Acoustical Design for a Round Auditorium
With Performance Validation Test Results – A Case Study

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Résumé
This case study discusses the design of a round auditorium and expansion rooms for optimum acoustics. Validation measurements for reverberation decay, continuous background noise, and acoustical separation will be presented and compared with design estimates.

I. INTRODUCTION
A speech and presentation auditorium was proposed for medical conferences and training. The architect envisioned the auditorium as a round room, 19.5 m (64 ft) in diameter, two structural bays in height (basement and ground floors). Double door entries are on both sides of the room. A front stage with podium and large rear projection screen faces a curved rear wall. The curved rear wall is formed by operable partition panels on a curved track, which opened into four rectangular, single story (basement level) “breakout rooms” to expand the seating area, each approximately 37 m² (400 ft²). With the operable partitions deployed, the breakout rooms can be used as individual conference or seminar rooms. The floors are horizontal and flat. Although a sloped ceiling was desired to compliment the flat floor, very little articulation was possible, due to structural height limitations.

II. PRESENTATION OF THE PROBLEM
As acoustical consultants to the architects, JEAcoustics was challenged with conceiving and developing designs to suppress center focus, achieve good speech intelligibility in the round room, and project sound into the rear breakout rooms when operable partitions are open. In addition, when operable partitions are deployed, adequate acoustical separation is required to conduct functions simultaneously in the auditorium and breakout rooms.

II.1. Acoustical Design Criteria
Acoustical design criteria were established for speech presentation as the principal function of the auditorium. Pre-recorded music tracks also could be included in audio-visual presentations. Reverberation decay time and continuous ambient sound level should promote speech intelligibility and the richness of music.

• Reverberation Decay Time ($T_{60}$): 1.0 sec., 500 - 2000 Hz
• Continuous Ambient Noise (HVAC): NC-25 / RC-30

Simultaneous use of the Round Auditorium and Breakout Rooms should accommodate both (a) amplified sound in the auditorium and (b) natural speech in the breakout rooms. Sound isolation criteria:

• Operable Partition: NIC 47 (STC 52)
• Breakout Room Demising Partitions: NIC > 50 (STC > 55)

II.2. Acoustical Design Issues
Special design issues arise from the shapes of the auditorium and breakout rooms. Control of direct reflection patterns and suppression of room center focus are equally important to reverberation control. The geometry of the two-story auditorium with one-story rear expansion rooms is acoustically similar to seating below a rear balcony. Based on the circular room shape, a design approach was developed to use sidewall absorption in conjunction with ceiling and wall diffusion for reinforcement of sound in rear of auditorium and in breakout rooms. Noise control for building mechanical systems was needed to prevent speech interference and coloring of music.
III. ACOUSTICAL DESIGN CONCEPTS

III.1. Room Acoustics Design Concepts
Reverberation decay analysis by classic Sabine Formula\(^2\) indicated a need for absorption. Ray diagram analysis\(^3\) of sound propagation patterns demonstrated the (expected) requirement of diffusion to avoid center focus and to create more even distribution of sound to side and rear seating areas. Sidewall design therefore incorporated “sawtooth” splaying in listener elevations, 1m (3’) – 2.5 m (8’) above the floor. Uniform shaping of the splays on the circular perimeter would still result in center focusing, so the splay angles were varied to direct sound energy toward the rear of the room.

Wall areas above and below the diffusion panels were specified to be acoustically absorptive. Since the operable partitions at the rear of the room would form a curved rear surface (focusing reflections toward the front center), acoustically absorptive panel surfaces were recommended to face into the auditorium. Breakout room rear walls (exposed with operable partitions open) were also recommended to be acoustically absorptive.

Although the floor to structural deck (above) height limited the vertical space for ceiling articulation, sloped ceiling panels were recommended to reflect sound toward the rear of the room. Based on our recommendations for minimum angles of slope, the architect developed a ceiling design with a series of horizontally semi-circular shapes (to be architecturally compatible with the room shape).

In doing so, longitudinal and transverse sound reflections were directed to both rear and side areas of the circular room for more even dispersion. This technique compensated for a lack of reinforcement from weak, diffused sidewall sound reflections.

III.2. Sound Isolation Design Concepts
The building design isolated the auditorium from other occupied spaces with a pre-function lobby and corridors. Resiliently suspended acoustical barriers were designed for the upper ceiling plenum areas to isolate airborne and impact noise transmissions from occupied areas above the auditorium, and to prevent amplified sound in the auditorium from disturbing areas above the auditorium. Entry doors on either side of the auditorium were specified with acoustical seals to prevent intrusion of noise from the Lobby and corridor.

Acoustical separation of the auditorium and breakout rooms during simultaneous uses (with operable partitions deployed) was the greatest challenge. The operable partitions were designed as flat panels suspended from a curved track. They deployed from side pockets, meeting at the center breakout room partition. Normal operable partitions are designed to be aligned with an acoustical seal at the butt joint. The curved track resulted in a 5° - 7° angle at each panel joint (shown in a manufacturer’s detail below). Therefore, the panels were specified to be trapezoidal (in section) to create edge joint seal alignment, and to be rated for STC > 52, NIC 47.

