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3aAAb5. Planning, design, and installation experience with subterranean installation of a fully-anechoic acoustical testing chamber including preliminary performance figures

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One of the purposes of a fully-anechoic chamber is to provide a very quiet, near-echo-free environment simulating free-field acoustical conditions. From design specification to completion, installation of a fully-anechoic chamber can be an enormous undertaking as compared to installation of conventional sound-attenuated acoustical test rooms, which generally are smaller in physical size and have less stringent sound attenuation requirements. The authors had the opportunity to oversee the planning, design, and installation of a fully-anechoic chamber designed to support near-full-frequency, human-hearing range acoustical experiments at the VA National Center for Rehabilitative Auditory Research (NCRAR), located in Portland, OR, USA. Design and installation of the NCRAR chamber to support entry at laboratory floor level was complicated by the job site location, a subterranean area beneath a structure that accommodates clinical and research offices on the upper floors, and serves as a parking garage on the lower floors. In addition to ambient noise considerations, existing architectural restrictions included parking traffic patterns, below-grade earthquake beams, limited overhead clearance, ground water seepage, and storm water flow patterns. The purpose of this paper is to share pictorial-illustrated experiential results on specification, design, installation, and chamber performance as well as architectural considerations, site preparation, and construction detail.

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INTRODUCTION

A development process to realize a fully-anechoic chamber for wide-frequency-range human hearing research is presented. Opportunities to build these generally massive, expensive test rooms are not routinely found and a committed organization might have few chances to “do it right”. Although anechoic chambers are used for both electro-magnetic and acoustical wave studies, we are primarily interested in the acoustical sound waves audible to humans. There are few anechoic chambers designed specifically to test human hearing. Most chambers installed in the USA are used for industrial and product testing purposes. Audiometric chambers are in general designed for frequencies up to 8 kHz—very few are designed to test human hearing out to 20 kHz. Those suitable for additional experimentation in supra-human, ultrasonic frequency ranges from 20 kHz to 100 kHz are extremely rare.

The chamber we describe is located at the Department of Veterans Affairs National Center for Rehabilitative Auditory Research, (NCRAR) in the Portland VA Medical Center in Portland, Oregon USA. Although the number of institutions with similar facilities is quite small, the owners and investigators at several existing facilities have made helpful contributions to the success of our project. It is our hope this article will be of assistance to others undertaking chamber projects. Presented here is an overview of our chamber development process including planning, design, installation, and preliminary acoustic performance results. Anechoic chamber fundamental physics can be found in [Beranek & Sleeper 1946] and anechoic chamber design is discussed in [Duda 1977]. Information on chamber performance verification is found in [Cunefare et al. 2003] including extensive chamber-related references.

METHODS

The primary design goal was to include support for the widest variety of acoustic experimentation and to accommodate known specific auditory research experiments. Therefore, early project work involved surveying investigators for auditory-research-project chamber needs and projections of general-purpose acoustical research needs. Studies identified included: a) hearing aid directionality/sound localization, b) headphone passive attenuation measurement, c) surround sound virtualization investigation, and, d) characterization of loudspeaker acoustical dispersal patterns. Literature and researchers at other institutions were also consulted during this process to gather input and suggestions on features, specifications, and acoustical performance testing.

Our hearing research facility occupies a portion of an underground concrete structure originally built in 1990 to be used for electro-magnetically-shielded clinics and laboratory space. Unused portions of the underground space are used for motor vehicle parking. We chose to locate the chamber on-site which presented challenges in architectural design and materials, chamber physical size, and noise intrusion. To open a wider discussion, a report listing desirable chamber features, location opportunities and limitations was created and shared with the community of chamber manufacturers and consultants.

From early project discussions, it was clear chamber entry had to be near office floor level so lifts and long ramps would not be necessary for transporting physically impaired research subjects into the chamber. This would require one third of the fully-anechoic chamber to be installed below grade. According to [Beranek & Sleeper 1946], the first consideration to make when designing an anechoic chamber should be to make it as large as possible. Located throughout the parking structure location are immoveable, subterranean grade beams approximately 12m (40’) in length with spacing varying between 6m (20’) and 6.7m (22’). These beams are fundamental to the structural strength of the seven story structure, in particular its ability to withstand earthquakes. The lower portions of our chamber would need to fit between these existing beams. To maximize the usable area of our chamber, there was only one 6.7m location available which unfortunately was directly under a maze of noisy steam piping and flanked by a required vehicle-access-way.

