Recent Improvements to the Acoustical Testing Laboratory at the NASA Glenn Research Center

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The Acoustical Testing Laboratory (ATL) consists of a 27 by 23 by 20 ft (height) convertible hemi/anechoic chamber and separate sound-attenuating test support enclosure. Absorptive fiberglass wedges in the test chamber provide an anechoic environment down to 100 Hz. A spring-isolated floor system affords vibration isolation above 3 Hz. These specifications, along with very low design background levels, enable the acquisition of accurate and repeatable acoustical measurements on test articles that produce very low sound pressures. Removable floor wedges allow the test chamber to operate in either a hemi-anechoic or anechoic configuration, depending on the size of the test article and the specific test being conducted. The test support enclosure functions as a control room during normal operations. Recently improvements were accomplished in support of continued usage of the ATL by NASA programs including an analysis of the ultra-sonic characteristics. A 3 dimensional traverse system inside the chamber was utilized for acquiring acoustic data for these tests. The traverse system drives a linear array of 13, ¼"-microphones spaced 3" apart (36" span). An updated data acquisition system was also incorporated into the facility.

I. Introduction

THE NASA Glenn Research Center Acoustical Testing Laboratory[1] (ATL) is a 100 Hz. vibration-isolation anechoic chamber. Removable floor wedges that allow the facility to be configured as either a hemianechoic or fully-anechoic chamber. A separate, sound-isolated control room doubles as a test support equipment enclosure when testing articles that require remote connections to high-noise support equipment and services. Movable modular furnishings facilitate reconfiguration of the enclosure so that data acquisition and test control functions may be easily relocated to an adjacent quiet area. As an in-house laboratory, the ATL provides an accessible, secure and flight-hardware-compatible acoustic testing environment to support the low-noise design of microgravity space flight hardware and aeronautical research concepts. During the 2000-2005 time frame[2] the ATL was primarily utilized for space hardware and related items.

In 2010 modifications to the ATL were performed in support of studies[3,4] on the effect of wing/body shielding on aircraft engine noise. The traverse system was upgraded to incorporate 3-D planar movement throughout the chamber. A linear microphone array consisting of 13 ¼ "-microphones spaced 3" apart was installed. This provided a span of 36" for each sweep of the array. An updated data acquisition system was incorporated. Also, the ultrasonic characteristics of the ATL chamber were investigated as a result of the shielding studies scaling requirements.

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II. Facility Description

The Acoustical Testing Laboratory (ATL) consists of an anechoic test chamber with 27-ft by 23-ft by 20-ft high outside dimensions (21-ft by 17-ft by 17-ft high interior working dimensions) and a separate sound-attenuating test-support enclosure located adjacent to the test chamber. Depending on the type of test being conducted, the test chamber can be arranged in a fully-anechoic configuration in which the walls, floor and ceiling are completely covered with sound-absorbing fiberglass wedges (see figure 1) or in a hemi-anechoic configuration in which the floor wedges are removed (see figure 2) to expose a concrete slab.

Normally, the adjacent test-support enclosure serves as a control room housing both test personnel and equipment. Since it is a sound-attenuating enclosure, it can also be used to isolate noisy test support equipment such as chillers, pumps, and power supplies from the article under test in the anechoic chamber thus allowing uncontaminated acoustic measurements. Insulated utility sleeves located in the wall between the test support enclosure and test chamber allow cables, tubing, power chords, etc. to pass between them.

The ATL can be used to make accurate and repeatable sound pressure and sound power level measurements of low-noise producing components ranging in size from a small ventilation fan to a full rack of equipment (approximately 3-ft by 3-ft by 6-ft tall). It is one of a small number of acoustical testing laboratories in the United States which have received accreditation by the National Voluntary Accreditation Program.

A. Test Chamber Design

The ATL test chamber was originally designed to provide an anechoic test environment down to 100 Hz. Dense rubber located in the prefabricated 4-inch thick walls of the test chamber prevents unwanted exterior noise from entering the chamber. Sound-absorbing, 34-inch deep Eckel wedges line the interior of the chamber. The wedges consist of an outer 22-gage perforated metal face sheet with 53% open area and an inner fiberglass core. An acoustically transparent fabric located between the outer face sheet and the fiberglass core serves to contain the fiberglass. The wedges are built as modular units. Each unit contains 2 wedge peaks and has a base area of 2-ft by 2-ft.

The floor wedges are mounted on rolling carts. They can be rolled in and out of the chamber through a set of 9-ft wide by 10-ft high double doors making it easy to reconfigure the chamber from fully- to hemi-anechoic and vice versa. Metal grating mounted on top of the floor wedges allows: 1) personnel to walk throughout the test chamber and 2) sound to pass through to the wedges below. If desired, all or part of the floor grating can be removed in an effort to reduce acoustic reflections. The concrete floor contains a system of springs that provides vibration isolation for frequencies above 3 Hz and test articles weighing less than 5000 lbs.

B. Traverse System

Figure 3 shows a photo of the traversable, linear microphone array that was recently developed for ATL. The array consists of thirteen ¼-inch diameter condenser microphones spaced 7.6 cm (3.0-in.) apart (36-in. span). As shown in the figure, the microphones point downward and are arranged horizontally in a line so that they are all the same distance from the floor.

An overhead, three-axis traverse can be operated remotely from the adjacent test support enclosure to position the array relative to the test article. Each axis of the traverse is powered separately by its own electric motor and provides positioning accuracy of ± 0.03 mm (± 0.001 in). The initial, vertical location of the array can also be adjusted manually using the set of concentric, telescoping support tubes shown in the figure. The maximum travel distances provided by the x, y, and z-axes are 4.85 m (15.9 ft), 3.41 m (11.2 ft), and 4.27 m (14.0 ft), respectively. The repeatability or accuracy of the traverse as a whole is 0.02". This is partly caused by the play in the long belt drive actuators.

