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Impulse Peak Insertion Loss of the 3M™ E-A-R™ Classic™ Earplug

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Executive Summary

The impulse peak insertion loss (IPIL) is the standard measure of attenuation provided by hearing protection devices (HPDs) in response to an impulsive noise. This technical memorandum describes the IPIL testing conducted and the calculated mean IPIL values for the uncorded 3M™ E-A-R™ Classic™ Earplug (E-A-R™ Classic™; Model: 310-1001). Testing was done in accordance with the American National Standards Institute (ANSI) standard S12.42-2010, Methods for the Measurement of Insertion Loss of Hearing Protection Devices in Continuous or Impulsive Noise Using Microphone-in-Real-Ear or Acoustic Test Fixture Procedures. All samples were tested at the nominal levels of 160 and 170 dBP (dBP, re: 20 µPa). A total of five samples were fitted to an acoustic test fixture two times each for a total of 10 trials per test level. No product samples were rejected. The mean and standard deviation (SD) IPIL value at 160 dBP was 58.7 (2.0) dB and at 170 dBP was 57.5 (1.8) dB (see Table 1). The E-A-R™ Classic™ (when properly fit and functional) will adequately protect (i.e., reduce exposure to levels less than 140 dBP) for impulses up to, but not exceeding 180.0 dBP.

Table 1.

E-A-R™ Classic™ mean (SD) IPIL value (in dB) for all test conditions.

160 dBP	170 dBP
58.7 (2.0)	57.5 (1.8)

Introduction

The 3M™ E-A-R™ Classic™ Earplug (E-A-R™ Classic™; 3M, St. Paul, MN) is an uncorded, cylindrical earplug made with slow recovery, flame, sweat, and moisture resistant PVC foam. The E-A-R™ Classic™ is available in two sizes: small and regular. Per manufacturer documentation, the slow recovery PVC material composing this passive earplug maximizes comfort via reduced ear canal pressure, and the cylindrical shape allows for an improved fit across a wide range of ear canal sizes compared to tapered plugs (3M, 2010). The E-A-R™ Classic™ is intended for single use.

This technical memorandum details the procedures followed, and the resulting calculated mean impulse peak insertion loss (IPIL) value for the E-A-R™ Classic™ Earplug. In addition to reporting an overall device IPIL, ear-specific IPILs are reported for the tested nominal levels.

Methods

Facility & Personnel

IPIL testing described herein was completed in the Naval Submarine Medical Research Laboratory (NSMRL) 1000 m³ anechoic chamber in order to minimize any effects of sound reflections.

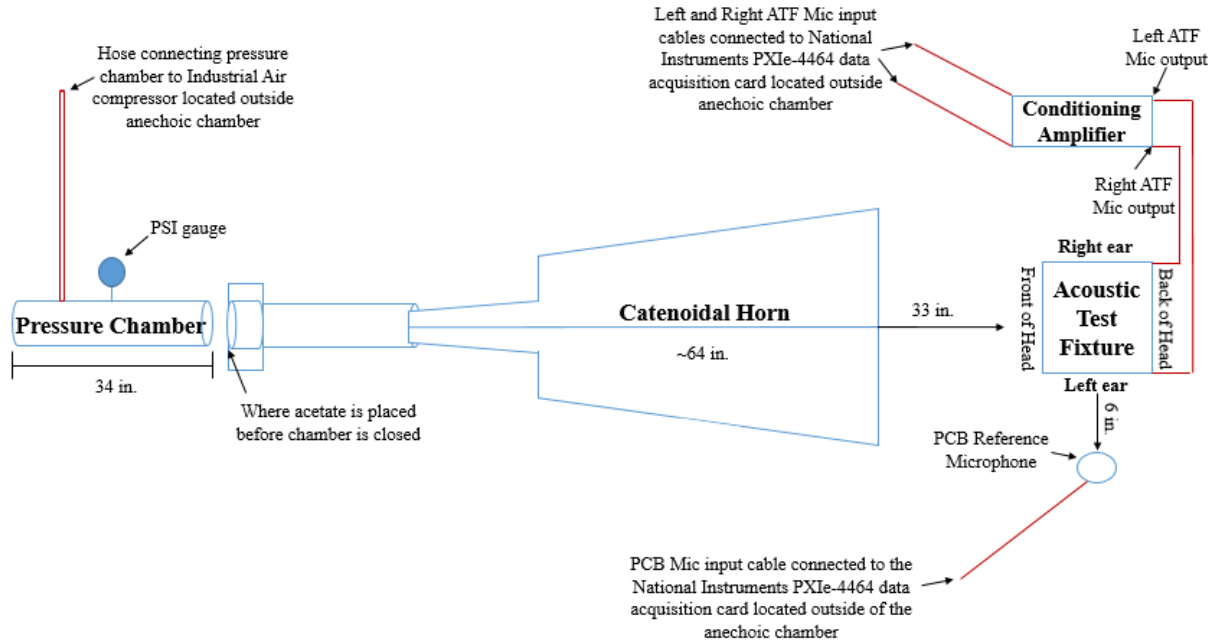
Equipment

Hardware. Acoustic impulses were generated by NSMRL's 4 inch (in.) shock tube (B/C Precision, Inc., Greendale, IN). The shock tube pressure chamber is approximately 34 in. long, with an inner diameter of 4 in. A 64 in. long catenoidal tube horn consisting of four welded steel flat-projection sheets forming a square cross section was connected to the shock tube using a PVC 4.5 in. coupler. An industrial air compressor (ILA#1883054; Industrial Air Corporation, Memphis, TN) supplied pressurized air (900 kilopascal) to the shock tube. For each trial, a 7 in. by 7 in., acetate sheet (Grafix Plastic, Maple Heights, OH) was used as a membrane between the pressurized chamber and the catenoidal tube horn to enable pressurization of the air chamber. Each acetate sheet was 0.002 in. (2 millimeters) thick.

All waveforms were recorded with the ANSI/ASA S12.42 (2010) compliant GRAS 45CB acoustic test fixture (ATF) along with GRAS RA0045-S7 Ear Simulators (GRAS Sound and Vibration, Twinsburg, OH). Additionally, the ATF was connected to a conditioning amplifier which served as the power supply (GRAS Type 12AA; GRAS Sound and Vibration, Twinsburg, OH). As required by ANSI/ASA S12.42/2010, the ATF was placed to front-face (i.e., nose facing) the catenoidal tube horn at 0° elevation and 0° azimuth.

A reference microphone (Type 378C20; PCB Piezotronics Inc., Depew, NY) was placed 6 in. from the ATF left pinna. The reference microphone, the left ATF microphone, and the right ATF microphone were calibrated each morning prior to data collection at 124 dB sound pressure level (SPL) using a 250 hertz (Hz) tone. A diagram depicting the aerial view of the NSMRL 4 in. shock tube and test system can be seen in Figure 1.

Figure 1.
Diagram of the NSMRL Acoustic Shock Tube and ATF.



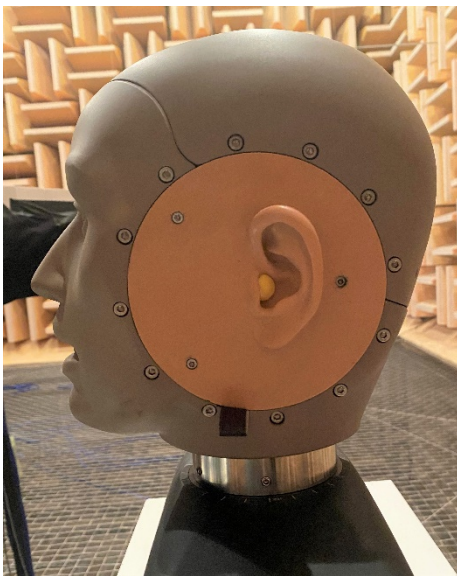
Data Acquisition System. The data acquisition system (NI chassis PXIe-1071 with NI PXIe-4460 and NI PXIe-4464; National Instruments Corp., Austin, TX) was controlled by a standalone laptop computer running project specific software (LabVIEW; National Instruments Corp., Austin, TX). The data acquisition system was connected to the laptop using an MXI cord and host interface card (NI PXIe-8360). The software controlled the acquisition of waveforms from the three source microphones (left ATF microphone, right ATF microphone, and a reference microphone) at a sampling rate of 204.8 k Samples/second during each impulse recording. Pre-trigger settings were 1024 samples per 0.005 seconds, with a trigger level of 110 dB SPL. Each recording was 0.3 seconds in duration. Deviating from ANSI/ASA S12.42-2010, an electronic anti-aliasing filter (corner frequency of 93.0 kHz [3 dB down]) was applied to all waveforms by the data acquisition system during data collection instead of a separate analog filter. This deviation was made due to equipment and software limitations.

The custom-written software program saved all recorded waveforms as files (.tdms), which were exported from the software for conversion into data files using an additional custom software programming script. The script compiled the reference PCB microphone, left ATF microphone, and right ATF microphone channels into a file (.mat) that saved variables for input to analysis script (MATLAB) similar to the script provided in Annex H of the ANSI/ASA S12.42-2010 standard. Minor alterations were made to the analysis script in order to accept 160 decibel peak (dBP) and 170 dBP data (see Data Analysis below). The revised script processed and outputted all IPIL values

reported herein, along with generating the closed-ear, open-ear, and free-field waveform plots (See Appendices A-F).

Hearing Protection Device Samples. Five samples of the E-A-R™ Classic™ Earplug (Manufacturer Product Number: 310-1001) were tested IAW ANSI/ASA S12.42-2010. All samples were regular size. Each sample, consisting of one set of two earplugs, was randomly assigned a number 1 through 5. Each earplug in the sampled set was labeled ‘L’ for left or ‘R’ for right to indicate which ATF ear they were to be inserted for all trials.

Figure 2.
3M™ E-A-R™ Classic™ Earplugs.



Procedure

Each sampled HPD set was fitted to the ATF twice, resulting in two trials (trials A and B) per sample, and 10 total trials per nominal level test condition (160 and 170 dB). No samples were rejected. To achieve an appropriate fit that would provide maximum attenuation, each sample was expertly fitted to the ATF IAW instructions on the device packaging. The manufacturer fitting guidelines stated that all samples be inspected for any wear, cracks, or damage prior to use. Once inspected, the earplug was rolled down to a thin crease-free cylinder, inserted into the ear canal, and held in place until fully expanded. Proper insertion was confirmed by ensuring that only the end of the earplug was visible. Earplugs were given at least two minutes to fully expand in the ATF ear canal before impulse testing was performed.

Impulse noises were presented to the ATF in the occluded (i.e., HPD inserted) and unoccluded (i.e., without the HPD inserted) test configurations. For all occluded measures, the earplugs were fitted on the ATF IAW the specifications outlined in ANSI/ASA S12.42-2010. Each HPD sample was exposed to two impulses at each tested nominal level. Adequate pressure for each impulse was determined by increasing

pressure (measured in pounds per square inch [psi]) to a point within a pre-specified range necessary for producing either 160 or 170 nominal level impulses using the NSMRL 4 in. acoustic shock tube (160 range: 19.5 to 22.1 psi, 170 range: 28.5 to 29.5 psi). The acetate was then punctured, releasing pressurized air into the catenoidal horn, which created an impulse wave through the catenoidal horn to the ATF. The peak decibel level emitted was dependent upon the amount of air pressure released.

In place of the ANSI/ASA S12.42-2010 standardized calibration impulses at 130 and 150 dBp, six calibration impulses were generated at the 160 dBp nominal level in the unoccluded (i.e., without HPD) test configuration. Three of these impulses were generated pre-, and three were generated post-testing at 160 dBp. Calibrations were not completed at the 170 dBp nominal level due to exposure limitations of the ATF right and left microphones.

A Butterworth filter (6th order, low-pass, corner frequency of 20 kHz [3 dB down]) was applied to all waveforms post-data collection by a programming software script (MATLAB, Natick, MA) post-processing.

Data Analysis

MATLAB (Natick, MA) was used to calculate IPIL values at the 160 and 170 dBp nominal levels and to generate all waveform graphs. The mean pressure of each waveform was subtracted from the waveforms to remove any constant offset. The peak levels were then calculated by converting the maximum absolute value of each waveform into dB SPL. The transfer functions of the free-field probe to each ear of the ATF was calculated for the unoccluded waveforms gathered at the 160 dBp nominal level. The mean transfer function for each ear was then calculated, and the first element of the transfer function was set to zero in order to avoid calculations at 0 Hz. The fit of the mean transfer function was tested by applying the mean transfer function for each ear to the free-field probe data gathered in the 160 dBp nominal level. The difference of the maximum absolute values of the calculated values and the measured values was then calculated, converted to dB SPL, and displayed.

The calculated IPIL value (in dB) equaled the mean difference of the maximum absolute value of the waveforms from the ears of the ATF in dB SPL and the maximum absolute value of the estimated values of the unoccluded ears in dB SPL. The estimated values of the unoccluded ears are the waveforms from the free-field probe with the mean transfer function applied to them. These values were calculated for each ear in each trial and condition. The mean values were calculated across both ears and trials, resulting in a displayed mean for each nominal level (i.e., 160 dBp and 170 dBp). Every waveform was plotted with time on the x-axis and pressure on the y-axis. The transfer functions were not plotted.

Results

As shown in Table 2, the overall mean IPIL value at the 160 dBp test condition was found to be 58.7 dB and at the 170 test condition 57.5 dB. Calculated IPIL values for all individual sample trials ranged between 54.6 and 61.5 dB at 160 dBp and between 54.3 and 60.3 dB at 170 dBp. Also presented in Table 2 are the individual attenuations for each sample, the ear-specific means and standard deviations (SD)

across all samples and trials, and the overall means and SD across all samples, trials, and ears. The waveforms for all trials with the E-A-R™ Classic™ are provided in Appendices A to F.

Table 2.

Mean (SD) IPIL values (in dB) for Tested E-A-R™ Classic™ Samples.

	160 dBP		170 dBP	
	<i>Right</i>	<i>Left</i>	<i>Right</i>	<i>Left</i>
HPD 1, Trial A	61.3	57.6	58.0	58.8
HPD 1, Trial B	61.2	58.9	59.2	59.3
HPD 2, Trial A	60.1	56.4	57.1	57.5
HPD 2, Trial B	59.7	54.6	57.4	58.5
HPD 3, Trial A	60.1	57.1	54.3	58.1
HPD 3, Trial B	60.1	56.3	54.6	58.3
HPD 4, Trial A	61.5	58.7	56.5	55.0
HPD 4, Trial B	61.4	58.6	58.0	56.3
HPD 5, Trial A	58.2	56.6	55.6	60.3
HPD 5, Trial B	59.0	56.5	55.9	60.3
Ear Specific Mean (SD)	60.3 (1.1)	57.1 (1.3)	56.7 (1.6)	58.2 (1.7)
Level Overall Mean (SD)	58.7 (2.0)		57.5 (1.8)	

Discussion

The aim of this report was to document the measured attenuation provided by the E-A-R™ Classic™ Earplug to impulsive noises through testing IAW ANSI/ASA S12.42-2010. Across ears, the individual trial IPIL values were found to vary as much as 6.9 dB at 160 dBP and 6.0 dB at 170 dBP. This may be due to a combination of inherent variance within the impulse system and/or the test-retest variability in the fit of each earplug. Results indicate that while the overall mean IPIL value was approximately 1 dB greater at 160 dBP, the standard deviation (SD) was also larger at this test level (2.0 dB), indicating a wider range of calculated attenuation at the individual trials.

In the current effort, deviations were made from the ANSI/ASA S12.42-2010 standard governing impulse noise testing due to equipment and software limitations. First, rather than using an in-line analog external Bessel filter (6th order, corner frequency 20.0 kHz [3 dB down]) to filter impulses during data acquisition, anti-alias filtering was accomplished by an analog filter and a digital filter. The analog filter was an anti-aliasing filter (corner frequency of 93.0 kHz [3 dB down]) applied to all waveforms by the National Instruments data acquisition hardware during data acquisition. The digital filter was a Butterworth filter (6th order, low-pass, corner frequency of 20 kHz [3 dB down]) applied by the MATLAB post-processing script.

This filter was used to mimic the effect of the ANSI/ASA S12.42-2010 standard required anti-aliasing Bessel filter.

Second, we omitted testing at the 130 dBP and 150 dBP nominal levels. The decision to exclude these test levels was the result of a prior analysis of impulse waveforms (unrelated to this report) generated at those levels with the NSMRL 4 in. shock tube resulted in signals without a shock front. In addition, impulse noise levels that are commonly observed in military occupational environments regularly exceed 150 dB resulting in test results at such levels of limited value for military application. At the measured levels described herein, all generated impulses had a shock front. It is important to note that these results do not guarantee similar E-A-R™ Classic™ product performance across all users and environments. Product performance may be impacted by factors including variability in physical fit of the device and HPD configuration (i.e., double- or triple- configuration with combat helmet, earmuffs, eye wear, etc.).

