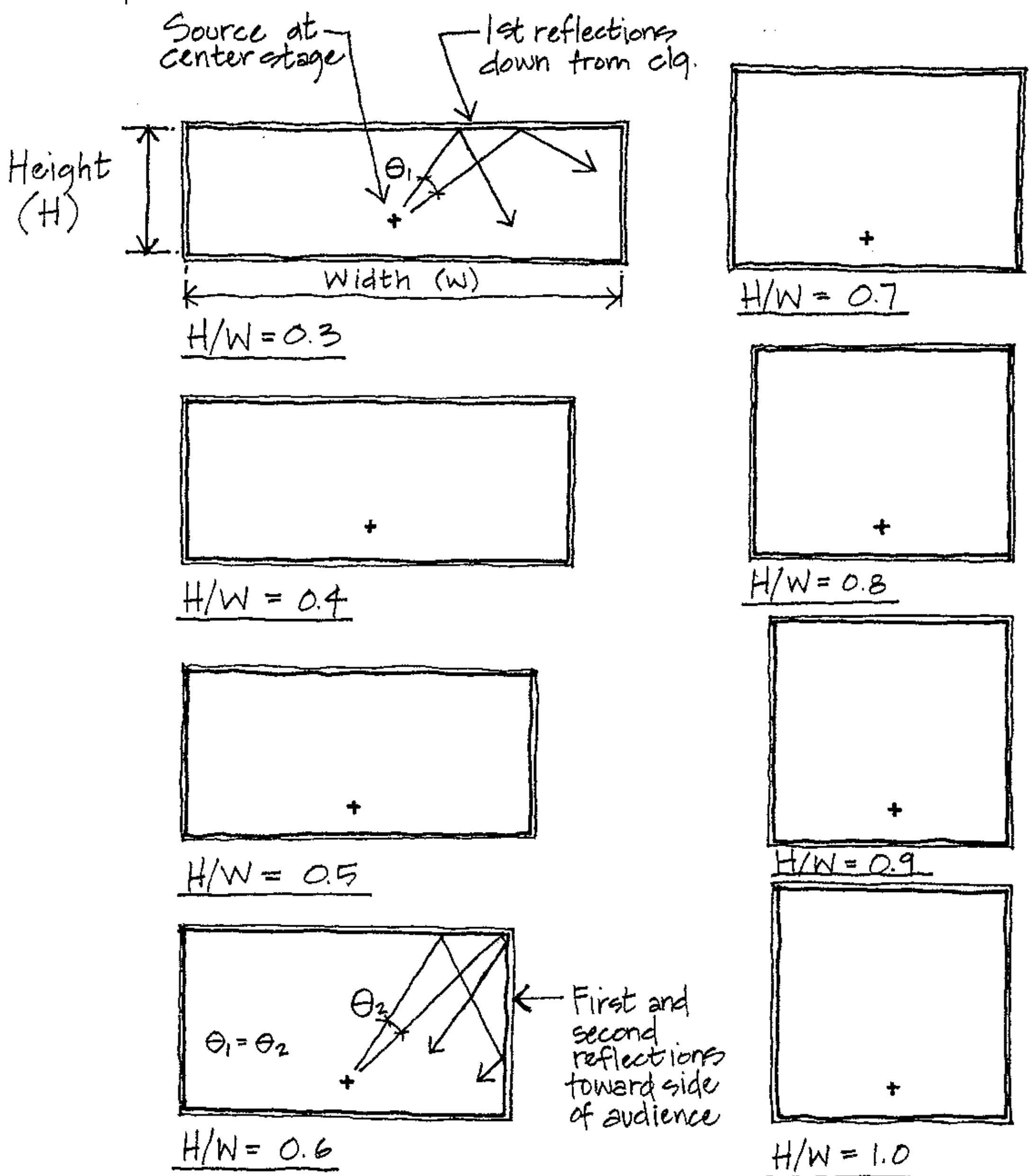
L. L. Beranek, *Concert and Opera Halls,* Acoustical Society of America, Woodbury, NY, 1996.

J. S. Bradley, "The Evolution of Newer Auditorium Acoustics Measures," Canadian Acoustics, October 1990.

T. Houtgast and H. J. M. Steeneken, "A Review of the MTF Concept in Room Acoustics," JASA, March 1985. [For additional case studies using RASTI to evaluate speech in rooms, contact Brüel & Kjaer, 2815 Colonnades Court, Norcross, GA 30071.]

LATERAL SOUND

The spatial impression of an auditorium has two subjective dimensions: apparent source width (ASW) and listener envelopment (LEV). ASW, a characteristic where music appears to come from a source wider than the actual source, is affected by the strength of early arriving lateral reflections. LEV is affected by later arriving lateral reflections. Envelopment seems best when loud reverberant sound arrives equally from all directions. Rectangular halls have higher LEV than fan-shaped halls.

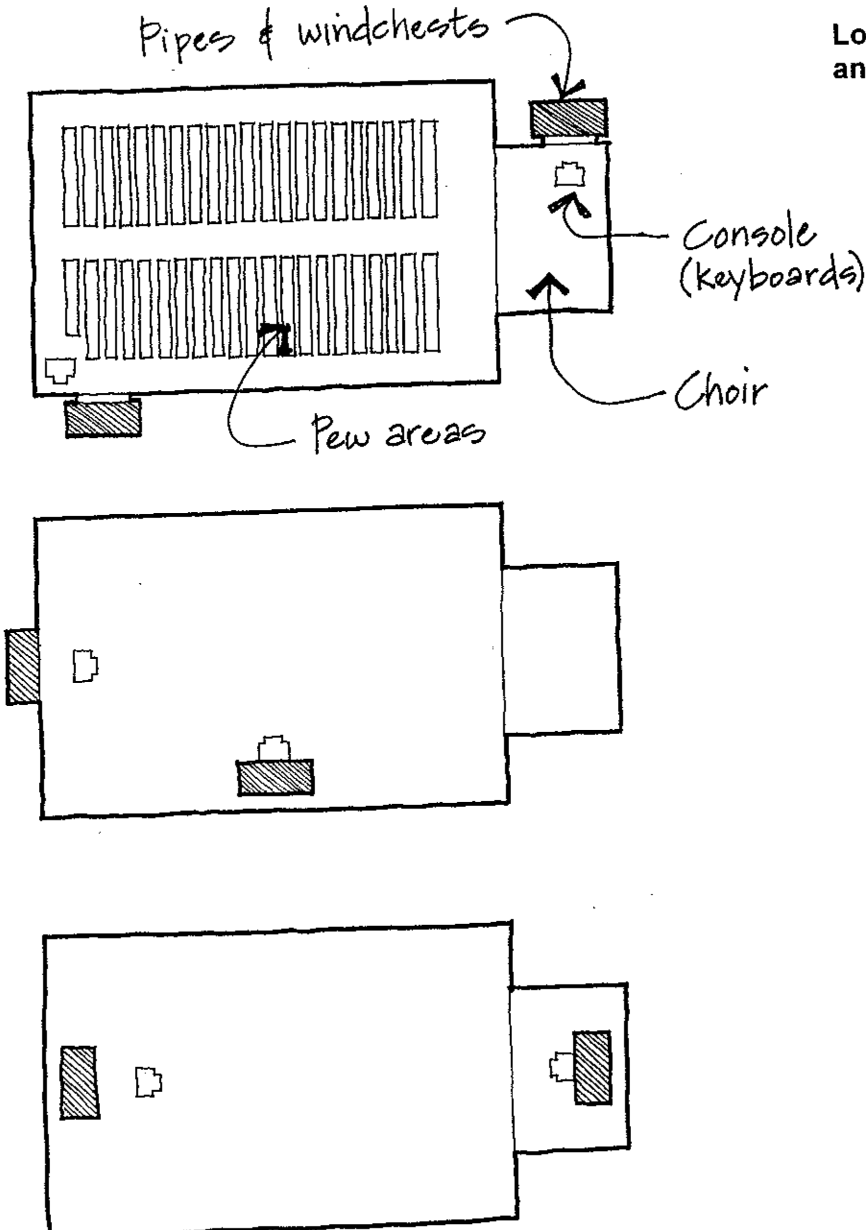


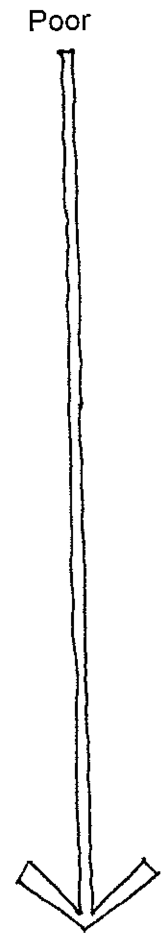
Note to Instructor: Use transverse sections to study effects of H/W ratio on lateral sound. Ask students to draw ray diagrams on enlarged transverse sections of rectangular halls. Be sure students accurately measure ∠i = ∠r to show first reflections off ceiling and walls from source at center stage.

PIPE ORGANS

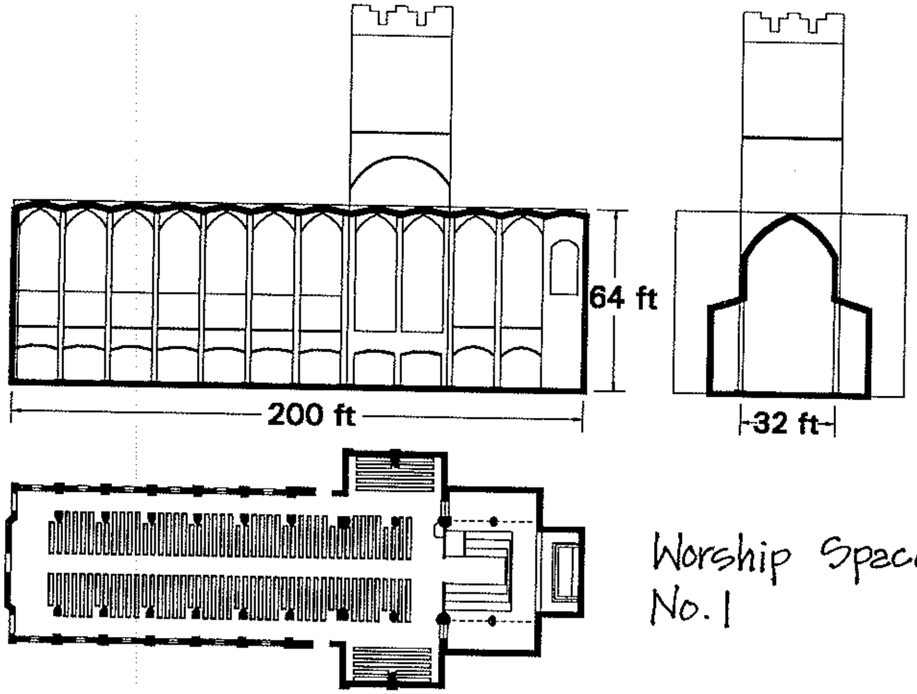
The natural acoustics of worship spaces (and auditoria) affects how pipe organs sound. Locate pipes so sound will be projected into the worship space. Also be sure to locate *organ*, *choir*, and *console* together. Example layouts for a rectangular plan are given below. For a checklist on acoustical design of worship spaces, refer to pages 119 to 122 in *Architectural Acoustics*.

Location for Pipes/Windchests and Console

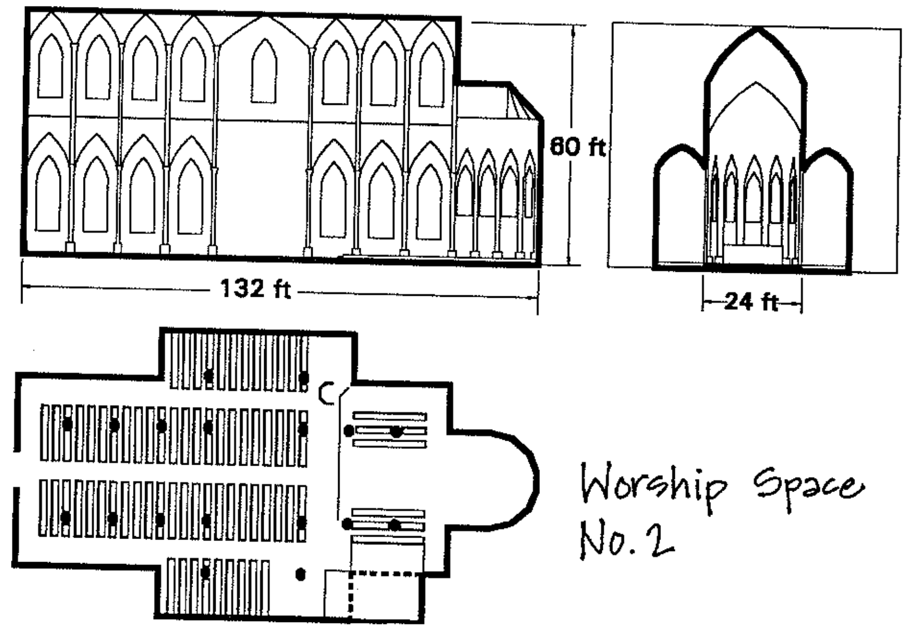




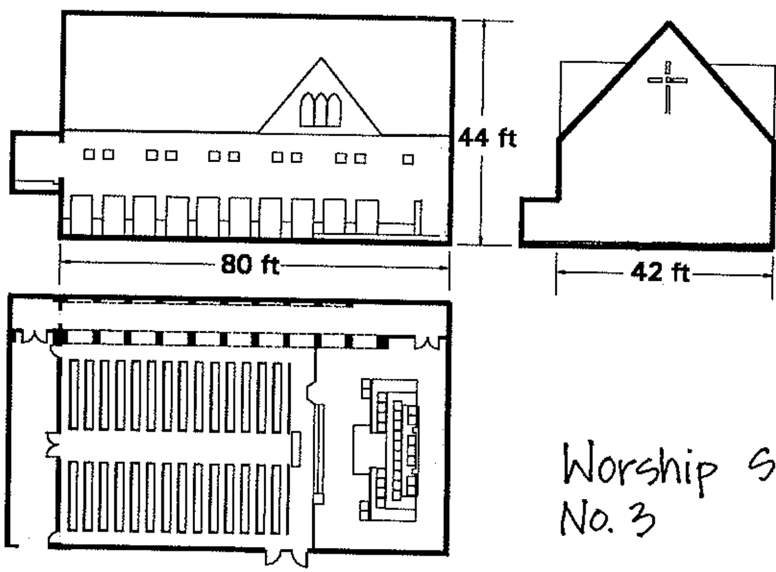
Note to Instructor: For class exercises, ask students to identify the optimum locations for pipes/windchests and console in the four worship spaces shown on the following page. Cite reasons why the preferred location should work best. Consult references of Associated Pipe Organ Builders of America (APOBA, P.O. Box 155, Chicago Ridge, IL 60415) such as "Planning Space for Pipe Organs," APOBA, 1992.



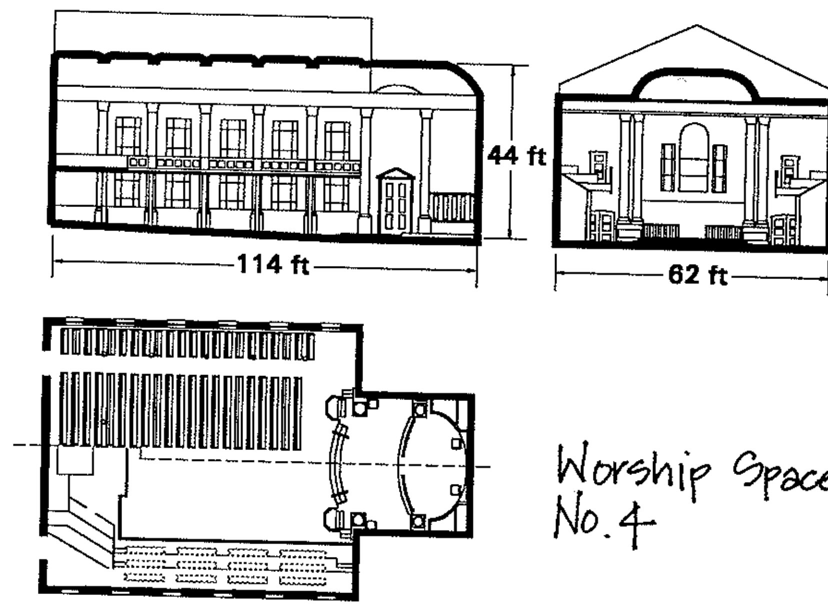
Worship Space
No. 1



Worship Space
No. 2

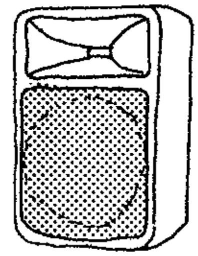


Worship Space
No. 3



Worship Space
No. 4

Courtesy of L. Gerald Marshall, FASA



ELECTRONIC SOUND SYSTEM IDENTIFICATION GUIDE

Neil Thompson Shade
American University

Objectives

Students are to visit a building such as an auditorium, lecture hall, or worship space to identify the type of sound system and major audio components used. Ask building owners which aspects of the sound system they believe to be good or bad. Use the guide to identify sound system functions and equipment. Perform a subjective listening test of the sound system and describe any needed improvements.

References

Prior to site visit, review material on sound systems from the following sources: 1. M. D. Egan, *Architectural Acoustics*, McGraw-Hill, 1988, pp. 356-386; 2. W. J. Cavanaugh and J. A. Wilkes (eds), *Architectural Acoustics: Principles and Practice*, Wiley, 1999, pp. 187-232; and 3. N. T. Shade, *Sound Systems Design Guide*, Newman Fund, Lincoln, MA, 1999.

Room Characteristics

1. Room dimensions: ______Length ______Width ______Height

2. Under balcony or transept seating? ______Yes ______No

3. Separate room for sound system controls? ______Yes ______No

4. Reverberation time: ______seconds (clap hands, estimate decay time using watch)

5. Draw small-scale floor plan and section in space below or on separate sheet. Identify audience seating and loudspeaker locations.

Sound System Function and Type (interview sound system contractor)

1. Functions: ____ Voice only ____ Music ____Playback of prerecorded audio media

2. Type of sound system: ______ Central cluster ______Distributed ceiling ______Distributed sound columns ______Other (describe)

3. Location of equipment rack (houses electrical equipment): ________________

4. Is equipment rack conveniently located? ____Yes ____No

5. Is there adequate clearance around the equipment rack for service and ventilation? Y N

6. Does sound system require permanent operator? _____Yes _____No

7. Estimate cost of sound system installation: $_______

8. Number of electrical power circuits: ________ Amperage rating: _______

Equipment Components (survey the individual equipment items which make up system)

Microphones (convert acoustical signals into electrical audio signals)

1. Microphone type(s): ____Podium ____Handheld ____Lavaliere ____Boundary Layer ____Wireless handheld ____Wireless lavaliere Total number of microphones:______

2. Location(s): ______________________________________

3. Types of connections: ____Wall plate ____Casework plate ____Wall box with cover _____Floor plate ____Floor box with cover

4. Are connections labeled or identified? _____ Yes _____ No

5. Distance between microphone and closest loudspeaker: ______ft

Assistive Listening System (enables hearing-impaired persons to hear audio program)

1. Is an assistive listening system used? _____ Yes _____ No

2. Type of assistive listening system: _____Infrared _____FM _____Induction loop

3. Do number of assistive listening headsets equal 4% of room occupancy? ___Yes ___No

4. Is there visible signage indicating that an assistive listening system is available? Y N

5. Are instructions for using equipment readily available? _____Yes _____No

Special Features (provide audio signal level adjustment and other functions)

1. Type of electronic signal processing used: ____Frequency equalizer _____Signal delay _____Active crossover _____Compressor/limiter

2. Type of electronic sound mixer used: _____Automatic type _____Manual type

3. Does sound system use computer control as part of its operation? ____Yes ____No

4. Is sound system operator located in the same room as loudspeakers? ____Yes ____No

Loudspeakers (convert electrical audio signals into acoustical signals radiated into room)

1. Loudspeaker type(s): _____Single loudspeaker enclosure above stage
   _____Multiple horn loudspeakers above stage
   _____Single loudspeaker both sides of stage
   _____Multiple small ceiling loudspeakers

2. Is the loudspeaker mounting height appropriate? _____Yes _____No

3. Are loudspeakers visible in the room? ___Yes ___No Total no. of loudspeakers:____

4. Do listeners have line-of-sight to all loudspeakers? _____Yes _____No

5. Describe support method used to mount loudspeakers.____________________

6. Distance from loudspeaker to farthest listener: ______ft

Subjective Listening Evaluation Test

First, request permission from the owner to perform this test. Then obtain instructions or assistance on using sound system. Set up a microphone 1 to 2 ft away from a talker. Listeners should be positioned along room centerline, approximately one-fourth length of room away from talker. The talker should read material not familiar to listeners, for 1 to 2 minutes duration. After listening to the material, listeners should reposition themselves. The talker should read the same material again. Next, sound system should be turned off or microphone disconnected and same material read without amplification. Compare listening experiences at different locations with and without use of sound system. Observe the following at different locations:

- Uniform sound level. [Sound level should not be noticeably lower as you move away from loudspeakers to perimeter or to underbalcony locations.]
- Clarity of individual consonant sounds and words.
- Frequency balance between bass and treble tones.
- Any audible feedback (such as ringing tones or hollow-sounding voices).
- Natural quality of vocal reproduction.
- Amplified sound should be loud enough (but not too loud) with mics 1 to 2 ft from talker.

5.0 SOUND ABSORPTION

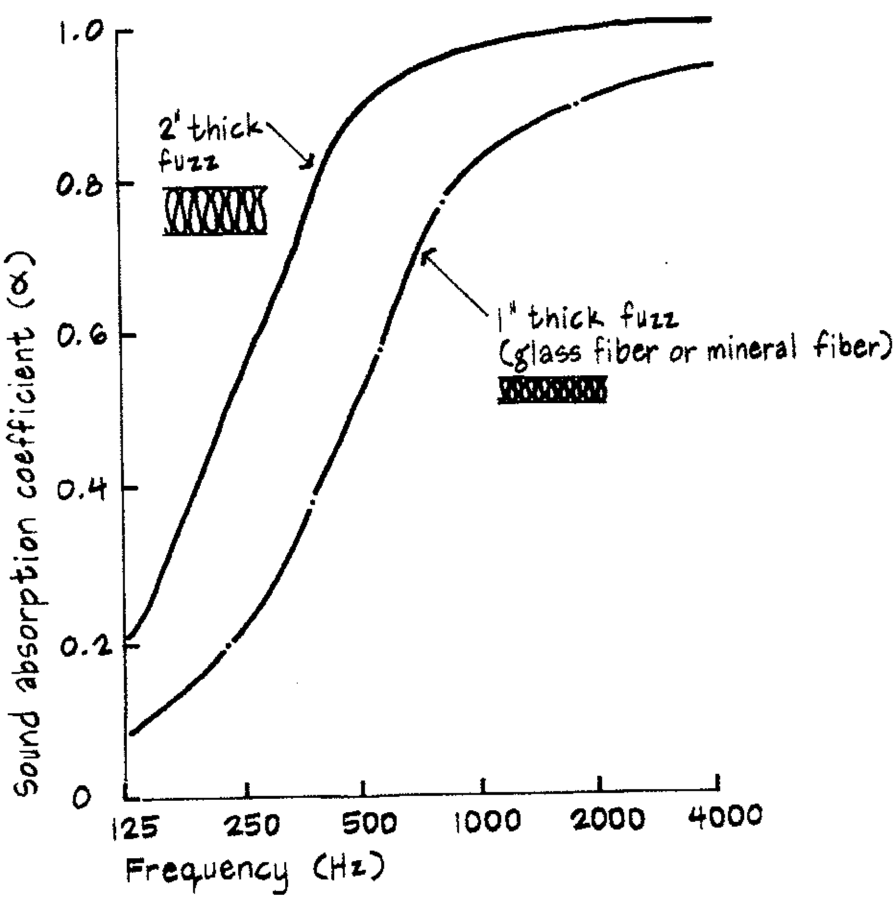
SOUND ABSORPTION PRINCIPLES

Porosity

Sound-absorption by porous sound absorbers (such as glass-fiber or mineral-fiber blankets and boards) is predominantly the indirect conversion of sound energy into thermal energy. The impinging sound wave has its energy reduced largely due to further flow resistance from the walls of the mazelike interconnected pores. Porous sound absorbers, however, are extremely poor sound isolators. Due to their soft, lightweight, interconnected structure, sound energy easily passes from one side of the material to the other.

Thickness

Thickness has a significant effect on the efficiency of porous sound absorbers. On exposed room surfaces, such as walls or ceilings, thick sound-absorbing board (or thin board with an airspace behind) will absorb far more sound energy at low frequencies (<1000 Hz) than thin sound-absorbing board. Sound absorption coefficients, in decimal percent, can vary from 0 (no sound energy absorbed) to 1.0 (perfect absorption).



Standard Test Mountings

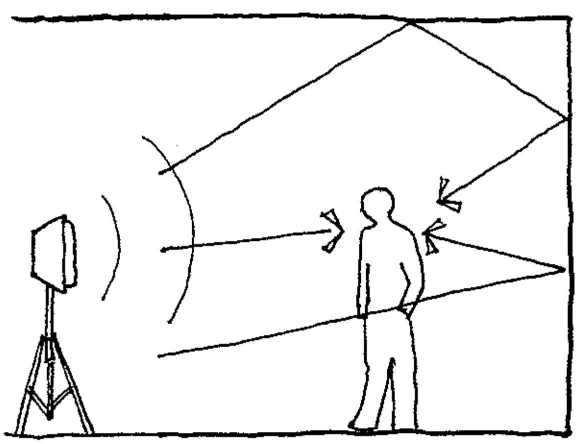
Laboratory tests to determine sound absorption efficiency should replicate the installation methods used on actual surfaces. For example, the ASTM C 423 test method describes several standard mountings (test specimen flat against backup surface, test specimen with shallow airspace behind, test specimen with deep airspace behind, and so on).

Common Absorbers Used in Building Construction

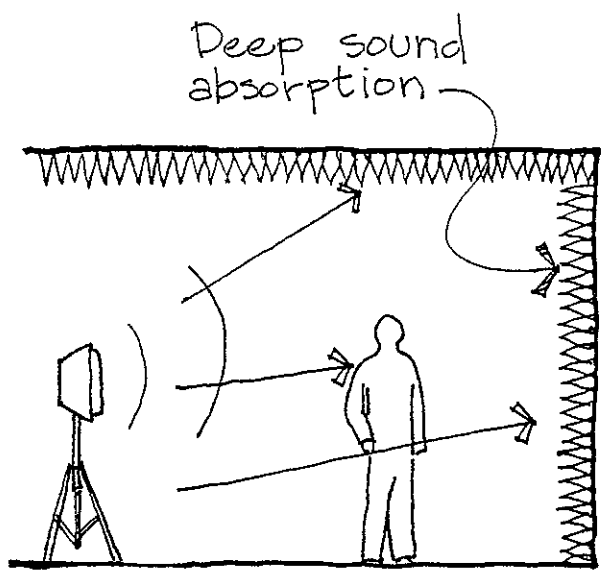
The most common sound absorbers used in building construction are glass-fiber blankets and boards, mineral-fiber blankets and boards, and spray-on cellulose coatings.

Facings

Needlepunched nonwoven mat can be used as facing material for sound-absorbing blankets and boards, provided mat porosity is high (>60 cfm/sq ft per ASTM D 737 test method). [Ref. K. P. Roy, "Thermal and Acoustical Performance of Needlepunch Fabrics", INDA 92.]

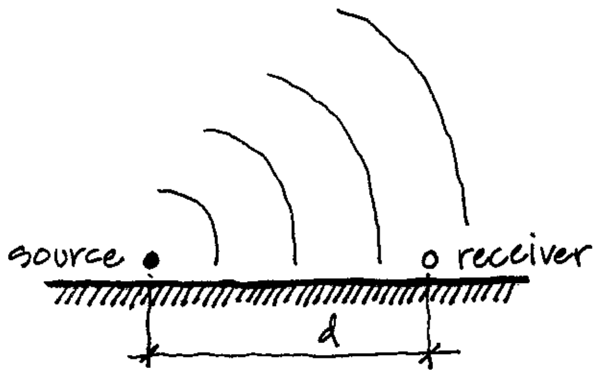


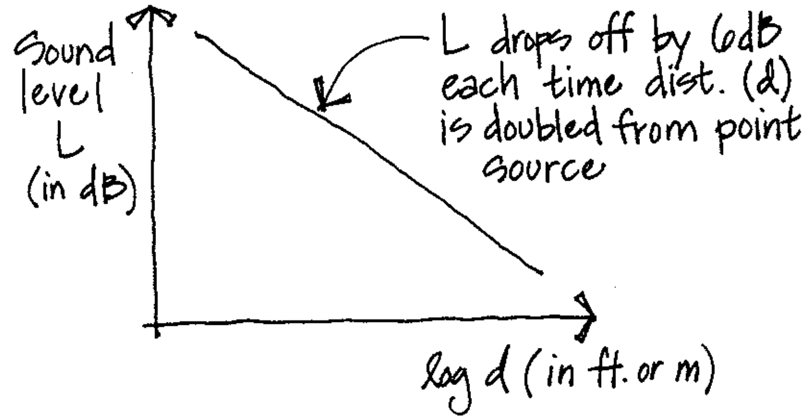
Sound-reflecting Surfaces



Sound-absorbing Surfaces

SOUND OUTDOORS (from point sources)



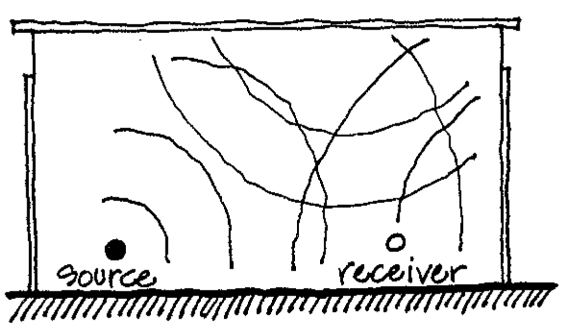


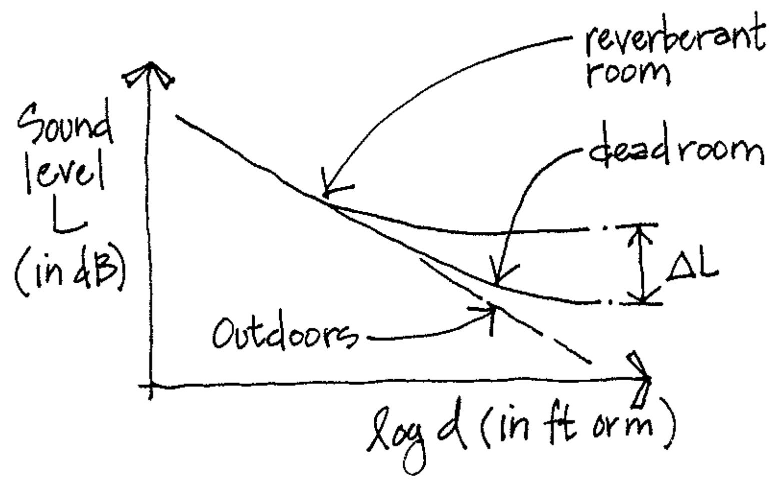
$$\Delta L = 10 \log \left(\frac{d_2}{d_1} \right)^2$$ and therefore

$$\Delta L = 20 \log \frac{d_2}{d_1}$$ where d is distance from source (in ft or m)

<u>Distance controls sound level</u>

SOUND INDOORS



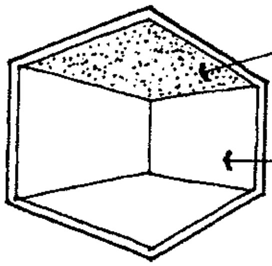


$$\Delta L = 10 \log \frac{a_2}{a_1}$$ where *a* is total absorption for two conditions (in sabins)

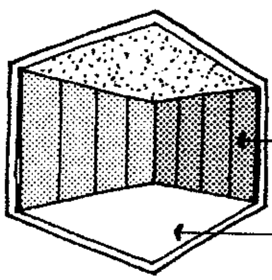
<u>Room absorption controls sound level</u>

NOISE REDUCTION DUE TO SOUND ABSORPTION

A small room 10 ft by 10 ft by 10 ft has all walls and floor finished in exposed concrete. The ceiling is completely covered with sound-absorbing spray-on material. Sound absorption coefficients α's are 0.02 for concrete and 0.70 for spray-on material, both at 500 Hz.



Find the noise reduction NR in this room if sound-absorbing panels are added to two adjacent walls. The sound absorption coefficient α is 0.85 for panels at 500 Hz.



1. Compute the surface areas S.

$$S = 5 \times 10 \times 10 = \boxed{500\ \text{ft}^2} \text{ of concrete}$$
$$S = 10 \times 10 = \boxed{100\ \text{ft}^2} \text{ of spray-on material}$$

2. Compute the total room absorption a_1 with spray-on material on the ceiling.

$$a_1 = \Sigma S\alpha = (500 \times 0.02) + (100 \times 0.70) = 10 + 70 = \boxed{80 \text{ sabins}}$$

3. Compute the total room absorption a_2 with sound-absorbing panels covering two walls and spray-on material on ceiling.

$$a_2 = \Sigma S\alpha = (300 \times 0.02) + (200 \times 0.85) + (100 \times 0.70)$$
$$= 6 + 170 + 70 = \boxed{246 \text{ sabins}}$$

4. Compute the noise reduction NR.

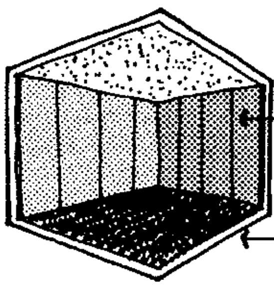
$$\text{NR} = 10 \log \frac{a_2}{a_1} = 10 \log \frac{246}{80} = 10 \log (3.075 \times 10^0)$$
$$= 10(0.4878) = \boxed{5 \text{ dB}}$$

This would be a "noticeable" improvement. With no treatment, the total absorption in the room would only be $600 \times 0.02 = 12$ sabins. Therefore, treating the ceiling alone provides

$$NR = 10 \log \frac{80}{12} = 10 \log 6.67 = 10(0.8241) = \boxed{8\text{ dB}}$$

which is a "significant" reduction. However, initial conditions of all hard surfaces in unfurnished rooms rarely occur.

Find the noise reduction NR if all four wall surfaces are treated with fabric-covered panels and the floor is carpeted. The sound absorption coefficient α of the carpet is 0.50 at 500 Hz.



1. Compute the total room absorption a_3 with sound-absorbing panels on all walls, spray-on material on ceiling, and carpet on floor.

$$a_3 = \Sigma S\alpha = (400 \times 0.85) + (100 \times 0.70) + (100 \times 0.50)$$
$$= 340 + 70 + 50 = \boxed{460\text{ sabins}}$$

2. Compute the noise reduction NR for these improvements compared to room conditions of spray-on ceiling treatment alone.

$$NR = 10 \log \frac{a_3}{a_1} = 10 \log \frac{460}{80} = 10 \log (5.75 \times 10^0)$$
$$= 10(0.7597) = \boxed{8\text{ dB}}$$

The results from both parts of the problem are summarized below.

Surfaces Treated (in addition to ceiling)	**Room NR** (at 500 Hz)
Two walls	5 dB
Four walls and floor	8 dB

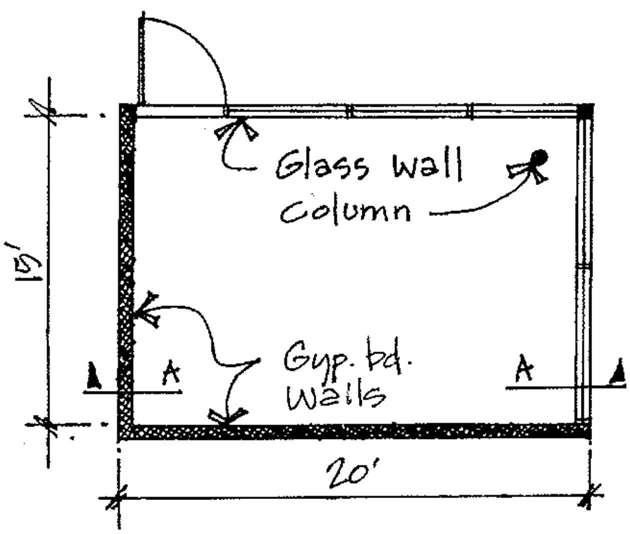
Note: The NRs given in the above table would not be as great at low frequencies because sound absorption coefficients usually are smaller at low frequencies than at mid- or high frequencies.

PROBLEM EXERCISES

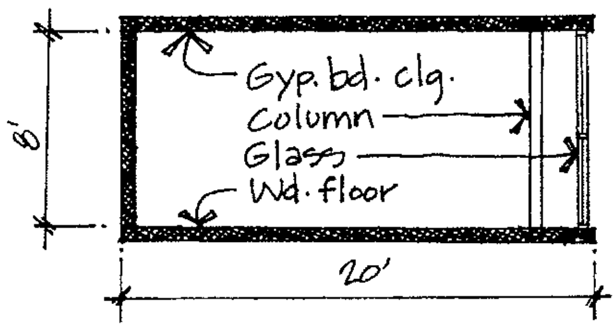
Find room noise reduction (NR) from adding floor carpet to the small gallery shown below.

Given: $\alpha_{glass} = 0.05$ $\alpha_{wood} = 0.08$

$\alpha_{gypsum\ board} = 0.10$ $\alpha_{carpet} = 0.50$



PLAN



SECTION A-A

Step 1. Find total absorption in room (wood floor exposed). Use a = Area x α.

Surface	Dimensions	Area (ft^2)	α	*a* (sabins)
Ceiling	15 ft x 20 ft			
Side wall	15 ft x 8 ft			
Side wall	15 ft x 8 ft			
Rear wall	20 ft x 8 ft			
Front wall	20 ft x 8 ft			
Floor	15 ft x 20 ft			

$a_1 =$ ______ sabins

Step 2. The owner decides to install wall-to-wall carpet. Find the new total absorption (a_2) in the room.

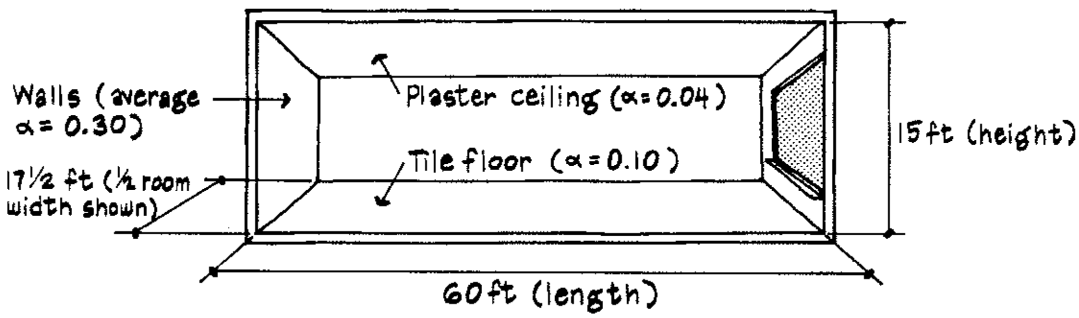
Surface	Dimensions	Area (ft^2)	α	*a* (sabins)
Ceiling	15 ft x 20 ft			
Side wall	15 ft x 8 ft			
Side wall	15 ft x 8 ft			
Rear wall	20 ft x 8 ft			
Front wall	20 ft x 8 ft			
Floor	15 ft x 20 ft			
			$a_2 =$	sabins

Step 3. Find noise reduction (NR) due to carpet absorption. Use $NR = 10 \log \frac{a_2}{a_1}$.

NR = ________dB

EXAMPLE PROBLEM (REVERBERATION TIME)

A classroom 60 ft long by 35 ft wide by 15 ft high has sound absorption coefficients α's of 0.30 for walls, 0.04 for ceiling, and 0.10 for floor. All α's are at 500 Hz.



Find the reverberation time T at 500 Hz in this space with no occupants and no sound-absorbing treatment.

1. Compute the room volume V.

$$V = 60 \times 35 \times 15 = \boxed{31{,}500 \text{ ft}^3}$$

2. Compute the surface areas S.

Ceiling	$S = 60 \times 35 = 2100 \text{ ft}^2$
Walls	$S = 2 \times 35 \times 15 = 1050 \text{ ft}^2$
	$S = 2 \times 60 \times 15 = 1800 \text{ ft}^2$
Floor	$S = 60 \times 35 = 2100 \text{ ft}^2$

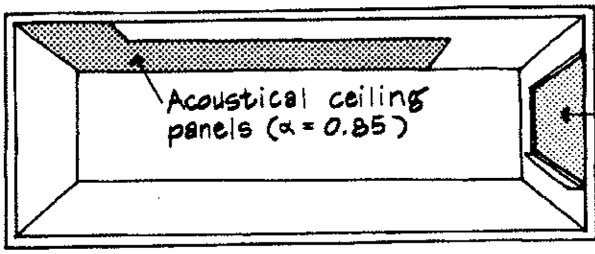
3. Compute the total room absorption a using $a = \Sigma S\alpha$.

	S	α	a (sabins)
Ceiling	2100 ×	0.04 =	84
Walls	2850 ×	0.30 =	855
Floor	2100 ×	0.10 =	210
		Total a =	1149 sabins

Note: Include air absorption in total for large rooms at frequencies greater than 1000 Hz.

4. Compute the reverberation time T using $T = 0.05\,\frac{V}{a}$.

$$T = 0.05\,\frac{V}{a} = \frac{0.05 \times 31{,}500}{1149} = \frac{1575}{1149} = \boxed{1.37\text{ s}} \text{ at 500 Hz}$$



Find the reverberation time T if 50 percent of the ceiling surface (along the perimeter of the room) is treated with acoustical panels at α of 0.85. The central area remains sound-reflecting to help distribute sound energy from lectern end toward rear of the room.

1. Compute the total room absorption a using $a = \Sigma S\alpha$.

	S	α	a (sabins)
Bare ceiling	1050	× 0.04 =	42
Treated ceiling	1050	× 0.85 =	892
Walls	2850	× 0.30 =	855
Floor	2100	× 0.10 =	210
		Total a =	1999 sabins

2. Compute new reverberation time T.

$$T = 0.05\,\frac{V}{a} = \frac{0.05 \times 31{,}500}{1999} = \frac{1575}{1999} = \boxed{0.79\text{ s}} \text{ at 500 Hz}$$

The reverberation time is reduced to below 1 s with 50 percent ceiling treatment for unoccupied conditions. This represents a reduction of $\frac{1.37 - 0.79}{1.37} \times 100 = 42$ percent, which is a "clearly noticeable" change. Absorption provided by teachers and students will further reduce reverberation depending on the number of occupants, their distribution throughout the room, and the clothing worn.

PROBLEM EXERCISES

1. Find the reverberation time for a conference room at Mushies Cereal Co. (*Mushies, the cereal that gets soggy without milk*). Dimensions are 40 ft long by 20 ft wide by 10 ft high. The sound absorption coefficients (α) are: 0.10 for the ceiling, 0.20 for the walls, and 0.05 for the floor.

a = ________sabins

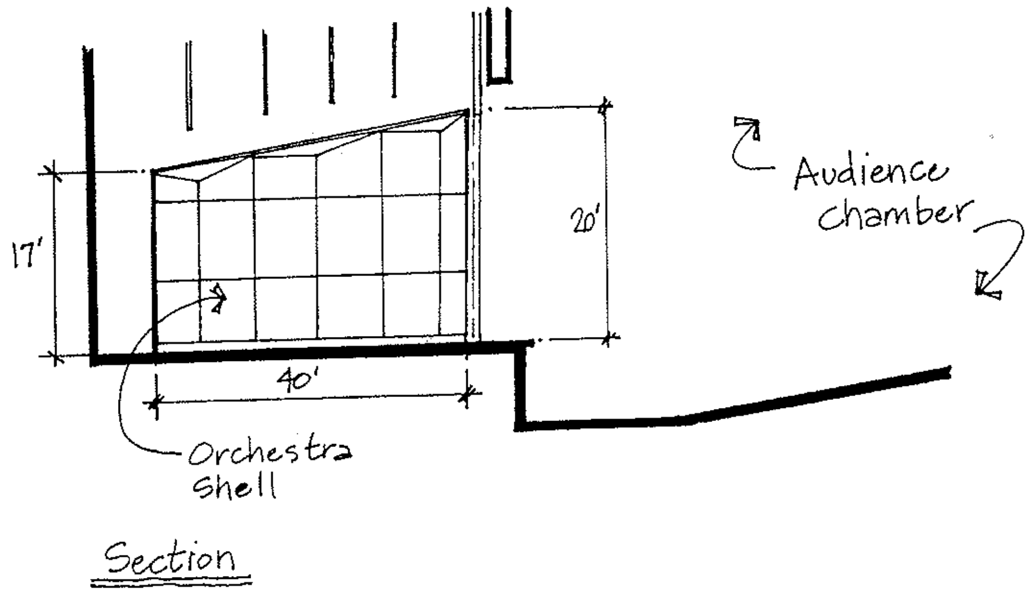
T = ________seconds

2. Find reverberation time for the Mushies conference room, if 75% of the ceiling is treated with acoustical panels having a sound absorption coefficient of 0.90.

a = ________sabins

T = ________seconds

3. A portable orchestra shell at the Mary Backstayge Theatre is 40 ft deep by 60 ft wide by 20 ft high. The sides, top panels, and stage floor all are finished in sound-reflecting materials having an absorption coefficient of 0.10. The 20 ft by 60 ft front end is completely open to the large volume of the audience chamber. Find the reverberation time within this shell designed by the McBeeBee twins. [HINT: Use absorption coefficient of 1.0 for open end facing audience chamber.]



