Army Research Laboratory

Using the Auditory Hazard Assessment Algorithm for Humans (AHAAH) Software, Beta Release W93e

by Mary S. Binseel, Joel T. Kalb, and G. Richard Price

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14. ABSTRACT
The Auditory Hazard Analysis Algorithm for Humans (AHAAH) calculates the risk to human hearing of impulse noises, such as gunfire or airbag deployment. It achieves this by modeling the effects of the sound pressure wave from the free field, through the middle ear, and into the inner ear. The output of the algorithm is the number of auditory risk units (ARUs) associated with exposure to the given impulse sound. ARUs predict hearing damage; values over 500 ARUs for a 24-h exposure are likely to produce permanent hearing loss. The algorithm is implemented in computer software. This report is a user's manual for the AHAAH software release W93e.

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1. Introduction

1.1 What Auditory Hazard Assessment Algorithm for Humans (AHAAH) Does

The AHAAH is an electro-acoustic model of the ear used to evaluate the hazard of impulse sounds to human hearing. The algorithm is implemented in computer software. It models the 95th percentile (most susceptible) human ear, and assumes sounds are traveling toward the side of the head (a worst-case condition). The model calculates the auditory hazard of intense sounds by modeling their effects from the free field, through the middle ear, and into the inner ear, where damage typically occurs. The model includes active middle ear muscle contractions, which can occur in response to the sound or in advance of the arrival of the sound. The output of the model is in auditory risk units (ARUs), which bear a physical relationship to calculated displacements in the inner ear and damage resulting from them. A total of 500 ARUs is the maximum allowable “dose” for occasional exposures within a 24-h period. Doses greater than 500 ARUs are predicted to produce permanent hearing loss. For daily or near daily occupational exposures, the limit should be reduced to 200 ARUs. AHAAH allows calculations for conditions when (a) no hearing protection, (b) a good hearing protection device (HPD) (an earplug or an earmuff), or (c) double hearing protection (plug and muff) are properly fitted and worn.

1.2 A Quick Overview

Digital pressure histories, recorded as specified in appendix A, must be imported into the model. During this process, the user provides the sampling frequency (determined by the digitizer at the time of recording) and edits the waveform to remove extraneous material and to calibrate it. When the edited waveform is saved, it acquires a header and an AHA extension.

To analyze a file with an AHA extension, the program is run and analysis options are chosen (single or double hearing protection and warned or unwarned middle ear muscle response). The AHAAH program provides numeric output in ARUs and creates a movie showing the action of the sound on the inner ear. An ASCII file could be a single impulse or it might consist of several impulses arranged as in a spreadsheet. For the typical case of a single impulse, if the default answers to the questions are accepted, the waveform will be read in and displayed on the bottom of the screen with a header at the top of the screen. If the file contains multiple impulses, you will be asked to identify which column you wish to import.

2. Preparing the AHAAH Model and the Impulse Waveform

This section discusses the steps required to set up the AHAAH software and prepare data files for analysis. A tutorial is included which will lead the user through the required steps. Tutorial steps are boxed and italicized. In general, the conventions for Windows* and mouse use are followed.

2.1 Contents of Compact Disk

The enclosed compact disk (CD) includes the following folders and files:

AHHAH Program Files [folder]
- AHAAH.exe – the AHAAH software program
- StandardSingle.txt – file required by the software for the single hearing protection analysis option
- StandardDouble.txt – file required by the software for the double hearing protection analysis option
- man.coe – file required by the software; contains coefficients for the algorithm parameters for humans
- EarModel.jpg – file required by the software to display the graphic of the AHAAH model

Data Files [folder]
- TestImpulse.txt – tutorial data in txt format
- TestImpulse.wav – tutorial data in wav format
- TestImpulse.aha – tutorial data in aha format, a format unique to AHAAH
- M16Rifle.wav – sample wav data file
- Howitzer.wav – sample wav data file

2.2 Preparing and Launching AHAAH

The AHAAH program may be run off the enclosed CD; however, it is recommended that you copy the contents to a hard drive, flash drive, or other storage device. Leave all of the program files in the same folder, as the program will look for these files in the folder in which it resides. The Data Files folder contents are needed for the tutorial and may be placed anywhere.

Double-click on the AHAAH.exe icon to launch the AHAAH software. A window with a graphic of the models opens.

2.3 Importing Files for Use

In order to be imported, edited, and analyzed by AHAAH, the data must have been collected in accordance with the provisions found in appendix A. The raw data files must consist of files stored in the Windows WAV format, or digitized pressure data stored in American Standard

*Windows is a trademark of Microsoft Corporation, Redmond, WA.

Code for Information Interchange (ASCII), with no text in the file. When importing a waveform, the program will open windows that allow you to browse folders and select the file you wish to import. Once a file has been selected, you will be asked questions about the file format.

Both types of files contain pressure histories which may not be calibrated with respect to amplitude. The raw data files typically do not contain calibration information, so when the data are collected it is imperative to collect information that can be used to calibrate the waveform. This could be either the peak pressure of the waveform, generally determined by use of a sound level meter; or calibration data gathered by the use of a calibration device, such as a pistonphone, applied to the microphone used in data collection. These two methods are referred to in AHAAH as “calibrating to a known peak pressure” and “calibrating to a known source,” respectively. If you use the “known source” method, you must determine the calibration factor before you start editing and analyzing your impulse data. See section 2.6.4.1 for information about determining the calibration factor. Note: you must open your calibration waveform file and obtain the calibration information before you open your impulse data file.

2.3.1 WAV Files

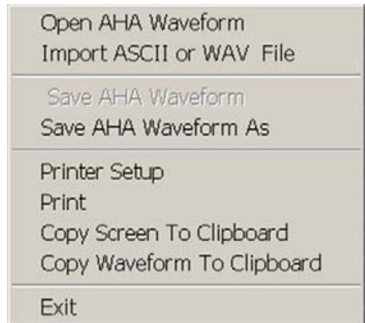
This file format is commonly used for recording music; thus, these are typically stereo files and contain a “right” and a “left” channel as well as a header. When you import a WAV file, you will be asked whether you wish to import the left channel. A “yes” answer imports the left channel and a “no” answer imports the right channel. The header includes, among other things, the sampling rate (the same for both channels), which the AHAAH software can read.

2.3.2 ASCII Files

Files stored in this format must not contain header information—just pressure data. You must know the sampling rate of the digitizer, which should be kept in a “readme” file that is maintained with the pressure data file.

An ASCII file could be a single impulse or it might consist of several impulses arranged as in a spreadsheet. For the typical case of a single impulse, if the default answers to the questions are accepted, the waveform will be read in and displayed on the bottom of the screen with a header at the top of the screen. If the file contains multiple impulses, you will be asked to identify which column to import.

When File is selected in the menu bar, the following menu drops down:



The **Copy** provisions in this menu allow the waveform and header or just the waveform to be copied to the clipboard for insertion in documents, slides, etc.

Tutorial goal: Import a waveform stored in ASCII format.

- *Select* File, *then* Import ASCII or WAV file.
- *Import the file* TestImpulse.txt, *which is in the folder* Data Files.
- *Select the* YES *button or hit your* ENTER *key when asked if the data are in a spreadsheet.*
- *The data are in a single column; therefore, select the* YES *button or hit your* ENTER *key to accept the 1 column default.*

After the user imports TestImpulse.txt, the window should appear as shown in figure 1.

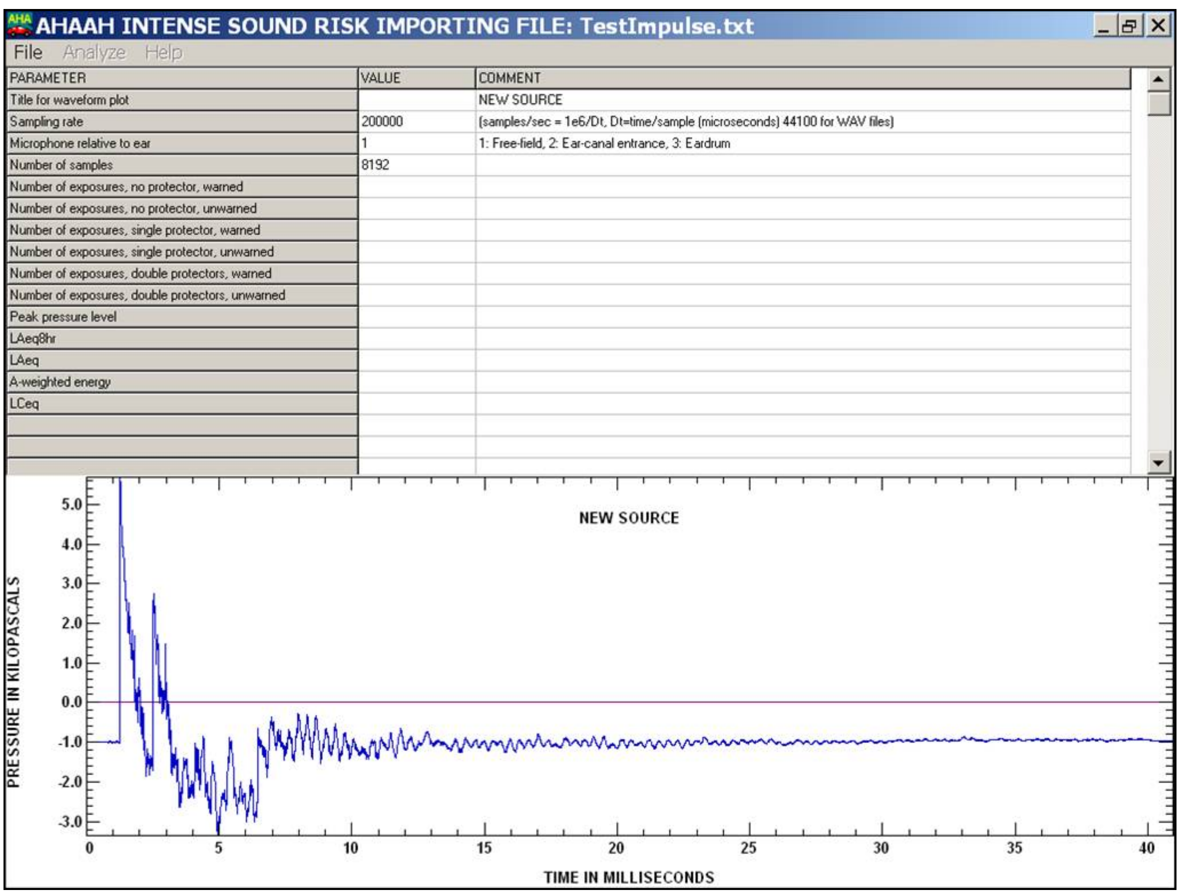


Figure 1. Screen view of imported waveform file in AHAAH.

