EDITOR
Dick Stern (AcousticsToday@aip.org)

CONTRIBUTORS
Michael A. Bahtiarian, Jack Freytag
Marshall Long, Elaine Moran,
Paul Schomer, Dick Stern,
Nancy S. Timmerman, Douglas F. Winker

ADDRESS
Acoustical Society of America
Suite 1NO1
2 Huntington Quadrangle
Melville, NY 11747-4502

ASA EXECUTIVE DIRECTOR
Charles E. Schmid

ASA EDITOR-IN-CHIEF
Allan D. Pierce

EDITORIAL PRODUCTION
Maya Flikop—Director, Special Publications
and Proceedings, AIP

ADVERTISING
Robert Finnegan, Director, Journal Advertising &
Exhibits

ACOUSTICAL SOCIETY OF AMERICA

The *Acoustical Society of America* was founded in 1929 to increase and diffuse the knowledge of acoustics and to promote its practical application. Any person or corporation interested in acoustics is eligible for membership in the Society. Further information concerning membership, as well as application forms, may be obtained by addressing Elaine Moran, ASA Office Manager, Acoustical Society of America, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747-4502, Telephone (516) 576-2360; Fax: 516-576-2377; E-mail: asa@aip.org; Web: http://asa.aip.org

FUTURE ARTICLES

Acoustical Scattering—Part 2

Feedback Design

Pitch Circularity

Bow Bells

Cavitation and Cetacean

Marine Mammals

SONAR

ACOUSTICS TODAY (ISSN 1557-0215, coden ATCODK) October 2009, volume 5, issue 4 is published quarterly by the Acoustical Society of America, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747-4502. Periodicals Postage rates are paid at Huntington Station, NY, and additional mailing offices. POSTMASTER: Send address changes to Acoustics Today, Acoustical Society of America, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747-4502.

DESIGNING AND BUILDING A LOW-NOISE HEMI-ANECHOIC CHAMBER

Douglas F. Winker
ETS-Lindgren
Cedar Park, Texas 78613

"The chamber exceeded the specification with a noise floor that was > 0 dBA for frequencies ≥100 Hz and only 5 dBA at 80 Hz."

Noise emission and noise control are common topics in the field of acoustics. Noise emission from devices needs to be measured to comply with noise standards and to develop quieter devices. To make these measurements, a quiet noise-controlled environment is required. A large convertible hemi-anechoic chamber was constructed at ETS-Lindgren's headquarters in Cedar Park, Texas for that purpose. The project was a noise control project unto itself with the goal to measure the noise produced by a wide variety of test specimens.

ETS-Lindgren Acoustic Systems operated a laboratory in south Austin, Texas beginning in 1985. The south Austin laboratory had a suite of reverberation chambers and a hemi-anechoic chamber with a 1-meter, precision-grade free field above 125 Hz. Over the years, tested product noise became lower and lower, especially for information technology (IT) equipment. As product noise emissions decreased, their acoustic performance began to encroach on the chamber's noise floor and the quietest of products were tested late at night when the ambient levels were at their lowest (approximately 17 dBA). Highway expansion was the main contributor to the noise floor increase. The laboratory was located less than 2 miles away from the Interstate 35 and US Highway 290 interchange. When the chamber was constructed, this interchange did not exist and was not part of the design parameters. After the construction of this interchange, low-frequency traffic noise became measurable inside the chamber.

In 2006, the decision was made to move the ETS-Lindgren Acoustic Systems' laboratory and production facilities to ETS-Lindgren's headquarters in Cedar Park, Texas. The team decided to decommission the old chambers and build an entirely new lab with a double-wall hemi-anechoic chamber (i.e., a chamber within a chamber) that had a larger free field and a much lower noise floor. Low-noise testing had to be possible at all times of the day regardless of the noise sources outside the chamber.

The chamber's design was dictated by the project's goal—a mandate to test a wide variety of devices. First, the ability to test low-noise products was required and a noise floor of NC-10 at any microphone on the measurement surface was specified. Additionally, low-noise testing had to be possible at any time regardless of the activities outside the chamber including future highway expansion. Second, a 2-meter radius precision-grade (ISO 3745:2003) hemispherical free field was required for frequencies ≥80 Hz. Third, using a parallelepiped array, two full height equipment racks must be able to be tested side by side. Fourth, the heating, ventilating, and air conditioning (HVAC) system must not affect the chamber's noise floor and must maintain controlled temperature levels of ± 2° C with a high heat load. An addition to the HVAC requirement was that the lighting system should not contribute additional heat to the chamber and the system must be low noise. The fifth design requirement has not been fully implemented—the chamber must be able to be converted into a fully anechoic chamber. As part of this requirement, the chamber's wedge basket doors were designed to accommodate removable floor wedge carts, but these carts have not been constructed.