There is the ability to set the speed at which the traverse moves, though the maximum speed is 4 inches per second. This is not limited by the motors itself, but rather the deceleration rate that was decided upon. A deceleration rate has been implemented to reduce the swaying of the traverse so that the microphones would be stationary while acquiring data.

C. Instrumentation and Electronics

The anechoic chamber of ATL was recently updated with the new microphone array, a data acquisition system and signal conditioning filters. The array is fitted with thirteen PCB Piezotronics 378C01 microphones. This model is comprised of a ¼" 377C01 prepolarized microphone capsule and a 426B03 preamplifier (figure 4). A typical frequency response curve of these microphones is shown in figure 5. Model 378C01 operates on ICP® sensor power, or any 2-20 mA constant current supplies. This design is preferred for portable measurements or operation in high humidity applications. Design advantages include the ability to utilize coaxial cables, usage and interchangeability with other ICP® sensors (accelerometers, pressure sensors, stain gages, etc.) resulting in shorter set-up times and low channel costs. The preamplifier incorporates TEDs technology. Devices with this technology have built in read/write memory that contains relevant information about the sensor and its use. Information includes manufacturer name, model number, serial number, sensitivity, etc. This microphone system includes a mated preamplifier, which contains the TEDS memory programed with both the microphone and preamplifier information. This is particularly helpful when using array set–up. The microphone is recommended for extreme accuracy applications where high frequencies or high acoustic amplitude measurements are required.

All microphones are powered by signal conditioning amplifiers built into the acquisition system, Genesis 2i. The Genesis 2i has physical signal conditioners for all common sensors or featuring isolation to acquire off-ground signals. The sample rates range from 100 kS/s to 100 MS/s per channel. The Genesis 2i system, purchased for the ATL, is capable of acquiring 64 high-speed channels and automatically identifying sensors via TEDS protocol. The 16/32 Channel Accel Card 250kS/s can be used in five application areas: as a differential amplifier; entry level electrical input amplifiers; Accelerometer mode; Charge mode; and Single ended mode. The cards are fully programmable, including filters. The cards can be used for many IEPE based sensors (accelerometers, microphones, etc.). The frequency response curve of the Sigma-Delta A/D converter is shown in figure 6. Anti-aliasing filter options include a 12-pole Bessel style IIR filter (sample rate divided by 10, 20, 40, or 100) or a 12-pole Butterworth style IIR filter (sample rate divided by 4, 10, 20, or 40)

Also available is a stand-alone 16-channel signal-conditioning filter. The PF-1UB-FA-Z by Precision Filters Inc. is a multi-channel programmable filter/amplifier system. This filter normally operates in "flat" mode (2Hz to 204.6 kHz). The "flat" mode provides pass-band characteristics very similar to an 8-pole Butterworth filter. The filter system may be controlled remotely via the Ethernet interface using the supplied spreadsheet-style GUI application running on a Windows PC. The GUI supports control of all the channels and system features.

III. Acoustic Characteristics

One group of tests conducted in ATL was intended to measure shielding of high frequency sound (up to 50 kHz) by barriers of multiple configurations. Numerical simulations using Fresnel diffraction theory showed that barrier insertion losses of up to 30 dB or more could be expected. In order to avoid contamination of shielded acoustic signals, the contribution from signals reflected from un-shielded room boundary elements should be approximately 6 dB or more below the diffracted signal. Since typical anechoic room designs are focused on the frequency range up to 20 kHz, a program was undertaken to assess reflections above this range.

A. Test System and Procedure

The test concept was to measure the impulse response between an acoustic "point source" located near the center of the laboratory (the ultimate location of the program test object) and microphone traverse positions planned for the program test scans. Impulse delays would verify the distances between source and microphones and secondary peaks in the response would correspond to reflection paths. The delayed signal paths would be mapped to potential reflection locations on the boundary of the laboratory, which would then be physically examined and treated as judged necessary.

The test source was chosen as an electrostatic loudspeaker, Tucker-Davis type ESL-1, which would be used as the source transducer in the shielding test, and which has significant output to above 80 kHz. The radiation surface of the loudspeaker is 0.6 inches diameter. To provide a better approximation to a point source, a hybrid catenary/exponential transition horn was designed and fabricated. The final radiation diameter is less than 0.1 inch. Reflections within the horn were minimal because of the low acoustic impedance of the speaker diaphragm, and radiated reflections were approximately -12 dB per reflection.

Impulse test signals with adequate amplitude were achieved by using Gallois sequence excitation. Often referred to as MLS (or maximum length sequence), these signals are period-modulated square waves with the convenient property that the circular correlation function is $\delta(t-t0)$. This allows the impulse response of a system to be assessed by cross-correlating its output with the excitation signal. In this test, a 2^{18} sample MLS was used to excite the test source and was simultaneously recorded on the data system with the outputs of the ATL microphone array.

The ATL microphone array was located at a sequence of "stops" on the traverse pattern designed for the program tests. The MLS signal was output to the ultrasonic calibration source at 100 kHz clock rate. The MLS signal and the outputs from 14 traversing microphones were recorded at 200 kHz sampling rate on a simultaneous data acquisition system.

B. Data Reduction and Analysis

Each microphone signal was cross-correlated with the excitation signal and with the Hilbert transform of the excitation signal. The sum of squares of these two correlation functions were converted to sound pressure level (SPL) vs. time, plotted and stored.

