ARL-TR-7639 ● MAR 2016

US Army Research Laboratory

Effects of Hearing Protection Device Attenuation on Unmanned Aerial Vehicle (UAV) Audio Signatures

by Melissa Bezandry, Adrienne Raglin, and John Noble

NOTICES

Disclaimers

ARL-TR-7639 ● MAR 2016

US Army Research Laboratory

Effects of Hearing Protection Device Attenuation on Unmanned Aerial Vehicle (UAV) Audio Signatures

by Melissa Bezandry, Adrienne Raglin, and John Noble
Computational and Information Sciences Directorate, ARL

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)* March 2016	**2. REPORT TYPE** Final	**3. DATES COVERED (From - To)** May 2014–August 2015
4. TITLE AND SUBTITLE Effects of Hearing Protection Device Attenuation on Unmanned Aerial Vehicle (UAV) Audio Signatures		**5a. CONTRACT NUMBER** **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHOR(S) Melissa Bezandry, Adrienne Raglin, and John Noble		**5d. PROJECT NUMBER** **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) US Army Research Laboratory ATTN: RDRL-CIE-S 2800 Powder Mill Road Adelphi, MD 20783-1138		**8. PERFORMING ORGANIZATION REPORT NUMBER** ARL-TR-7639
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		**10. SPONSOR/MONITOR'S ACRONYM(S)** **11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The goals of this study were to investigate the measure of attenuation of hearing protection devices (HPDs) and to develop a filter that uses parameters of HPDs to alter acoustic signatures of Unmanned Aircraft Systems (UASs). The results could be used to select appropriate HPDs for environments where noise from UASs may be distracting. Implemented in Matrix Laboratory (MATLAB), the filter's interface stored several HPDs and their protector factors—Single Number Rating and High-Middle-Low ratings. In custom mode, user-defined HPD parameters were imported into the program. Once a UAS sound file was loaded, the program read it as signal data and displayed graphs of its magnitudes with respect to time and frequency. In the filtering process, the program retrieved the signal's magnitudes and applied different decibel attenuations at certain frequency bands. It then returned the attenuated signal and graphs of its new magnitudes to be compared with the original signal data. The new sounds along with other data displayed in the interface were exported for further study. In the future, the work could aid in the development of a filter to attenuate unmanned aerial vehicle noise in different environmental conditions and to test the effectiveness of HPDs with impulse noise.

15. SUBJECT TERMS

hearing protection, audio signature, sound modification, sound attenuation, filters

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Adrienne Raglin
Unclassified	Unclassified	Unclassified	UU	20	**19b. TELEPHONE NUMBER (Include area code)** 301-394-0210

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Contents

List of Figures

List of Tables

Acknowledgments

The author wishes to acknowledge the guidance of Andre Harrison, Deryck James, and Leelinda Dawson.

INTENTIONALLY LEFT BLANK.

1. Introduction/Background

Noise-induced hearing loss is becoming a serious health concern, affecting "15 percent of Americans between the ages of 20 and 69".[1] This type of hearing loss occurs when excessive sound intensity damages the ears' inner hair cells, which channel sound signals to nerve cells. Impulse noise can kill hair cells with instantaneous excessive pressure, whereas chronic noise exposure attacks hearing with continuous damaging pressure. Because hair cells do not regenerate, this hearing loss is irreversible. Hearing protection can be used to mitigate noise-induced hearing loss.

Hearing protection is essential for people exposed to dangerous environmental noises, such as those from certain types of unmanned aircraft systems (UASs). Some UASs emit steady-state low-frequency noises as loud as 110 dB—severe enough to induce permanent hearing loss after less than 7 min of exposure.[2] Individuals who work near these UASs encounter these noises every day, wearing appropriate hearing protection devices (HPDs) that provide some protection.

HPDs attenuate noise either passively or actively. Passive HPDs form a physical barrier to effectively block noise. This barrier is most effective against high-frequency noise and much less effective against low-frequency noise. In contrast, active HPDs use destructive interference to effectively counteract low-frequency noise. Active HPDs have microphones that sense the noise, process the noise to create an "anti-noise" signal, and then use speakers to broadcast an equal and opposite signal to cancel out the original noise. Several types of HPDs can employ these means of attenuation with different methods.

