



## In-Depth Survey Report

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Comparison of Three Noise Reduction Rating Calculators for Passive and Active Hearing Protection Devices.

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## **Abstract**

Active Noise Cancellation (ANC) hearing protection devices (HPDs) are evaluated for their passive attenuation and the active contribution to the total attenuation when the device is worn. The USAF Air Force Research Laboratory (AFRL) at Wright Patterson Air Force Base (WPAFB) conducted measurements of the real-ear attenuation at threshold (REAT) and microphone in real ear (MIRE) performance of four ANC earmuffs: Bose A20 Aviation headset, Pilot Independence DNC PA1779T headset, Sennheiser HMEC headset and the Telex Stratus Heli-XT Aviation headset. The octave band REAT attenuations were measured according to the ANSI/ASA S12.6-2008 standard. The one-third octave band MIRE data were measured and combined according to the ANSI/ASA S12.42-2010 standard to estimate the active component by measuring the device when it is turned on versus off. The total attenuation ratings from three calculators were compared for the overall Noise Level Reduction Statistic for A-weighting ( $NRS_A$ ) and the four values resulting from the Graphical Noise Level Reduction Statistics computed according to the ANSI/ASA S12.68-2007 standard. The three calculators were MATLAB<sup>®</sup> code, the ANSI/ASA S12.68 Excel spreadsheet and the HPDCalc software developed by NIOSH for the EPA. The rounded  $NRS_A$  rating values for the 10<sup>th</sup> and 90<sup>th</sup> protection percentiles agreed. The  $NRS_G$  values were determined to the hundredth of a decibel and the three calculators agreed to within 0.1 decibels.

## List of Abbreviations and Acronyms

Symbol	Definition
AIL	Active Insertion Loss
ANC	Active Noise Control
ANSI	American National Standards Institute
ASA	Acoustical Society of America
EPA	Environmental Protection Agency
HPD	Hearing Protection Device
MIRE	Microphone in Real Ear
NIOSH	National Institute for Occupational Safety and Health
NRSA	Noise Reduction Statistic for A-weighting
NRSG	Graphical Noise Reduction Statistic
REAT	Real Ear Attenuation at Threshold
WPAFB	Wright Patterson Air Force Base

## 1. Introduction

The United States Environmental Protection Agency (EPA) requires that all hearing protection devices (HPDs) entered into commerce in the United States be tested and labeled accordingly to provide the consumer an indication of the potential noise reduction capability of the device (EPA, 1979). In 2003, the EPA hosted a three-day workshop in Washington D.C. to determine the essential elements of a revised regulation for labeling HPDs in light of numerous technological advances. Active noise cancellation, sound restoration, and nonlinear amplitude sensitive devices were foremost amongst the new technologies not specifically covered under the present regulation. The EPA's workshop highlighted the need to develop new testing and rating methods for these newer classes of products and identified the need to communicate to the public the meaning of the new ratings.

Using this roadmap, the members of the American National Standards Institute (ANSI) accredited standards committee on Noise S12, Working Group 11 developed a new standard for rating the passive performance of HPDs, ANSI/ASA S12.68-2007 (Gauger and Berger 2004). The new rating standard uses the Real Ear Attenuation at Threshold (REAT) data to estimate noise reduction across the panel of test subjects and across a representative set of noise spectra drawn from industrial and aeronautical measurements. Murphy et al. (2009) investigated two protocols for REAT testing according to the ANSI S12.6-2008 standard and found that the trained subject-fit protocol yielded less intra-laboratory variability than the naive inexperienced subject-fit protocol. Murphy et al. (2011) further evaluated the S12.6 and S12.68 standards to determine the effectiveness of three training methods. Although the trained subject-fit protocol yielded higher noise reductions than the inexperienced subject-fit protocol, the Noise Reduction Statistic for A-weighting ( $NRS_A$ ) from ANSI S12.68-2007 was used to demonstrate that the differences were statistically significant. The ANSI S12.68 standard utilized the bootstrap computational statistic to estimate the error for the  $NRS_A$  rating at the 20<sup>th</sup> and 80<sup>th</sup> protection percentiles.

In 2009, the EPA proposed a revised rule for labeling HPDs using the ANSI/ASA S12.6-2008 measurement and the ANSI/ASA S12.68-2007 rating standards. The EPA also proposed to use the newly developed methods to assess the impulse noise reduction and the active noise cancellation (ANC) noise reduction later described in the ANSI/ASA S12.42-2010 measurement standard. During the course of developing the proposed rule, the S12 WG11 members worked with the EPA to create a measurement method that was

specifically designed for active noise cancellation hearing protectors, both earmuffs and earplugs. Active noise cancellation HPDs sample the environmental sound and create an out-of-phase signal that is played into the occluded volume to cancel the transmitted noise. Error correction microphones within the occluded volume permit the electronics to dynamically control the cancellation parameters to maximize the attenuation. Typical ANC earmuffs effectively cancel low-frequency noises below 500 Hz while ANC earplugs have been demonstrated to have effective active attenuation up to 3000 Hz. The ANSI/ASA S12.42-2010 standard has defined the measurement of the active attenuation for earmuffs and earplugs using humans with a Microphone in Real Ear (MIRE) technique and with an acoustic test fixture. The standard further stipulated how the active contribution should be combined with the passive attenuation measured with REAT to create a total attenuation. The MIRE and REAT attenuations can be added together and the  $NRS_A$  rating can then be calculated according to the S12.68 standard. The MIRE measurements assess the additional attenuation afforded by the ANC process are assumed to yield an additive effect with the passive REAT. This report does not assess whether the assumption of additivity is valid, rather it is evaluating the calculations.

REAT and MIRE attenuations for four ANC earmuffs were measured at the Air Force Research Laboratory, Wright Patterson Air Force Base (WPAFB). The noise reduction ratings (NRR) were computed with three independent implementations of the  $NRS_A$  rating method: Microsoft Excel, MATLAB and a custom Windows® program – HPDCalc. This report will examine the computation methods and compare the ratings.

## **2. Methods**

### **2.1 Measurements**

Ten subjects were recruited and participated in the study at the Air Force Research Laboratory at WPAFB in compliance with an approved human use protocol (F-WR-2007-0008-H). Five male and five female subjects were tested for their audiometric thresholds that were better than 15-dB Hearing Threshold Level. WPAFB collected the data from each of the test subjects

and stored the results into an Excel spreadsheet for each protector. The REAT data consisted of two trials for each subject. The MIRE one-third octave band data consisted of three trials for each subject and were also entered into an Excel spreadsheet.

REAT was measured with ANSI/ASA S12.6-2008 Method A for measurement of Real Ear Attenuation at Threshold. Subjects were trained in the test method to demonstrate reproducible unoccluded thresholds with a range no larger than 6 dB. The unoccluded and occluded thresholds were assessed at seven frequencies. The subjects were trained in the proper fitting techniques for the earmuffs. The occluded thresholds were measured with the device turned off.

The active contribution of the hearing protectors was measured using the ANSI/ASA S12.42-2010 Microphone in Real Ear (MIRE) method with a microphone mounted in an earplug and centered in the ear canal opening. Measurements of a broadband noise were made and recorded in one-third octave bands for the right and left ears. Measurements of the spectra were collected for three placements of the earmuffs on the subject's head. The spectra for each ear were averaged and the median value of the six one-third octave band values within each octave band was selected to provide a representative value for the subject (e.g. 800, 1000, 1250 Hz in the right and left ears). The one-third octave bands have the potential to capture more detail of the response of the protector and were a compromise from using narrow-band measurements ( $1/6^{\text{th}}$  or  $1/12^{\text{th}}$  octave band) and the broader octave band noise.

## 2.2 Computations

The ANSI/ASA S12.68-2007 standard prescribed the method for determining the Noise Level Reduction Statistic for use with A-weighting ( $NRS_A$ ) and Graphical Noise Level Reduction Statistic ( $NRS_G$ ). The  $NRS_A$  yielded a more general noise level reduction that was intended to be simple to use: Protected exposure level was the exposure level minus the  $NRS_A$  rating.

To determine the  $NRS_A$ , the attenuation was measured for each subject at frequencies 125 to 8000 Hz and those data were used to estimate the attenuation that would be realized for the 100 NIOSH noises (Kroes et al., 1975) for each subject,

$$\Delta L_{Apn} = L_{An} - L'_{Apn} = 10 \log \sum_{k=1}^7 10^{0.1(L_{nf(k)} + A_{f(k)})} - 10 \log \sum_{k=1}^7 10^{0.1(L_{nf(k)} + A_{f(k)} - R_{pf(k)})} \quad (1)$$

where  $f(k)$  represents the octave-band center frequencies from 125 Hz ( $k = 1$ ) to 8000 Hz ( $k = 7$ );  $n$  is the noise spectrum index ranging from  $N = 1$  to 100 ( $N$  is the number of noises;  $L_{n,f(k)}$  is the sound pressure level in decibels for the octave band centered on  $f(k)$  for the  $n^{\text{th}}$  noise in the National Institute for Occupational NIOSH 100 spectra;  $A_{f(k)}$  are the A-weighted corrections for the octave band frequencies  $f(k)$  in accordance with the ANSI S1.4;  $p$  is the subject index ranging from 1 to  $P$  ( $P$  is the number of subjects); and  $R_{p,f(k)}$  is the attenuation in decibels measured for the hearing protector on the  $p^{\text{th}}$  subject at the octave band center frequencies,  $f(k)$ , averaged across trials.

The noise reduction statistic depended upon two factors, the fit of the hearing protector on the individual and the noise spectra in which the protector was worn. The mean attenuation for each subject,  $p$ , was determined across noises. Likewise the mean attenuation for each noise,  $n$ , was determined across subjects,

$$m_p = \frac{1}{N} \sum_{n=1}^N \Delta L_{Apn} \quad (2)$$

$$m_n = \frac{1}{P} \sum_{p=1}^P \Delta L_{Apn} \quad (3)$$

The overall mean was determined across both subjects and noises.

$$m = \frac{1}{PN} \sum_{n=1}^N \sum_{p=1}^P \Delta L_{Apn} \quad (4)$$

To determine the standard deviation for the protector, the standard deviations across spectra and subject were determined as follows,

$$s_{\text{subject}} = \sqrt{\frac{1}{P-1} \sum_{p=1}^P (m_p - m)^2} \quad (5)$$

$$s_{\text{spectrum}} = \sqrt{\frac{1}{N-1} \sum_{n=1}^N (m_n - m)^2} \quad (6)$$

The protection percentiles were determined by combining the overall mean with the subject and spectrum standard deviations,

$$\text{NRS}_{Ax} = m - \alpha_x \sqrt{s_{\text{subject}}^2 + s_{\text{spectrum}}^2} \quad (7)$$

where  $\alpha_x$  was the number of standard deviations as specified in Table 1 of ANSI/ASA S12.68-2007. For the 80<sup>th</sup> and 20<sup>th</sup> protection percentiles,  $\alpha_x = \pm 0.8416$  and for the 90<sup>th</sup> and 10<sup>th</sup> protection percentiles,  $\alpha_x = \pm 1.2816$ .

## 2.3 Total Attenuation

The total attenuation of active earmuffs and helmets can be computed as follows:

- a) Compute the average REAT attenuation values for the repeated fits;
- b) Compute the average MIRE AIL values for the repeated fits using the same subject/HPD pairings as used in the REAT attenuation;
- c) Compute the median of the six MIRE AIL values (three for each ear) for the one-third octave bands at and adjacent to the REAT octave frequencies;
- d) Compute the total attenuation by adding the mean REAT attenuation value and the associated median MIRE AIL value for each of the REAT octave test frequencies.

The noise reduction statistics for A-weighting and the graphical methods are then determined with the octave band REAT data and again for the octave band total attenuation data. In this way, one can compare the additional benefit of the ANC system. For some devices, the benefit of the ANC may be rather minimal due to any number of factors. If the protector provides good attenuation in the low frequencies, then the ANC may provide little additional protection. For some devices as the signal becomes dominated by low-frequency energy, the passive and active performance will be observed to diverge. That is, the passive REAT performance of earmuffs typically decreases as low frequency energy increases. A well designed ANC hearing

protector will provide additional low frequency performance and will yield a more constant level of protection as the low-frequency energy increases.