The six boundary surfaces of the laboratory were divided into 3x3 inch grids and the microphone rake traverse track was divided into 3-inch segments. The distance from the point source to each grid point and from each grid point to the microphone position were computed and sorted. The distance from the point source to the microphone was computed and divided by the speed of sound. The resultant time delay was compared to the initial arrival delay of the test signal to verify signal integrity. The delay time of any significant reflections noted in the echogram was compared to the sorted list of potential source-boundary-microphone paths. The five boundary locations with closest delay correspondence with the measured delay were printed out for physical investigation and possible treatment. A reflection is considered significant if its SPL exceeds $SPL_{direct} + 20 \log (t_{direct}/t_{reflected}) - 20$ dB. In other words, if the effective reflection coefficient exceeded 0.1.

Histograms of "hits" were prepared for each room boundary grid point taken over all traverse stops and microphone positions to help locate the most probable reflection elements. The histograms were weighted by the reflection coefficients of the identified reflections and the results were displayed as 2 dimensional color-intensity plots for each of the room surfaces and line plots for the elements of the traverse track.

C. Results Example

Figure 7 is the test point example that showed the single highest reflection coefficient. The upper graph is the measured echogram, showing the initial signal at delay 7.82 ms and SPL 44.7 dB. This is followed by a series of horn reflection peaks about 0.6 ms apart and -12 dB per reflection.

The strongest reflected signal indication is at delay 15.76 ms with SPL 26 dB indicating a refection coefficient of 0.24. The lower graph shows the sorted distribution of delays for all potential boundary grid points. The title shows the expected initial signal delay, in this case 7.48 ms. The 0.34 ms discrepancy between this and the measured initial delay is accounted for by the length of the coupling horn, 4.6 inches. The nearest potential reflection point is printed at the left of the distribution plot.

The boundary reflection color maps are shown in the following figures (8-14). The figures are oriented so that they represent actual plans/elevations of the boundaries. The intent is to allow test personnel to identify reflective "hot spots" that aren't visually obvious, so that additional absorption treatment or other remedies could be applied.

Figure 8 shows that the floor grating is generally reflective, with a coefficient of 0.1 and an occasional point up to around 0.2. This indication led test personnel to remove portions of the grating that could have influenced the shielding measurements.

Figure 9 shows reflections from the ceiling to be much sparser than from the floor grading, with only a few spots exceeding 0.1 reflection coefficient. Visual inspection indicated that at least some of these reflective points corresponded to flood lamps, which were removed for the shielding measurements.

Figures 10 and 11 show a few clusters of relatively high reflection, with coefficients up to 0.24 (see Figure 7). These clusters are primarily on the right side wall, which includes the main loading door and its support poles. The poles were wrapped with sound absorbing treatment for the shielding measurements.

Figures 12 and 13 show sparse reflections from the two end walls, with relatively strong (0.2 range) coefficients in the area of the ventilation duct.

Finally, figure 14 shows that relatively minor reflections were introduced by the microphone traverse track shown in Figure 1. The track is treated with sound absorbing material, with a few gaps that may correspond to the points shown in the figure. However, more specular reflections are expected from flat surfaces on the track as opposed to the wedges and cylindrical poles of the other boundaries, so that at ultrasonic frequencies, their effect would be observed only at a limited range of microphone/source position pairs.

IV. Conclusion

The NASA Glenn Research Center's Acoustical Testing Laboratory has been recently modified to accommodate more research oriented testing. The traverse system was upgraded to provide a more detailed mapping arrangement of the acoustic field in the chamber. Upgrades to the data acquisition system were made to emphasize the details of the acoustic field. The chamber was evaluated for ultra-sonic conditions up to 50kHz.

Further improvements to be made include adding acoustic treatments to the reflection areas in order to reduce the influence of room boundaries on the acoustic field. The Z-traverse telescoping mechanism should be improved to enable true 3-dimensional sweeps to be achieved. A tighter integration between the traverse control and the data acquisition system would improve operational efficiency.

Acknowledgments

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[4] Daniel L. Sutliff, Clifford A. Brown, and Bruce E. Walker, "Hybrid Wing Body Shielding Studies Using an Ultrasonic Configurable Fan Artificial Noise Source Generating Typical Turbofan Modes ", AIAA–2014-0256, June 2014.