Conclusions

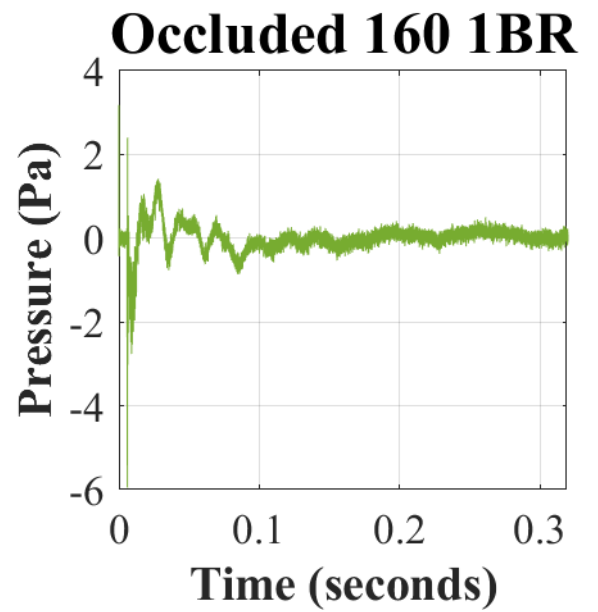
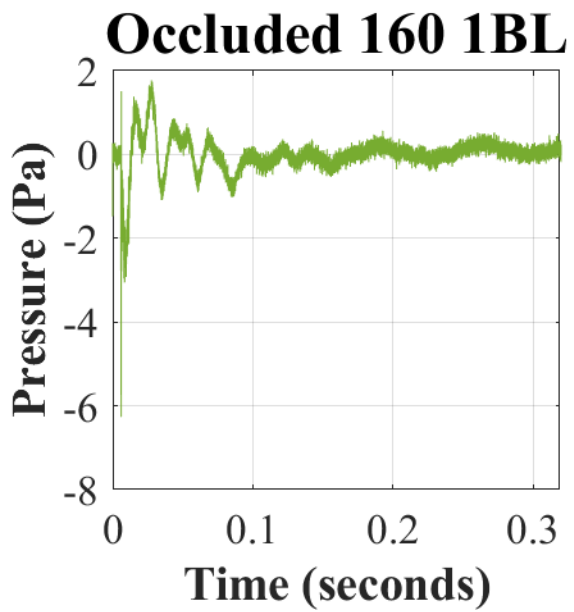
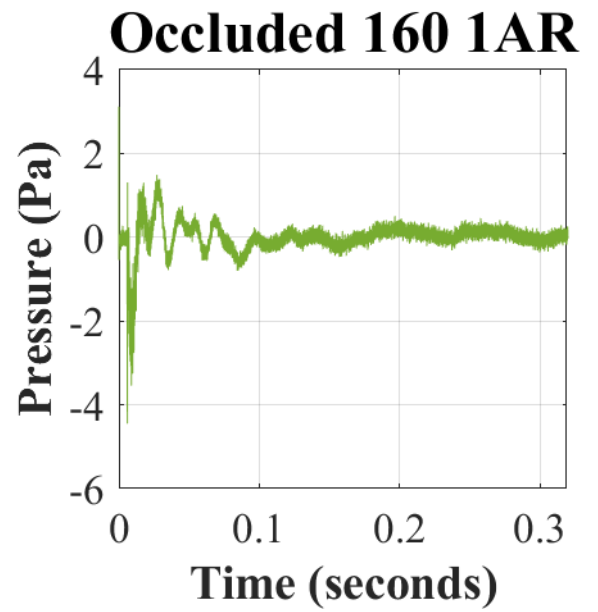
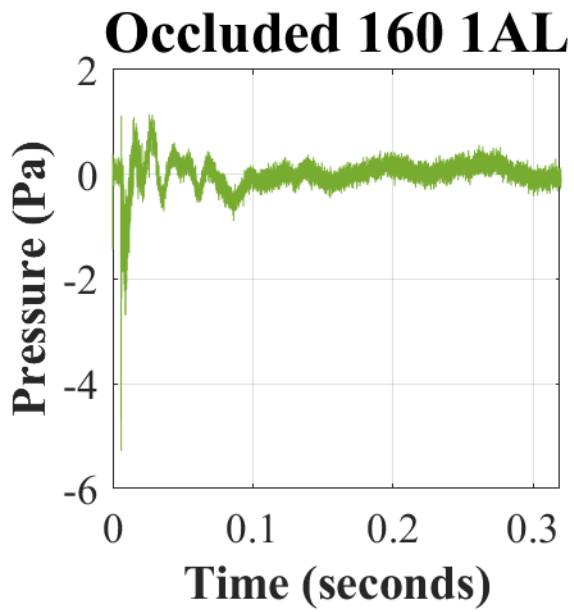
This report described the determination of the mean impulse peak insertion loss (IPIL) values provided by the E-A-R™ Classic™ Earplug at 160 dBP and 170 dBP nominal levels. The calculated overall mean (SD) impulse peak insertion loss (IPIL) values for the E-A-R™ Classic™ was found to be 58.7 (2.0) dB at 160 dBP and 57.5 (1.8) dB at 170 dBP.

Within the Department of Defense (DoD), the exposure limit for impulse noise is 140 dBP (Office of the Under Secretary of Defense for Personnel and Readiness, 2019, Department of Defense, 2015). At exposure levels equal to and/or exceeding 140 dBP, hearing conservation efforts must be put into place. One such measure is the use of an HPD such as an earplug or earmuff to reduce the impulse below the 140 dBP threshold. The E-A-R™ Classic™ earplug (when properly fit and functional) will adequately protect the user from impulses up to, but not including 180 dBP.

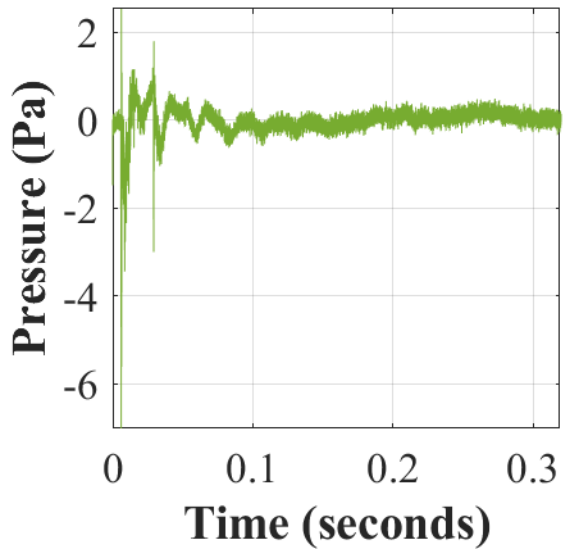
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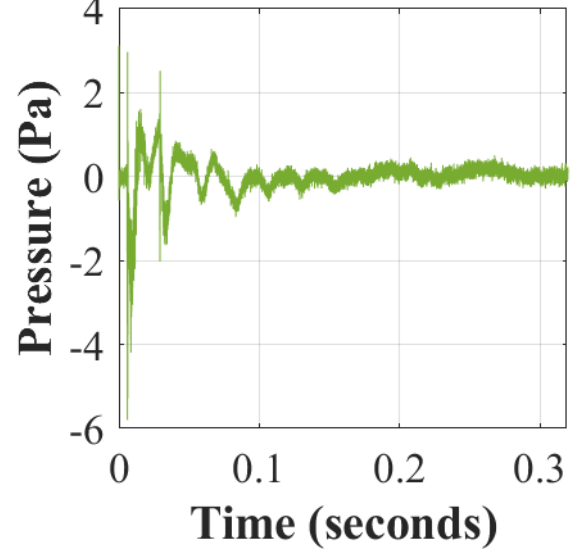
Appendix A. Recorded occluded (closed-ear) waveforms in response to 160 dBp with the E-A-R™ Classic™ Earplug.



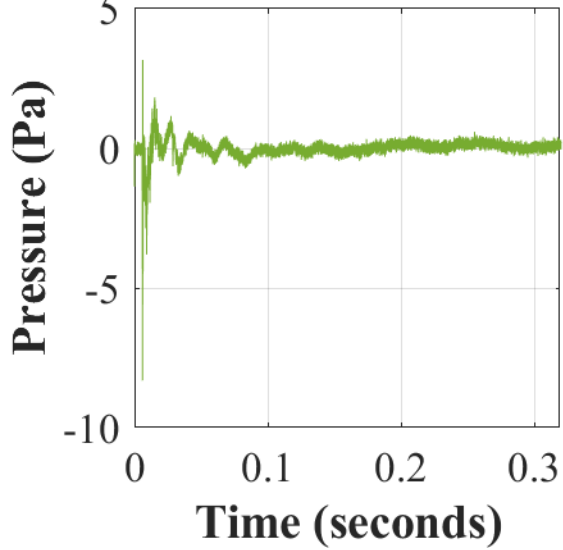
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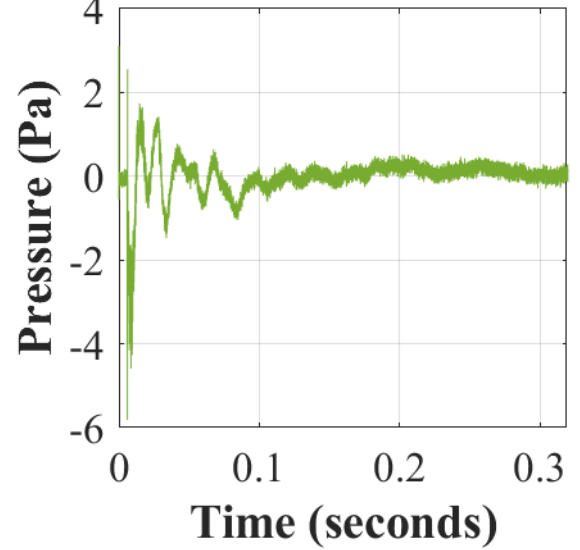
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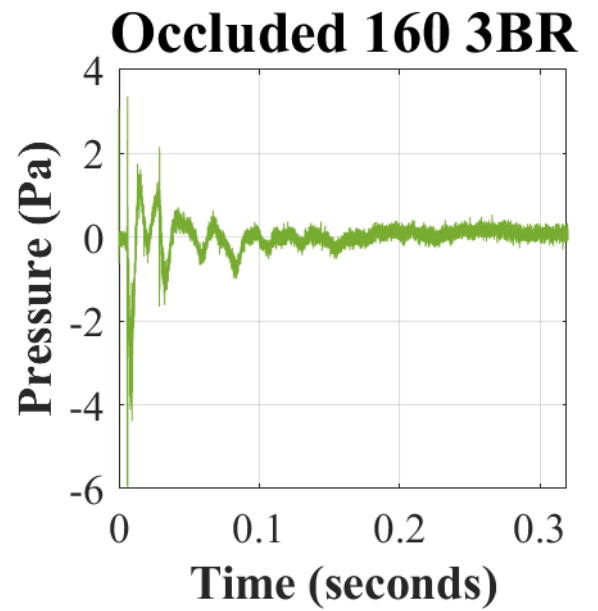
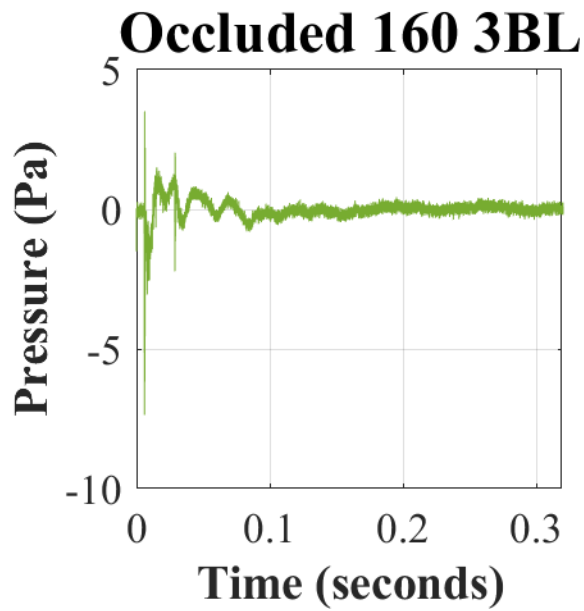
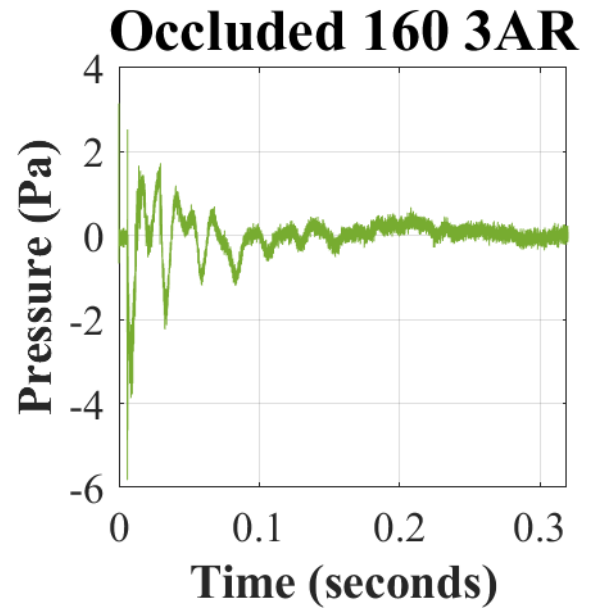
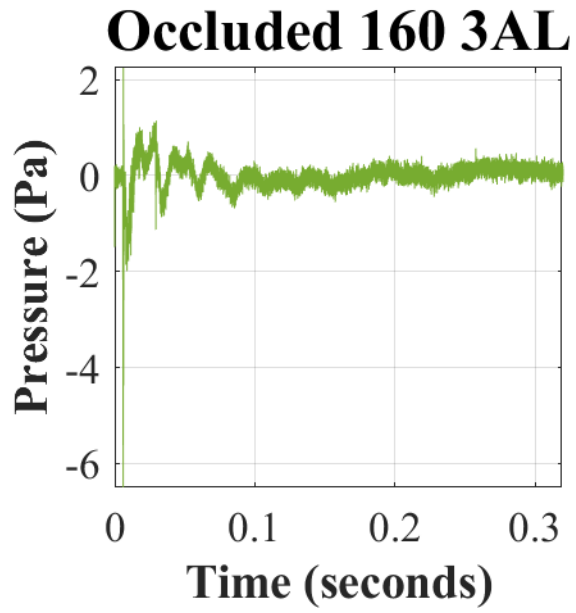