V = ________ ft^3

a = ________ sabins

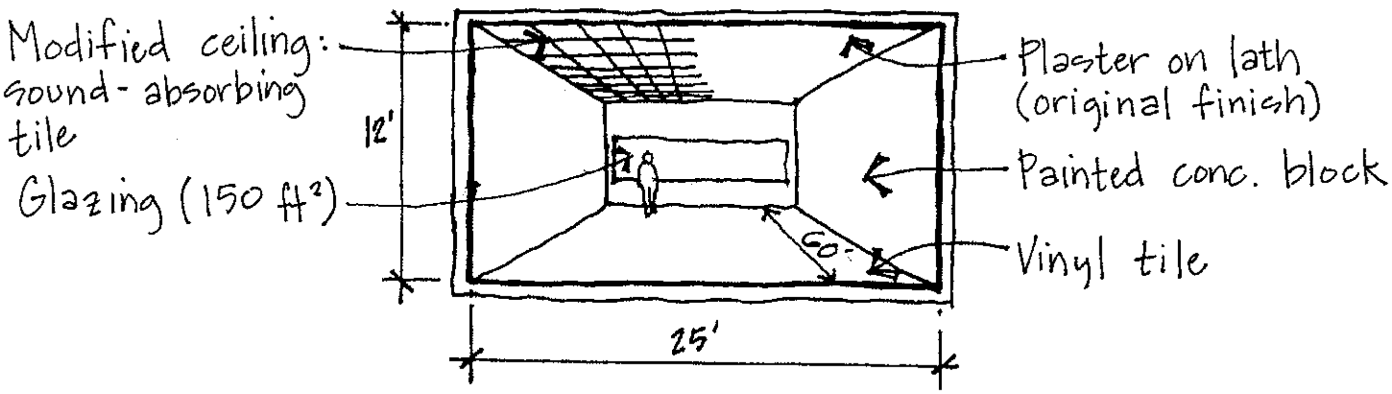
T = ________ sec

4. Recommend preferred mid-frequency design reverberation times (average of reverberation at 500 and 1000 Hz) for the following spaces you are designing.

Classroom (lecture) ______________ Broadcast Studio ________

Multi-purpose Auditorium__________ Symphony Hall __________

5. A laboratory for Whizzo Chocolates (*Whizzo, the makers of chocolate-covered frogs*) is finished entirely in sound-reflecting surfaces: plaster, painted concrete block, glass, and vinyl tile. The sound absorption coefficient (α) for these materials is 0.05. Laboratory dimensions are: 60 ft long by 25 ft wide by 12 ft high. What is the reverberation time (T_1) in this laboratory with windows closed? If a sound-absorbing tile, having a coefficient of 0.75, is glued to the entire ceiling surface and the 150 sq ft glass area is completely open to the outdoors, what will be the reduced reverberation time (T_2)? With windows closed, what will be noise reduction (NR) from adding sound absorption to the ceiling?



T_1 = ________sec

T_2 = ________sec

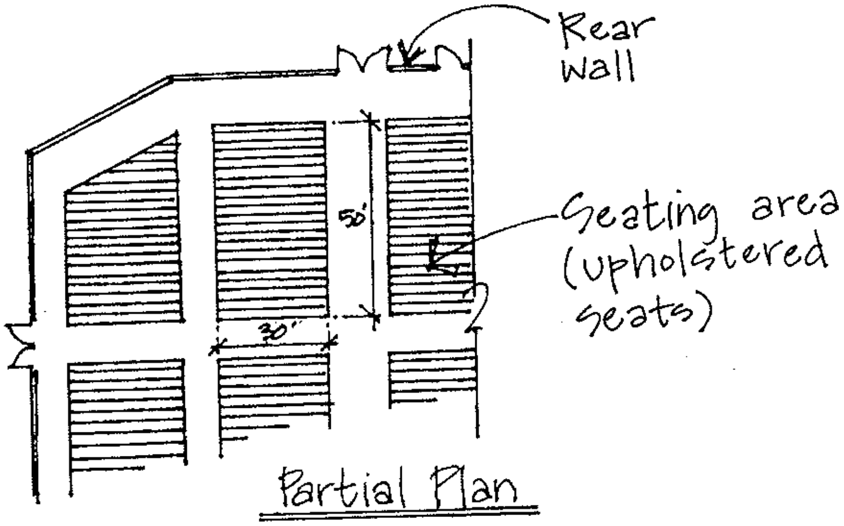
NR = ________dB

6. Find noise reduction coefficient (NRC) for material having the following sound absorption coefficients: 0.40 at 125 Hz, 0.50 at 250 Hz, 0.65 at 500 Hz, 0.60 at 1000 Hz, and 0.50 at 2000 Hz. [HINT: NRC is average of only four absorption coefficients! Round answer to nearest 0.05 increment.]

NRC = ________

7. In concert halls, over half the sound absorption is due to the audience and orchestra. An audience absorbs like a thick carpet with exposed edges. For an explanation on why absorption must be accurately predicted, see L. L. Beranek, "The Acoustical Design of Concert Halls," Journal of Building Acoustics, Vol. 1, No. 1, 1994, pp. 4-7. Find absorption from an audience seated in the 30 ft by 50 ft area in the auditorium shown below.

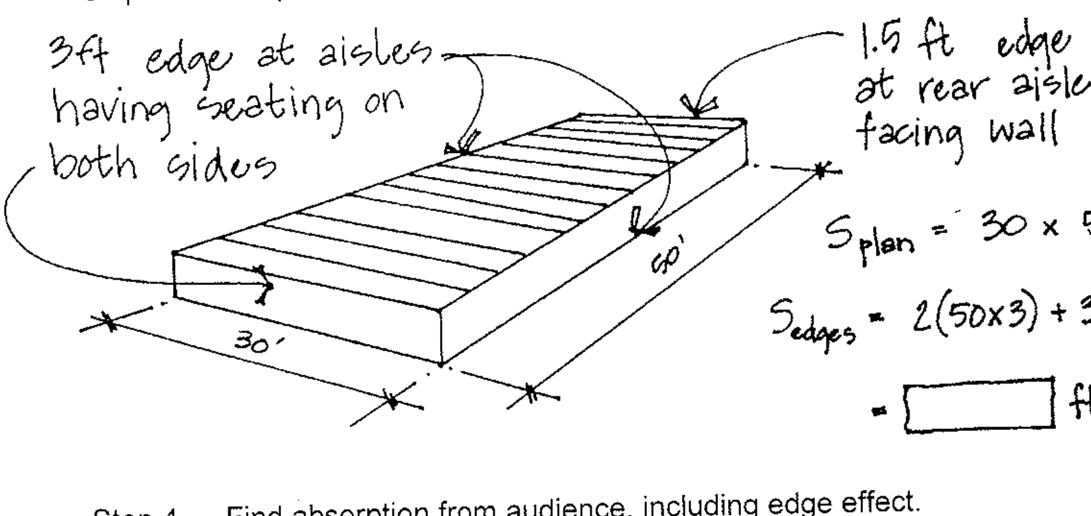
Step 1. Identify edge boundary conditions. Three sides of seating area face audience across an aisle. One side faces the rear wall.



Step 2. Find α at 1000 Hz on page 53 in *Architectural Acoustics.* Audience will be seated in upholstered seats.

α = ________

Step 3. Compute area of seating and area of all edges. Use $S_{tot.} = \sum S_{plan} + S_{edges}$.



$S_{plan} = 30 \times 50 = \square\ ft^2$

$S_{edges} = 2(50 \times 3) + 30 \times \square + 30 \times \square$

$= \square\ ft^2$

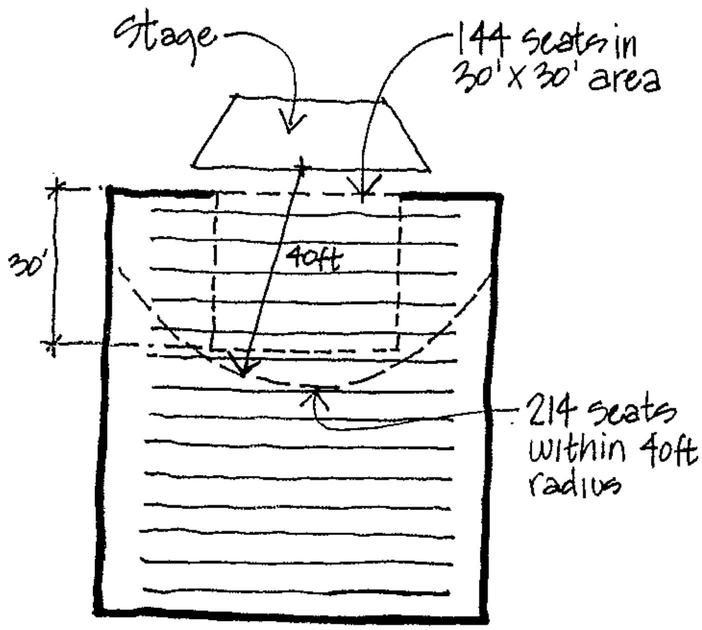
Step 4. Find absorption from audience, including edge effect.

$a = S_{tot.} \times \alpha = \square \times 0.94 = \square$ sabins

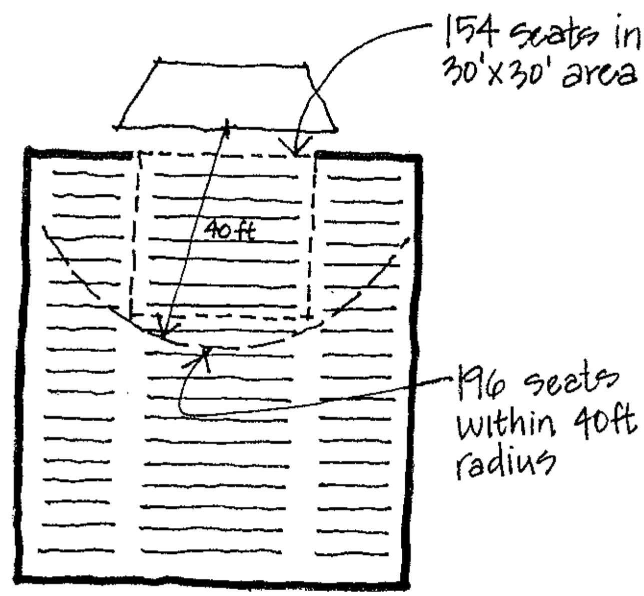
AUDIENCE SEATING

Students are to compare the characteristics of continental seating and conventional multiple-aisle seating. Evaluate the attributes listed in the table and also circle: Yes (Y) or No (N) and High (H) or Low (L). *Note to Instructor:* For an overview of sightline principles, see "Theater Design Criteria" by P. H. Frink in J. R. Hoke (ed), *Architectural Graphic Standards,* John Wiley, New York, 1994, pp. 839 to 841. To review life safety principles, see Chapter 6 in M. D. Egan, *Concepts in Building Firesafety,* Krieger Publishing, Malabar, Florida, 1986.

Attribute	**Continental**	**Conventional**
Supports focus of audience on event, not on each other.	Y N	Y N
Enhances "performance attentive" experience.	Y N	Y N
Enhances "shared event" feelings.	Y N	Y N
More than two choices for exiting.	Y N	Y N
Short evacuation times due to limited "exit access" options.	Y N	Y N
Flexibility to shape audience seating areas.	H L	H L
Impact on achieving good sightlines.	H L	H L



Continental (more seats within 40ft. radius)



Conventional (more seats in 30' x 30' center area)

CHECKLIST FOR USE OF SOUND ABSORPTION

1. Use sound-absorbing materials to control noise buildup, reverberation, and echoes.

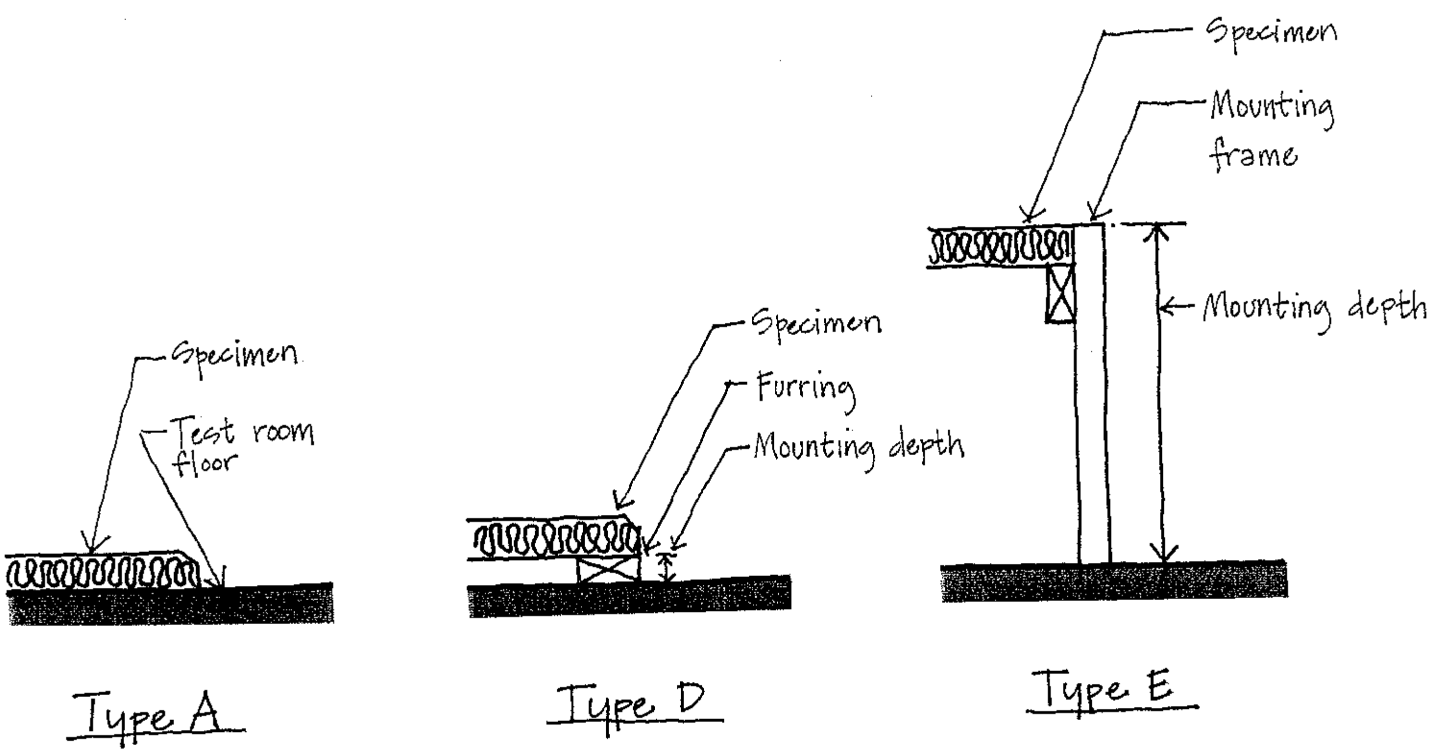
2. Do not use sound-absorbing materials on surfaces that should reflect sound, such as ceilings over podiums.

3. Be sure installation method will provide desired absorption. Actual mountings in rooms should be the same as ASTM standard mounting used to determine absorption coefficients in testing laboratory.

4. Do not depend on significant noise reduction from sound absorption. For most situations, the practical limit is about 6 dB.

5. Remember, the noise reduction coefficient (NRC) is an average number, rounded to the nearest 0.05 increment. It does not account for absorption at low frequencies (below 250 Hz) or high frequencies (above 2000 Hz).

6. Before specifying a material, evaluate the absorption coefficients across the frequency spectrum. Always specify absorption performance of a material along with the corresponding mounting method.



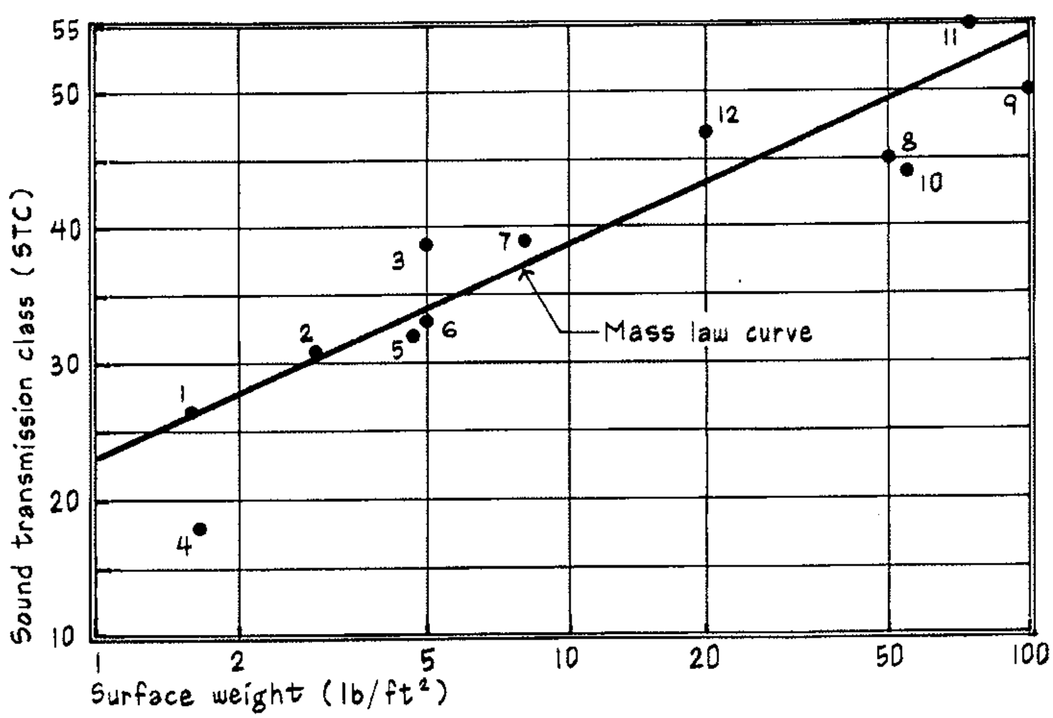
ASTM Standard Mountings

6.0 SOUND ISOLATION

SOUND ISOLATION PRINCIPLES

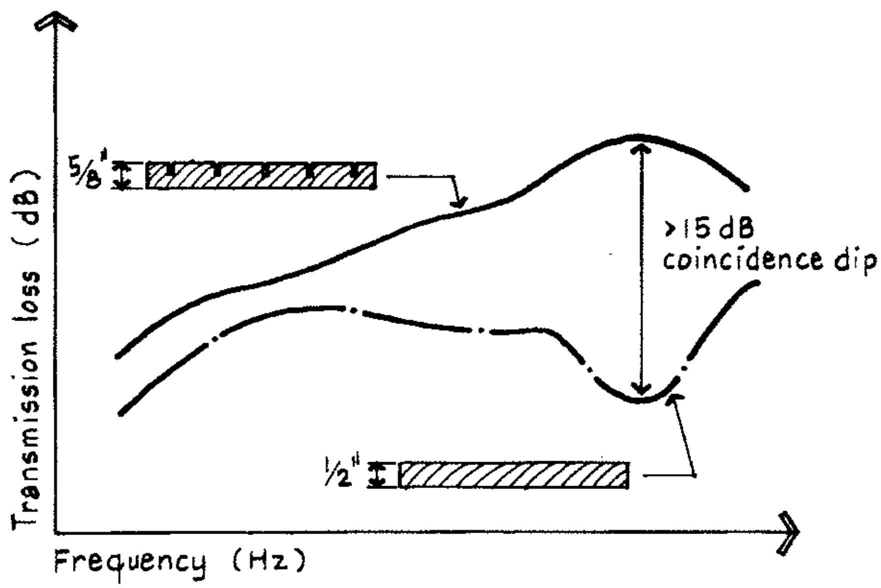
Mass

Sound waves impinging on surfaces produce a back-and-forth motion. The magnitude of this motion depends on the weight (or mass) – the greater the weight (lb/sq ft), the greater the resistance to motion and therefore less sound energy will be transmitted. Sound transmission class (STC) is a measure of sound isolation effectiveness. The higher the STC, the better the sound isolation within the speech frequency range (250 Hz to 4000 Hz). Numbers on the graph below represent twelve different building constructions: windows, doors, walls, and floor/ceilings.



Stiffness

The sound isolation efficiency of a material also depends on its stiffness. Less stiff materials and configurations provide better sound isolation. For example, when two plywood panels of identical weight are tested, the grooved less stiff layer has much higher sound isolation performance, evaluated by the transmission loss (TL) in dB. The TL is the difference in sound levels measured in rooms on opposite sides of a test specimen installed in the common wall (ASTM E90).



Cavity Absorption

When walls or floor/ceiling assemblies have an airspace between layers, sound-absorbing material can be used to dissipate sound energy within this cavity, thereby improving sound isolation.

Airtightness

Because sound transmission is logarithmic, very small holes, open seams, or gaps can significantly reduce sound isolation. Flexible, non-hardening sealant (Shore A durometer at <35) can be used to prevent the passage of sound through gaps and cracks. If light can pass through an opening, so will sound.

EXAMPLE PROBLEMS (TRANSMISSION LOSS)

1. Find the TL of a material that has a sound transmission coefficient τ of 6.0×10^{-4}.

$$TL = 10 \log \frac{1}{\tau}$$

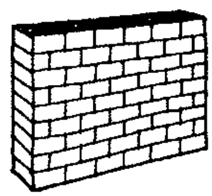
$$= 10 \log \frac{1}{6 \times 10^{-4}}$$

$$= 10 \log (0.167 \times 10^4)$$

$$= 10 \log (1.67 \times 10^3)$$

$$TL = 10\ (3.2227) = \boxed{32\ \text{dB}}$$

2. The TL of a heavy concrete block wall construction is 40 dB. Find the τ for this wall.



$$TL = 10 \log \frac{1}{\tau}$$

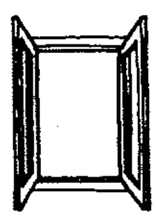
$$40 = 10 \log \frac{1}{\tau}$$

$$4 = \log \frac{1}{\tau}$$

$$\frac{1}{\tau} = 1 \times 10^4$$

$\tau = \boxed{10^{-4}}$ or 0.0001 of incident sound energy is transmitted.

3. An open casement window has a TL of 0 dB. Find the τ for this opening.



$$TL = 10 \log \frac{1}{\tau}$$

$$0 = 10 \log \frac{1}{\tau}$$

Because $\log 1 = 0$

$$\frac{1}{\tau} = 1$$

$\tau = \boxed{1}$ for an opening (all incident sound energy is transmitted!)

EXAMPLE PROBLEMS (NOISE REDUCTION)

1. In an apartment building, two adjacent living rooms have a party wall constructed of 4-in-thick brick which has a TL of 40 dB at 500 Hz. The surface area S of the wall is 200 ft², and both rooms have 300 sabins of absorption a_2 at 500 Hz. Find the sound level L_2 in room 2 if the sound level L_1 in room 1 is 74 dB.

   First, find the noise reduction NR between the rooms.

   $$NR = TL + 10 \log \frac{a_2}{S}$$

   $$= 40 + 10 \log \frac{300}{200} = 40 + 10 \log 1.5$$

   $$NR = 40 + 10\,(0.1761) = 41.8 \text{ dB}$$

   Next, find the sound level L_2.

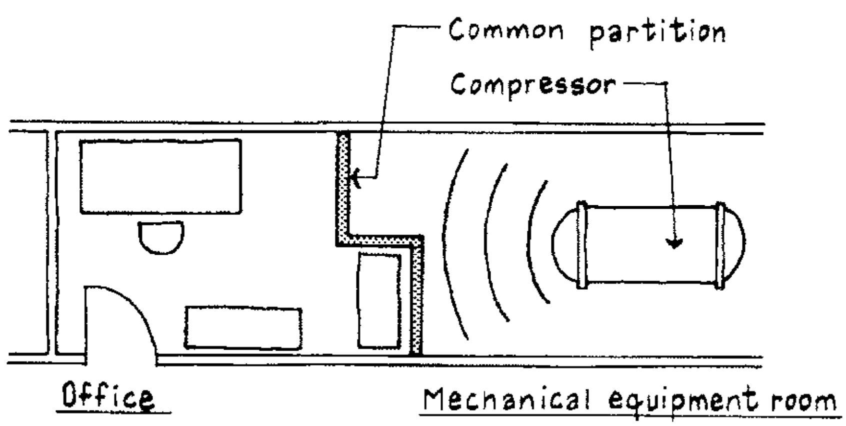
   $$NR = L_1 - L_2$$

   and therefore

   $$L_2 = L_1 - NR$$

   $$L_2 = 74 - 41.8 = 32.2 \simeq \boxed{32\text{dB}} \text{ at 500 Hz in room 2}$$

2. The common partition between a private office and a mechanical equipment room has a surface area of 100 ft² and a TL of 35 dB. The office has 200 sabins of absorption. Find the sound level L_2 in the office if the sound level L_1 in the mechanical equipment room is 98 dB.



   First, find the noise reduction NR between the rooms.

   $$NR = TL + 10 \log \frac{a_2}{S}$$

   $$= 35 + 10 \log \frac{200}{100} = 35 + 10 \log 2$$

   $$NR = 35 + 10\,(0.3010) = \boxed{38 \text{ dB}}$$

Next, find the sound level L_2 in the office.

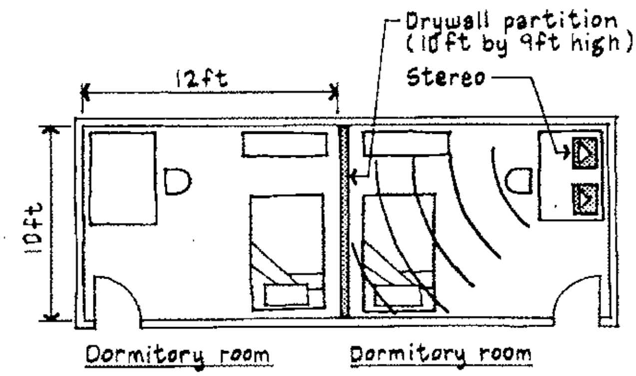
$NR = L_1 - L_2$

and therefore

$L_2 = L_1 - NR$

$L_2 = 98 - 38 = \boxed{60\ dB}$ which would be perceived as noisy by most listeners

3. Find the TL for the 90-ft² common partition between the two adjoining dormitory rooms shown below. Ceiling height in the rooms is 9 ft. Sound absorption coefficients α's are 0.04 for gypsum board walls and ceiling, and 0.69 for the carpeted floor. Absorption of the bed is 15 sabins. Noise level in the receiving room should not exceed 22 dB. Likely noise level from a stereo in the source room is 82 dB.



First, find the absorption in the receiving room using the formula $a = \Sigma S\alpha$.

	Surface area (ft²)	α	a
Walls	2(12 × 9) = 216		
	2(10 × 9) = 180		
Ceiling	10 × 12 = 120		
	516	× 0.04 =	21
Floor	10 × 12 = 120	× 0.69 =	83
Bed			15
		a_2 =	119 sabins

Next, find the required NR.

$NR = L_1 - L_2$

$NR = 82 - 22 = \boxed{60\ dB}$

Finally, find the required TL.

$$TL = NR - 10 \log \frac{a_2}{S}$$

$$= 60 - 10 \log \frac{119}{90}$$

$$= 60 - 10 \log (1.3) = 60 - 10\ (0.1139)$$

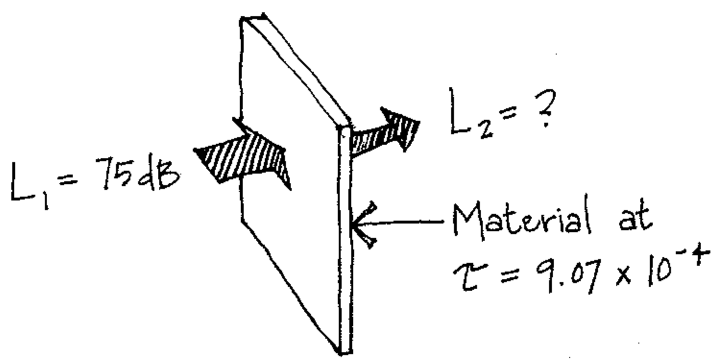
$$TL = 60 - 1 = \boxed{59\ dB}$$

PROBLEM EXERCISES (TL)

1. What would be the transmission loss (TL) of a construction having a sound transmission coefficient (τ) of 8.0 x 10^{-6}?

TL = ________ dB

2. What would be the transmission loss (TL) of a material having a sound transmission coefficient (τ) of 90,686 x 10^{-8}? Find the transmitted sound level (L_2), if 75 dB impinges on this material. [HINT: First arrange numbers for τ as digit times 10 to a power.]



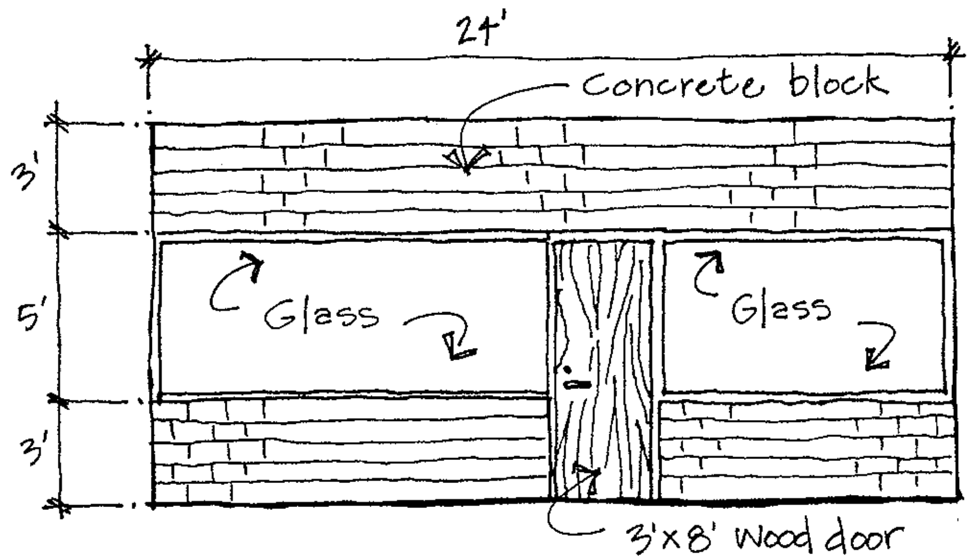
TL = ________ dB

L_2 = ________ dB

3. Find Composite TL for the wall construction shown below.

Given:	Concrete block	TL = 45 dB
	Solid-core wood door	TL = 34 dB
	Single-pane glass	TL = 31 dB

Remember: Composite TL = 10 log $\frac{\sum S}{\sum \tau S}$.



Elevation

Step 1. Find sound transmission coefficients (τ). Use 10 log $\frac{1}{\tau}$.

- Concrete block

τ = ________

- Wood door

τ = ________

- Single-pane glass

τ = ________

Step 2. Find area of each component of wall. S is symbol for surface area.

- Concrete block

  S = ________ ft²

- Wood door

  S = ________ ft²

- Single-pane glass

  S = ________ ft²

Step 3. Compute τ x S for each component of wall.

- Concrete block

  τS = ________

- Wood door

  τS = ________

- Single-pane glass

  τS = ________

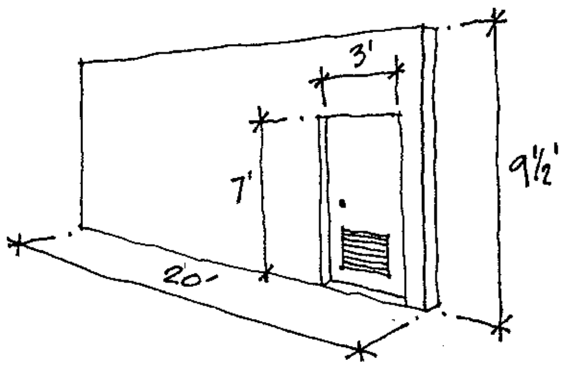
Step 4. Find Composite TL.

total from step 2

$$CompositeTL = 10 \log \frac{\sum s}{\sum \tau s} = 10 \log \frac{\boxed{}}{\boxed{}} = \boxed{} \text{ dB}$$

total from step 3

4. One wall of the library at Springfield Elementary School contains a louvered door. The wall is 20 ft long by 9½ ft high. The TL of the drywall construction is 40 dB, but the TL of the 3 ft by 7 ft louvered door is only 10 dB. Find the composite TL for this wall-door construction.



Comp. TL = ________dB

Principal Seymour Skinner replaces the louvered door with a solid-core wood door, gasketed to be airtight when closed. If the TL of the new door is 32 dB, find the improved composite TL.

Comp. TL = ________dB

5. The common wall between Wally Ballou's office and a mechanical room has a surface area of 150 ft^2 and a TL of 38 dB. Noise level in the mechanical room is 87 dB. Ballou's office has 400 sabins of absorption. What sound level (L_2) will be transmitted to the office?

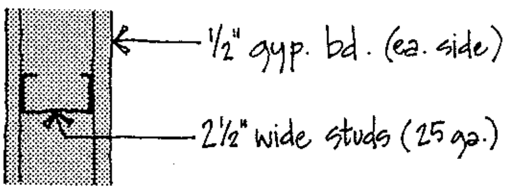
NR = ______ dB

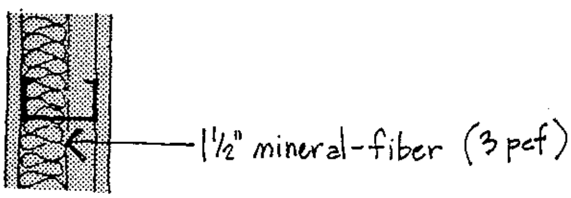
L_2 = ______ dB

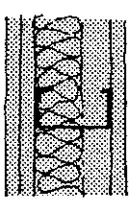
SOUND TRANSMISSION CLASS RATINGS

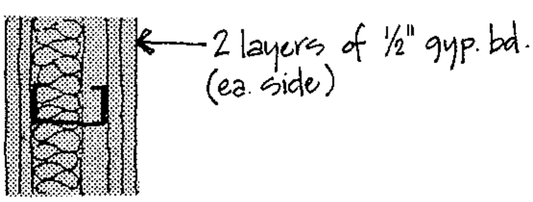
Estimate the STC for the following drywall constructions. For multi-family dwellings, an STC below 50 for the common wall normally will be unsatisfactory. When occupants hear noise from their neighbors transmitted through the common walls, they tend to blame their neighbors *not* the wall. As a consequence, poor acoustical design and/or faulty building construction contribute to social problems. Cite test references used to estimate STC rating. The most reliable sources of data are independent acoustical laboratories accredited by NVLAP to perform ASTM E 90 tests.

Drywall Construction	STC using Light-gage Metal Studs	STC using Wood Studs	Test Reference



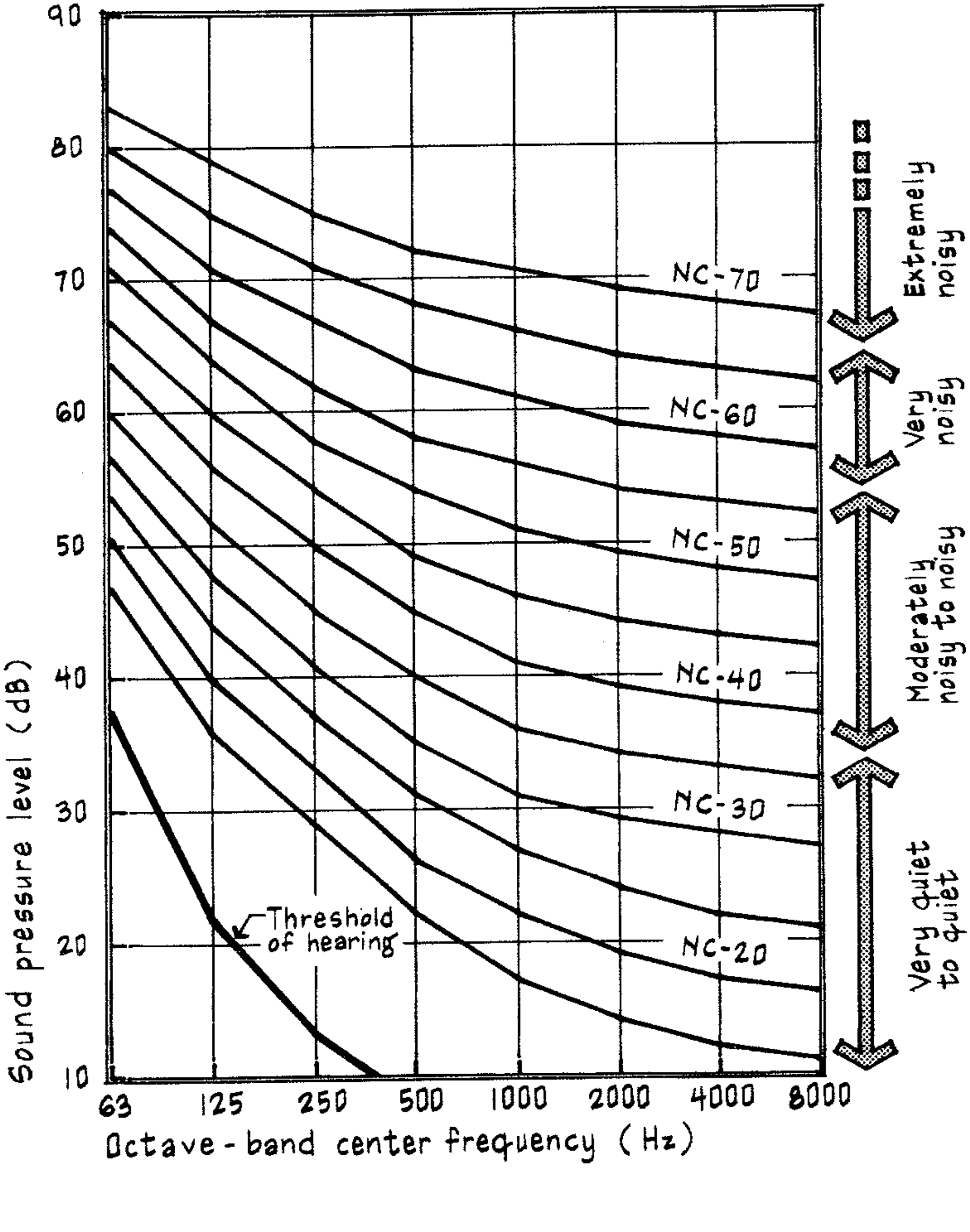






WARNING: STC ratings from sound-isolation performance measured in the laboratory are normally far higher than field STC ratings for nominally identical constructions.

NOISE CRITERIA CURVES



PROBLEM EXERCISES (Noise Criteria)

1. Noise criterion (NC) curves can be used to specify octave-band sound level limits over the audible frequency range. What criteria limit or range would be appropriate for the following spaces you are designing?

	NC	dBA
Music Recital Hall	________	________
High School Auditorium	________	________
Lobby of Office Building	________	________
Small Enclosed Office	________	________

HINT: Consult current edition of *ASHRAE Handbook* ("Sound and Vibration" chapter) or refer to pages 232 to 238 in *Architectural Acoustics.*

2. The following noise levels are measured in a large conference room: 50 dB at 125 Hz, 44 dB at 250 Hz, 38 dB at 500 Hz, 37 dB at 1000 Hz, 38 dB at 2000 Hz, and 36 dB at 4000 Hz. Plot data on graph on following page to determine NC rating. Is the noise rumbly or hissy? [HINT: Refer to page 288 in *Architectural Acoustics*.]

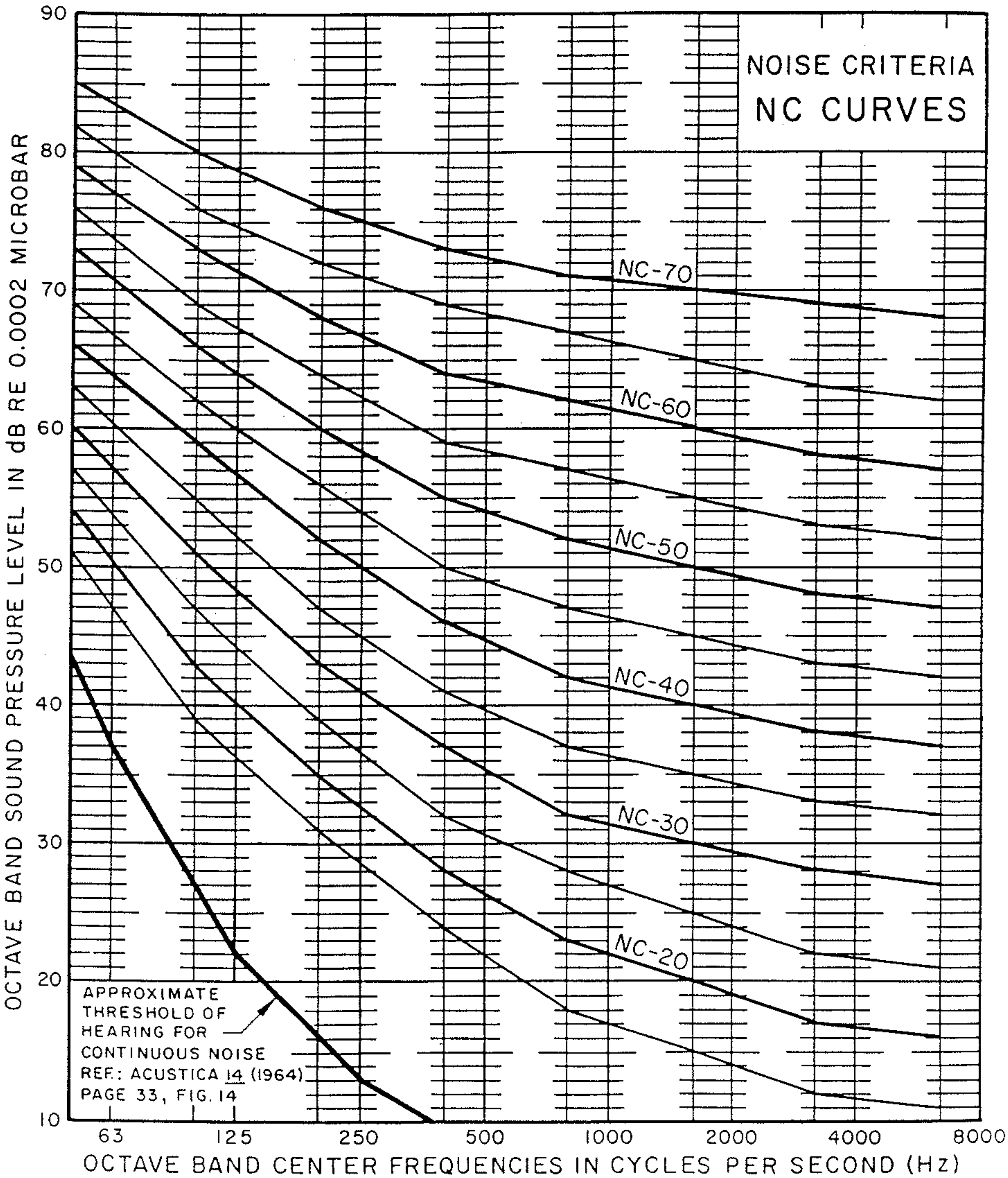
NC = __________

3. The following noise levels are measured in a school competition gymnasium: 56 dB at 125 Hz, 55 dB at 250 Hz, 55 dB at 500 Hz, 50 dB at 1000 Hz, 43 dB at 2000 Hz, and 32 dB at 4000 Hz. Plot data on graph on following page to determine NC rating. Is the noise rumbly or hissy?

