Baltimore, Maryland
NOISE-CON 2010
2010 April 19-21

The development of NASA Auditory Demonstrations Laboratory for measurement of real ear attenuation of hearing protection devices

Jeff G. Schmitt1
ViAcoustics
2512 Star Grass Circle
Austin, TX 78745

Beth A. Cooper[2]
NASA Glenn Research Center
21000 Brookpark Road
Cleveland, OH 44135

David A. Nelson[3]
Nelson Acoustics
PO Box 879
Elgin, TX 78621

The measurement of the Real Ear Attenuation at Threshold (REAT) of hearing protection devices in accordance with industry standards, such as ANSI S12.6, is a key metric for evaluating the effectiveness of a hearing protector and for establishing its NRR rating. The REAT measurement procedure relies on the determination of both the open ear and occluded hearing thresholds by normal hearing subjects, which in turn requires test chambers that provide low ambient sound levels, signal generation equipment and sound systems capable of generating calibrated sound fields and software to control stimulus presentation and response. Under contract to the NASA Glenn Research Center, the authors have constructed a REAT laboratory facility and developed a software application that operates on commercially available National Instruments data acquisition and digital signal generation equipment that implements the REAT measurement procedure. The NASA *REATMaster* software application is being made available by NASA to qualified laboratories in the hearing protection community, in an effort to promote hearing conservation by facilitating hearing protector design and testing. This paper will outline the key features of the NASA Auditory Demonstrations Laboratory facility and the *REATMaster* software application.

[1] Email address: jeffs@prodigy.net
[2] Email address: beth.a.cooper@nasa.gov
[3] Email address: david@nelsonacoustical.com

1 INTRODUCTION

The NASA Auditory Demonstration Laboratory (ADL) is a multi-purpose auditory and acoustical laboratory for the development and presentation of auditory demonstrations related to hearing conservation and acoustical concepts and the measurement of the performance of hearing protection devices in critical user applications.[1]

The development of the Real Ear Attenuation at Threshold (REAT) test facility and test system at the ADL was started in the fall of 2007 and consisted of the following major scope of work elements:

- Design, construction and installation of an acoustic test chamber at the NASA ADL host facility
- Design and installation of a REAT stimulus presentation sound system
- Design and installation of a stimulus signal generation and data acquisition system
- Development of a software application for REAT measurements in accordance with industry standard ANSI S12.6[2].
- System calibration and sound field qualification per industry standards

A REAT test laboratory requires both very low background noise levels, to provide an environment sufficient for the detection of open ear threshold of hearing or normal hearing subjects, while at the same time being equipped with a sound system capable of generating test stimuli at very high sound pressure levels. In the case of the NASA Auditory Demonstration Laboratory the sound system may be required to generate launch level sound fields, evaluate the performance of layers of hearing protection and/or evaluate non-linear hearing protection devices designed to provide protection only at very high sound pressure levels. This presents some unique acoustic and audio design challenges. Figures 1-5 provide photographs of the completed ADL facility.

2 ACOUSTIC TEST CHAMBER

The acoustic test chamber in a REAT test laboratory has two primary functions; (1) provide acoustic attenuation needed to achieve the required background sound pressure levels and (2) create the diffuse sound field environment needed to meet the sound field uniformity and directivity requirements. An ETS-Lindgren custom-designed, pre-fabricated steel reverberant test chamber was constructed and installed in the ADL to meet these objectives.

2.1 Acoustic Attenuation and Background Sound Pressure Levels

The ADL was constructed at a site that was ideally suited for the location of a low noise acoustic measurement laboratory. Located in the basement of a building with concrete construction walls and roof cap and heavy steel doors, the site had sufficiently low background noise levels to allow for the construction of a single wall reverberant test chamber. Because the reverberant interior properties of a REAT test chamber limit the effective noise reduction that can be achieved using a single wall acoustic test chamber, it is possible to achieve only about 20 dB of isolation at 125 Hz, rising to about 45 dB at frequencies about 500 Hz. The heavy construction of the host site allowed a single wall test chamber to provide the required isolation.