There are various types of HPDs, such as preformed earplugs, hand-formed earplugs, and noise muffs.[3] Aside from appearance, these HPDs use different mechanisms for attenuating noise. Hand-formed earplugs passively reduce noise by using foam to efficiently absorb sound. Preformed earplugs attenuate by using either level-dependent or non-level-dependent mechanisms. Level-dependent earplugs have thin filters that weaken impulse noise and keep lower-frequency sounds intact. Non-level-dependent earplugs attenuate linearly—decreasing sound levels by 3 dB, 6 dB, 9 dB, or more—to efficiently counteract steady-state noise. Double-ended preformed earplugs combine level-dependent and non-level-dependent modes, whereas single-ended earplugs are level-dependent only. Noise muffs can take 2 broad approaches to attenuation. They can passively attenuate noise with sound-absorbing ear cups or perform active noise control with electronic circuits. Some expensive noise muffs combine both of these features to block noise more efficiently. Apart from their means of noise reduction, HPDs can be distinguished by their attenuation values measured in decibels.

Each HPD attenuates sound by the level of decibels. There are various methods of rating attenuation: Noise Reduction Rating (NRR), the Single Number Rating (SNR), and the High-Middle-Low Rating (HML).[4] The NRR is a single number estimate of attenuation (in decibels) with 98% protection performance—or the minimum attenuation attained by 98% of the laboratory subjects. Similarly, the SNR is also a single number estimate; it can be calculated for different protection performance levels.[4] The HML rating calculates 3 numbers that indicate attenuation for 3 frequency bands—high, middle, and low—corresponding to frequency ranges of greater than 2000 Hz, 1000 Hz, and 2000 Hz, and less than 1000 Hz, respectively. Though these ratings provide numeric estimates of attenuation, a computer simulation can further demonstrate how these ratings affect sound.

Analyzing sound requires signal processing. Signal processing techniques, such as Fourier transforms, can manipulate signals to return information of interest. Fast Fourier transform, in particular, converts signals from a function of time into a function of frequency. Thus, it can extract the sample sound signals' magnitudes, or sound intensity, at certain frequencies. Inverse Fourier transforms can convert the magnitudes from the frequency domain back into amplitudes from the time domain. In this study, a program using these techniques will be created to simulate these HPD ratings and its effects on acoustic signatures of unmanned aerial vehicle (UAV) noise.

2. Experiment/Calculations

The goal of this study was to develop a filter that replicates UASs' acoustic signatures attenuated by HPDs. Sound samples of a UAS are needed to test this filter. Noise samples of a UAS's engine were recorded at a public airfield with a high-definition camcorder. Videos of the UAV were exported to a computer and were converted to a stereo waveform audio (WAV) file format with a preinstalled audio file converter.

Nine HPDs were tested from 3 hearing protector types: preformed earplugs, hand-formed earplugs, and noise muffs. To compare the attenuation of these HPDs, the SNR and HML ratings of each HPD were collected from their corresponding user guides (see the following Table). HML ratings were used since they provide more information about attenuation at different frequencies. The SNRs were also collected to compare the HPDs by single number values.

Table. Attenuation values of hearing protection devices

Hearing protector type	Hearing protection brand name	Single number rating (dB)	High-Middle-Low rating
Preformed earplugs	3M Combat Arms Passive Hearing Protector, double ended	24	26-21-19
	3M Combat Arms Passive Hearing Protector, single ended	15	20-11-6
	3M Combat Arms Hear-Through Protection	24	25-20-17
Hand-formed earplugs	3M Classic Passive Hearing Protector, foam	28	30-24-22
	Deci Damp	30	31-26-23
	Sound-Fit	28	31-25-22
Noise muffs	3M Peltor Bullseye I	27	32-24-15
	3M Peltor Bullseye Optime III	35	40-32-23
	UltraSonic HB-650	34	35-32-24

In the filtering process, the UAS's signal data are distributed into a 2-column matrix containing amplitudes from the left and right audio channels. The amplitudes were converted into a function of frequency by a fast Fourier transform. The filter then computed the absolute value of the amplitudes to retrieve a matrix of magnitudes. The phase of the original signal was stored in a matrix. The filter subtracted the signals' magnitudes by certain decibel attenuation values; these values were defined by the ratings of the HPD being tested. The filter employed a variation of the 20-log rule—the ratio between the acoustic gain and the amplitude of sound pressure levels is expressed in the following equations:

$$G = 20 \log_{10} (A_n/A_r) \,, \tag{1}$$

$$A_n = A_r \times 10^{(G/20)} \,, \tag{2}$$

where A_n is the new amplitude generated by the reference amplitude A_r and the gain G. Using the original phase and magnitudes calculated from the 20-log rule, we converted the attenuated signal in the frequency domain from a polar to complex array using the following equation:

$$z \equiv x + iy = |z|e^{i\theta}, \tag{3}$$

where z is the complex number calculated from the magnitude $|z|$ and the phase Θ. The filter then applied an inverse Fourier transform to signal data to return the attenuated signal data as a function of time.