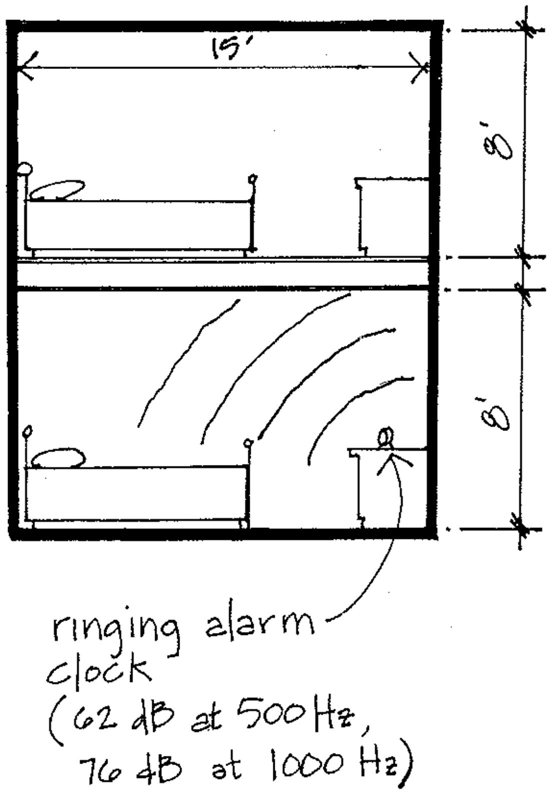
NC = __________

4. In open-plan offices, what continuous background *masking* level should *not* be exceeded? [HINT: Occupants tend to raise their voice levels to be heard when this background level has been reached.]

Background Sound Level = _________dBA


NOISE CRITERIA
NC CURVES
OCTAVE BAND SOUND PRESSURE LEVEL IN dB RE 0.0002 MICROBAR
90
80
70
60
50
40
30
20
10
NC-70
NC-60
NC-50
NC-40
NC-30
NC-20
APPROXIMATE THRESHOLD OF HEARING FOR CONTINUOUS NOISE
REF.: ACUSTICA 14 (1964) PAGE 33, FIG. 14
63
125
250
500
1000
2000
4000
8000
OCTAVE BAND CENTER FREQUENCIES IN CYCLES PER SECOND (Hz)

5. Find the required TL in dB for the floor/ceiling construction separating bedrooms in the Ewan McTeagle Apartments. Finishes and furnishings are given below. Each bedroom is 10 ft wide. At night, background noise drops to NC-20. Specify the floor/ceiling construction necessary to provide sufficient sound isolation.



Walls: plaster on brick

floors: heavy carpet on foam rubber

ceiling: 1/2" gypsum board

absorption of bed & furniture = 90 sabins @ 500 Hz
120 sabins @ 1000 Hz

NR = _______ dB at 500 Hz

NR = _______ dB at 1000 Hz

TL = _______ dB at 500 Hz

TL = _______ dB at 1000 Hz

Construction type _______________

PROBLEM EXERCISES (Outdoor Barriers)

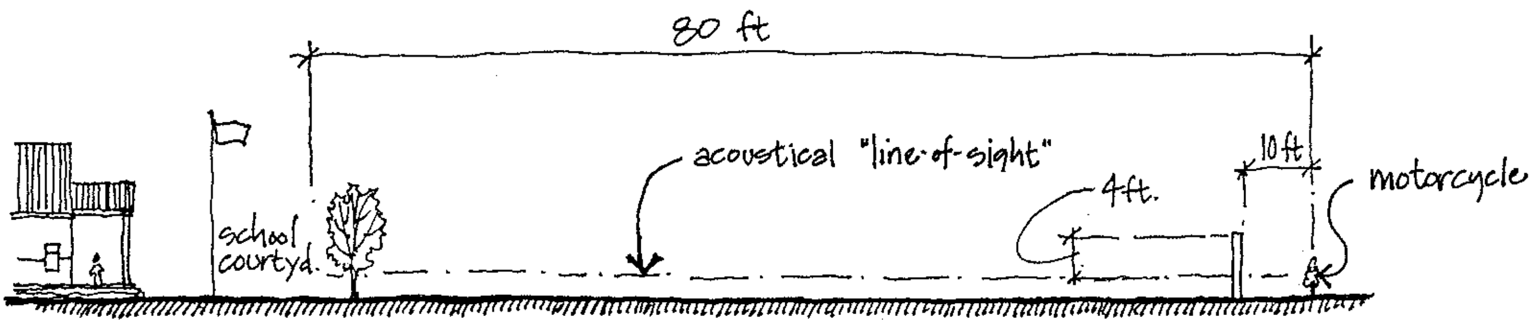
1. Traffic noise should not exceed 54 dB at 250 Hz in a school courtyard located 80 ft from a busy highway. The highway department plans to build a continuous, solid barrier 10 ft from the highway. The barrier will extend 4 ft above the acoustical *line-of-sight*. If a motorcycle on the highway produces a noise level of 82 dB at 20 ft away, what will be the noise level (L) in the courtyard? Will sound attenuation (A) from spreading and the barrier sufficiently reduce the motorcycle noise?

Spreading A = ________dB

Barrier A = ________ dB at 250 Hz

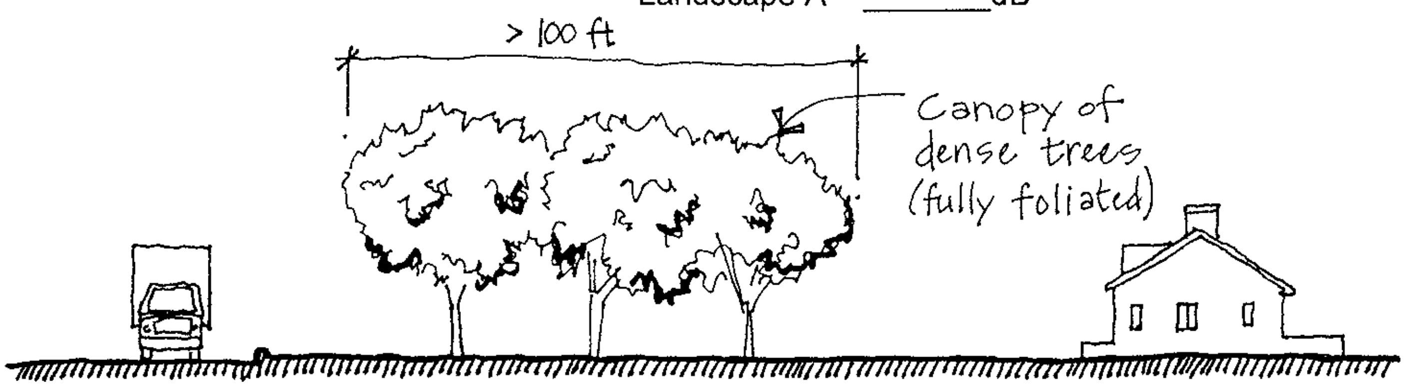
L = _______dB at courtyard

Satisfactory? Yes No

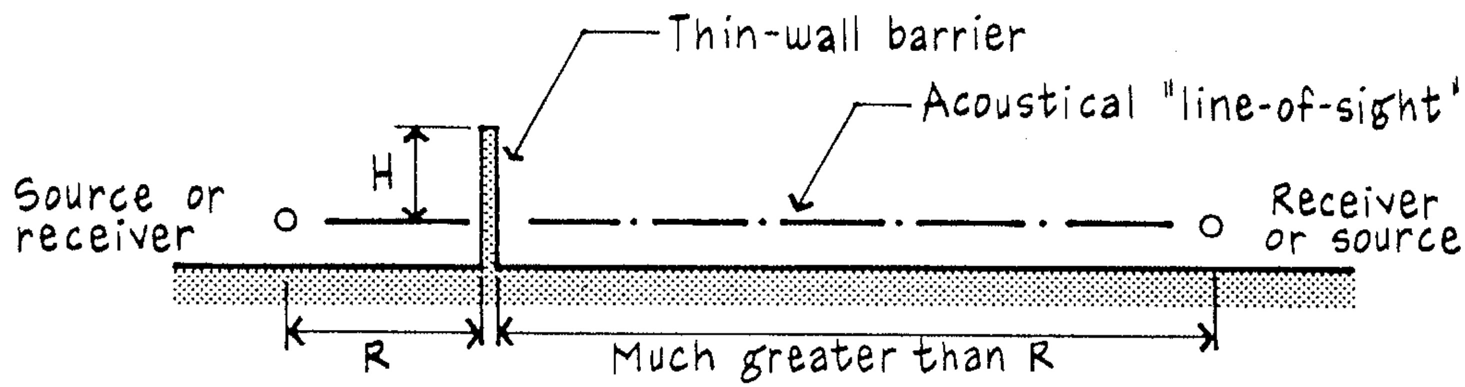


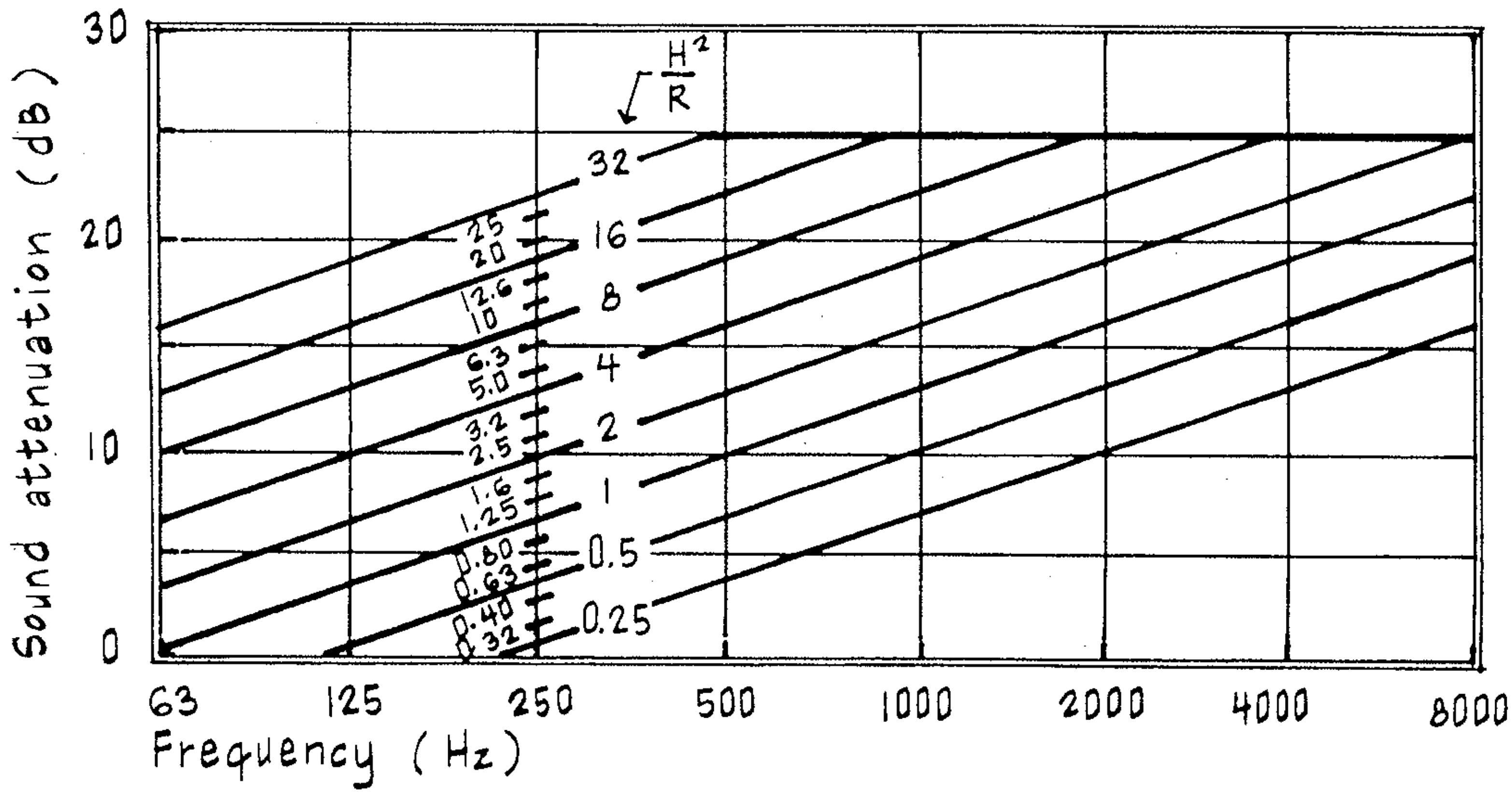
2. To reduce traffic noise from a nearby highway, a lumberjack suggests planting a 100 ft deep band of deciduous trees. At 1000 Hz, what attenuation (A) in dB would you anticipate when the trees mature and are fully foliated? [HINT: Refer to graph on page 264 in *Architectural Acoustics*.]

Landscape A = _______dB



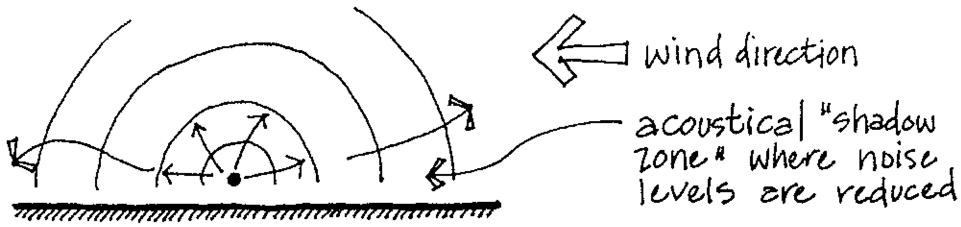
Barrier Attenuation Graph



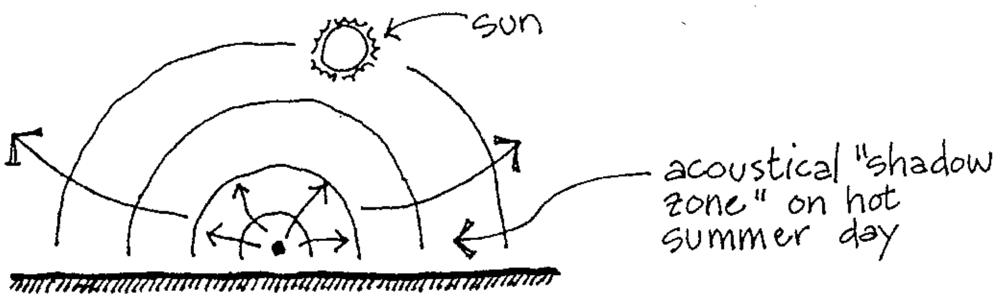


CHECKLIST OF OUTDOOR NOISE REDUCTIONS

1. **WIND GRADIENTS** (can increase or decrease sound by 10 dB or more)

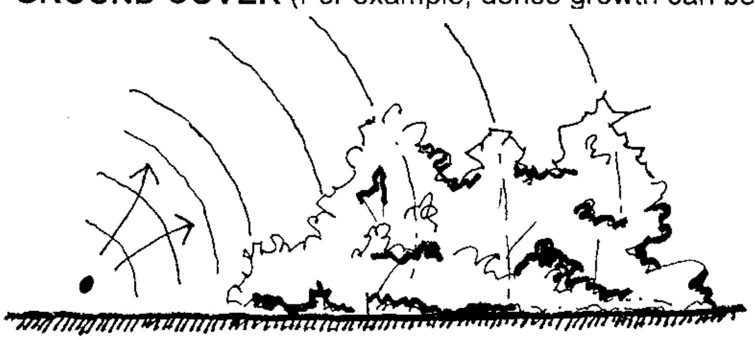


2. **TEMPERATURE GRADIENTS** (similar effects to those from wind)

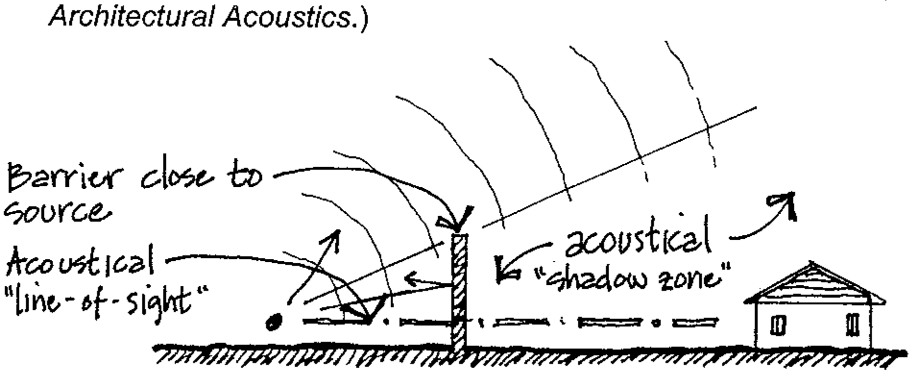


3. **HUMIDITY** (For example, at 1000 Hz, 20° C, & 60% RH, attenuation will be 0.003 dB/m.)

4. **GROUND COVER** (For example, dense growth can be 0.12 dB/m.)



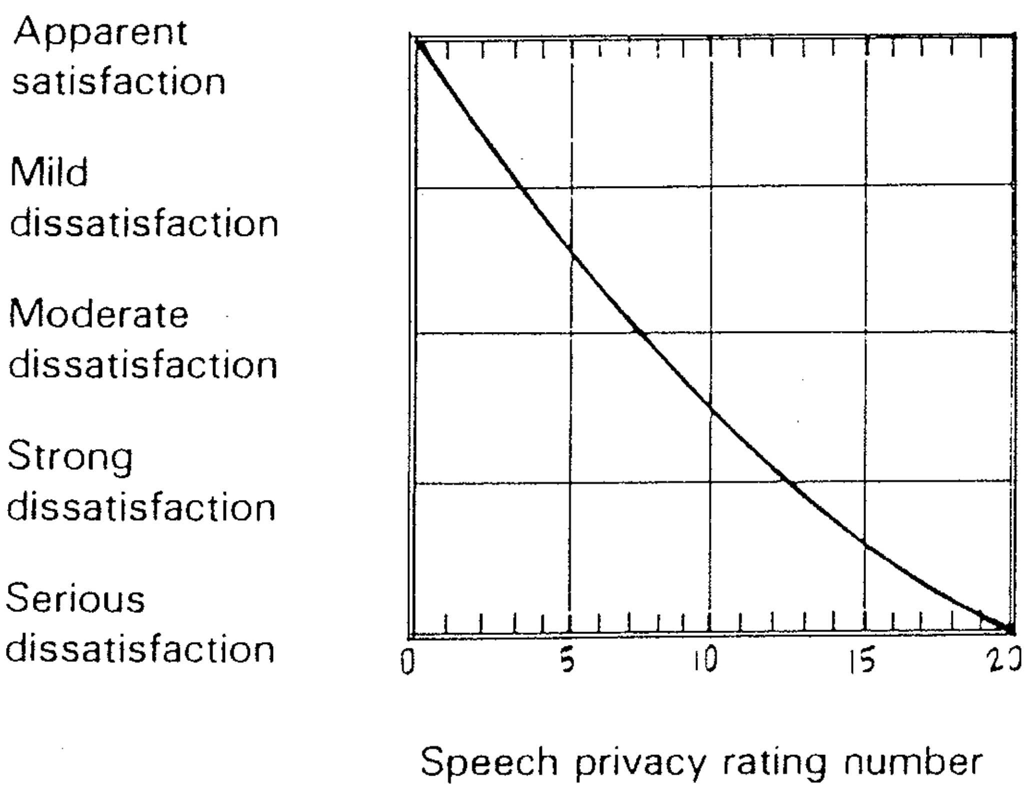
5. **LINE-OF-SIGHT BARRIERS** (Attenuation can be up to 15 dB, depending on sound frequency, barrier geometry, and other factors. Refer to pages 255 to 258 in *Architectural Acoustics*.)



SPEECH PRIVACY

Speech privacy depends on *signal-to-noise* ratio between the intruding speech *(signal)* and the steady background sound *(noise)*. Level of intruding speech depends on how loud people talk and degree of noise reduction from common wall, flanking paths, and room finishes. Background noise primarily is due to the din from activities of people and HVAC systems, or the steady sound from electronic masking. [Refer to Chapter 6 in *Architectural Acoustics*.]

The curve on the graph below shows *average* response of people to intruding speech based on a rating number determined by subtracting the isolation rating from the speech rating. For example, if an office design has a speech privacy rating number of 10, the likely response by occupants would be from *moderate* to *strong* dissatisfaction.



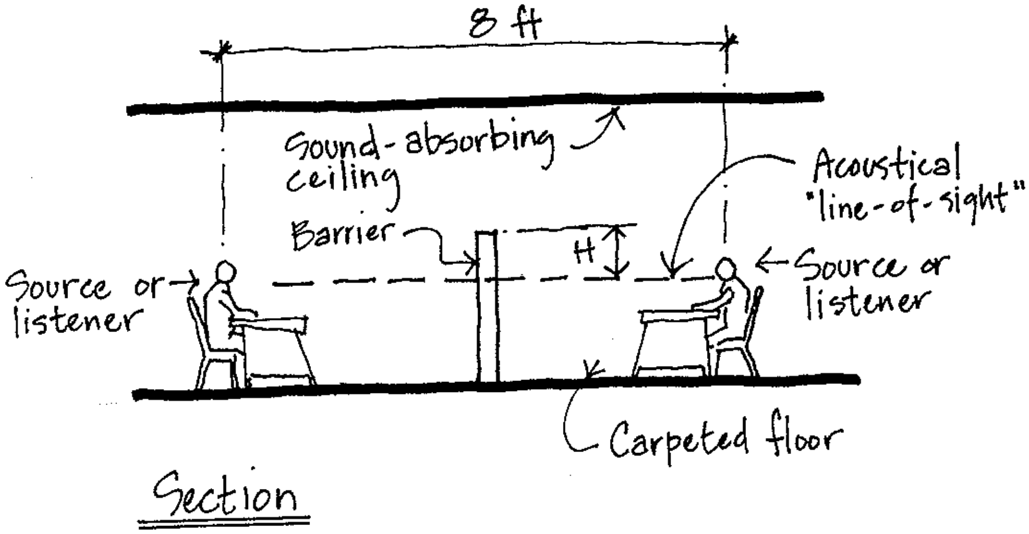
References

W. J. Cavanaugh et al, "Speech Privacy in Buildings," Journal of the Acoustical Society of America, April 1962.

R. W. Young, "Re-Vision of the Speech Privacy Calculations," Journal of the Acoustical Society of America, October 1965.

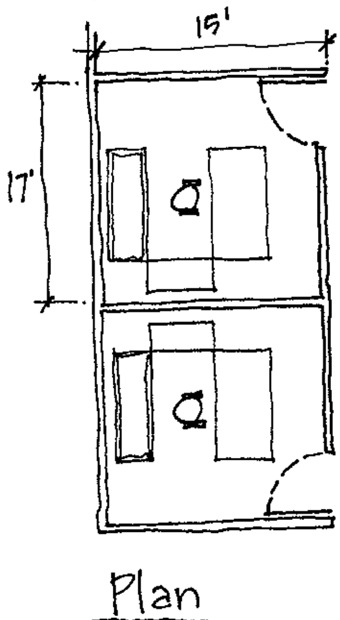
PROBLEM EXERCISES (Speech Privacy)

1. A *normal* degree of speech privacy is desired in the Einbinder Flypaper open-plan office where workers talk at *conversational* voice levels. Background noise from an electronic masking sound system is 51 dBA. Workers will be seated 8 ft apart and separated by partial-height barriers. How high (H) must the barriers be above the acoustical line-of-sight? [HINT: Refer to pages 344 to 348 in *Architectural Acoustics*.]



H = ________ft

2. Two adjacent private offices for Elmer W. Litzinger, Spy are 17 ft by 15 ft in plan. The common wall is 15 ft long by 8½ ft high. Background noise levels in the offices are 35 dBA. If occupants often speak at *raised* voice levels and *normal* degree of acoustical privacy is desired, what STC-rated wall would you specify to achieve *apparent satisfaction*? [HINT: Use enclosed-plan speech privacy method presented on pages 329 to 333 in *Architectural Acoustics*. Set *speech privacy rating number* equal to 0.]



A_1 = ________ ft^2

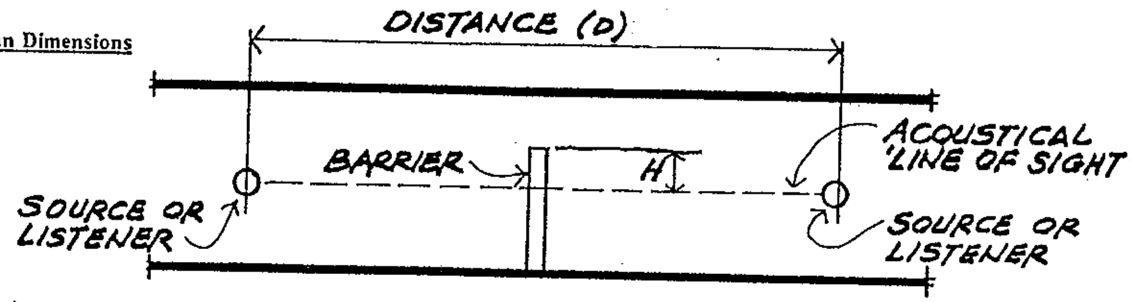
A_2/S = ________

STC = ________

SPEECH PRIVACY ANALYSIS WORKSHEET (Open Plan)

Anticipated Response to Privacy Situation

Open Plan Dimensions



Speech Rating

		A	B
1. Speech effort: how people talk in room.	Loud 72 — Raised 66 — Conversational 60	___	___
2. Privacy allowance: degree of privacy desired.	Confidential 15 — Normal 9	___	___
	●Speech rating total (S)	___	___

Isolation Rating

3. Distance from source to listener: effect of room sound absorption and sound level falloff with distance (D) from source to listener.

Room finishes: Ceiling	Floor	Distance D. ft.: 3	6	12	25	50	100
Reflecting	Reflecting	0	3	6	9	12	15
Reflecting	Absorbing	0	4	8	12	16	20
Absorbing	Reflecting	0	5	10	15	20	25
Absorbing	Absorbing	0	6	12	18	24	30

___ ___

4. Partial - height barrier: Attenuation from barrier with ceiling absorption based on NRC of 0.75. Barrier width should be at least twice its total height.

Barrier height H (above acoustical "line-of-sight" in feet.)	Distance D. ft.: 3	6	12	25	50	100
1	11	7	4	2	0	0
2	14	10	7	4	3	2
3	15	11	8	5	4	3
4	16	12	9	6	5	4

___ ___

5. Room background noise level (dBA): Masking sound available. ___ ___

Speech Privacy Rating Number

●Isolation rating total (I) ___ ___

Speech Privacy Rating (SPR) = (S) - (I) ___ ___

CONSTRUCTION OF SOUND ISOLATION ENCLOSURE

1. Students are to select an annoyingly loud noise source such as an alarm clock, electric shaver, warning siren, or car horn. The louder the noise source the better, because the achieved noise reduction only can be evaluated if the transmitted noise can be detected above the background noise outside the enclosure.

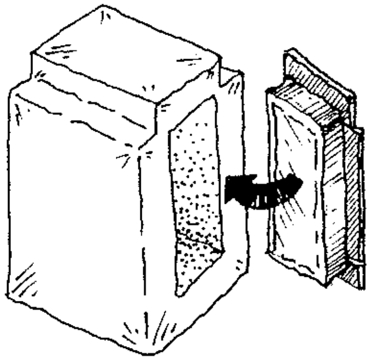
2. Using the principles of noise control covered by Chapters 2 and 4 in *Architectural Acoustics*, design and construct an enclosure that significantly reduces the noise level of your source. The noise control enclosure should be portable and lightweight, *not* weighing more than 20 lbs.

3. The effectiveness of your enclosure will be determined by measuring the noise level before and after the noise source is covered. Measurements will be recorded in A-weighted decibels (dBA) and decibels (dB) at 125 Hz. The procedure will be similar to the field noise isolation class (field NIC) measurement according to ASTM E 336.

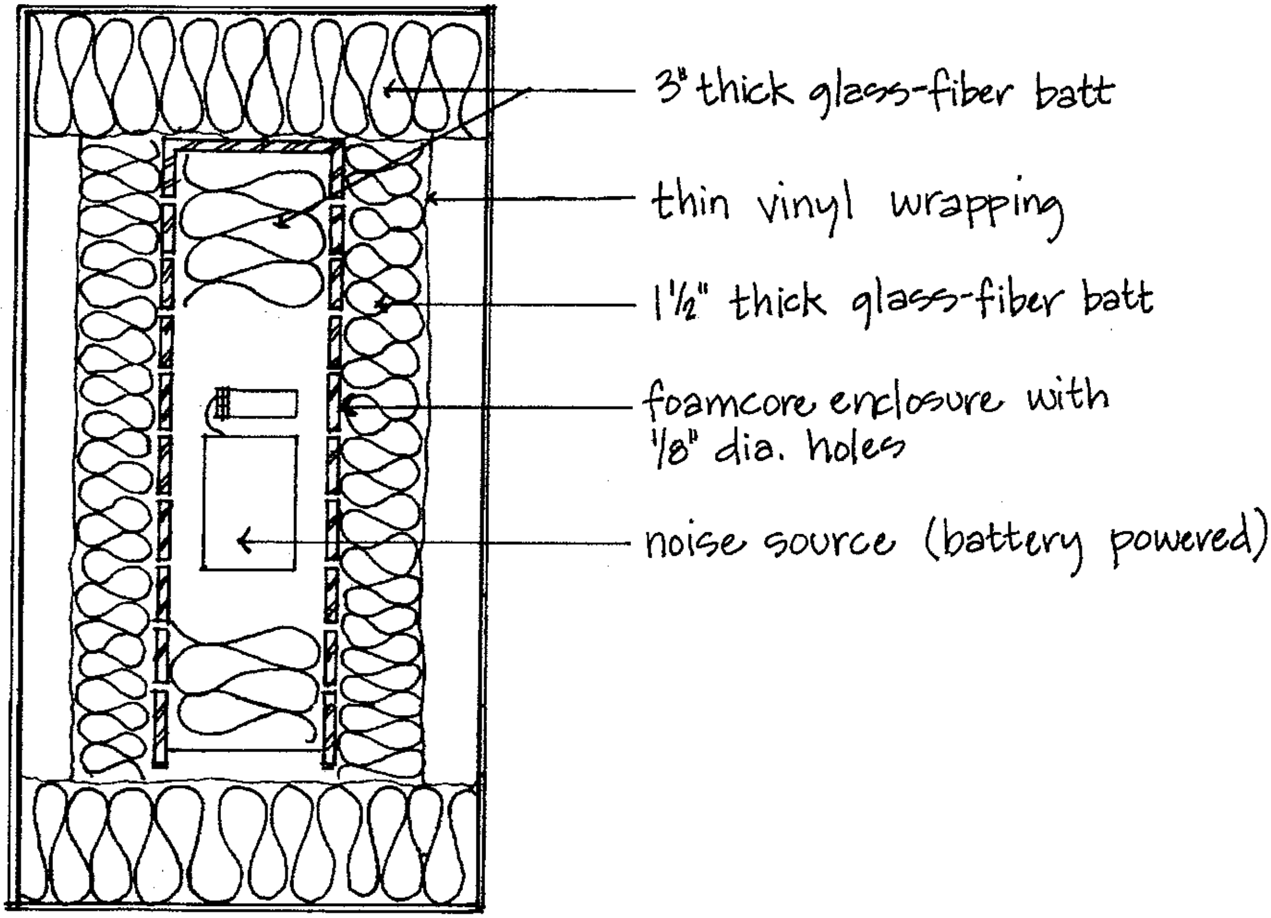
4. Your report should describe the noise source, the design process used to achieve noise reduction, and the enclosure. Comment on what worked and what didn't. Include plan and section drawings showing the important details of your enclosure.

5. Final evaluation will be based on: achieved NIC, noise reduction effectiveness per lb of enclosure, and quality of your written report.

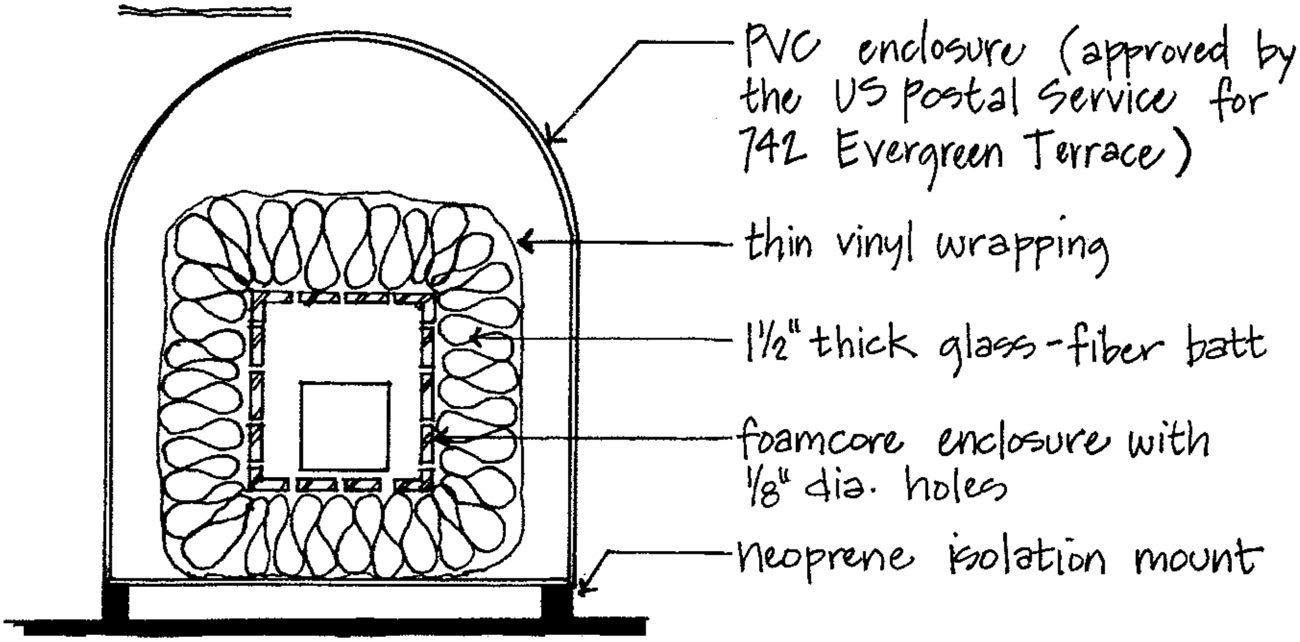
Note to Instructor: To measure noise reduction of students' enclosures, borrow a sound level meter from the department of physics, environmental engineering, or occupational safety & health. The meter should be classified ANSI Type 1, manufactured by Brüel & Kjaer, Larson Davis, Rion, or equal. Weigh enclosures on a bathroom scale that measures in ounces, available from K-Mart, Sears, and the like.



EXAMPLE SOUND ISOLATION ENCLOSURE (UNCC Students)



Plan



Section

COMMON NOISE PROBLEMS IN BUILDINGS

Students should practice listening to their academic, recreational, and residential built environments. When acoustics problems are discovered, try to see if the cause can be identified and solutions proposed. Be careful when discussing problems with owners because diagnosis by those who have not studied acoustics often is misleading. Where there are multiple noise sources, turn off all sources and listen to each, turned back on one at a time. Use the table to practice on the symptoms presented and to record your experiences. [HINT: For example solutions, refer to Chapters 2 and 4 to 6 in *Architectural Acoustics*.]

Symptom	Probable Cause	Likely Solutions
Cafeteria is so loud one must almost yell to communicate.		
Sound seems to come through common wall of rooms in *dormitory*.	1. Sound leaks in wall. 2. Sound transmitted by wall (lightweight or too stiff). 3. Room too quiet.	1. Caulk openings and seal back-to-back electrical boxes. 2. Add mass to wall and/or enhance stud system. 3. Consider electronic masking sound system.
People walking in overhead *apartment* are clearly heard below.		
Environmental noise from nearby highway makes it hard to concentrate in *classroom*.		
Sounds of telephone conversations can be heard throughout *open-plan office*.		

7.0 ACOUSTICAL DESIGN PROJECTS

CLASSROOM DESIGN

Students are to evaluate the room acoustics and modify the interior of the historic university classroom described by the following plan and section drawings. Determine all physical dimensions based on proportions to the given dimensions. The report should present information in a clear, understandable format.

Acoustical Objectives

Modify interior surface shapes and determine finishes to achieve satisfactory listening conditions for the following activities performed on the platform.

- lectures and debates
- small chorus singing
- chamber music recitals

Report Elements

The following are important acoustical parameters that should be part of your report.

1. Compute cubic volume (ft^3). Show all subdivided volumes used to find total cubic volume. Compute volume-to-seating ratio (ft^3 per person).

2. Analyze reverberation time conditions.

   a. Find reverberation time (sec) at 125, 500, and 4000 Hz for empty and fully-occupied conditions. Show results on graph of reverberation time (sec) versus frequency (Hz). Comment and show on sketches any improvements you recommend.

   b. Select finish improvements for ceiling, walls, and floor. Identify finish and area (ft^2) of any sound-absorbing treatment on drawings submitted with your report. Use sound absorption data from pages 52 and 53 in *Architectural Acoustics*. Existing finishes are: ceiling - plaster on lath (#40), walls - plaster on block (#12), floor and platform - wood (#18), bench seating (#56), and people (#55). Be sure to include "edge effect" for seated audience. Cite sources for sound absorption coefficients of your proposed modifications.

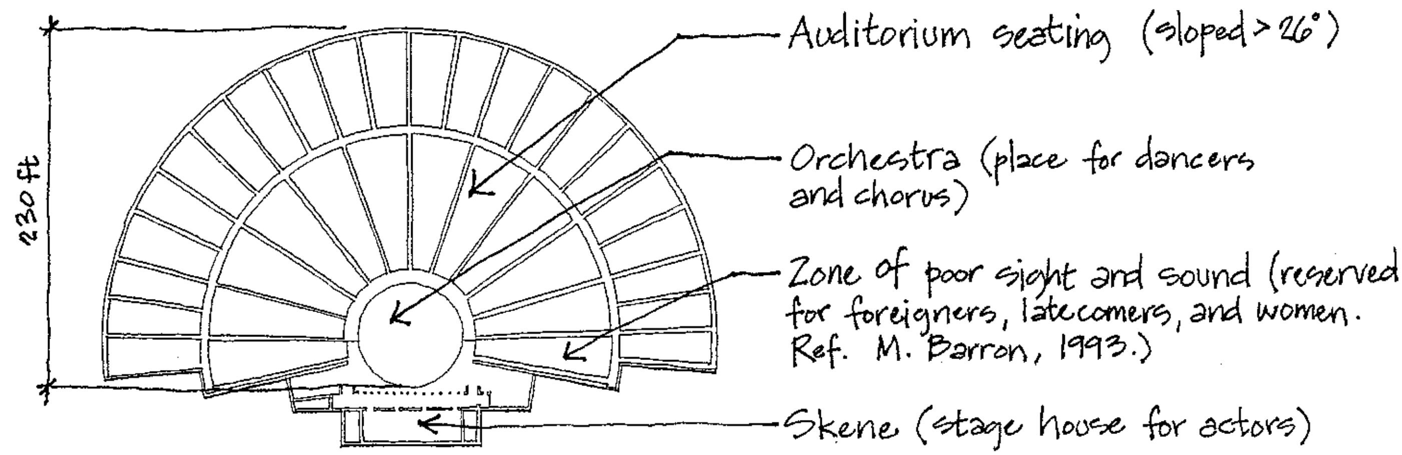
3. By ray-diagram analysis, show how sound is distributed by reflections off ceiling surfaces above and in front of platform. Show recommended improvements.

4. Show initial time-delay gap (ITDG) in ft (and msec) by rays off side walls and ceiling. ITDG can be found by subtracting the direct sound path from the reflected sound path to a listening position near the center line, half-way between the source position on platform and rear wall.

5. To reinforce speech, loudspeakers are to be positioned above the platform. On plan and section drawings, show preferred location for loudspeakers and best location for sound system controls.

6. Suggest preferred layout of reflecting and diffusing panels to support chamber music performances. [Refer to R. S. Shankland, "Acoustical Designing for Performers," Journal of the Acoustical Society of America, January 1979 and A. H. Marshall et al, "Acoustical Conditions Preferred for Ensemble," Journal of the Acoustical Society of America, November 1978.]

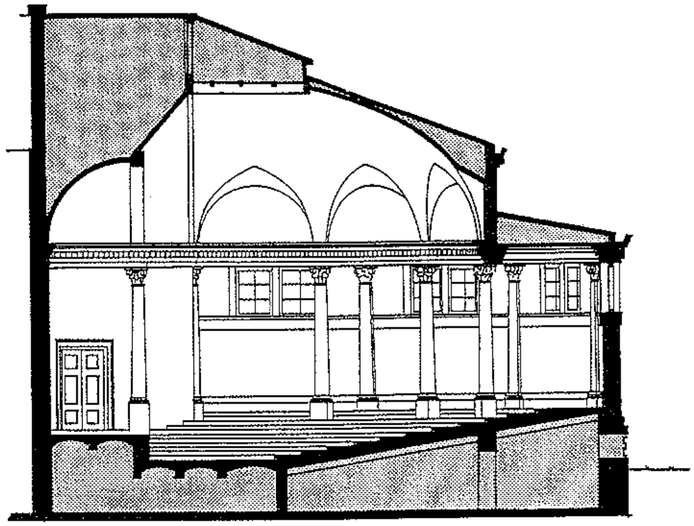
Note to Instructor: Prior to assigning this problem, you may wish to read about the role of this historic lecture hall in the advancement of the science of architectural acoustics. See Chap. 11 in P. L. Galison and E. A. Thompson, *The Architecture of Science*, The MIT Press, Cambridge, MA, 1999. For a review of acoustical problems in modern classrooms, see pages 82 to 86 in R. E. Apfel, *Deaf Architects & Blind Acousticians?*, Apple Enterprises Press, New Haven, CT, 1998.



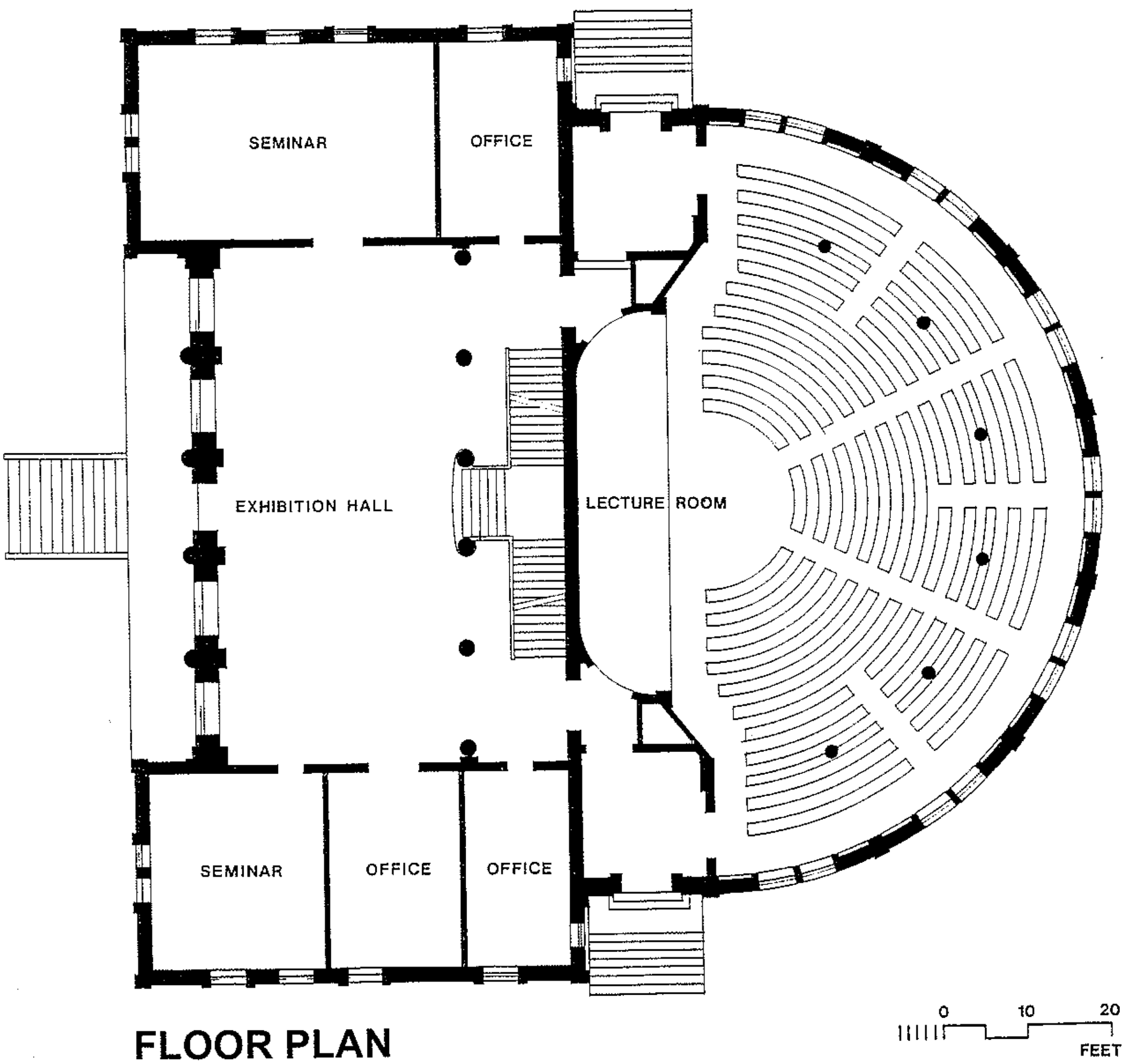
Classical Greek Theatre, Epidaurus (350 BC)

"In order that hearing may be good in any auditorium, it is necessary that the sound should be sufficiently loud; that the simultaneous components of a complex sound should maintain their proper relative intensities; and that the successive sounds in rapidly moving articulation, either of speech or music, should be clear and distinct, free from each other and from extraneous noises."