Tutorial goal: Change the name of the waveform.

- *Highlight the text in the* Title for waveform plot *row and* COMMENT *column.*
- *Type* Sample Waveform.
- *Press the* Enter *key.*

Note that the name of the waveform has been changed on the waveform plot in the lower panel.

2.4 Setting the Sampling Rate

For WAV files, AHAAH should have read the sampling rate from the header in the file. For ASCII files, a default sampling rate is assigned by the model in order to display of the waveform. It is critical that the sampling rate be set to the actual rate at which the data were collected. You should have this rate for your own recordings; for TestImpulse, the rate is 50,000.

Tutorial goal: Change the sampling rate of the waveform.

- *Highlight the text in the* Sampling rate *row and* VALUE *column in the header area.*
- *Type* 50000.
- *Press the* Enter *key.*

The AHAAH window should now appear as shown in figure 2. Note the change in the x-axis scale (time).

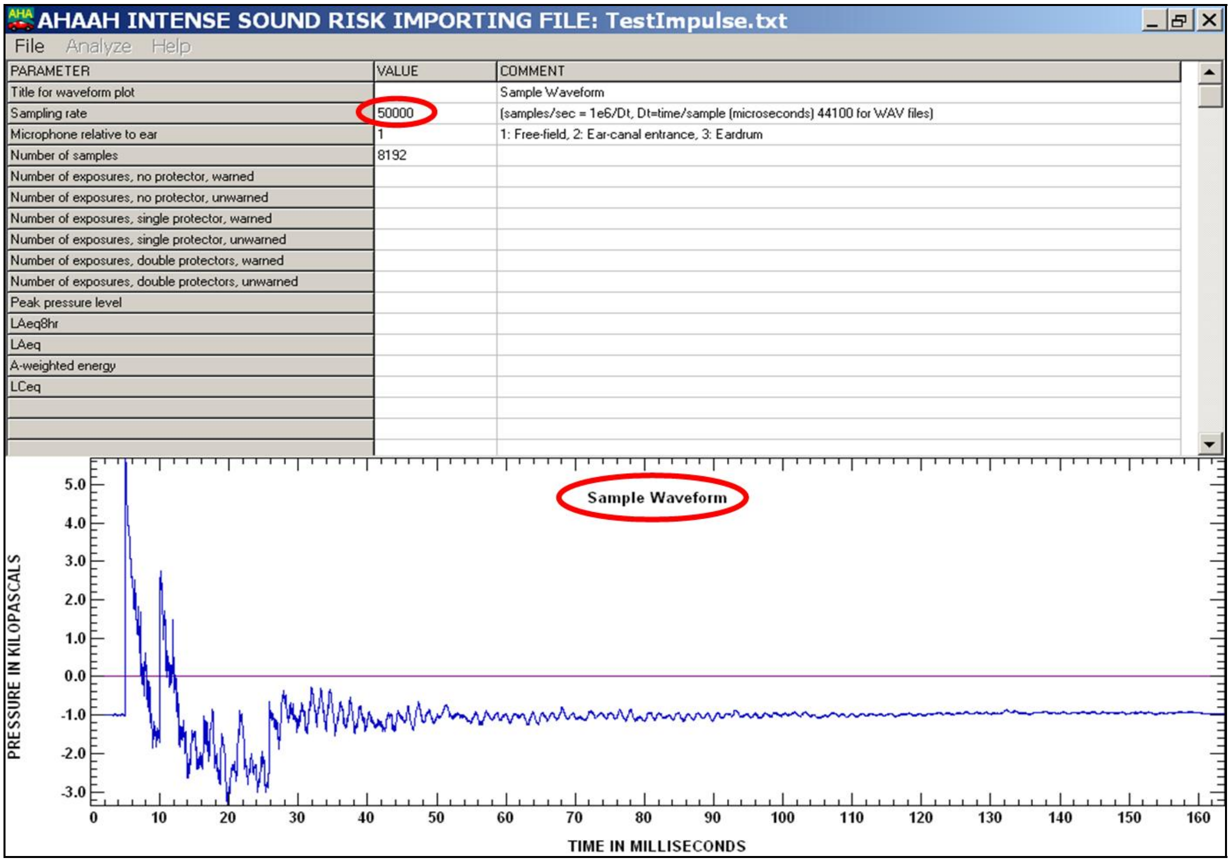


Figure 2. AHAAH screen view of sample waveform after changing the waveform name and setting the sampling rate (see circled areas).

2.5 Specifying Microphone Location

AHAAH allows the user flexibility in microphone location during data collection. There are three locations which are allowed: (1) in the free-field; (2) at the entrance to the ear canal; and (3) at the location of the eardrum. In order to perform its analyses, AHAAH must know at which location the recording was made. The default is free-field. You can change to another location by typing your choice (1, 2, or 3) in the **VALUE** column of the **Microphone relative to ear** row of the header. Your choices are enumerated in the **COMMENT** column.

· TestImpulse.txt *was recorded in the free-field, so the microphone location does not need to be changed from the default selection.*

2.6 Editing the Waveform

An accurate AHAAH analysis requires the waveform to be edited before the analysis is run. Because some editing functions assume that the waveform was already corrected in some way, it is important to follow the editing steps in the order in which they are presented in the pop-up editing menu, with the exception of the "Resample" function which, if needed, is performed first.

A right click anywhere below the menu bar within the AHAAH window opens the following menu:

Each of these functions is discussed in the following sections.

2.6.1 Resampling

Clicking on **Resample** allows the user to resample the waveform at a higher or lower frequency. Resampling at a lower frequency is a way of reducing the number of points in the waveform. This is useful if the digitization rate had been unnecessarily high at the time the data were recorded. Note that if the resampling rate is too low (below 40 kHz), important information may be lost and the hazard calculation may be spuriously low. Resampling at a higher rate increases the number of points but does not increase the amount of information in the waveform. If your data points are too close together for proper visual inspection, using this option may make editing the waveform easier because it will "spread out" the waveform plot.

· TestImpulse.txt *does not need to be resampled*.

2.6.2 Selecting the Appropriate Segment

The data file may include information from before and after the impulsive event(s) of interest (e.g., from when the recording device was turned on until an impulse event). **Select Segment** is used to discard these extraneous data. When **Select Segment** is chosen, two selector bars appear in the plot, which can be positioned to bracket the portion of the plot which is of interest. The bars can be "dragged" (by left clicking and holding as the bar is dragged) and "dropped" (by releasing the mouse button) at any location in the waveform. (The left selector bar is on the far left of the window and may not be visible; left clicking and holding then dragging on the left edge of the plot area will move the line and make it visible.) As the bars are moved, the **Number of Samples** entry in the header changes to indicate the size of the selection between the bars. When the **Done** button (which appears after **Select Segment** is chosen) is left clicked, the plot area is redrawn, displaying only the section selected. The non-selected portion of the waveform is discarded. This procedure can be repeated as often as necessary to select the segment of the waveform to be analyzed.

The waveform in TestImpulse.txt *includes only valid data points and may be left as is.*

2.6.3 Setting the Baseline

If the digitized waveform contains a DC offset that is not part of the true acoustic data (sometimes deliberately induced in recording to maximize the digitizer's dynamic range), it must be removed. When **Set Baseline** is clicked, an **Expand Selection** button and two selector bars appear on the waveform (again, the left selector bar may not be visible). The bars should be dragged and dropped so that they bracket the general area of the waveform that is believed to be at the level of the true acoustic baseline. The button **Expand Selection** should then be clicked. The area between the cursors expands to fill the screen and the bars reappear along with a **Select** button. The bars can be repositioned if desired to better identify the true acoustic baseline. When the **Select** button is clicked, the program takes the average pressure between the bars, subtracts it from the entire waveform, and replots the baseline-corrected waveform.

Tutorial goal: Remove the DC offset included in TestImpulse.txt.

- *Select* Set Baseline.
- *Drag and drop selector bars to bracket the portion of the waveform that includes the offset only (the far left side of the waveform).*
- Expand Selection.
- *If necessary, move the selector bars again to refine the selected area of offset*.
- Select *the portion of the waveform that includes the offset.*

The AHHAH window should now appear as shown in figure 3. Note the waveform has shifted up with respect to the y-axis (pressure).