The chamber would be exposed to noise both from ongoing vehicular traffic and overhead steam lines 24 hours per day. Noise studies were conducted to determine the required acoustical attenuation for human hearing threshold testing inside the chamber. Unable to identify published anechoic room ambient noise standards, we developed target ambient noise level specifications based upon published standards [ANSI S3.1 1999] for auditory test room noise limits and minimum audible field (MAF) values from Robinson-Dadson ISO 226:1987 as in Table 1. Ideally the chamber ambient level would be down at least 10 dB from MAF values. However, the Project Target Maximum Range figures were derived using the published standards as a maximum level taking into account real-world attenuation characteristics of common building wall materials and construction methods.

Noise measurements were logged for 24 hour periods with spot checking in other campus parking garage structures. Analysis showed frequent wide-bandwidth high-average-noise-level events exceeding 110dB SPL and hand-captured random noise events exceeding 115 dBA SPL. Note: all dB values cited in this paper are relative 20
µPa. The dominant steam noise frequencies ranged from 1 kHz to 5 kHz and could be reduced with pipe and bracket acoustic insulation blanketing. Attenuating random vehicle noise events would be more difficult due to wide-band-noise emissions with high-energy, low-frequency content. Research showed typical manufactured sound room walls themselves would be insufficient. Additional acoustic insulating layers would need to enclose a manufactured chamber room. The proposed control room location under steam piping would also require additional acoustic insulation. Hence, the anechoic chamber facility would consist of three main components: 1) a free-standing, anechoic acoustical room, the chamber core, purchased from a manufacturer, 2) a sound attenuating box to shield the chamber core from vehicle noise, the chamber shell enclosure, and, 3) a control room which would contain laboratory instrumentation and support equipment.

We could only estimate the future chamber’s size until the precise location and spacing of grade beams were determined. Construction started with soil excavation of the chamber core pit area to a depth of 2.3m (7.5’) as shown in Figure 1. The grade beams were as expected but the south grade beam had a bulge reducing the beam span by approximately three inches. Architectural X-ray inspection and analysis showed the beam could be trimmed to restore the span without sacrificing structural integrity. A study was undertaken to investigate the impact of grade beam vibrations due to parking structure traffic on ambient chamber noise levels. Grade beam vibration paths affecting chamber noise levels could be conducted or air-transmitted. One third octave acceleration spectra levels corresponding to NC-20 Noise Criterion curves [Miller 1981] were established for a large vibrating surface such as the beam. Similar acceleration levels were also established that would produce radiated sound levels in a room equivalent to 10 dB less than ANSI Minimum Audible Pressure thresholds of hearing for continuous noise [Harris 1991]. The study estimated typical test room spring isolators would take care of conductive noise while the 21 dB attenuation of air-transmitted impacts in the 1 kHz region could be provided by a chamber wall sound transmission loss of 53 to 58 dB at this frequency. Overall, the study predicted chamber noise impacts from traffic-related, vibration-induced noise would be well below the target noise level.

As is generally understood, the bigger the internal volume of the chamber core, the better are its acoustical properties and more broadly useful is the test room. The maximum overall north-south size for the chamber core area