In addition to the sound isolation aspects of the test chamber design, special consideration had to be given to the sound levels generated by the HVAC systems, both inside the chamber and in the control space outside of the chamber, where there will often be open microphones and where good speech intelligibility is required. While the host site was ideal in terms of its massive shell construction, its older technology, chilled water, forced air ventilation system presented a design challenge. Several massive silencer units were installed in series between the host facility supply openings and the laboratory control space and test chamber to attenuate the low frequency rumble and to slow the flow rates before air exited into each space. Flow rate controls were installed that allowed the ventilation systems to be operated in “High”, “Test” and “Off” states.

Figure 7, “Sound Systems Off” shows the ambient sound pressure levels that were achieved in the ADL test chamber, at the subject position, prior to activation of the sound systems and with the ventilation systems operating in their “Test” l mode. Ambient sound pressure levels are 5 dB to 20 dB below the ANSI S12.6 requirements.

2.2 Reverberant Properties for Diffuse Sound Field

The acoustic test chamber must also provide a reverberant environment suitable for creating a diffuse sound field while at the same time keeping reverberation times low enough to prevent reverberant smearing of the pulsed stimulus used in the REAT test procedure. The ADL test chamber was sized in accordance with length-to-width-to-height ratios typically used in reverberation room design to assure good modal distribution and overlap. The solid steel interior surfaces of the test chamber provided the acoustically reflective surface needed to create a reverberant sound field. Three (3) sound diffusing panels, mounted to create non-parallel reflective surfaces, helped insure that oblique and tangential modes were excited by the sound system. Because the ADL wished to have test capabilities at frequencies as low as 63 Hz, the chamber was sized such that two of its dimensions were greater than ½ wavelength at 63 Hz, with the length being almost a full wavelength. Chamber size and the sound absorptive properties of its surface determine the reverberation time in the chamber, which may not exceed 1.6 seconds to comply with ANSI S12.6 requirements. Figure 9 shows the reverberation times of the ADL acoustic test chamber.

3 SOUND SYSTEM

The stimulus presentation sound system for the ADL was designed to meet the following requirements.

- Create diffuse field sound pressure levels sufficient to allow REAT or fixture-based testing of multiple-layer or non-linear hearing protection systems.
- Provide stable gain and high slew rate output
- Operate quietly when operated at full gain, but without an input signal, such that system-generated noises (hum, hiss, static, etc.) are below the ambient noise requirements of ANSI S12.6, when operated at full gain but without an input

The sound system in the ADL is a three (3) channel system, utilizing ElectroVoice T251 horn loaded loudspeakers that are driven by a Bryston 6BSST power amplifier. The amplifier delivers 300 watts per channel, more than 110 dB of signal to noise ratio and has a fixed gain input setting that facilitates system calibration.

In order to achieve the very low background noise levels needed for open ear threshold of hearing testing, the audio system also employs a high-power 30 dB L-pad load box attenuator unit between the outputs of the amplifier and the inputs to the loudspeaker systems. Even with the highest quality power amplification and high end wiring, without the L-pad attenuators, occasional, intermittent static would be just audible at the subject position. The L-pad attenuator eliminates any audible, and almost all measureable, noise from the sound system, as shown in Figure 7. The L-pad attenuator can be removed from the system when very high sound levels are needed.

4 SIGNAL GENERATION AND DATA ACQUISTION

One of the primary goals was to build an automated system that used commercially available signal generation and data acquisition hardware. Previous automated test implementations of the REAT test method have required the use of very expensive and specialized digital signal processing (DSP) hardware. Recent advances in PC-based digital signal generation and analysis hardware have made 24 bit technology both affordable and available in several modular form factors. In the case of the ADL, the National Instruments PXI platform was selected, and two (2) each of the PXI-4461 2-input, 2-output, 24-bit Digital Signal Generation/Acquisition boards were used, providing a 4-input, 4-output, simultaneous generation/sampling system for both stimulus generation and acoustic measurement. For detection of subject response, via a variety of response switch options, a National Instruments PXI-6220 digital I/O board with a custom response switch interface was utilized.