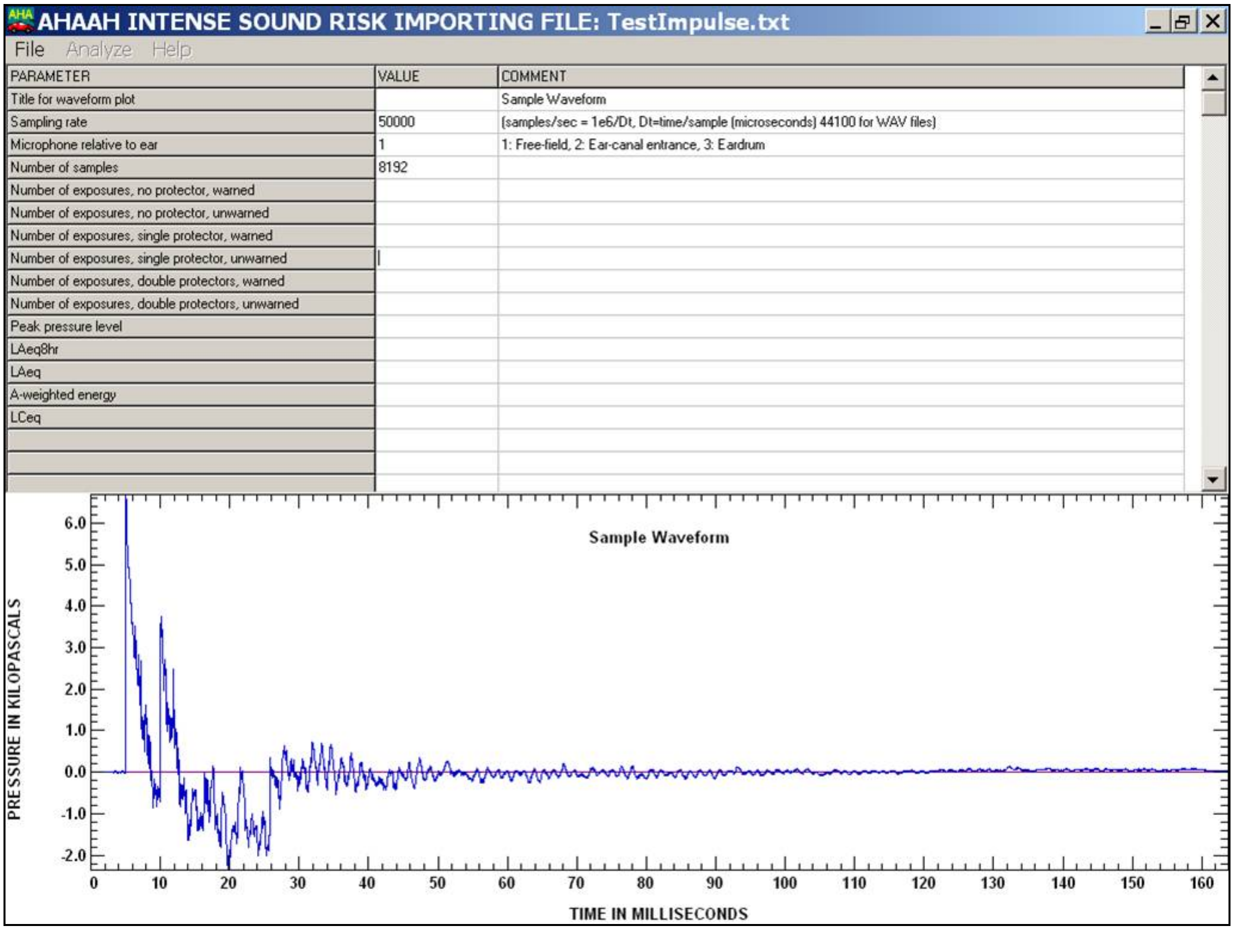


Figure 3. AHAAH screen view of sample waveform after removing the DC offset.

2.6.4 Calibration

Data values to be analyzed must be pressures in Pascals. If they are not, they must be adjusted to the correct values. There are two general approaches to calibrating the waveform: calibration to a known source; and calibration to a known peak pressure.

Before beginning calibration, note that the output of condenser microphones is inverted (positive pressure downward). The AHAAH model is sensitive to the polarity of the pressure, which means that any inverted waveform needs to be re-inverted for AHAAH to calculate the proper hazard. If your waveform is inverted, re-invert it at this time; see the end of section 2.6.4.1 for information regarding how to accomplish this.

Note that if the **Set Baseline** feature is to be used, it must be done before calibration because changing the baseline affects peak pressures.

2.6.4.1 Calibrating to a Known Source. To calibrate to a known source, at the time of measurement a calibrated acoustic source is applied to the measuring microphone and the output waveform recorded and stored as a digital file. Such sources typically produce a pure tone of 250 Hz (for pistonphones) or 1 kHz (for oscillator-driven calibrators). The root mean square (rms) acoustic levels produced by these calibrators commonly range from 94 to 124 dB. Given the recorded waveform and the known acoustic pressure of the source, it is possible to determine an overall calibration factor for the full system and apply it to the waveforms subsequently recorded with it.

The calibration waveform should be imported via the **Import ASCII** or **WAV file** menu option. A small section typical of the waveform should be selected (~100 ms of data). A right click anywhere below the menu bar within the AHAAH window opens a pop-up menu. Select **Statistics**, which puts two bars on the selected section of the calibration waveform. Move the bars so that most of the waveform is selected and the statistics applicable to the section will appear in the header. The entry for C-weighted energy level is the apparent rms level in the waveform (the algorithm treats the numbers as though they were pressures in Pascals). This procedure works for both 250-Hz and 1-kHz calibration tones because C-weighting is essentially flat from 50 Hz to 10 kHz.

If the calculated level differs from the ideal calibration level, the data in the measured waveforms will have to be corrected to be represented properly. Specifically, the C-weighted level for the calibration waveform should be subtracted from the nominal level of the calibrator. The data waveforms then need to be corrected by that number of decibels. Thus, a 114-dB calibrator whose output appeared to be 94 dB would require that levels in the data be adjusted upward by 20 dB. This must be converted to a multiplication factor for correcting the pressure in Pascals. Note that decibels are a logarithmic function, expressing, in this case, the ratio of the desired calibrated pressure to the recorded pressure, i.e.,

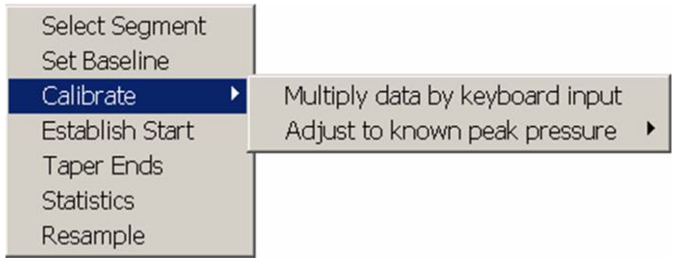
$$dB = 20 \log_{10} (P_{cal}/P_{rec}) \ . \quad (1)$$

Therefore, the multiplication factor P_{cal}/P_{rec} can be calculated from

$$(P_{cal}/P_{rec}) = \text{antilog}_{10}(dB/20) \ . \quad (2)$$

Following the example, for a desired increase of 20 dB, the multiplication factor is 10. Similarly, a 0.5 factor would be a change of –6 dB (a decrease of 6 dB).

To apply the multiplication factor, again right click anywhere below the menu bar and select **Calibrate**, then **Multiply data by keyboard input**.



After selection, a window will open where a numeric multiplier may be entered. The multiplier range is –1,000,000.000 to 1,000,000.000. The multiplier entered is applied when **OK** is clicked. Note that a negative multiplier inverts the waveform (a useful feature); multiplying by –1 flips the waveform over without changing its magnitude.

2.6.4.2 Calibrating to a Known Peak Pressure. For this method, at the time of measurement a calibrated instrument, such as a sound level meter, is used to measure the peak pressure level of the test waveform at the same location as the recording microphone. This datum can then be used to adjust the numbers in the digitized test waveforms so that the true peak pressure appears in the data.

If **Calibrate**, then **Adjust to known peak pressure** is selected, a submenu opens that allows the selection of one of nine sets of units (atmospheres, bars, peak pressure level in decibels, dynes per square centimeter, millibars or hectoPascals, kiloPascals, or pounds per square inch). Select the units to be used and enter the appropriate level in the window that opens. When **OK** is clicked, the peak positive pressure in the waveform will be adjusted to the level entered. If the peak was negative, invert the waveform first, then adjust the peak level, and re-invert it.

- *In the case of the Test impulse.txt file, measurements are already in Pascals and can be left without adjustment.*

2.6.5 Establishing the Analytical Starting Point

Before this editing function is run, it is important that the ***Sampling Rate*** *(in the header) be set correctly; otherwise, the* ***Start*** *will be based on an incorrect estimate of timing. The user must also have calibrated the waveform before setting the start time because establishing the start involves an estimate of the stimulus intensity.*

Middle ear muscle contractions reduce the energy entering the ear by stiffening the annular ligament in the middle ear, thereby protecting the cochlea. AHAAH includes the effect of middle ear muscle contractions in its calculations. The **Establish Start** function tells the model where to trigger these middle ear muscle contractions. The AHAAH default for these contractions is the point where the acoustic event reaches 134 dB. Most users should use this default setting. However, for advanced users, there may be waveforms for which you wish to change when the middle ear contractions are triggered. For example, there may be a smaller impulse leading the large impulse of interest which could trigger the contraction.

2.6.5.1 Using Establish Start. When **Establish Start** is clicked, the program expands the waveform at the beginning of the file, places the selector bar at the likely trigger point (the first data point at 134 dB or higher) and provides a **Done** button to confirm the start location.

The bar can be moved by dragging, and as it moves, the **Establish start level** entry in the header changes to reflect the sound pressure level at the cursor. When the desired bar placement is achieved, click on **Done**.

NOTE: AHAAH analyzes the waveform starting at 5 ms before the established start. If there are not 5 ms of data before the start, AHAAH lengthens the waveform so that there is a 5 ms interval in advance of the bar location by adding data at 0 Pa.

Tutorial goal: View AHAAH's determination of the correct start point of the TestImpulse.txt impulse.
In the impulse in TestImpulse.txt*, the start of the impulse is clearly the nearly instantaneous rise to the peak pressure. AHAAH's calculated start point is acceptable.*

- *Select* Establish Start.
- *Note the location of the start cursor bar in the plot and the sound pressure level (in decibels) at this point (this information is in the header section)—about 159 dB, which is the first data point ≥134 dB.*
- *Select* Done.

