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Impulse Peak Insertion Loss Testing of the 3M™ Combat Arms™ Generation 4.0 Earplug

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Executive Summary

The standard measure of attenuation provided by a hearing protection device (HPD) in response to an impulsive noise is the impulse peak insertion loss (IPIL). This technical memorandum describes the IPIL testing conducted 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” on the 3M™ Combat Arms™ Generation 4.0 earplug (CAE Gen 4.0; [Model 6515-01-576-8861]) in two test modes: open (i.e., vented) and closed (i.e., unvented). Rather than testing at the nominal test levels specified by ANSI S12.42-2010 (i.e., 130, 150, and 170 decibel peak (dB_P, re: 20 μPa)), all samples were tested at the nominal levels of 160 and 170 dB_P, as these higher levels are more representative of military occupation impulse noise exposures. A total of five samples were fitted to an acoustic test fixture two times each for a total of 10 trials per test level for both HPD modes. No samples were rejected. The mean and standard deviation (SD) IPIL values for each nominal level are documented in Table 1. Results of the testing revealed overall higher mean IPIL values when the CAE Gen 4.0 was in the closed mode compared to the open mode at both nominal test levels. Greater IPIL values were also measured for the 170 dB_P test condition compared to 160 dB_P for both the open and closed modes.

Table 1.

CAE Gen 4.0 mean (SD) IPIL value (in dB) for all test conditions.

	160 dB_P	170 dB_P
Open	29.2 (2.2)	34.1 (0.8)
Closed	42.3 (1.9)	43.5 (2.4)

Introduction

The 3M™ Combat Arms™ Generation 4.0 earplug (CAE Gen 4.0; 3M, St. Paul, MN) is a level-dependent triple-flange corded earplug that is available in three sizes: small, regular, and large. Level-dependent earplugs, like the CAE Gen 4.0, provide varied levels of attenuation as a function of the environmental noise level(s). The CAE GEN 4.0 design utilizes a finger-touch rocker cover, which allows the user to manually select an open (i.e., vented) or closed (i.e., unvented) mode. Per manufacturer package instructions, the purpose of the open mode is to provide ample situational awareness by allowing the passage of quiet sounds while instantaneously attenuating loud impulse noise such as weapon fire. The purpose of the closed mode is to protect against continuous loud noises such as “aircraft, vehicles, watercraft, generators, etc.” (3M Occupational Health, 2010).

This technical memorandum details the procedures followed to determine the impulse peak insertion loss (IPIL) value for the CAE Gen 4.0 in the open and closed modes. 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 at the Naval Submarine Medical Research Laboratory (NSMRL) by Regional Hearing Conservation Program of Record personnel. All testing was completed in a 1000 m³ anechoic chamber in order to minimize any effects of sound reflections.