5 NASA *REATMASTER* SOFTWARE

The NASA ***REATMaster*** software application was developed by Nelson Acoustics to provide the ADL with a software application that would conduct calibrated real ear attenuation at threshold measurements using the National Instruments hardware. National Instruments LabView programming language was used to develop the user interface, signal generation, system calibration and test automation software. ***REATMaster*** is then compiled into an executable application providing plug-and-play installation. Figure 6 shows the front panel of ***REATMaster*** in the Automatic Test Mode.

The NASA ***REATMaster*** software application has the following features:

- Flexible configuration of system hardware for 1 to 4 channels of signal generation
- System calibration tools that provide for both level and frequency calibration of each channel.
- Bekesey (per ANSI S12.6 standard), or Hughson-Westlake audiometric protocols, with user-defined threshold-seeking settings
- Architected to allow other audiometric threshold-seeking protocols to be added.
- Manual operating mode that supports system function verification, calibration and subject training.
- Automated threshold-seeking for both unoccluded and occluded conditions using user defined frequencies and presentation order.

- Utilizes standard audio WAV files for stimulus generation, allowing for user defined stimulus waveforms.
- Exports thresholds, and level versus time history, to MSExcel for post-process analysis and reporting

6 SYSTEM CALIBRATION AND SOUND FIELD QUALIFICATION

On completion of the test chamber and equipment installation and software development phases of the project, the entire system was calibrated and qualified per the requirements outlined in ANSI S12.6. Using a GRAS 40AQ random incidence microphone and the analog inputs on the National Instruments Digital Signal Analysis boards, the Nelson Acoustics Trident acoustic measurement application was used to conduct the level calibration and frequency equalization of the sound system. The Trident application was also used to measure the background sound pressure levels, using a GRAS 40 HF low noise microphone system and verify compliance with the reverberation time requirements discussed above.

Next, the diffuse sound field properties of the chamber were evaluated for sound pressure level uniformity and directionality at the location of the subject’s head. ANSI S12.6 outlines a measurement procedure and criteria for these parameters, with the intent being the creation of a very uniform and highly omni-directional sound field in the region surrounding the subject’s head, so as to minimize the measurement uncertainty associated with the hearing protector attenuation as a result of uncertainties in the measurement of the sound pressure levels presented to the subject. Figures 8 and 10 show the results of these measurements, along with the ANSI S12.6 criteria. In all cases the NASA GRC ADL real ear attenuation system was able to meet or exceed the criteria.