<table>
<thead>
<tr>
<th>Octave Band (Hz)</th>
<th>ANSI S3.1 (1999) Ambient Noise Limits (ears uncovered)</th>
<th>0 HL MAF (Robinson-Dadson)</th>
<th>Project Target Maximum Range</th>
<th>Predicted Maximum Ambient Noise Levels Inside Chamber Using Various Wall Designs</th>
</tr>
</thead>
<tbody>
<tr>
<td>31.5</td>
<td>59</td>
<td>59</td>
<td>57 to 60</td>
<td>62 62 62 62 62 62 62 62 62 62</td>
</tr>
<tr>
<td>63</td>
<td>36</td>
<td>35</td>
<td>43 to 46**</td>
<td>60 58 56 43 43 38 33 8 8 8</td>
</tr>
<tr>
<td>125</td>
<td>35</td>
<td>19</td>
<td>29 to 32</td>
<td>40 38 33 8 8 8 8 8 8 8</td>
</tr>
<tr>
<td>250</td>
<td>21</td>
<td>10</td>
<td>15 to 18</td>
<td>11 8 -3 -5 -5 -5 -5 -5 -5</td>
</tr>
<tr>
<td>1000</td>
<td>13</td>
<td>2</td>
<td>-3 to 0</td>
<td>11 8 -3 -5 -5 -5 -5 -5 -5</td>
</tr>
<tr>
<td>2000</td>
<td>14</td>
<td>-3</td>
<td>-1 to 2</td>
<td>11 8 -3 -5 -5 -5 -5 -5 -5</td>
</tr>
<tr>
<td>4000</td>
<td>11</td>
<td>-5</td>
<td>-1 to 3</td>
<td>11 8 -3 -5 -5 -5 -5 -5 -5</td>
</tr>
<tr>
<td>8000</td>
<td>14</td>
<td>12</td>
<td>0 to 3</td>
<td>11 8 -3 -5 -5 -5 -5 -5 -5</td>
</tr>
</tbody>
</table>

* Study selected wall design: double stud, insulated walls, dual 6” dead airspaces. Actual wall design was slightly modified.
** Increased target values as frequency range has low transmission loss (STC) using prospective chamber wall construction.

![FIGURE 1.](image-url)
was set by the grade beam span (6.7m). The maximum east-west extent was limited by the easterly vehicle accessway (7m) and height was limited by parking structure vertical clearance of 5.5m. The maximum area available for the chamber core was also reduced by a) the thickness of the knee-walls (6") shoring up the sides of the pit area and also serving as the foundation for the walls comprising the chamber shell enclosure, and, b) the required dead air space between chamber core wall and knee-wall (4"), for a maximum north-south, chamber-core external dimension of 6.2 m(20'4''). The east-west chamber core dimension could have been slightly larger but after considerable administrative and technical discussion, the decision was made to equalize the east-west as well as the overall height to the north-south dimension.

Comments were received the proposed chamber area did not have to be so big to support the envisioned research projects. It was helpful to create a “useful anechoic volume” sketch to illustrate the overall size required to establish a “theoretical” anechoic space. Table 1 contains estimated anechoic volume assuming a full-surround-sound speaker configuration, ¼-wavelength wedge depths, and a 20'4” external core.

To help select the lower cutoff frequency we consulted anechoic chamber owners and hearing investigators. Although we received conflicting responses: ‘go for less space, better acoustics’ vs. ‘go for maximum’, it was generally agreed 200 Hz or lower was suitable, and a wedge tip-tip area of 16 feet square would be a relatively comfortable working environment. We settled on a low frequency design of 150 Hz. The design upper frequency was generally agreed 200 Hz or lower was suitable, and a wedge tip-tip area of 16 feet square would be a relatively comfortable working environment. We settled on a low frequency design of 150 Hz. The design upper frequency was mostly set at 100 kHz to support ultrasonic testing. The chamber performance at these upper frequencies will be mostly inside the chamber to sub-threshold levels. Four wall designs were evaluated:

1. Single 6” solid concrete block wall 10” air space, 4” glass fiber insulation between chamber wall and block wall.
2. Single 12” solid concrete block wall with 4” air space, 4” glass fiber between chamber wall and block wall.
3. Single 6” metal stud wall with 12” air space and 4” glass fiber insulation between chamber wall and stud wall. Stud wall has two layers of ½" gypsum one side directly to studs, 5” fiberglass batting inside and two layers of ½” gypsum outside using resilient channel supports attached to studs.