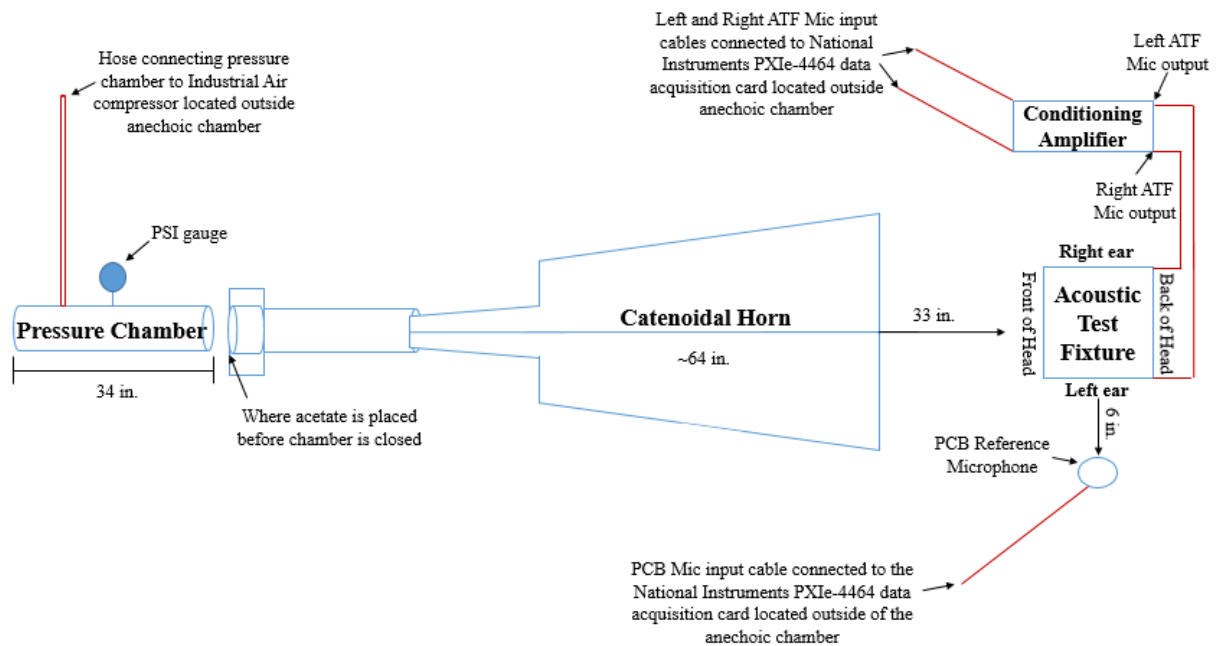
Equipment

Hardware. Acoustic impulses were generated by NSMRL’s 4-inch shock tube (B/C Precision, Inc., Greendale, IN). The shock tube pressure chamber is approximately 34 inches (in.) long, with an inner diameter of 4.0 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 7in. by 7in., 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 2 millimeters (mil.) thick.

The acoustic test fixture (ATF) used (GRAS 45CB; GRAS Sound and Vibration, Twinsburg, OH) for all data acquisition was set up in accordance with (IAW) ANSI/ASA 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”. The ATF was connected to a conditioning amplifier which also served as the power supply (GRAS Type 12AA; GRAS Sound and Vibration, Twinsburg, OH). 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 Hz tone. A diagram depicting the aerial view of the NSMRL 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 custom software (LabVIEW; National Instruments Corp., Austin, TX) written by NSMRL personnel, and was connected to three inputs: the left ATF microphone, right ATF microphone, and reference microphone. 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 at a sampling rate of 204.8 kSamples/second during each impulse recording. Pre-trigger settings were 1024 samples per 0.01 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 an analog filter.

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-L).

Hearing Protection Device Samples. Five samples of the CAE Gen 4.0 corded reusable earplugs (Manufacturer Product Number: 6515-01-576-8861) 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.

Procedure

Two HPD modes (i.e., open or vented, closed or unvented) were tested for each of the five samples of the CAE Gen 4.0. 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 dBp). No samples were rejected. All five HPD samples were tested in the open (i.e., vented) and closed (i.e., unvented) mode. 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 rocker cover was placed in the closed or open position and the earplug was inserted into the ear canal by holding near the rocker cover. Once inserted, appropriate fit of each earplug was confirmed by pulling gently on the earplug to confirm it did not easily come out of the canal.

Impulse noises were presented to the ATF in the occluded (i.e., HPD inserted in open or closed mode) 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 in each test condition. 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 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 dB 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 dB 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 zero 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 dB 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 dB and 170 dB). Every waveform was plotted with time on the x-axis and pressure on the y-axis. The transfer functions were not plotted.

Results

At both nominal test levels, greater IPILs were obtained when the earplug rocker cover was closed (i.e., unvented) compared to when it was open (i.e., vented). Also, greater IPIL values were calculated at the 170 dB nominal level compared to the 160 dB nominal level for both tested HPD modes (i.e., closed, open). Calculations resulted in mean IPIL values of 29.2 and 34.1 dB for the 160 dB open and closed modes, respectively. Mean IPIL values were 42.3 and 43.5 for the 170 dB open and closed modes, respectively. Calculated IPIL values for all sample trials in the open mode ranged between 26.1 to 31.3 dB at 160 dB and 32.2 to 35.1 dB at 170 dB, while all tested sample trials in the closed mode ranged between 38.4 to 45.9 dB at 160 dB and between 39.0 to 47.2 dB at 170 dB. Differences of approximately 5 to 7 dB across trials in both tested HPD modes may be due to a combination of inherent variance within the impulse system and test-retest variability. The individual attenuations for each sample and trial for the two tested HPD modes (i.e., open, closed) at 160 and 170 dB are shown in Table 2. Also presented in Table 2 are the ear-specific means and standard deviations (SD) across all samples and trials, and the overall means and standard deviations (SD) across all samples, trials, and both ears for each mode.