The filter was implemented in Matrix Laboratory (MATLAB). Its graphical user interface (GUI) was constructed with MATLAB's GUI Design Environment (GUIDE).

3. Results and Discussion

3.1 Features of HPDfilter

The HPDfilter, the final program, had several features to test the performance of HPDs. In the GUI (Fig. 1), WAV files were selected and tested. In the Select File section, the sound file was selected by clicking "Browse" and uploaded by clicking "Load Audio". The original and modified audio files were also played and stopped by pressing the "Play" and "Stop" buttons. Once the audio had been loaded, the GUI displayed the sound file's waveform and produced its magnitude versus frequency plots. In the HPD selection drop menu, the sound file was attenuated with the parameters of a preinstalled or custom HPD. To create custom HPD parameters, "Custom" was selected in the HPD selection drop menu, and values were entered for the SNR or HML rating. In Fig. 1, the DeciDamp hand-formed earplug was chosen. When the "Modify Audio" button was clicked, the GUI calculated the attenuated sound's new waveform and magnitudes. The new waveform and magnitude versus frequency plots were displayed juxtaposed to the original waveform and plots. The amplitudes of the original audio and modified audio were compared using the axes and the data point selection feature. The HPD's attenuation versus frequency plot in the top-right corner was also displayed to illustrate the amount of decibels lost with respect to different frequencies. The sound files and graphs created in the GUI were exported for future use.

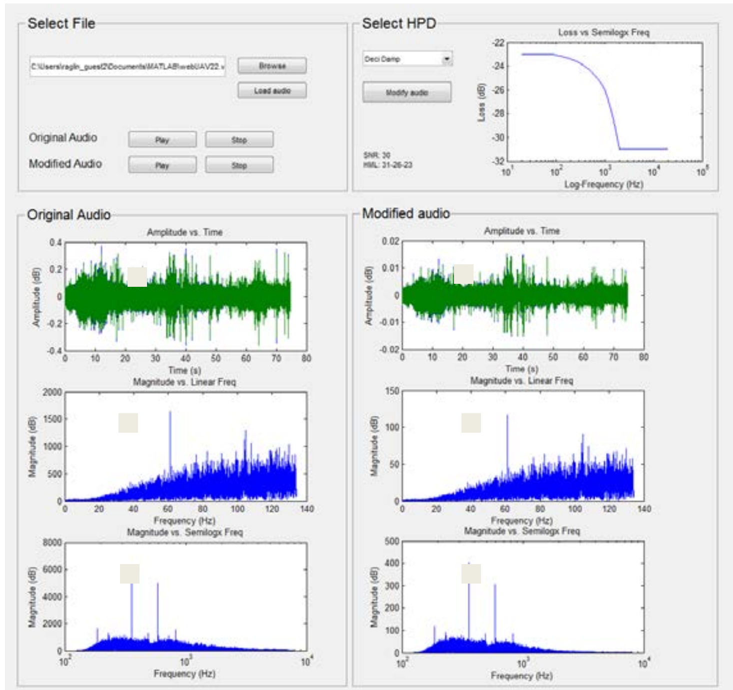

Fig. 1 GUI of the HPDfilter program

3.2 GUI Attenuation Samples

The SoundFit hand-formed earplugs, the single-ended 3M Combat Arms preformed earplugs, and the UltraSonic noise muffs were tested. The attenuated sound file's magnitude showed a reduction in the sound.

3.3 Observations

The SNR of the HPDs indicated the average sound attenuation. The preformed earplugs had an SNR from 15 to 25 dB, the hand-formed earplugs had an SNR from 28 to 30 dB, and the noise muffs had an SNR from 27 to 35 dB. After we applied attenuation, the new sound file, as shown in the sample GUI results in Figs. 2–4, retained the same waveforms with diminished magnitudes and amplitudes. The new sound file, when played, was less loud and more muffled than the original file. Each HPD type showed attenuation of the signal.