### Table 1

<table>
<thead>
<tr>
<th>Lower Cutoff Freq.</th>
<th>Wave length cm(in)</th>
<th>Wedge Depth cm(in)</th>
<th>Wall-Wall cm(in)</th>
<th>Tip-Tip cm(in)</th>
<th>Minimum Useable Anechoic Region^1</th>
</tr>
</thead>
<tbody>
<tr>
<td>100Hz</td>
<td>343.0(135.0)</td>
<td>85.833(33.8)</td>
<td>619.8(244)</td>
<td>448.4(175.6)</td>
<td>0.1m(0.2yd)</td>
</tr>
<tr>
<td>125Hz</td>
<td>335.4(131.8)</td>
<td>82.794(32.6)</td>
<td>619.8(244)</td>
<td>443.6(173.2)</td>
<td>0.15m(0.3yd)</td>
</tr>
<tr>
<td>150Hz</td>
<td>328.0(128.9)</td>
<td>80.012(31.4)</td>
<td>619.8(244)</td>
<td>438.6(170.8)</td>
<td>0.18m(0.36yd)</td>
</tr>
<tr>
<td>175Hz</td>
<td>320.8(126.5)</td>
<td>77.562(30.6)</td>
<td>619.8(244)</td>
<td>433.6(168.4)</td>
<td>0.2m(0.4yd)</td>
</tr>
<tr>
<td>200Hz</td>
<td>313.7(124.6)</td>
<td>75.266(29.7)</td>
<td>619.8(244)</td>
<td>428.6(166.0)</td>
<td>0.24m(0.48yd)</td>
</tr>
<tr>
<td>225Hz</td>
<td>306.8(122.0)</td>
<td>73.100(29.0)</td>
<td>619.8(244)</td>
<td>423.6(163.6)</td>
<td>0.28m(0.56yd)</td>
</tr>
</tbody>
</table>

^1 Minimum Useable Anechoic Region = (Tip-Tip – 4m)^2. 

In our opinion, glass wedges would provide the best performance over the specified wide-operating frequency range. Based upon preliminary design discussions a detailed chamber core specification was drawn up and Eckel Industries, Inc. (Cambridge, MA) was hired for fabrication and installation.

Based upon the noise investigation, designs were studied for an enclosure wall system adequate to attenuate noise inside the chamber to sub-threshold levels. Four wall designs were evaluated:

1. Single 6” solid concrete block wall 10” air space, 4” glass fiber insulation between chamber wall and block wall.
2. Single 12” solid concrete block wall with 4” air space, 4” glass fiber between chamber wall and block wall.
3. Single 6” metal stud wall with 12” air space and 4” glass fiber insulation between chamber wall and stud wall. Stud wall has two layers of ½" gypsum one side directly to studs, 5” fiberglass batting inside and two layers of ½” gypsum outside using resilient channel supports attached to studs.

The floor of a full anechoic chamber is typically a grid of spring-tensioned aircraft-cable. To accommodate wheelchair-bound subjects, and for the occasional need for stable flooring, the chamber would need to have a removable floor panel system. To support the wide variety of planned projects, we envisioned a complete grid system of instrument hangers on all walls, ceiling, and floor. To minimize exposed cabling, multiple cable-routing sleeves were requested on the ceiling, each side wall, and the chamber control wall. The interior of the chamber was to have a removable floor panel system. To support the wide variety of planned projects, we envisioned a complete grid system of instrument hangers on all walls, ceiling, and floor. To minimize exposed cabling, multiple cable-routing sleeves were requested on the ceiling, each side wall, and the chamber control wall. The interior of the chamber was to have three separate electrical outlets and six separate ceiling lighting sockets on separate circuits leading up to an electrical junction box located on the roof of the chamber core.

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4. Double stud wall design with each wall constructed as in (3) above and with 6” air spaces between chamber wall and stud wall and between studded walls.

TABLE 2. Key NCRAR chamber design specification of chamber core module.

<table>
<thead>
<tr>
<th>Key Design Specification</th>
<th>Contractual Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chamber of full anechoic design</td>
<td>EMI (RF) shielded to 100kHz</td>
</tr>
<tr>
<td>Chamber module external dimension</td>
<td>6.20m (20’4”) cubed</td>
</tr>
<tr>
<td>Internal chamber horizontal dimension above cable floor</td>
<td>5.05m (16’’) wedge tip-tip</td>
</tr>
<tr>
<td>Design lower and upper cutoff frequencies</td>
<td>150 Hz and 100 kHz</td>
</tr>
<tr>
<td>Chamber wall STC</td>
<td>55</td>
</tr>
<tr>
<td>Instrument sleeves</td>
<td>Ceiling:6; sides:2; control room:2</td>
</tr>
<tr>
<td>Chamber spring supports</td>
<td>Metal, 3Hz lower cutoff freq.</td>
</tr>
<tr>
<td>Chamber internal wiring</td>
<td>Ceiling lights:6; duplex outlets:3</td>
</tr>
<tr>
<td>Acoustical performance testing parameters</td>
<td>Tones, noise bands to 20kHz, noise bands to 100kHz</td>
</tr>
<tr>
<td>Chamber external and hatch doors</td>
<td>1-hour fire rated, STC 54</td>
</tr>
<tr>
<td>Chamber flooring panels, flexible positioning**</td>
<td>Removable with coverage to 33% of chamber floor area</td>
</tr>
<tr>
<td>Equipment attachment stanchions</td>
<td>Walls and ceiling, 2ft x 2ft grid spacing</td>
</tr>
<tr>
<td>Non-suppressed fire rating to allow non-sprinkling</td>
<td>One hour.</td>
</tr>
<tr>
<td>Ventilation silencers, intake and exhaust</td>
<td>Jackets and plenums, designed to 1000 CFM</td>
</tr>
<tr>
<td>Weight</td>
<td>20,000kg (44,100 lb)</td>
</tr>
</tbody>
</table>