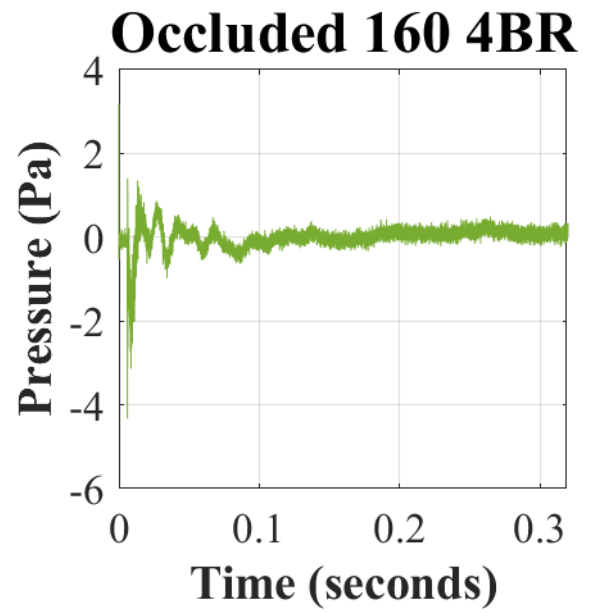
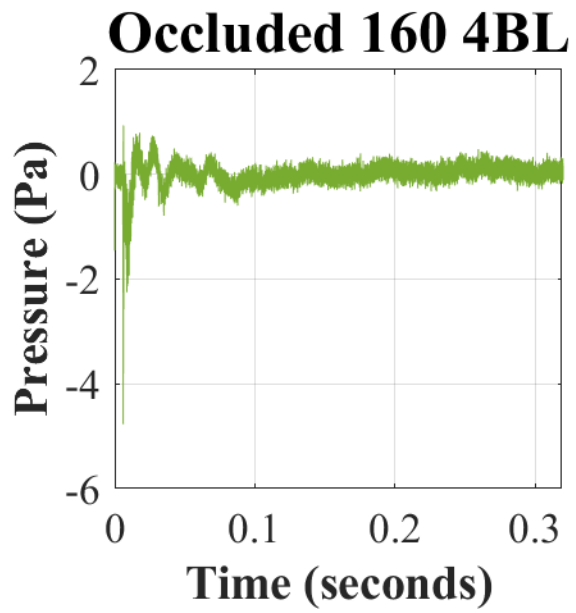
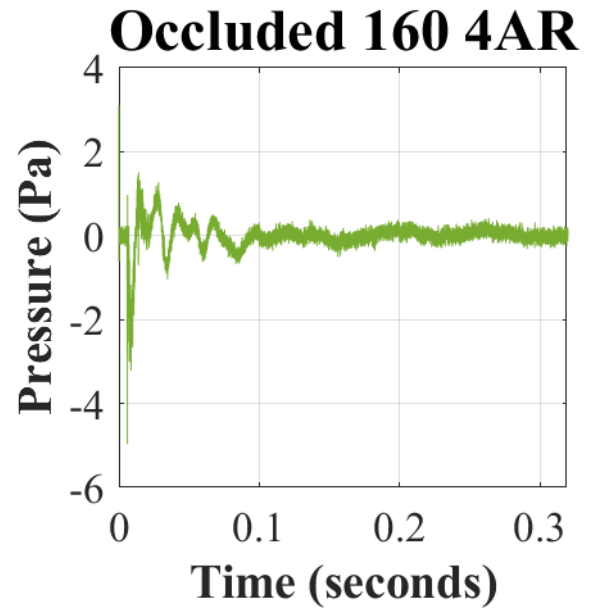
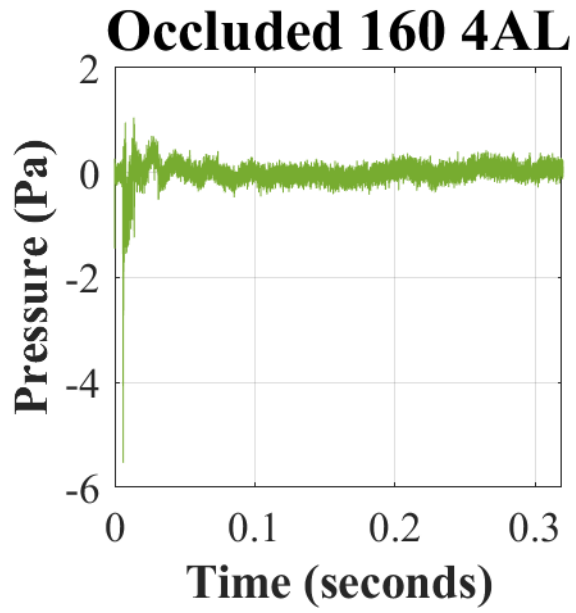
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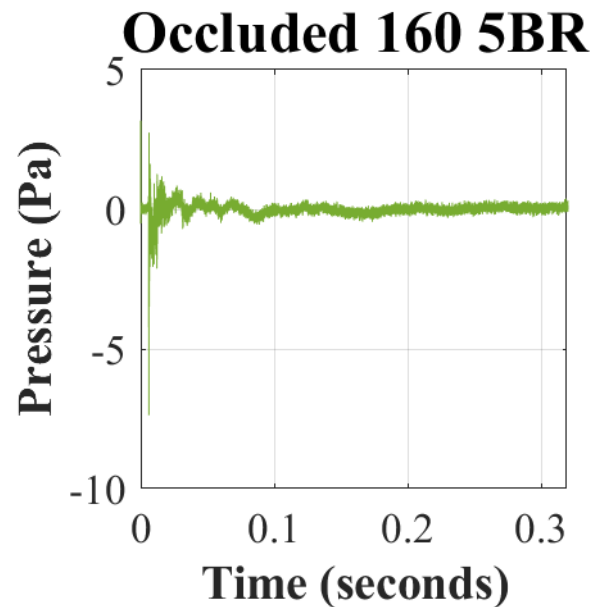
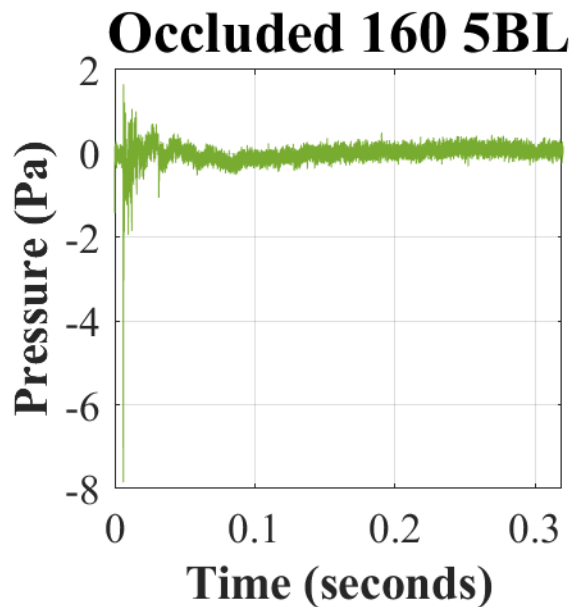
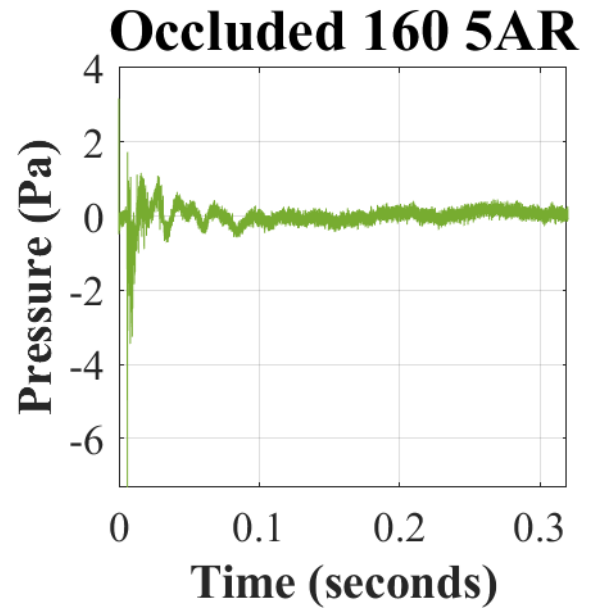
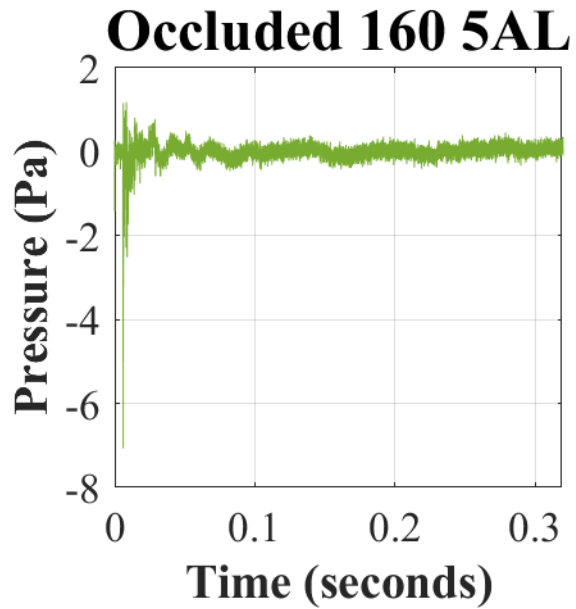


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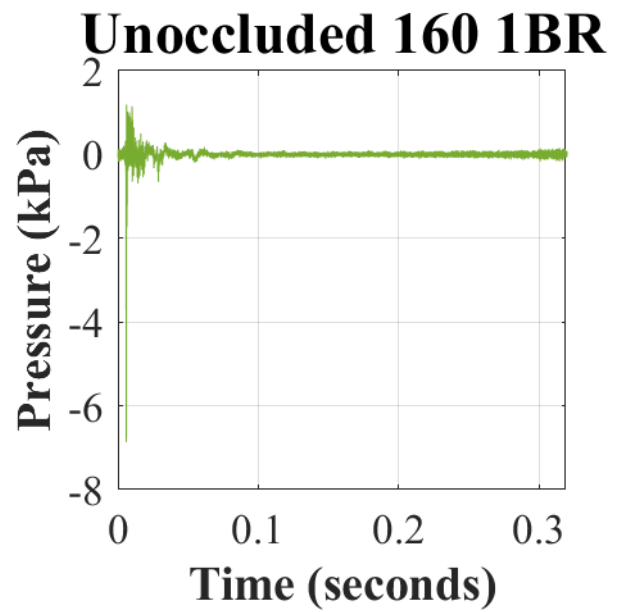
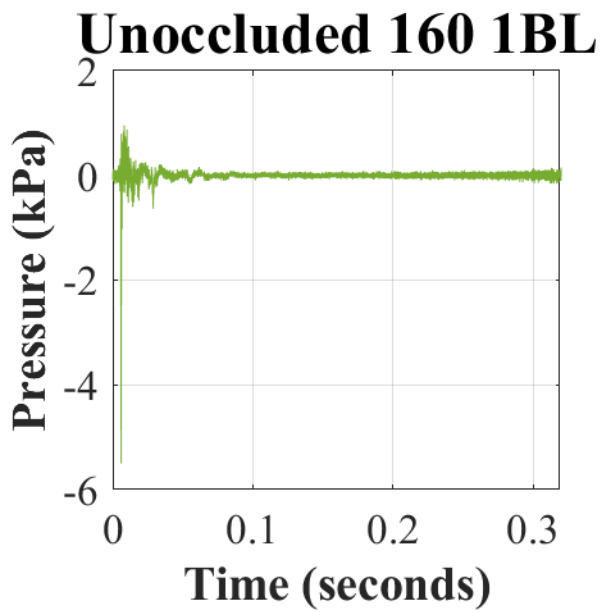
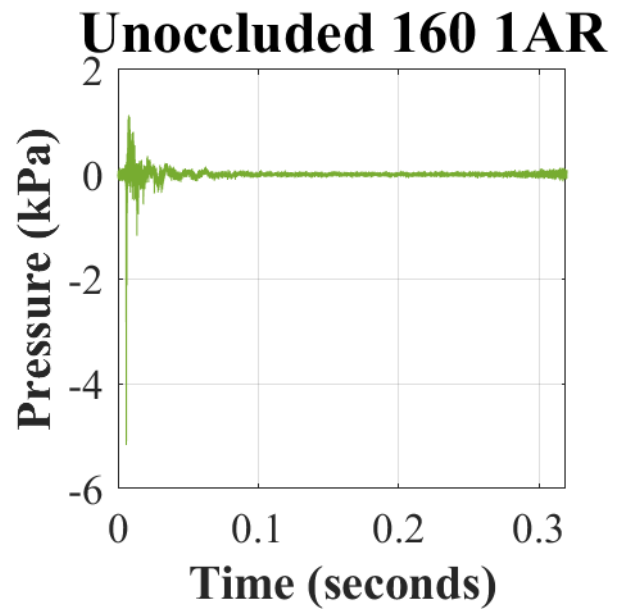
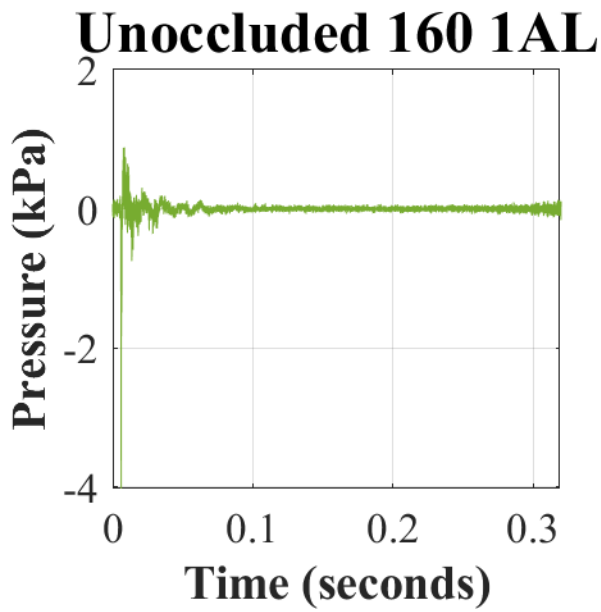


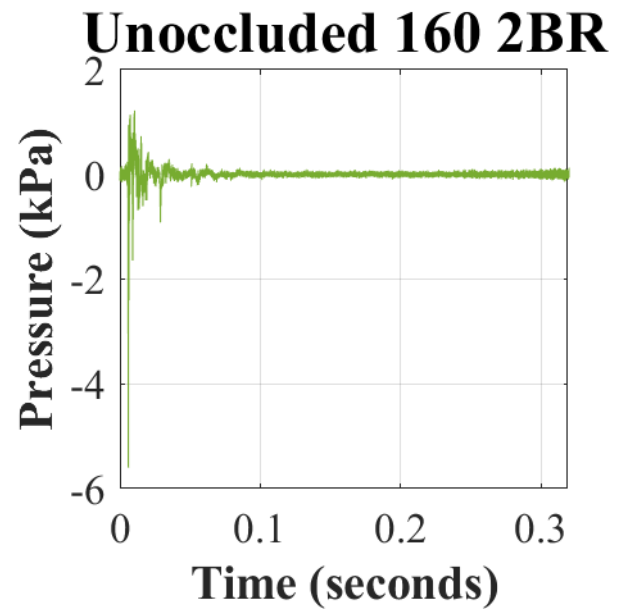
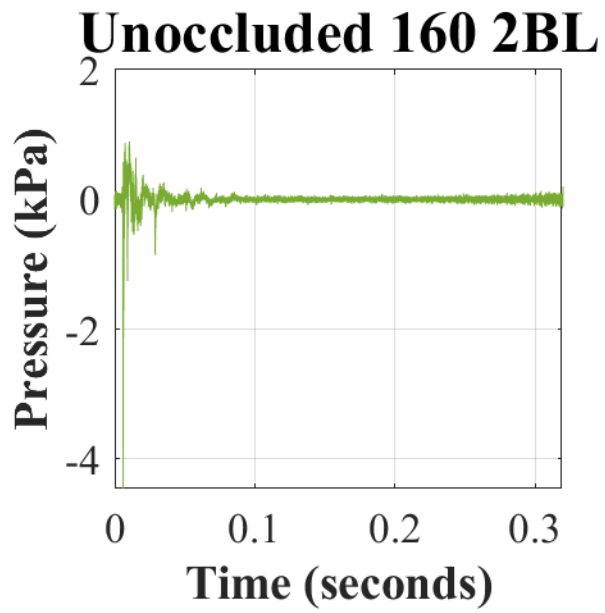
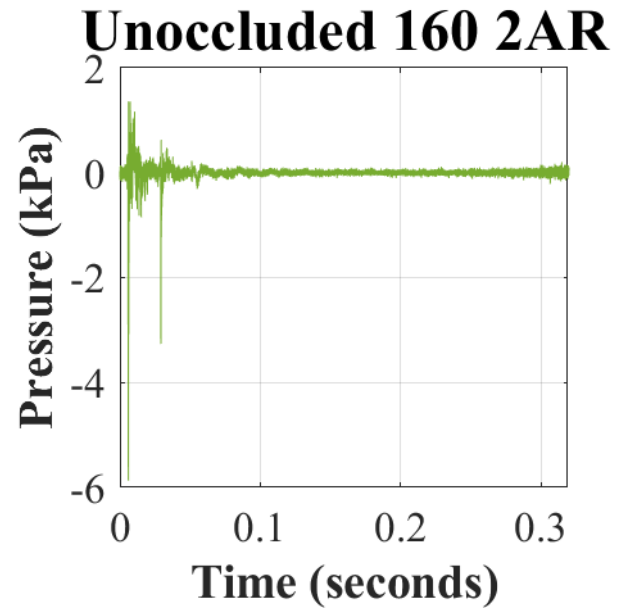
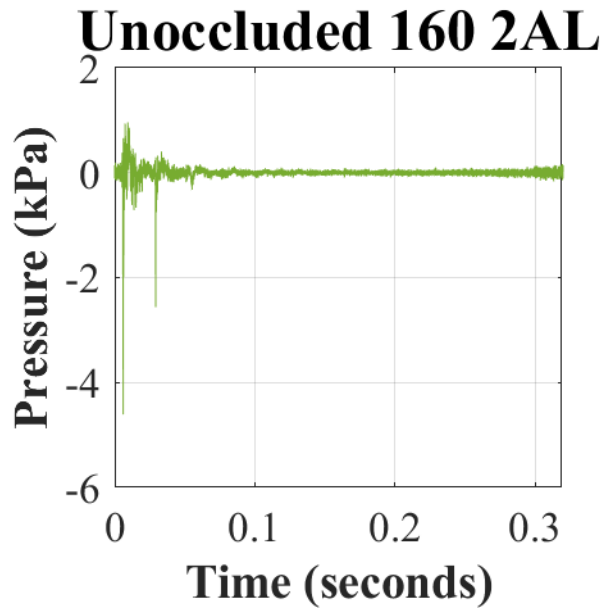