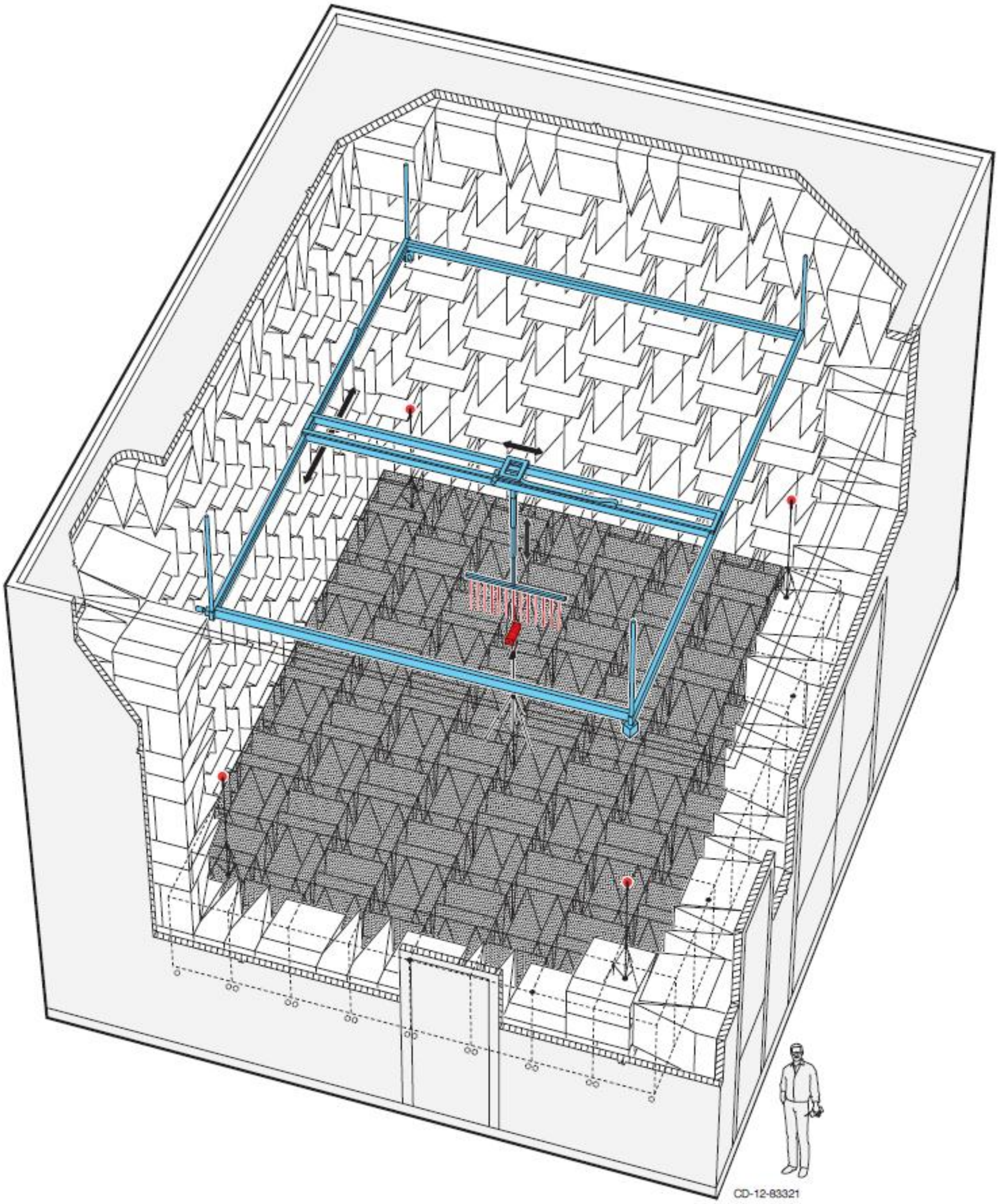

Figure 1. Schematic showing ATL in fully anechoic configuration with fiberglass wedges covering walls, floor, and ceiling of the test chamber.

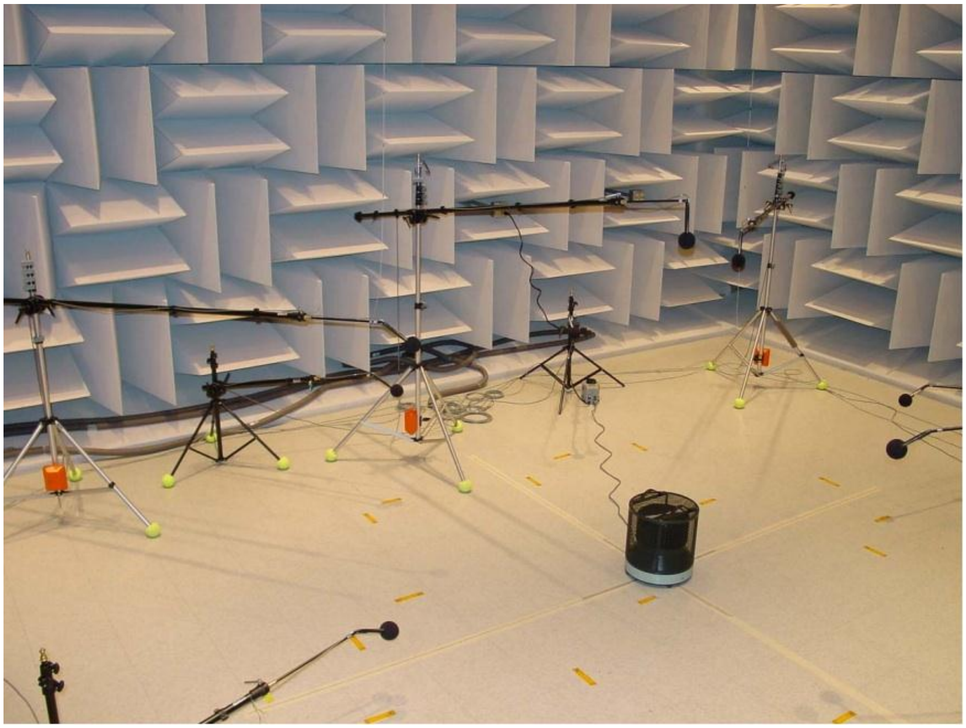

Figure 2. Photo showing acoustic test hardware on the concrete floor of ATL (hemianechoic configuration with floor wedges removed).

Figure 3. Photo of the linear traverse array suspended from 3D traverse.

Figure 4: Photograph of microphone style used in ATL.