## 2.4 Calculators

Three different calculation programs have been implemented to estimate the  $NRS_A$  and  $NRS_G$  metrics: MATLAB libraries, Microsoft Excel spreadsheet and a Windows application entitled HPDCalc. The MATLAB codes were used during the development of the ANSI/ASA S12.68 standard. The Microsoft Excel worksheets were developed for distribution with the S12.68 standard. The HPDCalc application was intended to provide a reporting tool that could be easily used by the U.S. EPA.

### 2.4.1 MATLAB

The MATLAB codes used in this report for the  $NRS_A$  and  $NRS_G$  ratings were developed between 2004 and 2007 and are included in the Appendices of this report. The S12.68 computations consists of three MATLAB subroutines: `NRSANoiseData`, `NRSA` and `NRSARating`. The data must be averaged across subjects before being passed to `NRSA` and `NRSARating`. The difference between the `NRSA` and `NRSARating` functions lies in the level of flexibility. The `NRSA` function allows the user to supply everything to the calculation, the noise matrix, the attenuations and the protection percentiles. The `NRSARating` function was designed to accept just the attenuation data and provide an option to the user to specify the protection percentiles. The default protection percentiles are 90 and 10 percent. Since this report documents the complete implementation of the  $NRS_A$  computation, two other files are included. `BoseA20AviationHeadset.m` provides an example dataset used with all three calculators. The `groupmean` MATLAB function was developed to estimate the mean across subjects. The inputs to the function were an array of data, the subject numbers, and the column in which the function should seek to find the repeated measurements. The `groupmean` function returns the average across rows of the data matrix that have the same subject index.

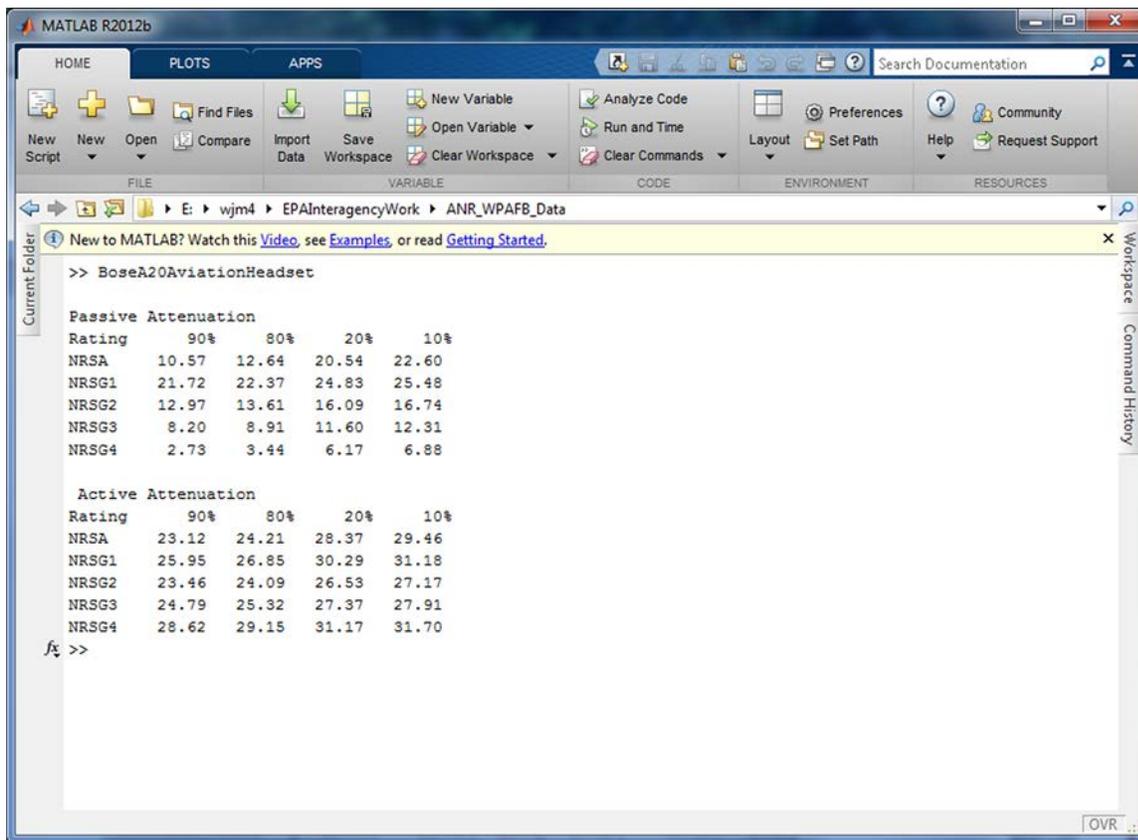


Figure 1. The MATLAB Command Line Console with the output from analyzing the Bose A20 Aviation headset. The detailed analysis code is provided in the Appendix of the report. To run the code, the name of the script is typed at the command prompt in MATLAB's console window.

## 2.4.2 ANSI S12.68-2007 Microsoft Excel spreadsheet

The ANSI S12.68-2007 Method to estimate A-weighted exposure when hearing protectors are worn includes both the mathematical theory to calculate the Noise Reduction Statistic for A-weighting and a Microsoft Excel spreadsheet that will assist the user to implement the computation. The worksheet has four tabs: Inputs & Calculations, Ratings, Confidence Intervals, and Reference Data. The user supplies the REAT data and the REAT + MIRE data to compute the  $NRS_A$  statistics. In the spreadsheet's current implementation, the user needs to create two separate spreadsheets to perform the passive rating and the active rating. In essence, the user creates a table of attenuations measured at the seven frequencies (125,

250, 500, 1000, 2000, 4000, 8000 Hz) with two trials per subject and then enters that data into the Inputs & Calculations worksheet shown in Figure 2.

The attenuation results at each frequency were averaged across trials for a given subject. The average attenuations were used to estimate the A-weighted attenuation for each of the noise spectra contained in the Reference Data tab. The noise spectra are a collection of noises including the NIOSH 100 and Air Force 50 noises described in Johnson and Nixon (1974). An additional 20 noises were that were sample spectra from civil aviation noises. The civil aviation noise tend to have more low frequency noise content than the NIOSH 100 noises, which were selected from a range of industries. The average and standard deviations were computed across subjects and across noises in the Inputs & Calculations tab. The results were then combined to calculate the  $NRS_A$  rating on the Ratings tab shown in Figure 3.

The Confidence Interval tab calculated the confidence intervals by randomly sampling with replacement the overall subject attenuation results. For instance, if ten subjects were tested, the random selection of subject data might be subjects (9 4 7 8 9 5 2 6 7 6). In this case, subjects 9 and 6 were repeatedly sampled. The random sampling with replacement was referred to as a bootstrap and was used to estimate the confidence interval for the  $NRS_A$  rating values. In the Inputs & Calculations tab, the rating has been set to compute the 90<sup>th</sup> and 10<sup>th</sup> percentile  $NRS_A$  values: Mean  $\pm$  1.2816 Standard Deviation. By calculating the bootstrap of the values for the subjects, variability of the  $NRS_A$  computation was assessed by assuming that the subjects represented the larger general population and resampling them provided an adequate estimate of how the population would vary if they were sampled. An extensive statistical literature for bootstrapping has been developed over the years. More details can be found in the ANSI S12.68 (2007) standard as well as work published by Efron and Tibshirani (1993) and Martinez and Martinez (2002).

With respect to calculating the  $NRS_A$  for the active condition, the MIRE data from an individual subject were averaged as described in Section 2.1. The individual's averaged MIRE data were added to the first and second REAT trials to create the array of 20 subjects, 2 trials per subject and attenuations at seven frequencies. The combined attenuations, REAT + MIRE, were pasted into the Excel spreadsheet at the same location as the REAT only



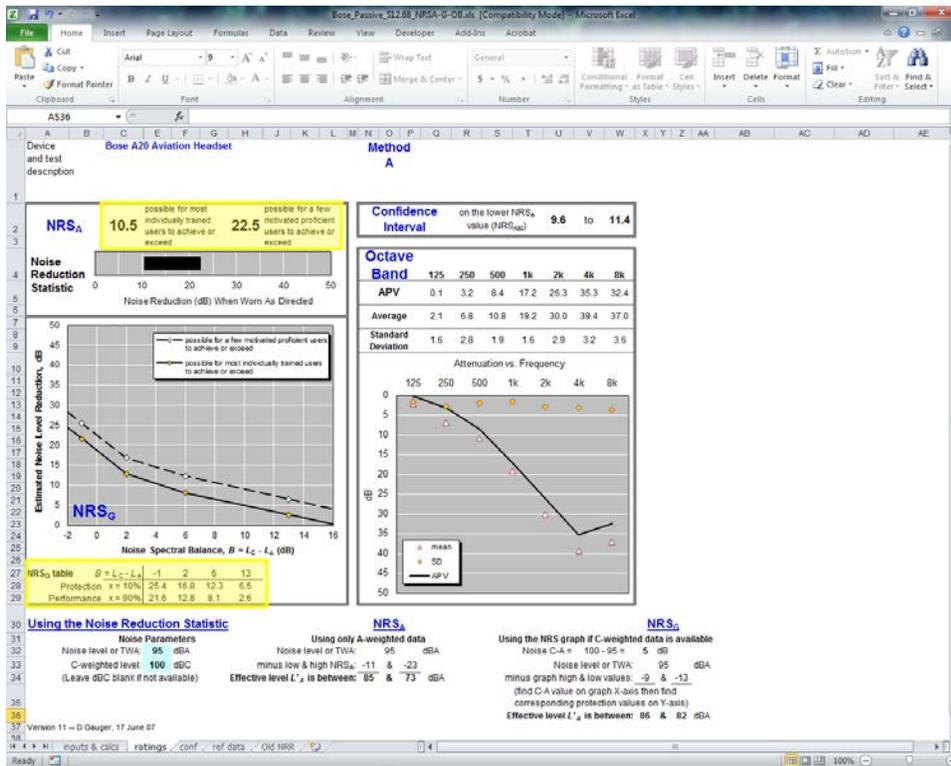


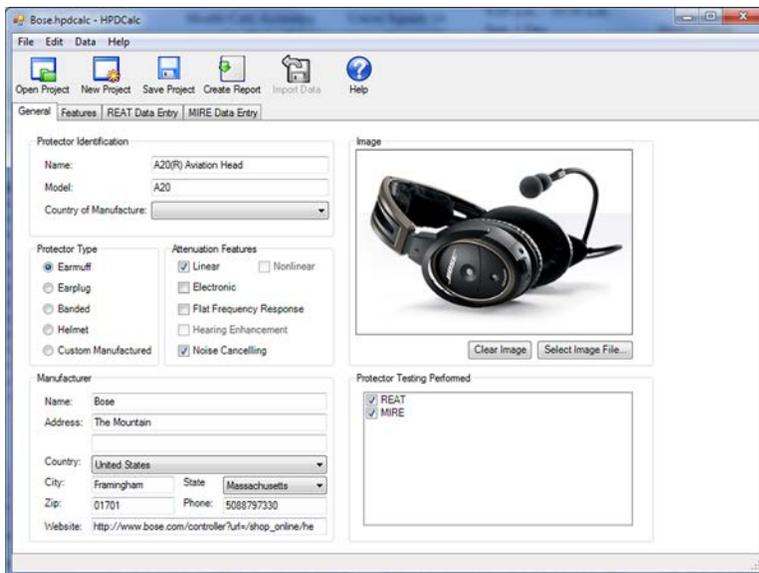
Figure 3. The ratings tab in the ANSI S12.68 Microsoft Excel spreadsheet. The NRS<sub>A</sub> values are displayed near the top of the page (highlighted in yellow) and the NRS<sub>G</sub> values are displayed below the graph of the NRS<sub>G</sub> results (also highlighted in yellow). Octave band attenuation data and confidence intervals on the NRS<sub>A</sub> rating are displayed.