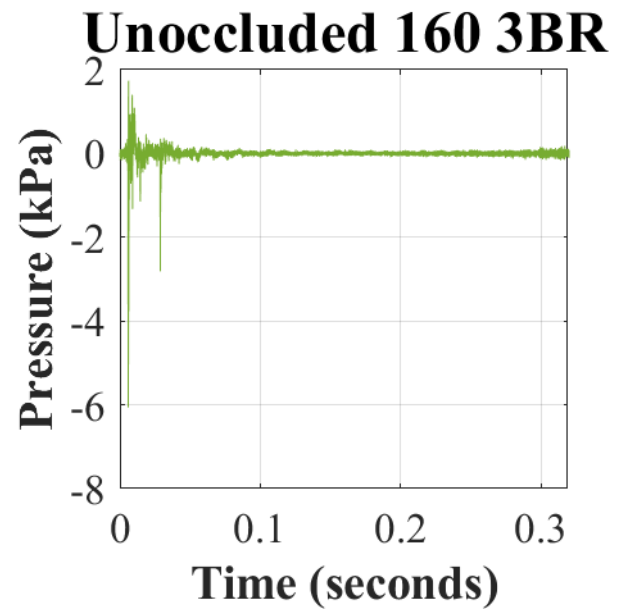
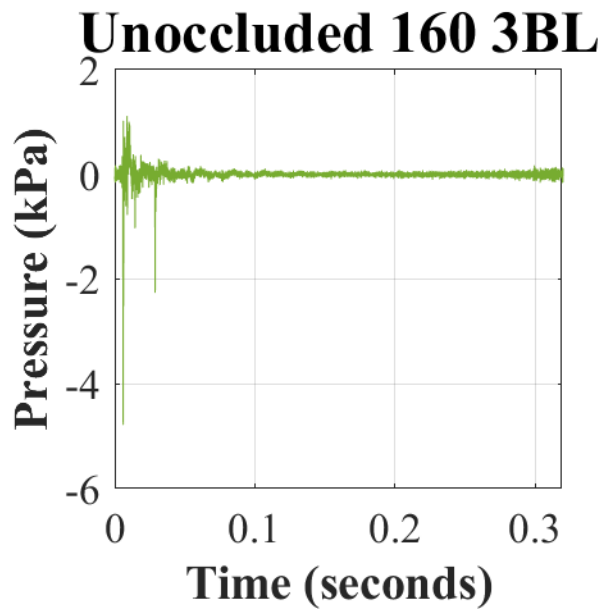
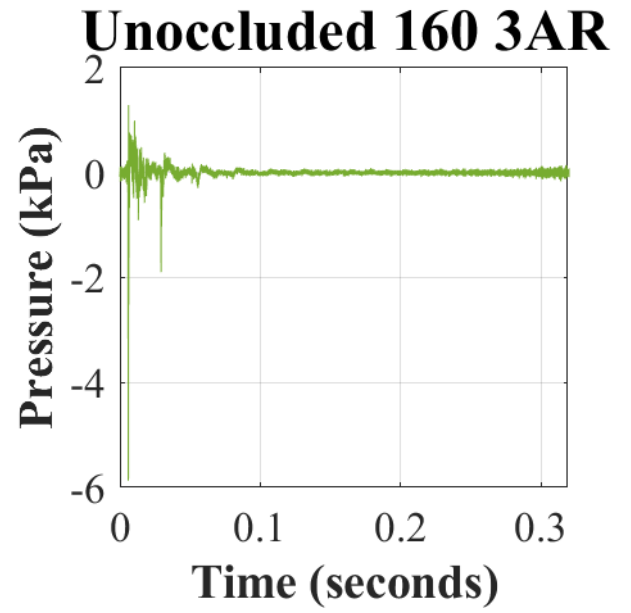
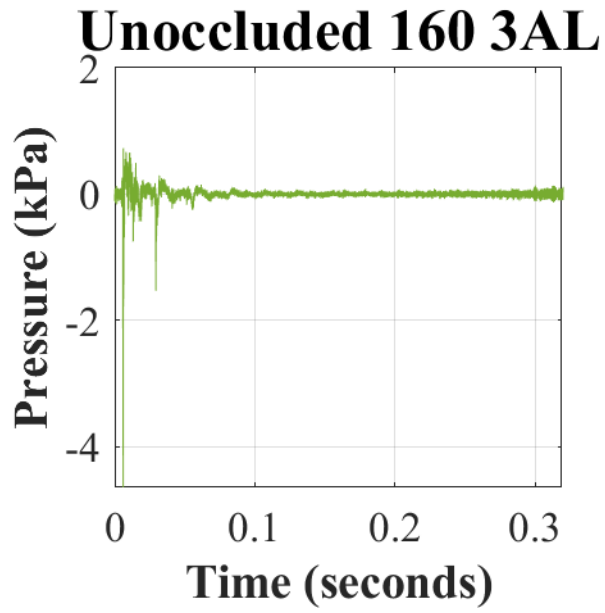


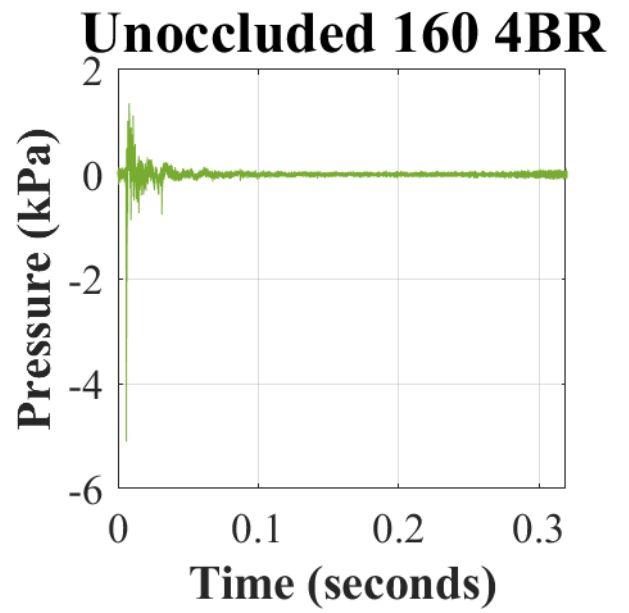
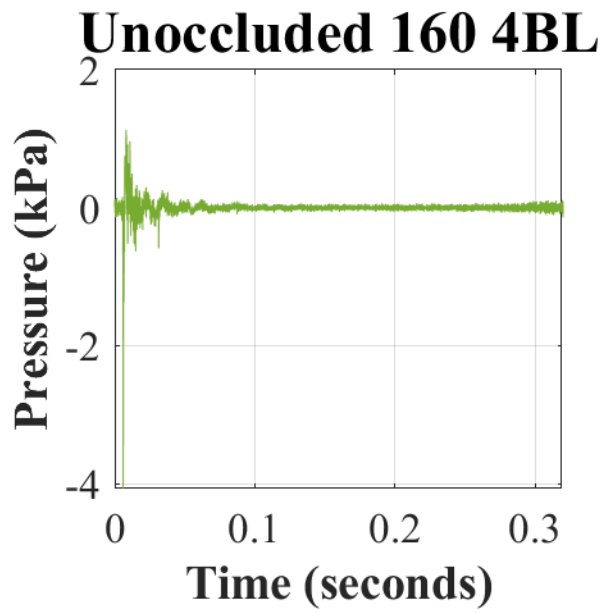
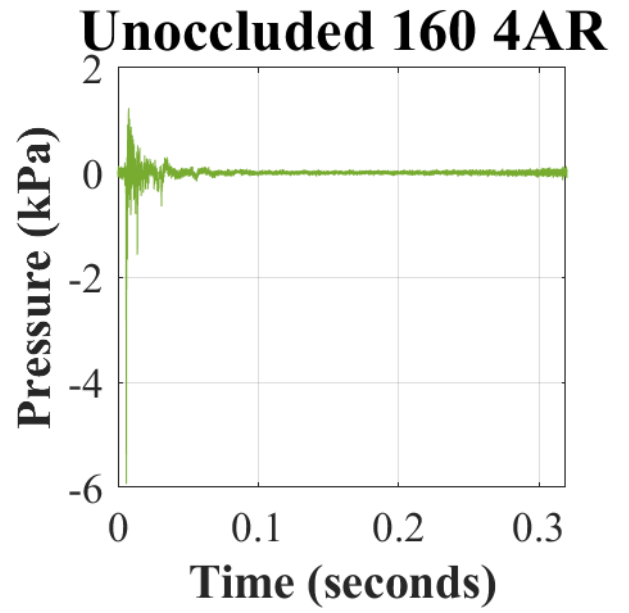
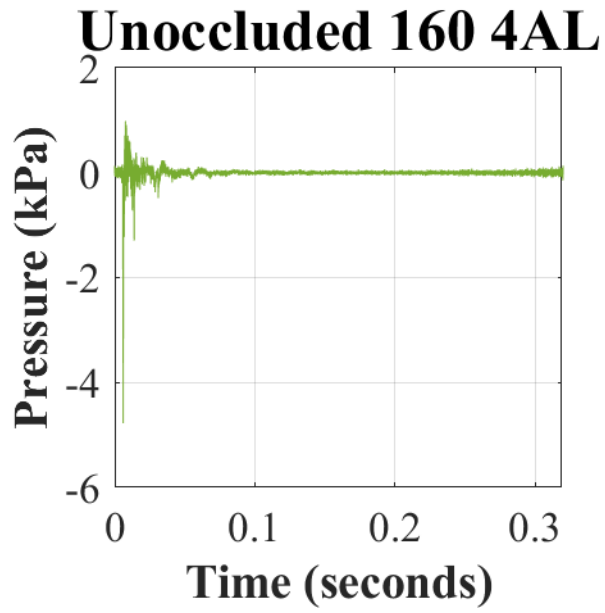
Note. The naming convention for all occluded waveforms is “Occluded LvL NnX”, where ‘Occluded’ is the test condition (i.e., ATF has the HPD donned), ‘LvL’ is the nominal test level (i.e., 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or B) indicating HPD fit (i.e., first or second, respectively), and ‘X’ indicates from what ATF microphone the recording is from (i.e., right (R) or left (L) pinnae).

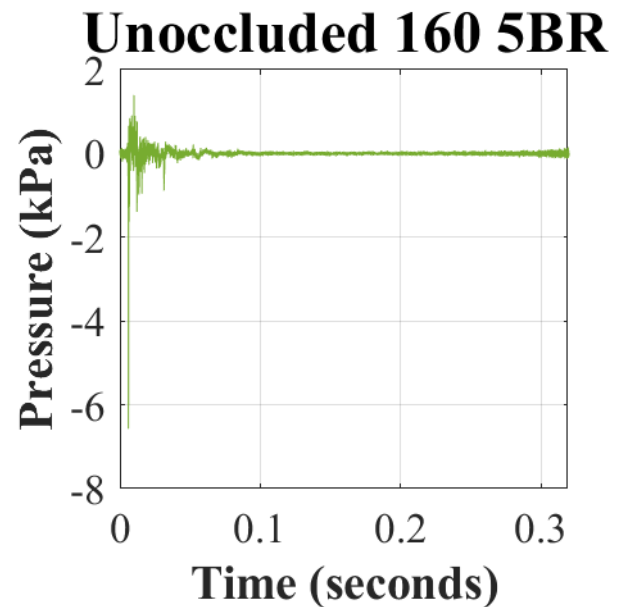
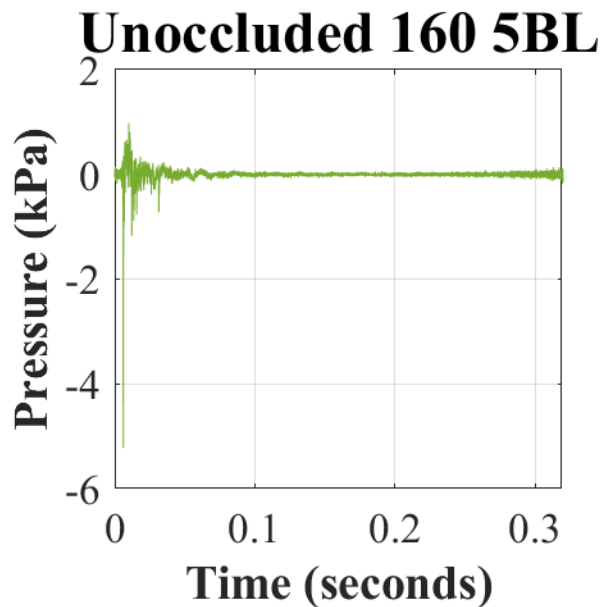
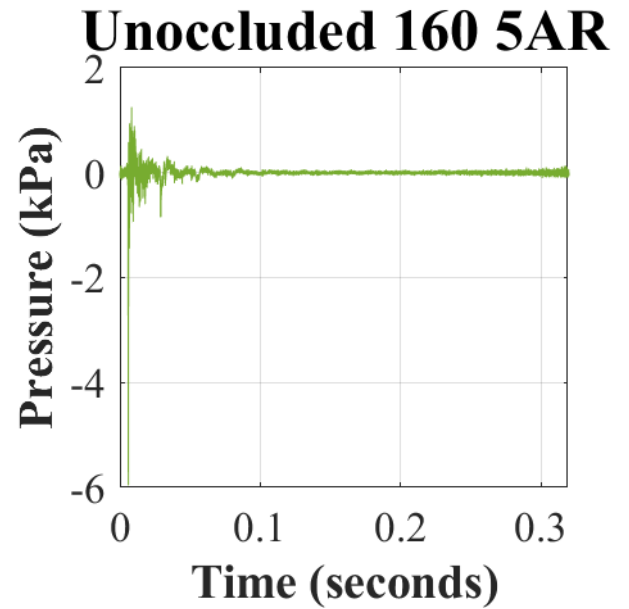
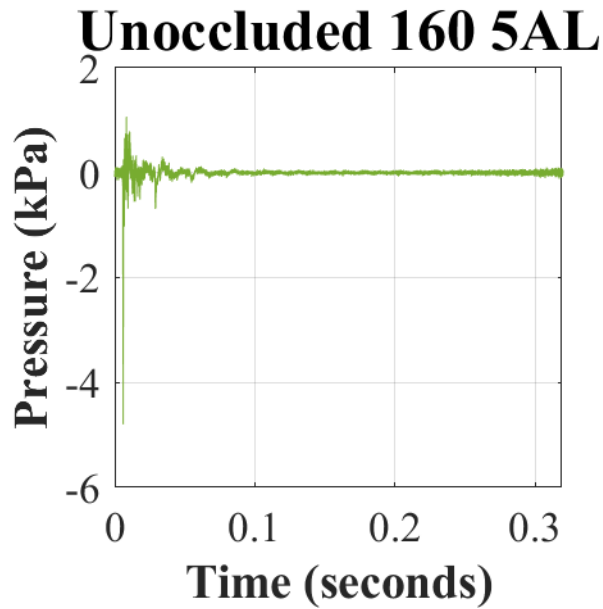
Appendix B. Estimated unoccluded (open-ear) waveforms in response to 160 dBp with the E-A-R™ Classic™ Earplug.





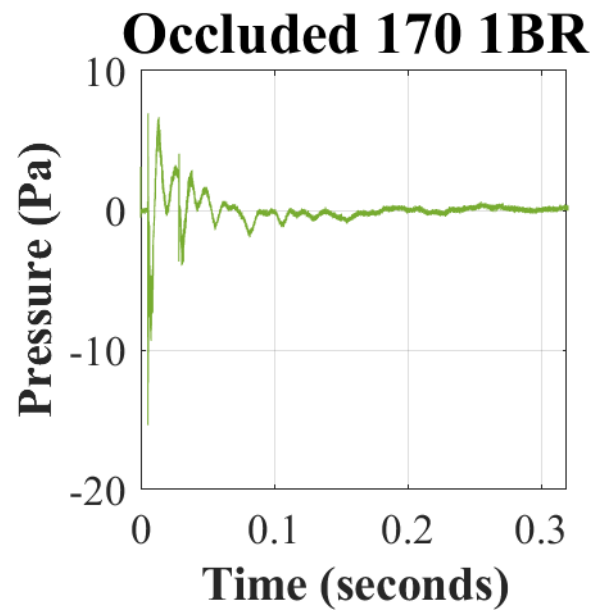
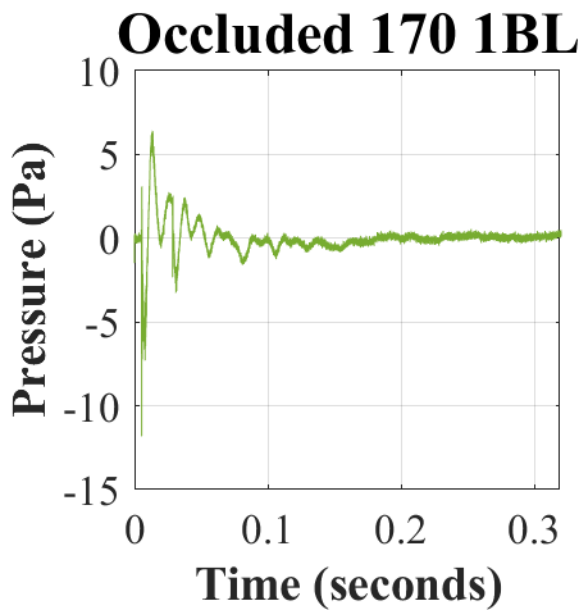
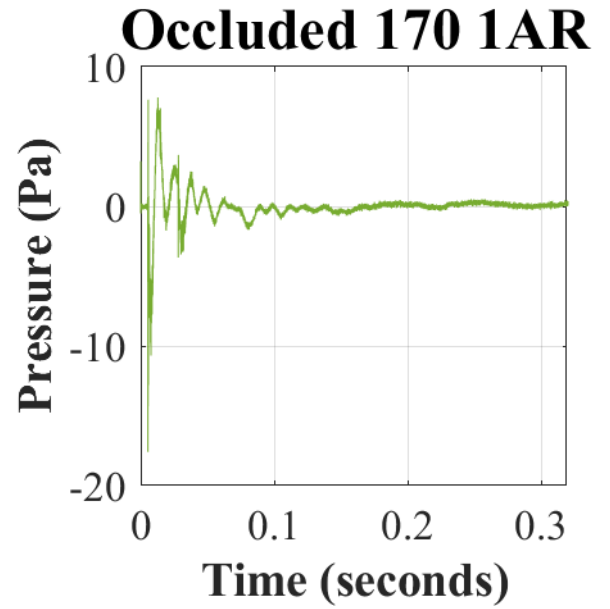
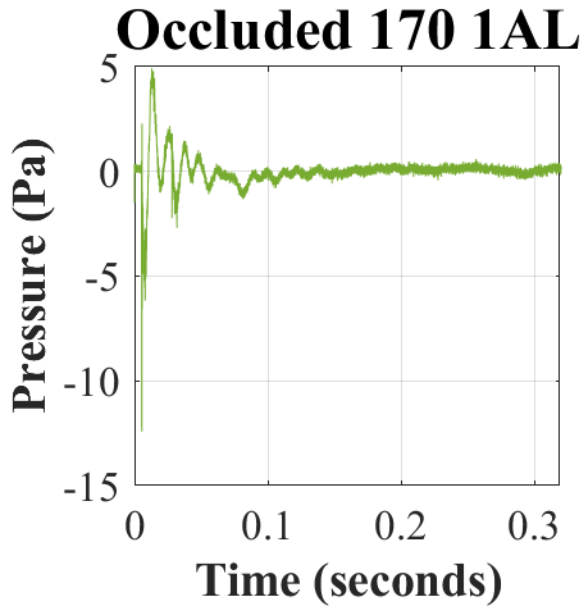