Wallace Clement Sabine, 1898



SECTION



FLOOR PLAN

CALCULATION SHEET

REVERBERATION TIME

PROJECT		ROOM
SEATING CAPACITY	ROOM VOLUME ft^3	RECOMMENDED REVERBERATION TIME AT 500 Hz sec

ROOM SURFACE	S (ft^2)	125 Hz		250 Hz		500 Hz		1000 Hz		2000 Hz		4000 Hz	
		α	a (ft^2)	α	a (ft^2)	α	a (ft^2)	α	a (ft^2)	α	a (ft^2)	α	a (ft^2)
TOTALS													

CALCULATIONS

CINEMA/LECTURE HALL DESIGN

Students are to evaluate the room acoustics and sound isolation of the 270-seat auditorium described by the following plan and section drawings. Determine all physical dimensions based on proportions to the given dimensions. The report should present information in a clear, understandable format.

Acoustical Objectives

Suggest improvements needed to achieve satisfactory listening conditions for the following functions.

- films
- lectures
- panel discussions
- instrumental recitals

Problems

The following elements of design make it extremely difficult to use the auditorium.

1. Excessive noise from regularly scheduled social events in nearby atrium intrudes through pivoting doors at balcony level. [If pivoting doors can be effectively gasketed, show details of your solution.]

2. Noise buildup in lobby to auditorium is excessive. It also intrudes through doors. [Show details to reduce noise.]

3. Unamplified speech from stage platform is not intelligible throughout seating areas.

4. Existing electronic sound system does not evenly distribute sound to audience.

Report Elements

The following are important acoustical parameters that should be part of your report.

1. Compute cubic volume (ft^3). Show all subdivided volumes used to find total cubic volume. Compute volume-to-seating ratio (ft^3 per person).

2. Analyze reverberation time conditions.

   a. Find reverberation time (sec) at 125, 500, and 4000 Hz for empty and fully-occupied conditions. Show results on graph of reverberation time (sec) versus frequency (Hz). Comment and show on sketches any improvements you recommend.

b. Finishes in auditorium are: walls and ceiling- plaster board (#9) and glazing (#5); stage floor- wood (#18); and floor and bench seating- covered with indoor-outdoor carpet (#36). Use sound absorption data from pages 52 and 53 in *Architectural Acoustics*.

c. Compute bass ratio (divide reverberation at 125 Hz by mid-frequency reverberation at 500 Hz).

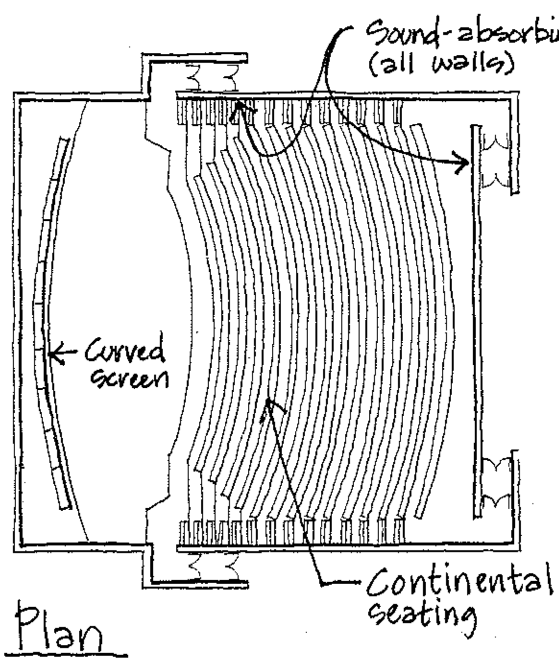
3. By ray-diagram analysis, show if sound is distributed to seating areas by reflections off surfaces above stage. Show recommended improvements.

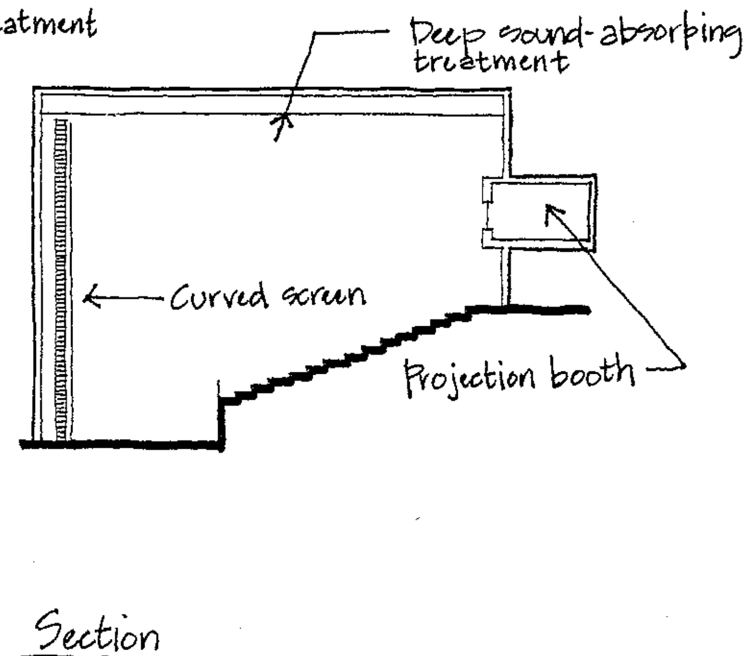
4. Electronic speech-reinforcing system loudspeakers are located in face of stage apron. Show location for preferred system cluster and best location for control console.

5. Rear wall has two 36 ft^2 areas of fixed 1/8 in thick float glass. Show how to correct this serious sound leak.

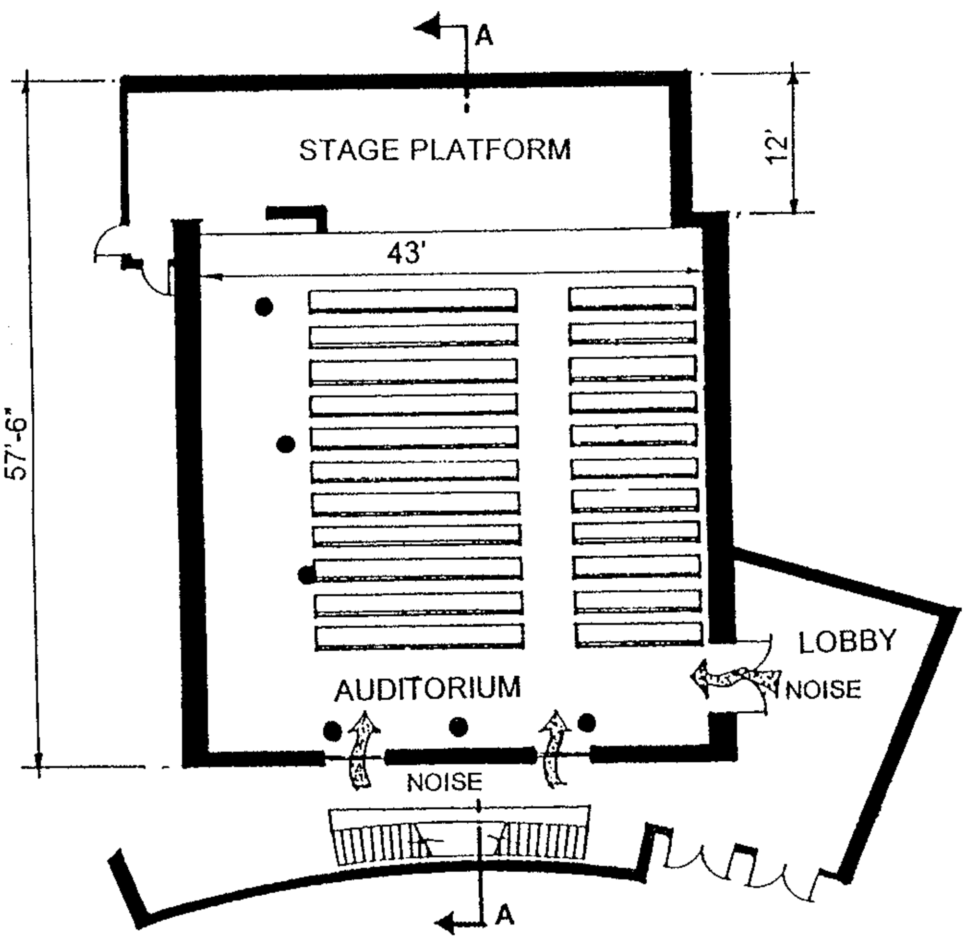
6. Wall at lower level of entrance lobby has loudspeaker mounted in it. Enclosure box penetrates gypsum board layer on opposite side from lobby. Show how to surface mount or enclose this 2 ft X 1 ft X 6 in deep loudspeaker so it will not disturb activities in auditorium.

Note to Instructor: For acoustical criteria for the modern cinema, see latest edition of T. Holman, *THX Sound System Program Instruction Manual Architect's and Engineer's Edition*, Lucasfilm Ltd., Nicasio, CA. (Order from: Lucasfilm Ltd., P.O. Box 2009, San Rafael, CA 94912-2009.) For a quick review of important design elements affecting speech intelligibility in lecture halls, see page 88 in *Architectural Acoustics*.

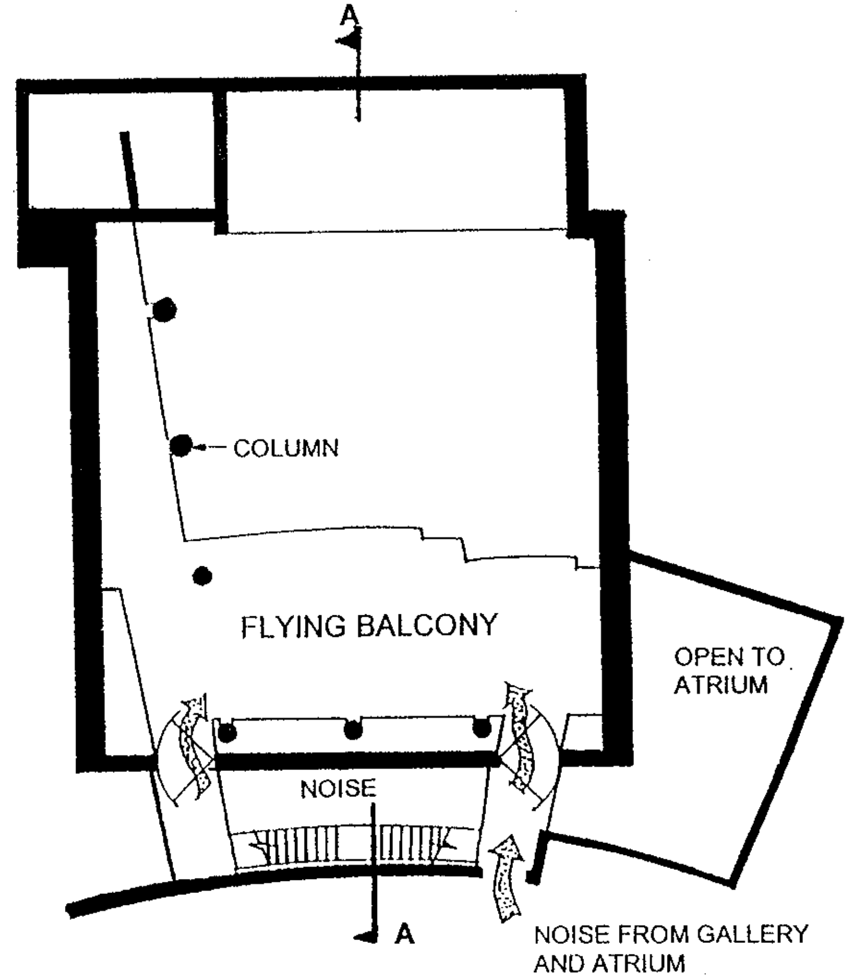




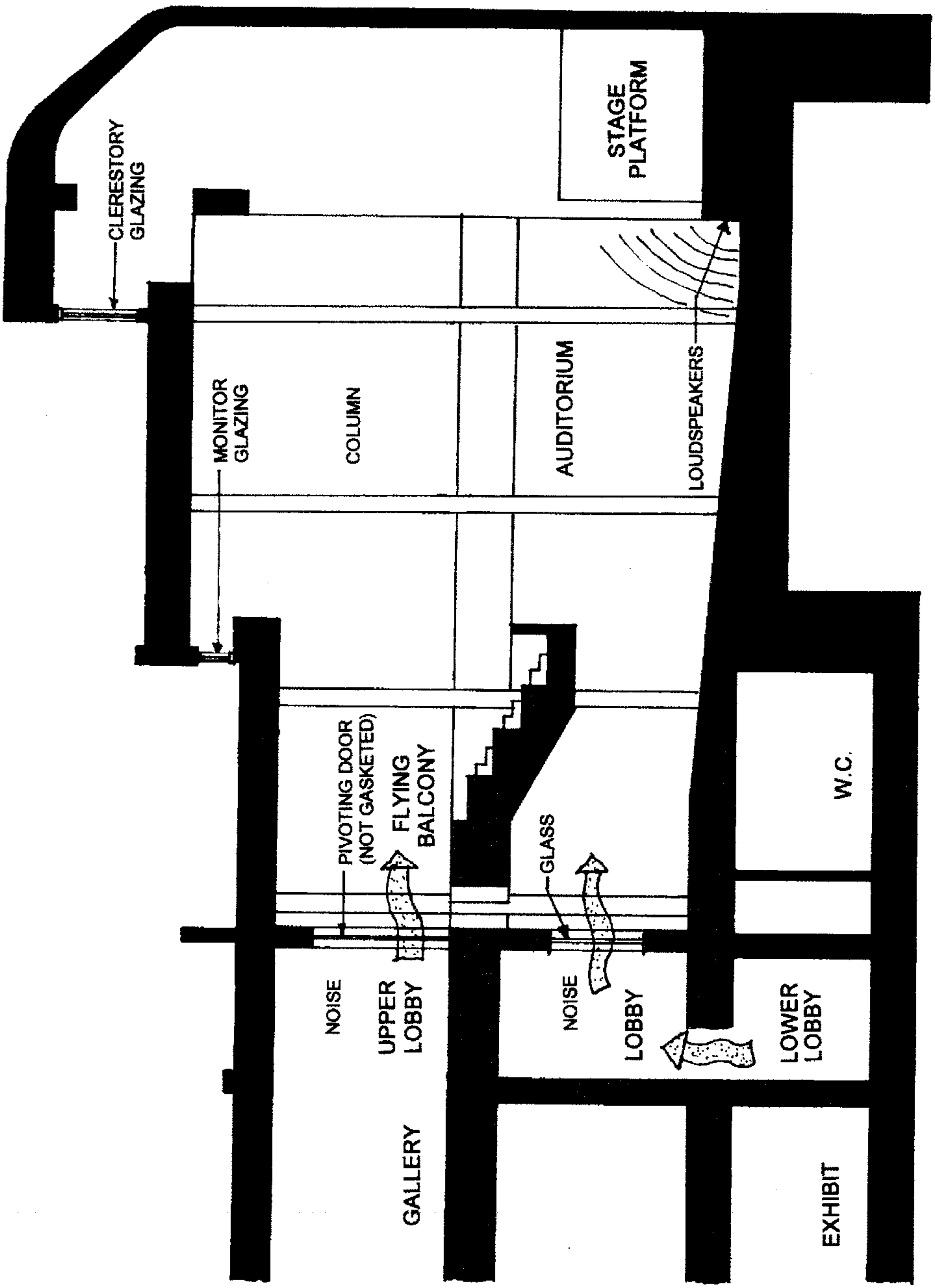
Example Cinema (> 300 seats)



MAIN FLOOR PLAN
(200 Capacity, Bench Seating)



BALCONY PLAN
(70 Capacity, Bench Seating)


STAGE PLATFORM
CLERESTORY GLAZING
MONITOR GLAZING
COLUMN
AUDITORIUM
LOUDSPEAKERS
W.C.
PIVOTING DOOR (NOT GASKETED)
FLYING BALCONY
GLASS
NOISE
UPPER LOBBY
NOISE
LOBBY
LOWER LOBBY
GALLERY
EXHIBIT

SECTION A-A

CALCULATION SHEET

REVERBERATION TIME

PROJECT		ROOM
SEATING CAPACITY	ROOM VOLUME ft^3	RECOMMENDED REVERBERATION TIME AT 500 Hz sec

ROOM SURFACE	S (ft^2)	125 Hz		250 Hz		500 Hz		1000 Hz		2000 Hz		4000 Hz	
		α	a (ft^2)	α	a (ft^2)	α	a (ft^2)	α	a (ft^2)	α	a (ft^2)	α	a (ft^2)
TOTALS													

CALCULATIONS

CIVIC AUDITORIUM DESIGN

Students are to evaluate the room acoustics and sound isolation of the 2,500-seat multi-purpose auditorium described by the following plan and section drawings. Determine all physical dimensions based on proportions to the given dimensions. The report should present information in a clear, understandable format.

Acoustical Objectives

Suggest improvements needed to achieve satisfactory listening conditions for the following functions.

- drama events on stage
- orchestral and music recitals by small groups and soloists
- lectures, speeches, and panel discussions
- trade and professional organization convention activities on main floor (with seating removed)
- dancing for school graduation and military balls on main floor (with seating removed)

Problems

The primary uses of the auditorium are speech, music, and convention activities. The following are aspects of the original auditorium design that cause serious acoustics problems. Consideration is being given to demolishing the building if the acoustics are not improved.

1. Loud noise intrusion from dining rooms, kitchen, and mechanical equipment room located underneath auditorium. [Specify details for improvement.]

2. Noise buildup in lobby and corridors surrounding auditorium is excessive and intrudes through entry doors. [Show details to correct this problem.]

3. Strong echoes off concave ceiling and concave face of balcony.

Report Elements

The following are important acoustical parameters that should be part of your report.

1. Compute cubic volume (ft^3). Show all subdivided volumes used to find total cubic volume. Compute volume-to-seating ratio (ft^3 per person).

2. Analyze reverberation time conditions.

   a. Find reverberation time (sec) at 125, 500, and 4000 Hz for empty and fully-occupied conditions. Show results on graph of reverberation time (sec) versus frequency (Hz). Comment and show on sketches any improvements you recommend.

b. Finishes in the auditorium are: domed ceiling- plaster on lath (#13); walls- plastered concrete block (#12) and single glass (#5); stage floor- wood (#18); auditorium main and balcony floor- carpet (#33) and seating (see table below). Use sound absorption data from pages 52 and 53 in *Architectural Acoustics*. Cite reference if other sources for sound absorption coefficients are used.

Seating Absorption (sabins per seat)

	125 Hz	**500 Hz**	**4000 Hz**
Occupied	3.3	6.4	6.8
Unoccupied	0.7	2.3	1.3

c. Compute bass ratio (divide reverberation at 125 Hz by mid-frequency reverberation at 500 Hz). Comment on why longer reverberance at low frequencies may be desired for music. Remember bass ratios greater than 1.2 are usually judged to be excellent, below 0.9 to be poor.

3. By ray-diagram analysis, show how sound is distributed by reflections off ceiling surfaces above and in front of stage. Show recommended improvements. [Refer to L. L. Beranek, "Acoustics and the Concert Hall," Journal of the Acoustical Society of America, June 1975 and C. Jaffe, "Acoustics of Concert Halls," Architectural Record, March 1979.]

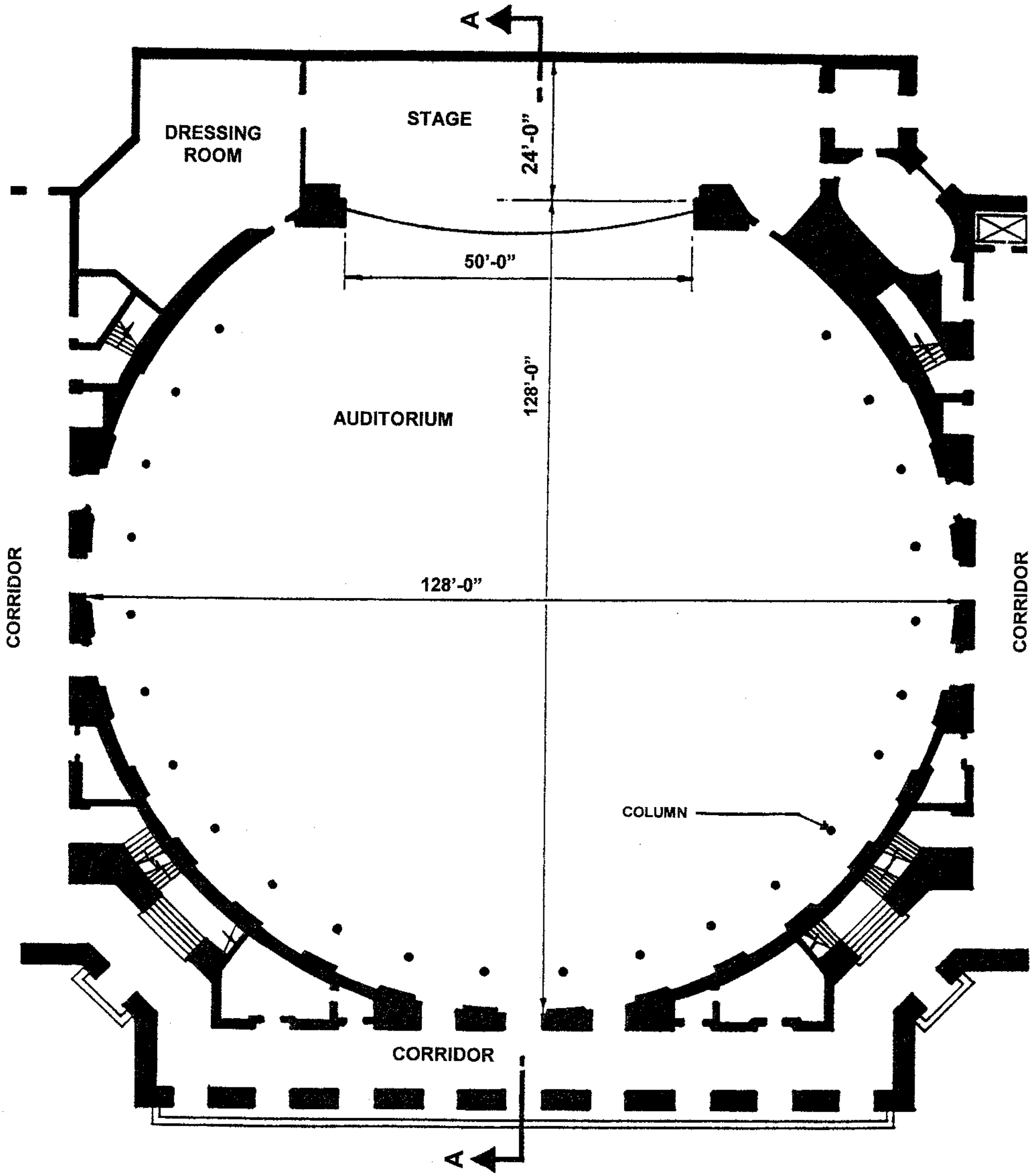
4. Show initial time-delay gap (ITDG) in ft (and msec) by rays off side walls. ITDG can be found by subtracting the direct sound path from the reflected sound path to a listening position near the center line, half-way between the source position on stage and rear wall.

5. Curved surfaces cause echoes and "hot spots." Identify problem areas and show alternate construction details to correct serious acoustical defects.

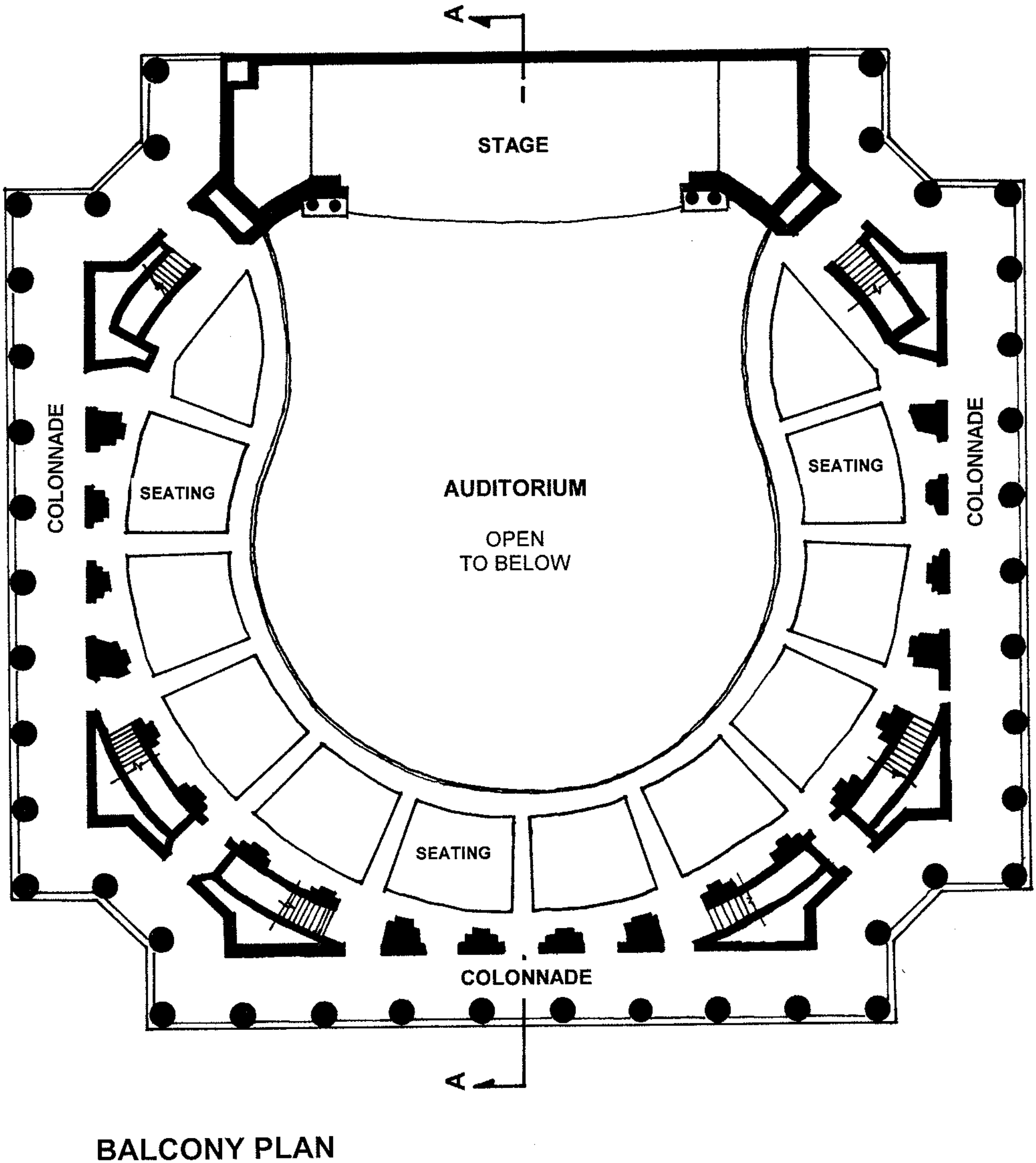
6. A new electronic sound system will have loudspeakers positioned above the stage apron. Show preferred location for loudspeaker cluster and best location for control console. Resolve the viewing requirement to maintain unobstructed line-of-sight to the historic mural on the proscenium wall.

7. Exterior walls of the building have several large areas of single glazing (roughly 30% of total wall surface area). Show how to correct these sound leaks. The masonry portion of exterior walls is rated STC-65.

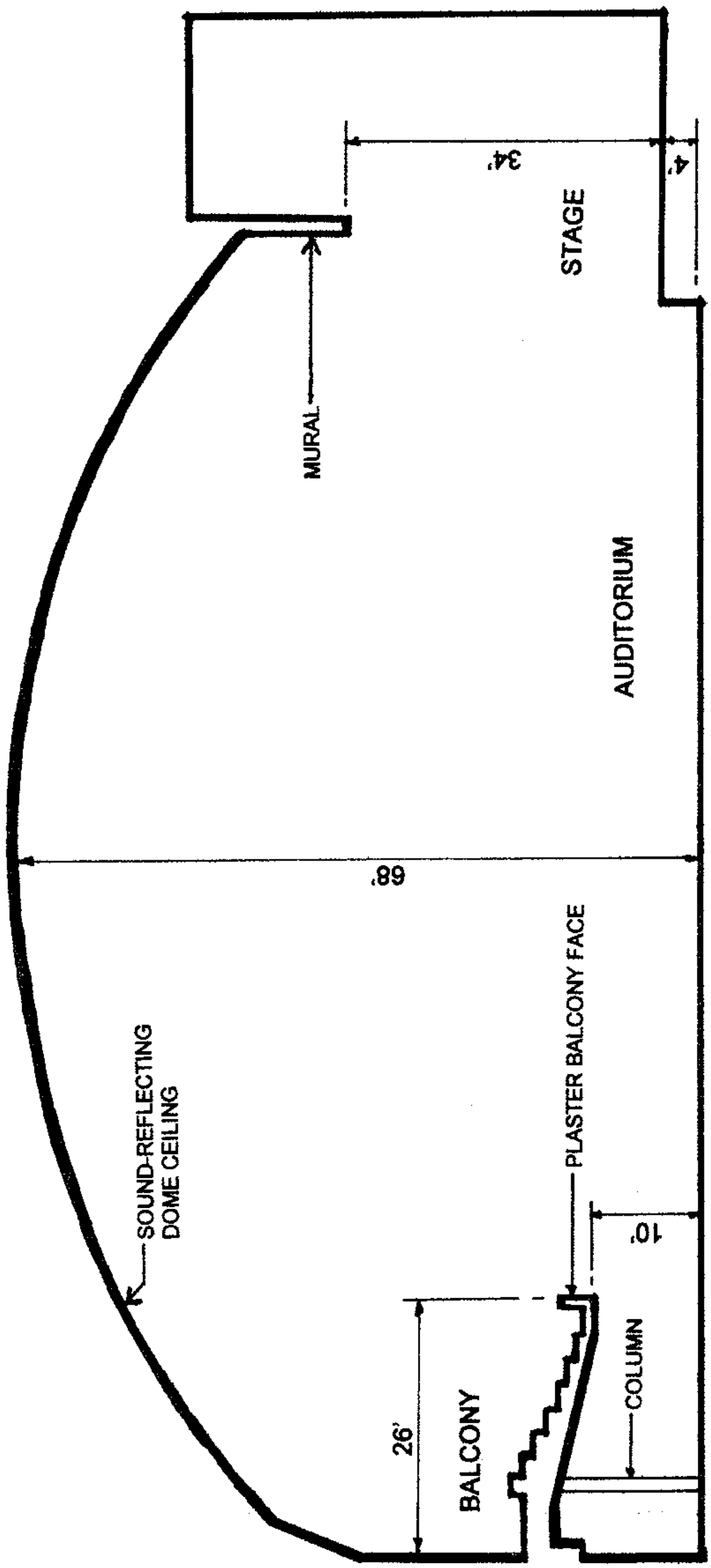
8. Suggest preferred layout of reflecting and diffusing panels to form an orchestra enclosure on stage. [Refer to R. S. Shankland, "Acoustical Designing for Performers," Journal of the Acoustical Society of America, January 1979 and A. H. Marshall et al, "Acoustical Conditions Preferred for Ensemble", Journal of the Acoustical Society of America, November 1978.]



MAIN FLOOR PLAN



BALCONY PLAN
(See Plan of Main Level for Dimensions)


SOUND-REFLECTING DOME CEILING
MURAL
STAGE
34'
4'
AUDITORIUM
68'
PLASTER BALCONY FACE
10'
26'
BALCONY
COLUMN

SECTION A-A

CALCULATION SHEET

REVERBERATION TIME

PROJECT		ROOM
SEATING CAPACITY	ROOM VOLUME ft^3	RECOMMENDED REVERBERATION TIME AT 500 Hz sec

ROOM SURFACE	S (ft^2)	125 Hz		250 Hz		500 Hz		1000 Hz		2000 Hz		4000 Hz	
		α	a (ft^2)	α	a (ft^2)	α	a (ft^2)	α	a (ft^2)	α	a (ft^2)	α	a (ft^2)
TOTALS													

CALCULATIONS

WORSHIP SPACE DESIGN

Students are to design the ceiling for a worship space seating 400 persons. The pulpit platform is 3 ft above the floor. Evaluate the room acoustics after you have determined a preferred ceiling height. Determine all physical dimensions based on proportions to the given dimensions. The report should present information in a clear, understandable format.

Acoustical Objectives

Design and modify interior shapes and finishes to achieve proper listening conditions for the following activities.

- Speech (from pulpit platform)
- Singing (from choir and congregation)
- Small instrumental groups on platform
- Pipe organ

Report Elements

The following are important acoustical parameters that should be part of your report.

1. Compute cubic volume (ft^3). Show all subdivided volumes used to find total cubic volume. Compute volume-to-seating ratio (ft^3 per person).

2. Analyze reverberation time conditions.

   a. Find reverberation time (sec) at 125, 500, and 4000 Hz for empty and fully-occupied conditions. Show results on graph of reverberation time (sec) versus frequency (Hz). Comment and show on sketches any improvements you recommend.

   b. Proposed finishes are: ceiling and walls- 5/8" thick gypsum board (#8), aisles- carpeted (#33), and seated people (#55). Use sound absorption data from pages 52 and 53 in *Architectural Acoustics*. Cite references if other sources for sound absorption coefficients are used.

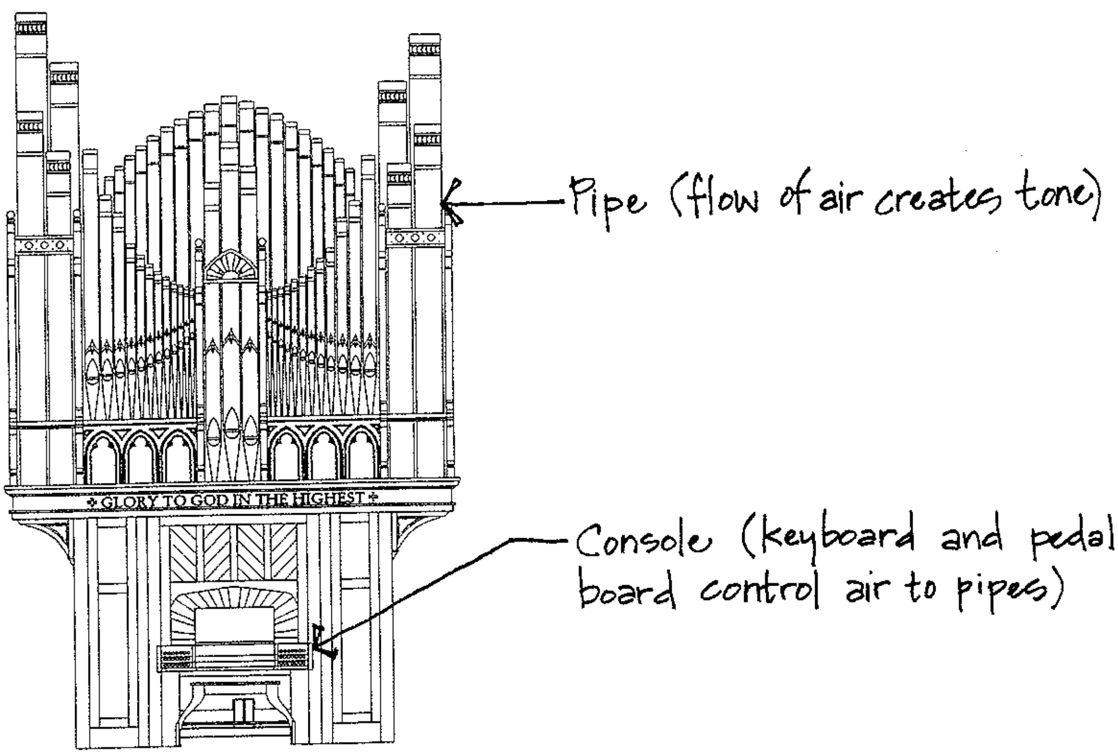
   c. Compute bass ratio (divide reverberation at 125 Hz by mid-frequency reverberation at 500 Hz). Comment on why longer reverberance at low frequencies may be desired for music. Remember bass ratios greater than 1.2 are usually judged to be excellent, below 0.9 to be poor.

3. By ray-diagram analysis, show how sound is distributed by reflections off ceiling surfaces and side walls. Show recommended improvements.

4. Show initial time-delay gap (ITDG) in ft (and msec) by rays off side walls and ceiling. ITDG can be found by subtracting the direct sound path from the reflected sound path to a listening position near the centerline, half way between the source position and the rear wall.

5. Suggest preferred layout of reflecting and diffusing surfaces to form an effective environment near choir. [Refer to R. S. Shankland, "Acoustical Designing for Performers," Journal of the Acoustical Society of America, January 1979 and A. H. Marshall et al, "Acoustical Conditions Preferred for Ensemble", Journal of the Acoustical Society of America, November 1978.]

Note to Instructor: For architectural drawings, photos, and acoustical data on over forty worship spaces, see D. Lubman and E. A. Wetherill, *Acoustics of Worship Spaces*, American Institute of Physics, New York, 1985. For a review of liturgical design principles, refer to M. Mauck, *Shaping a House for the Church*, Liturgy Training Publications, Chicago, IL, 1990.



Pipe Organ

ACOUSTICAL PROGRAMMING GUIDE FOR WORSHIP SPACES

The following questions are intended to help define goals for acoustical design of worship spaces. Comment in spaces provided or in margins. Building committee members also should cite existing worship spaces they believe meet their acoustical aspirations.

1. Will the main sanctuary also be used for secular activities? Yes No

2. Identify the preferred acoustical environment for music. [Circle preference.]

   Cathedral-like Reverberant Moderately-reverberant Dry

3. Is singing by worshipers a primary concern? Yes Somewhat No

4. Rank the following in order of importance [1 highest to 5 lowest].

   __________ Speech __________ Soloists

   __________ Organ __________ Instrumentalists

   __________ Choir __________

5. Choir size will be __________voices. Orchestra __________members.
   Rehearsal needs include:

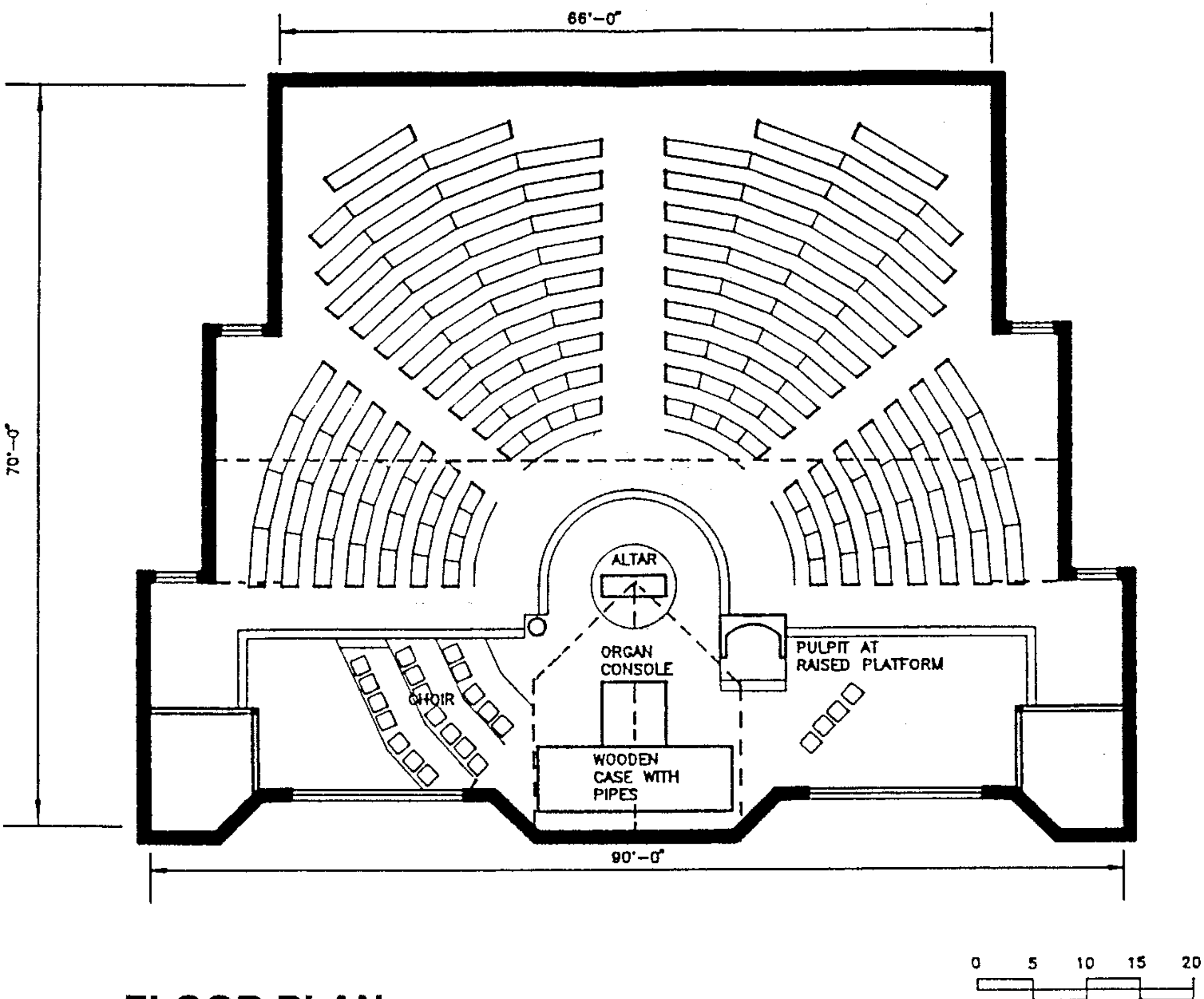
6. Secular activities (such as: guest orchestra, musical or theatrical productions, cinema) include:

7. Will the electronic sound system be required to support music? Yes No

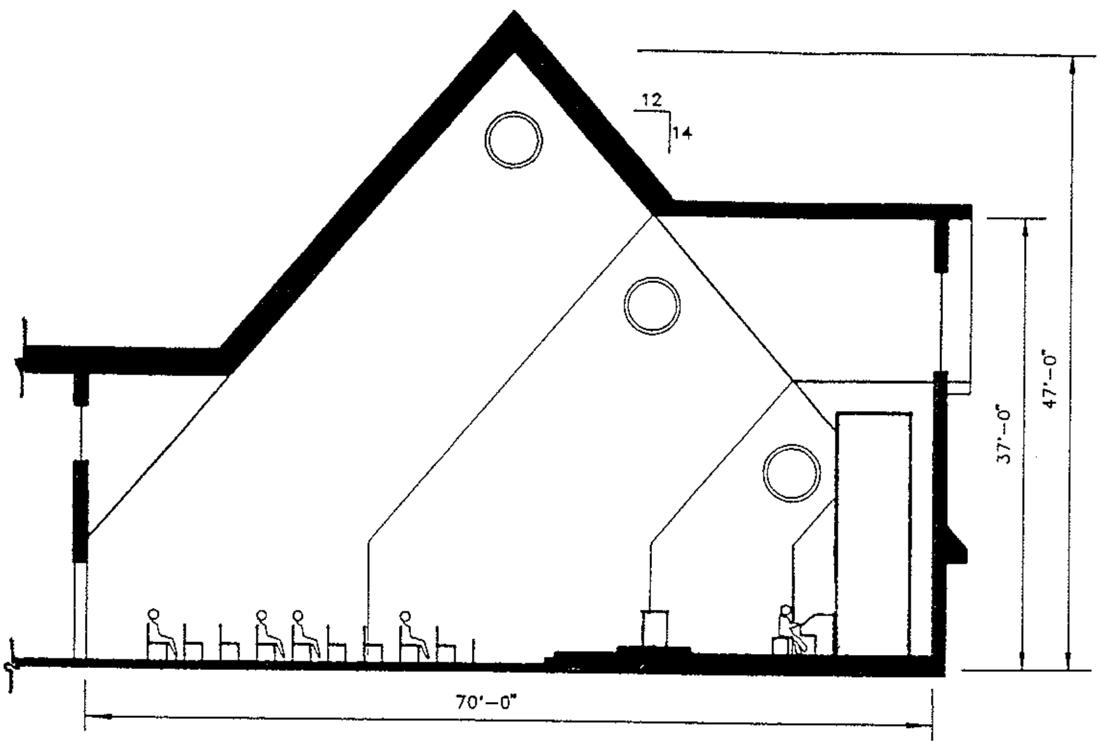
8. Recording and broadcast activities (such as: TV, radio, archival) include:

9. What are specific needs for hearing-impaired persons?

10. List video recording and playback needs.


66'-0"
70'-0"
ALTAR
ORGAN CONSOLE
PULPIT AT RAISED PLATFORM
CHOIR
WOODEN CASE WITH PIPES
90'-0"
0 5 10 15 20

FLOOR PLAN



BUILDING SECTION

CALCULATION SHEET

REVERBERATION TIME

PROJECT		ROOM
SEATING CAPACITY	ROOM VOLUME ft^3	RECOMMENDED REVERBERATION TIME AT 500 Hz sec

ROOM SURFACE	S (ft^2)	125 Hz		250 Hz		500 Hz		1000 Hz		2000 Hz		4000 Hz	
		α	a (ft^2)	α	a (ft^2)	α	a (ft^2)	α	a (ft^2)	α	a (ft^2)	α	a (ft^2)
TOTALS													

CALCULATIONS

CONCERT HALL DESIGNS

Students are to evaluate the room acoustics of two proposed designs to renovate a 2000-seat auditorium described by the following section drawings.