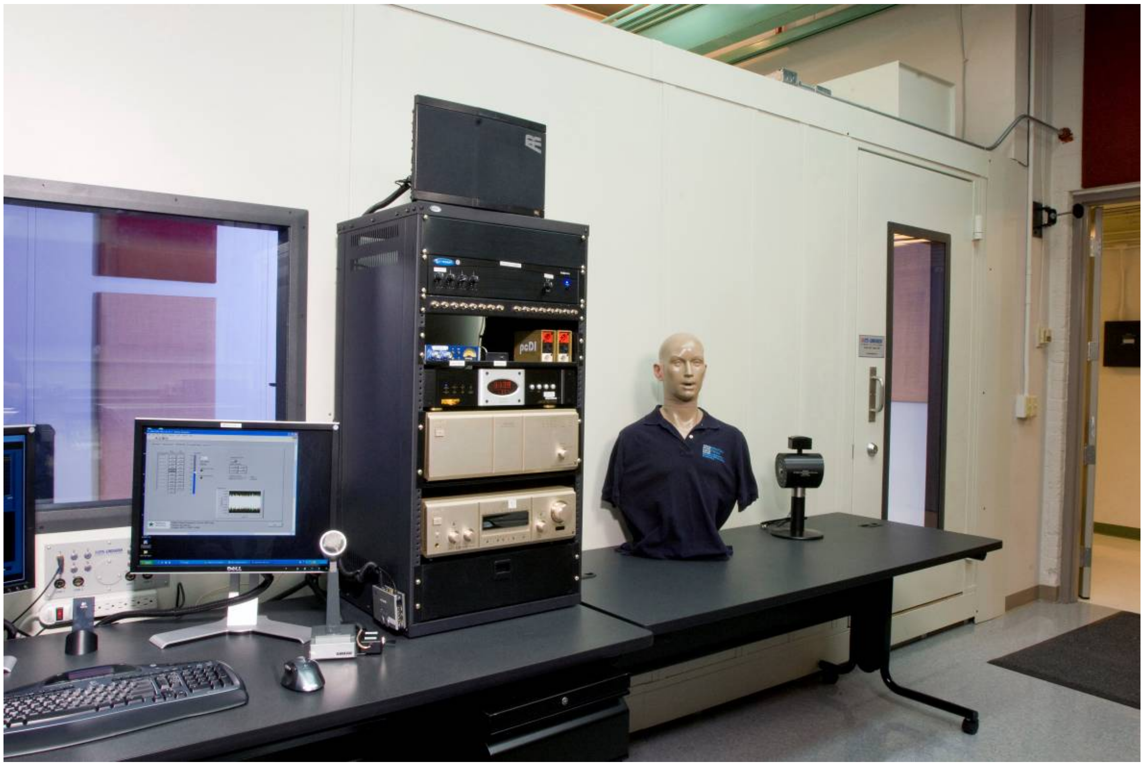

Figure 1 – Exterior View of the NASA GRC Auditory Demonstrations Laboratory Real Ear Attenuation test chamber, control space and test fixtures.

Figure 2 – NASA GRC Auditory Demonstration Laboratory control room with NASA ***REATMaster*** and Stimulus Presentation Sound System Rack (left) and Auditory Demonstrations Rack (right)

Figure 3 – Interior View of NASA GRC Auditory Demonstrations Laboratory REAT Test chamber, showing diffusing panel, intercom speaker system and subject instruction video display

Figure 4 – Interior view of NASA GRC Auditory Demonstrations Laboratory REAT test chamber, showing ElectroVoice speakers, diffusing panels and GRAS low noise microphone system used for background noise measurement.

Figure 5 – The fabric panels in the ADL test chamber are removed from the test chamber when it is used for REAT testing. The fabric panels add the absorption needed to make the chamber convertible for use in presenting auditory demonstrations using the secondary audio sound system.