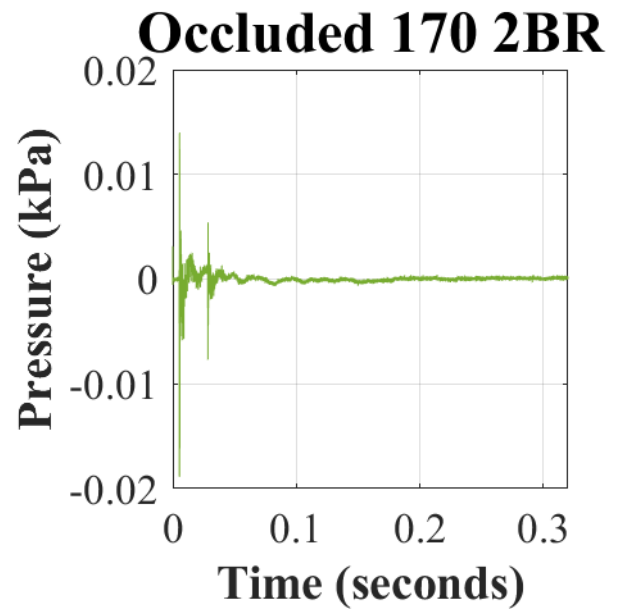
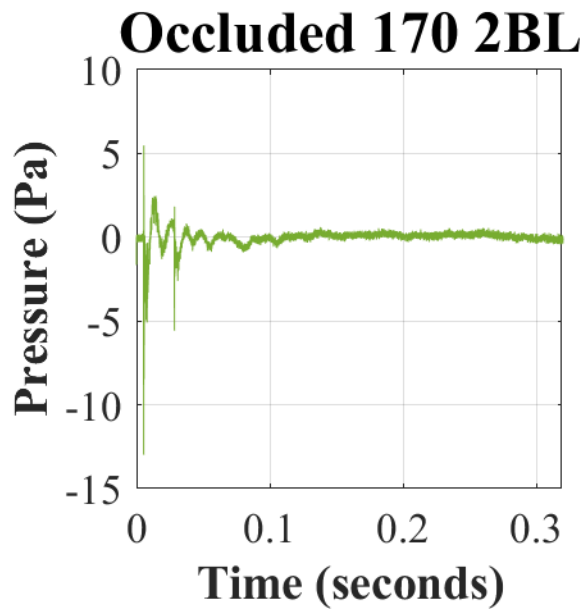
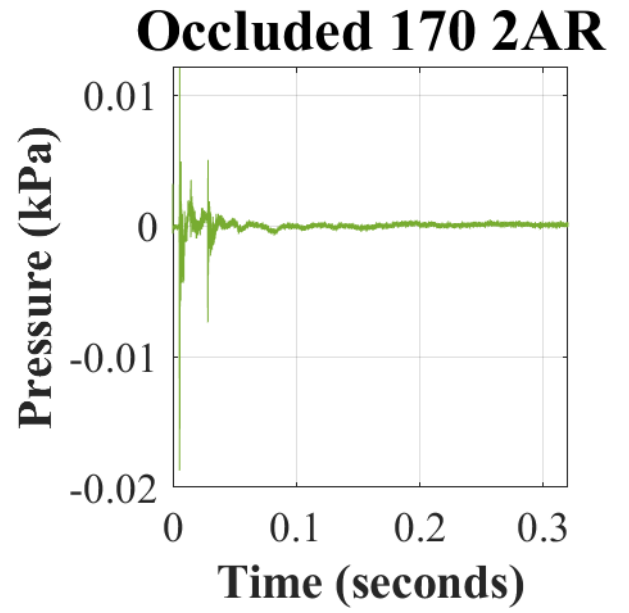
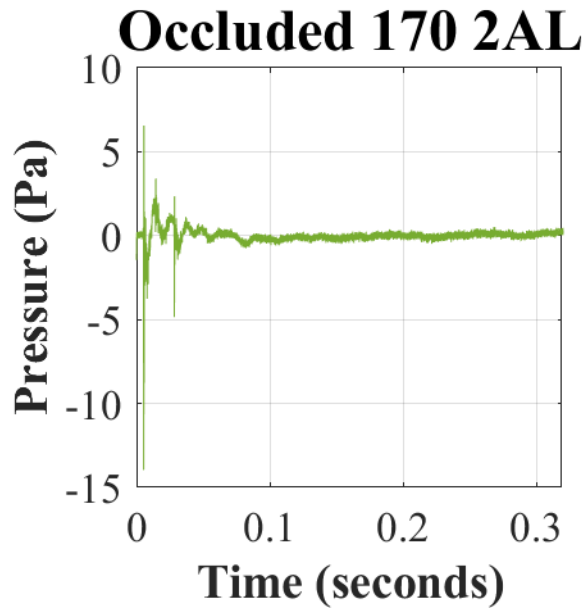


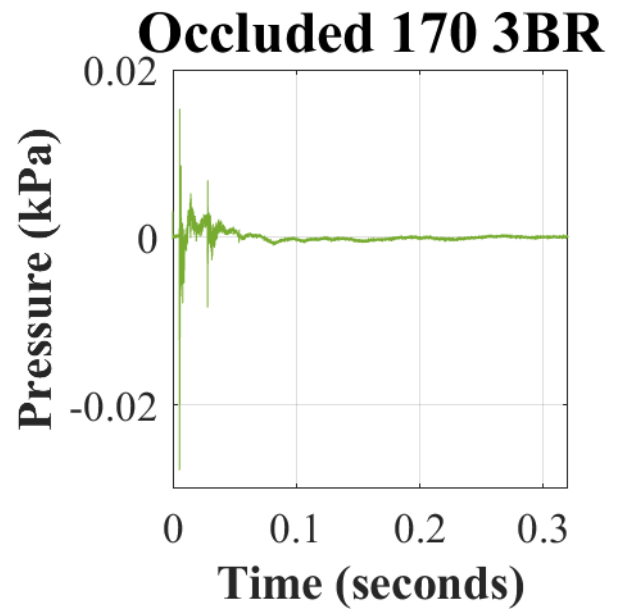
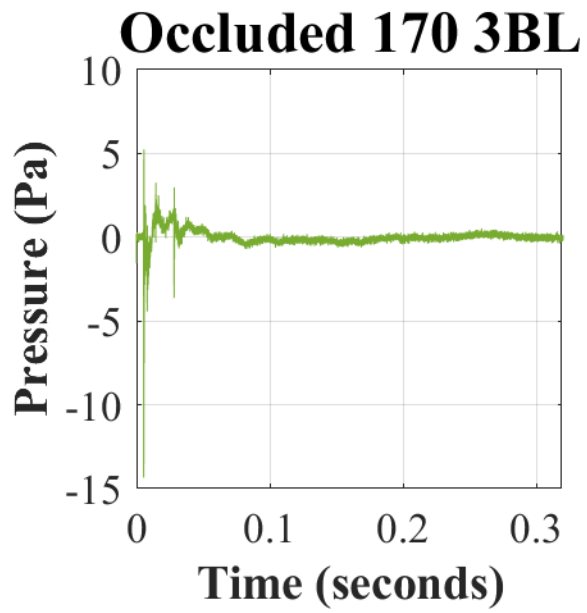
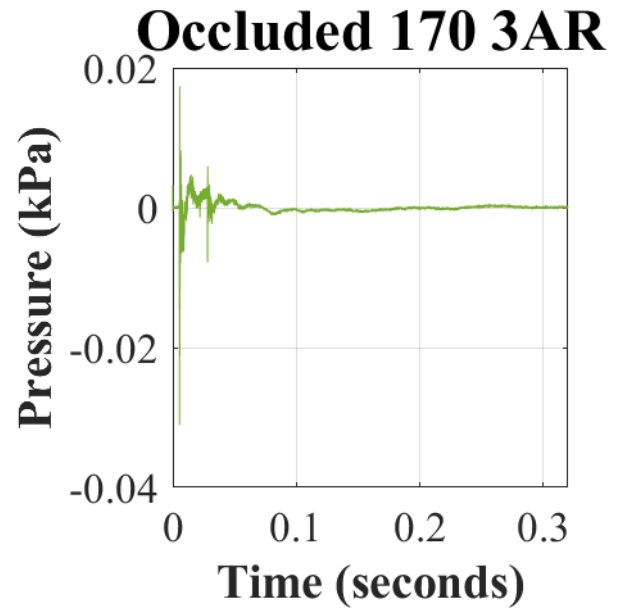
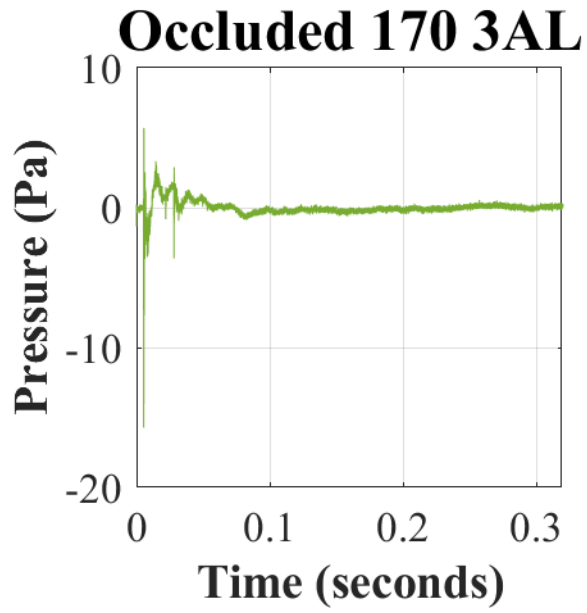


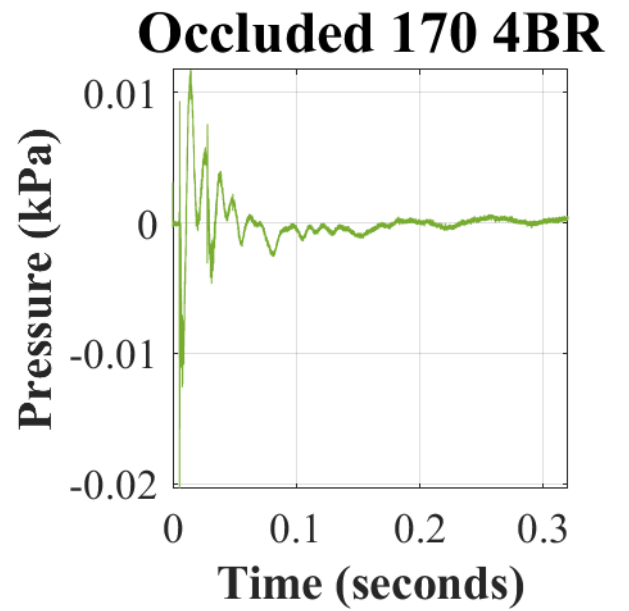
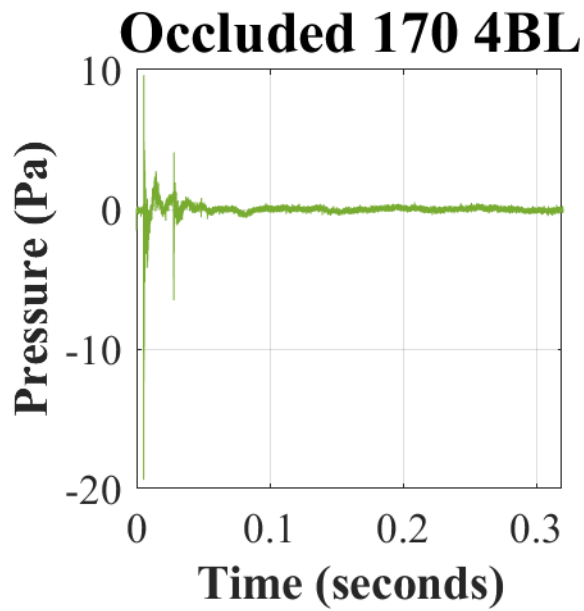
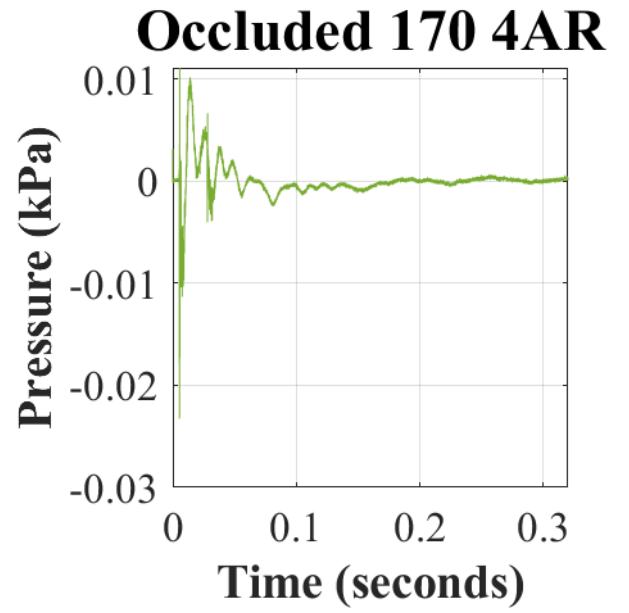
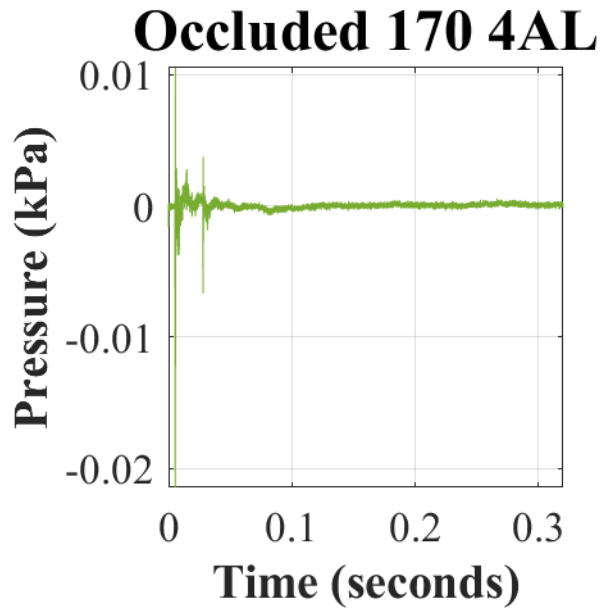
Note. The naming convention for all occluded waveforms is “Unoccluded LvL NnX”, where ‘Unoccluded’ is the test condition (i.e., ATF has the HPD doffed), ‘LvL’ is the nominal test level (i.e., 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or B) indicating HPD fit (i.e., first or second, respectively), and ‘X’ indicates from what ATF microphone the recording is from (i.e., right (R) or left (L) pinnae).