*Sound Transmission Class: single-number rating of assembly to resist airborne sound transmission within 125–4 kHz band.

**Grated floor could add reflections in 5-7 kHz range depending on angles of incidence.

Table 3 shows the results of the study and our target maximum ambient noise levels inside the chamber. The study predicted a double-studded-wall noise attenuation (design 4) and STC 54 chamber wall would be sufficient to acoustically insulate the enclosure against extremely loud motor vehicles. The installed design is illustrated in Figure 3(d). Once the precise dimensions of the chamber core were known, footings 300 mm (12”) thick were laid around the perimeter of the pit floor. Knee-type walls 150 mm (6”) thick were poured on top of the footings as shown in Figure 2(a). A 200 mm (8”) slab was then poured on top of the footings between knee walls. The slab (not shown) would support the entire chamber core weight of 20,000 kg and be slanted 1/8” per foot from the perimeter to a central floor drain. The knee-walls shouldered the weight of the chamber’s enclosing shell.

The parking structure itself has been built into the side of a small mountain whose excavation exposed several veins of water infiltration. To prevent the area under the pit from holding water, a drainage and sump pump system was designed. The concrete knee-walls were also single-poured to help prevent water seepage and to add strength to the knee-wall structure. Unfortunately, one of the forms slipped and a 4” bulge formed near the top of the knee-wall. Rather than partially remove and re-pour the bulging knee-wall, the bulge an inch and the chamber core was shifted 2” to the north after consultants determined the unsymmetrical dead air spaces between core, foundation and enclosures would be inconsequential to the ultimate chamber acoustic performance. Interestingly, it was debated during design meetings that to maximize chamber internal volume the manufacturer’s recommended 4” air gap between the chamber core and the knee-walls should be reduced. Fortunately, by following the recommendations, there was sufficient air gap to absorb the concrete knee-wall bulge impact and prevent significant project delay.
The control room was sited along the south side of the chamber. A significantly noisy steam pipe chase is situated above this area. The lower pipe height at the west wall of the control room required acoustic isolation soffits. This reduced a portion of the control room finished ceiling height from ten feet to eight feet. The two pipes immediately above the south knee-wall had to be moved to construct the chamber exterior enclosure. The very noisy, larger pipe, a medium-pressure supply line to another building, had to be routed outside the chamber enclosure to minimize chamber noise intrusion.

The majority of the chamber core installation took one month. As previously mentioned, to meet the baseline ambient noise criteria inside the chamber, the completed anechoic chamber structure was encased in a complex double-walled sound attenuating shell. During chamber installation, carpenters worked in parallel to construct the enclosure walls. Careful cooperation on erection, studding, and sheathing interior wall panels was necessary to enable the chamber box to be constructed within the double studded wall boxes.

As shown in Figures 3 and 4, the chamber core structure itself is constructed of sixty prefabricated, steel-clad, acoustical panels with steel plenums, each approximately 100 mm (4”) thick, 1.2 m (4’) wide, and 3 m (10’) long, weighing about 250 Kg (550 lb). A steel I-beam runs across the ceiling, resting on the outside of the structure to carry the weight of the ceiling panels. A boom crane accessing the area from the north was necessary to erect the chamber. Complete enclosure walls on the west and south and a partial east wall could be built before chamber core installation commenced. However, the final north wall could not be completed until the chamber core installation shell and boom crane work was completed.