2.6.6 Tapering the Ends

Discontinuities may exist in the original data file (e.g., a discontinuity at the end of a data file when a microphone is turned off) or may have been created during the editing process (e.g., discontinuities at the beginning and end of the waveform when **Select Segment** was performed). AHAAH interprets all points on the waveform as valid data, including any discontinuities at the start or end of the stored waveform. Therefore, the waveform must be "windowed" to eliminate these discontinuities. Left clicking on **Taper Ends** puts two selector bars on the waveform along with a **Done** button. The bars should be placed just inside any discontinuity. When the **Done** button is clicked, the waveform outside the bars is tapered off by a cosine function. Leave as much of the waveform as possible inside the cursors, consistent with a tapering of the acoustic data. For some impulses, the parts of the waveform that look insignificant to the eye may nevertheless contain oscillations damaging to the ear.

Tutorial goal: Taper the ends of TestImpulse.txt to eliminate discontinuities.
In order to save as much data as possible, taper just the very last points of the impulse data.

- *Select* Taper Ends.
- *Move the selector bars very near the ends of the waveform.*
- *Select* Done.

The AHAAH window should now appear as shown in figure 4.

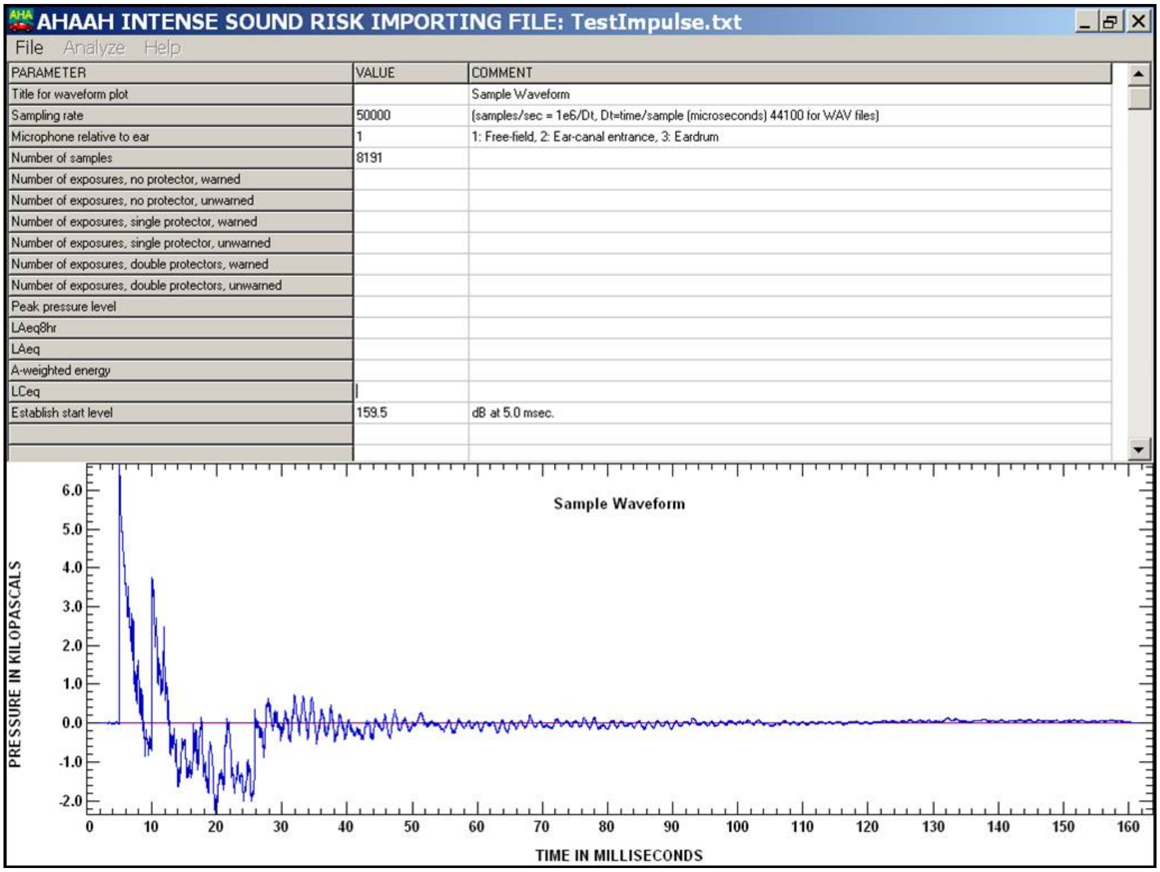


Figure 4. AHAAH screen view of sample waveform after completing waveform editing.

Tutorial review
The specific editing steps that should have been taken are

1) In the header, set the sampling rate to 50,000 Hz.
2) Correct the baseline to remove the DC offset
3) Establish the start at the leading edge of impulse.
4) Taper the extreme right and left ends of the waveform, leaving as much of the waveform for analysis as possible.

2.6.7 Saving the Edited Data File as an AHA File

When all of the waveform editing is completed, the resulting waveform must be saved as an AHA file. The resulting AHA file will be used for analyses. It is not good practice to perform analyses on the modified-but-unsaved waveform.

Select **File**, then **Save AHA Waveform As.** The file may have any Windows-legal name and is automatically given the AHA extension when it is saved. For mathematical considerations, the waveform is also expanded in length to a size that is a power of 2 (if it is not already a power of 2). It may be stored in any directory you choose and may be opened for analysis when you click on **File,** then **Open AHA Waveform.**

· *The edited waveform has already been saved as* TestImpulse.aha.

2.6.8 Other Sample Files

The **Data Files** included with this standard includes two WAV files not discussed so far: **Howitzer** and **M16Rifle**. They are included for practice in working with WAV files and with calibrating to a known source. Remember that AHAAH reads sampling rate from WAV files, so you do not have to enter it.

The left channel of the **Howitzer** file contains a calibration signal (250 Hz at 124 dB rms). The C-weighted level should be 149.8 dB. The actual calibration level was 124 dB; therefore, the data in the measured waveforms would need to be reduced by 25.8 dB (124–149.8 = –25.8 dB), for a multiplier of 0.05 (see section 2.6.4.1). The right channel contains low-level digitizer noise, in which one can easily see the “stepped” waveform that results at the digitizer’s limits at its low end. This recording contains no usable data.

In **M16Rifle**, both channels contain data from a single firing of an M16 rifle. The microphones were approximately co-located at the position of a shooter’s ear. The left channel was recorded underneath an earmuff-style hearing protector which had been placed on a mannequin; therefore, the microphone placement you need to specify in the AHAAH header is **3**. The right channel was recorded just outside the earmuff; its free-field position is entered as **1**. If you had recorded this file, you would have had to determine the peak pressure for both channels at the time of recording or have recorded a calibration signal as in the previous case; however, for this example, assume the known peak pressure of the right channel is 165 dB and that of the left is 140 dB.

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3. Analyzing Waveforms for Auditory Risk Units

The waveform analysis tutorial will use the file TestImpulse.aha, which is stored in the Data Files folder provided with the AHAAH model.

Tutorial goal: Open the AHA file needed for analysis.

- *Select* File, *then* Open AHAAH Waveform.
- *Navigate to and open* TestImpulse.aha.

3.1 Statistics

Right-clicking anywhere in the lower panel of the AHAAH window and selecting **Statistics** from the pop-up menu puts two selector bars on the screen along with a **Done** button. When the bars are moved, the values of five statistics for the segment of the waveform selected (the part of the waveform between the bars) are displayed in the header. These statistics are:

- Peak pressure level: both the level and the time at which it occurs are displayed
- LAeq8hr: equivalent A-weighted 8-h exposure level

- LAeq: equivalent A-weighted exposure level
- A-weighted energy: energy flow in Joules per square meter
- LCeq: equivalent C-weighted exposure level (this is the measurement used in calculating the calibration multiplier if you calibrate to a known source)

Viewing statistics does not change the waveform.

Tutorial goal: Observe the Statistics function.
Move the selector bars and note the changes in the header section.

3.2 Analyzing the Waveform

Once the AHA waveform has been opened, a click on **Analyze** on the tool bar provides six analytical choices:

3.2.1 Selecting the Warning State

The middle ear muscles can contract reflexively to intense sounds or, because they are connected to the central nervous system, can contract for other reasons–in anticipation of firing a round, for example. AHAAH permits hazard analyses for both of these conditions.

3.2.1.1 Muscles Contracted Prior to the Impulse. The middle ear muscles may already be contracted when the impulse(s) being analyzed arrive. This can happen when there is some warning that an impulsive event is about to occur; for example, when Soldiers fire their own weapons. It can also occur when there is a precursor acoustic event not included in the waveform, like another impulse or high background noise. For these cases, a **Warned** condition should be selected. It is good practice to run an **Unwarned** state also, as a measure of the sensitivity of the results to the muscle state and to obtain a more conservative estimate of hazard.

3.2.1.2 Muscles Contract in Response to the Impulse. If you can assume that the person exposed was unaware that the impulse was coming, then an **Unwarned** condition should be selected. AHAAH assumes that middle ear muscle contractions are triggered when the acoustic event reaches 134 dB. At this point, a reflex latency of 9.2 ms begins in the model. After 9.2 ms, AHAAH increases the modeled stiffness of the annular ligament element by a time constant of 11.9 ms until complete contraction (maximum stiffness) occurs, at which point complete contraction is held until the end of the analysis.

3.2.2 Selecting Hearing Protection

Hearing protection options are **No protector**, **Single protector**, and **Double protectors**. A single protector is either earplugs or earmuffs; double protectors are both worn together. The worst-case scenario for hazard is no protection; the best is double protection. By examining the results of all three options, and considering the operational environment in which you expect the exposure to occur, you can reach conclusions about the safety of the exposure. Operational considerations include the likelihood of multiple exposures to the analyzed noise and/or other noise, the hearing protection typically worn in the scenario, and the feasibility of wearing single or double hearing protection.

Tutorial goal: Analyze the hazard of the TestImpulse.aha impulse.