### 2.4.3 HPDCalc

HPDCalc was developed by NIOSH to simplify and unify the data reporting requirements for the Environmental Protection Agency’s proposed changes to the rule for Labeling of Hearing Protection Devices (40 CFR 211 Subpart B). The HPDCalc software implemented the ANSI S12.68-2007 computations for the NRS<sub>A</sub> rating. When the American National Standards Institute completed the ANSI S12.42-2010 standard, additional features were added to the HPDCalc software so that it could calculate the passive noise reduction, the active noise reduction (noise cancelling on) and the impulse noise reduction. The passive and active noise reduction features will be considered in this report.

As illustrated in Figure 4, the features of the hearing protector can be entered. Different protector types can be selected: earmuff, earplug,

banded protector, helmet or custom manufactured device. In Figure 5, several features associated with the protectors (e.g., detectability, latex free, compatibility with other personal protective equipment) could be selected. Most importantly, the manufacturer must identify the tests which were performed on the product. Specifically, REAT, MIRE and IMPULSE were the three tests that can be reported. As illustrated in Figures 6 and 7, REAT and MIRE data were entered in two separate tabs of the interface. The data were placed in rows and columns. Each subject has N trials and each row contains the data for test frequencies 125 to 8000 Hz. Similarly for the MIRE measurement the subjects and trials can be set and then the data were entered for the electronics turned off and the electronics turned on.



**Figure 4.** The opening frame for the HPDCalc software. Users enter the protector information, type, attenuation features, manufacturer information, and type of tests performed on the product. The Noise Cancelling box must be selected in order to create a MIRE Data Entry tab.

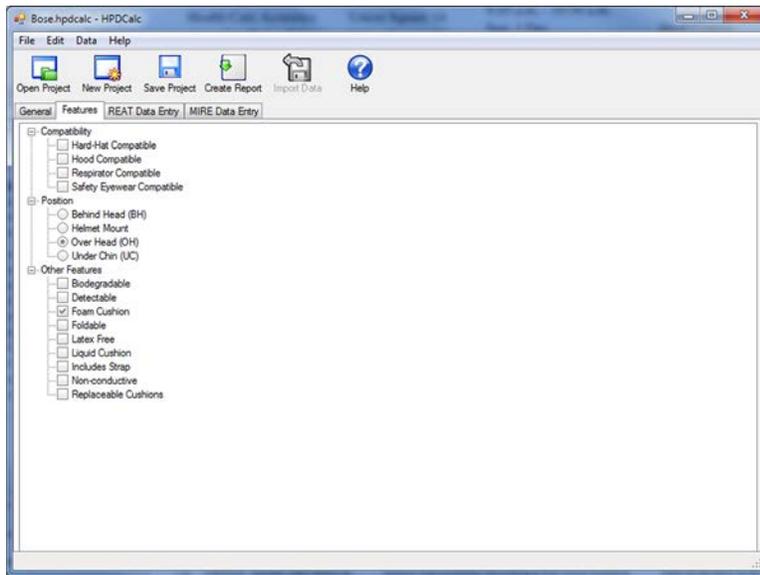


Figure 5. The features tab for the HPDCalc software. Depending upon whether the user has selected earplug or earmuff, various options will be available for the user to describe the unique characteristics of the protector. In this case, the main categories for muffs include Compatibility, Position, and Other Features.

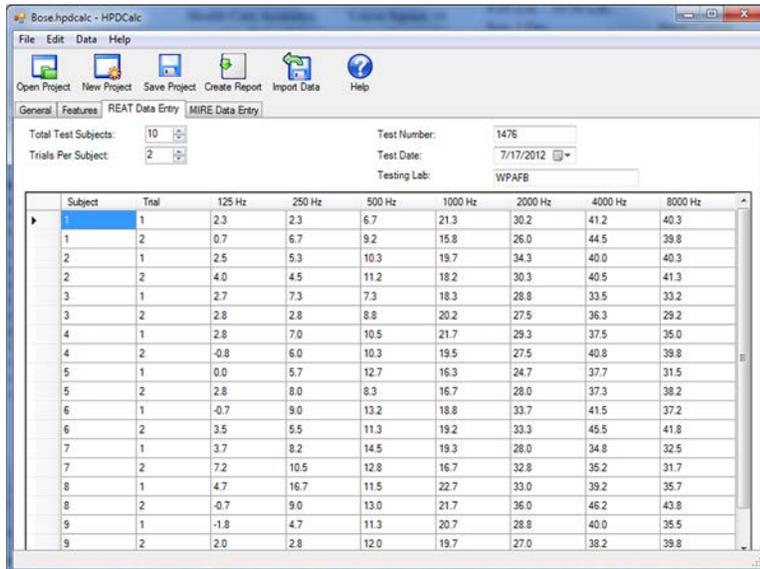


Figure 6. REAT data entry tab. Users are required to indicate the number of subjects, the number of trials per subject, test number, test date and test lab.

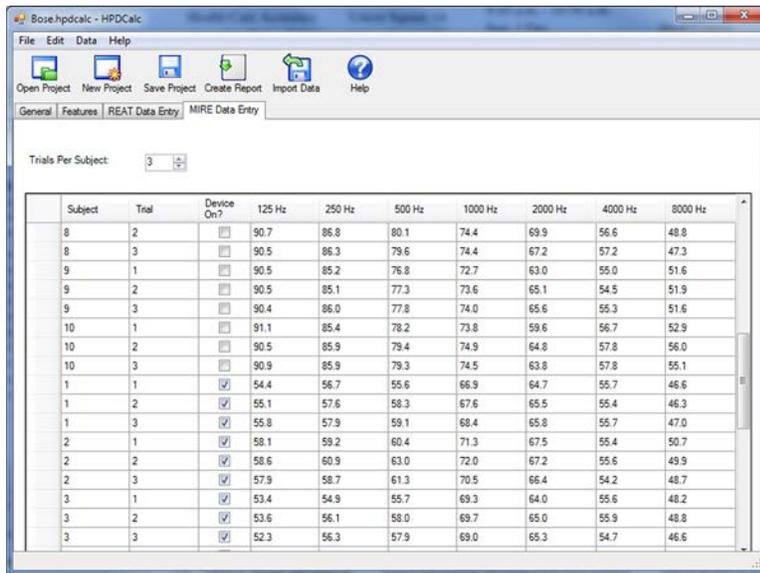


Figure 7. MIRE data entry tab. The user is required to enter the number of measurements per subject. Note that the 3<sup>rd</sup> column is where the status of the noise cancellation electronics must be entered. MIRE data must pre-processed into the octave band values.

### 3 Results

The results for the different protectors are given in Tables 1-5 and are listed for the passive and active conditions on separate rows. The MATLAB results for the 90<sup>th</sup> and 10<sup>th</sup> percentiles are in columns 2 and 5 in each table, respectively.

Table 1. Comparison of NRS<sub>A</sub> values for four ANC earmuffs for the 90<sup>th</sup> and 10<sup>th</sup> percentiles. HPDCalc only reports integer values for the percentile ratings. By default the Excel spreadsheet reports the ratings to a tenth of a decibel. MATLAB can provide greater precision. Rating values are reported to 0.01 dB if available to facilitate comparisons.

Protector/Condition	NRS <sub>A</sub> 90 <sup>th</sup> percentile			NRS <sub>A</sub> 10 <sup>th</sup> percentile		
	MATLAB	HPDCalc	Excel	MATLAB	HPDCalc	Excel
Bose / Passive	10.57	11	10.6	22.60	23	22.6
Bose / Active	23.12	23	23.1	29.46	29	29.5
Pilot / Passive	13.42	13	13.4	27.71	28	27.7
Pilot / Active	19.03	19	19.0	32.67	33	32.7
Sennheiser/Passive	5.89	6	5.9	16.12	16	16.1
Sennheiser/Active	9.84	10	9.8	15.61	16	15.6
Telex / Passive	12.63	13	12.6	24.87	25	24.9
Telex / Active	13.84	14	13.9	25.19	25	25.2

For each calculator, the  $NRS_A$  ratings for the 90<sup>th</sup> and 10<sup>th</sup> percentiles were determined. The HPDCalc software reports the  $NRS_A$  values as integers because the EPA Noise Reduction Rating is reported as integer values. For the Excel spreadsheets, the  $NRS_A$  values were computed to a tenth of a decibel and the  $NRS_G$  values were computed to the hundredth of a decibel. For MATLAB, the values of  $NRS_A$  and  $NRS_G$  are reported to the hundredth of a decibel only for the purpose of comparing results. In the ANSI/ASA S12.68 standard, calculations are to be carried out to the hundredth of a decibel. A tenth of a decibel is appropriate for estimating the ratings and exposures using the  $NRS_A$  and  $NRS_G$  values. However, to compare the accuracy of the three calculators, the values are reported to the hundredth of a decibel when the precision is available.

In Tables 2 to 5, the  $NRS_{G1}$ ,  $NRS_{G2}$ ,  $NRS_{G3}$ , and  $NRS_{G4}$  coefficients are computed for each of the protectors. The  $NRS_G$  coefficients are used to create the piecewise continuous curves to estimate attenuations for noises that have more extreme low and high frequency spectra. The 10<sup>th</sup> and 90<sup>th</sup> percentile values for each coefficient are given in the tables.

**Table 2. Comparison of  $NRS_{G1}$  values for four ANC earmuffs for the 90<sup>th</sup> and 10<sup>th</sup> percentiles**

Protector/Condition	$NRS_{G1}$ 90 <sup>th</sup> percentile			$NRS_{G1}$ 10 <sup>th</sup> percentile		
	MATLAB	HPDCalc	Excel	MATLAB	HPDCalc	Excel
Bose / Passive	21.72	21.73	21.7	25.48	25.48	25.5
Bose / Active	25.95	25.95	25.9	31.18	31.18	31.2
Pilot / Passive	22.09	22.10	22.1	32.02	32.01	32.0
Pilot / Active	23.72	23.72	23.7	35.82	35.81	35.8
Sennheiser/Passive	14.20	14.20	14.2	18.20	18.20	18.2
Sennheiser/Active	13.70	13.70	13.7	17.43	17.43	17.4
Telex / Passive	21.39	21.39	21.4	28.20	28.20	28.2
Telex / Active	21.01	21.02	21.0	28.19	28.18	28.2

**Table 3. Comparison of  $NRS_{G2}$  values for four ANC earmuffs for the 90<sup>th</sup> and 10<sup>th</sup> percentiles.**

Protector/Condition	$NRS_{G2}$ 90 <sup>th</sup> percentile			$NRS_{G2}$ 10 <sup>th</sup> percentile		
	MATLAB	HPDCalc	Excel	MATLAB	HPDCalc	Excel
Bose / Passive	12.97	12.97	13.0	16.74	16.74	16.7
Bose / Active	23.46	23.46	23.5	27.17	27.17	27.2
Pilot / Passive	14.08	14.08	14.1	23.39	23.39	23.4
Pilot / Active	18.39	18.39	18.4	30.55	30.54	30.5

Sennheiser/Passive	7.38	7.38	7.4	12.14	12.14	12.1
Sennheiser/Active	10.38	10.38	10.4	13.30	13.29	13.3
Telex / Passive	12.99	13.00	13.0	20.12	20.12	20.1
Telex / Active	13.62	13.63	13.6	21.38	21.37	21.4

**Table 4. Comparison of  $NRS_{G3}$  values for four ANC earmuffs for the 90<sup>th</sup> and 10<sup>th</sup> percentiles.**

Protector/Condition	$NRS_{G3}$ 90 <sup>th</sup> percentile			$NRS_{G3}$ 10 <sup>th</sup> percentile		
	MATLAB	HPDCalc	Excel	MATLAB	HPDCalc	Excel
Bose / Passive	8.20	8.20	8.2	12.31	12.31	12.3
Bose / Active	24.79	24.79	24.8	27.91	27.90	27.9
Pilot / Passive	10.19	10.20	10.2	18.78	18.77	18.8
Pilot / Active	16.71	16.72	16.7	27.86	27.86	27.9
Sennheiser/Passive	2.61	2.62	2.6	8.35	8.35	8.4
Sennheiser/Active	8.31	8.31	8.3	12.22	12.21	12.2
Telex / Passive	10.31	10.31	10.3	17.05	17.04	17.0
Telex / Active	11.77	11.78	11.8	19.40	19.39	19.4

**Table 5. Comparison of  $NRS_{G4}$  values for four ANC earmuffs for the 90<sup>th</sup> and 10<sup>th</sup> percentiles.**

Protector/Condition	$NRS_{G4}$ 90 <sup>th</sup> percentile			$NRS_{G4}$ 10 <sup>th</sup> percentile		
	MATLAB	HPDCalc	Excel	MATLAB	HPDCalc	Excel
Bose / Passive	2.73	2.73	2.7	6.88	6.88	6.9
Bose / Active	28.62	28.63	28.6	31.70	31.70	31.7
Pilot / Passive	6.17	6.17	6.2	13.30	13.29	13.3
Pilot / Active	17.83	17.83	17.8	25.83	25.82	25.8
Sennheiser/Passive	-1.23	-1.23	-1.2	4.36	4.36	4.4
Sennheiser/Active	7.81	7.82	7.8	12.85	12.84	12.8
Telex / Passive	11.04	11.04	11.0	15.90	15.89	15.9
Telex / Active	15.46	15.47	15.5	22.07	22.07	22.1

## 4 Discussion

The discussion will focus upon two aspects: how to use the calculators and how to estimate noise exposures for workers when wearing hearing protectors with active noise cancellation.