Demising partitions between the breakout rooms were designed to be multi-layered drywall, using an assembly rated for STC > 55. Wall penetrations for ducts, pipes, conduits, etc. were to be avoided, and details were developed to acoustically seal unavoidable penetrations.

III.3. Mechanical Noise Control Concepts
The allowable continuous noise criteria for the auditorium and breakout rooms required physical
separation of external sound sources, attenuation of fan, duct and fitting noise, and vibration isolation of equipment, pipes, and ducts. Ambient noise control of building mechanical and air conditioning systems incorporated location planning to separate central plant and mechanical equipment rooms from the auditorium and breakout rooms. Air handler and duct attenuation was designed to minimize fan noise. Duct and fitting velocities were specified to avoid turbulence noise. Diffusers, registers, and volume dampers were specified for quiet operation. Pipes and ducts that served other spaces were not permitted to be routed through the auditorium and breakout room ceiling plenums or walls. Flexible couplings and vibration isolators were sized to achieve > 90% transmission loss of force.

IV. ACOUSTICAL DESIGN IMPLEMENTATION

The majority of design concepts for acoustics, sound isolation, and mechanical noise control were implemented by the architects and engineers, including absorptive/diffusive elements in side walls, articulated ceiling, high transmission loss wall assemblies, and mechanical noise control measures. Certain design features did not survive the design and construction process, resulting in minor degradation of the final result.

The operable partition panel joints were supplied with standard joints, in lieu of the angled edges specified. Since the panels meet at a small angle, the panels’ edge seals do not achieve optimal performance. Floor seals also have small gaps at joints, likely due to the angle of meeting joints.

The surface absorption originally recommended on the operable panels is not installed, resulting in a curved, reflective rear wall (when operable partitions are deployed) contributing to focus in the auditorium center. The double entry doors on either side of the auditorium form opposing parallel surfaces approximately 2.5 m (8’) high by 2.5 m (8’) wide. A minor flutter echo can develop between the doors. The typical seating configuration of the room has a cross aisle, thus the flutter echo does not significantly affect the seated occupants’ hearing.

V. ACOUSTICAL PERFORMANCE

Acoustical performance validation measurements were conducted at night, when the facility was substantially complete, except for the balancing of the HVAC system. The results demonstrate the success of implemented design concepts.

V.1. Reverberation Decay Time ($T_{60}$)

- Round Auditorium (Operable Partition Closed)
  - $T_{60} = 1.1$ sec @ 500 Hz (over criterion)
  - Moderate Focus at Center

- Extended Auditorium (with Breakout Rooms / Operable Partition Open)
  - $T_{60} = 1.0$ sec @ 500 Hz (meets criterion)
  - Minimal Focus at Center

The double entry doors on either side of the auditorium form opposing parallel surfaces approximately 2.5 m (8’) high by 2.5 m (8’) wide. A minor flutter echo can develop between the doors. The typical seating configuration of the room has a cross aisle, thus the flutter echo does not significantly affect the seated occupants’ hearing.
V.2. Sound Isolation/Transmission Loss (NIC)\(^6\)

- Round Auditorium to Breakout Rooms
  - Operable Partition Closed
  - NIC 35 (vs. criterion NIC 47)
- Room to Room (Between Breakout Rooms)
  - Operable Partition Closed
  - Demising Wall NIC 53 (meets criterion)

V.3. Continuous Background (HVAC) Noise\(^6\)

- Preliminary Results Prior to System Balance
  - Auditorium Only (Operable Partition Closed)
    - NC 29 / RC 29(N) (vs. criterion NC 25)
  - Breakout Rooms (Operable Partition Closed)
    - NC 35 / RC 29(R) (vs. criterion NC 30)
    - Average for Four Rooms

VI. POTENTIAL IMPROVEMENTS

VI.1 Focus and Reverberation

- Provide Acoustical Absorption on Rear Operable Partition Panels (Facing Auditorium) to Improve Round Room \(T_{60}\) and Reduce Focus
  - Alternate: Articulated Diffusion Surface Finish
  - Problem: Movable Panels Subject to Impact Abrasion

VI.2 Operable Partition Performance

- Operable Partition Panel Edges Meet at Angle, Resulting in Poor Seal
  - Alternate: Modify Edges to Properly Align Panel Edge Seals
  - Problem: Modification May Increase Total Operable Partition Width.

VI.3 Flutter Echo in Cross Aisle

- Re-align Side Entry Doors (Parallel Surfaces) to Reduce Flutter Echo Between Doors
  - Alternate 1: Articulated Diffusion Surface Finish
  - Alternate 2: Acoustically Absorptive Surface Finish
  - Problems: Expensive Modification for Minor Benefit. Is not compatible with aesthetic of architectural design

VII. CONCLUSIONS

The geometry of the round auditorium creates unique acoustical design issues. Control of focus, reflection patterns and reverberation decay time requires a combination of diffusion and absorption techniques. With some minor exceptions, the acoustical recommendations were accepted and implemented by the architect. The overall performance of the facility meets the acoustical criteria and design intent.

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REFERENCES