ICA 2013 Montreal
Montreal, Canada
2 - 7 June 2013

Architectural Acoustics
Session 3pAAb: Balancing Risk and Innovation in Acoustical Consulting

3pAAb5. Coping with curves in room design
Timothy Foulkes*

*Corresponding author's address: Cavanaugh Tocci Associates, 327F Boston Post Road, Sudbury, MA 01776, tfoulkes@cavtocci.com

Concave curves are pleasing to the eye but create a number of different acoustic anomalies. Depending on the included angle, radius of curvature, finish material, and position relative to source and receiver, one may hear a strong return echo, a noticeable coloration of the frequency balance, a dramatic shift in the acoustic image, or extended reverberation at low frequencies. The effects of standard curved forms such as the Capital dome are well known. These effects are of little consequence in a transient space such as a lobby, but become very important in rooms for speech and music presentation. Covering the entire surface with sound absorbing material is not always the best solution. In most cases the client will want to know the minimum acoustic treatment to avoid complaints. The author will present a series of case studies showing room designs with concave curves and the acoustic solutions.

Published by the Acoustical Society of America through the American Institute of Physics
INTRODUCTION

Concave curves are pleasing to the eye but create a number of different acoustic anomalies. Depending on the included angle, radius of curvature, finish material, and position relative to source and receiver, one may hear a strong return echo, a noticeable coloration of the frequency balance, a dramatic shift in the acoustic image, or extended reverberation at low frequencies. The effects of standard curved forms such as large domes are well known. These effects are of little consequence in a transient space such as a lobby, but become very important in rooms for speech and music presentation. Covering the entire surface with sound absorbing material is not always the best solution. In most cases the client will want to know the minimum acoustic treatment to avoid complaints. The author will present a series of case studies showing room designs with concave curves and the acoustic solutions.

What Is Sound Focusing?

Sound focusing refers to the convergence of sound reflections from a concave surface. The effect on room acoustics takes many forms, depending on the specific dimensions and geometry. The U.S. Capitol building (and many state capital buildings) features a large dome above the main lobby. This often creates a “whispering gallery” in which persons on opposite sides of the room can hear each other whisper even though the lobby is quite active with voices and foot traffic. Smaller domes above church sanctuaries, courtrooms, and other listening spaces can cause significant problems for speech and music, as sound reflections are concentrated in one area of the room while other areas are lack reflected sound. The focused sound often has unnatural frequency response and may arrive late, reducing the clarity.
Anticipating Focusing Problems In Design

During the design of a new project, the potential for focusing exists wherever walls or ceiling have concave curvature. It is easy to see these forms on the drawings, more difficult to decide whether changes are needed to prevent acoustical anomalies that will interfere with speech or music. One must consider the use of the space and the sound reflective characteristics of the curved surface. Other important factors include the location of sources and listeners relative to the center of curvature, and the included angle of the curve. Finally, the strength of the sound focus depends on whether the form is concave in one dimension or two.

ANALYSIS METHODS

Ray Diagrams

The easiest way to analyze the reflection patterns within a room is a ray diagram. Significant focusing will be apparent as an area where the first reflections converge. The reflection pattern will be highly dependent on the source location. There should be a ray diagram for each significant source location. Ray diagrams are quick and easy to draw, and serve as a good visual aid to help explain the potential problem.

Computer Model

Several software packages are available to facilitate visualization of the reflection patterns within the room, calculate reverberation time and other acoustic parameters, and create an aural simulation (auralization) of sound in the room. They allow different design options to be evaluated quickly. Currently popular software packages for acoustic scale modeling include EASE, Odeon, and CATT Acoustic.
CASE STUDIES

A series of case studies is presented to illustrate acoustic design strategies in listening spaces based on the author’s consulting experience. These are supplemented with a few iconic examples of concave curvature in large rooms. These small scale spaces serve as examples of successful acoustics coexisting with concave curvature of the walls or ceiling. Note that by nature of their geometry, it is often difficult to understand these rooms from 2D images.

Mapparium, Mary Baker Eddy Library, Boston, MA

The Mapparium is an exhibit within the Mary Baker Eddy Library in Boston. It consists of a glass sphere, 30 feet in diameter, with a pedestrian bridge running through the center. The sphere is translucent, with a color rendering of a map of the earth showing continents and countries painted on the inside surface. The Mapparium allows visitors to study the earth from the inside of a giant globe, providing a unique perspective. Built in 1935, the Mapparium was not a consulting project for me (or anyone I know), but it serves as a great reference point for studying the effects of acoustical focusing from concave surfaces.