## 4.1 Using the Calculators

### 4.1.1 ANSI/ASA S12.68-2007 Excel Spreadsheet

Differences exist between the Microsoft Excel spreadsheet, MATLAB code and the HPDCalc software with regards to data entry. In the Excel spreadsheet, the user must first determine the difference between the MIRE data measured with the device on and off and then add that result to the passive REAT values. The Excel spreadsheet must be duplicated to make the passive and active computations. The Excel spreadsheet calculates the confidence interval of the rating, an extremely useful feature when making comparisons between product tests. The range for the calculation may be adjusted from the 80<sup>th</sup> and 20<sup>th</sup> percentiles to reflect other intervals that were better descriptors of the data (e.g., 90<sup>th</sup> and 10<sup>th</sup> percentiles). The computation statistics of the basic spreadsheet determine the range for the 95% confidence interval of the ratings for the lower value (80<sup>th</sup> or 90<sup>th</sup> percentile). The spreadsheet as it is distributed with the ANSI/ASA S12.68 standard only calculates the confidence intervals for the lower percentiles (80<sup>th</sup> or 90<sup>th</sup>).

Data entry required some manipulation of the raw data to place it into the proper format for the table on the first tab of the Excel spreadsheet. Because the duplicate spreadsheets must be created to calculate the active and passive ratings, the potential for making an error was increased when manipulating the data with the Excel spreadsheet.

### 4.1.2 MATLAB

The MATLAB version of the  $NRS_A$  calculator was also complex. The user must be proficient with MATLAB with regards to importing the REAT and MIRE data, identifying the variables and programming the calculation correctly. Selection of different ranges, or multiple ranges was simple with the MATLAB code. The user chooses the confidence intervals to be calculated. While MATLAB was a commercial product that can cost thousands of dollars to maintain, the open-source program, Octave, is capable of performing all of the computations used in the MATLAB-based  $NRS_A/NRS_G$  calculator. The MATLAB code in the Appendix does not include the confidence interval computations. They have been implemented and

have been used to compare REAT data from different measurements and measurement groups (Murphy et al., 2011). Whereas the Microsoft Excel spreadsheet determines the confidence interval for the lower  $NRS_A$  rating only, the MATLAB code will generate the error bars for the  $NRS_A$  and  $NRS_G$  coefficients. Due to the substantial amount of programming involved in the MATLAB version, the potential for error was greatest relative to the other calculators.

### **4.1.3 HPDCalc Software**

The HPDCalc software was developed to facilitate the computation of the  $NRS_A$  and  $NRS_G$  statistics. The user was required to determine the octave band results for the MIRE measurement. Once the user has parsed the third-octave to full-octave band measurements, the effort to copy the results into the MIRE worksheet and to generate the ratings was minimal. Therefore, HPDCalc appeared to be the most expedient method to analyze the active noise cancellation hearing protectors.

In HPDCalc, if the user can correctly paste the data into the application, then the results could be generated and saved either in an Adobe Portable Document Format (PDF) or in an XML file format that was portable across operating systems. The HPDCalc software did not provide the confidence intervals.

## **4.2 Calculating Noise Exposures**

The ANSI/ASA S12.68-2007 standard describes three different methods for estimating the noise exposure when hearing protection is worn. In this report, we have shown how the passive REAT data may be combined with MIRE data measured for active noise cancellation HPDs to determine the  $NRS_A$  and  $NRS_G$  ratings of the products. In this section, we are going to step through the  $NRS_A$ ,  $NRS_G$  and the octave band noise reduction computations. These three computations provide progressively more accurate estimates of a worker's noise exposure if they were wearing the product in a manner consistent with how it was designed and tested. Whereas, the standard provides specific examples for passive hearing protection devices, this section applies the methods for an active noise cancellation hearing

protector to determine the ratings and to estimate noise exposures with four different noise spectra listed in Table 6.

**Table 6. Octave band noise levels from ANSI /ASA S12.68-2007 standard Annex A. Four noises were selected: NIOSH #99, Air Force #23, Air Force #45, and Air Force #39.**

	Source	Octave Band Noise Levels (dB)							Noise Levels (dB)		
		125	250	500	1000	2000	4000	8000	L <sub>C</sub>	L <sub>A</sub>	L <sub>C</sub> -L <sub>A</sub>
Noise 1	NIOSH #99	81	85	93	90	101	103	104	106.5	108.0	-1.5
Noise 2	Air Force #23	102	101	107	104	100	95	95	110.7	108.5	2.2
Noise 3	Air Force #45	110	111	111	95	92	89	84	115.5	109.4	6.1
Noise 4	Air Force #39	108	92	89	84	82	78	74	108.0	94.3	13.7

The four noises in Table 6 correspond to progressively more low frequency content. Noise 1 (NIOSH #99) has the greatest energy in the 4000 and 8000 Hz band and an L<sub>C</sub>-L<sub>A</sub> value of -1.5 dB. Noise 2 (Air Force #23) has the highest noise levels in the 500 and 1000 Hz bands and an L<sub>C</sub>-L<sub>A</sub> value of 2.2 dB. The highest band levels for Noise 3 (Air Force #45) are in the 250 and 500 Hz bands and an L<sub>C</sub>-L<sub>A</sub> value of 6.6 dB. Noise 4 has its highest level at 125 Hz and an L<sub>C</sub>-L<sub>A</sub> value of 13.7 dB.

#### 4.2.1 Application of the NRS<sub>A</sub> Rating

Using the 90<sup>th</sup> and 10<sup>th</sup> percentile NRS<sub>A</sub> protection ratings from Table 1, the estimated exposure levels were calculated by subtracting the NRS<sub>A</sub> values from 105 dBA<sup>1</sup>, the normalized A-weighted unprotected exposure. Examination of the results demonstrate that for the example of 105 dBA exposure level, none of the devices provided sufficient protection in the passive mode when the lower NRS<sub>A</sub> values were applied. The Bose and Pilot headsets both provided sufficient attenuation to satisfy the OSHA Permissible Exposure Level (PEL) of 90 dBA when operated in the active noise cancellation mode. The Bose headset had exposure levels below 85 dBA for both the upper and lower rating limits. The Telex and Sennheiser device had exposure levels that straddled the OSHA PEL, 90 dBA. Whereas the exposure level with the Telex device was less than the NIOSH

<sup>1</sup> 105 dBA was chosen based upon the noise exposures measured for a helicopter in which any of these ANR headsets could be used to communicate with the air traffic controller and other persons aboard the aircraft (Radtke et al. 2007).

Recommended Exposure Level (REL) of 85 dBA, the exposure level with the Sennheiser headset was greater than 85 dBA for both the passive or active modes (see Table 7.).

**Table 7. Exposure Levels estimated using  $L_A$  exposure level and  $NRS_A$  rating**

Protector/Condition	A-weighted Exposure Levels	
	105 dBA - $NRS_{A \text{ Lower}}$	105 dBA - $NRS_{A \text{ Upper}}$
Bose / Passive	94.4	82.4
Bose / Active	81.9	75.5
Pilot / Passive	91.6	77.3
Pilot / Active	86.0	72.3
Sennheiser/Passive	99.1	88.9
Sennheiser/Active	95.2	89.4
Telex / Passive	92.4	80.1
Telex / Active	91.1	79.8

#### 4.2.2 Application of the $NRS_G$ Rating

The  $NRS_G$  rating was determined from the four coefficients prescribed by the ANSI/ASA standard coupled with the difference in the  $L_C - L_A$  spectral balance. The difference was identified on the abscissa of the  $NRS_G$  plot and then the line was drawn vertically until it intersected the two curves for the upper and lower  $NRS_G$  ratings. The  $NRS_G$  rating were then determined by moving horizontally to the left ordinate axis. In Figure 8, the  $NRS_G$  graph is shown for the Bose Aviation headset. Using Noise #3 with a C-A spectral balance of 6.1 dB, the intersection yielded 24.9 dB and 28.0 dB for the rating. These values were subtracted from the A-weighted noise exposure to estimate the exposure when the headset is being worn. In this case, the exposures were approximately 80.3 and 77.2 dBA, both below the NIOSH REL of 85 dBA for eight hours.

Generally, the  $NRS_G$  rating decreases as the spectral balance increases for the headsets discussed in this report. The performance of earmuffs tend to have poorer attenuation at low frequencies, therefore predominantly low-frequency noise (High C-A) will significantly reduce the effectiveness of the protector. However, when the active noise cancellation was activated, the protection levels increased and, in the cases of the Bose and Telex headsets, actually increased as the low frequency content became more dominant.

The simplicity of the  $NRS_G$  method should not be dismissed. In the development of the tables for this report, considerable effort was invested to estimate numerically the  $NRS_G$  rating and to determine the exposure for an arbitrary noise. In fact, the numerical estimates for each protector, condition, and upper and lower  $NRS_G$  ratings were double-checked against the graphs that had been produced. The graphs were simple to use and yielded results sufficient to check the numerical codes.

The protection levels for the four protectors in the four example noises are detailed in Table 9. The differences between the active and passive ratings for the different headsets were about 3 to 5 dB for the predominantly high-frequency noises,  $L_C - L_A = -1.5$  dB. For noises that have strong low frequency content, the differences between the active and passive ratings ranged between 8 and 27 dB. These ratings reflect the high frequency bias in the protection afforded by earmuffs when operating in a passive mode. The active noise cancellation is most effective for frequencies below about 250 Hz in a headphone using current technology. Thus more efficient noise cancellation digital signal processing algorithms could significantly improve the protection provided in low frequency noise.