Table 2.*Mean (SD) IPIL values for Tested CAE Gen 4.0 Samples.*

	160 dBP				170 dBP			
	<i>Open</i>		<i>Closed</i>		<i>Open</i>		<i>Closed</i>	
	<i>Right</i>	<i>Left</i>	<i>Right</i>	<i>Left</i>	<i>Right</i>	<i>Left</i>	<i>Right</i>	<i>Left</i>
HPD 1, Trial A	31.1	30.3	38.4	41.6	34.6	33.9	43.7	39.0
HPD 1, Trial B	26.3	26.4	40.8	42.6	32.2	33.3	44.1	47.2
HPD 2, Trial A	30.2	30.1	40.3	39.6	33.9	33.4	46.1	41.4
HPD 2, Trial B	30.6	30.1	45.9	40.8	34.0	33.4	44.3	40.9
HPD 3, Trial A	31.1	31.1	42.8	41.1	34.7	34.4	46.0	44.3
HPD 3, Trial B	26.4	26.1	43.8	42.7	35.1	35.1	45.2	40.5
HPD 4, Trial A	30.5	29.7	43.7	44.9	34.5	34.6	43.9	44.8
HPD 4, Trial B	25.1	25.3	42.7	45.2	33.4	33.4	45.3	43.9
HPD 5, Trial A	30.8	31.3	42.6	40.8	33.7	34.5	40.3	42.7
HPD 5, Trial B	29.7	31.2	42.9	42.1	34.0	35.2	46.3	39.7
Ear Specific Mean (SD)	29.2 (2.3)	29.2 (2.3)	42.4 (2.1)	42.1 (1.8)	34.0 (0.8)	34.1 (0.7)	44.5 (1.8)	42.4 (2.6)
Level Overall Mean (SD)	29.2 (2.2)		42.3 (1.9)		34.1 (0.8)		43.5 (2.4)	

Note. Unit of measure is in decibel (dB). Emitted impulses are in peak decibel (dBP).

The waveforms for all trials with the CAE Gen. 4.0 – Open (i.e., vented) are provided in Appendices A-F. The waveforms for all trials with the CAE Gen. 4.0 – Closed (i.e., unvented) are provided in Appendices G-L. All waveforms for trials with the CAE Gen. 4.0 in the open mode are color-coded green. All waveforms for trials with the CAE Gen. 4.0 in the closed mode are color-coded orange.

Discussion

The CAE Gen 4.0 is a level-dependent earplug that can be worn and used in either an open (i.e., vented) or closed (i.e., unvented) mode by manipulating the earplug rocker cover. Per the manufacturer, the open mode provides users with situational awareness by allowing quiet sound to pass through while attenuating loud impulse noise. The purpose of the closed condition is to protect against continuous noise or when the user knows in advance of the noise exposure. Our IPIL testing did not evaluate situational awareness or continuous noise attenuation. Rather, it evaluated the attenuation of loud impulse noise in the two available HPD modes. Results showed greater IPIL values when the earplug was in the closed mode compared to the open mode at both nominal test levels. All mean IPIL values exceed the CAE Gen 4.0 manufacturer reported noise reduction rating (NRR) for continuous noise (i.e., 7 dB open/ 23 dB closed).

Deviations were made from the ANSI/ASA S12.42-2010 standard governing impulse noise testing. 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. This deviation was made due to equipment and software limitations.

Second, testing at the 130 dBP and 150 dBP nominal levels was omitted. 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 shock tube that 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. Inclusion of the 160 dBP nominal level was beneficial, as data at 160 and 170 dBP provided a more representative indication of device performance at military- relevant impulse noise levels. It is important to note that these results do not guarantee similar CAE Gen 4.0 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, earplugs, eye wear, etc.).

Conclusions

This report described the determination of the mean impulse peak insertion loss (IPIL) values provided by the CAE Gen 4.0 earplug (open and closed modes) at 160 dBP and 170 dBP nominal levels. Results revealed higher overall mean IPIL values for the closed mode compared to the open mode at both nominal levels. Additionally, greater attenuation was noted at 170 dBP compared to 160 dBP in both the open and closed mode. Table 3 presents the overall calculated mean (SD) IPIL values for each nominal level and test condition.