· *Select* **No protector, Warned** *from the* **Analyze** *drop-down menu. The results of the analysis, shown in the header, should be approximately 260 ARUs.*

· *Select* **No protector, Unwarned** *from the* **Analyze** *drop-down menu. The results of the analysis, shown in the header, should be approximately 800 ARUs.*

(NOTE: The number of ARUs may vary slightly in your files, depending on the specific editing selections made.)

The plot which results from the **No protector**, **Unwarned** analysis is shown in figure 5. The cyan line shows the progression of the contraction of the middle ear muscles, from 0% to 100%.

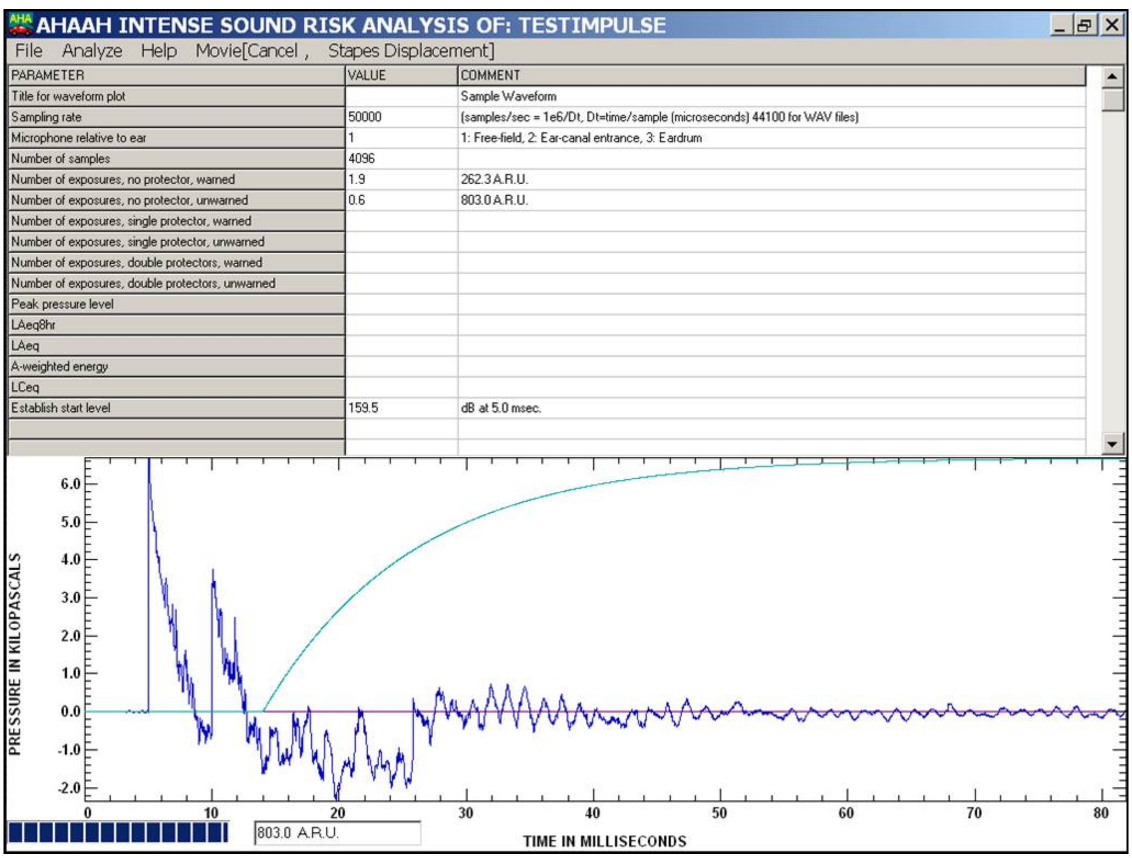

Figure 5. AHAAH screen view of sample waveform after **(No protector, Unwarned)** analysis.

3.3 Considerations in the Use and Interpretation of the Results

3.3.1 ARUs

The output of the program is Auditory Risk Units (ARUs), which have a specific physical definition inside the cochlea. The calculation is done at 23 evenly spaced locations along the basilar membrane, and the location with the largest value is reported. This value relates to change in hearing sensitivity. A dose of 500 ARUs is barely safe, meaning that there may be temporary shifts in hearing sensitivity of up to 25 dB, but recovery should occur within 24 h and no permanent hearing loss is expected from the exposure. A dose of 200 ARUs would be more reasonable as an occupational dose limit where daily or near daily exposures could occur. If multiple exposures approaching tolerable limits are likely, monitoring audiometry at frequent intervals is strongly recommended.

3.3.2 Multiple Exposures

The ARUs from separate impulses should be summed to arrive at the total dose within a 24-h period. One large impulse with 400 ARUs is equivalent to four impulses with 100 ARUs or 100 impulses with four ARUs, and so forth.

3.3.3 Proportion of the Population Protected

The program predicts auditory hazard for the 95th percentile ear (most susceptible ear).

3.3.4 Hearing Protectors

The attenuations assumed for hearing protectors appear in table 1. The attenuation values are intended to be typical of those achievable in the field by properly trained personnel using commonly available hearing protection devices. The values are based on the mean measured attenuation of multiple hearing protection devices, minus 1 standard deviation.

Table 1. Attenuation of hearing protection devices (HPDs) assumed in the standard.

Frequency (Hz)	Single HPD Attenuation	Double HPD Attenuation
125	13.6	24.1
250	14.7	21.7
500	16.4	28.4
1000	18.3	29.3
2000	26.3	34.3
4000	32.6	42.6
8000	31.3	39.8

4. The Movie: An Interpretive Tool

In calculating the effect of an impulse on the ear, the model calculates the behavior of the basilar membrane at 23 locations during the impulse duration. By reassembling this information and playing it back sequentially, it is possible to create a “movie” of the effect of the impulse. By comparing the movements of the basilar membrane to the instantaneous acoustic events, you can gain insight into what parts of the waveform are responsible for the accumulated hazard.

(Note: the movie that will be shown is for the <u>most recent</u> analysis run [e.g., No protector, Unwarned].)

4.1 Viewing the Movie

Once the hazard has been calculated, a new menu bar appears:

The selection of **Stapes Displacement** will create a plot showing the movement of the stapes during the acoustic event and will show the progression of the contraction of the middle ear muscles.

Tutorial goal: Plot the stapes displacement for the current analysis (No protector, Unwarned).
· *Click on* Stapes Displacement *within the* Movie *selections and the new screen shown in figure 6 appears*.

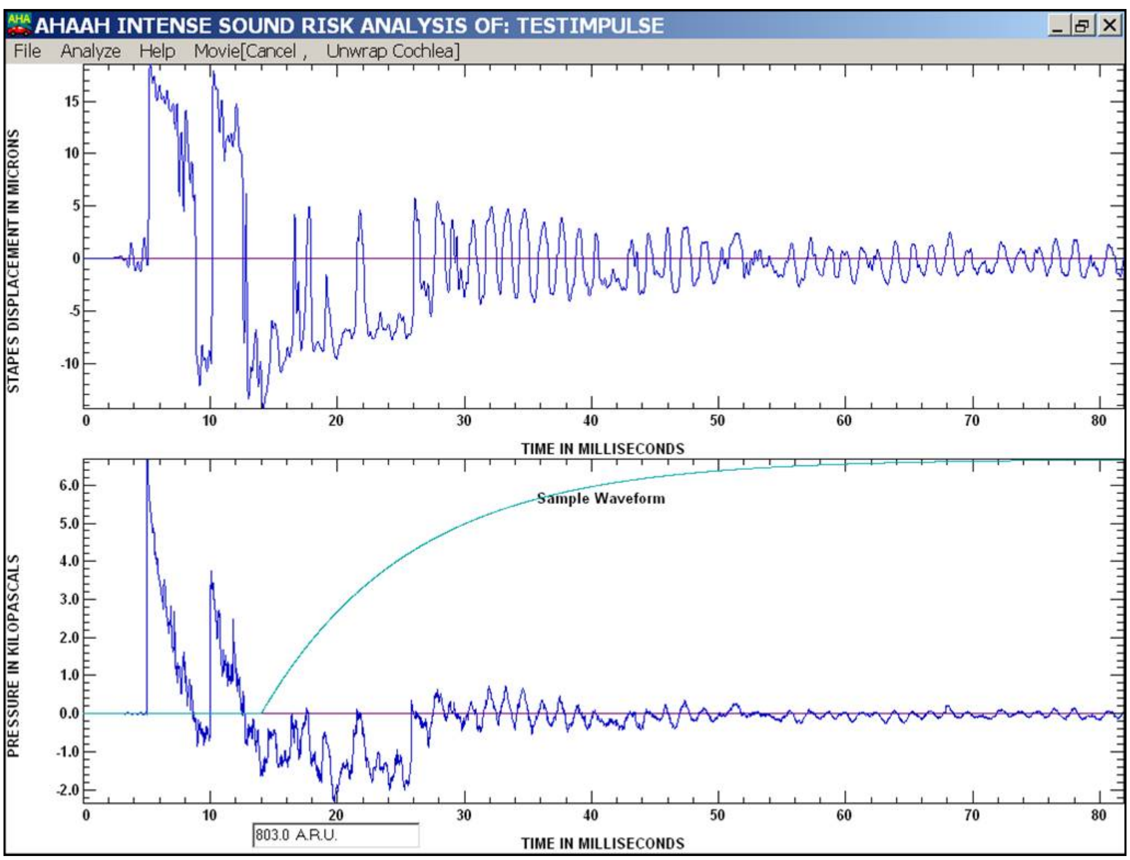

Figure 6. Stapes displacement screen (**No protector, Unwarned**) for TestImpulse.

The top plot shows the predicted stapes displacement during the impulse. The lower plot is the waveform just analyzed with the middle ear muscle contraction curve superimposed on it in cyan. (The contraction curve goes from zero to 100% effect.)