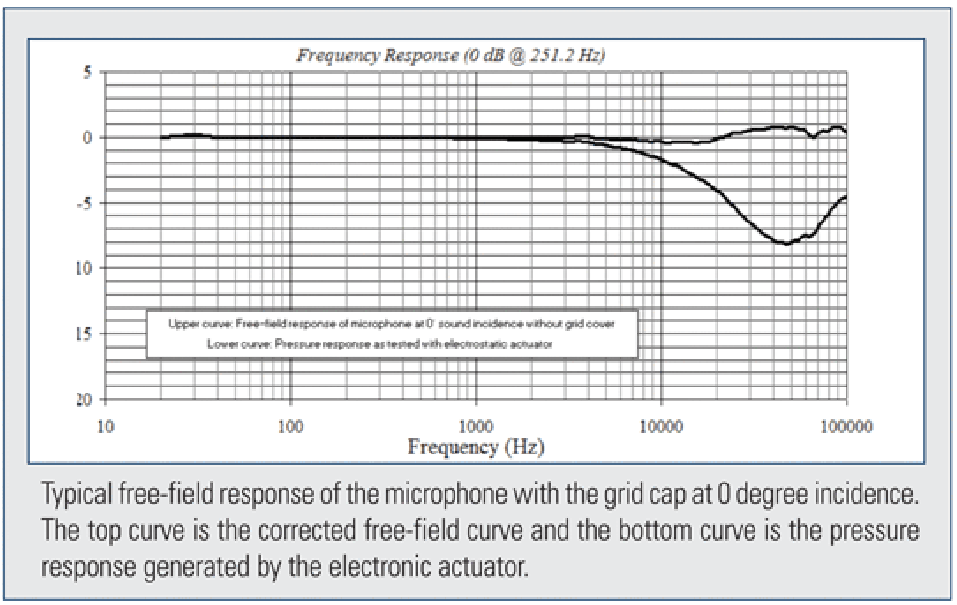

Figure 5: Typical Frequency Response Curve of Microphones used in ATL

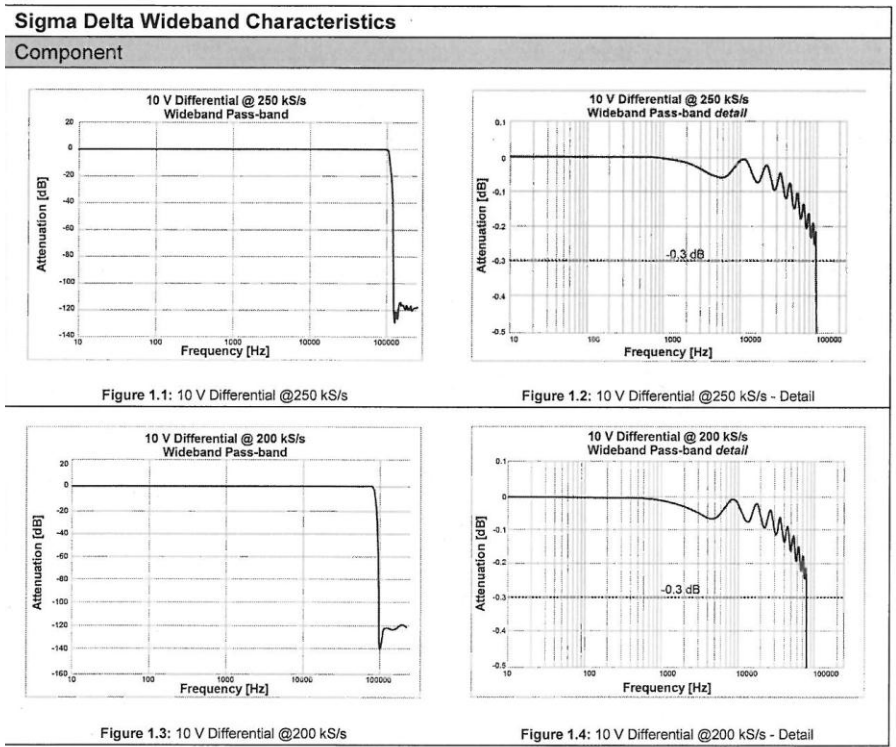

Figure 6: Filter Response Curves for ATL A/D Anti-aliasing Filters.

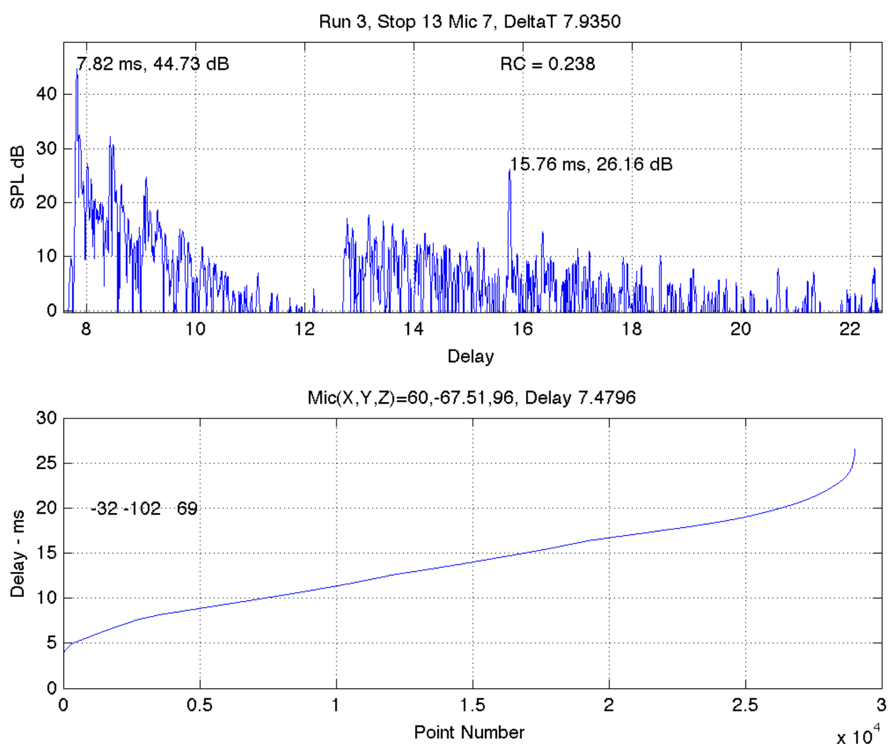

Figure 7: Typical Echogram.