Table 3.

CAE Gen 4.0 mean (SD) IPIL value (in dB) for all test conditions.

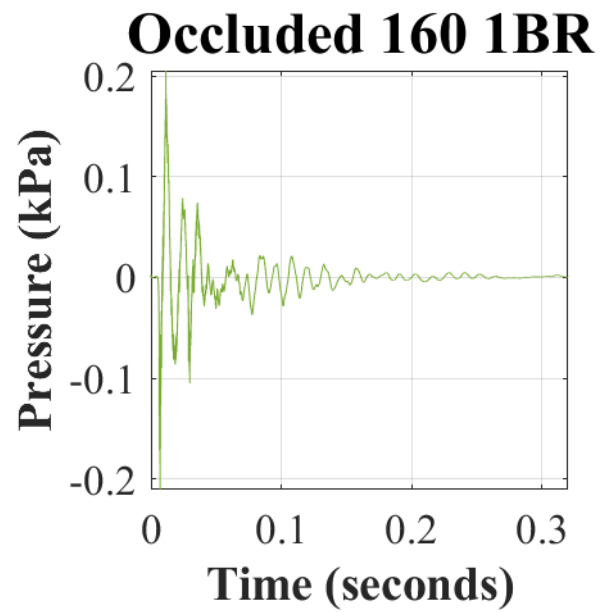
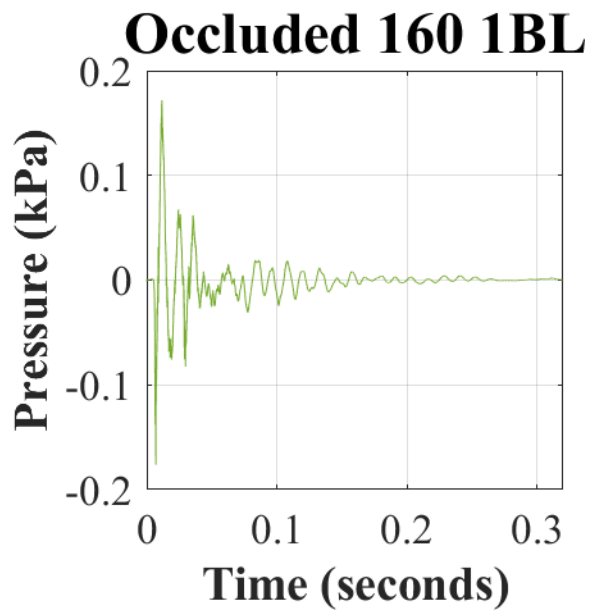
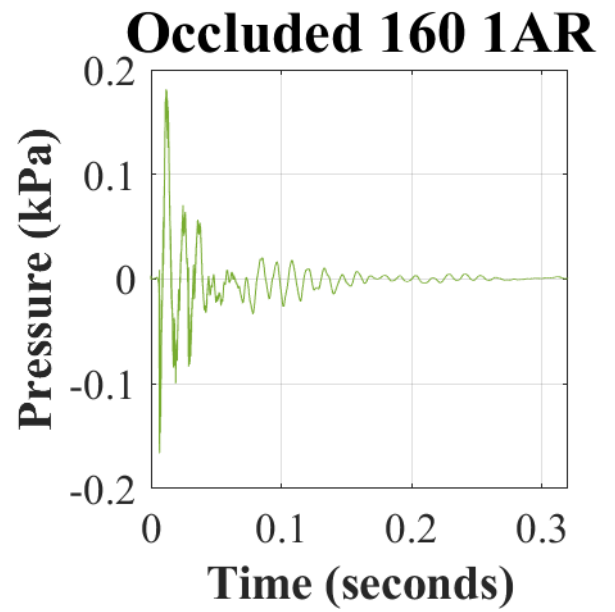
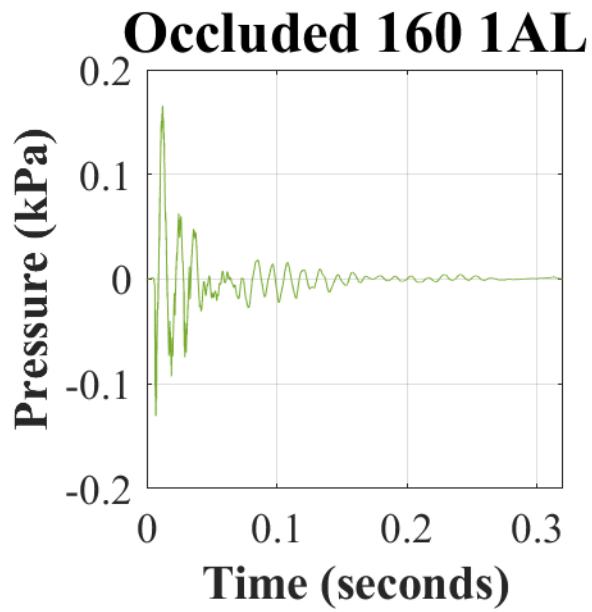
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Closed	42.3 (1.9)	43.5 (2.4)