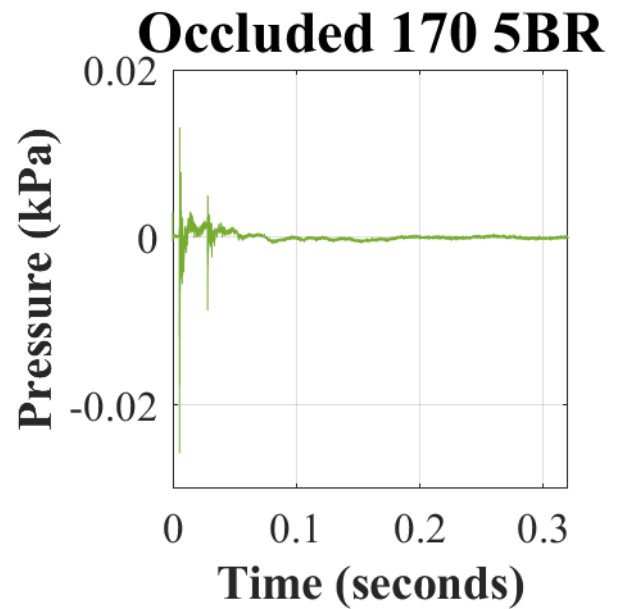
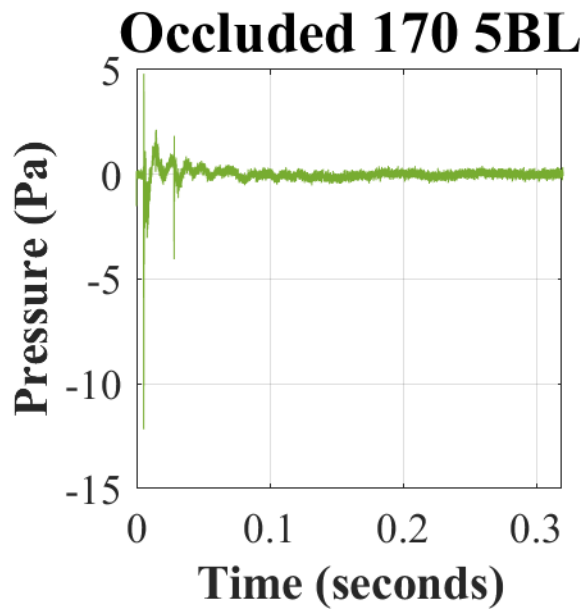
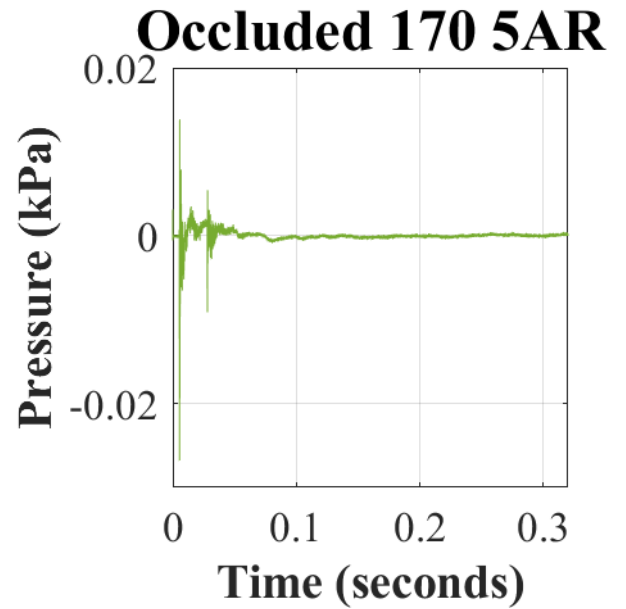
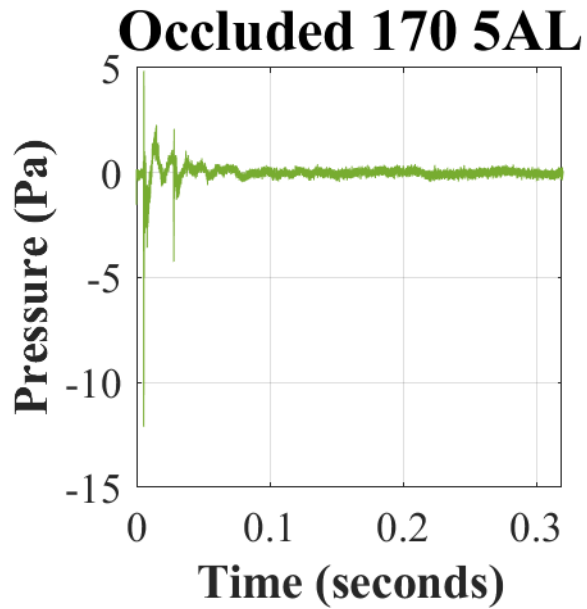
Appendix C. Recorded occluded (closed-ear) waveforms in response to 170 dBp with the E-A-R™ Classic™ Earplug.





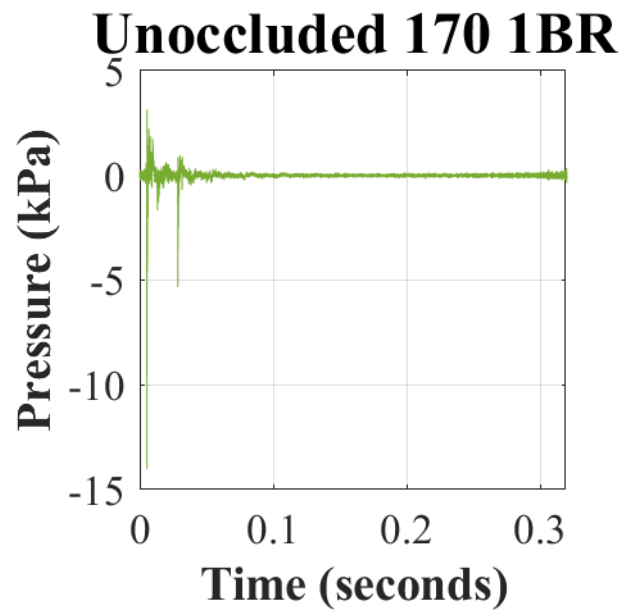
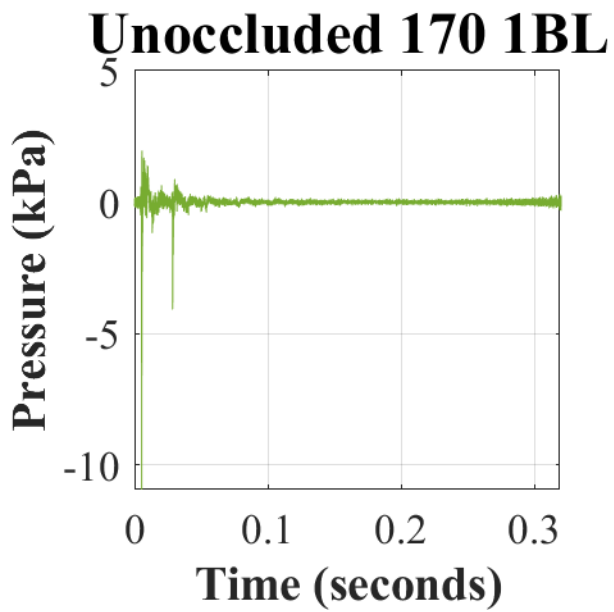
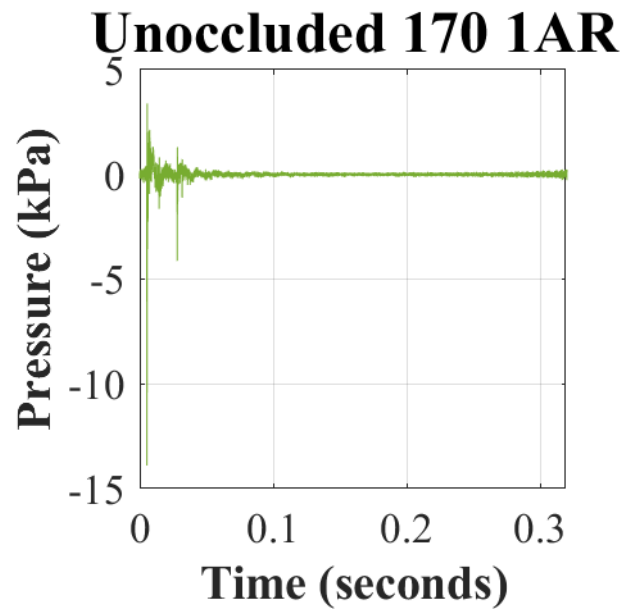
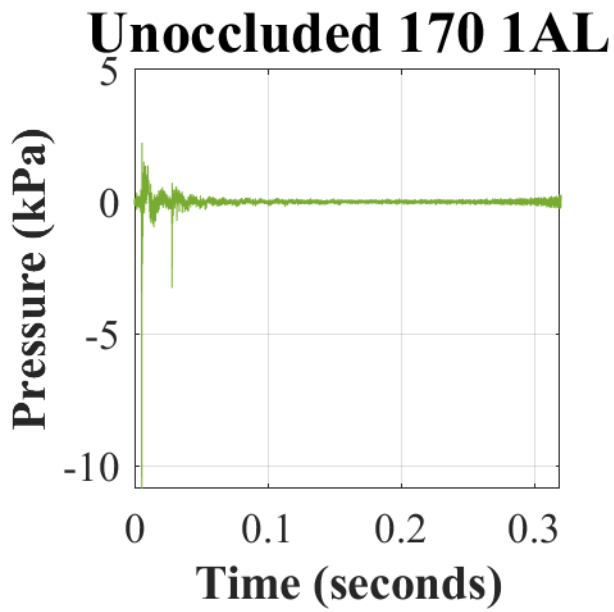


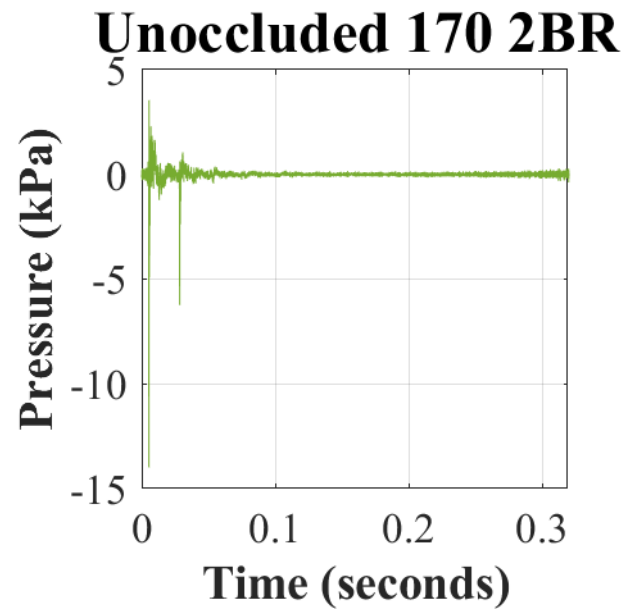
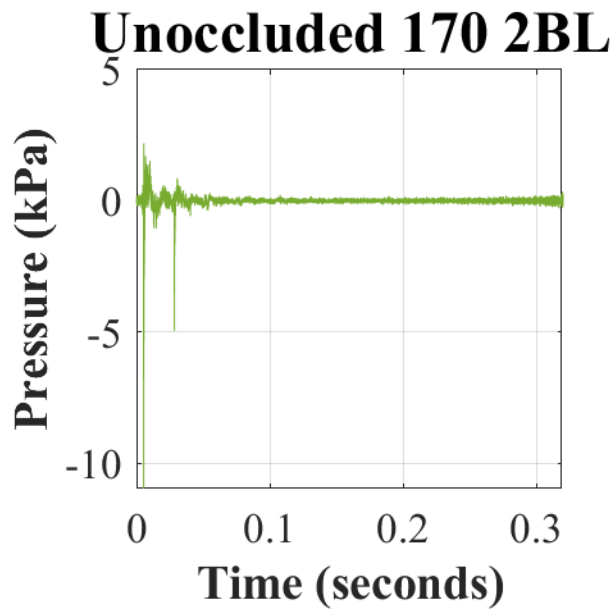
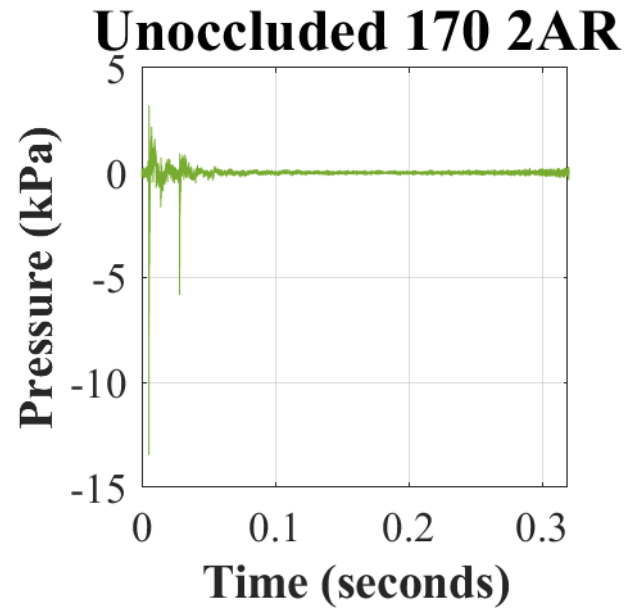
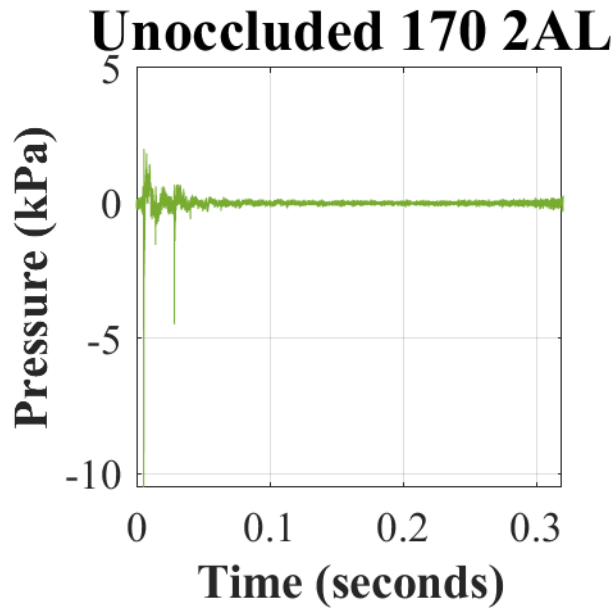


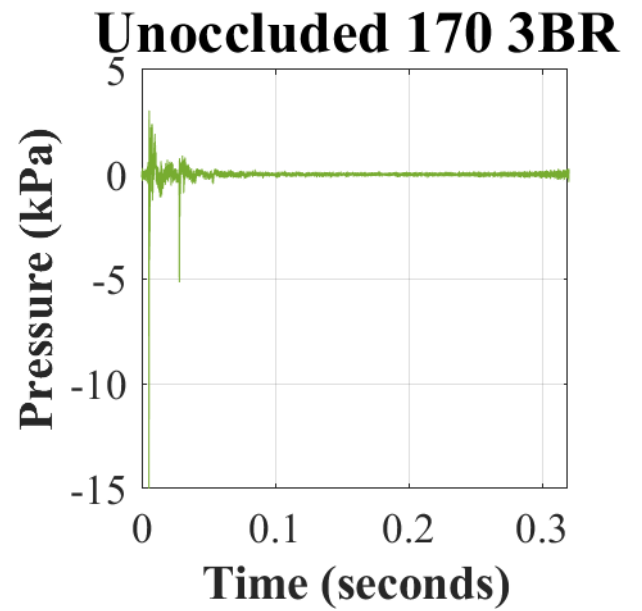
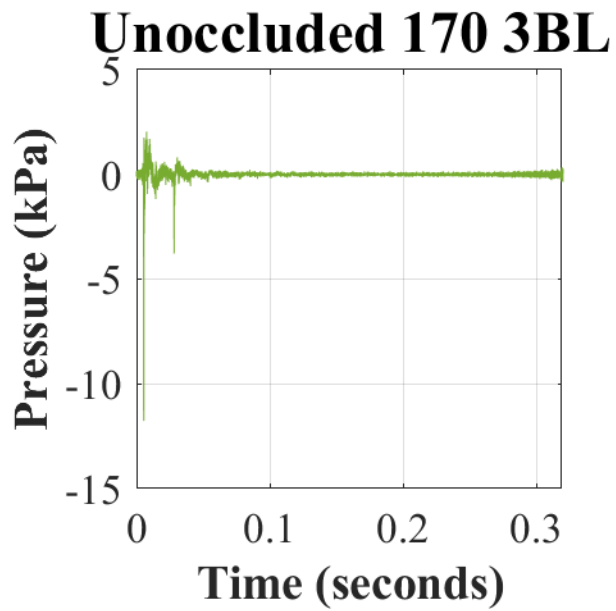
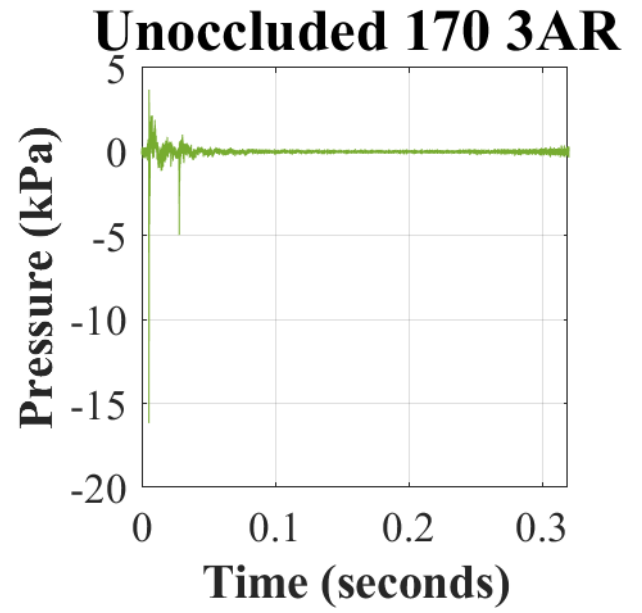
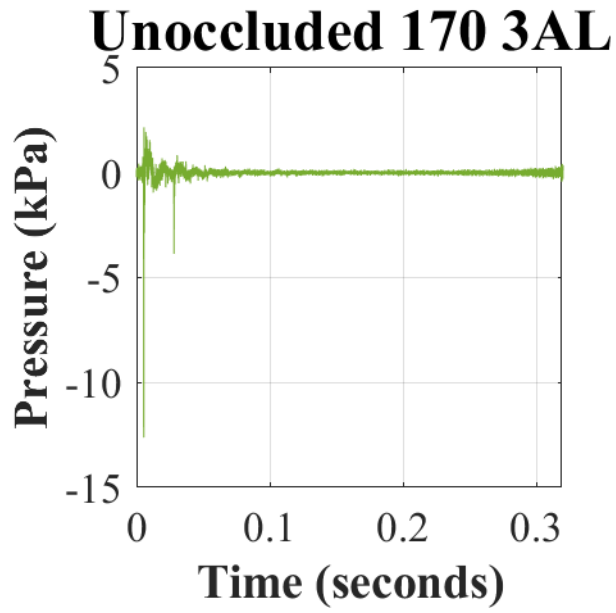