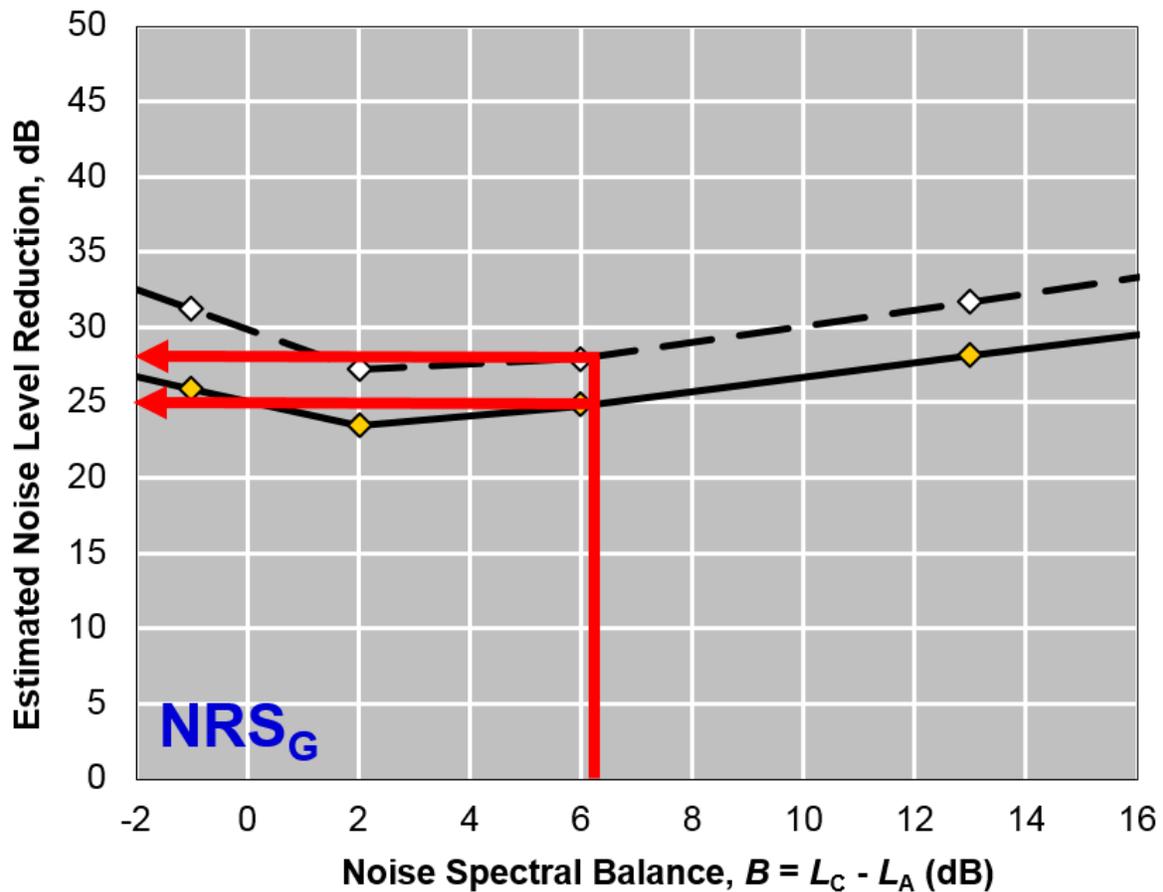


Figure 8. Example of the graphical method to estimate the  $NRS_G$  rating. The spectral balance is determined by subtracting the A-weighted level from the C-weighted sound pressure level. Find the spectral balance on the abscissa and identify where it intersects the two lines of the  $NRS_G$  curve. The value on the ordinate, 25 and 28 in this case, are the  $NRS_G$  values to be used with the specific noise.

Table 9 contains the protection levels Table 8 applied to the four noises that have the range of spectral balances from -1.5 dB to 13.7 dB. The noise levels were normalized to 105 dBA and the protection levels as determined with the  $NRS_G$  method were subtracted to estimate the noise exposure when the protector was worn. In contrast to the exposure levels reported in Table 7, which were constant across noises, the exposure levels derived from the  $NRS_G$  method vary with frequency content. Generally the exposure levels increased with greater low frequency content for the passive

condition. Because Noise 3 has the highest levels in the 250 and 500 Hz bands, the A-weighted exposure levels for the passive condition were greatest across all protectors. Of the four noises, Noise 1 had the most high-frequency content at 4000 and 8000 Hz. Because earmuffs tend to block high-frequency noise better than low-frequency noise the muffs were most effective for Noise 1.

**Table 8. Protection levels for four active noise cancellation headsets estimated with the NRS<sub>G</sub> Method.**

Protector/Condition	Exposure Levels Estimated with NRS <sub>G</sub> Rating							
	NRS <sub>G</sub> Lower				105 dBA – NRS <sub>G</sub> Upper			
Spectral Balance L <sub>C</sub> -L <sub>A</sub> (dB)	N1	N2	N3	N4	N1	N2	N3	N4
	-1.5	2.2	6.1	13.7	-1.5	2.2	6.1	13.7
Bose / Passive	23.1	12.8	8.1	2.1	27.0	16.5	12.2	6.4
Bose / Active	26.3	23.6	24.9	29.0	31.9	27.2	28.0	32.1
Pilot / Passive	23.4	13.9	10.1	5.8	33.4	23.2	18.7	12.7
Pilot / Active	24.6	18.3	16.7	17.9	36.7	30.4	27.9	25.6
Sennheiser/Passive	15.3	7.2	2.5	-1.6	19.2	11.9	8.3	4.0
Sennheiser/Active	14.3	10.3	8.3	7.8	18.1	13.2	12.2	12.9
Telex / Passive	22.8	12.9	10.3	11.1	29.5	19.9	17.0	15.8
Telex / Active	22.2	13.5	11.9	15.9	29.3	21.3	19.4	22.4

**Table 9. Exposure Levels estimated using L<sub>A</sub> exposure level and NRS<sub>G</sub> rating**

Protector/Condition	Exposure Levels Estimated with NRS <sub>G</sub> Rating							
	105 dBA – NRS <sub>G</sub> Lower				105 dBA – NRS <sub>G</sub> Upper			
	N1	N2	N3	N4	N1	N2	N3	N4
Bose / Passive	84.8	91.8	96.7	90.8	81.0	88.1	92.6	86.8
Bose / Active	79.5	81.6	80.3	84.4	74.5	77.8	77.2	81.3
Pilot / Passive	84.2	90.7	94.7	90.4	74.4	81.4	86.1	80.2
Pilot / Active	82.2	86.5	88.3	89.5	70.1	74.4	77.1	74.8
Sennheiser/Passive	91.9	97.4	102.3	98.2	87.8	92.7	96.5	92.2
Sennheiser/Active	91.8	94.5	96.7	96.2	88.3	91.6	92.8	93.5
Telex / Passive	85.0	91.9	94.7	95.5	78.1	84.7	88.0	86.8
Telex / Active	85.2	91.3	93.3	97.3	77.9	83.5	85.6	88.6

When the active noise cancellation was turned on, the headsets exhibited varying degrees of effectiveness. The Bose headset provided the most protection and the exposure levels were all below 85 dBA. The Pilot headset

has exposure levels that straddled the 85 dBA NIOSH REL. The upper NRS<sub>G</sub> rating yields exposures that were less than 85 dBA. For the lower NRS<sub>G</sub> rating, the exposure range was between 82.2 and 89.5 dBA. Thus depending upon how well the user fitted the protector, sufficient protection might be achieved in this hypothetical example. Similarly, the Telex headset in active mode straddles the 85 dBA REL. Noises 3 and 4 have predominantly low frequency content and the protected exposures for both the 90<sup>th</sup> and 10<sup>th</sup> percentiles were above 85 dBA. . The Sennheiser headset had the least protection and did not meet the NIOSH 85 dBA REL for any of the noises.

### 4.2.3 Application of the Octave-Band Method

To estimate the Octave-Band attenuation in Table 10, the attenuation means and standard deviations were used with the example noises. The Octave Band method was originally developed by NIOSH (Kroes et al. 1976) and was included in the ANSI/ASA S12.68-2008 standard. The A-weighting correction factors were applied to the noises and to the attenuated noises. The difference between the A-weighted noise exposure and the attenuated A-weighted noise yields the protection level. The attenuated A-weighted noise is the exposure level for the octave band method and are shown in Table 11.

**Table 10. The upper and lower protection levels for the four hearing protectors calculated using the Octave-Band Method.**

Protector/Condition	Protection Levels Estimated with Octave-band Method							
	$\Delta L_{A,Lower}$				$\Delta L_{A,Upper}$			
	N1	N2	N3	N4	N1	N2	N3	N4
Bose / Passive	24.3	11.3	6.5	2.0	29.7	16.3	12.0	7.0
Bose / Active	27.6	22.8	25.9	26.6	35.5	27.6	30.4	32.3
Pilot / Passive	23.9	11.9	8.1	5.8	34.1	21.7	17.5	13.0
Pilot / Active	25.5	16.5	14.4	17.7	37.8	28.7	25.7	26.1
Sennheiser/Passive	15.8	6.5	1.0	-0.9	21.6	12.1	7.8	5.2
Sennheiser/Active	14.9	9.0	6.7	8.2	20.5	13.2	11.6	14.5
Telex / Passive	23.0	10.0	6.9	10.4	30.2	17.5	14.3	17.0
Telex / Active	23.7	11.1	8.6	14.7	31.0	18.9	16.3	22.3

**Table 11 Exposure Levels estimated using LA exposure level and Octave-Band Method.**

Protector/Condition	Exposure Levels Estimated with Octave-band Method							
	N1	N2	N3	N4	N1	N2	N3	N4
Bose / Passive	80.7	93.7	98.5	103.0	75.3	88.7	93.0	98.0
Bose / Active	77.4	82.2	79.0	78.4	69.5	77.4	74.6	72.7
Pilot / Passive	81.1	93.1	96.9	99.2	70.9	83.3	87.5	92.0
Pilot / Active	79.5	88.5	90.6	87.3	67.2	76.3	79.3	78.9
Sennheiser/Passive	89.2	98.5	103.9	105.9	83.4	92.9	97.2	99.8
Sennheiser/Active	90.1	96.0	98.3	96.9	84.5	91.8	93.4	90.5
Telex / Passive	82.0	95.0	98.0	94.6	74.8	87.5	90.7	88.0
Telex / Active	81.4	93.9	96.3	90.3	74.0	86.1	88.6	82.7

## 5 Conclusions

This analysis demonstrated that the Excel, HPDCalc and MATLAB implementations of the ANSI S12.68 equations yield the same results. The Excel package was available to purchasers of the ANSI S12.68 standard, but the active noise cancellation was not an integral part of the spreadsheet. The end user must combine the MIRE measurements with the REAT measurements to determine the rating for the product. The HPDCalc software was less complicated to use than the Excel spreadsheet. The end user must have combined the data from the third octave band data to estimate the octave band values prior to copying the data into the tables for the MIRE data entry. Finally, the MATLAB implementation was perhaps the least user friendly, but the most flexible. The user should be aware of all the particulars of the data and add it to the MATLAB scripts correctly. The MATLAB environment provided the user a multitude of other computational statistics that were not necessarily easy to access within Excel and were not included in the HPDCalc software. Regardless, the user could confidently select the appropriate package and rest assured that the results will be consistent across implementations.

## 6 References

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## 7 Appendix

In this series of appendices, the MATLAB code for the  $NRS_A$  computations is presented as a series of four subroutines. In MATLAB, the **green text** preceded by a % sign indicates comments. **Magenta text** indicates a character string and is offset by single “, and **blue text** indicates a reserved functional command.

To compute the  $NRS_A$  and  $NRS_G$  ratings for passive devices, the REAT values must be passed to the functions `NRSA.m` and `NRSARating.m`. If the ratings are to be determined for the ANC devices, the REAT data must be first combined with the MIRE data. An example of the combined calculation is included in Appendix 7.4 for the Bose A20 Aviation headset.

### 7.1 NRSANoiseData.m

The first subroutine, `NRSANoiseData.m`, loads the 100 NIOSH noises, 50 Air Force noises and the 20 Civilian Aviation noises. When the code is run, the NIOSH 100 Noise will be available for calculations along with the indices into the entire set of noises to determine the  $NRS_{G1}$ ,  $NRS_{G2}$ ,  $NRS_{G3}$  and  $NRS_{G4}$  coefficients.