The inner chamber rests on an isolated concrete slab that was designed with the future in mind. The chamber's location in Cedar Park, Texas is approximately 40 km from downtown Austin and there is considerably less traffic in the area. While the area is somewhat remote now, continuing expansion will eventually engulf the area. With this expansion comes increased traffic and road noise. Highway expansion is underway and a light rail system will go online in the spring of 2010. The isolation system was designed with this growth in mind.

The concrete work began with excavating the host site and pouring a concrete pit so that the chamber's entry would be at floor level, which makes handling large test specimens much easier. The existing concrete was cut out and the underlying soil was excavated leaving a 7.92 x 7.92 x 0.56 m (*L x W x H*) depression. After the excavation, the pit was framed and concrete was poured. An expansion joint was left between the outer edge of the pit and the host slab to isolate the pit from host site noise. Figure 1 shows the pit while it was curing.

Fig. 1. Concrete pit.

Fig. 2. Spring isolators during installation.

Once the pit was poured, the isolated concrete slab could be framed and poured. The floating slab resides entirely in the pit and is supported by 54 spring isolators (Fig. 2). The spring isolators were placed in the pit and strapped together with reinforcing bar. Next, 45.46 metric tons of concrete were poured resulting in a 30.5 cm thick concrete slab with a footprint of 6.1 by 6.1 m. The floating slab acts as the chamber's reflecting plane. The slab also features a 30.5 by 30.5 by 10.2 cm (*L x W x H*) recess at its center to hold floor-mounted sound sources or to flush-mount a motorized turntable capable of rotating test specimens up to 225 kg. A 1.25 cm thick steel plate covers the opening when the turntable or sound source is not in use. A 30 cm wide cable recess allows cables to run into the pit without disturbing the reflecting plane. A series of 1.25 cm thick steel plates cover this recess. Several holes were bored into the slab and act as mounting points for the various microphone arrays used during testing. Finally, an epoxy finish was installed to create a smooth and durable finish.

The inner chamber was constructed on the isolated concrete slab and raised into position after construction. This was a tedious process that involved gradually raising each spring isolator in succession by a small amount and repeating the process until the isolated slab was flush with the host slab. This process can be seen in Fig. 3. Upon the completion of this operation, the bottom of the isolated slab was 7.62 cm above the floor of the pit.

The inner and outer chambers were constructed simultaneously after the concrete work was complete. The outer chamber walls are 10.16 cm thick and rest on the edge of the concrete pit. An 11-gauge steel perimeter channel was installed around the edge of the pit to receive the modular wall panels. A closed-cell foam gasket was installed beneath the perimeter channel to fill any voids that might exist between them and the concrete surface. Each of the wall panels was constructed in ETS-Lindgren's factory and transported to the job site. These panels were constructed to achieve high noise reduction. The outer surface of each panel is 16-gauge cold-rolled steel. Inside the panel, a 2.54 cm thick layer of gypsum board was laminated to the outer skin to increase the outer surface's overall mass. The remaining cavity was filled with cotton fiber fill that is 7.62 cm thick. The inner surface is another layer of 16-gauge cold-rolled steel. The assembly is held together by 16-gauge cold-rolled steel channels, which are welded in place. The wall panels fit into a labyrinth joiner system constructed using 11-gauge cold-rolled steel. Every joint and seam was filled with a bead of latex caulk. All of the steel in the chamber was powder coated for a lasting rust-free finish. The external dimensions of the outer chamber are 8.69 by 8.69 by 7.32 m (*L x W x H*) above the finished floor. Figure 4 shows an outer chamber wall installed in one of the perimeter channels.

The inner chamber walls are 30.5 cm thick and rest entirely in another 11-gauge steel perimeter channel that is attached to the isolated concrete slab. They are separated from the outer chamber walls by 30.5 cm. This space is filled

Fig. 3. Raising the inner chamber.

Fig. 4. Outer chamber wall install in a perimeter channel.