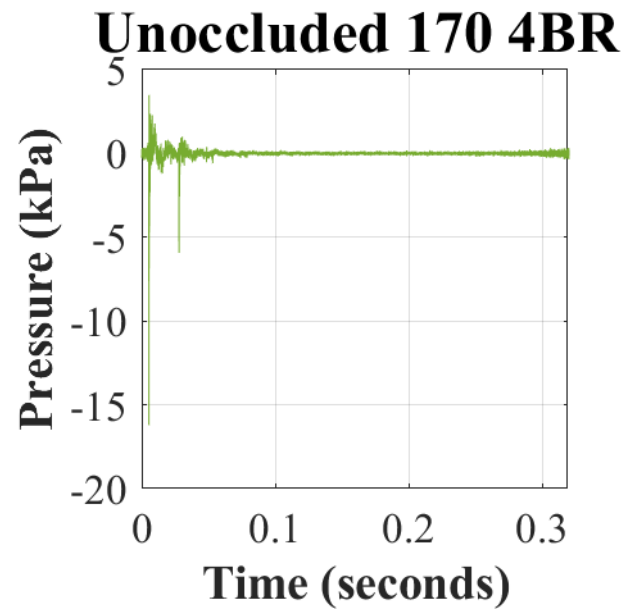
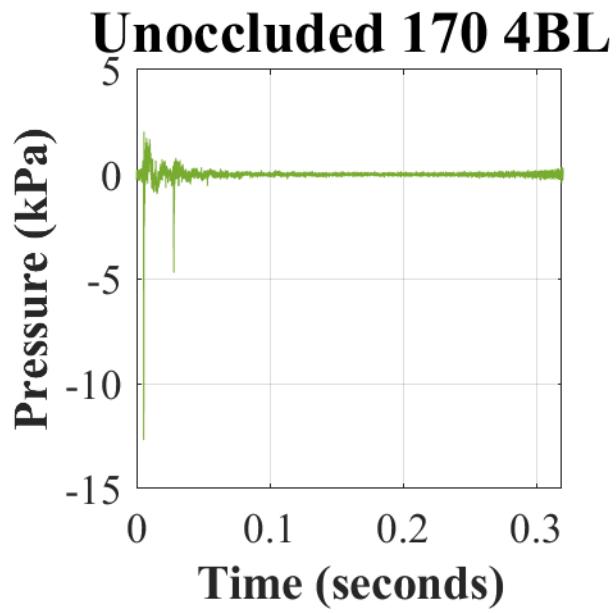
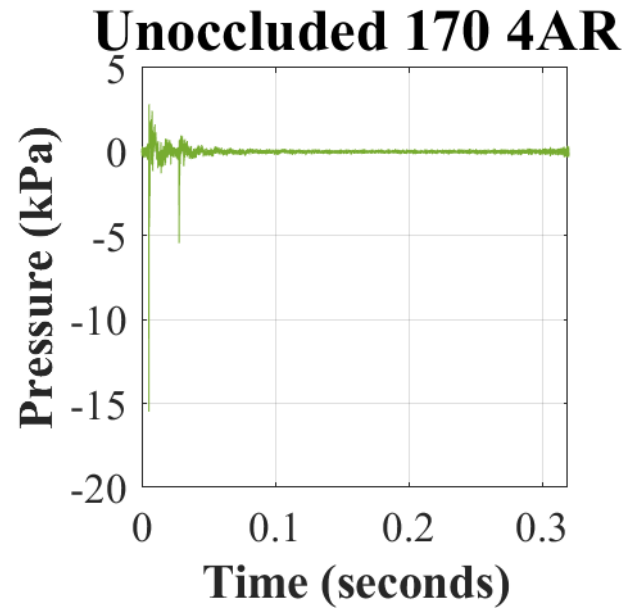
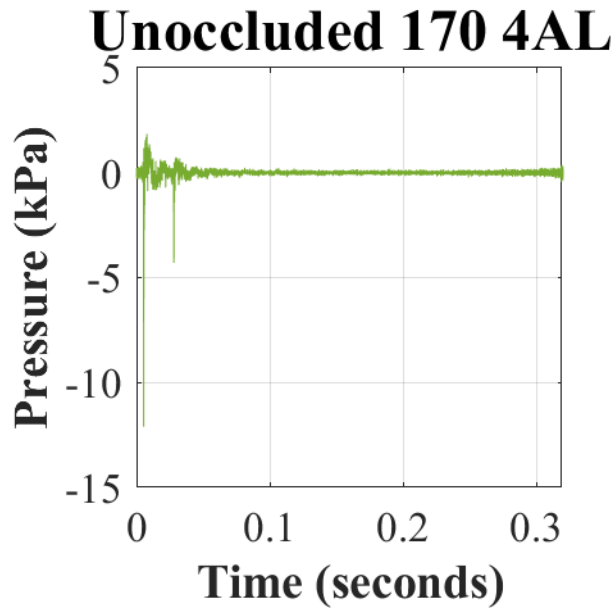
Note. The naming convention for all occluded waveforms is “Occluded LvL NnX”, where ‘Occluded’ is the test condition (i.e., ATF has the HPD donned), ‘LvL’ is the nominal test level (i.e., 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or B) indicating HPD fit (i.e., first or second, respectively), and ‘X’ indicates from what ATF microphone the recording is from (i.e., right (R) or left (L) pinnae).

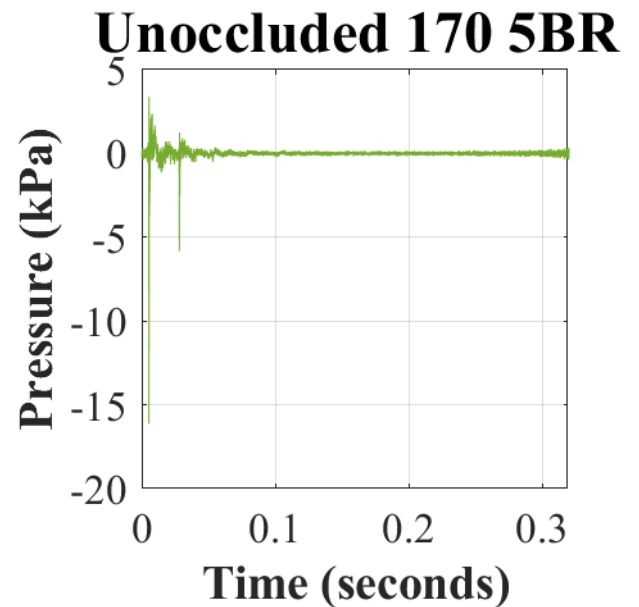
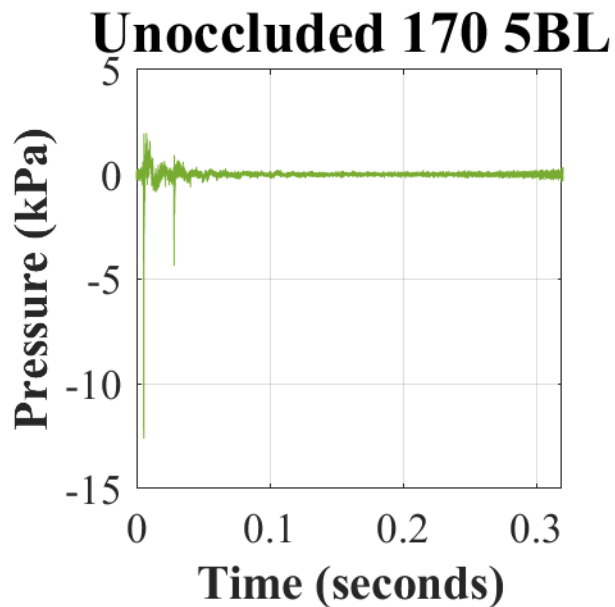
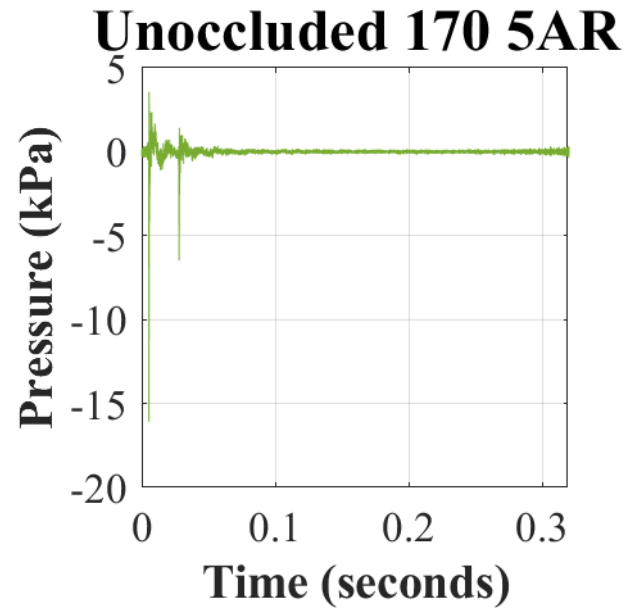
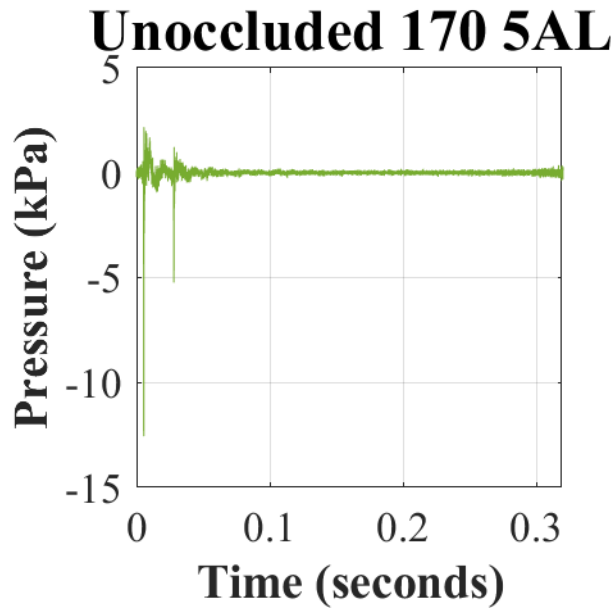
Appendix D. Estimated unoccluded (open-ear) waveforms in response to 170 dBp with the E-A-R™ Classic™ Earplug.





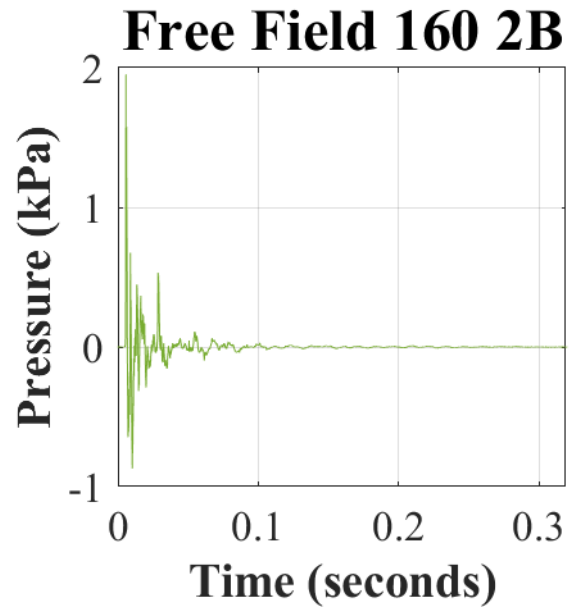
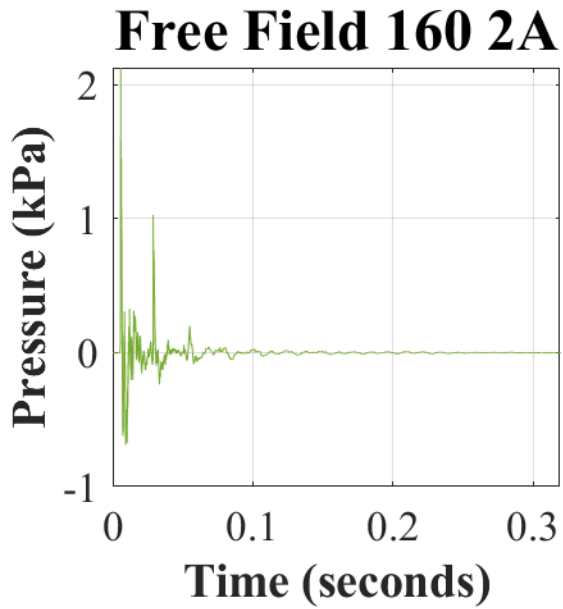
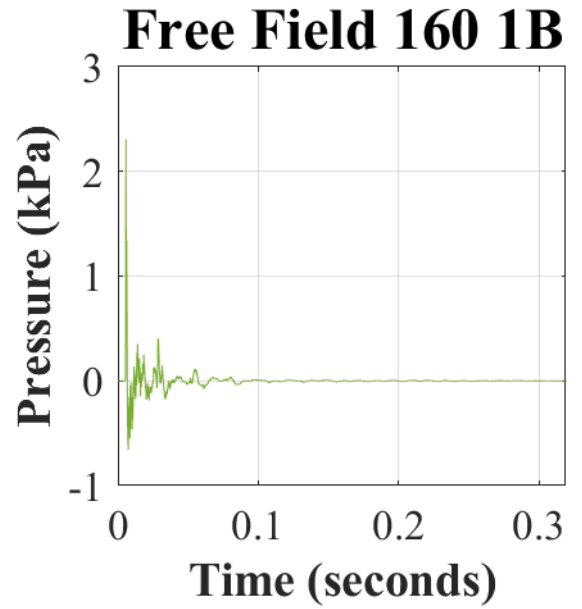
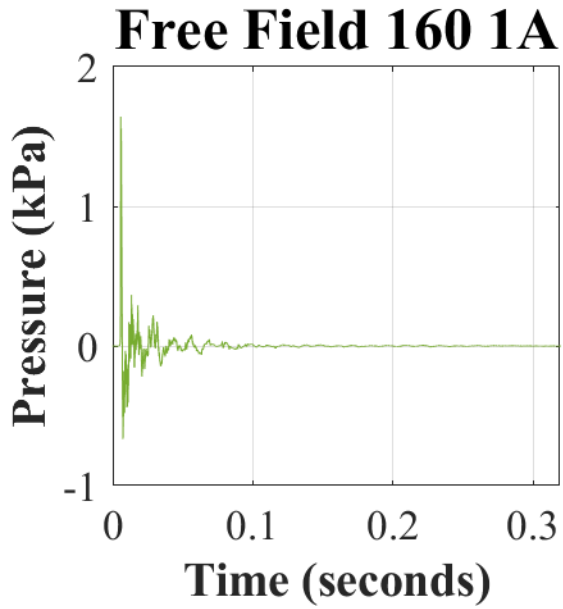