After stapes displacement is calculated, a new menu bar appears:

Tutorial goal: Prepare to view the movie
· *Click on* **Unwrap Cochlea**. *The screen now appears as shown in figure 7.*

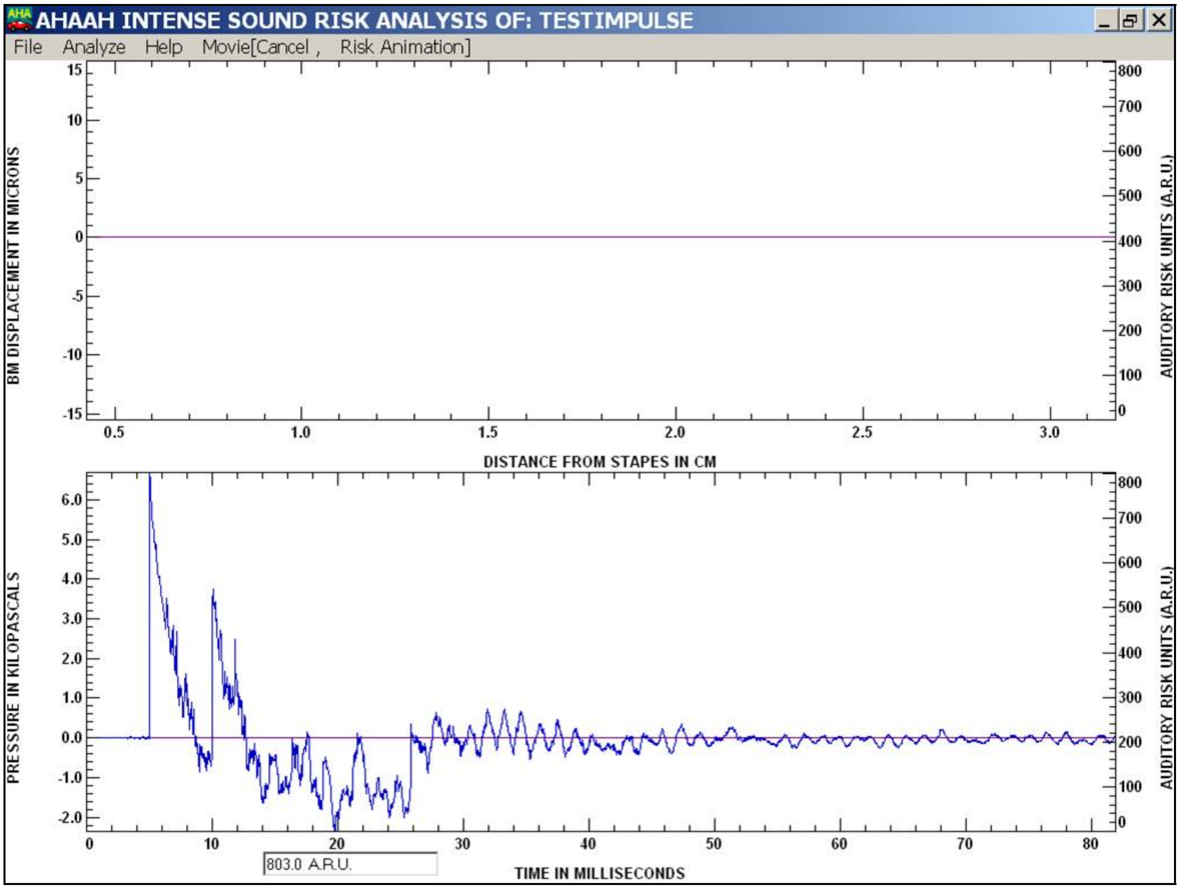

Figure 7. Unwrapped cochlea screen (**No protector, Unwarned**) for TestImpulse.

The top plot has become the un-rolled cochlea, basal end to the left, apex to the right. The line in the middle is the basilar membrane, with the scala vestibuli (driven by the stapes) above and the scala tympani below. The menu bar now contains a new option:

Tutorial goal: View the movie.
- *Click on* Risk Animation.

In the lower pane, the plot of the waveform changes color (from blue to green) as the analysis progresses through the pressure history. Also, as the analysis progresses, a new line (in red) is created which represents the summed risk at that point in the waveform. A sharp rise in this line indicates that risk has accumulated rapidly at that point. This line also is scaled to end at the top of the panel, which represents reaching 100% of the total calculated risk, independent of the magnitude of the risk.

In the upper plot panel, the green line is a plot of the instantaneous deflection of the basilar membrane, with the distance from the stapes increasing from left to right, as shown on the scale at the bottom. The outer blue lines represent the envelope of the history of basilar membrane movement from the beginning of the analysis to that point in time. In other words, all movements of the basilar membrane to this point in time can be enclosed by the blue lines. The deflection magnitude scale is on the left. The red line, which grows during the analysis, is the accumulated risk in ARUs mapped against where the risk has occurred on the basilar membrane. As in other graphs of the risk, this line is scaled so that the top of the plot is 100% of the accumulated risk, regardless of the magnitude of the risk. The ARU scale is on the right.

4.2 Interpreting the Movie: An Example

Figure 8 is a snapshot of the TestImpulse movie.

The total number of ARUs calculated for this exposure is 803. This is reflected in three places: in the ARU window near the bottom of the lower pane, by the maximum value of the right side scale of the lower pane, and by the maximum value of the right side scale of the upper pane. The ARUs at this moment are about 640, shown by the red lines in both panes and read on the right scales. In the top pane, the physical location on the basilar membrane at which this level of hazard (640 ARUs) is being experienced is about 1.3 cm in from the stapes, read on the bottom scale. Note that the overall risk reported in the AHAAH analysis is the maximum risk experienced at any point along the basilar membrane.

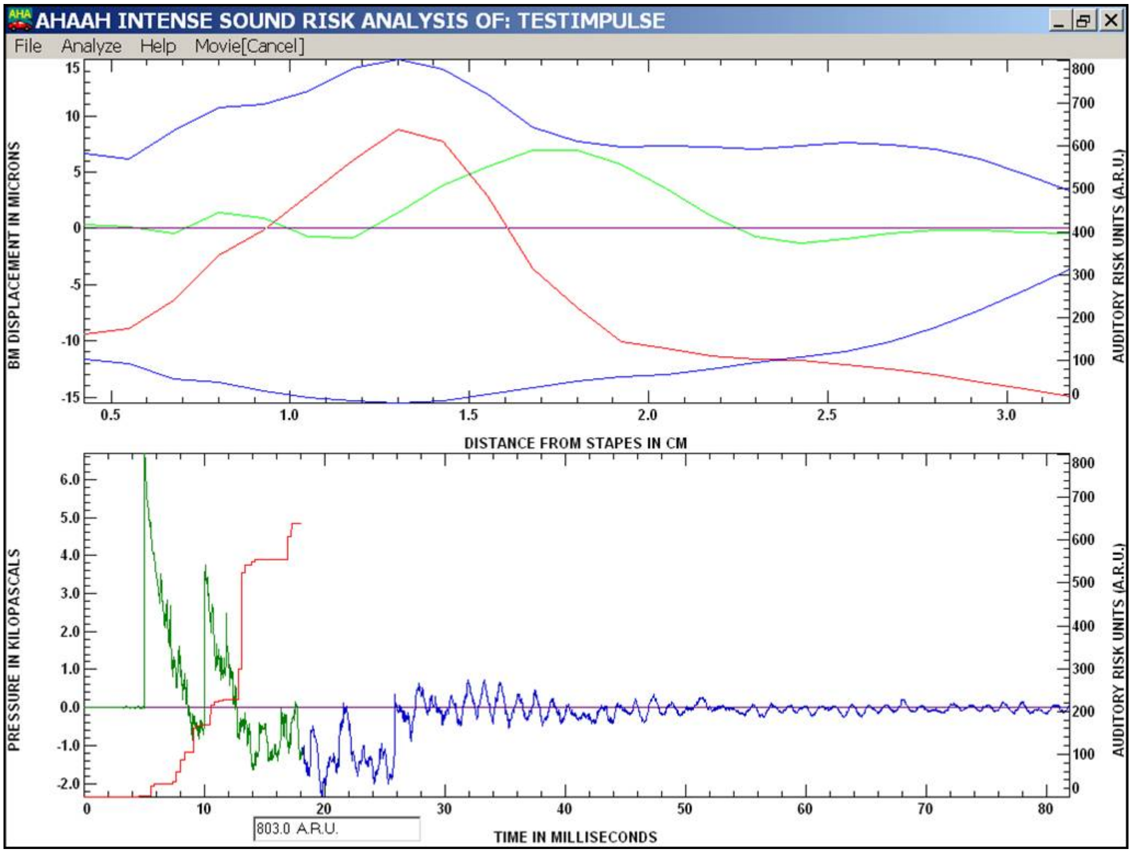

Figure 8. Movie of TestImpulse paused.

The analysis is currently at about 18 ms into the waveform, shown by the extent of the waveform which has changed from blue to green in the bottom pane, with the time scale along the bottom of the lower pane. In the top pane, at about 1.3 cm from the stapes (bottom scale), the basilar membrane has already reached the maximum deflection in both the direction of the scala vestibuli and the scala tympani that it will experience during the analysis (the blue lines at this distance have already reached the top and bottom of the total movement scale). In the top pane, the current instantaneous deflection of the basilar membrane is at a maximum at about 1.7 cm from the stapes (bottom scale) and is deflected about 7 µm in the direction of the scala vestibuli (left scale).

In the bottom pane, note that when the first positive peak passed at about 8 ms into the analysis, the hazard curve in the bottom panel had reached only about one-fifth of the total number of ARUs that will accumulate. This first peak contains about half of the total energy of the impulsive event, and it is this first peak upon which traditional analysis has tended to focus. However, the hazard at this point is manageable, and from an engineering standpoint, focusing on making the remaining part of the waveform safer would be good idea. The hazard accumulation line in the bottom panel further shows that for this particular impulse, about half the dose occurs when the second peak returns to atmospheric pressure. This feature of the model provides a powerful tool for engineering insight.

