AHAAH Hearing Protection Module (Version 2.1) with Level-dependent Parameters for the Double-ended Combat Arms Earplug

By Paul Fedele and Joel Kalb

The Auditory Hazard Assessment Algorithm for Humans (AHAAH) (http://www.arl.army.mil/ahaah) is an advance in the evaluation of hearing damage risk associated with impulsive noise. AHAAH applies pressure response dynamics measured for the external, middle, and inner ear, to bio-mechanically model the ear's physical response to impulsive sound and accurately determine the strain-induced fatigue occurring in the cochlea's organ of Corti. A report entitled "Using the Auditory Hazard Assessment Algorithm for Humans (AHAAH) With Hearing Protection Software, Release MIL-STD-1474E" (ARL-TR-6748) was published in December 2013 describing the use of AHAAH. This report includes version 2.0 of the AHAAH software suite.

The Hearing Protector Module (HPM) included with version 2.0 of the AHAAH software modeled all hearing protectors as passive level independent linear (LIL) devices. Hearing protectors listed in the software included several level dependent nonlinear (LDNL) hearing protector devices (HPDs). These LDNL HPDs were modeled linearly, based on Real Ear Attenuation at Threshold (REAT) measurements performed with the HPDs worn in the closed and the open modes. Since REAT measurements are made at low sound levels, modeling LDNL HPD performance linearly based on open mode REAT measurements provided a conservative estimate of HPD protection, because it does not include the increased insertion loss that the LDNL HPD provides against higher pressure sounds.

Typically, LDNL HPDs are designed to allow low-pressure sounds to penetrate through a small resistive orifice. When low pressure differences are applied across the small orifice, the sound propagation resistance is linear, i.e. the sound transmission is proportional to the pressure difference. At low sound pressures, insertion loss is minimal. As the pressure difference increases, flow energy is increasingly dissipated in the increasingly turbulent flow through the orifice. The sound propagation resistance increases as the pressure difference increases. This is the level dependent nonlinear process that increases insertion losses as sound pressure increases to levels usually associated with impulsive noise.

Hearing protection needed by military personnel must offer insertion losses that are low enough to promote situational awareness and allow effective communication. However, these low insertion loss levels are too low to protect military personal against hearing damage caused by exposure to intense sounds produced by weapon fire and munitions. Effective hearing protection must provide low insertion losses against low pressure sounds and high insertion losses against high-pressure sounds. These are exactly the characteristics offered by LDNL HPDs.

Since LDNL HPDs were introduced, improved designs now offer much lower insertion losses for low pressure sounds and significantly greater insertion losses for higher pressure sounds. When we first modeled HPDs, we recognized the potential for LDNL hearing protector performance and we included electro-acoustic parameters that could model LDNL performance, but these parameters were not applied because values had not been determined. We were familiar with the analysis techniques needed to model nonlinear propagation because we had used these techniques to model sound propagation through the middle ear, which itself is nonlinear. At that time however, there were no standards and little data on which to empirically determine appropriate parameter values that would accurately model LDNL HPD performance.

Now, this situation is changing. While data standards for characterizing LDNL HPDs remain to be developed, we have a limited number of data sets that can be used to characterize the performance of some LDNL HPDs.

To begin evaluating these LDNL HPDs against the large range of impulsive pressures encountered by military personnel, we added new HPD parameter sets to the HPD descriptions accessed by AHAAH. These new parameter sets model the performance of LDNL HPDs for which we have sufficient data to support LDNL performance modeling. The Hearing Protector Module in the newly released version 2.1 of AHAAH includes these level-dependent electro-acoustic parameters and applies them when evaluating performance of LDNL HPD.

The Table 1 shows the REAT data for the linear representation of the Dual Ended Combat Arms Earplug in the closed mode and in the open mode.

Table 1. REAT data for the Dual Ended Combat Arms Earplug in the closed mode and in the open mode

Hearing Protector Type & Configuration Mode	COMBAT ARMS DOUBLE-ENDED CLOSED MODE REAT VALUES		COMBAT ARMS DOUBLE-ENDED OPEN MODE REAT VALUES	
REAT Data (Mean Values)	Octave Band (KHz)	Insertion Loss (dB)	Octave Band (KHz)	Insertion Loss (dB)
	0.125	-24	0.125	0
	0.25	-24	0.25	-1
	0.5	-25	0.5	-5
	1	-28	1	-17
	2	-30	2	-23
	4	-32	4	-21
	8	-43	8	-21
Data Source:	AFRL-RH-WP-TR-2009-0031		AFRL-RH-WP-TR-2009-0031	
Data Method:	ANSI 12.6-1997		ANSI 12.6-1997	

The REAT levels for the closed mode are much greater than the REAT attenuation levels for the open mode. When applied linearly, the open mode insertion losses do not increase regardless of how high the sound pressure becomes.