`NRSANoiseData.m`

**% This data set includes the NIOSH 100 Noise, the Air Force 50 Noises and  
% 20 noises from Civilian Aviation.**

**% The subroutine will load up the different arrays of noises necessary for  
% the NRSA computation to proceed.**

**% Usage:**

**% NRSANoiseData**

`NRSANoises = {...`

```
1 'NIO99' 81 85 93 90 101 103 104 108.0 -1.5;  
2 'NIO95' 94 96 97 104 108 111 113 116.3 -1.5;  
3 'NIO93' 78 78 85 96 100 97 100 105.0 -1.3;  
4 'NIO80' 85 86 89 91 96 97 101 103.6 -1.3;  
5 'NIO73' 81 81 90 98 103 102 98 107.6 -1.3;  
6 'ArFrc03' 101 102 104 104 104 110 117 117.7 -1.3;  
7 'NIO72' 90 95 96 97 106 104 106 110.9 -1.2;  
8 'NIO87' 79 79 77 86 95 89 83 97.6 -1.2;  
9 'NIO55' 82 82 84 93 95 93 92 100.0 -1.0;
```

10 'ArFrc04' 83 91 91 88 90 94 101 101.9 -0.9;  
 11 'NIOH84' 91 89 95 100 101 101 100 107.1 -0.8;  
 12 'NIOH90' 78 79 75 74 79 84 88 89.8 -0.8;  
 13 'NIOH07' 82 80 84 87 92 90 85 96.3 -0.8;  
 14 'NIOH75' 84 83 90 109 109 100 96 113.0 -0.8;  
 15 'NIOH61' 85 85 85 92 94 93 92 99.5 -0.8;  
 16 'NIOH70' 81 86 84 88 95 90 82 98.0 -0.8;  
 17 'NIOH96' 81 90 91 99 99 96 98 104.6 -0.8;  
 18 'ArFrc08' 89 81 88 94 96 93 95 101.2 -0.7;  
 19 'NIOH09' 85 85 88 90 92 94 89 98.6 -0.6;  
 20 'NIOH38' 79 79 81 84 83 84 89 91.8 -0.6;  
 21 'NIOH86' 74 79 82 83 79 87 84 90.9 -0.5;  
 22 'NIOH15' 82 83 82 84 89 88 86 94.0 -0.5;  
 23 'NIOH89' 80 80 85 93 92 87 82 97.0 -0.4;  
 24 'NIOH47' 78 78 80 83 83 83 86 90.3 -0.4;  
 25 'NIOH20' 85 87 88 87 92 93 84 97.5 -0.4;  
 0 'ArFrc44' 94 90 96 95 97 99 98 104.3 -0.3;  
 0 'ArFrc26' 89 94 97 95 99 99 94 104.5 -0.2;  
 26 'NIOH02' 72 75 79 90 85 77 74 91.9 -0.2;  
 27 'NIOH11' 76 81 83 86 86 85 80 91.8 -0.2;  
 28 'NIOH06' 78 80 81 88 85 85 78 92.0 -0.2;  
 0 'ArFrc22' 95 88 95 101 97 99 89 105.0 0.0;  
 29 'NIOH08' 84 87 90 90 92 91 85 97.4 0.0;  
 30 'NIOH79' 86 90 92 95 92 90 95 99.9 0.1;  
 31 'NIOH24' 81 96 91 99 98 95 85 103.4 0.1;  
 32 'NIOH16' 85 81 75 81 85 85 86 91.1 0.2;  
 0 'ArFrc02' 97 99 107 106 106 104 102 112.1 0.2;  
 33 'NIOH30' 80 82 83 93 83 83 80 94.3 0.2;  
 34 'NIOH14' 84 85 84 84 86 88 84 92.9 0.3;  
 35 'NIOH13' 85 84 83 87 87 86 85 93.1 0.4;  
 36 'NIOH71' 101 102 103 104 104 104 103 110.7 0.4;  
 37 'NIOH77' 90 87 91 96 91 92 84 99.3 0.4;  
 38 'NIOH88' 88 87 87 98 88 84 83 99.0 0.5;  
 39 'NIOH92' 72 75 93 90 87 88 88 95.9 0.5;  
 40 'NIOH98' 115 116 112 113 114 115 120 122.7 0.5;  
 0 'ArFrc01' 94 89 97 96 96 96 88 102.4 0.5;  
 41 'NIOH18' 90 88 91 96 88 89 92 98.9 0.6;  
 42 'NIOH29' 90 88 91 96 88 89 92 98.9 0.6;  
 43 'NIOH91' 120 119 118 120 119 120 122 127.0 0.6;

44 'NIOH74' 91 89 87 94 91 90 88 98.0 0.7;  
 45 'NIOH58' 87 86 85 87 85 88 88 93.8 0.7;  
 46 'NIOH52' 83 85 86 86 87 85 79 92.4 0.7;  
 0 'ArFrc13' 105 105 104 100 99 107 107 111.4 0.9;  
 0 'ArFrc24' 94 102 105 104 103 100 94 109.2 0.9;  
 47 'NIOH69' 81 85 83 85 84 83 81 90.6 1.0;  
 48 'NIOH17' 83 73 73 75 75 81 82 85.7 1.1;  
 0 'ArFrc10' 105 102 95 94 104 103 101 108.8 1.2;  
 49 'NIOH33' 91 89 92 92 92 88 80 97.4 1.2;  
 50 'NIOH42' 91 89 92 92 92 88 80 97.4 1.2;  
 0 'ArFrc28' 108 109 109 107 108 108 107 114.8 1.3;  
 51 'NIOH54' 86 84 84 90 84 79 77 92.1 1.3;  
 52 'NIOH03' 90 82 94 96 86 70 77 97.6 1.4;  
 53 'NIOH94' 86 88 87 90 88 80 77 93.7 1.4;  
 54 'NIOH44' 95 91 95 96 94 90 78 100.2 1.5;  
 55 'NIOH100' 101 101 98 99 98 94 103 106.0 1.5;  
 56 'NIOH10' 86 84 80 84 84 84 75 90.1 1.5;  
 57 'NIOH78' 102 98 97 98 97 96 102 105.3 1.6;  
 58 'NIOH85' 87 88 86 92 83 81 81 93.8 1.6;  
 59 'NIOH40' 83 84 86 88 82 76 74 90.6 1.7;  
 60 'NIOH41' 82 86 85 89 82 72 70 90.9 1.7;  
 61 'NIOH51' 82 86 85 89 82 72 70 90.9 1.7;  
 62 'NIOH39' 84 86 83 87 84 79 76 90.5 1.7;  
 63 'ArFrc21' 98 97 98 99 96 94 89 103.2 1.8;  
 64 'NIOH19' 87 81 88 87 84 82 74 91.4 1.9;  
 65 'NIOH82' 90 83 87 93 79 72 77 93.9 1.9;  
 66 'NIOH25' 86 95 96 95 92 86 78 99.1 1.9;  
 67 'ArFrc19' 98 97 96 98 95 92 92 102.2 2.1;  
 68 'NIOH36' 81 94 95 94 88 86 78 97.6 2.1;  
 69 'ArFrc23' 102 101 107 104 100 95 95 108.5 2.2;  
 70 'ArFrc06' 81 86 83 84 82 76 75 88.4 2.3;  
 71 'NIOH22' 87 89 92 86 86 86 72 93.6 2.3;  
 72 'NIOH48' 85 87 84 86 82 82 71 90.1 2.4;  
 73 'NIOH67' 87 87 84 83 83 83 83 90.3 2.5;  
 74 'ArFrc05' 72 73 75 70 69 69 66 77.1 2.5;  
 75 'NIOH27' 86 92 92 84 78 90 74 94.1 2.6;  
 0 'ArFrc48' 90 93 92 90 89 84 80 95.4 2.7;  
 76 'NIOH21' 86 96 95 95 84 84 74 97.7 2.8;  
 77 'NIOH97' 99 95 92 95 92 93 91 100.1 2.8;

0 'ArFrc50' 91 94 95 92 84 84 90 96.9 2.8;  
 0 'ArFrc07' 86 88 88 85 83 80 78 90.6 2.9;  
 78 'NIOSH04' 91 87 87 88 86 80 77 92.2 3.0;  
 79 'NIOSH01' 91 90 89 90 84 80 84 93.4 3.1;  
 80 'NIOSH35' 89 87 86 86 83 82 78 90.8 3.1;  
 81 'NIOSH31' 94 88 85 91 87 82 83 94.1 3.1;  
 82 'NIOSH60' 93 101 101 99 90 78 66 102.3 3.2;  
 83 'NIOSH23' 89 96 88 84 89 89 85 95.3 3.2;  
 0 'ArFrc30' 104 104 103 100 99 98 94 106.4 3.3;  
 0 'ArFrc12' 104 109 108 103 101 97 103 110.0 3.3;  
 84 'NIOSH64' 88 91 92 85 83 83 84 93.0 3.3;  
 0 'ArFrc37' 112 107 107 105 106 104 99 112.0 3.4;  
 85 'NIOSH83' 90 88 87 88 81 81 74 91.2 3.5;  
 86 'NIOSH05' 86 91 91 88 80 76 73 92.1 3.6;  
 87 'NIOSH59' 92 90 89 88 87 78 72 92.9 3.6;  
 0 'ArFrc20' 104 95 95 101 93 91 86 102.9 3.7;  
 88 'NIOSH26' 85 91 86 84 83 81 73 90.3 3.8;  
 0 'ArFrc49' 79 73 77 73 72 68 62 79.0 3.8;  
 0 'ArFrc09' 89 89 87 83 83 82 77 90.3 3.9;  
 89 'NIOSH66' 91 94 94 91 82 76 65 94.9 3.9;  
 90 'NIOSH50' 92 83 83 83 87 73 64 90.2 4.0;  
 91 'NIOSH37' 87 90 91 86 79 75 60 91.1 4.0;  
 92 'NIOSH68' 93 91 92 91 78 72 75 93.7 4.1;  
 0 'ArFrc25' 98 92 93 92 90 85 83 96.8 4.2;  
 93 'NIOSH34' 94 91 89 90 84 82 78 93.4 4.3;  
 94 'NIOSH81' 90 87 87 84 82 78 77 89.6 4.3;  
 95 'NIOSH57' 92 86 82 82 81 86 70 90.0 4.3;  
 96 'NIOSH62' 92 86 82 82 81 86 70 90.0 4.3;  
 97 'NIOSH65' 90 89 87 83 82 82 74 90.0 4.4;  
 98 'NIOSH76' 100 98 97 94 91 90 86 99.7 4.4;  
 0 'ArFrc15' 94 95 95 88 84 84 81 95.3 4.6;  
 99 'NIOSH28' 91 93 88 89 78 74 77 91.9 4.8;  
 0 'ArFrc40' 99 98 95 92 91 85 88 98.3 4.8;  
 100 'ArFrc38' 105 103 103 98 95 91 85 104.0 5.0;  
 101 'NIOSH43' 98 93 89 92 88 83 75 95.4 5.0;  
 102 'NIOSH49' 98 93 89 92 88 83 75 95.4 5.0;  
 103 'CivAv02' 99 97 98 92 87 83 77 98.1 5.2;  
 104 'ArFrc16' 92 94 93 85 81 80 76 93.0 5.2;  
 105 'ArFrc35' 100 102 98 94 92 87 80 100.3 5.3;