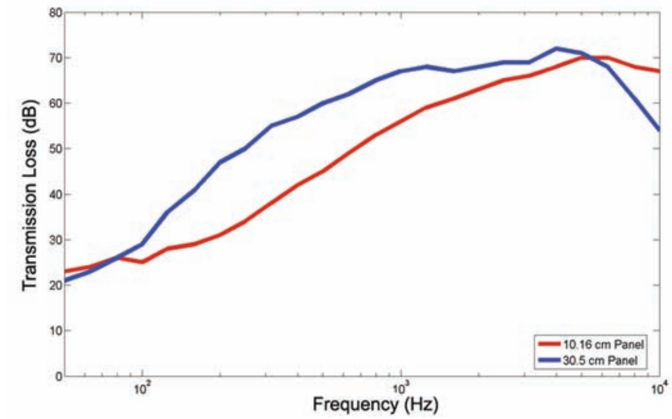

Fig. 6. Transmission loss for 10.16 cm and 30.5 cm thick panels (5.95 m² specimen area).

with Johns Mansville 30.5 cm thick R-30 fiberglass insulation. The installation of the chamber walls can be seen in Fig. 5. The inner chamber walls were constructed in a similar fashion to the outer chamber walls. They have the same 16-gauge outer skin with a 2.54 cm thick gypsum board lamination. Since the panels are thicker, the cotton fiber fill is 27.94 cm thick. The main difference between the two panel designs is the inner skin, which is made of 22-gauge perforated steel with 23% open area consisting of 1.59 mm holes spaced on 3.18 mm staggered centers. By perforating the inner skin, the absorptive properties of the fill material can be used in conjunction with the wedge system. With this system, greater low-frequency performance can be achieved with shallower wedges. The dimensions of the working area of the chamber (area inside the wedge tips) are 6.1 by 6.1 by 5.4 m (*L x W x H*).

To verify the performance of the design, the outer wall panels were tested in accordance with ASTM E90 (Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements) in ETS-Lindgren Acoustic System's reverberation chamber suite. The transmission loss of these panels appears in Fig. 6.

A structural mount was installed in the ceiling directly above the test specimen location in the center of the floor. A second turntable can be attached to this mounting point to rotate a microphone array around a test specimen when rotating the test specimen is not feasible.

The inner chamber is lined with wedges that are made from 48.26 cm deep monolithic melamine foam with a base that measures 20.32 cm by 60.96 cm. They are installed in alternating banks of three giving each bank a 60.96 by 60.96 cm footprint. Each wedge is secured using ETS-Lindgren's patented wedge clip system. The wedge clip system holds the base of each wedge 10.16 cm off of the inner panel skin, thereby creating a 10.16 cm airspace. The

Fig. 5. Inner and outer chamber walls during construction.

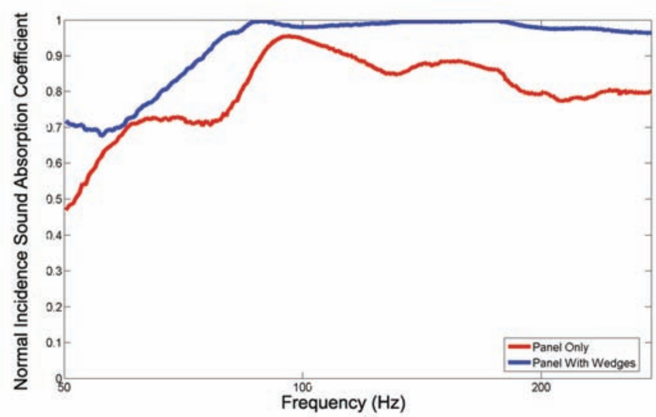

Fig. 7. ASTM E1050 normal incidence sound absorption test results for a 30.5 cm panel with and without wedges installed.

resulting total depth of treatment is 0.86 m. Figure 7 shows the results of an ASTM E1050 (Standard Test Method for Impedance and Absorption of Acoustical Materials Using A Tube, Two Microphones and A Digital Frequency Analysis System) normal incidence sound absorption test of the 30.5 cm panel by itself and with the wedges installed. The tests were performed in a 61 cm by 61 cm square cross section impedance tube.

Large test specimens are loaded into the chamber though two sets of double doors. The first set of doors is mounted in the outer chamber wall and has a 2.74 by 3.05 m clear opening. The second set of doors is mounted in the inner chamber wall and has a 2.44 by 2.74 m clear opening. Each door has its own automatic door opener. The automatic door openers are synchronized to open or close each door leaf in a specific order with the push of a single button. Figure 8 shows the completed chamber with the double door open. Inside the chamber two wedge doors cover the opening. Each wedge door measures 3.05 by 1.83 m (*H x W*) and moves out and sideways on a two-pivot hinge system and are shown in Fig. 9.