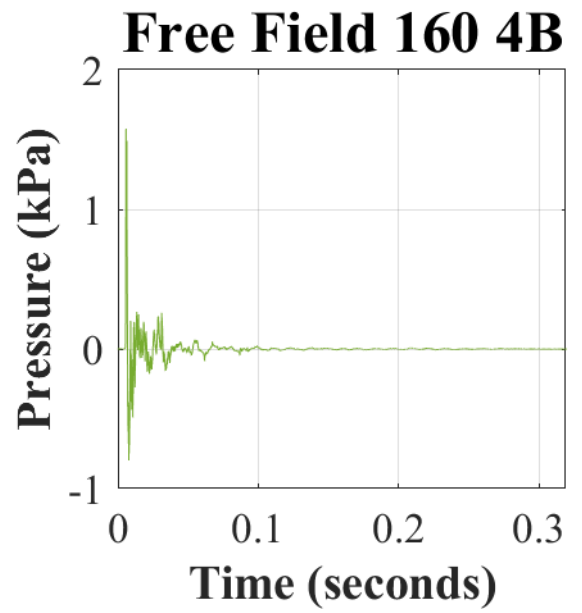
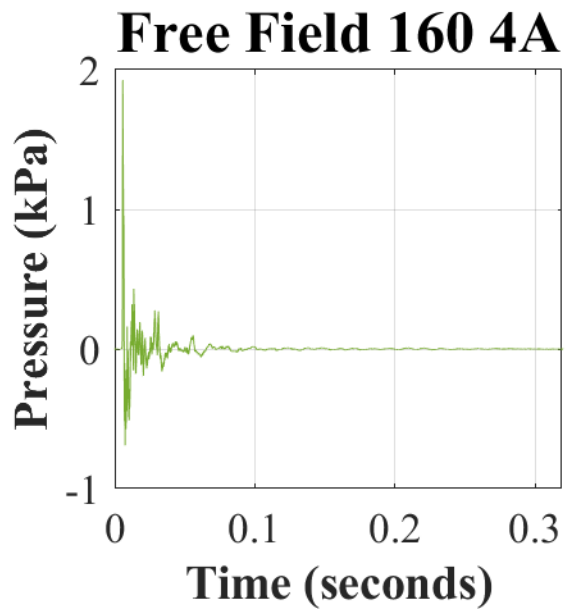
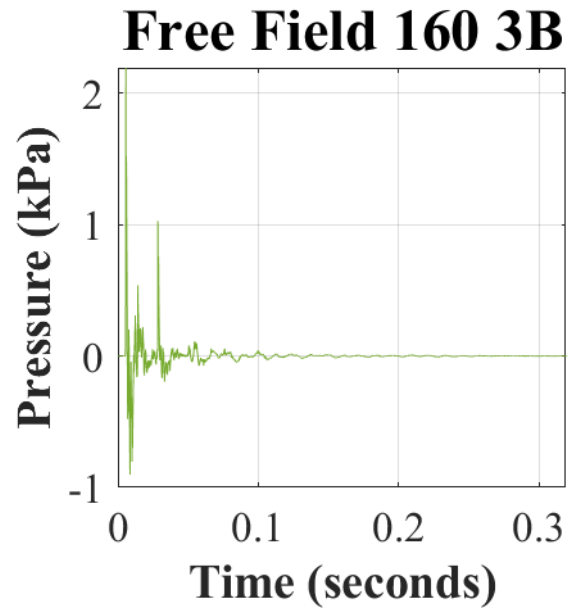
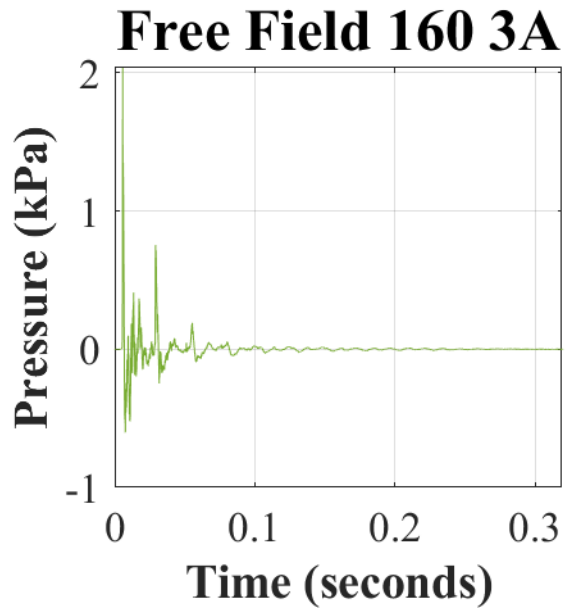


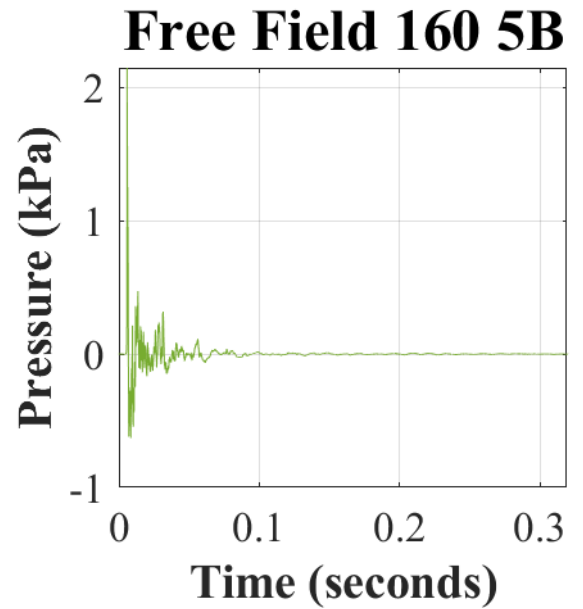
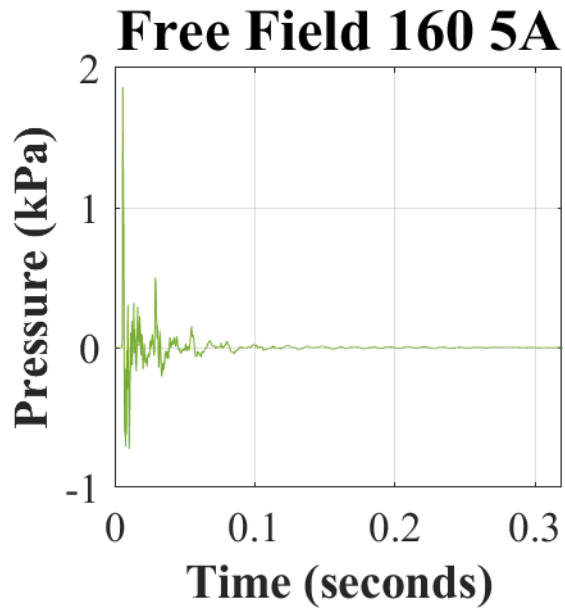


Note. The naming convention for all occluded waveforms is “Unoccluded LvL NnX”, where ‘Unoccluded’ is the test condition (i.e., ATF has the HPD doffed), ‘LvL’ is the nominal test level (i.e., 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or B) indicating HPD fit (i.e., first or second, respectively), and ‘X’ indicates from what ATF microphone the recording is from (i.e., right (R) or left (L) pinnae).

Appendix E. Recorded waveform of the impulse measured with the free-field probe at 160 dBp and the E-A-R™ Classic™ Earplug donned.

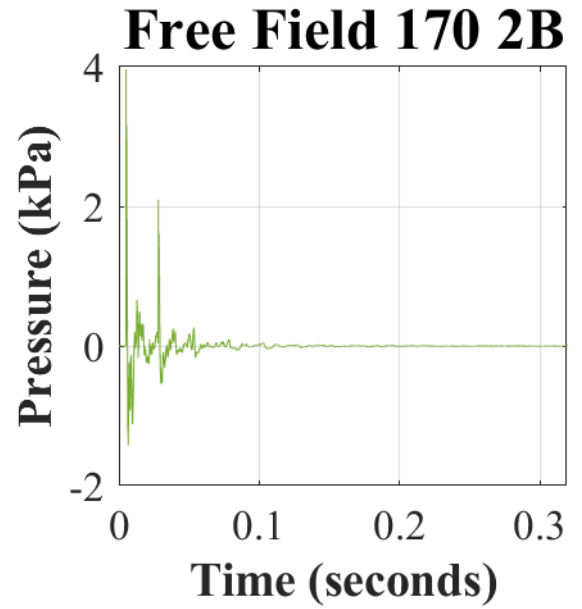
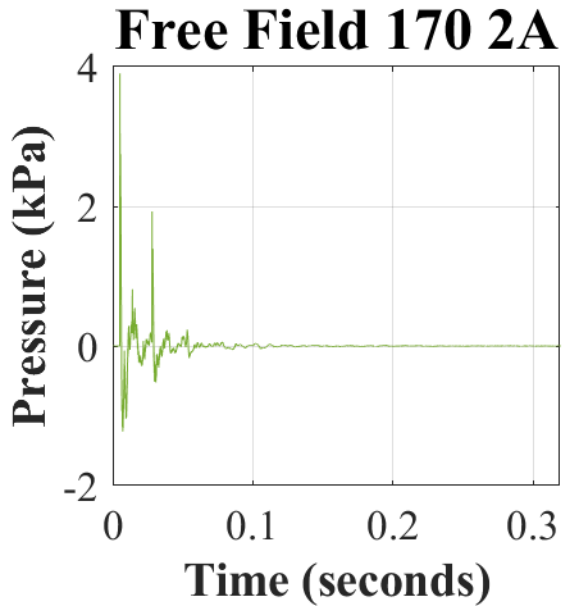
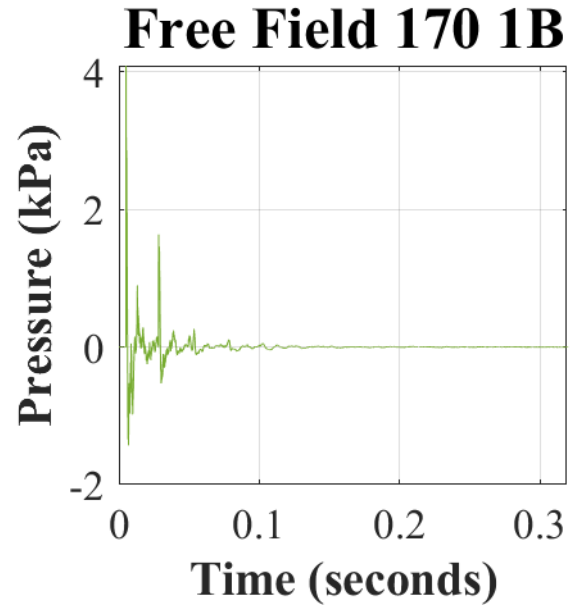
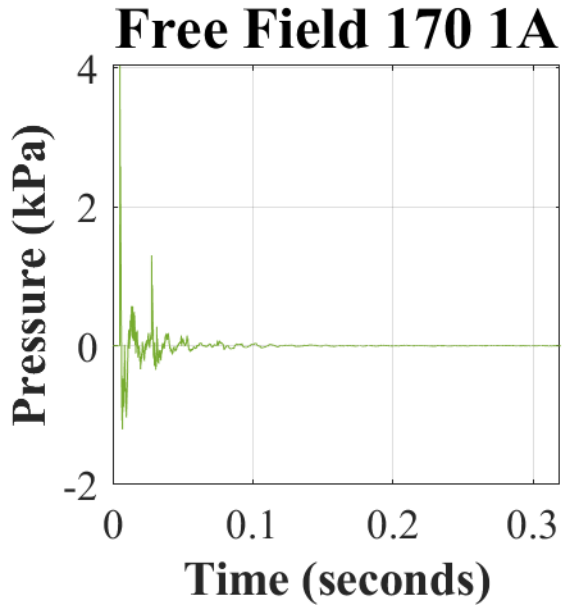


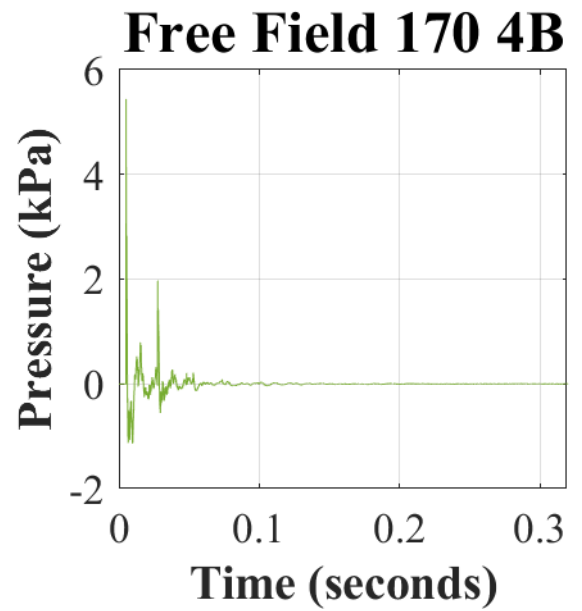
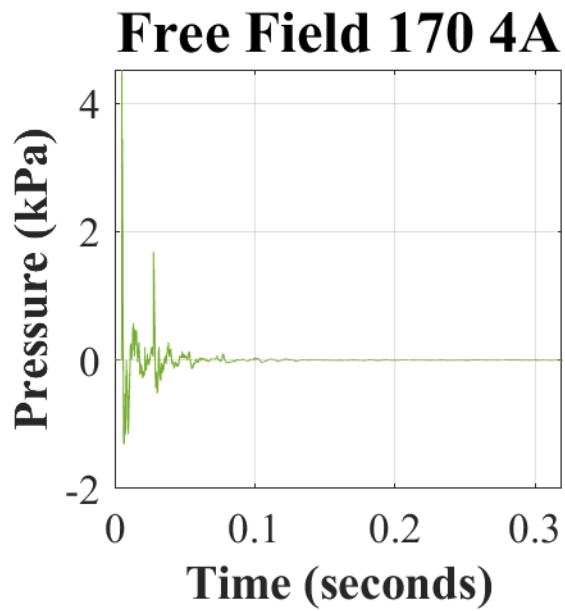
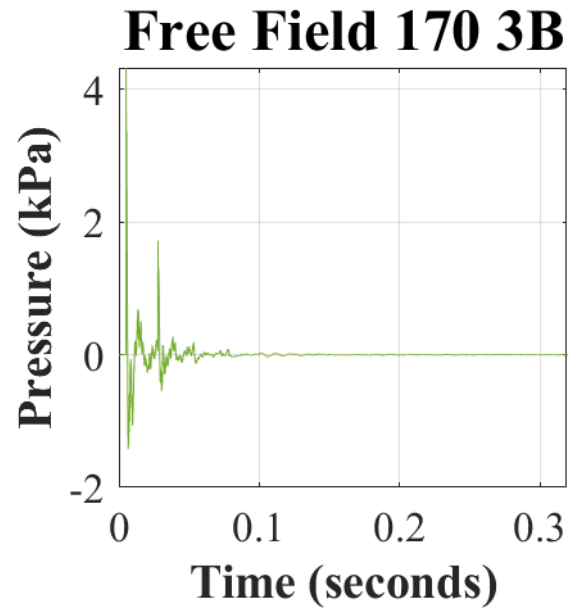
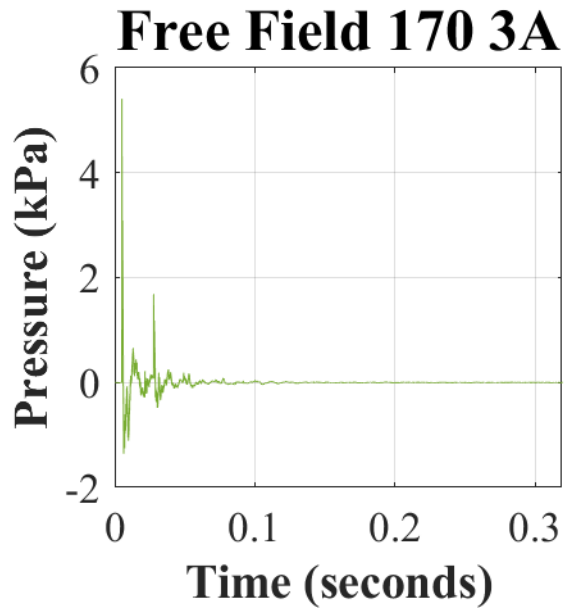


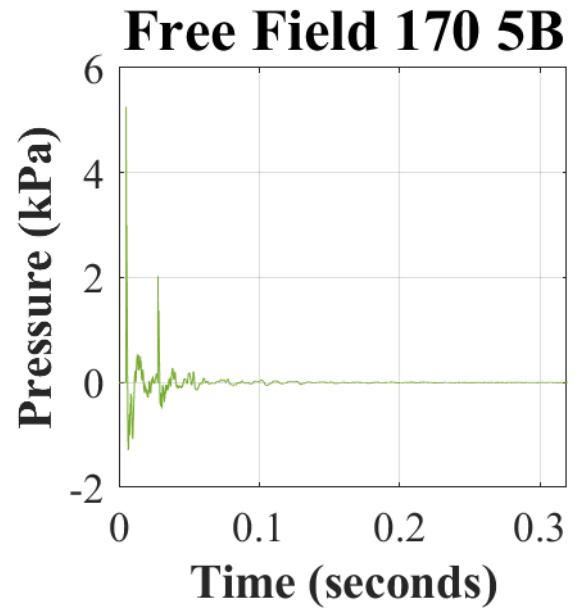
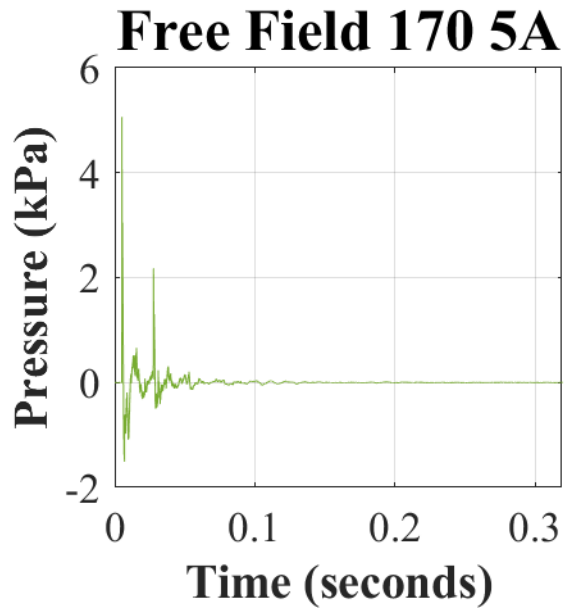


Note. The naming convention for all free-field waveforms is “Free Field LvL Nn”, where ‘Free Field’ indicates that the recording was obtained using the PCB reference microphone, ‘LvL’ is the nominal test level (170 dBp), ‘N’ is the device sample number (1 to 5), and ‘n’ is the device trial (i.e., A or B).

Appendix F. Recorded waveform of the impulse measured with the free-field probe at 170 dBp and the E-A-R™ Classic™ Earplug donned.







Note. The naming convention for all free-field waveforms is “Free Field LvL Nn”, where ‘Free Field’ indicates that the recording was obtained using the PCB reference microphone, ‘LvL’ is the nominal test level (170 dB), ‘N’ is the device sample number (1 to 5), and ‘n’ is the device trial (i.e., A or B).