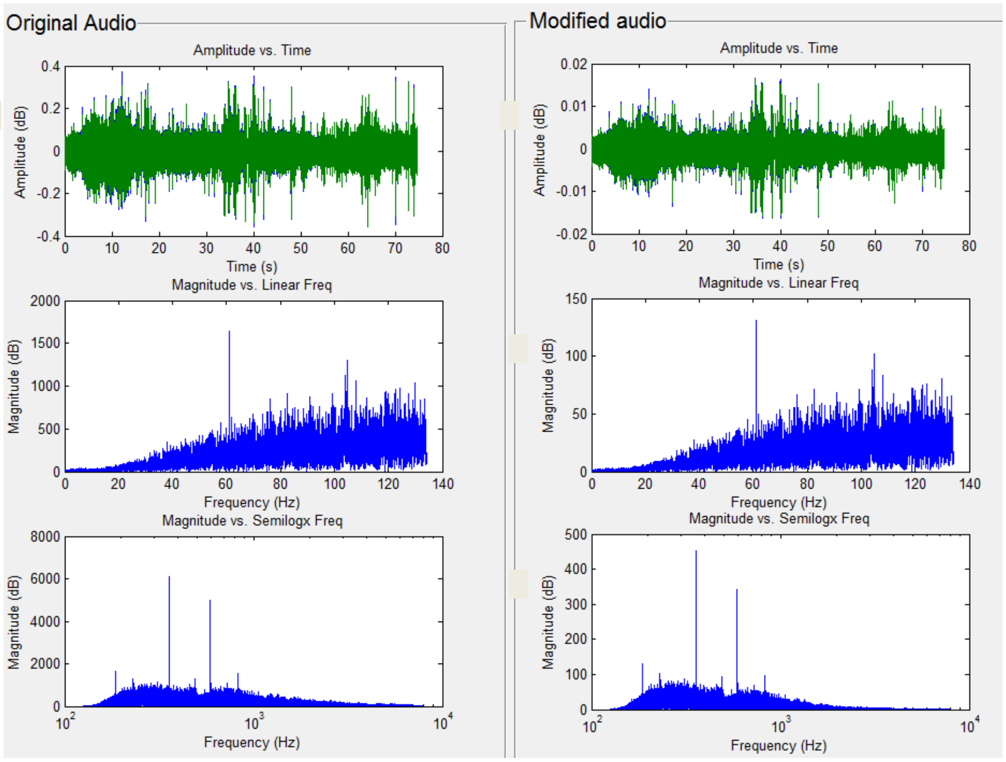

Fig. 2 Hand-formed earplug: SoundFit attenuation

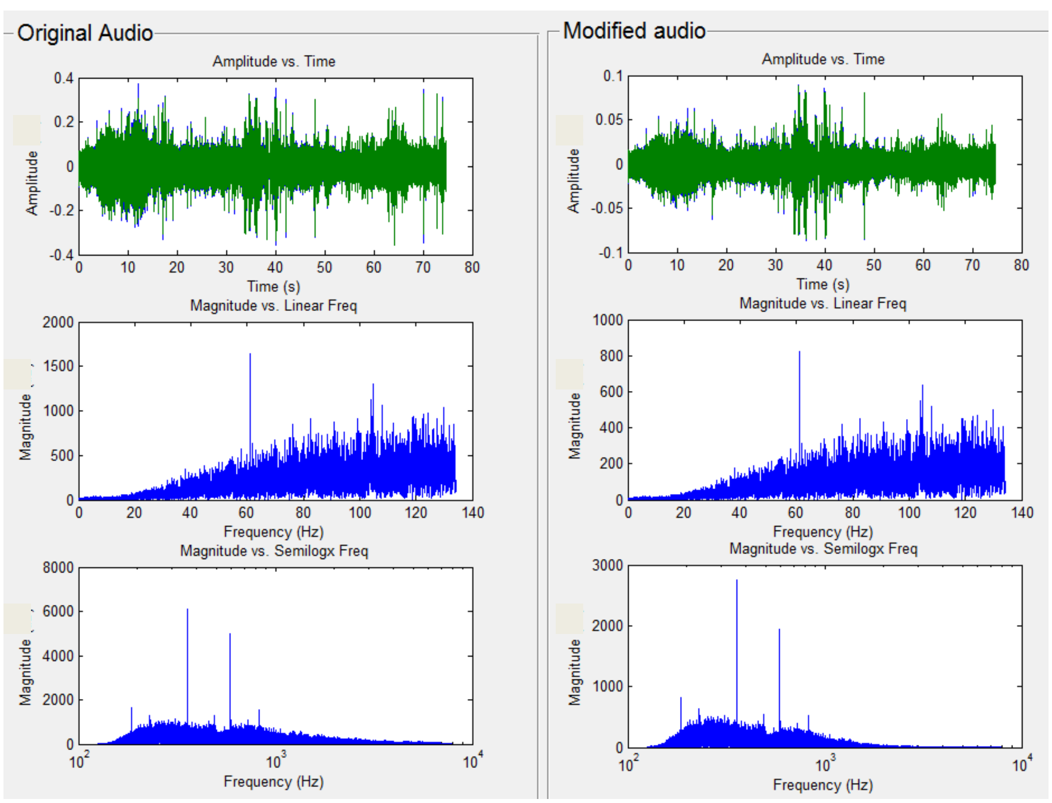

Fig. 3 Preformed earplug: 3M Combat Arms (single-ended) attenuation

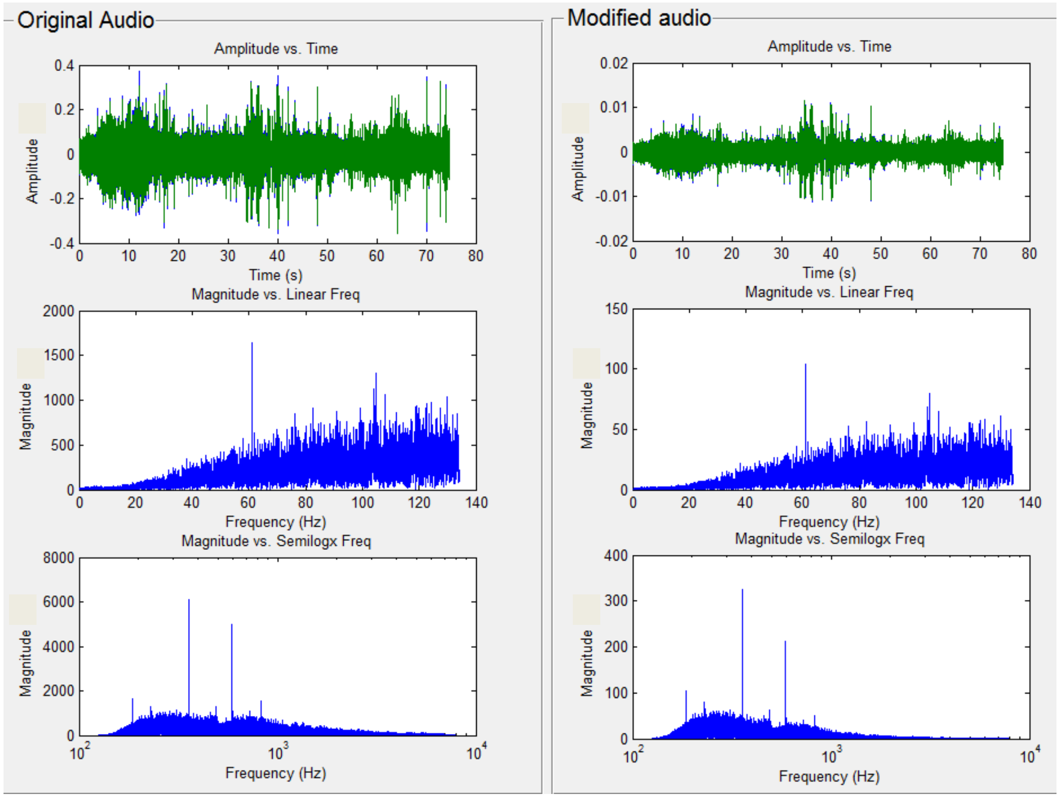

Fig. 4 Noise muff: UltraSonic attenuation

4. Summary and Conclusions

In general, assessing HPD performance depends on not only the decibel attenuation but also on the circumstances—for example, those requiring speech communications. An example would be aviators who need HPDs that can reduce noise to a safe level while distinguishing speech from other sounds. During this investigation, noise muffs were identified as HPDs that can offer the most protection, but speech could not be clearly heard when using this type of HPD. To distinguish speech from other sounds requires speech recognition or active noise reduction (ANR), which filters lower frequencies versus speech. Preformed earplugs are considered good substitutes to noise muffs if users need to hear speech and are not in close proximity to loud noises. Though they offer less protection, HPDs having an SNR less than 20 may be used for sound at a distance, which is less harmful and requires less attenuation. The environment and the experience of the wearer are also important to consider in selecting the appropriate HPD. Some HPDs are not suitable for environments that contain dangerous impulse noises. Combat Arms earplugs have an open mode, a specialized feature that can block impulse noise. However, blocking impulse noise requires ANR.