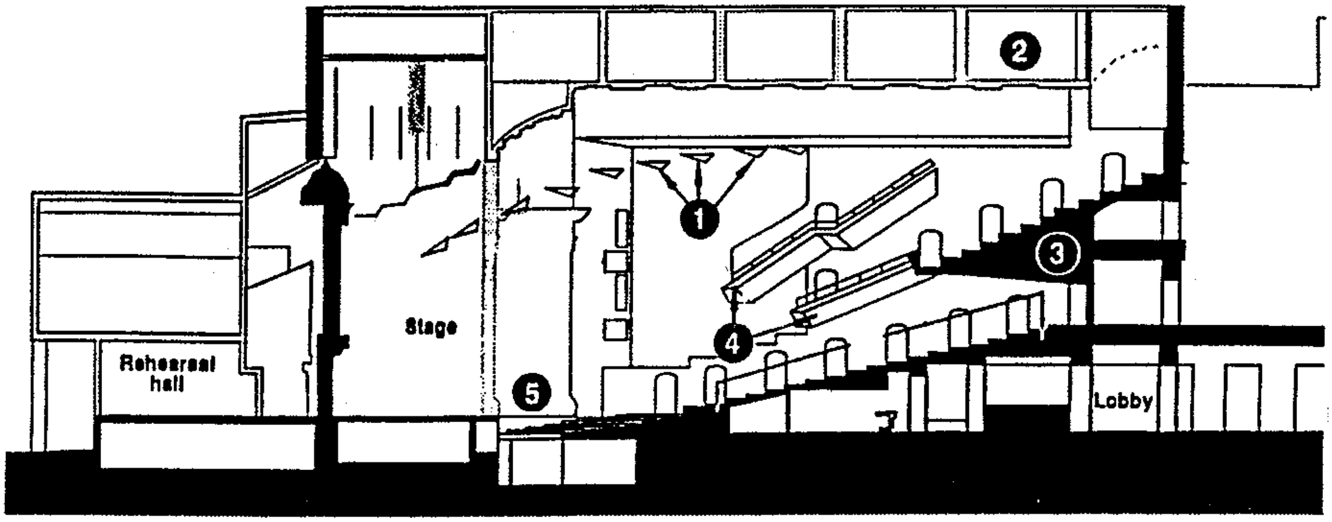
Report Elements

Complete the table below by listing your evaluation of the characteristics of the two designs. Important acoustical attributes are: reverberance, clarity, loudness, intimacy, diffusion, and stage environment (for support of musicians). The controlling architectural features to be compared are given in parentheses below.

Acoustical Attribute	Alternate A	Alternate B
Reverberance (cubic volumes)		
Clarity (widths of halls and ceiling canopy)		
Loudness (cubic volumes, compactness, finishes, and sight lines)		
Intimacy (how shapes connect stage to audience)		
Diffusion (extent of surfaces that scatter sound)		
Stage Environment (vertical and overhead panel configurations)		

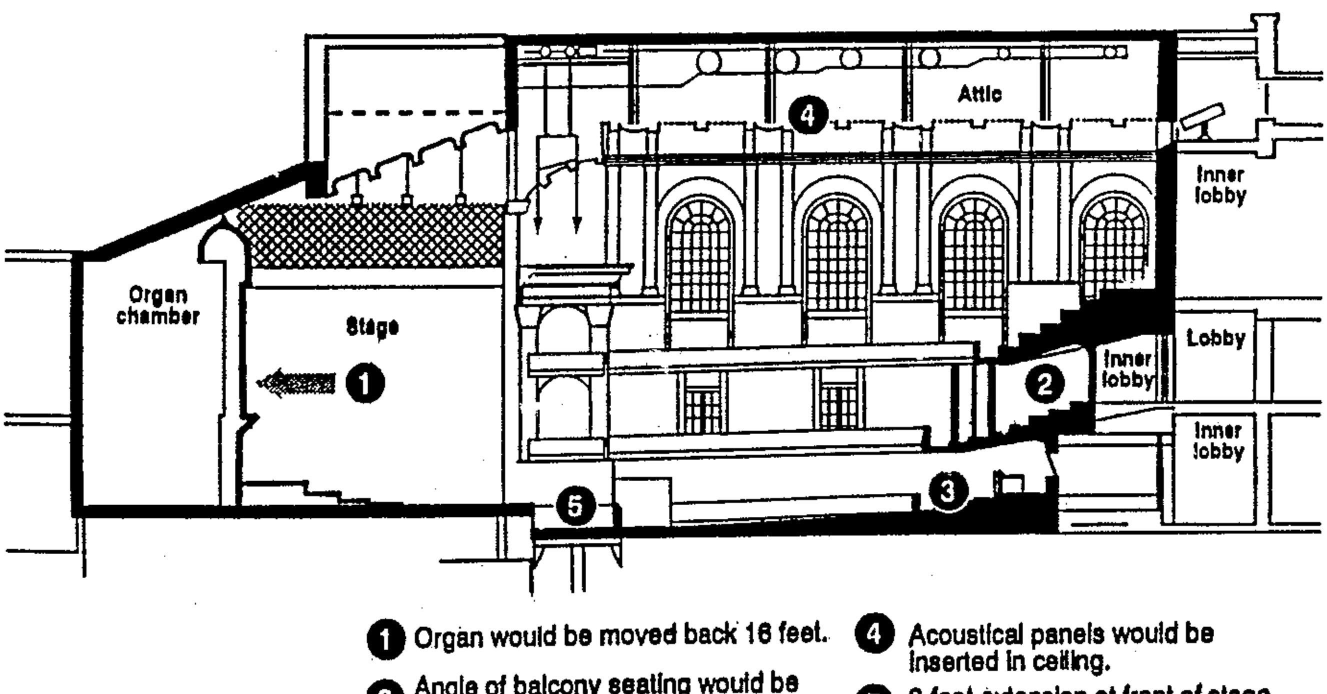
References

For tutorial on the four basic shapes for concert halls, see L. L. Beranek, "Concert Hall Acoustics," JASA, July 1992. For stage environments, see J. S. Bradley, "Some Effects of Orchestra Shells," JASA, August 1996. Refer also to page 151 in *Architectural Acoustics.*



1. Suspended acoustical panels to help project sound evenly.
2. Sound absorbent curtains, which would be lowered from ceiling and adjusted according to performance.
3. A single main balcony.
4. Secondary, "wing" balconies along sides with about 45 seats each.
5. Elevator at front of stage, to serve as orchestra pit in lowest position and stage extension in upper position.

Alternate A



1. Organ would be moved back 16 feet.
2. Angle of balcony seating would be increased to solve sightline problems.
3. Seating on back and sides of main floor would be raised.
4. Acoustical panels would be inserted in ceiling.
5. 6-foot extension at front of stage (added in 1967) would be removed. Orchestra pit would be constructed in front of stage.

Alternate B

[This page intentionally blank to
remind instructor to archive drawings
for student assignments.]

ETHICS IN ARCHITECTURE

The following excerpts are from J. P. Cramer, "Ethics: Bridge Over Troubled Waters," AIA Memo, June 1992. Cramer served as Executive VP/CEO of the American Institute of Architects (AIA).

Values Measure Success

There's a wonderful story about the gifted engineer Fazler Khan. In the 1950s, a highway scheme was proposed that would have carved Washington, DC, with concentric rings of beltways. An inner beltway was to dive under the Lincoln Memorial and come up for air at the Tidal Basin. Clearly something special was needed as an appropriate neighbor to the Jefferson and Lincoln memorials. So Khan was asked to design an elegant bridge.

Think of the recognition, the prestige, and the money! But when Khan looked at the site and then into himself, his response was: "Don't build it!"

Khan's greatest monument in our nation's capital is something he never designed nor was ever built. His courage, his integrity, his civic-mindedness. He lost the money, but he kept something that could never be taken away from him.

Achieving Excellence

Of course we should treasure those days when our accomplishments bring applause. But don't depend on them. The sound that will ring most true during both the high and low points will be your own inner voice saying, "I did my best!"

Note to Instructor: For advice on how to start an ethics course at a school of architecture, contact Clemson University, Iowa State University, or California State Polytechnic University at Pomona.

"Any system of education which does not inculcate moral values simply furnishes the intellectual equipment whereby men and women can better satisfy their pride, greed, and lust."

H. G. Rickover, 1974

RECOGNIZING RATIONALIZATIONS

Scholars have identified dozens of fallacies of logic. In daily life, most go unnoticed and unchallenged. It helps, therefore, to learn to recognize the rationalizations people use when facing an ethical dilemma. Rationalizations often are clever and attractive, but always are specious attempts to justify behavior. Although they may have the ring of truth, on examination they are false. Listed below are example rationalizations from the language of the ethically challenged (*warning signals*). For basic readings in moral philosophy, see J. Rachels, *The Right Thing to Do*, McGraw-Hill, New York, 1989 and V. E. Frankl, *Man's Search for Meaning*, Beacon Press, Boston, 1992.

Example Rationalizations

- "Everybody else does it." (*ad populum*)
- "If we don't do it, someone else will."
- "That's the way it's always been done."
- "We'll wait until the lawyers tell us it's wrong." (*ad vericordium*)
- "We made a good faith effort."
- "The system is so unfair." (*ad misericordium*)
- "It doesn't really hurt anyone."
- "We were not as smart as we should have been."
- "There was never any intent to mislead."
- "That's the way I feel about it."
- "We were just following orders."
- "We're only human."

Note to Instructor: Ask students to add to above list of rationalizations and to match rationalization to fallacy such as: *ad populum, ad vericordium, ad misericordium,* slippery slope, *petitio principii* (begging the question), and false analogy. For an overview of principles of reasoning and critical thinking, refer to D. C. Wilson, *A Guide to Good Reasoning*, McGraw-Hill, New York, 1999.

Reference

M. M. Jennings, *Case Studies in Business Ethics*, West Publishing, St. Paul, MN, 1996. [Presents more than 150 case studies. Comprehensive *Instructor's Manual* available.]

RESOLVING ETHICAL DILEMMAS

In resolving ethical dilemmas, consider if you want to be part of any activity that would pass legal tests but would be offensive to fellow design professionals. The Professor Laura Nash Model presented below gives a format to use for resolving ethical dilemmas by: 1. defining the problem, 2. examining alternatives, and 3. resolving any constraints. Where principles of ethics are involved, be deaf to expedient alternatives. Doing the right thing may sometimes be hard, but knowing right from wrong in everyday practice is *not* that difficult.

Define Problem

- Have you accurately defined the problem?
- How would you define the problem if you stood on the other side of the fence?
- As a design professional, to whom and to what do you owe loyalty?

Examine Alternatives

- What is your intention in making this decision?
- Whom could your decision injure?
- Can you discuss your decision with the affected persons?
- Are you confident that your action will be valid over a long period of time?

Resolve Constraints

- Under what circumstances would you make exceptions to your position?
- Could you discuss your decision with your boss, colleagues, friends, and family?
- What is the symbolic potential of your action?
- Would you be willing to see your decision reported on the front page of the local paper?

For an ethics book written for the profession of architecture, see B. L. Wasserman, P. Sullivan, and G. S. Palermo, *Ethics and The Practice of Architecture*, John Wiley, New York, 2000. The book includes thirty case studies, most taken from actual experiences documented by Professor Wasserman for his grant from the AIA Education Committee.

ETHICS IN ACOUSTICAL DESIGN

After an exhaustive national search, a major US city hired architect-acoustical consultant design team *A* to renovate the civic auditorium. The auditorium, designed in 1912 by a prominent New York firm, had poor acoustics: uneven distribution of sound from stage to audience, hot spots and focusing of sound due to concave surfaces, lack of balance for orchestra music on stage, and like problems. The renovation design proposed by consultant *A* would correct the acoustical problems, but generated controversy because it would remove the balconies. Local historic preservationists hired acoustical consultant *B* to propose a design that would save the balconies. The city now had two conflicting designs with no compromise in sight. According to press reports, consultants *A* and *B* had been feuding in public for months. Because the Building Committee did not feel competent to judge the acoustical merits of the two designs, they hired consultant *C* to serve as independent technical advisor. Consultant *C* concluded that either proposal could be developed to provide excellent acoustics, but the number of seats with good sight lines and construction costs likely would greatly differ. For background on core ethics values of the architectural profession, refer to "Rules of Conduct" by the National Council of Architectural Registration Boards (NCARB) and "Code of Ethics and Professional Conduct" by the American Institute of Architects (AIA).

Discussion Questions

- Should consultant *B* have accepted this project from the preservationists knowing that consultant *A* had a contract with the city? What conflicts would be avoided if consultant *B* had initially agreed to not be a replacement for consultant *A*? [Does legality alone set the standard for ethical behavior?]

- Should consultant *B* have publicly questioned the professional qualifications of consultant *A*? Consultant *A* was an internationally renowned designer and author of books on auditorium design. [Should peers be treated as rational persons rather than as a means to advance self-interest?]

- What should consultant *C* have done when it was alleged that consultant *B* had made false and misleading technical statements to the Building Committee? Would false statements be justified if it were believed everyone else would do the same?

- Would knowingly making false and misleading statements violate provisions of AIA Rule of Conduct 4.103? [Should saying what you know is not true be a matter of personal preference?]

- After the contract with consultant *A* was terminated, should consultant *C* accept an offer to become the new acoustical consultant for the project? Would acceptance be ethical if consultant *C* believed that, if offer was declined, someone else would accept?

References

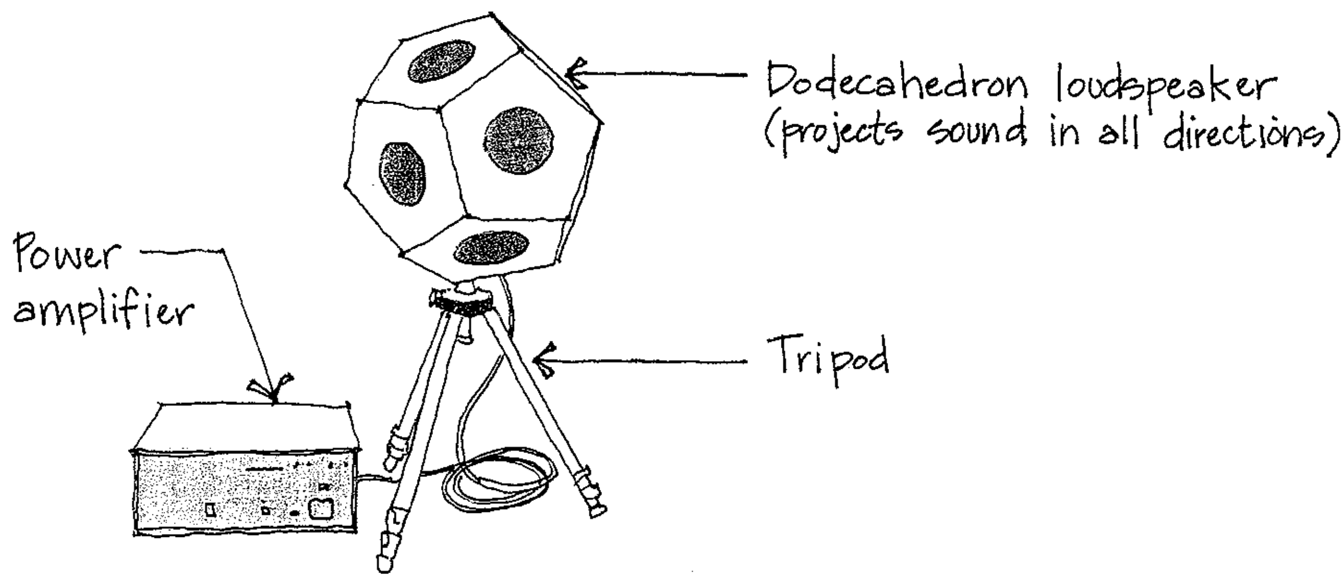
J. G. Brennan, *Foundations of Moral Obligations*, Presidio Press, Novato, CA, 1994.

J. Rachels, *The Elements of Moral Philosophy*, McGraw-Hill, New York, 1993. [Use the table on following page to compare theories and arguments presented by Rachels.]

MORAL THEORY	STRENGTHS	WEAKNESSES	BENEFITS	MODIFIED VERSIONS	CRITICAL REFERENCES
Cultural Relativism:					
Subjectivism:					
Divine Command Theory:					
Natural Law Theory:					
Psychological Egoism:					
Ethical Egoism:					
Utilitarianism:					
Kant's Categorical Imperative:					
Social Contract:					
Virtue Theory:					

HONESTY IN ACOUSTICAL RESEARCH

According to C. E. Harris et al in *Engineering Ethics*, Wadsworth Publishing, Belmont, CA, 1995, dishonesty in science and engineering can take several forms: trimming, cooking, forging, and plagiarism. To be honest in acoustical research means not to: *trim* (to smooth irregularities in measurements so data looks precise), *cook* (to retain data that fits and discard data that doesn't), *forge* (to invent data or report phantom experiments), and *plagiarize* (to use intellectual property of others without permission or credit). To avoid temptations or appearance of conflict of interest, the world-renowned acoustician Dr. A. Harold Marshall (University of Auckland, NZ) made sure acoustical data were measured by others in the concert halls he designed. For similar reasons, it is prudent to specify that acoustical performance of materials and building systems be certified by *independent laboratory* according to ASTM test methods such as C 423 for sound absorption coefficients and E 90 for airborne sound transmission losses.



Room Acoustics Testing Sound Source (ISO 140-3)

Note to Instructor: Principles and example case studies for modeling are covered by the following section. Use the acoustical design projects in this section as an additional source of drawings for optical modeling studies. Should students be reluctant to discuss ethical issues, such as the case study on feuding consultants, or cite the fog of "gray areas", recall the *Peanuts* cartoon by Charles Schulz where Lucy wonders aloud: "Are there more bad people in the world or are there more good people?" Charlie Brown responds with an expansive gesture: "Who is to say? Who is to say who is bad or who is good?" "I will!" says Lucy. For a discussion on why Lucy would be right to use moral reasoning, refer to pages 4 to 12 in S. Satris (ed), *Taking Sides*, Dushkin Publishing, Guilford, CT, 1996.

8.0 ACOUSTIC MODELS

OPTICAL MODELS FOR ACOUSTICS

Optical models can be used to design for good acoustics.[1] For example, models can be used during design development phase of projects to: identify focusing problems, locate surfaces which are echo-prone, and show patterns of useful reflected sound such as lateral sound from side walls in auditoriums.[2] There are numerous building types, particularly spaces for speech and music, which would benefit from optical model studies. Examples include: conference rooms, worship spaces, multi-purpose auditoriums, theaters, courtrooms, hotel function rooms, and atria.

Scale Ratio

Optical models are typically built at a scale of 1/4" = 1'-0", or larger (>1:48). Models of one-half the space studied can be used for symmetrical auditorium designs such as rectangular, fan, or reverse-trapezium shapes.

Model Materials

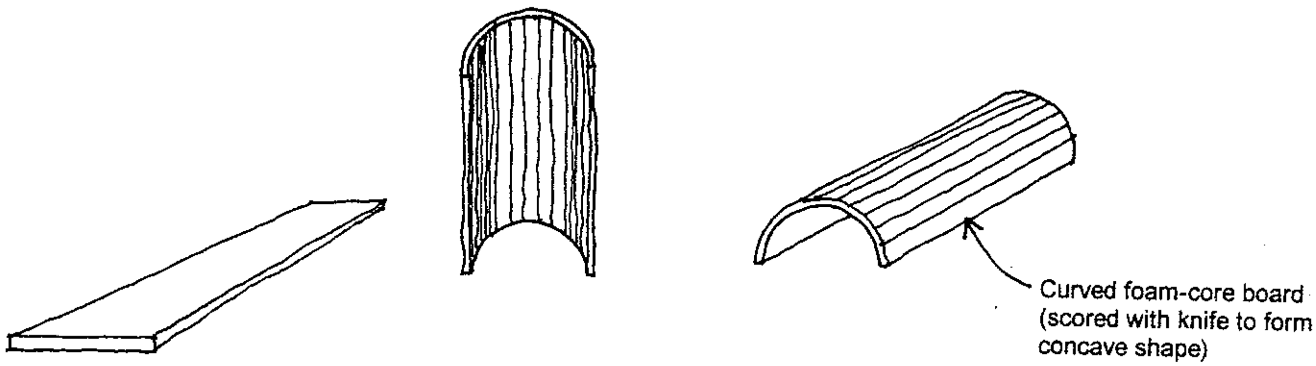
Basic materials needed to construct an optical model are listed below.[3,4]

Quantity (Minimum)	Item	Description
1 sheet	chipboard	neutral gray surface (easy to cut)
1 sheet	foam-core board	light-absorptive color
1 box	straight pins	steel (long)
1 bottle	white glue	*Elmer's* or equal
1 roll (or 2 sq ft)	aluminum foil or silver contact paper	specular silver finish (foil must be smooth, without bumps or ridges)
1 can	spray adhesive	*3M Super 77 Spray Adhesive* (spray only in well-ventilated areas or outdoors)
1 flashlight	adjustable, narrow beam	*Mini-Maglite* or equal

ATRIUM CASE STUDY

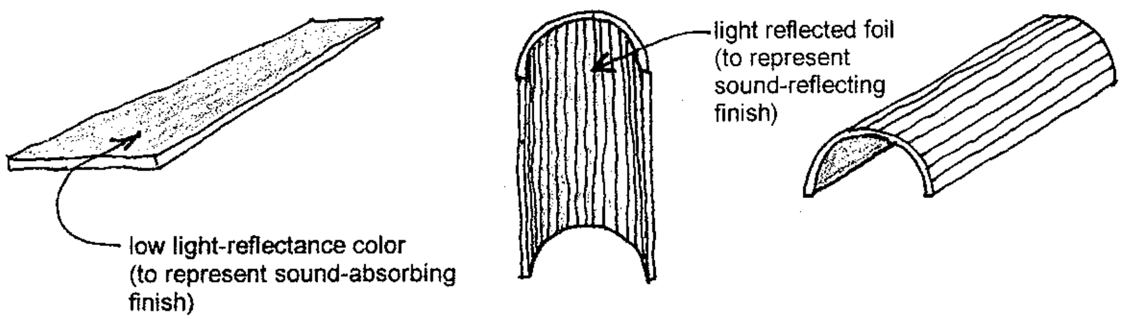
The design goal was to determine how to control the noise buildup and focusing in a linear atrium. The end walls are concave and the ceiling is vaulted. Functions in the atrium will include circulation, receptions, and lectures to small groups.

Step 1. Cut the floor, walls, and ceiling out of foam-core board. Do *not* use cardboard due to corrugated ridges on surface. Model surface must be smooth.



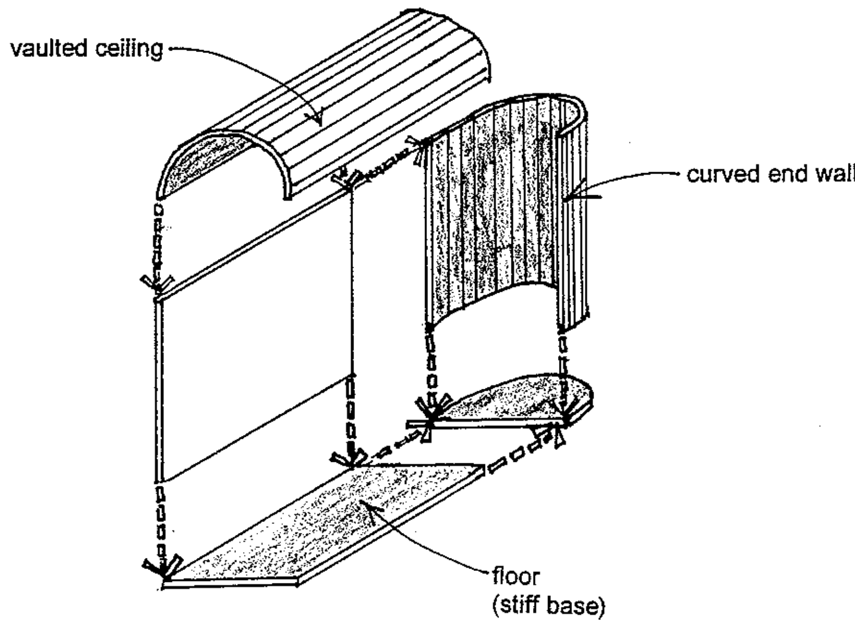
Floor **End Wall** **Ceiling**

Step 2. Apply dark-colored paper and reflective material to the appropriate surfaces. Use dark-colored paper to model sound-absorbing wall surfaces and aluminum foil to model sound-reflecting ceiling and end walls.



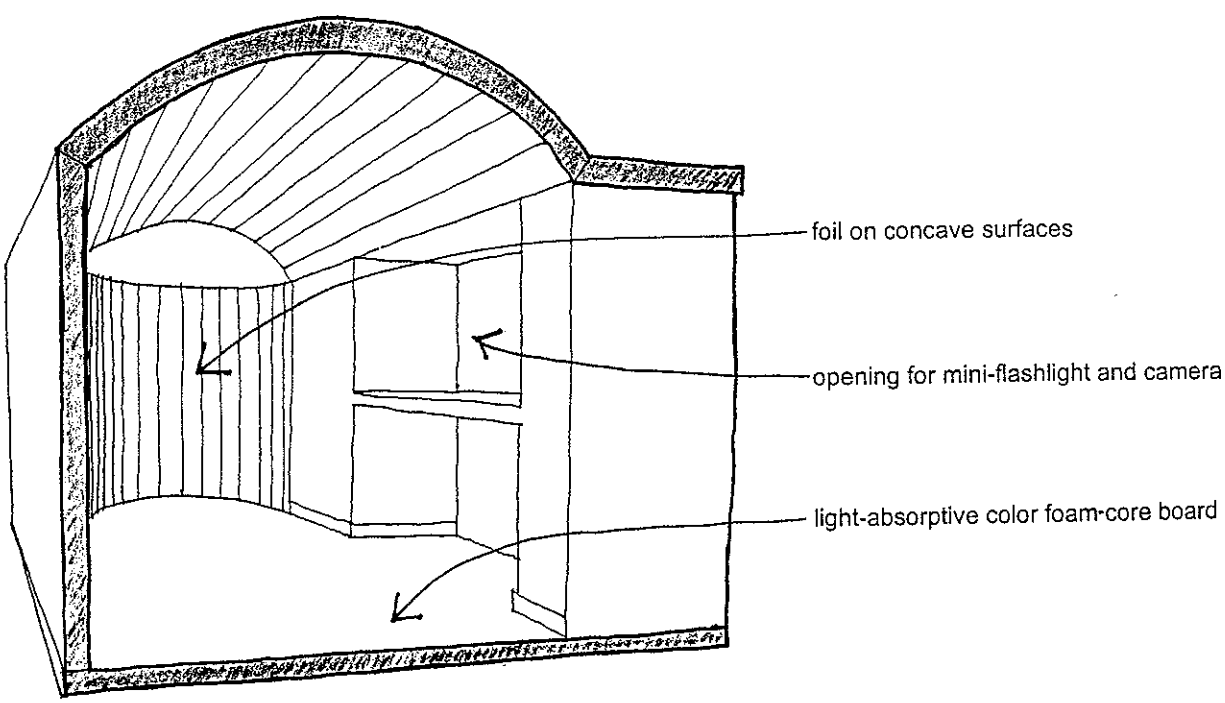
Floor **End Wall** **Ceiling**

Step 3. Assemble the model using white glue. Use straight pins where surfaces are to be removed to study alternative shapes or to photograph model.



Atrium Model

Step 4. Use mini-flashlight to experiment with light patterns to determine where sound is concentrated or spread. Photograph results from this study for further evaluation and documentation.

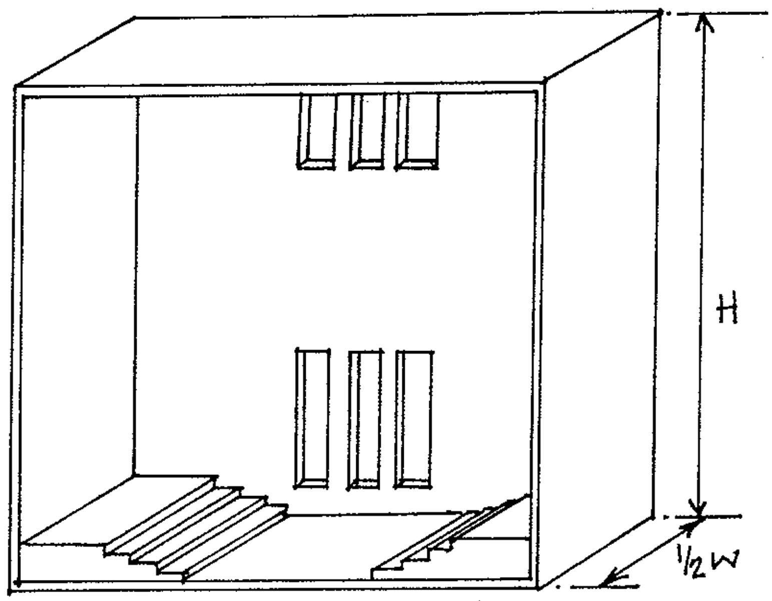


Perspective of Atrium Model

MUSIC REHEARSAL HALL CASE STUDY

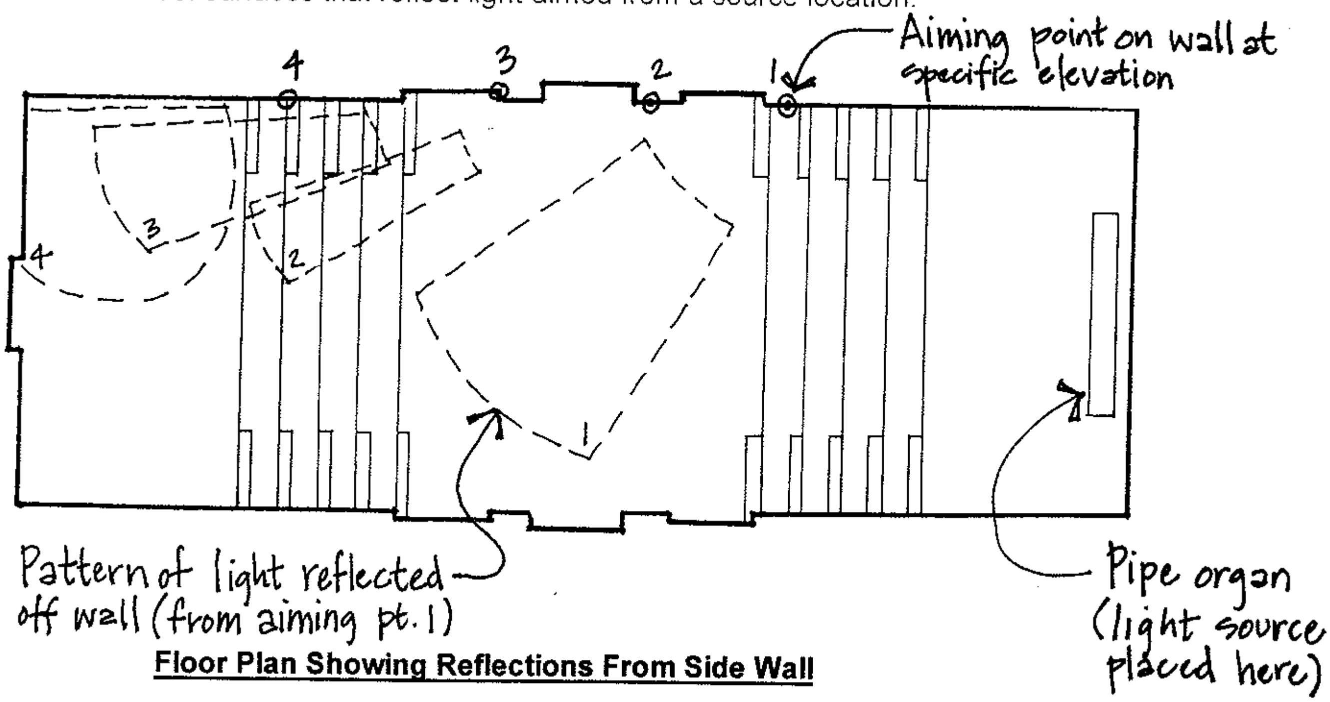
The design goal was to identify echo-prone surfaces and to shape sound-reflecting surfaces in a space for music rehearsal. The room has a large height-to-width (H / W) ratio.

Step 1. Construct the model. Cut a hole in floor so mini-flashlight will be at location of sound source.



Music Rehearsal Hall Model

Step 2. Record data on plan drawing. Use numbers and/or letters to identify points on model surfaces that reflect light aimed from a source location.



Floor Plan Showing Reflections From Side Wall

Summary

Optical models can be used to demonstrate principles of room acoustics. Because they can be constructed quickly and inexpensively, optical models complement more sophisticated tools such as computer ray tracing and costly frequency-scaled physical models.[5] For example, when models are used early in schematic and design development phases of projects, potential acoustical defects can be corrected. Because the light beam shows how sound reflects off surfaces, the design can be immediately altered if necessary. Surfaces also can be shaped to enhance good listening, such as optimizing lateral sound in spaces for music. Optical models can be a significant design aid to achieve good acoustics.

References

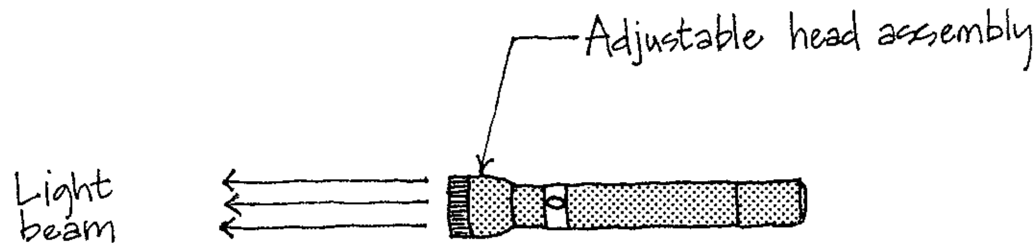
1. L. Cremer and H. A. Müller, *Principles and Applications of Room Acoustics*, Vol. 1, Applied Science Publishers, Barking, England, 1978, pp. 164-8.

2. M. D. Egan, *Architectural Acoustics*, McGraw-Hill, New York, 1988, pp. 105-7.

3. F. Moore, *Modelbuilder's Notebook*, McGraw-Hill, New York, 1990.

4. J. Taylor, *Model Building for Architects and Engineers*, McGraw-Hill, New York, 1971.

5. A. H. Marshall, "Recent Developments in Acoustical Design Process," Applied Acoustics Vol. 31, 1990, pp. 7-28.



Narrow-beam Light Source

ACOUSTICAL MODEL STUDIES

1. Students are to evaluate room acoustics of the spaces on the following pages. If necessary, reshape the walls and ceiling to improve listening conditions. Refer to the plan and section drawings for details and seating layouts. [*Note to Instructor:* Types of spaces listed below also are recommended, but do not limit optical model studies to them.]

Worship Space	Courtroom	Atrium
Cafetorium	Gymnasium	Music Rehearsal Room

2. Construct a study model of one-half of room to evaluate distribution of sound in existing space or preliminary design. Use a study model of the other half of the room to refine and demonstrate your improvements.

3. An acoustical study model should have the following elements.

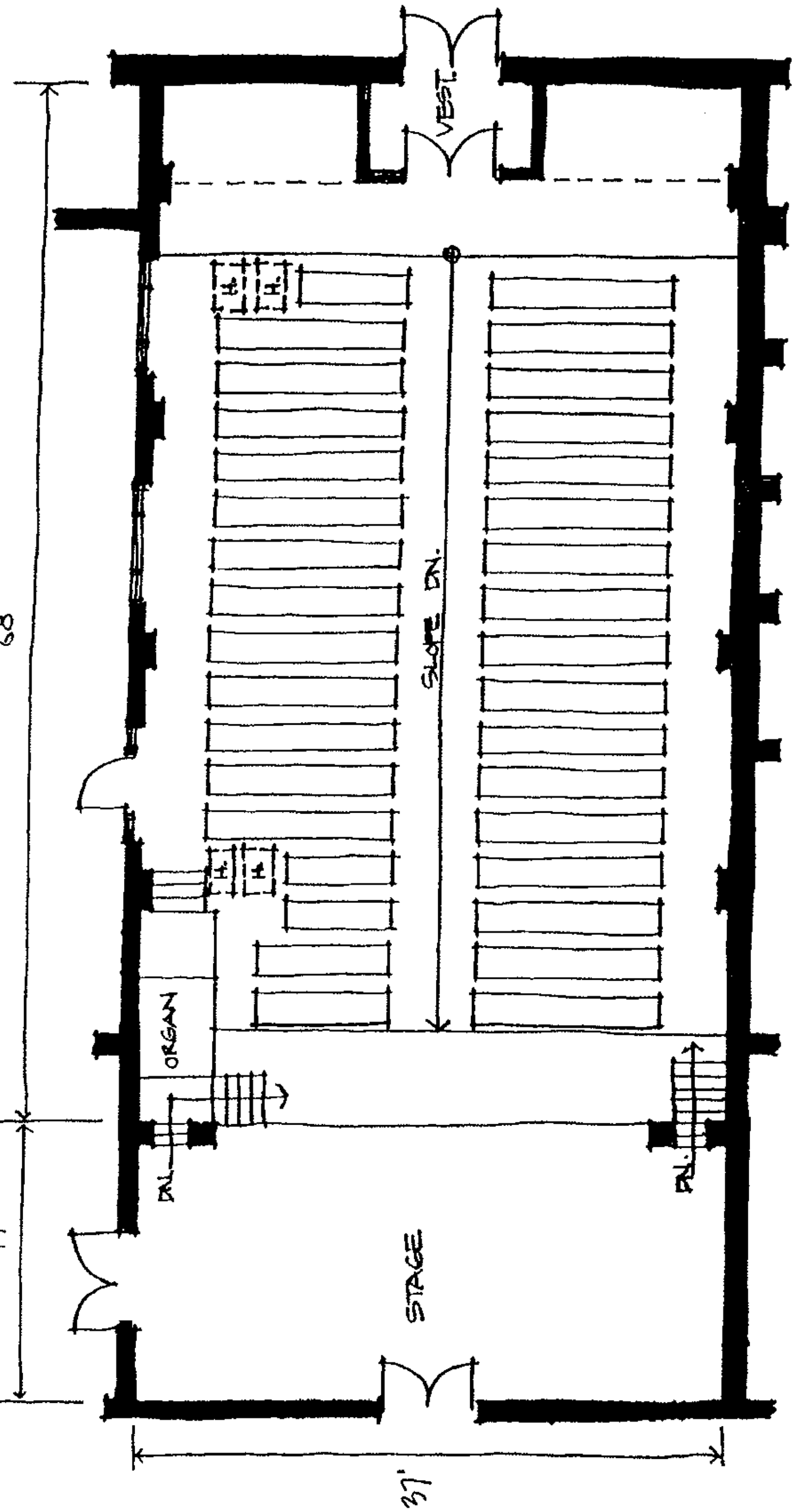
   - 1/4" scale (or larger).
   - To represent sound-reflecting surfaces, use light-reflective material such as shiny metallic contact paper or aluminum foil bonded to model board by spray adhesive. Make sure the material is applied smoothly without any bumps or ridges.
   - To represent sound-absorbing surfaces, use gray or dark brown paper.
   - On foam-core board, mark the area for the audience.
   - Use a narrow-beam flashlight or laser pointer to show pattern of reflected sound from walls and ceiling. Indicate distribution of light on seating areas by color code or other marking. Identify first reflections from aiming points on walls and ceiling.

4. The written report should describe how the model was constructed and indicate how it was used to redesign for better acoustics.

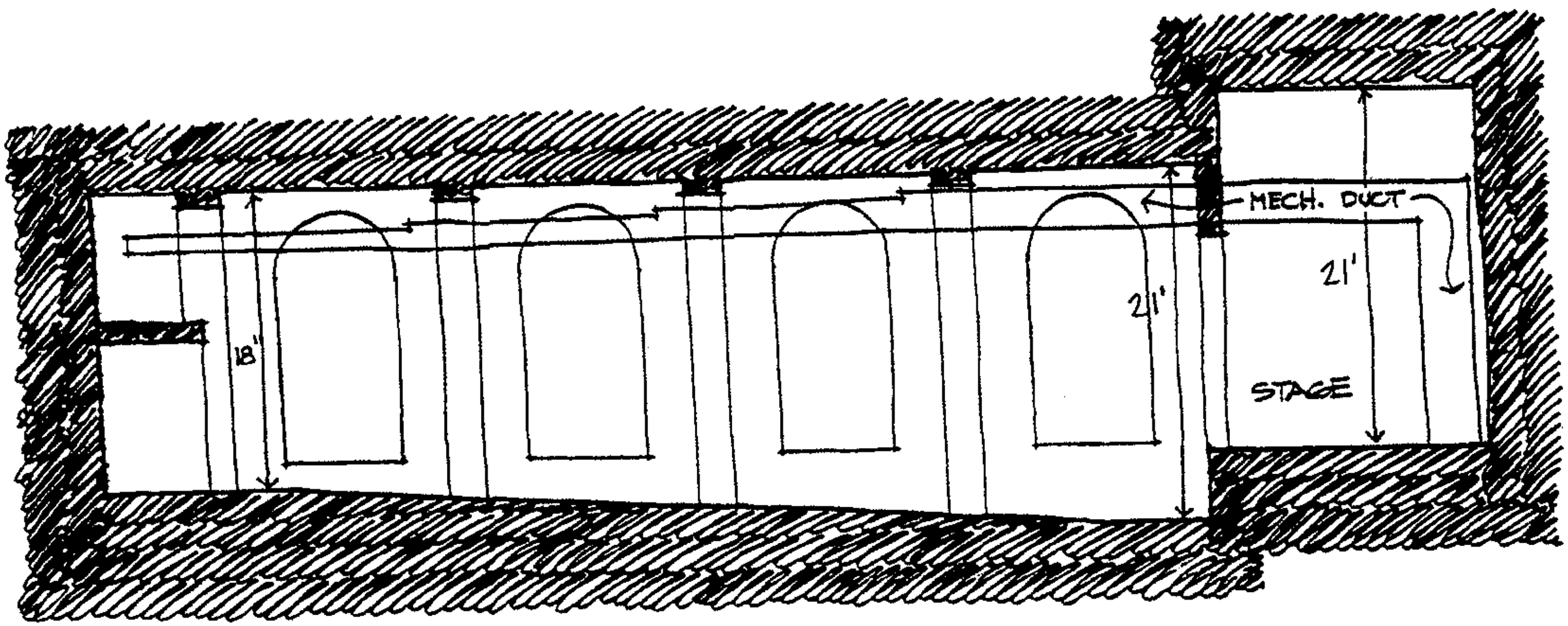
   - Include overlays of plan views showing patterns of reflected light before and after improvements.
   - Include conclusions and any recommendations for good room acoustics that you learned from this study.

5. A word about *craftsmanship....*
   Craftsmanship will affect the success of the model study. For example, be sure to achieve crisp edges, fully-bonded surfaces, and tight corners. The interior of the model must be carefully constructed, but the exterior will not affect the acoustics being studied.