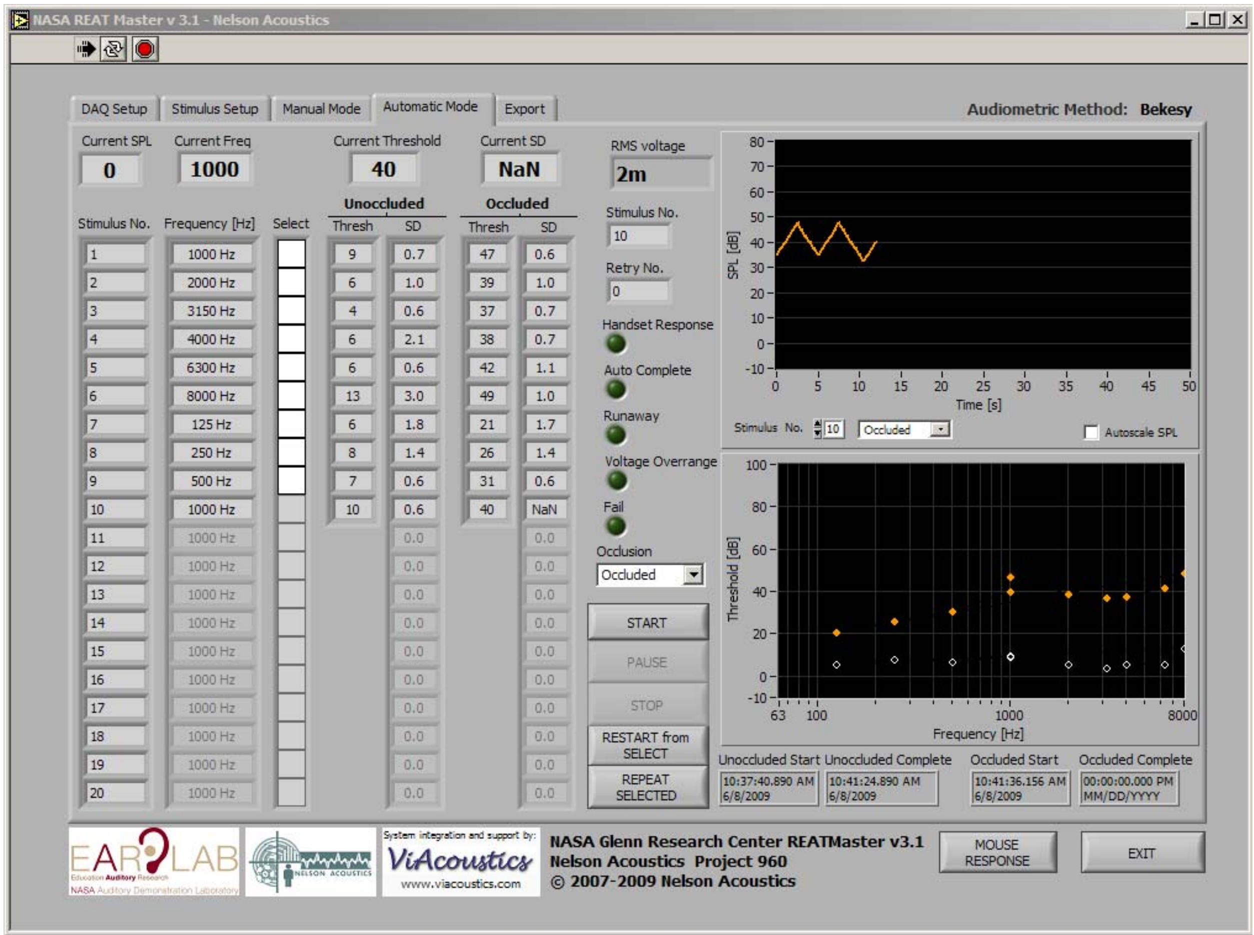

Figure 6 – NASA ***REATMaster*** automatic mode user interface. Upper display shows stimulus presentation level versus time for a Bekesey threshold-seeking trial while the lower graph shows unoccluded and occluded thresholds for the stimulus test sequence.

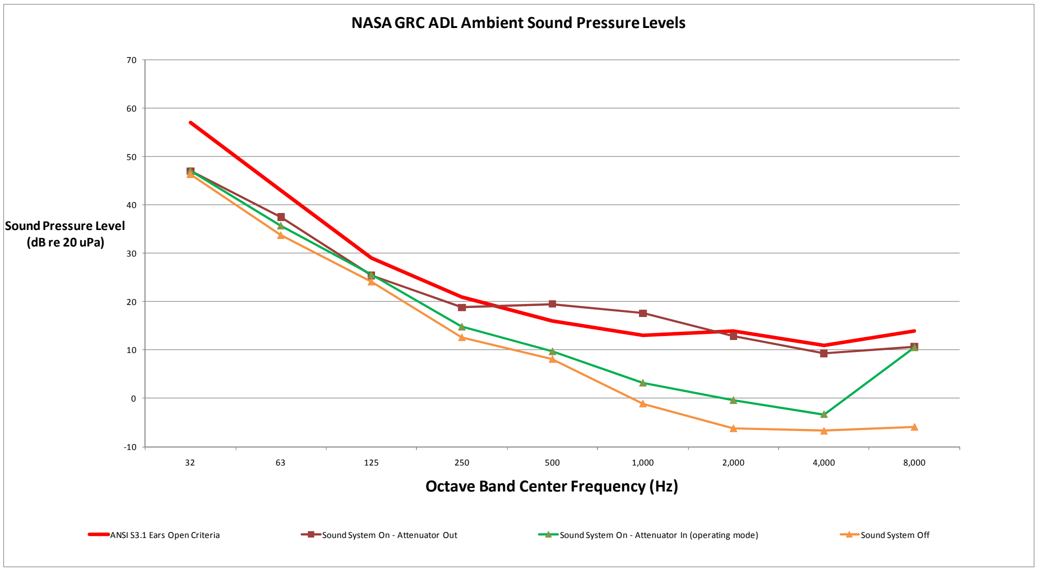

Figure 7 – Ambient sound pressure levels in the NASA GRC Auditory Demonstrations Laboratory REAT test chamber under several operating conditions:

- Sound System Off – No systems in operation, chamber background only
- Sound System On with the 30 dB Lpad Attenuator Out
- Sound System On with 30 dB Lpad Attenuator In and HVAC systems in Test Mode Operation

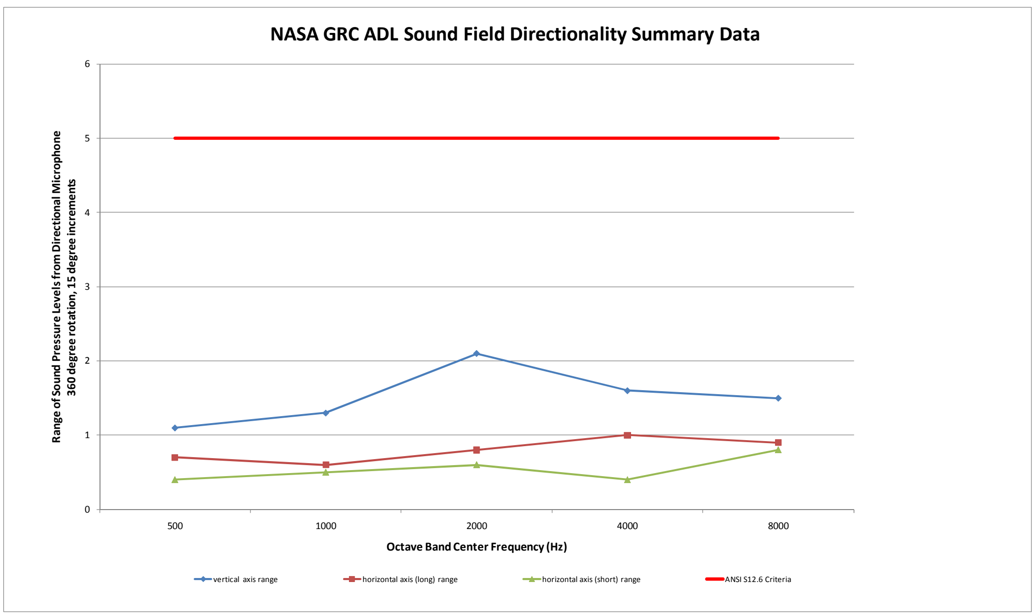

Figure 8 – Sound Field Directionality in NASA GRC Auditory Demonstrations Laboratory REAT test chamber. Results shown are the range of sound pressure levels measured as a cardiod microphone is rotated 360 degrees at 15 degree increments around all three chamber axes at the subject position, compared to the ANSI S12.6 criteria. Directionality criteria only applies at and above 500 Hz