Table 2 shows the HPD linear model parameters for the Dual Ended Combat Arms Earplug in the closed mode and in the open mode (Fedele, Binseel, Kalb, & Price, 2013). It also shows the LDNL HPD model parameters, which are described in Fedele & Kalb (in publication).

Table 2: HPD parameters for the Dual Ended Combat Arms Earplug

Hearing Protector Type & Configuration Mode	DUAL ENDED COMBAT ARMS EARPLUG CLOSED MODE LINEAR	DUAL ENDED COMBAT ARMS EARPLUG OPEN MODE LINEAR	DUAL ENDED COMBAT ARMS EARPLUG OPEN MODE NON-LINEAR
Linear Electro-Acoustic Circuit Parameters	Electro-acoustic Circuit Values	Electro-acoustic Circuit Values	Electro-acoustic Circuit Values
Lcup	1.03E+01	1.03E+01	1.03E+01
Kcup	8.71E+07	1.00E+05	4.07E+07
Kskin	1.65E+10	2.50E+11	2.43E+10
Rskin	4.74E+06	2.03E+06	1.96E+06
Kcush	1.65E+09	2.50E+10	2.43E+09
Rcush	4.74E+05	2.03E+05	1.96E+05
Lleak	2.21E+08	1.01E-02	2.00E-02
Rleak	2.77E+08	3.18E+01	2.00E+04
Kmat	4.81E+09	6.94E+05	6.14E+09
Lmat	7.75E+00	2.01E-04	2.90E+00
Rmat	1.95E+05	1.81E+01	1.58E+05
Nonlinear Electro-Acoustic Circuit Parameters	Nonlinear Parameter Values	Nonlinear Parameter Values	Nonlinear Parameter Values
Kcush2	0.00E+00	0.00E+00	0.00E+00
Rcush2	0.00E+00	0.00E+00	0.00E+00
Kmat2	0.00E+00	0.00E+00	1.00E+02
Rmat2	0.00E+00	0.00E+00	1.00E+02
i_0	NA	NA	3.16E+06
NL_{Power}	NA	NA	2.00E+00

With the nonlinear parameters shown above for the Dual Ended Combat Arms Earplug Open Mode Nonlinear model, the low insertion losses for the open mode transition to the larger insertion losses for the closed mode, as impulsive sound pressure levels increase from 120 dBP to 190 dBP. Note that the nonlinear parameters for the linear, REAT-based models are all zero. As indicated, these parameters were included in the Hearing Protector Module included with version 2.0 of AHAAH, but they were initially all set to zero, resulting in only linear performance. [See Table B-3 in ARL-TR-6748] Even now, not all the potential nonlinear paths are used to characterize LDNL HPD performance. K_{cush2} and R_{cush2} (parameters that describe nonlinear cushion response) are not used in characterizing this LDNL HPD performance because the Dual Ended Combat Arms Earplug has no nonlinear cushion components.

When using AHAAH version 2.1, LDNL HPDs can be selected to model the hearing protection offered by these HPDs against impulsive waveforms of variable pressure amplitudes and time dependencies. Table B-1 in ARL-TR-6748 includes 11 default HPDs and lists typical applications. Hearing Protection designated as "default 1" and "default 9" are both based on the Combat Arms Earplug in its level dependent (LDNL) mode.

Version 2.1 of AHAAH with level-dependent parameters for the double-ended combat arms earplug is available for download at http://www.arl.army.mil/ahaah.

As data standards and HPD data sets that can describe LDNL HPD performance become more available, we will be able to include additional LDNL HPDs in the Hearing Protection Module accessed by AHAAH. We emphasize these additions make no changes to the AHAAH analysis process, but they allow AHAAH users to more accurately apply a wider selection of hearing protectors in analyzing auditory risk caused by exposure to impulsive sounds and, when they are added, these additions will be noted by AHAAH version number updates.