106 'ArFrc27' 92 78 81 82 81 81 73 87.8 5.4;  
 107 'ArFrc46' 112 118 114 106 105 101 96 114.9 5.5;  
 108 'NIOSH46' 93 90 85 88 77 75 72 90.4 5.6;  
 109 'ArFrc41' 98 98 93 90 88 84 85 96.4 5.7;  
 110 'ArFrc47' 108 115 112 99 95 92 90 111.3 6.1;  
 111 'ArFrc45' 110 111 111 95 92 89 84 109.4 6.1;  
 112 'CivAv14' 74 75 70 68 59 52 48 72.4 6.2;  
 113 'NIOSH45' 99 94 94 90 84 82 75 95.2 6.3;  
 114 'CivAv01' 99 97 92 90 86 85 80 95.6 6.4;  
 115 'ArFrc14' 94 90 89 79 77 77 73 89.1 7.4;  
 116 'ArFrc34' 108 103 102 96 92 87 82 102.7 7.4;  
 117 'NIOSH12' 84 103 93 85 75 70 66 96.1 7.4;  
 118 'CivAv06' 98 92 90 86 82 79 75 92.0 7.7;  
 119 'NIOSH32' 97 98 85 87 81 80 82 93.1 7.7;  
 0 'ArFrc36' 106 101 99 93 90 86 80 100.2 7.7;  
 0 'ArFrc31' 99 96 89 82 82 84 87 93.4 7.8;  
 0 'ArFrc32' 80 79 72 66 66 63 55 75.2 7.8;  
 0 'CivAv11' 99 94 92 86 81 80 70 93.0 7.9;  
 0 'ArFrc33' 112 112 105 99 95 90 88 107.4 8.1;  
 120 'NIOSH56' 97 90 89 84 78 77 74 90.2 8.2;  
 0 'CivAv08' 100 96 89 86 84 83 77 93.4 8.4;  
 121 'NIOSH63' 101 98 92 85 85 83 76 94.7 8.5;  
 0 'CivAv16' 83 81 75 70 58 48 44 76.8 8.7;  
 0 'CivAv12' 101 98 94 85 78 77 73 94.6 8.7;  
 0 'ArFrc42' 104 97 95 89 85 82 80 96.3 8.9;  
 0 'CivAv18' 96 94 86 80 73 68 65 88.9 9.5;  
 0 'CivAv15' 81 77 70 66 60 54 49 73.1 9.6;  
 122 'NIOSH53' 110 109 101 89 82 79 80 103.1 9.6;  
 0 'CivAv03' 111 102 101 95 91 84 78 102.2 9.7;  
 0 'ArFrc18' 101 91 88 85 83 80 78 91.9 9.8;  
 0 'CivAv10' 97 94 85 80 77 74 65 89.1 9.8;  
 0 'ArFrc11' 91 87 81 73 68 60 55 82.8 9.9;  
 0 'ArFrc29' 108 106 95 88 85 83 80 100.0 10.2;  
 0 'CivAv13' 98 94 86 81 73 64 56 89.3 10.3;  
 0 'CivAv04' 98 95 85 75 71 65 60 89.0 10.8;  
 0 'ArFrc43' 114 109 99 93 87 82 75 103.8 11.4;  
 123 'ArFrc17' 109 101 94 89 86 82 79 98.1 11.5;  
 124 'CivAv05' 102 94 88 81 77 74 69 91.0 11.6;  
 125 'CivAv17' 97 90 82 73 68 59 56 85.6 12.1;

```
126 'CivAv20' 90 84 69 62 58 53 57 78.2 12.7;
127 'CivAv19' 98 89 79 76 64 58 55 85.4 13.0;
128 'CivAv07' 106 93 87 79 84 75 71 92.9 13.2;
129 'ArFrc39' 108 92 89 84 82 78 74 94.3 13.7;
130 'CivAv09' 116 97 90 84 78 74 68 100.5 15.3};
% Identify the four sets of NRSG Noises
NRSG_1 = 1:20;
NRSG_2 = 65:84;
NRSG_3 = 121:139;
NRSG_4 = 163:170;
% Create the array of the entire NRSA Noise set
AllNRSA noises = [NRSA noises{:,3};NRSA noises{:,4};NRSA noises{:,5}; ...
NRSA noises{:,6};NRSA noises{:,7};NRSA noises{:,8};NRSA noises{:,9}];
% Identify the array of 130 Noises from the first column of data
gronk = [NRSA noises{:,1}];
idx = find(gronk ~= 0);
SomeNRSA noises =
[NRSA noises{idx,3};NRSA noises{idx,4};NRSA noises{idx,5}; ...
NRSA noises{idx,6};NRSA noises{idx,7};NRSA noises{idx,8};NRSA noises{id
x,9}];
% Identify the NIOSH 100 Noises using the second column of data
gronk = char(NRSA noises{:,2});
NIOSH100idx = find(gronk(:,1) == 'N');
NIOSH100 noises = [...
NRSA noises{NIOSH100idx,3};NRSA noises{NIOSH100idx,4}; ...
NRSA noises{NIOSH100idx,5};NRSA noises{NIOSH100idx,6}; ...
NRSA noises{NIOSH100idx,7};NRSA noises{NIOSH100idx,8}; ...
NRSA noises{NIOSH100idx,9}];
```

## 7.2 NRSA.m

The second subroutine, NRSA.m, computes the rating for a set of noises, REAT attenuations and protection percentiles. The function is called by passing a set of noises in an Nx7 array, a set of REAT attenuation values in an Sx7 array and a set of protection percentiles ( $0 < \% < 1$ ).

```
function NRSA = NRSA(Noises,REATs,Percentiles)
% [NRSALow, NRSAHigh] = NRSA(Noises,REATs,Percentiles)
% Noises is an Nrows x 7 matrix of noise spectra
% REATs is an Srows x 7 matrix of REAT attenuations, one row per subject
% Percentiles is a 1 x M vector of values (0 < Percentiles <= 0.5)
%   for which NRSAmean +/- Pcnt * sdev will be calculated
% The low percentiles (<0.5) will be returned in
[Nrows Ncols] = size(Noises);
if ~((Ncols == 7) || (Nrows == 7))
    error('Noises must have dimension Nx7');
    return
end
[Srows Scols] = size(REATs);
if ~((Scols == 7) || (Srows == 7))
    error('REATs must have dimension Nx7');
    return
end
if Nrows == 7
    Noises = Noises';
    [Nrows Ncols] = size(Noises);
end
if Srows == 7
    HPDdata = REATs';
else
    HPDdata = REATs;
end
if sum(Percentiles <= 0 | Percentiles >=1)
    error('Percentiles must be greater than 0 and less than 1')
    return
end
[Srows Scols] = size(HPDdata);
%A-weighting Corrections
aweight = [-16.1, -8.6, -3.2, 0.0, 1.2, 1.0, -1.1];
% Compute the A-weighted noise levels and replicate the matrix
% to be the size of the number of subjects
AwUnprotected = repmat(Noises+ones(Nrows,1)*aweight,[1 1 Srows]);
% replicate the Attenuation data to be the size of the number of noises
Attens = shiftdim(repmat(HPDdata',[1 1 Nrows]),2);
% Compute the Aweighted protected exposures
```

```
AwProtected = AwUnprotected - Attens;
% Sum the data to get overall exposure levels
AwUnProt = squeeze(10*log10(sum(10.^(AwUnprotected/10),2)));
% Sum the data to get the protected levels
AwProt = squeeze(10*log10(sum(10.^(AwProtected/10),2)));
% Calculate the A-weighted attenuations
NRSamat = AwUnProt - AwProt;
% compute the mean attenuation and reshape
NRSamean = mean(reshape(NRSamat,1,numel(NRSamat)));
% compute the standard deviation across noises
sdNoise = std(mean(NRSamat,1),0);
% compute the standard deviation across subjects
sdSubject = std(mean(NRSamat,2),0);
% combine the variances to get the overall standard deviation
NRSAsd = sqrt(sdNoise^2+sdSubject^2);
% determine the Z-score corresponding to the Percentiles passed
Lp = length(Percentiles);
zval = sqrt(2)*erfcinv(2*Percentiles);
% Determine the NRSA for the given protection percentiles passed
NRSA = NRSamean - zval*NRSAsd;
```

### 7.3 NRSARating.m

The third subroutine, NRSARating.m, is more specific than the previous NRSA.m routine. NRSARating computes both the 10<sup>th</sup> and 90<sup>th</sup> protection percentiles for the attenuations passed into the function. As well, the function computes the NRS<sub>G</sub> values to allow the graphical method to be utilized. NRSARating allows one to customize the percentiles by passing a vector of values between 0 and 1. If the percentiles vector is not passed, the function defaults to the 10<sup>th</sup> and 90<sup>th</sup> protection percentiles.

```
function [NRSA, NRSg1, NRSg2, NRSg3, NRSg4] = NRSARating(REATs,
Percentiles)
% NRSARating computes the Noise Level Reduction Statistic for A-weighting
% and the Graphical Noise Level Reduction Statistics. The default
% percentiles are the 10th and 90th protection percentiles.
%
% [NRSA, NRSg1, NRSg2, NRSg3, NRSg4] = NRSA(REATs)
```

% REATs is an Srows x 7 matrix of REAT attenuations, one row per subject

% Load the NRSA Noise Data File and select NIOSH 100 Noises

```
if nargin == 1
    % Set the Percentiles
    Percentiles = [0.1 0.9 ];
else
    % Check that the Percentiles are between 0 and 1
    if sum(Percentiles <= 0 | Percentiles >=1)
        error('Percentiles must be greater than 0 and less than 1')
    end
end
```

%Load the NRSANoiseData

```
NRSANoiseData
Noises = AllNRSANoises;
[Nrows Ncols] = size(Noises);
[Srows Scols] = size(REATs);
if ~((Scols == 7) || (Srows == 7))
    error('REATs must have dimension Nx7');
    return
end
if Srows == 7
    HPDdata = REATs';
else
    HPDdata = REATs;
end
% get the size of the Subject data array
[Srows Scols] = size(HPDdata);
% A-weighting Correction factors
aweight = [-16.1, -8.6, -3.2, 0.0, 1.2, 1.0, -1.1];
% Compute the A-weighted noise levels and replicate the matrix
% to be the size of the number of subjects
AwUnprotected = repmat(Noises+ones(Nrows,1)*aweight,[1 1 Srows]);
% replicate the Attenuation data to be the size of the number of noises
Attens = shiftdim(repmat(HPDdata',[1 1 Nrows]),2);
```

% Compute the Aweighted protected exposures

```
AwProtected = AwUnprotected - Attens;
% Sum the data to get overall exposure levels
AwUnProt = squeeze(10*log10(sum(10.^(AwUnprotected/10),2)));
% Sum the data to get the protected levels
AwProt = squeeze(10*log10(sum(10.^(AwProtected/10),2)));
% Calculate the A-weighted attenuations
NRSamat = AwUnProt - AwProt;
% compute the mean across the Subjects
NRSgSubjMean = mean(NRSamat,1);
% compute the mean across noises
NRSgNoiseMean = mean(NRSamat,2);
% compute the standard deviation across subjects
NRSgSubjSD = std(NRSamat,[],1);
% compute the standard deviation across noises
NRSgNoiseSD = std(NRSamat,[],2);

% Compute the NRSA rating with the NIOSH 100 Noises,
% mean Awt ttenuation
NRSamean =
mean(reshape(NRSamat(NIOSH100idx,:),1,numel(NRSamat(NIOSH100idx,:
))));
%Compute standard deviation across noises
sdNoise = std(mean(NRSamat(NIOSH100idx,:),1),0);
%Compute standard deviation across subjects
sdSubject = std(mean(NRSamat(NIOSH100idx,:),2),0);
%Estimate combined standard deviation
NRSAsd = sqrt(sdNoise^2+sdSubject^2);
%Insert the Z-scores for 20 and 80 percentiles.
zval = sqrt(2)*erfcinv(2*Percentiles);
%Compute final value of NRSA
NRSA = NRSamean - zval*NRSAsd;

%Compute the Graphical NRSg values using the indices for the different
%subsets of noises. Note that the A-weighted attenuations have been
%computed for all of the noises in the database, these next lines of code
%determine the values for the subsets specific to the NRSg.
NRSg1 =
mean(( repmat(NRSgNoiseMean(NRSg_1),1,2)' + zval'*NRSgNoiseSD(NRSg_
1)')));
```

```

NRSG2 =
mean((repmat(NRSGNoiseMean(NRSG_2),1,2)'+zval'*NRSGNoiseSD(NRSG_
2)')));
NRSG3 =
mean((repmat(NRSGNoiseMean(NRSG_3),1,2)'+zval'*NRSGNoiseSD(NRSG_
3)')));
NRSG4 =
mean((repmat(NRSGNoiseMean(NRSG_4),1,2)'+zval'*NRSGNoiseSD(NRSG_
4)')));

```

## 7.4 BoseA20AviationHeadset.m

The final function for completing the computation is an example from the data used in the report. The REAT data are entered in a matrix indicating the subject ID number, the sequential subject number, the trial number and the REAT attenuations from 125 to 8000 Hz. The second matrix of numbers are the MIRE data measured with the electronics turned off. The columns of data are the subject ID number, the sequential subject number, the trial number, the status of the electronics (0 = off) and the levels measured at the octave band frequencies under the muff in the 105 dB SPL pink noise. The third matrix of numbers are the MIRE results with the electronics turned on. The columns are the same as those for the MIRE Off, except for the status of the electronics (1 = On). The procedure for the computation is documented in the comments.