A perfect sphere of glass, the Mapparium is perhaps the ultimate example of sound focusing. The acoustics are as memorable as the visual impact. In my experience, the bridge within the Mapparium was crowded with visitors, which provide sound absorption and some diffusion. I heard a jumble of voices, the auditory location of the voices seemed to be independent of their location within the sphere and, at times it was easier to understand voices from people 15 feet away than from two feet away. The loudness of any one voice seemed to be related to their proximity to the inside surface of the sphere rather than distance.
“Bubble” Conference Rooms, Novartis Pharmaceuticals, Cambridge, MA

These conference rooms at the Novartis Institute in Cambridge, MA are perfectly round in plan, with curved glass walls. Even the sliding glass door is curved at the same radius as the “walls”. The only relief to the curved geometry is an 8 foot wide marker board. The floor is carpet and the ceiling is acoustic tile. There are six of these rooms, each located at the intersections of major corridors.

The acoustics in this room are good, with some minor anomalies. The acoustical effect I found most noticeable during a 45 minute project meeting was image shift. When someone was standing up, speaking near the glass wall, their acoustic image would sometimes shift suddenly as they moved just one foot to the side or turned their head while talking. The main reason these rooms do not have acoustic problems is the large conference table in the center. The table prevents anyone from getting close to the center of curvature. In addition, reverberation is well controlled as a result of the acoustic tile ceiling and carpet. During the design process we created an auralization model using EASE to listen for acoustic problems, especially at the center of the table where a microphone for audio conferencing would be at the focal point. We did not detect any significant problems in the model, even with a virtual listener at the center of the table. After construction, we used the conferencing phone to place a call to one of our experienced AV designers, and he verified that the audio quality was very good with no unusual room sound.
The term “board room” implies a high level of acoustic quality where speech can be understood effortlessly. Many board rooms are fitted with expensive audio systems for teleconferencing, requiring excellent acoustics to achieve good audio at the other end of the phone line. This room is elliptical in plan with a gypsum board ceiling and carpet floor.

This image shows the presentation end of the room. The elliptical shape is apparent when looking at the wall/ceiling joint. A folding marker board built into a flat front storage cabinet that runs floor to ceiling. These elements mitigate the curvature at one end, but the other end is floor to ceiling glass (concave in plan), with no flat or diffusing elements. The curved end has operable curtains to provide visual privacy, and these can also be used to help control sound when needed. The two long “sides” of the room are glass walls curved with a much larger radius, so that the participants are not near the center of curvature. One of these sides has operable curtains, again for visual privacy but also available for sound control.

Our own explorations of the empty room showed some acoustic anomalies that could be excited with hand claps near the focal points, but no problems with speech intelligibility. Based on my discussions with the director of facilities, the users are very satisfied with the results.
This is a worship space with a capacity of 200 people. The owner requested good natural acoustics for speech and music, with flexibility to set up audience and musicians in different configurations. The building is on a hillside overlooking Lake Champlain and the Adirondack Mountains beyond, so large areas of glass are an important design feature.

The sanctuary is circular in plan. There are precedents for round worship spaces, but not many. For this project, the conical ceiling added to concerns about sound focusing. Large areas of the exterior wall were glass and thus not available for sound absorbing treatment. The images below show the round plan shape and conical ceiling.

A number of design features are used to prevent sound focusing. The lower walls are a series of niches and pilasters, so that the circular geometry is interrupted by large elements. The glass areas are bowed inward to create a slightly convex form (see Figure 7). Some of the opaque wall areas are finished with sound absorbing panels. The upper wall surface is finished with sound diffuser panels, alternately tilted up and down to create diffusion at a larger scale (see Figure 10). The ceiling features a large scale grid of wood elements to provide diffusion, and two dormers that interrupt the conical geometry of the ceiling (Figures 9 and 10).
FIGURE 7. Reflected Ceiling Plan for All Souls Interfaith Gathering
(Construction Drawing by Smith Alvarez Sienkiewycz Architects, Burlington, VT)

FIGURE 8. Composite Section of Sanctuary (Drawing by SAS Architects)
As a result of this carefully detailed design, the sound quality in the sanctuary is reported to be excellent for both speech and music, with no comments or concerns about acoustic anomalies. The owners, musicians, the worship community, are very thrilled with the acoustic quality. The images below show the finished space including the architectural features used to control focusing from the circular plan shape and the conical ceiling.

Figure 9. Sanctuary at All Souls Interfaith Gathering, nearing completion. Note deeply recessed windows, deep niches for bench seating at other perimeter walls, large scale wood beams on ceiling, all provide acoustic diffusion.
Figure 10. Closeup of Sanctuary Ceiling Showing Sound Diffusing Surfaces at All Souls Interfaith Gathering. Note wood diffuser panels on circular surface of soffit face, large wood timbers applied to conical areas of ceiling, and the peaked dormer (one of two) interrupts the conical ceiling.

ACKNOWLEDGMENTS

The author would like to acknowledge the contribution of the design architects and owners responsible for the projects used in the case studies, along with colleagues at Cavanaugh Tocci Associates who provided suggestions, photographs, and other assistance in preparing this manuscript.