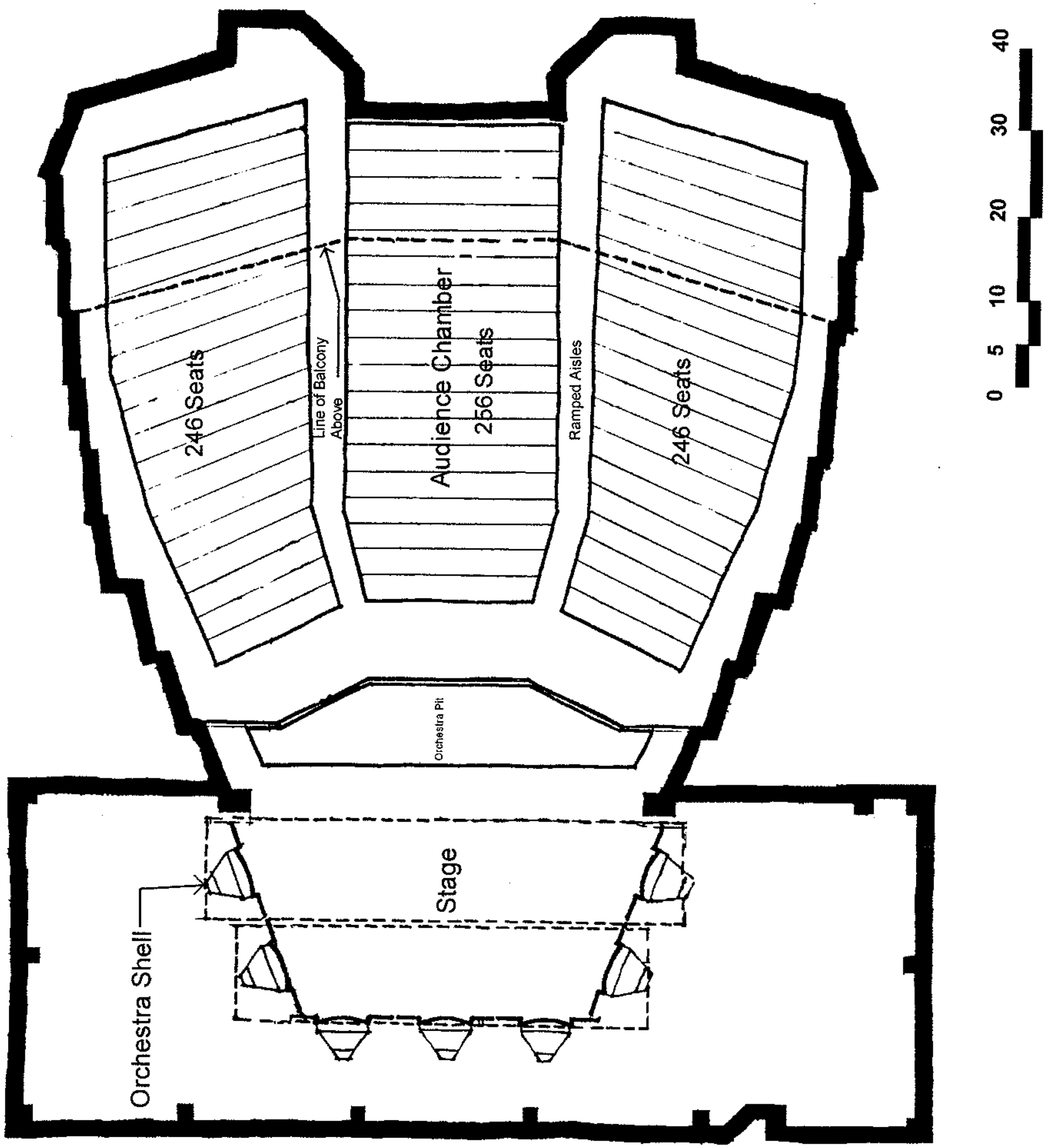
[This page intentionally blank to
remind instructor to archive drawings
for student assignments.]



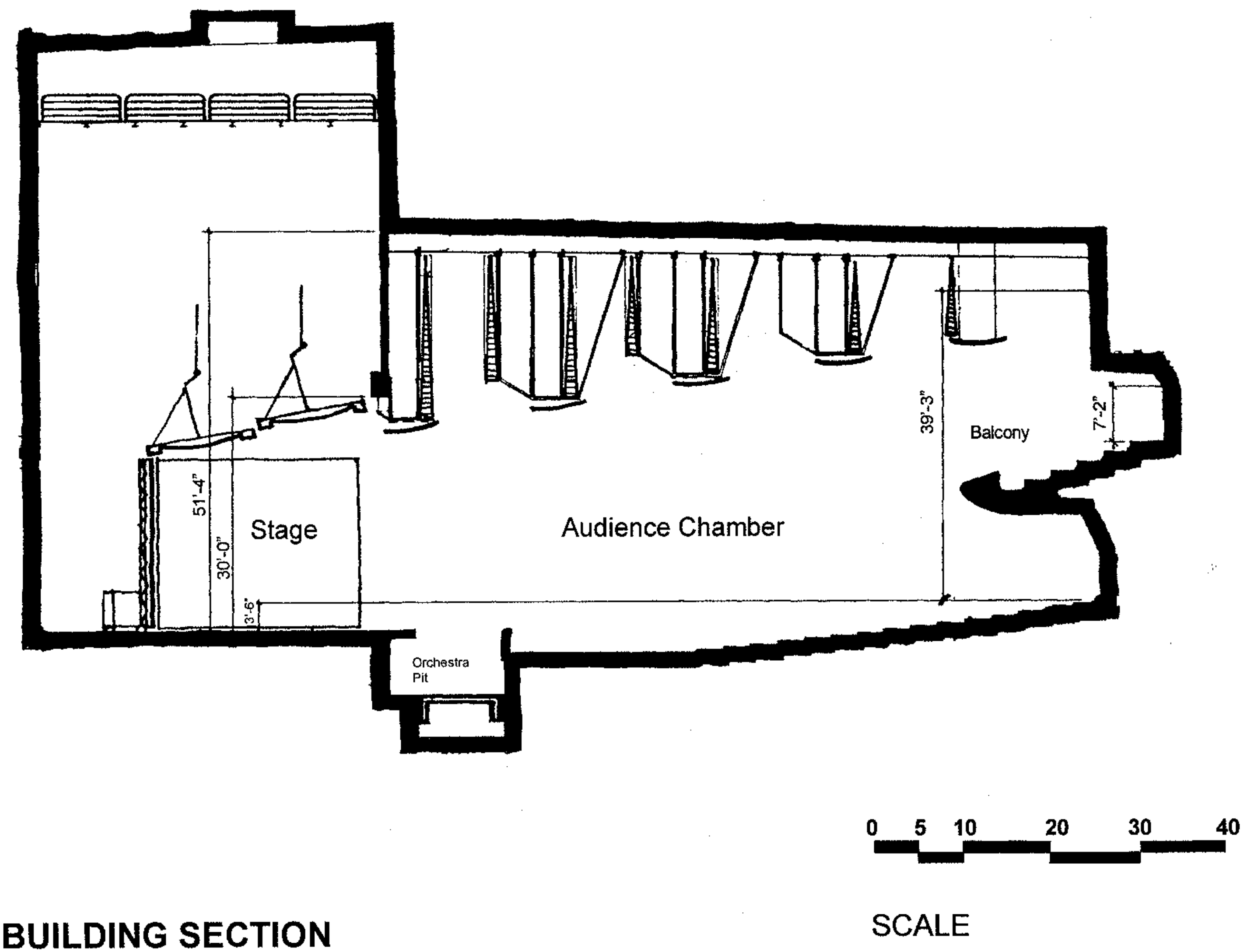
FLOOR PLAN (Recital Hall)



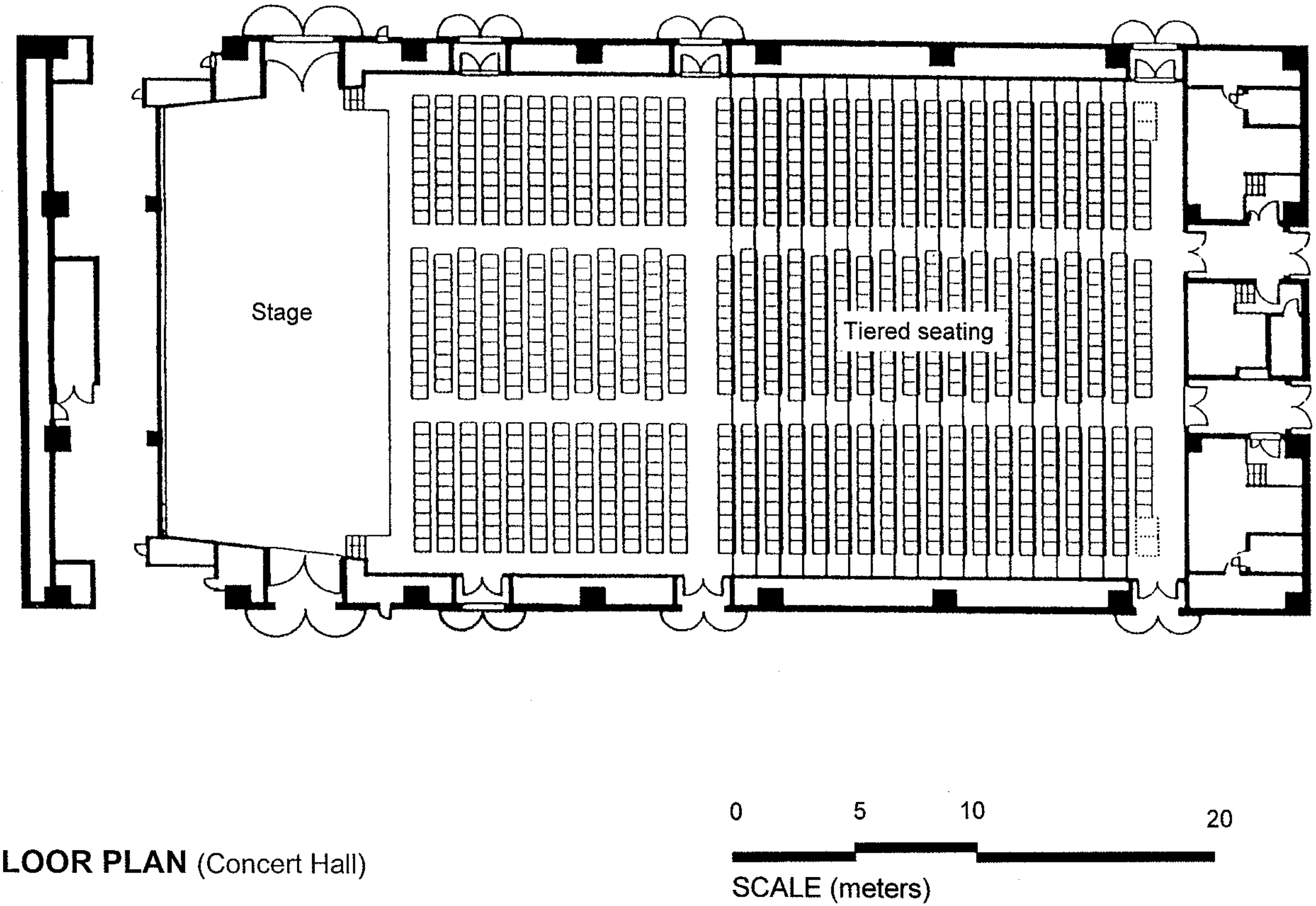
BUILDING SECTION



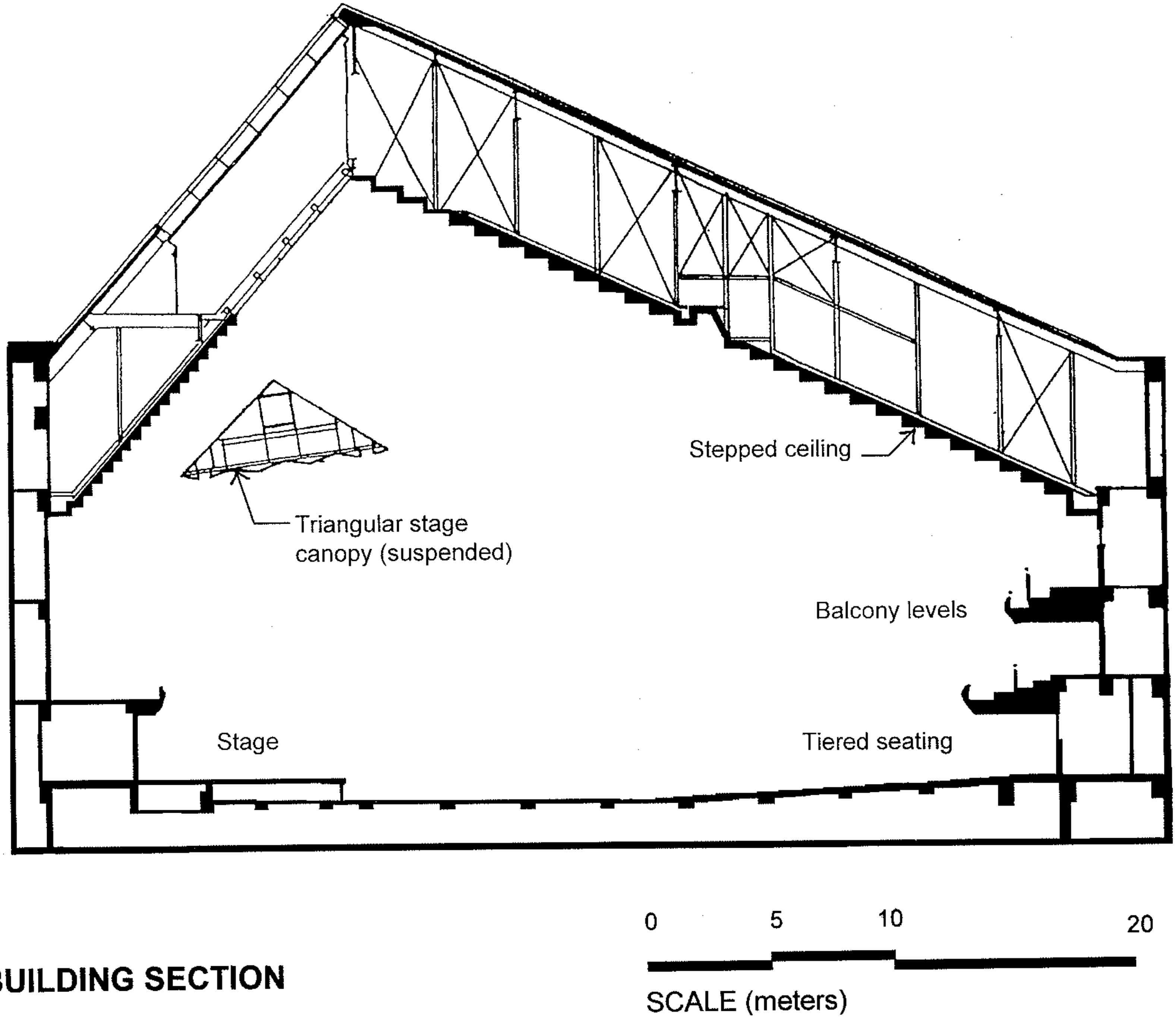
FLOOR PLAN (School Auditorium)



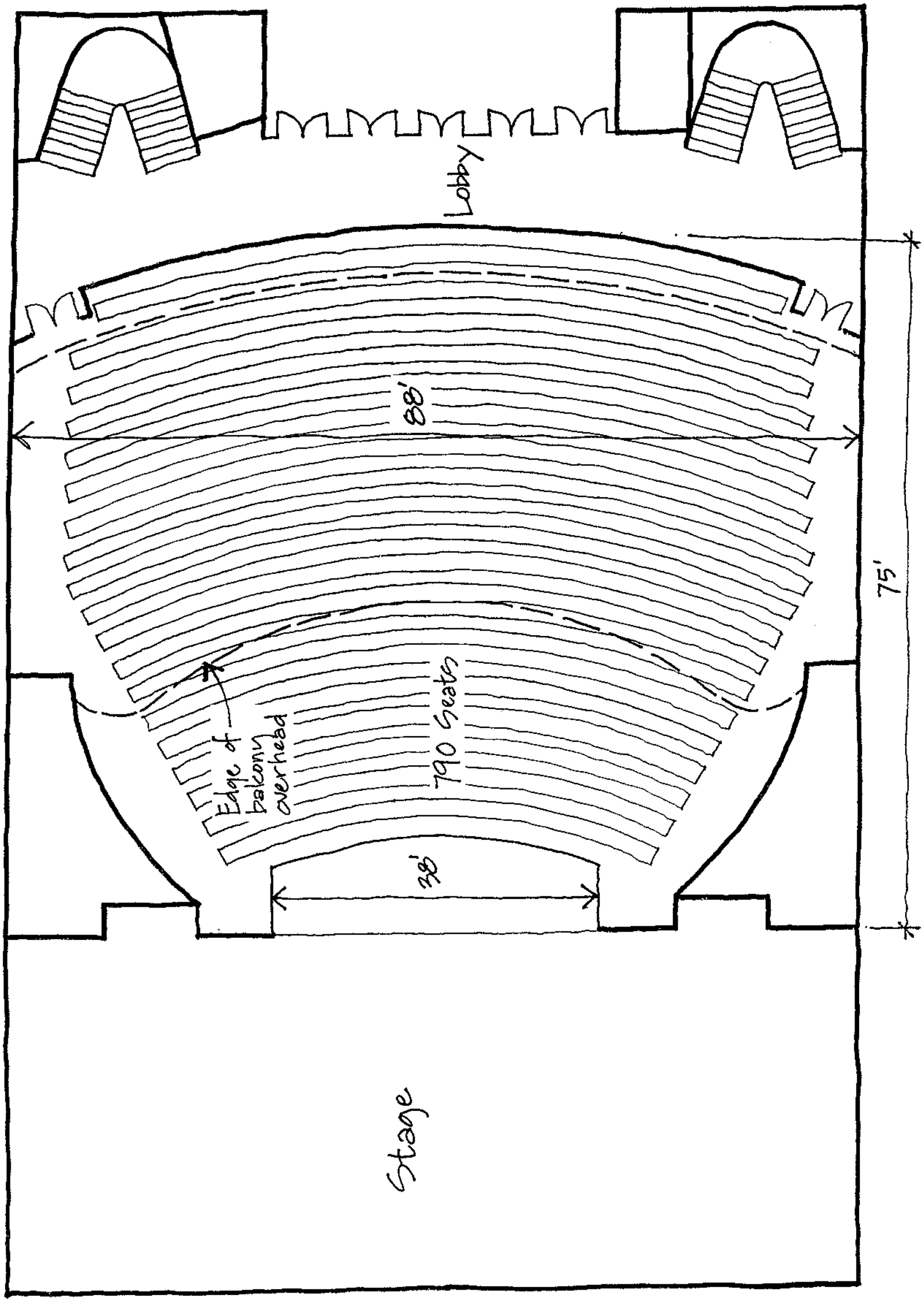
BUILDING SECTION



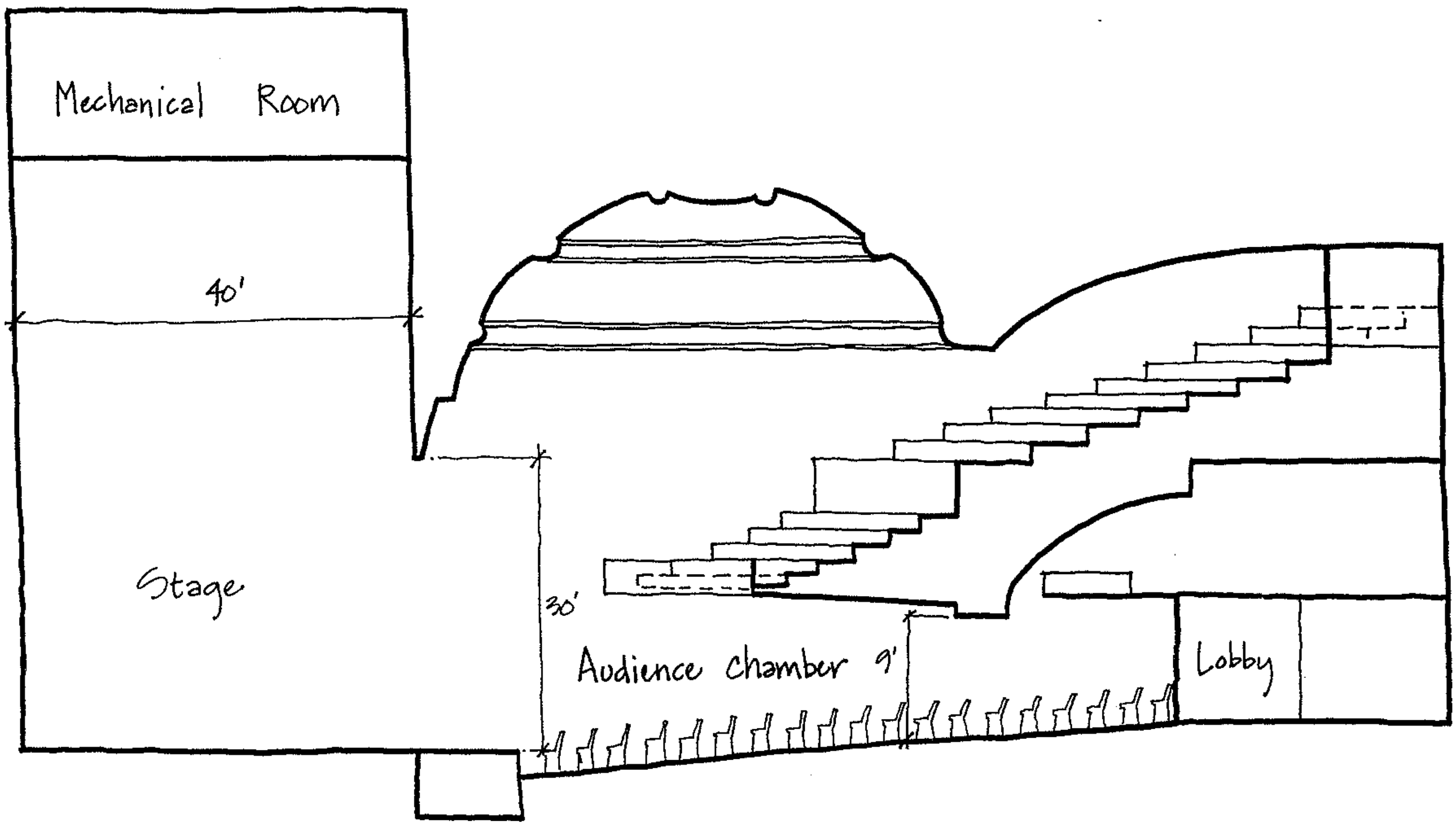
FLOOR PLAN (Concert Hall)



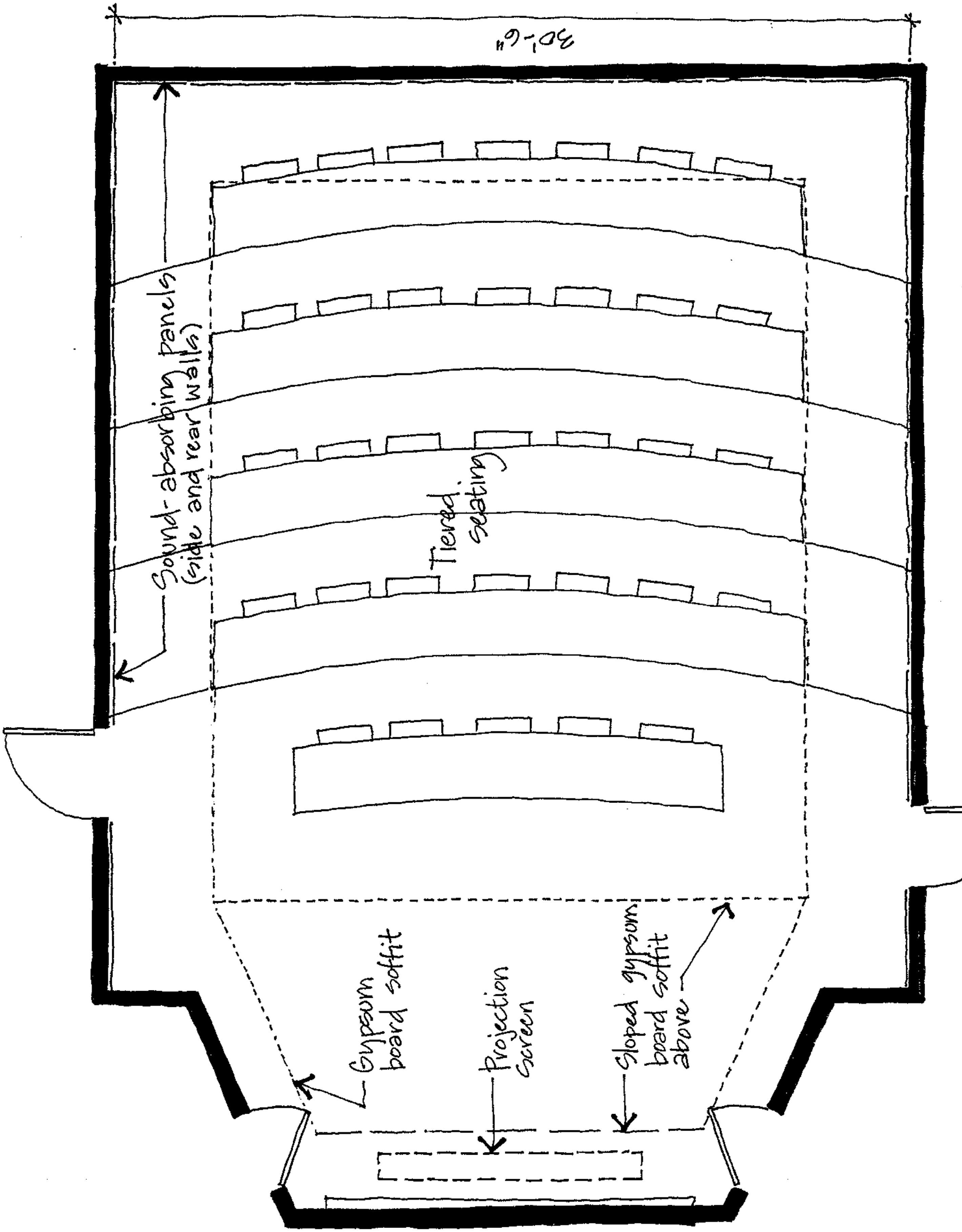
BUILDING SECTION



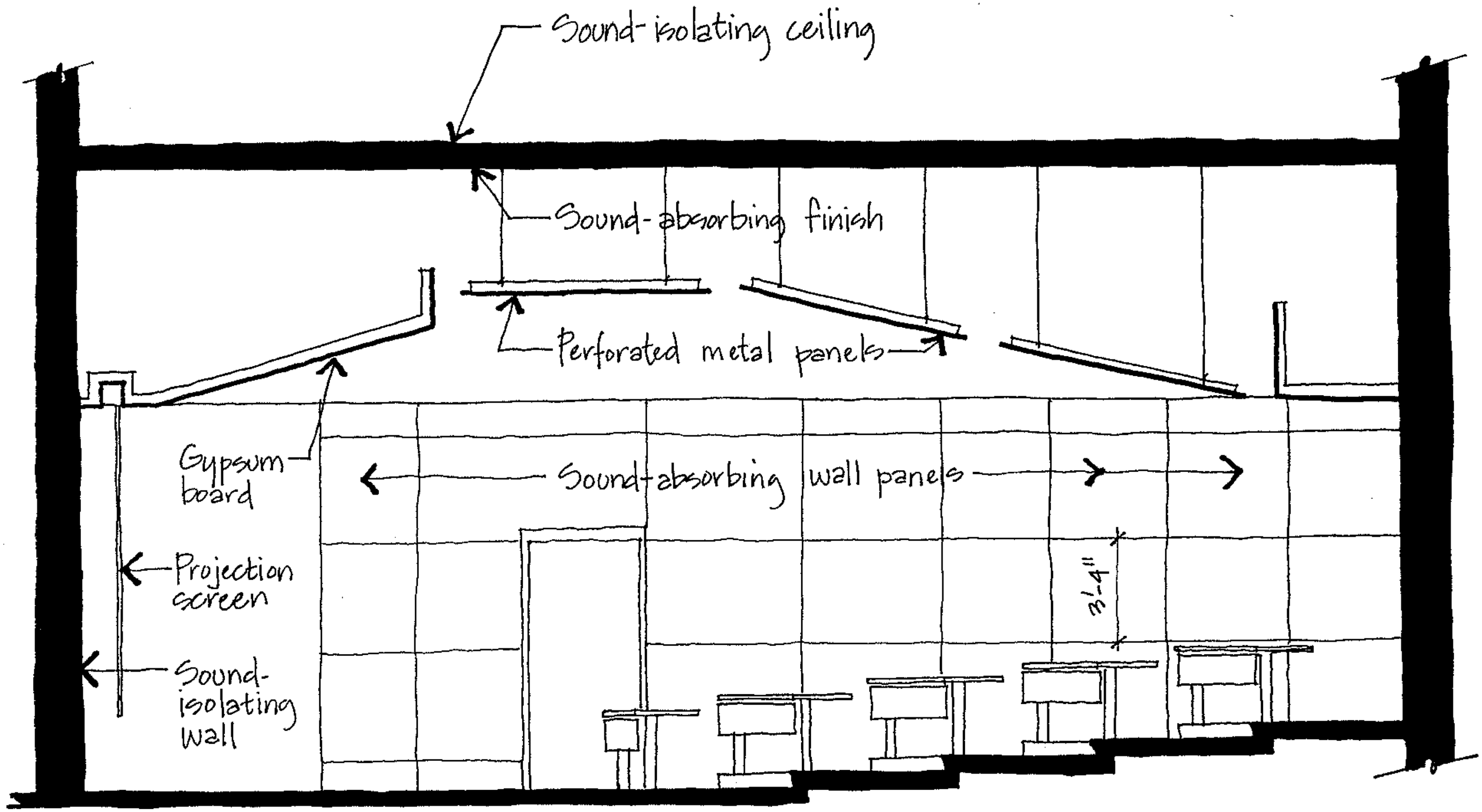
FLOOR PLAN (Multi-Purpose Auditorium)



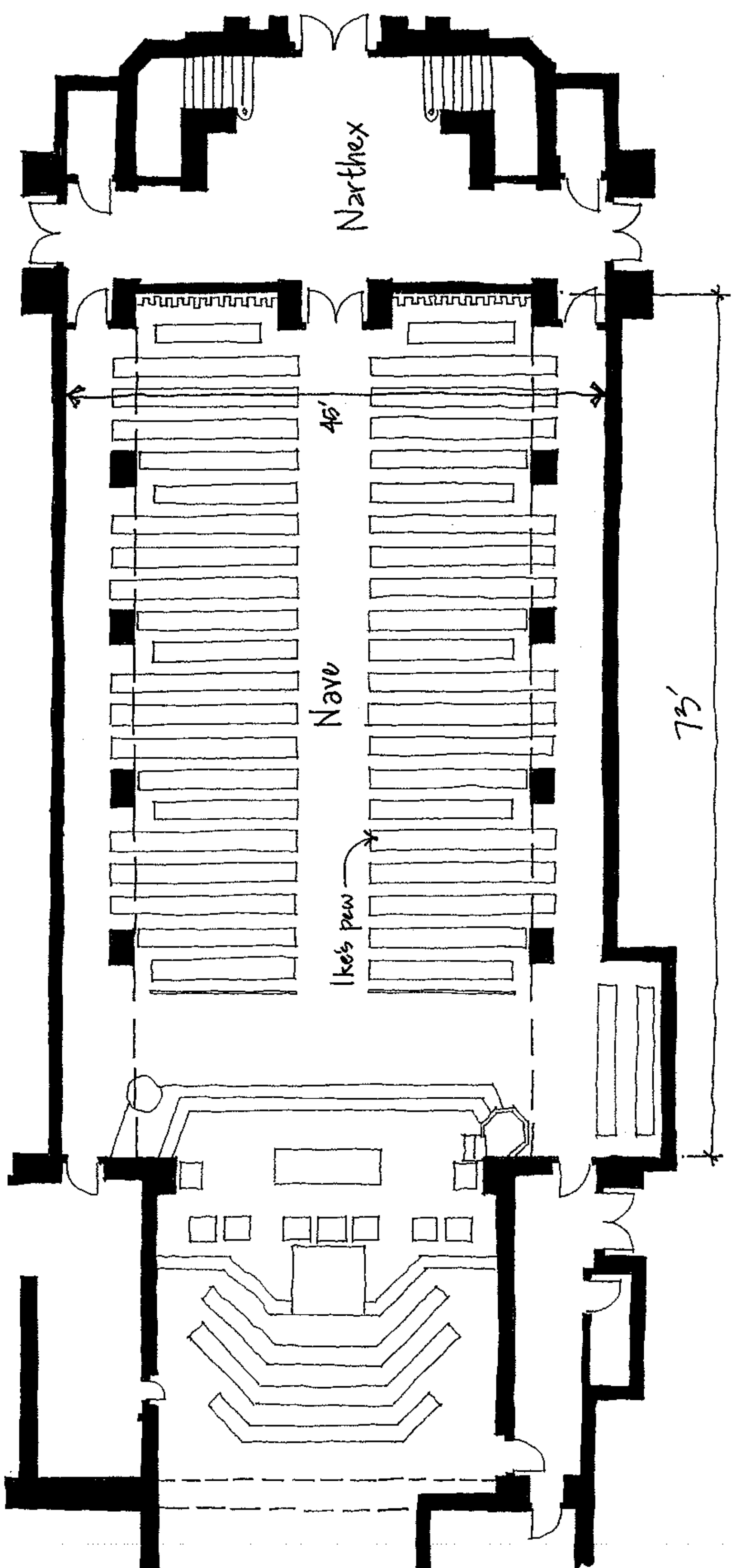
BUILDING SECTION



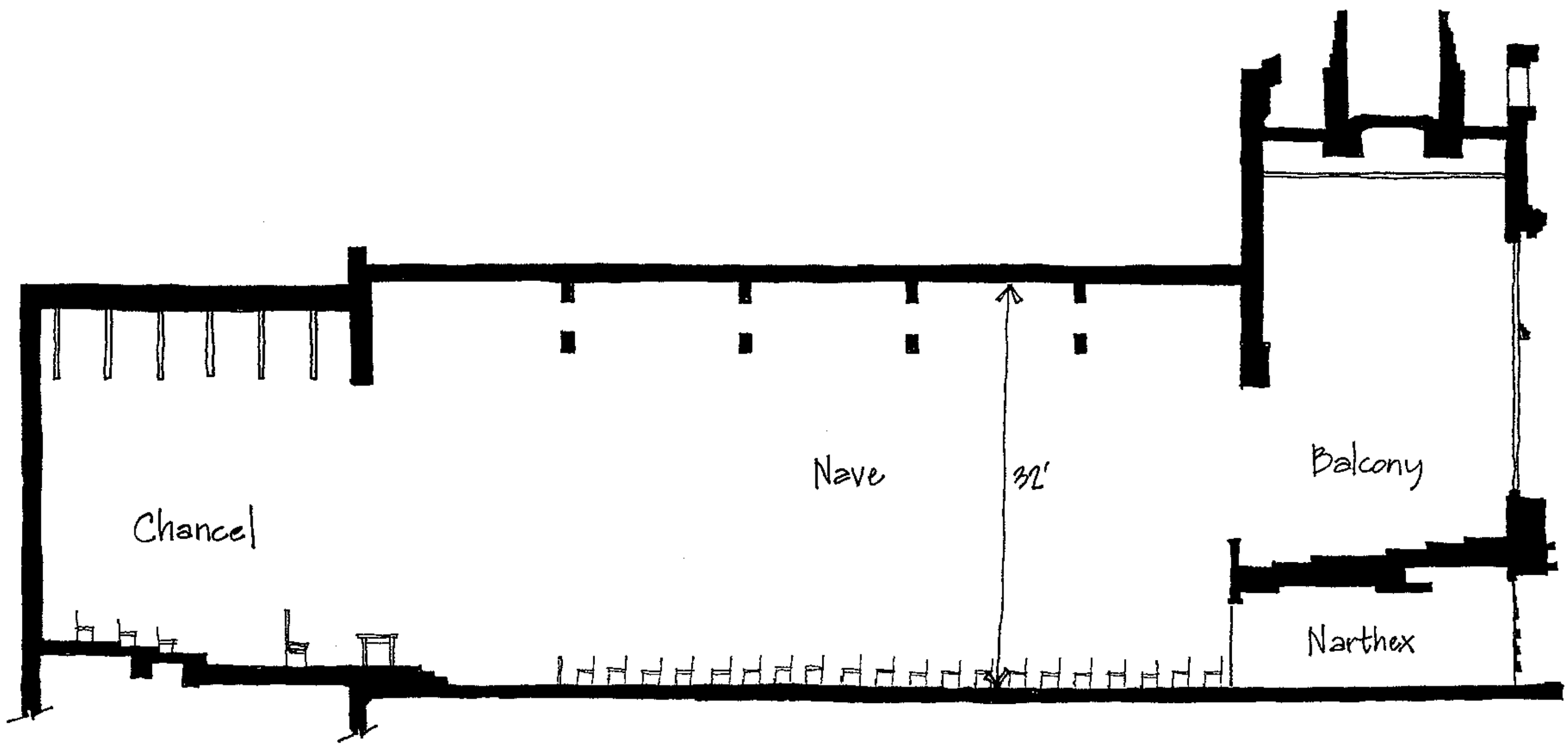
FLOOR PLAN (Classroom)



BUILDING SECTION



FLOOR PLAN (Worship Space)



BUILDING SECTION

9.0 TEACHING RESOURCES

REFERENCE BOOKS FOR FACULTY AND STUDENTS

Architectural Acoustics

M. Barron, *Auditorium Acoustics and Architectural Design*, Chapman & Hall, London, England,1993.

L. L. Beranek, *Music, Acoustics, and Architecture*, John Wiley, New York, 1962.

✓ L. L. Beranek, *Concert and Opera Halls*, Acoustical Society of America, Woodbury, NY, 1996.

✓ W. J. Cavanaugh and J. A Wilkes (eds), *Architectural Acoustics: Principles and Practice*, John Wiley, New York, 1999.

✓ J. P. Cowan, *Architectural Acoustics Design Guide*, McGraw-Hill, New York, 2000. [Interactive CD-ROM set by Acentech also is available from McGraw-Hill.]

L. Cremer and H. A. Müller, *Principles and Applications of Room Acoustics*, Vol. 1, Applied Science Publishers, Barking, England, 1978.

L. L. Doelle, *Environmental Acoustics*, McGraw-Hill, New York, 1972.

M. D. Egan, *Concepts in Architectural Acoustics*, McGraw-Hill, New York, 1972.

✓ M. D. Egan, *Architectural Acoustics*, McGraw-Hill, New York, 1988.

M. D. Egan, S. Hass, and C. Jaffe, "Acoustics: theory and applications, Part I" in D. Watson (ed), *Time-Saver Standards*, McGraw-Hill, New York, 1997.

✓ M. Forsyth, *Buildings for Music*, Cambridge University Press, Cambridge, England, 1985.

✓ L. K. Irvine and R. L. Richards, *Acoustics and Noise Control Handbook for Architects and Builders*, Krieger Publishing, Malabar, FL, 1998.

G. C. Izenour, *Theater Design*, McGraw-Hill, New York, 1977.

G. C. Izenour, *Theater Technology*, McGraw-Hill, New York, 1988. [Reprint edition of both Izenour books available from Yale University Press.]

✓ M. Mehta, J. Johnson, and J. Rocafort, *Architectural Acoustics: Principles and Design*, Prentice Hall, Upper Saddle River, NJ, 1999.

✓ W. C. Sabine, *Collected Papers on Acoustics*, Peninsula Publishing, Los Altos, CA, 1993. [Original edition printed in 1922.]

✓ C. M. Salter, *Acoustics: Architecture, Engineering, The Environment*, William Stout Publishers, San Francisco, CA, 1998.

Noise Control

✓ L. L. Beranek and I. L. Vér (eds), *Noise and Vibration Control Engineering*, John Wiley, New York, 1992.

M. J. Crocker (ed), *Handbook of Acoustics*, John Wiley, New York, 1998.

✓ C. Ebbing and W. Blazier (eds), *Application of Manufacturers' Sound Data*, ASHRAE, Inc., Atlanta, GA, 1998.

✓ C. M. Harris (ed), *Noise Control in Buildings*, McGraw-Hill, New York, 1994.

R. S. Jones, *Noise and Vibration Control in Buildings*, McGraw-Hill, New York, 1984.

✓ M. E. Schaffer, *A Practical Guide to Noise and Vibration Control for HVAC Systems*, ASHRAE, Inc., Atlanta, GA, 1991.

Electronic Sound Systems

✓ D. Davis and C. Davis, *Sound System Engineering*, Howard W. Sams, Indianapolis, IN, 1987.

J. F. Eiche (ed), *Guide to Sound Systems for Worship*, Hal Leonard Publishing, Milwaukee, WI, 1990.

✓ F. A. Everest, *The Master Handbook of Acoustics*, TAB Books, Blue Ridge Summit, PA, 1983.

T. Uzzle, R. A. Bushnell, and T. G. Bouliane, *Technical Fundamentals of Audio*, Intertec Publishing, Overland Park, KS, 1999. [Order from National Systems Contractors Association (NSCA), 625 First St. SE, Suite 420, Cedar Rapids, IA 52401.]

NOTE: The *Directory of Publishers*, available from the National Association of College Stores (NACS), provides information on how instructors may request complimentary desk copies of books being considered for course adoption. It is best to contact the publisher directly, rather than through your campus bookstore. To obtain a *Directory*, write to NACS at 500 East Lorain Street, Oberlin, OH 44074-1294.

Collected Papers on Acoustics

Wallace Clement Sabine (Preface by L. L. Beranek. Introduction by F. V. Hunt.)

Peninsula Publishing, Los Altos, CA, 1993.
xxi+279 pp. Price $35.95 USA, $37.95 Intl.

Next year will be the 100th anniversary of Professor Wallace Clement Sabine's historic studies from 1895 to 1898 to correct the atrocious listening conditions in the lecture room of the just completed Fogg Art Museum building at Harvard University. Peninsula Publishing has reprinted the landmark papers of Professor Sabine that have been out-of-print for more than a generation. These unabridged papers, originally written during the period of 1898 to 1917, were first collected together by Harvard University for publication in 1921. More than four decades later in 1964, Dover Publications reproduced the Harvard edition in a $5\frac{1}{2}\times 8\frac{1}{2}$ in. format paperback reprint edition. This reprint included a new Introduction by Professor Frederick V. Hunt of Harvard. In the Introduction, Professor Hunt concludes by noting that international standardization has honored Sabine by naming the area unit of sound absorption for him, bronze plaques memorialize him in Boston's Symphony Hall and in the lecture room of the Jefferson Physical Laboratory at Harvard, but later generations may remember him even longer and more fondly for his reverberation time discoveries and for his *Collected Papers on Acoustics*. This reviewer believes Hunt's prediction is true today and can be renewed with confidence.

As evident by the collected papers, Prof. Sabine was not only the founder of the science of architectural acoustics, but also a great communicator through his spoken presentations and technical papers written for scientists, architects, builders, and others in the construction industry. He believed in affecting progress in the building profession through education. He convinced architects and engineers to apply his discoveries to their designs by showing them the process of determining how buildings affect sound and how he could predict acoustical characteristics prior to construction. The Sabine papers are authoritative and still useful today because they cogently demonstrate how Sabine made his important discoveries.

The collected papers include a chapter on "Reverberation," which documents Sabine's meticulous experiments in the lecture room at Fogg and "calculation in advance of construction" for his first major acoustical consulting assignment, the new 2631-seat Boston Music Hall (McKim, Mead, and White, Architects). The Hall, now called Symphony Hall, is today universally acclaimed to be one of the finest halls for symphonic music in the world. In this paper, Sabine states "a knowledge of the volume of a room and of the coefficients of absorption of its various components, including the audience for which it is designed, will enable one to calculate in advance of construction the duration of audibility of the residual sound, which measures that acoustical property of a room commonly called reverberation." Imagine the impact this discovery had on architects and engineers at the turn of the century. Until then they could only faithfully copy existing rooms or leave acoustical results to chance.

A chapter on "Theatre Acoustics" contains examples of Sabine's consulting projects for Little Theatre, New York City (Ingalls and Hoffman, Architects); New Theatre, New York City (Carrère and Hastings, Architects); Scollay Square Theatre, Boston, MA (C. H. Blackall, Architect); and Harris Theatre, Minneapolis, MN (Chapman and Magney, Architects). These case studies include: architectural plan and section drawings, examples of Sabine's photographic method for studying sound reflections in small-scale models, and graphs of reverberation measured *in situ* by Sabine. In the Preface to the new Peninsula Publishing edition, Dr. Leo L. Beranek cites several additional important acoustical consulting commissions undertaken by Sabine during the period of 1908 until 1919, the year of his death at age 50. From 1916 to 1918, Sabine also patriotically worked for the War Department as scientist and advisor. Sent to France, where 2 million American "Doughboys" served during World War I, Sabine worked with the American Expeditionary Forces and advised the armed forces of France, Great Britain, and Italy. He developed acoustical detectors to locate enemy artillery, flew on missions behind enemy lines to photograph airdromes with his camera invention, and consulted on other essential, often dangerous, military problems. To complete his work for the War Department, Sabine deferred surgery until it was too late to save his life. The *Harvard Crimson* (January 15, 1919 issue) cited his service and concluded with: "The country honors and thanks him for the lives of many soldiers saved from German batteries located by his sound-stations."[1]

In *Collected Papers on Acoustics*, Sabine cautions against prescribing the best height, best width, or best length for a theatre by emphasizing the interdependence of cubic volume, seating layout, shape of boundary surfaces, finish materials, and so on. Throughout the papers, Sabine reveals the insight gained from working with full-scale physical models, as he did by measurements in completed buildings. Sabine also wisely cites the practical limitations of real world practice on the architect and acoustical consultant. (Refer to Fig. 1 from p. 84 in *Collected Papers on Acoustics* for illustration of a Sabine test apparatus used to conduct room acoustics experiments.)