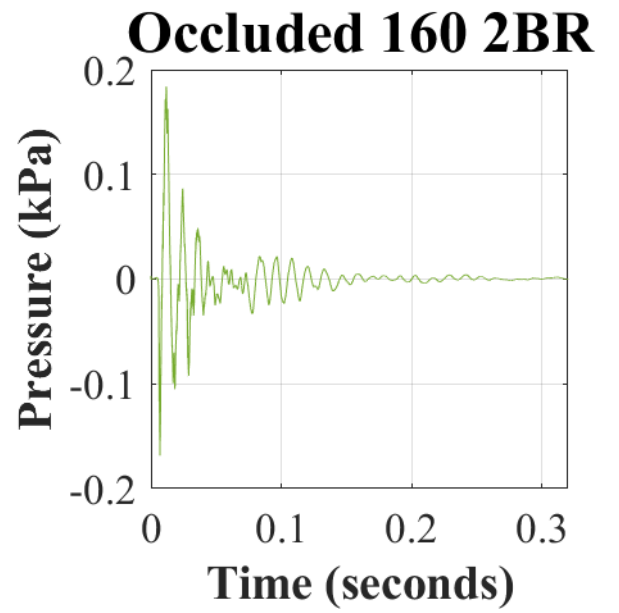
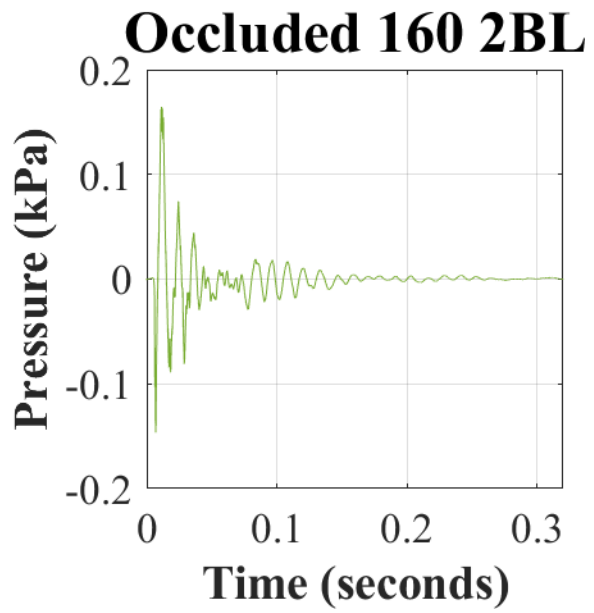
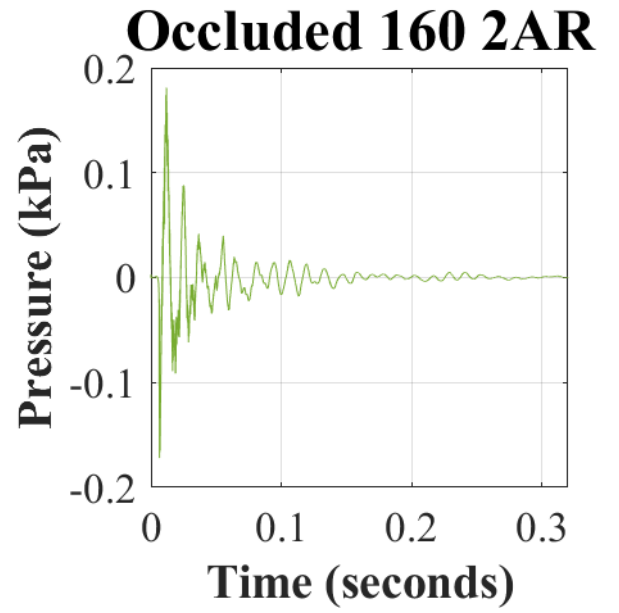
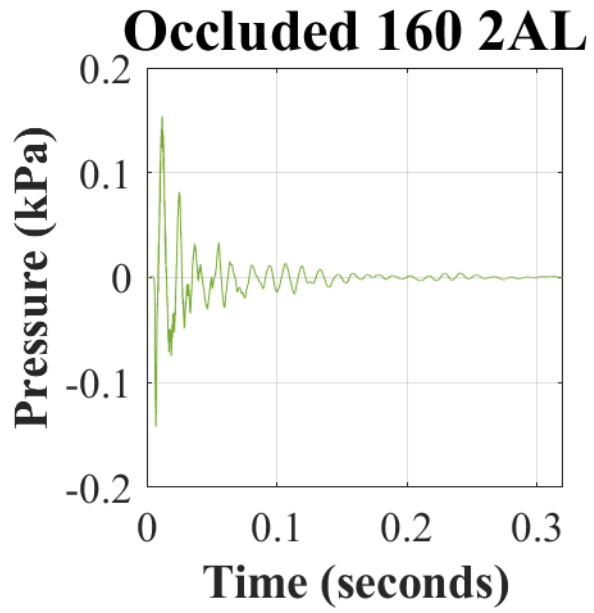