Once the external shell of the chamber core was installed, it was possible for carpenters to continue closing in the chamber enclosure walls. A view into the area inside the shell enclosure and on top of the chamber core is shown in Figures 5. The intake and exhaust air plenums located on the core roof are acoustically-treated to smooth the constant

![FIGURE 2](image)

(a) Foundation knee-walls with exterior and interior second-pour forms in place. Black square tube on left is sump pump access to chamber slab floor drain. (b) Results of finished footing and knee-wall pours looking west. Bulge can be seen in knee-wall which protrudes 4 inches into planned chamber dead air space. (c) View of knee-wall looking west. Control room will be located on the south side of the chamber. Bulge is approximately under planned chamber entry door location. Steam pipes overhead of control room location can be seen, some of which are directly overhead of chamber wall location which will need to be re-routed. (d) Foundation area ready for chamber slab pour. Distance from the top of the chamber slab to finished grade at top of knee walls will be seven feet. The rebar reinforced knee-walls will be tied into the finished facility slab.

The control room was sited along the south side of the chamber. A significantly noisy steam pipe chase is situated above this area. The lower pipe height at the west wall of the control room required acoustic isolation soffits. This reduced a portion of the control room finished ceiling height from ten feet to eight feet. The two pipes immediately above the south knee-wall had to be moved to construct the chamber exterior enclosure. The very noisy, larger pipe, a medium-pressure supply line to another building, had to be routed outside the chamber enclosure to minimize chamber noise intrusion.

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325 CFM air flow and minimize HVAC noise. The plenums are connected to the facility HVAC system with non-conductive flexible couplers for acoustic and electrical isolation. The manufacturer supplied the 1m x 1m hatch access door and acoustic-sealing and RF-shielded door frame.

The chamber sits on 3Hz resonant frequency springs. The chamber is free to move depending on internal activity of external forces applied to the core structure. Typical side to side sway movement amounts to 0.5”. The cavity surrounding the door frames between the chamber core and external wall enclosure is filled with 6”x6” foam for aesthetic and to help prevent items from falling into the area below. Figure 6 shows chamber core interior finish work.

With the cable floor and pit area complete, installation proceeded on the remainder of the interior walls and ceiling. Wedges were attached to the walls and ceiling by clipping them onto a resilient rail system. Before wedge placement, conduit was installed for each duplex outlet and ceiling light and base plates for the extensive instrument mounting system. Each plate was attached to the steel chamber core wall with four screws and can withstand a 900lb pullout force. A 3/8” steel threaded rod is screwed into each base plate flange terminating in a 2” coupler nut. The chamber area has independent 40A, 220VAC, isolated, EMI-filtered service with four 20A, 110VAC circuits in the control room, and one 20A, 110VAC outlet circuit and one 20A, 110VAC lighting circuit in the chamber. The subpanel and all switches are centrally located near the door of the chamber. Photographs of the completed enclosure, control room, and core are shown in Figure 7.

A third party acoustic engineer certified the NCRAR anechoic chamber to meet the requirements of ISO 3745:2003 and ANSI S12.35-1990 for room standards and test environments. The chamber met the standards for both pure tone and narrow band noise band measurements over the normal frequency range of interest from 150Hz to 20kHz at 1/3

FIGURE 4. Chamber floor and ceiling supports and enclosure detail. (a) The perimeter cable-flooring support frame is being installed. (b) Ceiling panel being installed. (c) Partially completed chamber core ceiling. One of two ventilation cutouts in ceiling is visible at upper left. (d) Final, overall acoustical insulation treatment applied to chamber.

FIGURE 5. Enclosure details. (a) East external wall skeleton. Chamber pit sump pump access hatch is visible in lower center. (b) Northeast corner instrument sleeve exiting core area through interior enclosure wall and leading straight into the control room to the left. All sleeves runs have rubber inline couplers to minimize acoustic conduction. Pump electrical and plumbing connections are also visible and resiliently mounted on the outside face of the interior enclosure wall. (c) Finished interior wall surface and framing detail for the exterior wall with 2 inch air gap. The inner wall has been double sheathed on both sides and filled with insulation batting. The outer wall will receive a double layer of sheathing on its exterior face, taped, and finished. (d) A manufacturer supplied, magnetically sealed, hatch provides access onto the roof of the chamber core from above control room ceiling. The ceiling and structural beams of the parking structure in this “attic” have received acoustical blanketing.
octave intervals. For reference purposes, the chamber has also been characterized using a wide band noise source from 20 kHz to 100 kHz at 1/3 octave intervals. The chamber is currently being modified for improved wheel chair access.