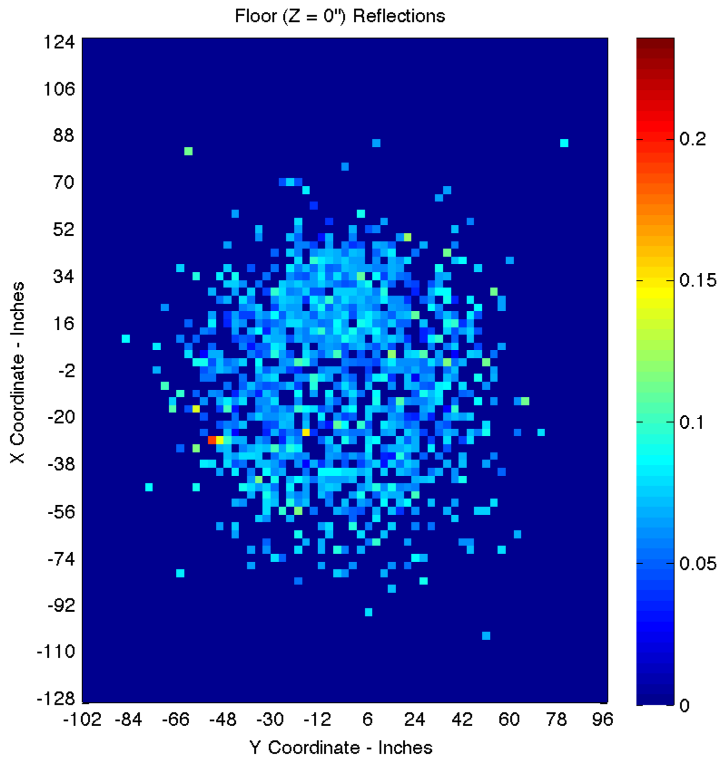

Figure 8. Weighted Histogram of Floor Reflections

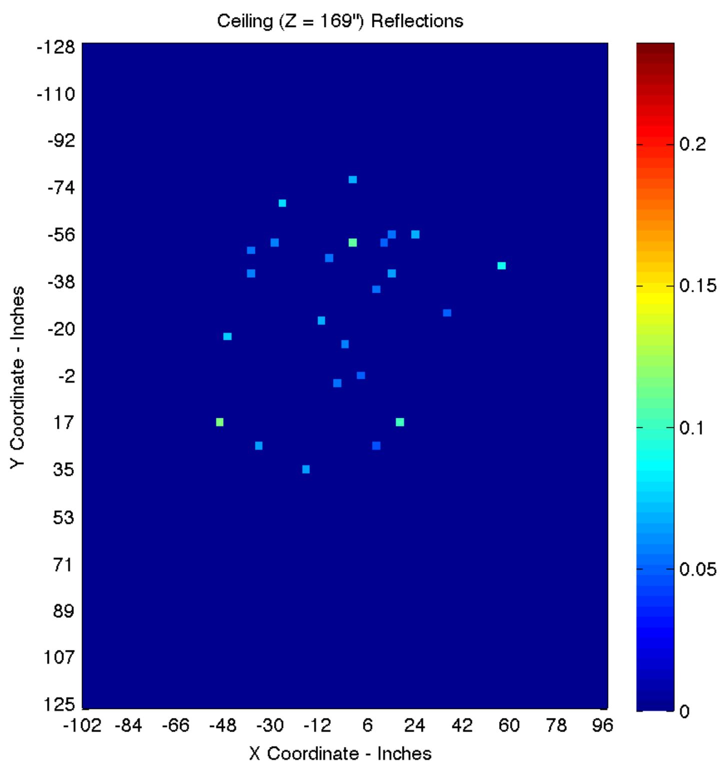

Figure 9. Weighted Histogram of Ceiling Reflections

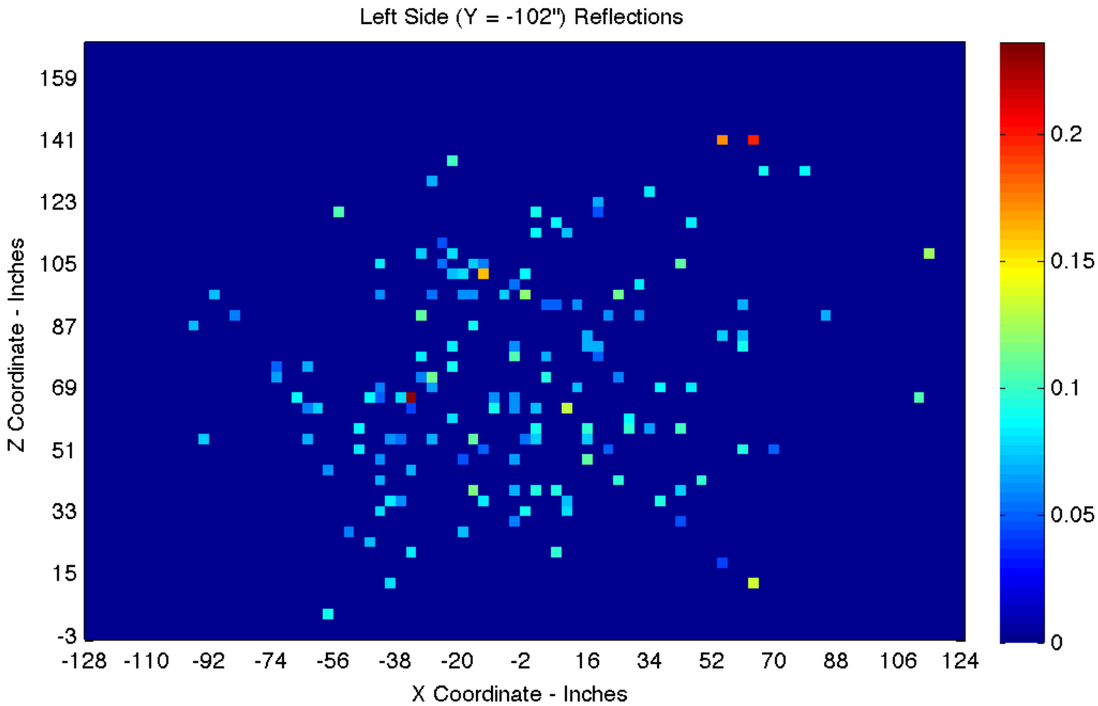