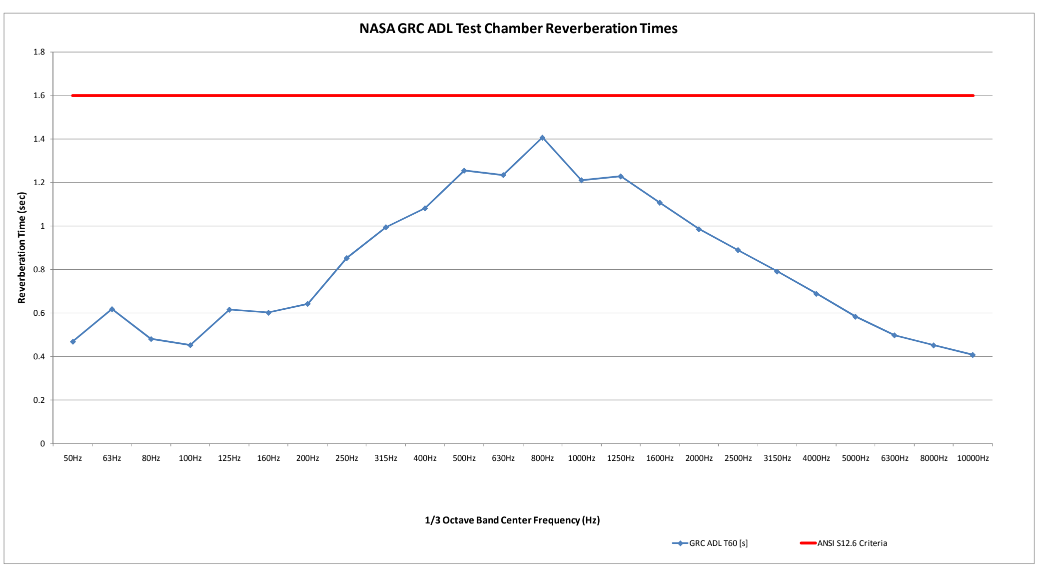

Figure 9 – Reverberation time measurements in the NASA GRC Auditory Demonstrations Laboratory REAT test chamber compared to the maximum reverberation time criteria in ANSI S12.6

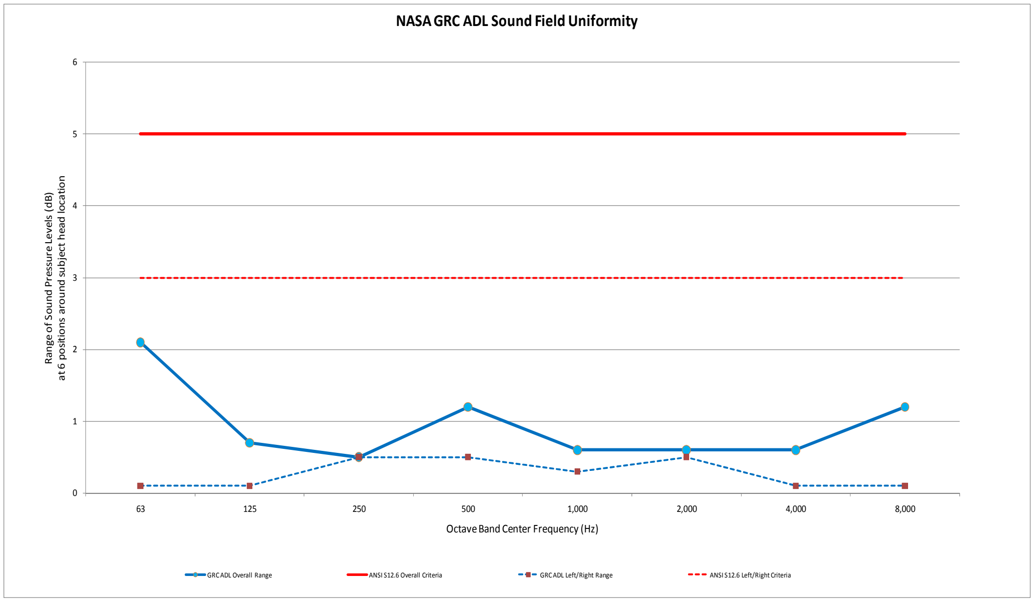

Figure 10 - Sound Field Uniformity Qualification results in the NASA GRC Auditory Demonstrations Laboratory REAT test chamber. Test results are the range of sound pressure levels measured at 6 positions around the subject position and are compared to the criteria in ANSI S12.6

7 CONCLUSIONS

As of this writing, the NASA GRC Auditory Demonstrations Laboratory Real Ear Attenuation at Threshold system development project has been completed. The test chamber and sound systems have been successfully designed, installed and qualified to the ANSI S12.6 test method. The NASA ***REATMaster*** software development project has resulted in a software tool that the ADL and other qualified hearing protector laboratories can employ using industry standard computer based digital signal generation and data acquisition hardware.

8 ACKNOWLEDGEMENTS

The authors would like to acknowledge the technical guidance provided by William Murphy and David Byrne at the National Institute of Occupational Safety and Health in Cincinnati, Ohio on audiometric protocols and their past experience developing similar software. Their input was invaluable in making the NASA ***REATMaster*** software development project a success.

9 REFERENCES

1 B.A Cooper, J.G. Schmitt, D.A. Nelson, Development of NASA Glenn Research Center Auditory Demonstration Laboratory facility and operational capabilities, Proceedings NoiseCon 2010, Baltimore, MD.

2 ANSI S12.6-2008, Methods for Measuring the Real-Ear Attenuation of Hearing Protectors