Preliminary chamber measurements for ambient noise levels and attenuation of environmental noise are shown in Figure 8. We are currently investigating the source of Figure 8(g) and 8(h) noise level excursions into the MAF range. According to enclosure wall design documents a wall design 4 would have prevented audible 8(h) events inside the chamber. The 125Hz event (g) is more difficult to explain. The measured level at 125Hz remains lower than the Project Target Maximum Range (Table 3) and it doubtful the level would interfere with speech and hearing testing. Yet, we are interested in reducing it and are looking at two sources: a) a pump in a nearby mechanical room or other external sources, and b) inherent chamber or even parking structure resonance building up some sort of self-oscillation. We have used our traversing measurement system [Ellingson & Bock 2013] to investigate the chamber low frequency acoustical response. Results confirm frequencies less than 150Hz in the chamber could be difficult to control. Environmental noises at upper frequencies such as the 3 kHz event 8(h) might only be eliminated by rebuilding the outer enclosure wall construction to wall design 4 construction standards or layering additional acoustic barriers onto the existing enclosure façade. Neither option sounds inexpensive…so since chances now might be limited, always: “Do it right the first time”!

![FIGURE 7](image1.png)

**FIGURE 7.** Completed enclosure, control room, chamber. (a) North east corner viewed from parking area. Acoustically treated steam pipes and re-routed medium-pressure supply line visible near ceiling. (b) Finished control room. Soffit below the steam lines is shown at top far wall. Manufacturer supplied, acoustic chamber door on right. Dedicated, isolated power panel for anechoic facility with master and individual outlet and light switching near left door frame. Both interior and exterior chamber doors are magnetically latched and sealed. Removable interior floor panels visible to right of chamber door. (c) Chamber configured for hearing aid localization study. Subject is seated in center of a computerized loudspeaker array indicating detected sound source.

![FIGURE 8](image2.png)

**FIGURE 8.** Preliminary NCRAR chamber ambient levels (un-weighted). (a) Minimum Audible Field (MAF ISO226:2003) as calculated in [Tackett 2005]. (b) ANSI S3.1(1999) maximum test room noise, ears uncovered. (c) Chamber ambient noise level. (d) Control room ambient noise level. (e) Automobile horn in parking structure measured 1 m distance from east wall. (f) Chamber levels measured while horn on in parking structure. (g) Suspected external source or inherent room noise. (h) Car horn intrusion.
CONCLUSION

We presented an overview of planning, design, construction, and installation of an anechoic chamber facility retrofit to subgrade in a subterranean parking structure. The chamber was specifically developed to investigate wide-frequency range human hearing research but also designed to include features useful for general acoustic experimentation out to 100 kHz. The chamber is unique in performance and capabilities suitable for supporting a variety of acoustical testing. The chamber is currently supporting acoustic experiments in the auditory research field. The reconfigurable interior design features have so far proved flexible in the instrumentation needs of NCRAR research projects.

At least some of the chamber ambient-noise-level performance issues we encountered might have been avoided by not deviating from the recommended wall construction methods. It is disappointing to have missed this design goal, but in reality most chamber work will be unaffected. However, investigators conducting experiments at minimum auditory threshold levels should well take account the effect of these performance anomalies.

The realization of this chamber facility depended on significant attention, coordination, and support from a project team selected from wide variety of fields including auditory researchers, acousticians, facility engineers, and administrators. The project’s successful completion hinged upon strong specification and design as well as careful project planning and staging of construction activities. The success of this project, in particular the feature set specification, benefited greatly from collaboration with other knowledgeable and experienced acoustical researchers. The work required to complete the chamber facility encompassed at least four major stages: planning and design, facility site preparation, chamber core installation, and chamber core shell enclosure construction. Every chamber installation is unique according to the experience of the vendor on this project whose company has constructed hundreds of acoustic room installations. The successful development of our institution’s unique chamber facility fully depended on a project team and chamber core vendor with a sincere desire to go several extra miles, patiently identifying, working-through, and wrapping up a myriad of project details both small and large in scope.

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