In the chapter on "The Insulation of Sound," Sabine uses convincing analogies to demonstrate the principles of sound isolation by mass, multiple-layer construction, and the importance of physical separation. In an interesting case study at the Institute of Musical Art, New York City, Sabine identifies flanking of sound energy due to overstressed "deadening sheet" and the negligible effects of boundary surface absorption on sound

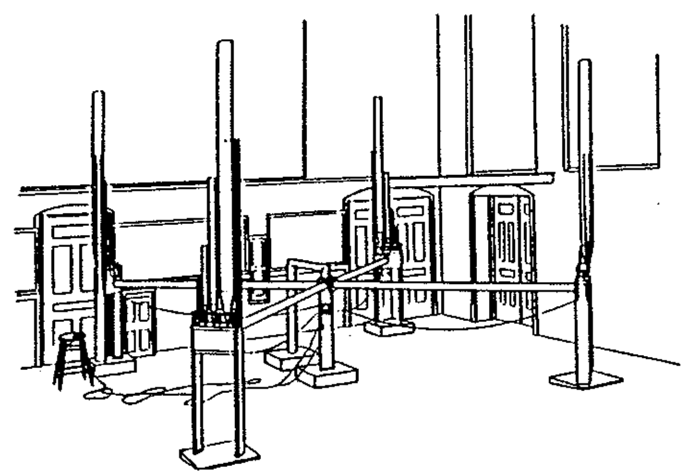


FIG. 1. Illustration of the Sabine test apparatus used to conduct room acoustics experiments.

transmission. His test setup and analysis procedures for acoustical field measurements are described in detail.

In overview, the *Collected Papers on Acoustics* is organized as follows: Chap. 1, Reverberation; Chap. 2, The Accuracy of Musical Taste in Regard to Architectural Acoustics. The Variation in Reverberation with Variation in Pitch; Chap. 3, Melody and the Origin of the Musical Scale; Chap. 4, Effects of Air Currents and of Temperature; Chap. 5, Sense of Loudness; Chap. 6, The Correction of Acoustical Difficulties; Chap. 7, Theatre Acoustics; Chap. 8, Building Material and Musical Pitch; Chap. 9, Architectural Acoustics; Chap. 10, The Insulation of Sound; Chap. 11, Whispering Galleries; and Appendix (additional paper on measurement of intensity of sound, translated from Sabine's notes which were written in French for his very popular lectures at the Sorbonne during World War I).

This reviewer believes ASA members interested in the built environment will be delighted to own a copy of this historic and yet still eminently practical document. The book is hardbound in a large format—much easier to read than the long out-of-print Dover edition. The dust jacket illustration of St. Paul's Cathedral, Detroit, Michigan is superb. Every school of architecture, engineering, interior design, and construction science should have copies of the book in their library. Students and faculty alike should be exposed to the insights uniquely revealed by Sabine's steps of discovery during the genesis of the science of architectural acoustics. Wallace Clement Sabine was a great scientist, dedicated teacher, acoustical consultant, author, and a man who literally gave his life for his country.[2]

M. DAVID EGAN
College of Architecture
Clemson University
Clemson, South Carolina 29634-0507

[1] W. D. Orcutt, *Wallace Clement Sabine: A Study in Achievement* (Plimpton, Norwood, MA, 1933), p. 335.
[2] See Ref. 1, pp. 290–338.

Auditorium Acoustics and Architectural Design

Michael Barron

E&FN Spon, 2-6 Boundary Row, London SE 1 8HN, UK, 1993. 443 pp., 12 chapters Price $125.00.

This may be the most comprehensive single volume published to date on acoustical and architectural design for listening spaces. Barron provides in one book some of the historical perspective of Michael Forsyth's *Buildings for Music* and George Izenour's *Theatre Design*, some of the technical discussion of Beranek's *Music, Acoustics and Architecture*; and some of the fundamentals and practical details of Egan's *Architectural Acoustics*.

This book is written primarily for acousticians, and there is more detail here than the average architect or musician will be interested in. This is also one of the most technical books on the subject, but there is a wealth of information for readers at all levels of expertise.

The strength of this book is its separate chapters on acoustical design for recital halls, theaters, concert halls, opera houses, and multipurpose auditoriums. For each of these types there are separate chapters providing a discussion of the acoustical design objectives, historical development of the form, and examples of existing halls. Readers looking for information on a particular type of performance hall will appreciate this format.

The book is illustrated throughout with valuable figures; Fig. 1 is an example.

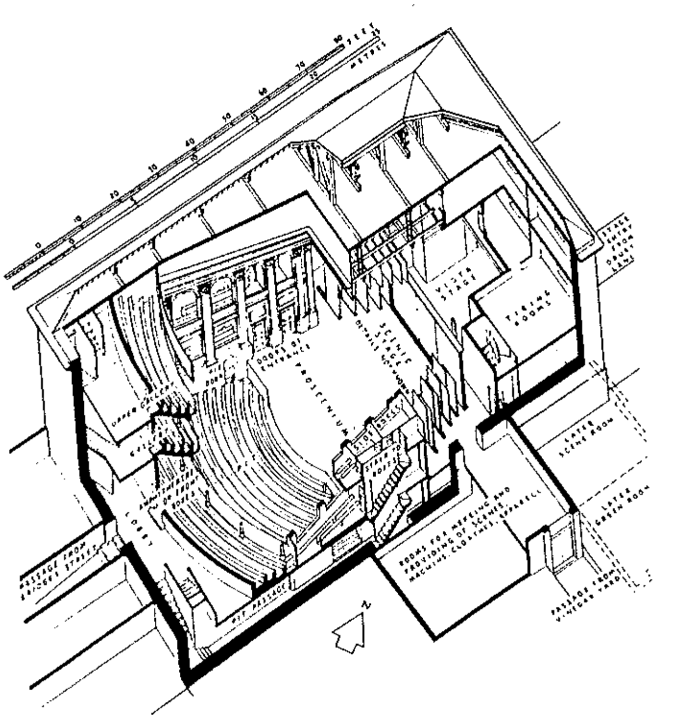


FIG. 1. Axonometric view of Wren's Drury Lane Theatre, London of 1674 (Fig. 8.8, p. 250).

The sections on specific hall types are augmented by general chapters on fundamentals of sound and room acoustics, techniques for analysis of room acoustics during design (including a good section on scale modeling), and acoustical measurement parameters for objective testing in finished projects. These general reference sections are limited in their depth of coverage. Readers who are new to the subject will find them a good introduction to other references for a more detailed presentation of these topics. The strongest feature of the fundamental chapter is a thorough explanation of reverberation time, including criteria and prediction methods.

The brief appendices on acoustical measurements are helpful but disappointing considering the author's considerable experience. Barron could have gone much further in his presentation of measurement parameters. He does provide an overview of some of the "new" acoustical measurement parameters, including C80, G (loudness), lateral energy fraction, ST1 (objective support), and early decay time. There are several other important variables that should have been included here. Of course it is difficult to find agreement among acoustical researchers and consultants on what measurements are important, and there is continuing discussion on the finer points of integration times, filtering techniques and microphone setups. There is a good description of the measurements in mathematical and qualitative terms, but there is very little information on the equipment and methodology for measurements. Barron has made and published many such measurements and is well qualified to tell us how it is done. This is a topic that should be expanded in the next edition.

Barron believes in learning from the results of existing halls, and he backs this up by including numerous case studies. Some of the case studies are examples of good acoustics, others illustrate mistakes to be avoided. There is a strong emphasis on case studies of British halls, understandable since the author lives and works there. Unfortunately, some of the British examples are rather ordinary facilities. While they do serve to illustrate a point, they may be of limited interest to readers from other countries.

One of the highlights of the book is the chapter on development of the concert hall. The description of early concert rooms as they developed from private ballrooms provides valuable perspective. Barron traces the history of concert halls from the Schloss Eisenstadt (used by Haydn in 1760) to Roy Thompson Hall in Toronto (completed in 1982). This chapter includes illustrated discussions of the world's most famous halls including the Leipzig Gewandhaus, the Concertgebouw Amsterdam, Boston Symphony Hall, and Berlin Philharmonic. One problem in this chapter is Barron's discussion of Philharmonic Hall at Lincoln Center (New York City). He insists on once again raking this unfortunate history over the coals, giving it more coverage than he gives to even the most successful halls including Berlin and Boston. His assessment of Philharmonic Hall as an "acoustical disaster" is particularly inappropriate, only serving to undermine the credibility of the acoustical consultanting profession.

Two special sections of the book are especially worthy of mention. The first is a special section on designing concert stages for performers, written by Anders Gade. This important topic has been getting much greater attention in recent years, and rightfully so since an ensemble cannot be their best unless they are confident of their own sound quality through proper on-stage reflections. The second special topic is electronic reverberation enhancement (in the section on multipurpose halls). This section provides more detail than any previous book, including descriptions of several proprietary systems that have been installed in major halls.

Even with a few minor concerns, this book offers the most detailed and up-to-date coverage of auditorium acoustics available in any single volume.

TIMOTHY J. FOULKES
Cavanaugh Tocci Associates
327 F Boston Post Road
Sudbury, Massachusetts 01776

Architectural Acoustics: Principles and Practice

William J. Cavanaugh and Joseph A. Wilkes

John Wiley & Sons, Inc., New York, NY, 1999.
xvii+332 pp. Price: $69.95.

The new textbook *Architectural Acoustics: Principles and Practice* by William J. Cavanaugh and Joseph A. Wilkes is an exceptionally welcome addition to the limited number of textbooks specifically written to teach architects the basic principles of building acoustics.

Each of the six chapters is authored or co-authored by a practicing acoustic consultant with expertise in specific areas of architectural acoustic design. Mr. Cavanaugh and Mr. Wilkes have assembled an impressive team of individuals who offer the reader an opportunity to understand both the principles of the subject as well as how to apply these principles.

The key introductory chapter is written by William Cavanaugh, former Director of BBN's Architectural Technology Division and currently the principal and founder of Cavanaugh Tocci Associates, Inc. of Sudbury, Massachusetts, one of the country's leading consultancies in architectural acoustics. Having taught and lectured on the subject for over 30 years, Mr. Cavanaugh is well aware of the need to differentiate between teaching architects and teaching engineers or physicists. His Introductory Chapter on Basic Concepts and Design Criteria is extremely clear and concise. Both the text and graphics are well organized and within the 54 page Introduction, I counted only 4 simple algebraic equations. Nothing quite scares an architecture student as much as opening an engineering textbook on acoustics and being faced with page after page of equation derivations. The material in this textbook is primarily explained through the use of text, charts, graphs, tables and nomograms.

Subjects covered are basic measurements of sound, wavelengths, the audible frequency range, and units of sound intensity. The design criteria portion explains NC curves, STC numbers, and other typical architectural criteria. In addition, Mr. Cavanaugh emphasizes the importance of involving the acoustic specialist at the beginning of the design process in order to meet required program objectives such as privacy, speech intelligibility and musical liveness, warmth and definition.

Chapter two, written by Rein Pirn of Acentech, Inc. of Cambridge Massachusetts, is devoted to descriptions of construction materials and their ability to absorb, reflect, or transmit sound. Mr. Pirn was the acoustician who first advised his colleagues that the power of musical sources must determine the volume of recital halls rather than the amount of absorption represented by seated audience members. Also, in researching rehearsal and recital hall usage, he found that musicians preferred lowering the reverberation times in these spaces through added absorption when the power levels of source ensembles were too high. Mr. Pirn begins his section with the acoustician's anthem to architects. Materials that absorb sound cannot be used to isolate sound. Fiberglass batts, boards, and ceiling tiles, as well as lightweight panels, have very low transmission loss characteristics and must not be used as sound isolation partitions. A particularly valuable section of this chapter is 12 pages of construction details with corresponding tables of Sound Transmission Class, Surface Weight, Overall Thickness, and Fire-Resistive Ratings. A brief overview of vibration isolation devices is included here, although more detailed information regarding this subject can be found in the next chapter.

The third chapter, authored by Greg Tocci, co-founder of Cavanaugh Tocci Associates, Inc. and currently the Associate Editor of *Noise Control Engineering Journal*, is devoted to noise and vibration control. Mr. Tocci analyzes noise from its multiple sources through their paths to the ultimate receivers and describes the controls necessary to assure privacy and acoustical comfort. Systems described include building partitions, floor/ceiling construction, building envelopes, and HVAC mechanical systems and their distribution networks. It is a shame that the acoustics profession as well as the Standards Committees of a number of our learned societies have not arrived at a single standard to measure steady state background noise in rooms. The section of this chapter devoted to explaining the differences between NC (Noise Criteria), RC (Room Criteria), and NCB (Balanced Noise Criteria) may tend to confuse the architect rather than assist him in his design efforts. On the other hand, Mr. Tocci's explanations and graphics depicting the differences between these criteria will be of great assistance to practicing acousticians who may be somewhat befuddled by the controversy on this subject now raging in our midst.

David Klepper and L. Gerald Marshall, co-founders with Larry King of KMK Associates, were brave enough to tackle chapter four, Room Acoustics. They did an excellent job in explaining how sound reflection patterns in a listening room affect musical quality and speech intelligibility, and describe why the reproduction of these patterns determines the acoustic quality of a space rather than its geometric shape.

There are a few comments with which one might take issue. I do not believe that the authors are correct in stating that poor orchestral balance will be found behind the orchestra platform in a surround hall. It is the high power levels and uni-directional characteristics of horns, trumpets, and trombones that are more likely to create orchestral imbalance in shoebox concert halls when the rear wall of the room reinforces the brass sections to the detriment of the lower powered string instruments. I might have expected a little more historical transition from the Greek and Roman Theatres to those of the Court Theatres of the Italian Renaissance and Elizabethan England. These latter building types are gaining great favor with Contemporary theatre consultants and are causing acousticians to rethink acoustic criteria for multi-use performance facilities. On the whole, an A plus for this section.

The fifth chapter of the book covers sound reinforcement systems and describes how they must be tailored to match the acoustical design of public rooms. J. Jacek Figwer, an independent consultant from Concord, Massachusetts, wrote this section and provides the reader with a clear description of the type of systems required to meet the program uses of a variety of different spaces (Theatres, Meeting Rooms, Plenary Halls, Churches, Music Schools, Sports Arenas, etc.). I am not sure the numerous system schematic drawings shown in the Case Studies portion of the chapter will be of use to architects. However, practicing sound system design professionals will find them of immense value.

One topic I found missing from this chapter is a warning to architects that loudspeakers are three-dimensional objects which must be integrated into an architectural design at the earliest possible moment. Dreaming of recreating the proscenium arch of the La Scala Opera House is an invitation to aesthetic disaster. Rooms such as La Scala were built well before the era of electronic sound reinforcement. Once pictures of your new facility have been taken for the architectural press, the theatre crew (doing whatever is necessary to develop good speech intelligibility in the room), will hang loudspeakers helter skelter all over your beautiful proscenium arch.

The final chapter was written by Professors Gary S. Siebein and Bertram Y. Kinsey of the University of Florida. Both men played key roles in setting up the Architectural Technology Research Center at the school and have established independent consultancies in the State. This section of the book seeks to record the most recent progress in acoustic research in developing methods of evaluating, modeling and predicting the acoustical characteristics of buildings. Here, again, we may find design professionals better able to evaluate these tools and determine when to use them than architects or students of architecture. We are at an early stage in the development of these techniques and one cannot overemphasize the importance of adding a skilled, knowledgeable, and experienced practitioner to the design team in order to insure the successful culmination of acoustically sensitive building projects.

One is hesitant to offer superlatives when addressing scientists and engineers. However, this book deserves all our accolades. It is a welcome addition to every architect's and acoustician's bookshelf and is a must for every University and College library here and abroad.

DR. J. CHRISTOPHER JAFFE
Jaffe Holden Scarbrough Acoustics, Inc.
114A Washington Street
Norwalk, Connecticut 06854

A THOROUGH LOOK AT ACOUSTICS

Reviewed by Mark R. Gander

Charles Salter and Associates, *Acoustics: Architecture, Engineering and the Environment*, William Stout Publishers, San Francisco, May, 1998; hardcover, ISBN 0-9651144-6-5, $75.00.

Charles M. Salter and Associates is a well-known, San Francisco-based consulting firm specializing primarily in architectural and environmental acoustics and A-V and presentation technology. Its staff of 30 is involved in more than 400 projects per year. Readers will perhaps be most familiar with such well-known Salter signature projects as Disney/MGM Studios, the Lucasfilm Technical Building at Skywalker Ranch, San Francisco Museum of Modern Art, the Rock and Roll Hall of Fame, Dolby Laboratories screening room, and CBS Studios.

The company has pooled its knowledge and experience to create a large-format colorful reference book and educational text covering the disciplines within which they work. The book also includes a wide range of case studies that demonstrates the breadth of their activities and provides instructive examples of the many problems, approaches and solutions encountered within the acoustics disciplines.

Of those 30 employees, 28 have contributed to the book's 21 chapters. Beginning with history and fundamentals, then moving on through psychoacoustics and hearing, and measurements, the first chapters review the basics of acoustics. Each chapter is nicely illustrated with sketches and architectural drawings, much of it in color. Even charts that might appear in clinical form in another book are rendered with colorful contrast and creative typeface. This style is typical of architectural reference texts, but it serves to enhance the ease of communication to all readers, not just visually oriented architects.

More lengthy chapters on environmental noise, room acoustics, and sound insulation give background on the theoretical principles as well as specific practical details of design methods to achieve specific goals. Chapters on sound insulation, building vibration, and mechanical and electrical systems are full of guidelines and typical implementations. The chapters on active reduction of noise and sound amplification systems are brief and limited in scope, but those covering one of Salter's avowed specialties, A-V and acoustical simulations in the multimedia age, bring the experience of traditional disciplines up to modern surround-sound and virtual-reality standards.

Audio forensics is discussed, mostly in its typical context of tape-recorded material for consideration as legal evidence. Design and construction issues and costs and benefits discuss value engineering and the documentation and project process and compare specific tradeoff options in the choice of architectural and noise-reduction elements.

Some 32 case studies are briefly presented, each with a single accompanying photograph. These include theaters, performing arts centers and concert halls; boardrooms, courtrooms and council chambers; theme parks and museums, studios and scoring stages, and residences, hospitals and industrial facilities. Each vignette provides insight into the characteristic problems inherent in the type of facility as well as the specific solutions employed within each example.

Problems and solutions for multi-family housing, office acoustics and speech privacy, and industrial noise control include sample calculations and predictive formulas and algorithms. Of particular interest is the final chapter covering legal issues. The firm provides expert witness testimony in court cases involving acoustics, and a discussion of such legal principles as negligence, breach of contract and liability is supplemented by 18 legal case studies. Most of these are typical noise complaint and hearing loss claims, many relating to the misapplication or installation of acoustical materials. Some are fascinating examples of the role that sound can play in the problems and conflicts of our everyday lives, such as the audible fire alarm that might have saved a life.

The book includes as appendices a reasonably complete glossary of acoustical terminology and a brief listing of essential units and equations, but it unfortunately has a spotty index. It will find its place on my shelf of architectural acoustics and noise control books, alongside the classic M. David Egan book *Architectural Acoustics*. It serves a useful need in communicating the problems and opportunities of acoustics to architects, interior designers, developers and planners, and the case studies and legal case examples provide reference points for comparison to other similar projects. S&VC

Gander, B.S., M.S.E.E; Fellow-AES, Member, ASA, IEEE, SMPTE, is vice president, strategic development with JBL Professional. Northridge, CA.

The history of acoustics – Sabine to the present

Reviewed by M. David Egan

J. David Quirt, ed., *Proceedings of the Wallace Clement Sabine Centennial Symposium*, Acoustical Society of America, 1994, xviii +393 pp., paper, $38 (U.S.), $40 (outside the U.S.); (ASA members, less $5).

This 393-page, soft-bound book should be in the library of every school of architecture and building construction and should be owned by everyone interested in the history of architectural acoustics, the achievements of researchers and acoustical consultants during the 20th century, and the future of the profession.

The book, edited by J. David Quirt, contains more than 80 historical, scientific and engineering papers on room acoustics. Also included are case studies on a variety of auditoria and reports on scale modeling and acoustical simulations. Quirt organized the papers into a practical volume with four major themes: historical background, scientific principles, measurements and criteria, and performing-arts auditorium applications.

Egan is Principal Consultant, Egan Acoustics, Anderson, SC, and Distinguished Professor of the Association of Collegiate Schools of Architecture (ACSA).

The Acoustical Society of America published the book for the Wallace Clement Sabine Centennial Symposium, June 5-7, 1994, Cambridge, MA. The 3-day symposium at MIT honored the pioneering work of Harvard University Professor Sabine, the father of the modern science of architectural acoustics.

During World War I, Sabine took leave from teaching to work with the American Expeditionary Forces in Europe. Near the French town of Verdun, he was a target of German artillery because the German high-command knew about his significant contributions to the war effort. This was a rare and unwelcomed military tribute to a civilian scientist.

However, Sabine was more than a scientist. He was a teacher, acoustical consultant on numerous prestigious projects (including Boston Symphony Hall), author and founder of Harvard's Army ROTC program. He was a man who literally gave his life for his country: He died at age 51 because he delayed surgery so he could continue serving the doughboys in France.

The *Proceedings* publication is not a book in the traditional sense because its numerous authors each have written in an independent style. Nevertheless, the volume should prove to be so useful that most of the papers could be considered mini-chapters. The readers of *S&VC* who work in the area of room acoustics and audio engineering should find this book a valuable addition to their professional libraries.

The reader should first scan the *Proceedings* to look at all of the papers, or chapters, noting the interesting sketches and graphs and the useful and concise conclusions. The first pleasant surprise might be the discovery that insights to recent and current performing-arts auditorium projects and seminal writings on room acoustics are included by the following authors: George C. Izenour (author of the classic *Theatre Design*, McGraw-Hill, 1977, and *Roofed Theatres of Classical Antiquity*, Yale University Press, 1992), Leo L. Beranek (an updated and greatly expanded version of his classic *Music, Acoustics, and Architecture*, Wiley, 1962, will be published soon), and Michael Barron (author of *Architectural Acoustics and Auditorium Design*, Chapman & Hall, 1993, reviewed in *S&VC*, Nov. 20, 1994, pages 72-73).

The *Proceedings* will help readers decide whether books by these authors should be added to their libraries. Also of considerable interest are the chapters by Beranek, John Kopec and Emily Thompson that present biosketches of prominent 19th- and 20th-century acousticians and their contributions to the understanding of room acoustics.

The chapter by Neil Shaw et al. summarizes more than 30 important books on architectural acoustics published from the mid-1850s to the 1980s. Most chapters end with a reference list.

The chapter by Jürgen Meyer presents recent discoveries on orchestral stage environments and methods to achieve successful stage acoustics. His reference list highlights the foremost studies needed by anyone who seeks to understand the development of this aspect of musical acoustics.

Jerald Hyde presents design criteria for the objective room-acoustics parameters. He recommends sources of concise background summary information for the origin of objective parameters, such as early-to-late sound index or "clarity" index (C50 and C80), early decay time (EDT), sound strength at 10m from source (G), lateral energy fraction (LEF) and interaural cross-correlation coefficient (IACC).

An author index is at the back of the book; unfortunately, a subject index is not included. However, the schedule of events for the 20 symposium sessions on pages ix through xvii can be used as a table of contents. A perusal of these pages will confirm the enormous scope of the book.

The *Proceedings* covers the history of room acoustics dating from Sabine's discoveries in 1895 to the present. Included are two reprinted papers by Kopec and Beranek, previously published in *J. Acoust. Soc. Am.* These papers, along with *The Collected Papers on Acoustics* by W.C. Sabine (reprinted edition by Peninsula Publishing, Los Altos, CA, 1993) and *Wallace Clement Sabine: A Study in Achievement* by W.D. Orcutt (out of print, but might be available in libraries), are the comprehensive record of Sabine and his influence on buildings throughout the 20th century. For this reason alone, I recommend the *Proceedings*. S&VC

ACOUSTICS EDUCATION RESOURCES FOR INSTRUCTORS

Manufacturers and Building Product Associations

- Wenger Corporation
  P.O. Box 448
  Owatonna, MN 55060-0448
  [Tel: 800/268-0148]

  A Planning Guide for School Music Facilities, 1998. This 50-page 8½" x 11" size booklet presents guidelines on design of spaces for music teaching and performance. Numerous illustrations and useful rule-of-thumb tables.

  Compact disk (CD) and audio cassette decks available to demonstrate rehearsal, practice, and performance area problems and solutions.

- U.S. Gypsum Co. [USG]
  P.O. Box 806278
  Chicago, IL 60680-4124
  [Tel: 312/606-4065]

  ✓ 2/8/01

  Construction Selector, 1999. This 8½"x11" size booklet presents STC and MTC ratings for construction assemblies. The MTC, developed by USG, accounts for low-frequency performance of tested assembly. The MTC method provides essential ratings where loud music or mechanical equipment must be isolated.

  Form & Function reprints of "Technical Feature" papers on acoustical design for sound isolation such as: "Design aid for office acoustics" (1986), "Stereo TV, a new challenge in hotel sound isolation" (1988), and "Sound Control Construction" (1995).

  Videos such as presentation on basics of acoustics and sound isolation (in production).

- Solutia, Inc.
  P.O. Box 66760
  St. Louis, MO 63166-6760
  [Tel: 314/694-4011]

  Laminated Architectural Glass Specification Guide, 1999. This 8½"x11" size booklet includes STC and TL ratings for a wide variety of glass constructions.

Acoustical Glazing Design Guide, 1997. This comprehensive three-ring binder guide, prepared by consultants Cavanaugh Tocci Associates, presents an analytical procedure to help determine acoustical requirements early in the design development phase of projects. It covers use of exterior glazing exposed to environmental noise of: aircraft, highway traffic, and rail transportation.

- Industrial Perforators Association [IPA]
  5157 Deerhurst Crescent Circle
  Boca Raton, FL 33486
  [Tel: 561/447-7511] ✓ 2/8/01

  Acoustical Uses for Perforated Metals: Principles and Applications, 1986. This 77-page 8½"x11" size booklet, prepared by Dr. Theodore J. Schultz, covers how to use perforated metal to protect fragile sound-absorbing boards and blankets, how to design resonant sound absorbers, and includes case studies and design charts. [Riverbank Acoustical Labs. test data report also is available from IPA.]
  (Also on CD, if want for students)

- Armstrong World Industries, Inc.
  P.O. Box 3511
  Lancaster, PA 17604
  [Tel: 800/448-1405]

  CD demonstration of open-plan office acoustic performance. The demo simulates sound performance of ten different spaces with various degrees of wall and ceiling acoustic treatment. [An 8½"x11" size *Reference Book* is available to use with the CD.]

Professional Societies and Foundations

- Acoustical Society of America [ASA]
  Suite 1N01
  2 Huntington Quadrangle
  Melville, NY 11747-4502
  [Tel: 516/576-2360]

  Sponsors student acoustical design competitions. Cash awards. Biannual meetings have numerous sessions on architectural acoustics and education. Low annual membership fee for students enrolled half time or more. No meeting registration fee for student members. Grants available to fund student travel expenses to attend meetings.

- Institute of Noise Control Engineering [INCE]
  P.O. Box 220
  Saddle River, NJ 07458
  [Tel: 201/760-1101]

  Sponsors annual student paper competition. Cash awards to winners.

- Robert B. Newman Student Award Fund
  P.O. Box 6349
  Lincoln, MA 01773
  [Tel: 781/259-9299]

  Offers support to faculty teaching acoustics (Schultz Grant, videos, books, and annual newsletter). Provides Medals to students for "merit in architectural acoustics" at qualified schools worldwide. [Refer to Section 10 for more information.]

- American Institute of Architects [AIA]
  1735 New York Avenue, NW
  Washington, DC 20006-5292
  [Tel: 202/626-7358]

  Sponsors annual AIA Education Honors Award program to recognize achievements of faculty and to provide public exposure of innovative teaching methods. AIA College of Fellows provides annual grants for programs and projects that promote awareness of architecture and mentor young architects.

- Association of Collegiate Schools of Architecture [ACSA]
  1735 New York Avenue, NW
  Washington, DC 20006
  [Tel: 202/785-2324]

  Sponsors annual ACSA Technology Conference and continuing education programs, such as annual Construction Materials and Technology Institute (CMTI), to assist faculty in remaining up-to-date on latest developments. CMTI includes acoustics workshop.

- Society of Building Science Educators [SBSE]
  Editor, SBSE News
  c/o Department of Architecture
  University of Idaho
  Moscow, ID 83844-2451

  Organizes workshops and retreats for environmental control systems faculty. SBSE archives instructional written materials, computer software, videos, and thousands of slides, available at cost to support teaching activities. The prime focus of most SBSE members is energy-conscious design.

STUDENT DESIGN COMPETITION

The program for the Opera Hall described below is adapted from one of the annual Student Design Competitions sponsored by the Technical Committee on Architectural Acoustics (TCAA) of the Acoustical Society of America (ASA) and the National Council of Acoustical Consultants (NCAC). Individual entries, or entries by teams of two or three students, are submitted to TCAA/ASA for display at the spring meeting of ASA. A jury of architects and acoustical consultants judges the designs and cash awards are given to the best designs.

Purpose

The purpose of the design competition is to encourage students enrolled in architecture, architectural engineering, and related studies in building design to demonstrate their knowledge of architectural acoustics. Each year, a new building type is selected for the competition. Because every space has an acoustical environment, students learn to design for good hearing and freedom from noise.

Submission Elements

Competition entries should emphasize the acoustical elements of the design. Drawings should present comprehensive solutions in schematic design format. In addition to plan and section drawings, entries can include acoustical calculations, acoustical criteria, and construction details. Indicate noise and vibration controls for air handling, electrical power, and theatrical lighting systems. It is not necessary to prepare exterior building elevation drawings.

Design Information

A liberal arts college proposes building a new performance hall. The primary use of the hall will be opera, but it also will be used for symphonic orchestra, chamber music, chorus, and dance. The relatively flat site is located 200 ft from a 6-lane highway and 3 miles from an airport. Typically, departing aircraft will be 5,500 ft overhead when passing the site. Departing aircraft produce higher noise levels than arriving aircraft.

Program Requirements

<u>Performance Hall</u>

Audience Chamber should seat 1,200, with 40% of seats in two or three levels of side and rear balconies. Seating may be conventional aisle or continental. Provide variable absorption to accommodate variety of uses in the hall.

Stage should be 6,000 ft^2, 60 ft deep, and have easy access to loading dock.

Proscenium should be at least 50 ft wide by 30 ft high.

Stagehouse height from stage floor to gridiron should be at least 2.5 times opening height of proscenium. Portable *stage enclosure* will be needed for instrumental and choral performances on stage. Refer to pages 139 to 142 in *Architectural Acoustics.*

Orchestra Pit should accommodate 80 musicians. Provide at least one pit lift with highest position at stage level. Be sure to include variable absorption in the pit.

Scene Shop

Scene shop should be 3,200 ft^2, with access to stage and loading dock. Provide one large door with dimensions at least 18 ft wide by 25 ft high to accommodate scenery. It is anticipated that the shop will be used during rehearsals and performances in the hall.

Dressing Rooms

Provide two 600 ft^2 dressing rooms for chorus and eight 70 ft^2 dressing rooms for individuals. The rooms also will be used for music practice.

Green Room

Green room should be 500 ft^2 and also will be used as a meeting room.

Lobby

Lobby will serve as entrance to the performance hall, contain ticket and house manager's offices, and also will be used for special events such as luncheons and receptions.

Mechanical Room

Mechanical room should be at least 1,500 ft^2 to house air handlers. Chilled water and steam are available from central energy plant.

Site Noise

Noise levels from aircraft flyovers and highway traffic are presented below. The data represent *worst case* conditions measured at the perimeter of the site, 200 ft from highway.

	Sound Pressure Level (dB)						
	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Departing Aircraft[1]	68-77	73-87	71-87	71-86	65-82	58-75	55-62
Vehicular Traffic[2]	63-68	66-70	59-61	60-61	60-63	54-57	42-45

NOTES:

1. Sound levels were measured at octave-band frequencies for loudest and quietest flyovers during a one-hour period when aircraft departures were frequent.
2. Sound levels represent range measured at octave-band frequencies for a 20-minute period during heavy traffic.

JOURNALS AND MAGAZINES ON ACOUSTICS

Architecture school libraries should subscribe to the following peer-refereed journals and trade magazines. These publications focus on acoustics and its application to the built environment. Although *JASA* covers all aspects of acoustics in its monthly 1" thick publication, the papers on architectural acoustics, noise, and engineering acoustics should be of greatest use. Several papers from *JASA* are cited in this *Workbook*.

- The Journal of the Acoustical Society of America (*JASA*)
  2 Huntington Quadrangle
  Melville, NY 11747-4502

- Canadian Acoustics
  P.O. Box 1351, Station F
  Toronto, Ontario, M4Y 2V9, CANADA

- Journal of the Audio Engineering Society (*JAES*)
  60 East 42nd Street
  New York, NY 10165-2520

- Sound & Video Contractor
  P.O. Box 12960
  Overland Park, KS 66282-2960

- Noise Control Engineering Journal (*NCEJ*)
  P.O. Box 220
  Saddle River, NJ 07458

- Sound and Vibration
  P.O. Box 40416
  Bay Village, OH 44140

- Sound & Communications
  25 Willowdale Avenue
  Port Washington, NY 11050

ACOUSTICAL SOCIETY OF AMERICA PUBLICATIONS ON ACOUSTICS

ACOUSTICAL DESIGN OF MUSIC EDUCATION FACILITIES, Edward R. McCue and Richard H. Talaske, Eds. Plans, photographs, and descriptions of 50 facilities from around the world, with supplementary explanatory text and essays on the design process. 236 pp, paper 1990. Price: ASA members $20; Nonmembers $26. **Item # 0-88318-8104**

ACOUSTICAL DESIGNING IN ARCHITECTURE, Vern O. Knudsen and Cyril M. Harris. Comprehensive, non-mathematical treatment of architectural acoustics; covers general principles of acoustical designing with specific applications. 408 pp, paper 1980 (originally published 1950). Price: ASA members $20; Nonmembers $26. **Item # 0-88318-267X**

ACOUSTICAL MEASUREMENTS, Leo L. Beranek. Classic text with more than half the pages and chapters revised or rewritten to cover new developments in acoustical instruments and measurement procedures. 841 pp, hardcover 1989 (originally published 1948). Price: ASA members $35; Nonmembers $46. **Item # 0-88318-5903**

ACOUSTICS, Leo L. Beranek. Indispensable source of practical acoustical concepts and theory, with new information on microphones, loudspeakers and speaker enclosures, room acoustics, and acoustical applications of electro-mechanical circuit theory. 491 pp, hardcover 1986 (originally published 1954). Price: ASA members $25; Nonmembers $33. **Item # 0-88318-494X**

ACOUSTICS—AN INTRODUCTION TO ITS PHYSICAL PRINCIPLES AND APPLICATIONS, Allan D. Pierce. Textbook introducing the physical principles and theoretical basis of acoustics, concentrating on concepts and points of view that have proven useful in applications such as noise control, underwater sound, architectural acoustics, audio engineering, nondestructive testing, remote sensing, and medical ultrasonics. Supplemented by problems answers. 678 pp, hardcover 1989 (originally published 1981). Price: ASA members $30; Nonmembers $39. **Item # 0-88318-6128**

ACOUSTICS, ELASTICITY AND THERMODYNAMICS OF POROUS MEDIA: TWENTY-ONE PAPERS BY M. A. BIOT, Ivan Tolstoy, Ed. This collection of reprint articles presents Biot's theory of porous media with applications to acoustic wave propagation, geophysics, seismology, soil mechanics, strength of porous materials, and viscoelasticity. 272 pp, hardcover 1991. Price: ASA members $25; Nonmembers $33. **Item # 1-56396-0141**

ACOUSTICS OF AUDITORIUMS IN PUBLIC BUILDINGS, Leonid I. Makrinenko, John S. Bradley, Ed. Presents developments resulting from studies of building physics; attempts to elucidate problems related to acoustical quality in halls of public buildings. 172 pp, hardcover 1994 (originally published 1986). Price: ASA members $35; Nonmembers $46. **Item # 1-56396-3604**

ACOUSTICS OF WORSHIP SPACES, David Lubman and Ewart A. Wetherill, Eds. Drawings, photographs, and accompanying data of worship houses provide vital information on problems and answers concerning the acoustical design of chapels, churches, mosques, temples, and synagogues. 91 pp, paper 1985. Price: ASA members $20; Nonmembers $26. **Item # 0-88318-4664**

ASA EDITION OF SPEECH AND HEARING IN COMMUNICATION. Harvey Fletcher; Jont B. Allen, Ed. Summary of Harvey Fletcher's 33 years of acoustics work at Bell Labs. A new introduction, index, and complete bibliography of Fletcher's work are important additions to this classic volume. 487 pp, hardcover 1995 (originally published 1953). Price: ASA members $38; Nonmembers $49. **Item # 1-56396-3930**

AEROACOUSTICS OF FLIGHT VEHICLES: THEORY AND PRACTICE, Harvey H. Hubbard, Ed. This two-volume set is oriented toward flight vehicles and emphasizes the underlying concepts of noise generation, propagation, predicting and control. Volume 1 includes ten chapters that relate directly to the sources of flight vehicle noise such as Propeller and Propfan Noise, Rotor Noise, Sonic Boom. Volume 2 contains eight chapters that relate to flight vehicle noise control and operations such as Atmospheric Propagation, Jet Noise Suppression, Interior Noise. Vol. 1-589 pp/Vol. 2 426 pp, hardcover 1994 (originally published 1991). Price per 2-vol. set: ASA members $55; Nonmembers $72. **Item # 1-56396-404X**

COLLECTED PAPERS ON ACOUSTICS, Wallace Clement Sabine. Classic work on acoustics for architects and acousticians. 304 pp, hardcover 1993 (originally published 1921). Price: ASA members $25; Nonmembers: $33. **Item # 0-932146-600**

CONCERT & OPERA HALLS: HOW THEY SOUND. Leo L. Beranek. Extensively illustrated guide to the world's important concert and opera halls, examining their acoustical quality as judged by conductors and music critics. Descriptions and photographs of 76 concert and opera halls and appendices on modern acoustical data on 80 halls included. 643 pp, hardcover 1996. Price: ASA members $39.95; Nonmembers $49.95. **Item # 1-56396-5305**

THE EAR AS A COMMUNICATION RECEIVER. Eberhard Zwicker and Richard Feldtkeller. Das Ohr Als Nachrichtenempfänger, the original title of this classic text, was published in 1967. This English-language translation is written as a textbook aimed at communication engineers and sensory psychologists alike. The book is respected for its comprehensive coverage of the excitation pattern model and loudness calculation schemes and is an excellent source of experimental data, which are presented in 217 figures. 297 pp, hardcover 1999. Price: ASA members $50; Nonmembers $70. **Item # 1-56396-881-9**

ELECTROACOUSTICS: THE ANALYSIS OF TRANSDUCTION, AND ITS HISTORICAL BACKGROUND, Frederick V. Hunt. Comprehensive analysis of the conceptual development of electroacoustics including the origins of echo ranging, the crystal oscillator, the evolution of the dynamic loudspeaker, and electromechanical coupling, 260 pp, paper 1982 (originally published 1954). Price: ASA members $20; Nonmembers $26. **Item # 0-88318-401X**

EXPERIMENTS IN HEARING, Georg von Békésy. A classic on hearing containing some of the vital roots of contemporary auditory knowledge. 760 pp, paper 1989 (originally published in 1960). Price: ASA members $20; Nonmembers $26. **Item # 0-88318-6306**

HALLS FOR MUSIC PERFORMANCE: TWO DECADES OF EXPERIENCE, 1962–1982, Richard H. Talaske, Ewart A. Wetherill, and William J. Cavanaugh, Eds. Drawings, photographs, and technical and physical data on 80 halls; examines standards of quality and technical capabilities of performing arts facilities. 192 pp, paper 1982. Price: ASA members $20; Nonmembers $26. **Item # 0-88318-4125**

HANDBOOK OF ACOUSTICAL MEASUREMENTS, THIRD EDITION, Cyril M. Harris. Comprehensive coverage of noise control and measuring instruments in a single volume containing over 50 chapters written by top experts in the field. 1024 pp, hardcover 1998 (originally published in 1991). Price: ASA members $49; Nonmembers $70. **Item # 1-56396-774**

HEARING: ITS PSYCHOLOGY AND PHYSIOLOGY, Stanley Smith Stevens and Hallowell Davis. This volume leads readers from the fundamentals of the psychophysiology of hearing to a complete understanding of the anatomy and physiology of the ear. 512 pp, paper 1983 (originally published 1938). Price: ASA members $20; Nonmembers $26. **Item # 0-88318-4265**

NONLINEAR ACOUSTICS, Robert T. Beyer. A concise overview of the depth and breadth of nonlinear acoustics with an appendix containing references to new developments. 452 pp., hardcover, 1997 (originally published in 1974). Price: ASA members $40; Nonmembers: $55. **Item # 1-56396-724-3**

NONLINEAR UNDERWATER ACOUSTICS, B. K. Novikov, O. V. Rudenko, V. I. Timoshenko. Translated by Robert T. Beyer. Applies the basic theory of nonlinear acoustic propagation to directional sound sources and receivers, including design nomographs and construction details of parametric arrays. 272 pp, paper 1987. Price: ASA members $30; Nonmembers $39. **Item # 0-88318-5229**

OCEAN ACOUSTICS, Ivan Tolstoy and Clarence S. Clay. Presents the theory of sound propagation in the ocean and compares the theoretical predictions with experimental data. Updated with reprints of papers by the authors supplementing and clarifying the material in the original edition. 381 pp, paper 1987 (originally published 1966); Price: ASA members $20; Nonmembers $26. **Item # 0-88318-527X**

ORIGINS IN ACOUSTICS, Frederick V. Hunt. History of acoustics from antiquity to the time of Isaac Newton. 224 pp, hardcover 1992. Price: ASA members $15; Nonmembers $20. **Item # 0-300-022204**

PAPERS IN SPEECH COMMUNICATION. Three-volume series containing reprint papers charting four decades of progress in understanding the nature of human speech production and perception, and in applying this knowledge to problems of speech processing. Contains important papers from a wide range of journals from such fields as engineering, linguistics, physics, psychology, and speech and hearing science. 1991, hardcover.

Speech Production, Raymond D. Kent, Bishnu S. Atal, Joanne L. Miller, Eds. 880 pp. **Item # 0-88318-9585**

Speech Perception, Joanne L. Miller, Raymond D. Kent, Bishnu S. Atal, Eds., 874 pp. **Item # 0-88318-9593**

Speech Processing, Bishnu S. Atal, Raymond D. Kent, Joanne L. Miller, Eds. 672 pp. **Item # 0-88318-9607**

3-volume set. **Item # 0-88318-KIT**

Price: ASA members $35 ea.; $95 for three-volume set. Nonmembers $46 ea.; $129 for three-volume set.