Figure 10. Weighed Histogram of Left Sidewall Reflections

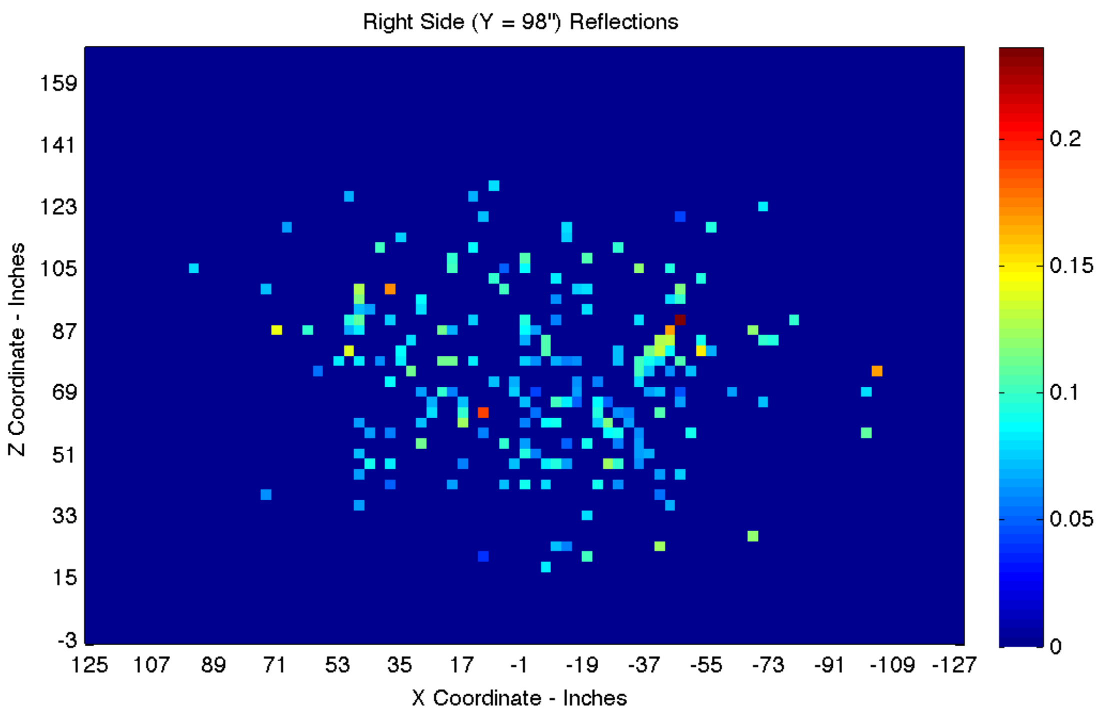

Figure 11. Weighted Histogram of Right Sidewall Reflections

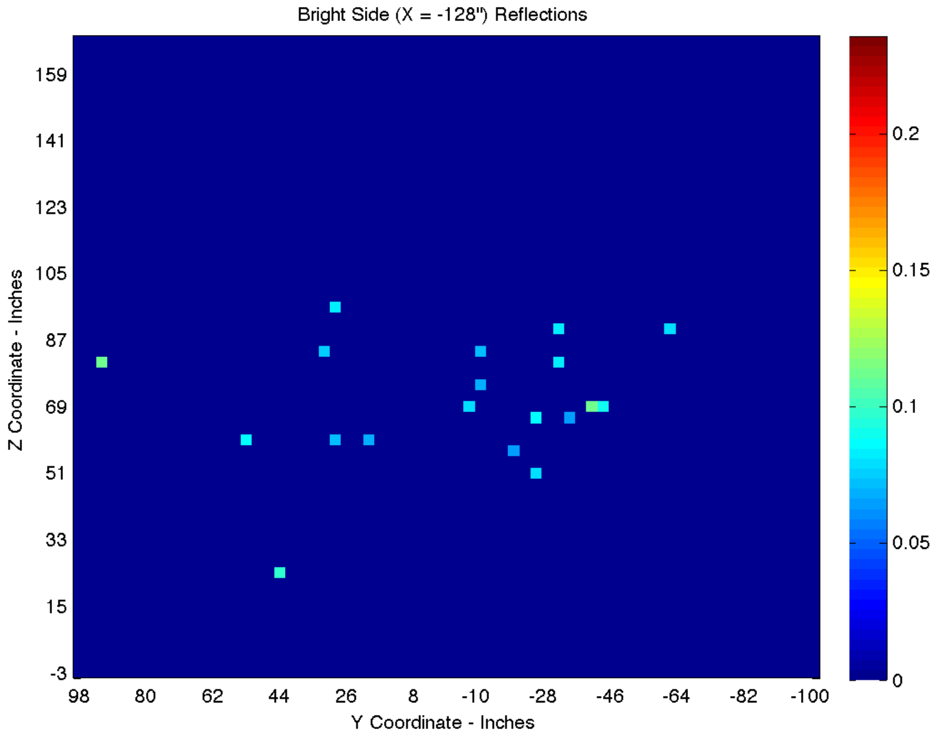

Figure 12 Weighted Histogram of "Bright" End Wall Reflections