4.3 Keyboard Movie Controls

Certain keys on your keyboard can control the action of the movie. These keys are:

"Enter"	Freezes the animation so that you may examine the instantaneous plot in more detail; press again to resume the animation
Up arrow	Increases animation speed (repeat to increase speed more)
Down arrow	Slows animation speed (repeat to decrease speed more)
"Home"	Restarts animation from beginning

Once the movie has reached completion, in order to see it again you must reload the waveform, analyze the risk, and start the animation again.

The **Movie [cancel]** selection returns you to the analysis window.

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5. Software Output

After a waveform has been analyzed for risk, a new file is written in the Data Files folder (or whatever folder the waveform being analyzed came from) with a RSK extension. It includes a chart, overwritten during each analysis of a waveform of the same name,* which contains the numeric data for the risk calculation. These RSK files are tab-delimited ASCII files which may be opened with a spreadsheet or word processor program of your choice. Table 2 is the output of the TestImpulse.aha analysis, opened with Excel. The risk analysis program always reports the highest value seen, regardless of location.

*You must rename the file to save the results for a particular analysis.

Table 2. Example of AHAAH hazard calculation output.

BIndex[a]	Freq (kHz)	Risk (ARU)	Distance (cm)
1	11.76	20.49717	0.425
2	10.06	24.43384	0.550
3	8.60	31.96293	0.675
4	7.36	40.30924	0.800
5	6.29	55.17605	0.925
6	5.38	66.47134	1.050
7	4.60	102.24000	1.175
8	3.94	97.43627	1.300
9	3.37	83.95955	1.425
10	2.88	77.44102	1.550
11	2.46	94.28170	1.675
12	2.11	102.10875	1.800
13	1.80	88.55192	1.925
14	1.54	58.23620	2.050
15	1.32	33.66449	2.175
16	1.13	18.04959	2.300
17	0.97	10.80725	2.425
18	0.83	7.10492	2.550
19	0.71	4.54934	2.675
20	0.60	2.82806	2.800
21	0.52	1.31767	2.925
22	0.44	0.72073	3.050
23	0.38	0.33389	3.175

[a]In which BIndex is the number of the site along the basilar membrane; freq (Hz) is the ideal tuning for that site; risk (ARU) is the risk associated with that site; distance (cm) is the distance along the basilar membrane from the basal end.

6. For Further Information

There are numerous resources to learn more about the theory, development, and validation of the AHAAH model. Appendix B is a chronologically organized bibliography of publications and presentations on these topics. You may also visit the AHAAH Web pages on the U.S. Army Research Laboratory (ARL) Web site. Go to www.arl.army.mil and use the search engine or site map to find the AHAAH pages. As of the date of publication of this report, the pages were under the Human Research and Engineering Directorate organizational section of the ARL Web site.

7. Conclusion

The AHAAH algorithm, as implemented in the accompanying software, is a valuable tool for estimating the auditory hazard of impulsive acoustic events. It yields more realistic results than previous methodologies, providing a more accurate estimate of events such as the allowable number of rounds that can be fired in training and firing scenarios (such as firing from within enclosed spaces). By using the movie, which animates the effect of the impulsive event, weapons developers can determine where in the waveform damage accrues and where mitigation could most critically impact the results of the analysis.

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Appendix A. Waveform Recording Specification

A.1 Instrumentation

A.1.1 Instrument specifications

A.1.1.1 Transducers

a. For measurements above 40 kPa (186 dB), pointed or disc-shaped piezoelectric or piezoresistive probes with good aerodynamic characteristics shall be used.

b. For measurements below 40 kPa (186 dB), piezoelectric or piezoresistive probes having a blunt cylinder shape may be used.

c. For measurements below 7 kPa (171 dB), condenser microphones operating at standard 200v polarization voltage may be used. If the polarization voltage is reduced to 28v, the limit for use of the condenser microphone can be raised to 186 dB.

A.1.1.1.1 Undamped Resonance. There shall be no undamped resonance ($\Delta L > 5$dB) at frequencies below 100 kHz.

A.1.1.1.2 Low Frequency Response. The low frequency response of the transducer shall be sufficient to capture the lowest frequencies present in the signal. In enclosures, this may require a low frequency cut-off of 0.5 Hz.

A.1.1.1.3 Non-linearity. Total harmonic distortion shall be not greater than 3% of full-scale output.

A.1.1.1.4. Sensor Surfaces and Holders. Diameters of sensor surfaces shall be not more than 6.4 mm. Transducer holders should be small and minimize flow interference over the sensor surface.

A.1.1.1.5 Rise-time. Rise time capability shall be less than 1/20 of the measured A-duration of the impulse (duration of largest positive pressure) and not more than 20 µs. Cables causing an increase in measured rise time shall not be used.

A.1.1.1.6 Acceleration Sensitivity. Acceleration sensitivity of the transducer shall be less than 0.014 kPa/g in the axial direction and less than 0.069 kPa/g in the transverse direction.

A.1.1.1.7 Temperature Effects.

A.1.1.1.7.1 Selection. Transducers shall be chosen to minimize the effects of temperature under the expected recording conditions. Output shall be corrected from temperature vs. sensitivity curves for the individual transducer.

A.1.1.1.7.2 Protection. If necessary, transducers should be protected from flash and thermal effects by smoothly covering the sensing surface with a layer of black vinyl electrical tape plus a layer of silver tape, or equivalent, which does not modify the sensitivity or frequency response of the transducer.

A.1.1.1.8 Shock, Vibration, and Ground Path Isolation. Transducers shall be isolated from any accelerating surfaces to prevent acceleration-induced artifacts. Cables should be protected from shock waves by taping them to the stand in a location that minimizes exposure to shock waves. They should be positioned in a direction away from the propagation of the shock wave. All connectors should be electrically isolated from the stand and other grounded objects to prevent multiple ground paths.

A.1.1.1.9 Wind Screen. A microphone windscreen may be used provided that its effect is less than 1 dB under zero wind velocity conditions for the noise source being measured.

A.1.1.2 Recording Systems

A.1.1.2.1 Signal-to-Noise Ratio. The complete data acquisition system shall provide a minimum of 80 dB signal-to-noise ratio.

A.1.1.2.2 Frequency Response. The frequency response of the recording system must extend from 0.5 Hz to 20 kHz (±1 dB).

A.1.1.2.3 Digital Recording

a. Sampling rate shall be a minimum of 44.1 kHz.

b. Anti-aliasing filters shall be used.

c. Digitizers shall have a resolution of 16 bits or greater.

A.1.1.2.4 Data storage conventions.

a. Pressures shall be stored in units of Pascals or sufficient information shall be provided to allow conversion to Pascals.

b. Pressures shall be stored

    a. in ASCII characters, with no header or

    b. as WAV files

c. The sampling frequency must be kept with the raw data, in a “readme” file if necessary.

d. Individual raw data waveform files should be no larger than 16.6 MB.

A.1.2 Calibration

A.1.2.1 General

Calibration procedures, which include consideration for the influence of transducers, cables, amplifiers, recorders, and other instrumentation, shall be accomplished at least daily.

A.1.2.2 Calibration Method

Transducers shall be calibrated in a manner consistent with their time constant. Methods may employ sinusoidal pressure generators, pulse calibrators, dead weight calibrators, or shock tubes.

A.1.2.3 Electrical Calibration

Electrical calibration of all instrumentation following the transducer is acceptable for field use, provided one of the aforementioned calibrations is accomplished on the transducer immediately before and after field use.

A.2 Measurement Procedure

A.2.1 Single-Impulse Systems

The pressure history of the impulse noise shall be obtained by producing one impulse at a time.

A.2.2 Repetitive Systems

A pressure history of the full range of noises produced of the system shall be recorded, e.g. a full burst.

A.2.3 Multicharge Systems

For systems with various charges (e.g., separately loaded artillery ammunition), all possible charges shall be measured.

A.2.4 Weapon Position

Weapons shall be tested in all positions and in the system locations from which they are normally fired. Standing position for shoulder-fired and hand-held weapons is defined as being mounted with the barrel or tube centerline 160 cm above and parallel to the ground.

A.2.5 Transducer Locations

For shoulder-fired and hand-held weapons, transducers shall be located at the center of each operator or crewmember's probable head location. For other weapons the transducer shall be positioned 160 cm above the ground surface; for sitting locations it shall be 80 cm above the seat. When the operator must be present, the measurement shall be made 15 cm from the ear closest to the major noise source (i.e., muzzle or breech) on a line between the operator's ear and the noise source.

A.2.5.1 Equal Pressure Contours

Equal pressure contours shall be determined from measurements made at positions around the major noise source of the weapon at angular increments not greater than 45°. The muzzle, muzzle extension, or breech, whichever is the major source, shall be at the grid center. The line of fire shall be in the 0°-direction. The measurement shall be made as close as possible to the distance that produces the peak pressure level being established. If this distance is too great, the pressure may be extrapolated from measurements somewhat nearer to the weapon (in the free field) assuming a spherical divergence decay rate (6 dB per doubling of distance).

A.2.6 Transducer Orientation

Blunt cylinder shaped transducers shall be positioned with the sensing surface facing up if possible. Transducers shall be oriented with respect to the noise source so that the plane passing through the sensing surface includes the noise source. This orientation is defined as grazing incidence (90°). If more than one source is present, such as from a rocket launcher, transducers shall be oriented so that the plane passing through the sensing surface includes the centerline of the tube. This technique will tend to minimize the arrival of shock waves at transducer incidence angles between 0 and 90°, which may cause ringing and overshoot.

A.2.6.1 Interior Measurements

For interior measurements, such as inside a combat vehicle or other reverberant space where the direction of travel of the major shock wave is uncertain (or where major shock waves are expected to arrive from many directions), transducers shall be positioned with the sensing surface facing up, if possible. Transducers shall be oriented at grazing incidence to the center of the major suspected source, e.g., the muzzle or an open hatch.