One of the challenges with such a low noise floor was the need for silent environmental control. The chamber's internal volume is 200 m^3 and has an air change every 6 minutes. To accommodate the required air flow rate and eliminate any duct-borne noise, a series of HVAC silencers were installed. Only one inlet path and one outlet path were used on the chamber with two HVAC silencers installed in each path. The first silencer, in the inlet path, is housed in a 10.16 cm thick panelized housing. The outer layer of the housing is 16-gauge steel with a 2.54 cm thick layer of gypsum board laminated to its inner surface. Next, 7.62 cm of fiberglass-free sound absorbing material was added and then the inner skin, a second layer of 16-gauge steel, was applied. Inside this housing, a 3.05 m long, high-performance splitter-type silencer with a 0.61 by 0.61 m cross section was installed. This housing was suspended from the host building's ceiling with vibration isolation mounts to decouple any vibrations that might be transmitted from the building or the HVAC system even though it was attached to the HVAC system with flexible duct work. The outer HVAC silencer housing passes through the chamber's ceiling through an isolated collar, which physically separates it

Fig. 8. Completed chamber with double doors open.

Fig. 9. One wedge basket door in operation.

from the chamber's structure.

A second HVAC silencer for the inlet path was installed between the outer and inner shells of the chamber. Due to its location between the chamber walls, a separate housing was not constructed around this silencer. The inner silencer is similar in construction except that it has a cross section of 0.30 by 0.91 m. The end of this silencer terminates with a 90 degree turn through the top of the inner chamber. Acoustic turning vanes are in all 90 degree turns within the HVAC system to maintain laminar flow and provide sound attenuation. No vent grilles were used at the opening inside the chamber in order to eliminate flow-generated noise. The inlet and outlet path silencer solutions are identical except for the orientation of the silencers due to the air flow direction.

Two different sets of lights were installed in the chamber. Each style of light met the design requirements of not introducing heat into the chamber and not contributing to the noise floor. Normally, only one style of light is installed but both types were installed for demonstration purposes. The first style of light uses a standard can-type housing with a light emitting diode (LED) bulb system. The second lighting system is a fiber optic system. The system consists of two 150-watt metal halide bulbs that are mounted outside of the chamber. Light is delivered by eight fiber optic bundles that pass through the ceiling of both the inner and outer chambers and terminate inside the chamber. All of the fiber optic bundle penetrations were treated to eliminate flanking paths.

To accommodate a wide variety of test specimens, a collection of electrical outlets was installed on the chamber. The electrical outlets range from 110 V_{ac} single phase to 480 V_{ac} three phase service. Both 50 Hz and 60 Hz service is available. The electrical panel is located on the outside of the outer chamber and the required electrical lines are passed through an acoustically treated penetration in the chamber walls. The reason for mounting the electrical panel outside of the chamber was to minimize the number of penetrations through the chamber walls.

To maintain client confidentiality and secure client test devices, a control room was constructed adjacent to the chamber. The control room consists of three walls and a ceiling, which was constructed using 10.1 cm thick panels. These panels are the same type of panel as used in the outer chamber walls. The fourth wall of control room is a section of the outer chamber's wall, which contains a personnel access door into the chamber. Instead of attaching the control room walls and ceiling to the outer chamber walls, the control room is separated from the outer chamber wall by 1 cm and the ceiling along this wall is supported by columns that attach to the host slab and not to the isolated pit. The gap between the walls was filled with a high-density neoprene foam gasket. The control room measures 8.69 by 3.66 by 3.05 m (*L x W x H*). This room is fed by a separate HVAC and silencer system to eliminate the possibility of noise flanking into the chamber from the control room through the HVAC system. The control room is shown in Fig. 10.

Fig. 10. Control room.

Once construction was completed, performance verification testing began. The first test conducted was to measure the chamber's noise floor to confirm that it met the specification of a level not exceeding NC-10 at any of the microphone positions on the measurement hemisphere. The chamber was tested at each location using a GRAS Type 40 HH low-noise microphone. The chamber exceeded the specification with a noise floor that was > 0 dBA for frequencies ≥100 Hz and only 5 dBA at 80 Hz. The noise floor is shown in Fig. 11. The noise floor is verified regularly as part of the laboratory's accreditation program and has not increased even though substantial highway construction has been completed and traffic has increased in the area. Also, several construction projects are ongoing in the area and none of them has affected the noise floor in the chamber.