RESEARCH PAPERS IN VIOLIN ACOUSTICS 1975–1993. Carleen M. Hutchins, Ed., Virginia Benade, Assoc. Ed. Contains 120 definitive research papers with an annotated bibliography of over 400 references. Introductory essay relates the development of the violin to the scientific advances from the early 15th Century to the present. Vol. 1, 656 pp; Vol. 2, 656 pp. hardcover 1996. Price: ASA members: $120 for the two-volume set; Nonmembers: $155 for the two-volume set. **Item # 1-56396-6093**

THE SABINES AT RIVERBANK. John W. Kopec. The history of Riverbank Laboratories and the role of the Sabines (Wallace Clement, Paul Earls, and Hale Johnson) in the science of architectural acoustics. 210 pp. hardcover 1997. Price: ASA members: $15, Nonmembers: $20. **Item # 0-932146-61-9**

SOUND, STRUCTURES, AND THEIR INTERACTION, Miguel C. Junger and David Feit. Covers theoretical acoustics, structural vibrations, and the interaction of elastic structures with an ambient acoustic medium. 451 pp, hardcover 1993 (originally published 1972). Price: ASA members $20; Nonmembers $26. **Item # 0-262-100347**

THEATRES FOR DRAMA PERFORMANCE: RECENT EXPERIENCE IN ACOUSTICAL DESIGN, Richard H. Talaske and Richard E. Boner, Eds. Plans, photographs, and descriptions of theatre designs, supplemented by essays on theatre design and an extensive bibliography. 167 pp, paper 1987. Price: ASA members $20; Nonmembers $26. **Item # 0-88318-5164**

VIBRATION AND SOUND, Philip M. Morse. Provides students and professionalswith the broad spectrum of acoustics theory, including wave motion, radiation problems, the propagation of sound waves, and transient phenomena. 468 pp, hardcover 1981 (originally published 1936). Price: ASA members $25; Nonmembers $33. **Item # 0-88318-2874**

VIBRATION OF PLATES, Arthur W. Leissa. 353 pp, hardcover 1993 (originally published 1969). **Item # 1-56396-2942**

VIBRATION OF SHELLS, Arthur W. Leissa. 428 pp, hardcover 1993 (originally published 1973). **Item # 1-56396-2934**

Monographs dedicated to the organization and summarization of knowledge existing in the field of continuum vibrations. Price: ASA members $25 ea.; $45 for two-volume set. Nonmembers $33 ea.; $59 for two-volume set. **SET ITEM # 1-56396-KIT**

VIDEOTAPES, COMPACT DISC, AND CD ROMS

Measuring Speech Production. Maureen Stone, producer. Three-tape collection containing demonstrations for use in teaching courses on speech acoustics, physiology, and instrumentation. Includes text booklet describing the demonstrations and bibliographies for additional information. Issued in 1993. Price: VHS format $47.00 per set: PAL format $56.00 per set. **Item # MSP-VD-KIT**

Speech Perception. A video presentation by Patricia K. Kuhl on Speech Perception. Segments include the following: I. General Introduction to Speech/Language processing: Academic, business and society interest in this topic; Spoken Language Processing; II. Classic Issues in Speech Perception; III. Phonetic Perception; IV. Model of Developmental Speech Perception; V. Cross-modal speech perception: Links to production; VI. Biology and Neuroscience Connections; VII. Summary and Conclusions. Issued in 1997. VHS format. Price: $75.00. **Item # SP-VID**

Auditory Demonstrations on Compact Disc. A useful teaching adjunct for lectures or a course on hearing and auditory effects, and provides signals for teaching laboratories. Contains 39 sections demonstrating various characteristics of hearing. Includes text booklet containing introductions and narrations of each topic and bibliographies for more detailed information. Issued in 1989. Price: ASA members $20; Nonmembers $26. **Item # AD-CD-BK**

Proceedings of the Sabine Centennial Symposium on CD ROM. Contains proceedings of the Sabine Centennial Symposium held in June 1994 plus proceedings of several conferences published by the Institute of Noise Control Engineering including INTER-NOISE 95, ACTIVE 95, and INTER-NOISE 94. Also contains a catalog of standards published by the ASA with links to the abstracts of the standards. Price: $95. **Item # INCE25-CD**

ORDER FORM

1. Payment must accompany all orders. Payment may be made by check or international money order in U.S. funds drawn on U.S. bank or by VISA, MasterCard, or American Express credit card.
2. Orders should be sent to Acoustical Society of America, Publications, P. O. Box 1020, Sewickley, PA 15143-9998; Tel.: 412-741-1979; Fax: 412-741-0609.
3. A 10% discount applies on orders of 5 or more copies of the same title only. Discount does not apply to JASA CD ROM.
4. Postage and handling charges (surface mail): U.S. orders—$5.00 for first item and $2.00 each additional item. Non-U.S.orders—$9.00 for first item $3.00 each additional item. Call for prices for UPS or priority delivery.
5. Returns are not accepted.

Name ______________________ ☐ ASA member ☐ Nonmember

Address ______________________

____

City ________ State ________ ZIP ________ Country ________

Tel.: ________ Fax: ________

Please send me the following:

Quantity	*Item #*	*Publication*	*Unit price*	*Total Cost*
			Subtotal	
			Deduct 10% discount for 5 or more copies of same title (see #3 above)	
			Postage and Handling (see #4 above)	
			TOTAL	

☐ Check or money order enclosed for $ ________ (U.S. funds/drawn on U.S. bank)

☐ American Express ☐ VISA ☐ MasterCard Signature ______________________

(Credit card orders must be signed)

Account # ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐ Expires Mo. ☐☐ Yr. ☐☐

The NOISE-CON Series of National Conferences on Noise Control Engineering

A National Conference on Noise Control Engineering (NOISE-CON) is sponsored by the Institute of Noise Control Engineering in the years when the International Congress on Noise Control Engineering (INTER-NOISE) is held overseas. The series began in 1973. The Proceedings of these conferences have proved to be a valuable source of information on national noise control technology. The Proceedings of most of these conferences are available for immediate shipment from the Institute of Noise Control Engineering. The proceedings which have been published as a multi-volume set are available only as a multi-volume set.

NOISE-CON 98

Theme: *Transporting Noise Control to the 21st Century: Planning for a Quiet Future*

Proceedings edited by J. Stuart Bolton and Luc Mongeau
xviii + 679 pp., softcover 8 1/2" x 11"
Held in Ypsilanti Michigan on 1998 April 5-8 in conjunction with the 1998 Sound Quality Symposium. One hundred and twelve papers related to control of transportation noise sources, information technology equipment, machinery noise, community noise, structure-borne noise, and other topics.

NOISE-CON 97

Theme: *Frontiers of Noise Control*

Proceedings Book 1 edited by Courtney B. Burroughs. Book 2 edited by Scott Sommerfeldt.
Softcover, 8 1/2" x 11". Book 1, *xviii* + 554 pp. devoted to numerical methods for noise control, machinery diagnostics, and general noise control engineering. Book 2, *xiv* + 386 pp. devoted to active noise and vibration control. Held in University Park, Pennsylvania on 1997 June 15-17.

NOISE-CON 96

Theme: *Visions for the Next Twenty-Five Years*

Proceedings edited by James D. Chalupnik, Steven E. Marshall, & Ray C. Klein.
Vol. 1, 520 + *xxi* pp, Vol. 2, 448 + *xxi* pp, softcover, 8 1/2"x11".
Held in Bellevue, Washington on 1996 September 29 - October 02. One hundred and seventy-one papers on all aspects of noise control engineering including aircraft noise control, community noise control, highway and traffic noise, active control methods, automotive sound quality, sound power measurement, room noise criteria, structure-borne noise, noise from weapons, noise from helicopters, noise from rail vehicles, tire/road noise, test facilities and instrumentation, and numerical methods.

NOISE-CON 94

Theme: *Progress in Noise Control for Industry*

Proceedings edited by Joseph M. Cuschieri, Stewart A. L. Glegg, and David M. Yeager.
1060 + *xxvii* pp, softcover, 6x9.
Held in Fort Lauderdale, Florida on 1994 May 01-04. One hundred and sixty five papers covering all aspects of noise control engineering were presented.

NOISE-CON 93

Theme: *Noise Control in Aeroacoustics*

Proceedings edited by Harvey H. Hubbard
652 + *xx* pp, softcover, 6"x9"
Held in Williamsburg, Virginia on 1993 May 2-5. One hundred and six papers related to aeroacoustics including fan noise control, airport noise monitoring, practical applications of active noise and vibration control, keeping aircraft noise out of buildings, aircraft interior noise, community noise sources, human response to aeroacoustic sources, and jet noise.

NOISE-CON 91

Theme: *Noise Control: Twenty Years of Progress and Future Trends*

Proceedings edited by Daniel A. Quinlan and Marehalli G. Prasad
766 + *xviii* pp, softcover, 6"x9"
Held in Tarrytown, New York on the 20th anniversary of the founding of the Institute of Noise Control Engineering. Eighty seven papers related to noise control policy, quality and noise control, active control of noise, binaural measurement techniques, loudness, sound intensity, noise emission, and computer and business equipment noise control.

NOISE-CON 90

Theme: *Reducing the Annoyance of Noise*

Proceedings edited by Ilene J. Busch-Vishniac
494 + *xviii* pp, softcover, 6"x9"
Held at the University of Texas at Austin, Austin, Texas on 1990 October 15-17. Eighty-one papers related to reducing the annoyance of noise, reduction of environmental noise, vibration of small fans, road traffic noise, annoyance of community noise, loudness, room qualification for determination of noise emission, noise modeling, sound intensity, instrumentation for noise measurements, and statistical energy analysis.

NOISE-CON 88

Theme: *Noise Control Design: Methods and Practice*

Proceedings edited by Stuart Bolton
636 + *xx* pp, softcover, 6"x9"
Held at Purdue University, West Lafayette, Indiana on 1988 June 20-22. One hundred papers on many advanced topics in noise control engineering. Topics include fan noise control, interior noise of aircraft, absorption of sound in the atmosphere, active noise control, the acoustics of open plan offices, sound power determination, acoustic holography and sound intensity.

NOISE-CON 87

Theme: *Advanced Technology for Noise Control*
Proceedings edited by Jiri Tichy and Sabih Hayek
780 + *xx* pp, softcover, 6"x9"
Held at The Pennsylvania State University, State College, Pennsylvania on 1987 June 8-10. One hundred and twenty-five papers on many advanced topics in noise control engineering. Topics include noise emitted by gears, valves and steam tubes, axial and centrifugal fan noise, drill noise, chain saw noise, combustion noise, noise barriers, highway noise, sound absorptive materials, active noise cancellation, noise control of ships, and sound intensity techniques.

NOISE-CON 85

Theme: *Computers for Noise Control*
Proceedings edited by Raj Singh
536 + *xxii* pp, softcover, 6"x9"
Held at the Ohio State University, Columbus, Ohio on 1985 June 3-5. Seventy-five papers related to the use of computers in noise control engineering. Topics covered include numerical methods in noise control, computer aided design and modal analysis, noise control solutions, damping and brake squeal, computer-aided design of ducts and mufflers, signal processing, spreadsheet analysis in noise control and sound intensity measurements.

NOISE-CON 83

Theme: *Quieting the Noise Source*
Proceedings edited by Robert Lotz
490 + *xxii* pp, softcover, 6"x9"
Held at the Massachusetts Institute of Technology, Cambridge, Massachusetts, 1983 March 21-23 Fifty-six papers related to noise control at the source. Among the subjects covered in the Proceedings are noise control of valves and orifices, printer and mechanism noise control, structural design, noise control of fans and turbomachinery, control of noise from air conditioners, motors, transformers and forming machines and tire road interactions.

NOISE-CON 81

Theme: *Applied Noise Control Technology*
Proceedings edited by Larry H. Royster, Franklin D. Hart and Noral D. Stewart
470 + *viii* pp, softcover, 6"x9"
Held at the North Carolina State University, Raleigh, North Carolina on 1981 June 8-10 Eighty-eight papers on a variety of topics related to applied noise control technology. Topics include noise source identification, mufflers, barriers and enclosures, hearing protective devices, community noise control, and applications of damping materials. Papers on noise control in selected industries are also included.

NOISE-CON 79

Theme: *Machinery Noise Control*
Proceedings edited by Joseph W. Sullivan and Malcolm J. Crocker
394 + *x* pp, softcover, 6"x9"
Held at Purdue University, West Lafayette, Indiana on 1979 April 30-May 2. Forty-six technical papers devoted to machinery noise control. Topics include EPA and DOL industrial noise activity, noise control for other industrial machinery and transportation noise control.

NOISE-CON 77

Theme: *Transportation Noise Control*
Proceedings edited by George C, Maling, Jr.
502 + *ix* pp, softcover, 6"x9"
Held at the NASA-Langley Research Center in Hampton, Virginia on 1977 October 17-19. thirty-six technical papers related to transportation noise control. Topics include government programs in transportation noise, noise impact and environments, prediction of noise levels, surface vehicle noise, transit system noise including wheel/rail noise, traffic noise prediction, aircraft noise, aircraft engine noise control, and airport noise monitoring.

NOISE-CON 75

Theme: *Standards, Regulations, and Federal Programs for Noise Control*
Proceedings edited by William W. Lang
458 + *ix* pp, softcover, 6"x9"
Held at the National Bureau of Standards, Gaithersburg, Maryland on 1975 September 15-17. Forty technical papers which cover five broad areas: Distinguished Lectures on noise control engineering, federal programs, international and national standards, professional society activity in noise control and research activities of various organizations.

NOISE-CON 73

Theme: *General Noise Control Engineering: Programs for Noise Control*
Proceedings edited by David R. Tree
578 + *xiv* pp, softcover, 7"x10"
Held in Washington, DC on 1973 October 15-17. Ninety-four technical papers devoted to specialized topics in noise control engineering. Subjects include the impact of state and local regulation, truck noise, the design of highways to reduce noise, design of new facilities for noise reduction, machinery noise control, acoustical technology in buildings, machinery noise problems in buildings, and construction methods and materials to reduce building noise.

The INTER-NOISE Series of International Congresses on Noise Control Engineering

The INTER-NOISE Series of International Conferences on Noise Control Engineering began in the United States in 1972. Since 1972, the conferences have been held each year either in the United States or overseas. The Proceedings of these conferences have proved to be a valuable source of information on world-wide noise control technology. The Proceedings of most of these conferences are available for immediate shipment from the Institute of Noise Control Engineering. Those Proceedings which have been published as a multi-volume set are available only as multi-volume set.

INTER-NOISE 98. Held in Christchurch, New Zealand on 1998 November 16-18. Proceedings edited by V.C. Goodwin and D.C. Stevenson. Vol.1, *xxxiii*+p. 1-578; Vol.2, *xxxiii*+p.597-1210; Vol. 3, *xxxiii*+p.1219-1738. ISBN 0-473-05439-6 (set of three volumes).

INTER-NOISE 97. Held in Budapest, Hungary on 1997 August 25-27. Proceedings edited by Fulöp Augusztinovicz. Vol. 1, *xxxii* + pp 1-592, Vol.2, *xxx* + pp 593-1174, Vol. 3, *xxx* + pp 1175-1744, ISBN 963 8241 62 0 (Set of three volumes)

INTER-NOISE 96. Held in Liverpool, United Kingdom on 1996 July 30- August 02. Proceedings edited by F. Allison Hill and Roy Lawrence. Book 1, pp 1-544, Book 2, pp 545-1050, Book 3, pp 1051-1648, Book 4, pp 1649-2188, Book 5, pp 2189-2780, Book 6, pp 2781-3362. ISBN 1 873082 91 6 (Set of six volumes).

INTER-NOISE 95. Held in Newport Beach, California, USA on 1995 July 10-12. Proceedings edited by Robert J. Bernhard and J. Stuart Bolton. 324 papers. Vol. 1, *xxxii* + 716 technical pages, Vol. 2, *xxiv* + 734 technical pages. ISBN 0-931784-32-8 (set of two volumes).

INTER-NOISE 94. Held in Yokohama, Japan on 1994 August 29-31. Proceedings edited by Sonoko Kuwano. 488 papers. Vol 1, xlvi + 716 technical pages, Vol 2, *xxiv* + 706 technical pages, Vol. 3, *xxiv* + 718 technical pages. ISBN 9900282-4-4 (set of three volumes).

INTER-NOISE 93. Held in Leuven, Belgium on 1993 August 24-26. Proceedings edited by Pierre Chapelle and Gerrit Vemier. 404 papers. Vol. 1, xl + 632 technical pages, Vol. 2, xl + 622 technical pages, Vol. 3, xl + 642 technical pages. ISBN 90-5204-024-9 (set of three volumes).

INTER-NOISE 92. Held in Toronto, Canada on 1992 July 20-22. Proceedings edited by Gilles A. Daigle and Michael R. Stinson. 270 papers; Vol. 1 *xxxii* + 636 technical pages, Vol. 2 *xxxii* + 628 technical pages. ISBN 0 931784-25-5 (set of two volumes).

INTER-NOISE 91. Held in Sydney, Australia on 1991 December 2-4. Proceedings edited by Anita Lawrence. 311 papers; Vol. 1, xviii + 746 technical pages, Vol. 2, xvi + 543 technical pages. ISBN 0-909882 12 6 (set of two volumes).

INTER-NOISE 90. Held in Gothenburg, Sweden on 1990 August 13-15. Proceedings edited by Hans Jonassen. 331 papers; Vol. 1, *xxii* + 710 technical pages, Vol. 2, *xxii* + 734 technical pages. ISBN: 91-7848-224-0 (set of two volumes). ISSN 0105-175X.

INTER-NOISE 89. Held in Newport Beach, California on 1989 December 4-6. Proceedings edited by George C. Maling, Jr. 263 papers; Vol. 1, xl + 700 technical pages, Vol. 2, xl + 612 technical pages. ISBN: 0-931784- 20-4 (set of two volumes). ISSN: 0105-175X.

INTER-NOISE 88. Held in Avignon, France on 1988 30 August-1 September. Proceedings edited by Michael Bockhoff. 396 papers; Vol. 1, *xxi* + 598 technical pages, Vol. 2, *xxi* + 568 technical pages, Vol. 3, *xxi* + 572 technical pages. ISSN: 0105-175X. Set of three volumes.

INTER-NOISE 87. Held in Beijing, China on 1987 September 15-17. Proceedings edited by Li Pei-zi. 412 papers; Vol. 1, *xxxvi* + 878 technical pages, Vol. 2, *xxxvi* + 806 technical pages. Set of two volumes.

INTER-NOISE 86. Held in Cambridge, Massachusetts, USA on 1986 July 21-23. Proceedings edited by Robert Lotz. 271 papers; Vol. 1, *xxxv* + 796 pp., Vol. 2, *xxxv* + 676 pp. ISBN: 0-931784-15-8 (set of two volumes). ISSN: 0105-175X.

INTER-NOISE 85. Held in Munich, Federal Republic of Germany on 1985 September 18-20. Bundesanstalt fur Arbeitsschutz, Ed. 351 papers; Vol 1, viii + 740 pp., Vol 2, viii + 760 pp. Set of two volumes.

INTER-NOISE 84. Held in Honolulu, Hawaii, USA on 1984 December 3-5. Proceedings edited by George C. Maling, Jr. 299 papers; Vol 1, *xxxviii* + 748 pp., Vol 2, *xxxvii* + 678 pp. ISBN: 0-931784-11-5 (set of two volumes). ISSN: 0105-175X

INTER-NOISE 83. Held in Edinburgh, Scotland on 1983 July 13-15. Proceedings edited by R. Lawrence. 294 papers; Vol. 1, lii + 552 pp., Vol 2, xliii + 690 pp. ISBN 0-946731-00-4 (set of two volumes).

INTER-NOISE 82. Held in San Francisco, California, USA on 1982 May 17-19. Proceedings edited by J.G. Seebold. 198 papers; Vol. 1, *xxxiv* + 358 pp., Vol 2, *xxxiv* + 506 pp. ISBN: 0-931784-07-7 (set of two volumes).

INTER-NOISE 81. Held in Amsterdam, The Netherlands on 1981 October 6-8. Proceedings edited by A. DeBruijn. 248 papers: Vol. 1, *xxxiv* + 592 pp., Vol II, *xxxiv* + 550 pp. ISBN: 90-9000-222-7 (set of two volumes).

INTER-NOISE 80. Held in Miami, Florida, USA on 1980 December 8-10. Proceedings edited by George C. Maling, Jr. 253 papers; Vol. 1, *xxxvi* + 556 pp., Vol. 2., *xxxvi* + 638 pp. Library of Congress Catalog Number: 72-91606, ISBN: 0-931784-03-4 (set of two volumes).

INTER-NOISE 79. Held in Warsaw, Poland on 1979 September 11-13. Proceedings edited by Stefan Czarnecki. 182 papers; Vol. 1, *xxiii* + 474 pp., Vol. 2, *xxiii* + 470 pp. ISSN: 0105-175X. Set of two volumes.

INTER-NOISE 78. Held in San Francisco, California, USA on 1978 May 8-10. Proceedings edited by William W. Lang. 166 papers, *xxx* + 1058 pp. Library of Congress Catalog Number: 78-55436, ISBN: 0-931784-00-X, ISSN: 0105-175X.

INTER-NOISE 77. Held in Zurich, Switzerland on 1977 March 1-3. Proceedings edited by Eric J. Rathe. 138 papers, *xxiv* + 986 pp.

INTER-NOISE 76. Held in Washington, DC, USA on 1976 April 5-7. Proceedings edited by R. Kerlin. 129 papers, *xxxi* + 529 pp. Library of Congress Catalog Number: 762229.

INTER-NOISE 75. Held in Sendai, Japan on 1975 August 27-29. Proceedings edited by Ken'iti Kido. 147 papers, *xxvi* + 760 pp.

INTER-NOISE 74. Held in Washington, DC, USA on 1974 September 30-October 02. Proceedings edited by John C. Snowdon. 140 papers, *xxxi* + 660 pp. Library of Congress Catalog Number: 72-91606.

INTER-NOISE 73. Held in Copenhagen, Denmark on 1973 August 22-24. Proceedings edited by O. J. Petersen. 96 papers, *xviii* + 634 pp.

INTER-NOISE 72. Held in Washington, DC, USA on 1972 October 4-6. Proceedings edited by Malcolm J. Crocker. 92 papers, *xv* + 565 pages. Library of Congress Catalog Number: 72-91606.

10.0 THE ROBERT BRADFORD NEWMAN STUDENT AWARD FUND

THE ROBERT BRADFORD NEWMAN STUDENT AWARD FUND

Background

In 1985, a Student Award Fund in memory of Robert Bradford Newman was established to recognize merit in architectural acoustics.

For over thirty years, Robert Bradford Newman was a faculty member in the School of Architecture and Planning, Massachusetts Institute of Technology and in the Graduate School of Design, Harvard University and a founding partner of the consulting firm, Bolt Beranek and Newman Inc. He was widely known as a teacher with extraordinary ability to communicate the essentials of architectural acoustics. In both teaching and consulting, his work enhanced knowledge in architectural acoustics and encouraged others to study and to seek practical solutions.

The Newman Student Medal for "Merit in Architectural Acoustics" was established to strengthen the tradition of excellence in the study and teaching of architectural acoustics, which began with outstanding teachers such as Wallace Clement Sabine, Vern Oliver Knudsen, Charles Paul Boner, and was extended by Professor Newman.

The Fund annually provides Medal awards to honor outstanding students at qualifying institutions throughout the world and the Schultz Grant to support teachers and researchers in architectural acoustics. The Fund is a continuing tribute to this distinguished teacher whose enthusiasm and personal warmth inspired generations of students.

Robert Bradford Newman •1917–1983

A paraphrase of the Acoustical Society's stated purpose, *to increase and diffuse the knowledge of architectural acoustics and to promote its applications in the practice of architecture,* personifies the professional life of Robert Bradford Newman. His death on 2 October 1983 in Lincoln, Massachusetts, left an irreparable void in the lives of his family, friends, students, faculty colleagues, and fellow architects and acousticians.

Bob Newman was born 5 November 1917, in Ungkung, Kwangtung Province, China. He was the first of four sons of medical missionary parents, Henry Ware Newman, M.D., and Ethel Smith Newman. When the family returned to the United States in 1925, Bob was speaking Chinese like a Mandarin and English like a teacher of grammar, capabilities that led to his amusing mixture of tongues at parties and his compelling insistence on correct usage of written and spoken English.

In 1938 Bob graduated from the University of Texas with a B.A. degree in physics, in which he also received an M.A. degree in 1939. There he studied under and worked with Professor Charles Paul Boner, 25th ASA President, who inspired Bob to develop a life-long love of architectural acoustics. From Professor Boner he acquired a professional skill in tuning organs and a strikingly effective style of teaching by use of amusing anecdotes to illustrate important points and drive them home.

After receiving his degrees in Texas, Bob went east to work at RCA, where during 1939–40 he started applying his knowledge of acoustics to the solution of communications problems. In 1941 he went to the Harvard Electro-Acoustics Laboratory under the direction of Dr. Leo L. Beranek, to work on problems of voice communication in noisy combat vehicles. As an expert in testing microphones and loudspeakers, Bob ran the electroacoustic testing facility for the Laboratory. Because of this special capability, Bob was "drafted" in 1943 to upgrade and manage the electroacoustic transducer test facility at the Naval Aeronautics Engineering Station in Philadelphia, where he worked until the end of the war. During these years, Bob formed friendships with many acoustic workers in war-time laboratories, including persons whom he would join later as colleagues throughout the rest of his life.

In January 1946 Bob enrolled in the Physics Department at M.I.T. to obtain a doctor's degree under Professor Richard H. Bolt, then Director of the Acoustics Laboratory. Upon learning that Dick had received a degree in architecture before he obtained his degrees in physics, Bob asked whether he should take some courses in architecture and Dick encouraged him to do so. He did, and he never returned to physics.

In 1949 he was awarded a master's degree in architecture, only three years after starting with no previous study in the field. Even so, his academic performance was of such high quality that he was immediately offered a faculty post in the M.I.T. Department of Architecture, where he served successively as Instructor, Assistant Professor, and Associate Professor until 1976, and then as Adjunct Professor the rest of his life.

The other major event that followed directly after Bob received his master's degree was his entry into a lifelong association with an organization devoted to acoustics. Together, Leo Beranek, who was then a professor in the M.I.T. Electrical Engineering Department, and Dick Bolt invited Bob to become the third partner in the firm they had formed in order to undertake the acoustics consulting on the United Nations Permanent Headquarters. Thus was formed Bolt Beranek and Newman Inc., in which Bob conducted a vigorous consulting practice until his death. He also had been a Senior Vice President and a member of the Board of Directors.

In his first teaching assignment at M.I.T. he took on the architectural acoustics course that Dick had started earlier, and Bob then molded it into an extraordinarily effective and popular course. He gave his last lecture in that course four days before he died.

Further to express his love of teaching, Bob started lecturing at other academic institutions. Throughout his career he lectured at several dozen universities including the Universities of Arkansas, Auburn, California, Guadalajara, Minnesota, Nebraska, Oregon, Pennsylvania, Princeton, Singapore, Texas, Toronto, Utah, and Yale.

In parallel with his academic duties at M.I.T., Bob enjoyed a special relation with Harvard. There he was Visiting Lecturer in Acoustics from 1955 to 1971, and then was appointed Professor of Architectural Technology, the position he held until his death.

Today thousands of his former students in many countries around the world, including "students" who were consulting clients as well as attendees at lecture series and seminars in meetings of the AIA and other organizations—all who heard him lecture remember Bob's amusing disdain of old saws such as "sound is round" and "wood is good." They would not dare put "fuzz" on the ceiling of a church or lecture hall. They would stop short of making "stupid" acoustical mistakes when they remembered his sometimes hilarious presentations, such as vocally mimicking noise sources. Of course what made his approach so effective were the great clarity, precision, authenticity, and empathy with which he conveyed the information.

Bob's consulting achievements in acoustical designing are well known to the architectural profession, both from his many articles and technical papers published in the architectural literature and from published credits to his participation in a large number of architectural projects. A modest sample of projects on which he worked would include the following ones, starting with some of his earliest work and ending with recent projects: Aula Magna in Caracas, Oberlin College School of Music, TWA Terminal at JFK Airport, Air Force Academy, World Zionist Congress Hall in Jerusalem, First and Second Unitarian Church in Boston, Art Gallery At Yale, Goa Art Center in Goa, India, Musical Arts Center at Indiana University, Hall of Energy in Boston Museum of Science, the Rotunda at University of Virginia, Sydney Myer Music Bowl in Melbourne, State Secretariat Assembly in Shah Alam, Malaysia, Knesset Building in Jerusalem, Roy Thomson Hall in Toronto, Davies Symphony Hall in San Francisco, Victorian Arts Center in Melbourne, the Meyerhoff Hall in Baltimore, and projects not completed when Bob died, including the TVA Office of Power in Chattanooga. Beyond these and other projects in which Bob was the sole or major consultant, he contributed to very many team projects.

In his distinctive style of professional activity, Bob increased, diffused, and applied knowledge through a continuous, unified process. His projects were simultaneously sources of new data and insights, examples for students, and acoustically advanced facilities for clients. He often said "real buildings with real people using them are our research laboratories." His students were not only persons enrolled in college but also architects designing buildings. In discussing the relatively low level of acoustic literacy generally, his family background showed through when he talked about "converting the great unwashed architectural profession."

A quantitative review of Bob's career in teaching and consulting suggests that he established a unique record. He instructed several thousand students in architectural acoustics and he worked on several thousand acoustics projects in architecture. This combined achievement might never be surpassed.

Bob was a Fellow of the Acoustical Society of America, and a member of Phi Beta Kappa and Tau Beta Pi. In 1959 he was Senior Fulbright Scholar at the Royal Danish Academy of Fine Arts. He was an honorary member of the Instituto Brasileiro de Acoustica. In 1966, on behalf of Bolt Beranek and Newman Inc., he received the Brown Medal of the Franklin Institute, for contributions to the building industry. He was a director of the Boston Architectural Center, the Carroll School in Lincoln, and the DeCordova Museum, of which he was president 1971–74. In 1977 Bob was awarded the Quarter Century Citation by the Building Research Advisory Board of the National Research Council, for his "significant...contributions to building science and technology."

An event of great significance for Bob took place just four months before he died: he and Mrs. Newman went to China, the land of his birth. Professor Maa Dah-You, head of the Acoustics Institute of the Chinese Academy of Science, invited Bob to give several lectures as a guest of the Ministry of Education. During the period from 15 May to 10 June 1983, Bob lectured at Tongji University in Shanghai, Nanjing Institute of Technology in Nanjing, and Chinghua University in Beijing. During the same period, Bob and Mary visited Zhenjiang and found the hospital and house that had been built for Bob's father. The buildings are still in use as part of a larger hospital complex, the Number 1 People's Hospital.

Professional and academic achievements alone do not mark the full measure of a person. Bob Newman had those added attributes that made him a whole human. His warmth and affection for everything that life offers were thoroughly shared with his beloved wife, Mary Shaw Newman, his sons Henry Ware 2nd of Marblehead, MA and R. Bradford Newman, Jr. of Duxbury, MA, his daughter Catherine N. Kornyei of Lexington, MA, and his four grandchildren.

The Newman's gracious home in Lincoln, Massachusetts served as the focal point for regular social gatherings of Bob's students, consulting colleagues, professional friends, and neighbors. Bob often said he had the house designed with these parties in mind, and he lived life there to the fullest. His consummate friendliness and warmth, his charm and wit, his pleasant irreverence of all things and people he considered "phoney," endeared him to his countless friends and colleagues. His unique place in the history of architectural acoustics is assured.

We are grateful to several colleagues, especially Wm. J. Cavanaugh, for helping us prepare this memoir.

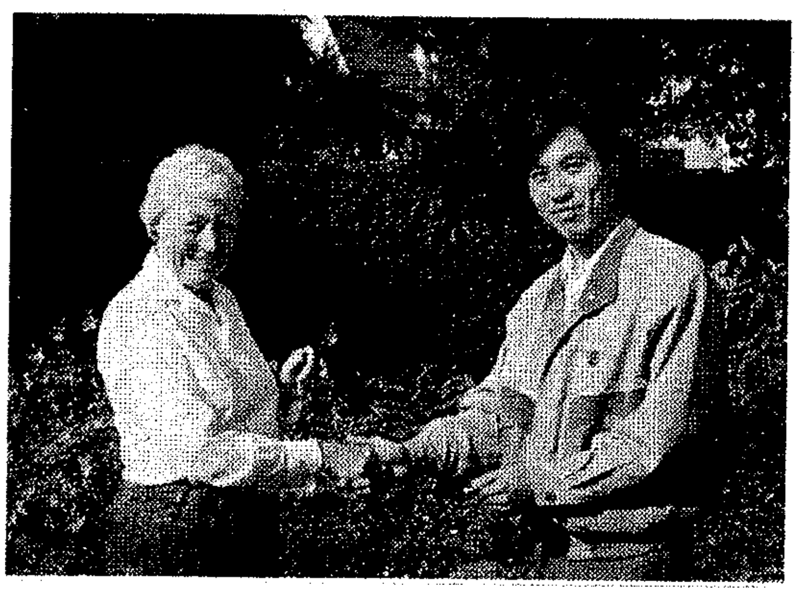
R. H. BOLT AND L. L. BERANEK

REVIEW OF MEDALISTS AND AWARD

During the first fourteen years of the Newman Student Award program, medals have been given to more than 100 students at 32 schools worldwide. Approximately one-third of the student projects involved research projects; the remainder, specific building applications.

In addition to medals, five books have been presented to the medalists. The Acoustical Society of America (ASA) books are:

- *Halls for Music Performance: Two Decades of Experience*, edited by R. H. Talaske, E. A. Wetherill and W. J. Cavanaugh (1982).
- *Acoustics of Worship Spaces*, edited by D. Lubman and E. A. Wetherill (1985).
- *Theaters for Drama Performance: Recent Experience in Acoustical Design*, edited by R. H. Talaske and R. E. Boner (1987).
- *Acoustical Design of Music Education Facilities*, edited by E. R. McCue and R. H. Talaske (1990).
- *Concert and Opera Halls* by L. L. Beranek (1996).



Mary Shaw Newman presenting the medal
to Jian Kang in Cambridge, England

ROSTER OF PARTICIPATING SCHOOLS

United States (26)	Number of Medalists
Berklee College of Music	1
Boston Architectural Center	6
California Polytechnic State University	1
Clemson University	14
Cornell University	1
Georgia Institute of Technology	1
Harvard Graduate School of Design	2
Iowa State University	4
Kent State University	1
Massachusetts Institute of Technology	9
Oklahoma State University	6
Pennsylvania State University	6
Princeton University	9
Rhode Island School of Design	8
Roger Williams University	5
Southern California Institute of Architecture	1
Syracuse University	1
University of Arizona	1
University of California, Los Angeles	1
University of Florida	14
University of Illinois	1
University of Kansas	7
University of Maryland	3
University of North Carolina at Charlotte	3
University of Texas at Arlington	1
Virginia Polytechnic Institute	1

International (6)

École d'Architecture de Paris, France	1
University of Auckland, New Zealand	7
University of Cambridge, England	1
Universidad Ricardo Palma, Lima, Peru	2
University of Waterloo, Ontario, Canada	1
University of Western Australia	1

P.O. Box 6349
Lincoln Center
Massachusetts 01773
Tel: 617-259-9299
FAX 617-259-8136

The Robert Bradford Newman Student Award Fund

The Robert Bradford Newman Medal • For Merit in Architectural Acoustics
The Theodore John Schultz Grant • For Advancement in Acoustical Education

Participating School Information Form

Date: ______________________________

School Name and
Complete Mailing Address: ______________________________
____
____
____________________ (   )

Dean or Department Head: ______________________________
Telephone: (   ) ____________

Principal Faculty Contact
and/or Teacher of Arch.
Acoustics course: ______________________________
Telephone: (   ) ____________
____
Telephone: (   ) ____________

Course Title and Catalog Number in which Architectural Acoustics is included:

____
____
____

Note: Attach course syllabus and other catalog descriptive material as appropriate.

Comments: *(Include any special information on the school's normal practice for presenting awards, contacts at school PR department who should be notified, etc.)*

____
____
____
____

The Greater Boston Chapter Acoustical Society of America with the Cooperation of:

The Association of Collegiate Schools of Architecture • Bolt Beranek and Newman Incorporated • The Boston Architectural Center • Committee on Education in Acoustics ASA • Harvard University Graduate School of Design • Institute of Noise Control Engineering • MIT School of Architecture and Planning • National Council of Acoustical Consultants • Rhode Island School of Design • Riverbank Acoustical Laboratory • Technical Committee on Architectural Acoustics ASA

P.O. Box 6349
Lincoln Center
Massachusetts 01773
Tel: 617-259-9299
FAX 617-259-8136

The Robert Bradford Newman Student Award Fund

The Robert Bradford Newman Medal • For Merit in Architectural Acoustics
The Theodore John Schultz Grant • For Advancement in Acoustical Education

Medalist Candidate Notification Form

Note: Please mail to Newman Student Award Fund, Attention: Mary Newman, approximately six weeks prior to date of award presentation ceremony or date receipt of engraved medal is desired.

Date: ______________________

School Name and Mailing Address: ______________________
____
____
______________ ( )

Faculty Contact: ______________________
Telephone: ( )______________

Medalist Candidate for Academic Year 19______:

Student's Full Name: (to be engraved on medal)
____

Student Mailing Address:
____
______________ ( )

Home (or post-graduation) Mailing Address:
____
______________ ( )

Title of Medalist's Thesis or brief description of Student Work(s) on which award was based:

(When available, please mail reduced copies of drawings and/or project reports to the Fund address above)

____
____
____

EDUCATIONAL MATERIALS ORDER FORM

The following books and VHS tape are available from the Robert Bradford Newman Student Award Fund.

Selection Title	Quantity	Total
Architectural Acoustics-Scale Modeling Demonstrations by Gary W. Siebein VHS tape-$50 Postpaid		
An Appreciation of Acoustics by K. Anthony Hoover $25 Postpaid		
Architectural Acoustics Workbook by M. David Egan $ Postpaid		
Sound Systems Design Guide by Neil Thompson Shade $ Postpaid		
	TOTAL	

Make checks payable to: RBN Award Fund
P.O. Box 6349
Lincoln, MA 01773

Inquiries: TEL 781/259-9299
FAX 781/259-8136

Please return the completed order form with your check or money order. Thank you.

Shipping Information:

Name______________________________

Address____________________________

City_______________________________

State_________ Zip Code_________ Daytime Tel_______________

ANSWERS TO PROBLEM EXERCISES

3.0 BASIC THEORY

3.5: 1. 110 dB; 86 dB; 139 dB; 0 dB.

3.6: 2. 3.16×10^{-2} W/m^2; 7.94×10^{-10} W/m^2; 6.3×10^{-6} W/m^2; 1.0×10^{-12} W/m^2.

3.9: 1. 107 dB. 2. 6.31×10^{-5} W/m^2.

3.10: 3. 1.58×10^{-4} W/m^2. 4. 452 Hz. 5. 69 dB (or 70 dB using different sequence to combine dBs two at a time by method on p. 23 in *Architectural Acoustics*). 6. L = 62 dB. 7. No [See p. 124 in S. S. Stevens and H. Davis, *Hearing*, John Wiley, New York, 1938.]

3.14: 1. L_1 = 60 dB; 12 dB; 15 dB; L_2 = 33 dB; No.

3.15: 2. 8.0×10^{-5} W/m^2. 3. 51 dB at 2000 Hz; L_2 = 39 dB.

3.16: 4. 3.16×10^{-3} W/m^2; 1.0×10^{-8} W/m^2; 11,243 ft (or 11,247 ft, using formula in NOTE).

3.17: 5. 67 dBA. 6. 82 dBA (or 83 dBA). 7. 47 additional tenors.

3.24: A. New Zealand. B. Minneapolis. C. Berlin. D. Baltimore. E. Caracas. F. Toronto.

4.0 STUDENT EXERCISES

4.21: BR is $RT_{125/250} \div RT_{500/1000}$; EDT ÷ RT= 0.9 [according to *in situ* measurements by the Concert Hall Research Group]; IACC (L) < 0.15; NC < 20. [Refer to pp. 411 to 565 in L. L. Beranek, *Concert and Opera Halls*, ASA, Woodbury, NY, 1996.]

5.0 SOUND ABSORPTION

5.6: a_1 = 96 sabins.

5.7: a_2 = 222 sabins; NR = 3.6 dB.

5.10: 1. 360 sabins; 1.11 sec. 2. 840 sabins; 0.48 sec.

5.11: 3. V = 44,400 ft^3; a = 1930.6 sabins; T = 1.15 sec. 4. 0.8 sec 0.5 sec
1.7 sec 2.0 sec

5.12: 5. a_1 = 294 sabins; T_1 = 3.1 sec; a_2 = 1487 sabins; T_2 = 0.61 sec; NR = 6.6 dB. [To avoid prosecution, Inspector Praline from the hygiene squad warned Wizzo to delete the words "crunchy frog" and replace with the legend "crunchy raw unboned real dead frog."]
6. 0.55.

5.13: S_T = 1935 ft^2; a = 1819 sabins.

5.14: 1. Y/N. 2. Y/N. 3. N/Y. 4. N/Y. 5. Y/N. 6. H/L. 7. H/H. [Continental or Conventional seating can be made to work for good sightlines.]

6.0 SOUND ISOLATION

6.6: 1. 51 dB. 2. 30 dB; 45 dB.

6.7: 1. 3.16×10^{-5}; 3.98×10^{-4}; 7.94×10^{-4}.

6.8: 2. 135 ft^2; 24 ft^2; 105 ft^2. 3. 0.00427; 0.00955; 0.08337. 4. 10 log (264 ÷ 0.09719) = 34.3 dB.

6.9: 4. 19.5 dB; 38 dB. 5. NR = 42.3 dB; L_2 = 44.7 dB.

6.12: 1.

< 20	< 30
< 30	< 38
< 45	< 52
< 35	< 42

2. Hissy; 38. 3. Rumbly; 51. 4. 50 dBA. [See p. 346 in *Architectural Acoustics*.]

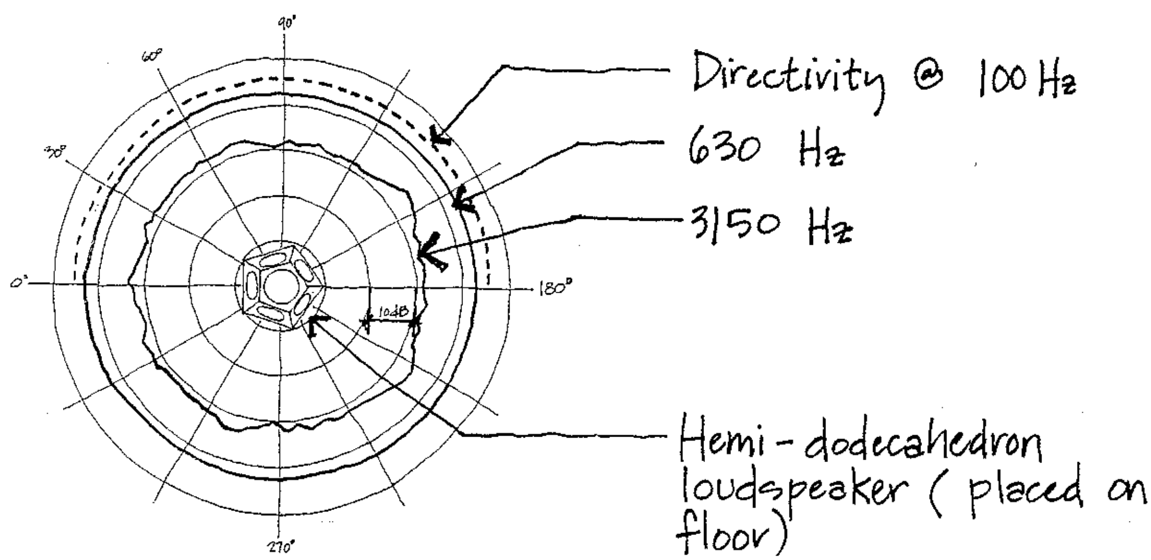
6.14: 5. NR_{500} = 36 dB; NR_{1000} = 54 dB; TL_{500} = 35 dB; TL_{1000} = 52 dB. Use 4" thick reinforced concrete slab. [See Construction No. 33 on p. 205 in *Architectural Acoustics*.]

6.15: 1. 12 dB; H^2/R = 1.6; 8 dB; L = 62 dB; No. 2. 7.5 dB ["He's a lumberjack and he's ok. He sleeps all night and he works all day." See p. 114 in *The Complete Monty Python's Flying Circus, Vol. I*, Pantheon Books, New York, 1989.]

6.19: 1. 4 ft. 2. A_1 = 255 ft^2; A_2/S = 2.0; STC = 46.

7.0 ACOUSTICAL DESIGN PROJECTS

7.28: 1. Use Laura Nash Model in your analysis. [No. Laws are reactive, they set minimum standards for ethical behavior. It may be legal to do something, but not ethical.]; 2. No. [Discuss Kant's categorical imperative.]; 3. For guidance on reporting unethical behavior, see Section 9.031 in AMAs *Code of Medical Ethics*. [No. Without truth there would be no secure professional interaction.]; 4. Yes [No]; 5. Discuss responsibility of custody of submittals to consultant C by consultants A and B. [No]



Directivity Pattern for Hemi-dodecahedron Loudspeaker

AFTERWORD

After completing the projects and problem exercises in the *Workbook*, continue to learn by observing why some acoustical designs are successful while others are not. When possible, question the designers, acoustical consultants, and owners. Learn from the mistakes of others, but do not try to enhance your image by diminishing theirs. Read the articles and books cited throughout the *Workbook*. Select one or two books from the lists in Section 9 to read each year. Look forward also to learning from books that are yet to be written and from designs yet to be built. Find pleasure in your studies and commitment to your chosen profession. Recognize that to be admired as a design professional, decency and integrity are more important than material success. *Bonne chance!*

ABOUT THE AUTHOR

M. David Egan is a Lifetime Distinguished Professor of the Association of Collegiate Schools of Architecture (ACSA), Honorary Member of the American Institute of Architects (AIA), and Professor Emeritus at Clemson University. Professor Egan has lectured and presented seminars at more than forty schools in the US, Canada, France, Saudi Arabia, and Singapore. In 1981, he was elected Fellow of the Acoustical Society of America (ASA) and is Board Certified by the Institute of Noise Control Engineering (INCE). The sole author of six books published in English and foreign language editions by McGraw-Hill, Wiley, and Prentice-Hall; he also has written chapters for *Time-Saver Standards for Architectural Design Data* (McGraw-Hill) and *Architectural Graphic Standards* (Wiley). His South Carolina based consulting firm *Egan Acoustics* has completed a wide variety of building projects throughout the US and abroad, including the US Embassy, Berlin, Germany. During the Cold War, his military service included command of a US Army Ordnance Corps unit stationed in the Forêt de Trois-Fontaines, France. Professor and Mrs. Egan are Honorary Citizens of Déols, France.