A.2.7 Ammunition Temperature

Where the impulse noise emanates from rapid burning of a propellant, additional measurements should be taken with the propellant at the upper and lower operating temperature conditions specified by the system requirements.

A.2.8 Personnel Limits and Locations During Tests

A.2.8.1 Operator(s)

During testing, the operator and/or crew shall not occupy the location(s) where the noise is being measured unless essential to the operation of the test item.

A.2.8.2 Interior Noise Measurements

Interior measurements shall be made with the minimum number of people in the area.

A.2.9 Guidelines

The following guidelines should be observed in addition to those specified in the instrument manufacturer's manual.

A.2.9.1 Systems

Care should be taken to maintain proper signal levels, terminating impedances, and cable lengths on multi-instrument measurement systems.

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Appendix B. A Chronologically Organized List of Selected Publications and Presentations on Noise and Modeling Associated With the Development and Use of AHAAH

2007

MIL-STD-1474D. (2007). "Department of defense design criteria. Noise limits," http://assist.daps.dla.mil/quicksearch/basic_profile.cfm?ident_number=36905. Last viewed 11 May 2009.

Price G. R. (2007). "Validation of the auditory hazard assessment algorithm for the human with impulse noise data," J. Acoust. Soc. Am., 122, 2787-2802.

Price, G. R. (2007). "Predicting mechanical damage to the organ of Corti." In Pharmacological Strategies for Prevention and Treatment of Hearing Loss and Tinnitus Hearing Res., Vol. 226, 5–13. http://dx.doi.org/10.1016/j.heares.2006.08.005. Last viewed 11 May 2009.

2006

Price, G. R. (2006). "Insights into hazard from airbag noise gained through the AHAAH model," Paper No. 2005-01-2397, Proceedings SAE 2005 Transactions Journal of Passenger Cars: Mechanical Systems, February, Book V114-6, ISBN 0-7680-1692-4.

2005

Kardous, C. A., Franks, J. R., and Davis, R. R. (2005). "NIOSH/NHCA Best-Practices Workshop on impulsive noise," Noise Control Eng. J., 53, 5353–5361.

Price, G. R. (2005). Critical Analysis and Comment on Patterson and Ahroon (2004). "Evaluation of an auditory hazard model using data from human volunteer studies," USAARL Report No. 2005-01. AHAnalysis Technical Report 190805. www.arl.army.mil/ARL-Directorates/HRED/AHAAH/_, Army Research Lab. Last viewed 11 May 2009.

Price G. R. (2005). "Insights into hazard from airbag inflation noise gained through the AHAAH model," SAE report 2005-01-2397.

Price, G. R. (2005). "A new method for rating hazard from intense sounds: Implications for hearing protection, speech intelligibility and situation awareness," Keynote 2 in NATO RTO-MP-HFM-123 Symposium "New directions for improving audio effectiveness," April 11–13, 2004, Amersfoort, The Netherlands, ISBN 92-837-1147-5 Available from www.rta.nato.int/pubs/rdp.asp?RDP=RTO-MP-HFM-123. Last viewed 11 May 2009.

2004

Patterson, J. D. and Ahroon, W. A. (2004). “Evaluation of an auditory hazard model using data from human volunteer studies,” USAARL Report No. 2005-01, U.S. Army Aeromedical Research Laboratory, Fort Rucker, AL.

Price G. R. (2004). “Hazard analysis of acoustic output of HIDA,” AHAnalysis Letter Report 150904.

2003

Dancer, A. (2003). “The LAeq8 an effective DRC for weapon noises,” NIOSH/NHCA Impulsive noise: A NORA Hearing Loss Team Best Practice Workshop, Cincinnati, OH, _http://www.cdc.gov/niosh/topics/noise/research/impulse_presentations.html. Last viewed 11 May 2009.

NATO RTO-TR-017 (2003). “Reconsideration of the effects of impulse noise,” RTO Technical Report No. TR-017/HFM-022, ISBN 92-837-1105x.

Price, G. R. (2003). “An examination of and response to “auditory standard issues” by Dr. James Stuhmiller, www.arl.army.mil/ARL-Directorates/HRED/AHAAH/_, Army Research Lab. Last viewed 11 May 2009.

Price, G. R. (2003). “Impulse noise and the cat cochlea,” http://www.arl.army.mil/ARL-Directorates/HRED/AHAAH_, Army Research Lab. Last viewed 11 May 2009.

Society of Automotive Engineers _SAE_ Standards. (2003). “J2531: Impulse noise from automotive inflatable devices,” http://www.sae.org/technical/standards/J2531_200311. Last viewed 11 May 2009.

2002

Fleischer, G., Muller, R., Heppelmann, G., and Bache, T. (2002). “Effects of acoustic impulses on hearing,” J. Acoust. Soc. Am., 111, 2335.

2001

Chan, P. C., Ho, K. C., Kan, K. K., Stuhmiller, J. H., and Mayorga, M. M. (2001). “Evaluation of impulse noise criteria using human volunteer data,” J. Acoust. Soc. Am., 110, 1967–1975.

Kalb, J. T. (2001) “Firing weapons from enclosures: Predicting the hearing hazard.” Presented at the International Conference on Military Noise, April 2001, Baltimore, MD.

Price, G. R. (2001) “New perspective on protecting hearing form intense impulse noise.” Presented at the International Conference on Military Noise, April 2001, Baltimore, MD.

2000

Buck, K. (2000). “Performance of hearing protectors in impulse noise,” RTO-ENP-11 AC/323_HFM_TP/31, pp. 3-1–3-10.

Dancer, A. (2000). Proposal for a new damage risk criterion. In report from NATO Research Study Group RSG 29_Panel 8 - AC/243_. “Reconsideration of effects of impulse noise,” TNO-Report No. TM-00-I008, pp. 11–15.

Price, G. R. (2000). “ARL Auditory Model Applied to MACS.” Invited presentation to MACS Project manager, Picatinny Arsenal, Dover, NJ (August 2000).

1999

Price, G. R. (1999). “Auditory hazard from airbags: New perspectives.” Invited talk to UBA-Commission on Socioacousis of the Federal Environmental Agency (Germany), March 1999, Berlin.

Price, G. R. and Kalb, J. T. (1999). “Auditory hazard from airbag noise exposure,” J. Acoust. Soc. Am., 106, 2629-2637.

Royster, J. D., Royster, L. H., Price, G. R., McMillan, P. M., and Kileny, P. R. (1999). “Hazard analysis for a bicycle horn which produced acoustic trauma.” 24th Annual NHCA Hearing Conservation Conference Proceedings, Atlanta, GA 25-27 Feb.

Price, G. R. and Kalb J. T. (1999). “Application of AHAAH to impulse noise from MAAWS.” Briefing to project engineers for MAAWS weapon system, APG, MD, 21 Jan 99.

Price, G. R. (1999). “Airbag noise as an issue on the highways.” Invited talk to Traffic Noise Committee of the National Transportation Research Board, Washington, DC, 12 Jan 99.

1998

Price, G. R. and Kalb, J. T. (1998). “A New Approach: The Auditory Hazard Assessment Algorithm (AHAA).” Talk to International Conference on Biological Effects of Noise - Australia, Conference Programme and Abstract Book, p. 127; also Conference Proceedings, 2, 725-728.

Price, G. R. and Kalb, J. T. (1998). “Design and noise measurement guidance for airbag design.” Talks presented to consortium of German automotive engineers at Porsche, Weissach, Germany, 26-27 Oct 98.

Price, G. R. and Kalb, J. T. (1998). “Implications of mathematical model of the human ear for weapons design.” Talk to design engineers, U.S. Army TACOM Armament Research, Development and Engineering Center, Picatinny Arsenal, NJ, 7 Oct 98.

Price, G. R. and Kalb, J. T. (1998). "Development and validation of an Auditory Hazard Assessment Algorithm for the Human ear (AHAAH) as a predictor of hearing hazard and as an engineering tool." In: TNO-report TM-00-I008, Report from NATO Research Study Group RSG.29 (Panel 8 - AC/243) Reconsideration of the effects on impulse noise, 1998 meeting, pp. 6-10; also presented at TNO, October 1998, Soesterburg, The Netherlands.

Price, G. R. (1998). "Airbag noise hazard: from theory toward validation," J. Acoust Soc. Am., 104, 1769. Invited presentation, Fall Meeting Acoustical Society of America, Norfolk, VA.

Price, G. R. (1998). "Susceptibility to hearing loss: physiological, physical, behavioral and probabilistic factors," J. Acoust. Soc. Am., 104, 1752. Invited presentation, fall meeting ASA, Norfolk, VA.

Price, G. R. and Kalb, J. T. (1998). "Hearing protectors and hazard from impulse noise: melding method and models," J. Acoust. Soc. Am., 103, 2878. Invited paper ICA/ASA meeting Seattle, WA; also paper in Proceedings ICA/ASA, pp. 1145-1146.

Kalb, J. T. and Price, G. R. (1998). "Modeling the effect of a hearing protector on the waveform of intense impulses," J. Acoust. Soc. Am., 103, 2878. Paper at joint ICA/ASA meeting Seattle, WA; also paper in Proceedings ICA/ASA pp. 1149-1150.

Price, G. R. (1998). "Standard for Damage Risk for Impact/Impulse Noise." In proceedings of 23rd Annual NHCA Hearing Conservation Conference, Albuquerque, NM, 10 pp (invited paper).

Price, G. R. (1998) "Modeling impulse noise susceptibility in marine mammals." Invited presentation to USNRL workshop on Noise and Marine Mammals, Washington, DC.

Price, G. R. (1998) "Engineering issues in reducing auditory hazard from airbags." Presentation to SAE Committee on Airbag Noise, Detroit, MI (invited).

Price, G. R. (1998). "Airbags and the ear - a story (of) unfolding." Invited article in NHCA's Spectrum.

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Price, G. R. (1997). "Airbag noise hazard examined with mathematical model of the human ear," J. Acoust. Soc. Am., 102, 3201.

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