The HPDfilter program developed for this project was used to investigate changes to sample sound files when modified by parameters that generalized different HPDs. The program, for example, attempted to replicate the Combat Arms earplugs in closed/constant protection mode that could be used to block impulse noise. However, HPDs that could be used to distinguish speech from other sounds are not yet included in the HPDfilter program. Improperly fitted HPDs can leak harmful noise to the wearer; the program cannot realistically assess what magnitudes would be heard.

In addition, for this project the HPDfilter program generated modified UAS sound files after attenuating the original files using HPD parameters, with varying effects. The sample waveforms of the modified sound files did not appear to change in shape, and the modified sounds, though significantly muted, did not appear to encounter distortions. However, observing the plotted results from different sample HPDs, the magnitudes and amplitudes appeared reduced by various amounts. It is noted here that displaying the magnitude of the results needs correcting in future updated versions of the program.

In the future, the program can include features to filter sounds more extensively and accurately according to the HPDs' features. It can be modified to filter speech, using ANR. The program may add a function to consider fit and include more types of HPDs, such as aviator helmets and flat attenuation earplugs. The filter may be able to attenuate impulse noise and to test how effectively HPDs attenuate various types of noise in different environmental conditions.

5. References

1. National Institute on Deafness and Other Communication Disorders. Noise-induced hearing loss. Washington (DC): National Institutes of Health; 2014 [accessed 2015 Dec 18] http://www.nidcd.nih.gov/health/hearing/pages/noise.aspx.

2. Rajguru R. Enhancing aircrew protection against noise induced hearing loss. Indian Journal of Aerospace Medicine. 2012;56(1):39–49.

3. United States Army Center for Health Promotion and Preventive Medicine. Personal hearing protective devices: their fitting, care and use; 2006 [accessed 2015 Dec 2015] http://phc.amedd.army.mil/PHC%20Resource%20Library /TG%20041%20(Personal%20Hearing%20Protection%20Devices).pdf.

4. Centers for Disease Control and Prevention. Methods for calculating and using reduction ratings. Washington (DC): Centers for Disease Control and Prevention; 1995 [accessed 2015 Dec 18]. http://www.cdc.gov/niosh/z-draft-under-review-do-not-cite /hpdcompdev/pdfs/NIOSH_Compendium_Calculation.pdf.

Bibliography

3M Occupational Health & Environmental Safety Division. (2012). The power to protect your world. Värnamo (Sweden): 3M; 2012 (accessed 2016 Jan 13). http://peltorcomms.3m.com/world/files/Military_Catalogue_EN_rev_2012.pdf.

Leight H. Inside the HML method. San Diego (CA): Howard Leight by Sperian; nd (accessed 2016 Jan 13). http://www.hearforever.org/userfiles/file/Regulations/InsideTheHMLMethod.pdf.

Nave CR. HyperPhysics: fast Fourier transforms. Atlanta (GA): Georgia State University; nd (accessed 2016 Jan 13). http://hyperphysics.phy-astr.gsu.edu/hbase /math /fft.html.

Sadasivan S, Gurubasavaraj M, Sekar S. Acoustic signature of an unmanned air vehicle exploitation for aircraft localisation and parameter estimation. Defence Science Journal. 2001;51(3):279–284.

Silex. Sound attenuation. Mississauga (ON): Silex; 2002 (accessed 2016 Jan 13). http://www.silex.com/pdfs/sound%20attenuation.pdf.

Weisstein EW. Complex argument. Champaign (IL): Wolfram Research, Inc.; nd (accessed 2016 Jan 13). http://mathworld.wolfram.com/ComplexArgument.html.

1 (PDF)	DEFENSE TECHNICAL INFORMATION CTR DTIC OCA
2 (PDF)	DIRECTOR US ARMY RESEARCH LAB RDRL CIO LL IMAL HRA MAIL & RECORDS MGMT
1 (PDF)	GOVT PRINTG OFC A MALHOTRA
2 (PDF)	DIR USARL RDRL CII B A RAGLIN RDRL CIE S J NOBLE

INTENTIONALLY LEFT BLANK.