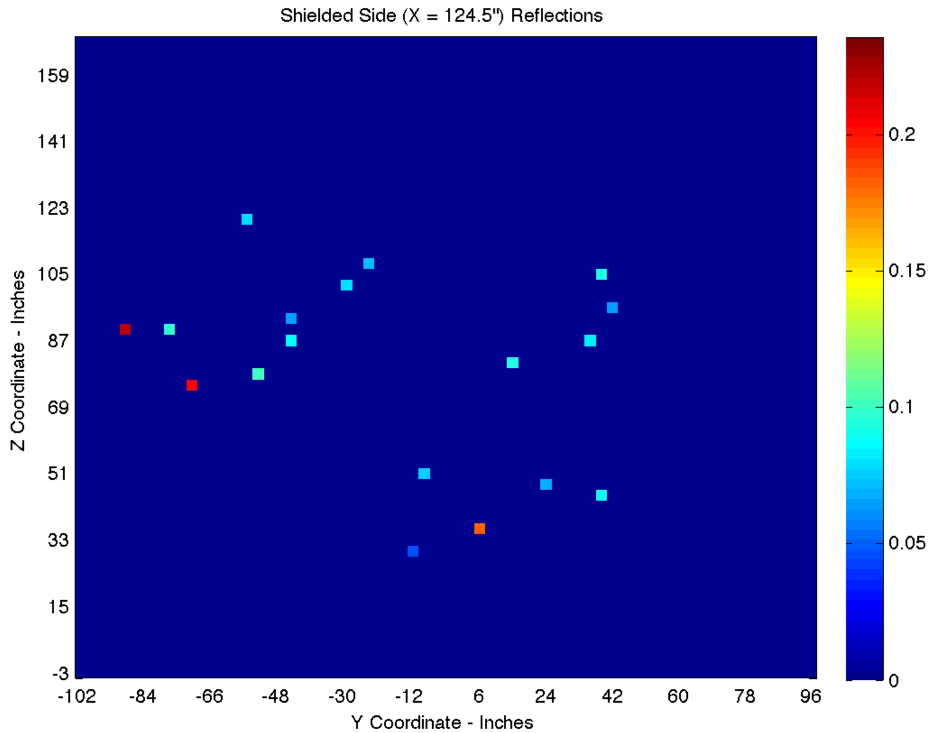

Figure 13. Weighted Histogram of "Shielded" End Wall Reflections

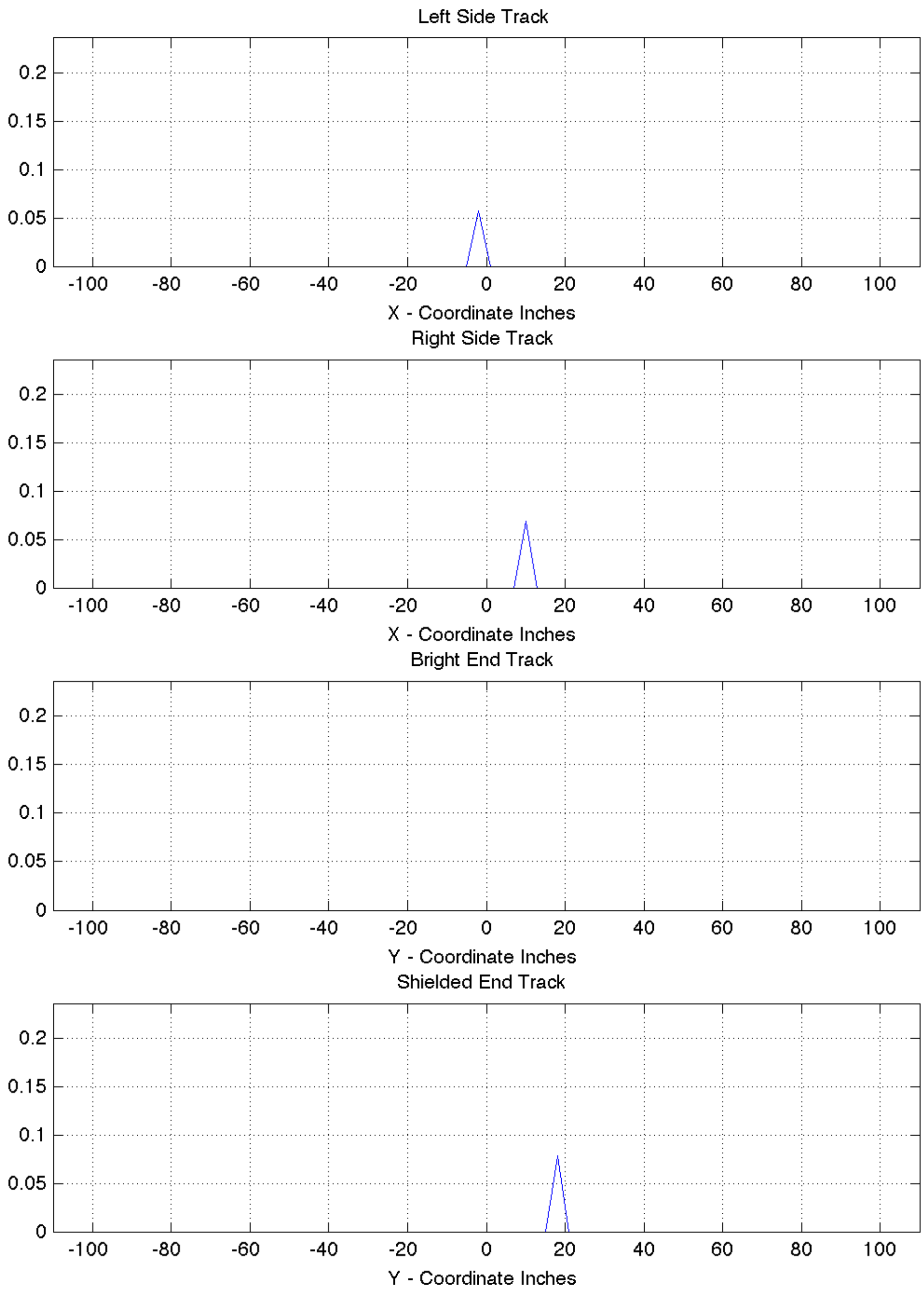

Figure 4. Weighted Histograms of Traverse Track Reflections