BoseA20AviationHeadset.m

```

%SubjectNum Subject Trial 125 250 500 1K 2K 4K 8K
REATData = [...
1427 1 1 2.33 2.33 6.67 21.33 30.17 41.17 40.33;
1427 1 2 0.67 6.67 9.17 15.83 26 44.5 39.83;
1401 2 1 2.5 5.33 10.33 19.67 34.33 40 40.33;
1401 2 2 4 4.5 11.17 18.17 30.33 40.5 41.33;
1485 3 1 2.67 7.33 7.33 18.33 28.83 33.5 33.17;
1485 3 2 2.83 2.83 8.83 20.17 27.5 36.33 29.17;
1438 4 1 2.83 7 10.5 21.67 29.33 37.5 35;
1438 4 2 -0.83 6 10.33 19.5 27.5 40.83 39.83;
1482 5 1 0 5.67 12.67 16.33 24.67 37.67 31.5;

```

```

1482 5 2 2.83 8 8.33 16.67 28 37.33 38.17;
1447 6 1 -0.67 9 13.17 18.83 33.67 41.5 37.17;
1447 6 2 3.5 5.5 11.33 19.17 33.33 45.5 41.83;
1503 7 1 3.67 8.17 14.5 19.33 28 34.83 32.5;
1503 7 2 7.17 10.5 12.83 16.67 32.83 35.17 31.67;
1487 8 1 4.67 16.67 11.5 22.67 33 39.17 35.67;
1487 8 2 -0.67 9 13 21.67 36 46.17 43.83;
1499 9 1 -1.83 4.67 11.33 20.67 28.83 40 35.5;
1499 9 2 2 2.83 12 19.67 27 38.17 39.83;
1208 10 1 7 7.5 9.33 24.67 36.67 38.17 35.17;
1208 10 2 4.5 5 10 21 34.17 39.33 37.67];

```

```

%SubNum Subject Trial Device On Med125 Med250 Med500 Med1000
%Med2000 Med4000 Med8000

```

MIREOFFData = [...

```

1427 1 1 0 90.95 84.45 76.05 71.95 61.4 52.35 46.4;
1427 1 2 0 90.35 84.3 76.85 72.4 62.45 52.95 46.9;
1427 1 3 0 90.25 84.3 77.3 72.8 62.7 53.65 47.2;
1401 2 1 0 90.9 86 78.05 73.6 64.7 52.2 49;
1401 2 2 0 91.2 86.1 79.55 74.9 65.3 53.15 49.6;
1401 2 3 0 91.4 85.4 78.75 74.2 64.1 51.9 49.6;
1485 3 1 0 91.3 84.1 76.05 72.65 60.45 54.05 48.35;
1485 3 2 0 90.9 83.55 76.65 73.3 61.65 53.75 48.4;
1485 3 3 0 90.7 83.9 76.35 73.1 61.35 52.85 46.5;
1438 4 1 0 91.55 87.75 80.4 75.2 67.25 62.1 55.35;
1438 4 2 0 91.65 88.15 81.2 75.85 67.85 61.6 57.5;
1438 4 3 0 92 89.05 82.7 76.15 68 60.85 60.1;
1482 5 1 0 90.75 83.75 76.65 72.2 62.65 52 48.3;
1482 5 2 0 91.55 84.95 77.55 72.2 60.95 53.35 48.4;
1482 5 3 0 91.5 84.9 77.9 72.05 62.5 53.85 51.8;
1447 6 1 0 91.45 85.8 77.25 72.7 58.9 54.3 51.85;
1447 6 2 0 91.35 85.05 79.05 74.05 65.05 54.55 51.65;
1447 6 3 0 91.65 85.5 79.1 73.9 64.95 54.05 52.35;
1503 7 1 0 92.55 88.95 81.6 76.55 70.3 57.8 56.7;
1503 7 2 0 92.5 89.5 81.65 77.1 69.2 58.8 55.65;
1503 7 3 0 92.95 88.95 81.95 76.6 68.55 58.95 50.25;
1487 8 1 0 90.65 86.15 78.95 74 69.3 56.8 48.95;
1487 8 2 0 90.65 86.8 80.05 74.4 69.85 56.55 48.8;

```

```

1487 8 3 0 90.5 86.25 79.55 74.35 67.15 57.2 47.3;
1499 9 1 0 90.45 85.15 76.75 72.7 62.95 55 51.55;
1499 9 2 0 90.5 85.1 77.3 73.55 65.05 54.5 51.9;
1499 9 3 0 90.35 86 77.8 74 65.6 55.3 51.6;
1208 10 1 0 91.05 85.4 78.2 73.75 59.6 56.7 52.9;
1208 10 2 0 90.45 85.85 79.35 74.85 64.75 57.8 55.95;
1208 10 3 0 90.85 85.85 79.3 74.45 63.8 57.8 55.1];

```

MIREONData = [...

```

1427 1 1 1 54.4 56.65 55.6 66.85 64.65 55.65 46.6;
1427 1 2 1 55.05 57.6 58.3 67.6 65.45 55.35 46.25;
1427 1 3 1 55.75 57.9 59.1 68.35 65.8 55.65 47;
1401 2 1 1 58.05 59.15 60.35 71.3 67.5 55.35 50.7;
1401 2 2 1 58.55 60.85 62.95 71.95 67.15 55.55 49.9;
1401 2 3 1 57.9 58.65 61.25 70.45 66.4 54.2 48.7;
1485 3 1 1 53.4 54.85 55.7 69.25 63.95 55.6 48.2;
1485 3 2 1 53.55 56.05 58 69.7 64.95 55.85 48.8;
1485 3 3 1 52.3 56.3 57.9 69 65.25 54.65 46.55;
1438 4 1 1 59.05 61.5 65.5 74.55 69.9 64.1 55.65;
1438 4 2 1 61.5 62.2 65.75 75.2 70.05 64.1 58.8;
1438 4 3 1 61.8 63.35 67.4 75.05 70.75 61.25 58.6;
1482 5 1 1 54.85 56.15 56.4 69.4 64.95 53.8 48.45;
1482 5 2 1 55.15 59.65 61.9 69.45 63.45 55.15 50.45;
1482 5 3 1 56.1 60 62.35 69.85 65.45 55.55 51.05;
1447 6 1 1 55.2 57.2 58.35 68.5 63.3 55.75 51.6;
1447 6 2 1 57.1 58.85 61 71.1 67.5 56.9 52.25;
1447 6 3 1 58.1 59.1 60.6 70.8 67.75 55.75 52.7;
1503 7 1 1 61.3 61.8 64 73.85 72.4 58.1 58.1;
1503 7 2 1 61.9 62.1 65.2 73.9 71.5 59.7 57;
1503 7 3 1 62.65 63.4 66.9 74.4 70.65 60.45 51.3;
1487 8 1 1 55.8 59.75 62.95 73.7 71.75 56 49.05;
1487 8 2 1 57.1 61 64.45 74.35 72.35 56.85 49.85;
1487 8 3 1 54.6 60.4 64.4 73 69.3 57.6 48.2;
1499 9 1 1 56.15 57.65 59.7 69.2 66.5 55.5 51.25;
1499 9 2 1 56.05 59.25 61.15 71 68 54.6 51.5;
1499 9 3 1 55.6 60.2 62.35 70.5 68.2 55.5 51.2;
1208 10 1 1 54.45 57.65 60.9 70 61.65 57.85 53.65;
1208 10 2 1 55 60.35 63.15 72.8 67.55 58.7 56.25;
1208 10 3 1 55.3 59.2 64.3 72.55 66.1 58.95 55.3];

```

```
% Load the NRSA Noise Data
NRSANoiseData;
% Average across the subjects using the groupmean function
AvgREAT = groupmean(REATData(:,2:10),[1:10]',1);
AvgMIREOn = groupmean(MIREONData(:,2:11),[1:10]',1);
AvgMIREOff = groupmean(MIREOFFData(:,2:11),[1:10]',1);
% Compute the Passive Rating
[BoseNRSAValues, BoseNRSG1, BoseNRSG2, BoseNRSG3, BoseNRSG4] = ...
    NRSARating(AvgREAT(:,3:9));
fprintf(1, 'Bose A20 Aviation Headset\n');
fprintf(1, '\t\t\tNRSA\tNRSG1\tNRSG2\tNRSG3\tNRSG4\n');
fprintf(1, 'Passive 90%%\t%5.2f\t%5.2f\t%5.2f\t%5.2f\t%5.2f\n', ...
    BoseNRSAValues(1), BoseNRSG1(4), BoseNRSG2(4), BoseNRSG3(4), ...
    BoseNRSG4(4))
fprintf(1, 'Passive 80%%\t%5.2f\t%5.2f\t%5.2f\t%5.2f\t%5.2f\n', ...
    BoseNRSAValues(2), BoseNRSG1(3), BoseNRSG2(3), BoseNRSG3(3), ...
    BoseNRSG4(3))
fprintf(1, 'Passive 20%%\t%5.2f\t%5.2f\t%5.2f\t%5.2f\t%5.2f\n', ...
    BoseNRSAValues(3), BoseNRSG1(2), BoseNRSG2(2), BoseNRSG3(2), ...
    BoseNRSG4(2))
fprintf(1, 'Passive 10%%\t%5.2f\t%5.2f\t%5.2f\t%5.2f\t%5.2f\n', ...
    BoseNRSAValues(4), BoseNRSG1(1), BoseNRSG2(1), BoseNRSG3(1), ...
    BoseNRSG4(1))
fprintf('\n');
% Compute the Active Rating
[BoseNRSAValues_ANR, BoseNRSG1_ANR, BoseNRSG2_ANR,
BoseNRSG3_ANR, ...
    BoseNRSG4_ANR] = NRSARating(AvgREAT(:,3:9)+ ...
    (AvgMIREOff(:,4:10) - AvgMIREOn(:,4:10)));
fprintf(1, 'Active 90%%\t%5.2f\t%5.2f\t%5.2f\t%5.2f\t%5.2f\n', ...
    BoseNRSAValues_ANR(1), BoseNRSG1_ANR(4), BoseNRSG2_ANR(4), ...
    BoseNRSG3_ANR(4), BoseNRSG4_ANR(4))
fprintf(1, 'Active 80%%\t%5.2f\t%5.2f\t%5.2f\t%5.2f\t%5.2f\n', ...
    BoseNRSAValues_ANR(2), BoseNRSG1_ANR(3), BoseNRSG2_ANR(3), ...
    BoseNRSG3_ANR(3), BoseNRSG4_ANR(3))
fprintf(1, 'Active 20%%\t%5.2f\t%5.2f\t%5.2f\t%5.2f\t%5.2f\n', ...
    BoseNRSAValues_ANR(3), BoseNRSG1_ANR(2), BoseNRSG2_ANR(2), ...
    BoseNRSG3_ANR(2), BoseNRSG4_ANR(2))
fprintf(1, 'Active 10%%\t%5.2f\t%5.2f\t%5.2f\t%5.2f\t%5.2f\n', ...
```

BoseNRSAValues\_ANR(4), BoseNRSG1\_ANR(1), BoseNRSG2\_ANR(1), ...  
BoseNRSG3\_ANR(1), BoseNRSG4\_ANR(1))

## 7.5 GroupMean.m

Groupmean is a function that was written to average a matrix based where repeated measurements are stored in separate rows of the matrix. Three arguments are passed to the function: the matrix to be averaged, the indices for the averaging operation, and the column in which the indices are found. While there may be more sophisticated methods to perform this average, the function is occasionally used and was written specifically for use with computing the noise reduction rating.

```
function ArrMeanOut = groupmean(ArrIn, groupIdx, dim)
% groupmean(ArrayIn, groupIndex, groupColumn)
% Calculates a group of means for rows matching the indices
% provided in GroupIndex
% AvgA = groupmean(A, [1:24]' ,2)
% AvgA will match the second column of A to the vector [1:24]'
% and return a 24 row matrix with the same number of columns as A.

% Determine the size of the input array
[nRIn nCIn] = size(ArrIn);
% Determine the size of the averaged output array
[nROut nCOut] = size(groupIdx);
% Create an array for the output
ArrMeanOut = zeros(nROut, nCIn);
% find the rows that match the index and average those rows together
for jdx = 1:nROut
    Idx = find(ArrIn(:,dim) == groupIdx(jdx));
    ArrMeanOut(jdx,:) = mean(ArrIn(Idx,:));
end
```



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