The next test program was to verify the chamber's free-field performance. Using ETS-Lindgren's automated traversing rig, several sets of traverse or draw away data were taken in accordance with ISO 3745:2003 (Acoustics—Determination of sound power levels of noise sources using sound pressure—Precision methods for anechoic and hemi-anechoic rooms). The chamber was found to have an ISO 3745:2003 compliant

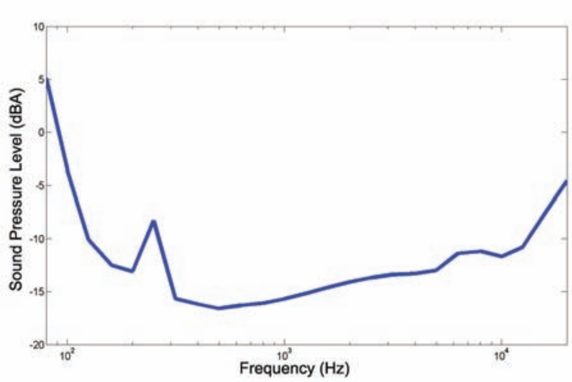

Fig. 11. Ambient sound pressure levels.

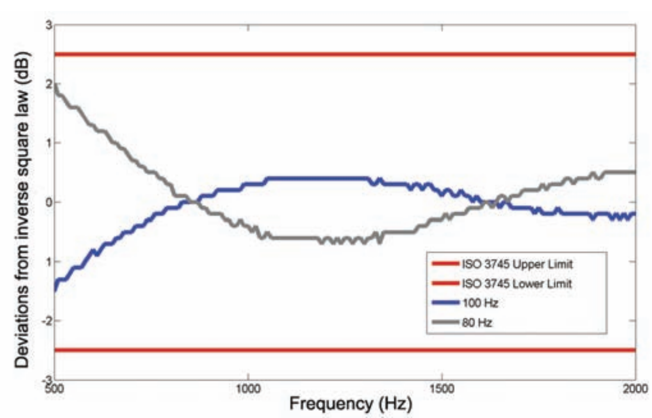

Fig. 12. Deviations from inverse square law at 100 Hz and 80 Hz.

field also accommodates a 3.6 by 3.35 by 3.0 m (*L x W x H*) parallelepiped for ISO 3744:1994 (Determination of sound power levels of noise sources using sound pressure—Engineer-ing method in an essentially free field over a reflecting plane) noise testing. The completed chamber is shown in Fig. 13.

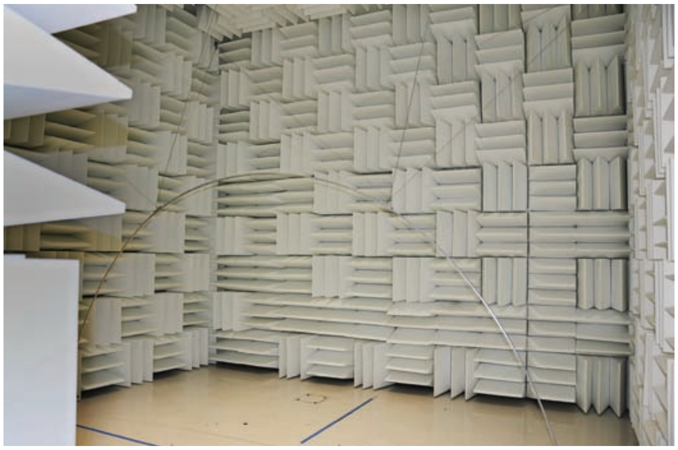

Fig. 13. Inside the completed chamber.

free field for frequencies ≥80 Hz at a distance of 2 m, which met the chamber's design specification. The free-field traverse data for 100 Hz and 80 Hz are shown in Fig. 12. The chamber's free

Conclusion

Several challenges arose during the design and construction of this project. The low-noise requirements, chamber flexibility, and free-field performance each provided a unique set of challenges. The chamber has been in operation since January 2008 and has tested a wide range of specimens. It has proved to be successful at meeting each of its design goals and has proven useful in the development of new sources for hemi-anechoic chamber qualification and free-field performance research. Due to the upfront planning and engineering, the chamber will continue to be a useful tool well into the future regardless of infrastructure growth and expansion in the area.**AT**

Douglas F. Winker is the principal acoustic engineer for ETS-Lindgren. He oversees the design of all of ETS-Lindgren's acoustic chambers, acoustics projects, and research and development. Doug received a Ph.D. in Acoustics from the Department of Electrical and Computer Engineering at The University of Texas at Austin, and holds a patent for a sound source used in anechoic chamber qualification. He is a member of the Acoustical Society of America, the Audio Engineering Society, the Institute of Noise Control Engineering, the Institute of Electrical and Electronics Engineers, and the Phi Kappa Phi honor society.