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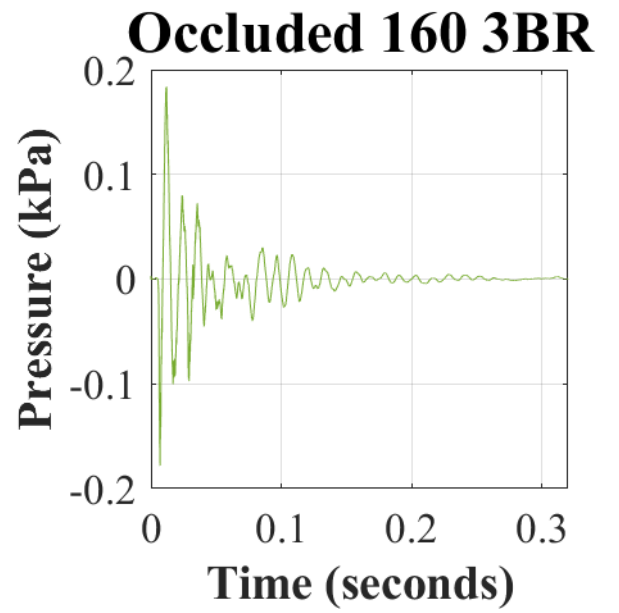
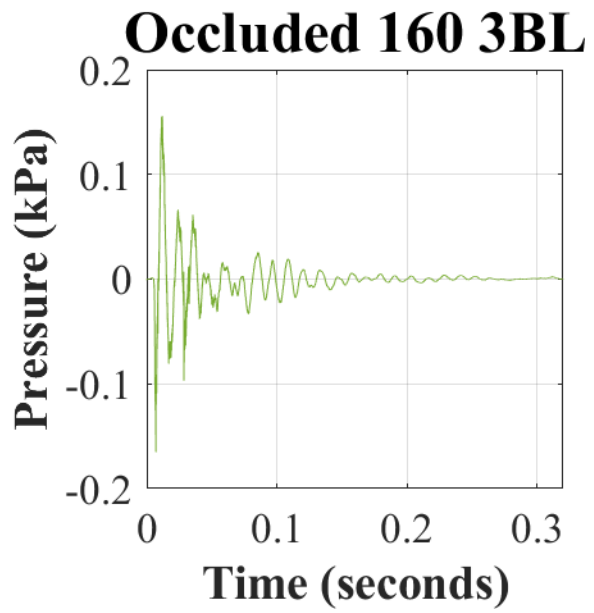
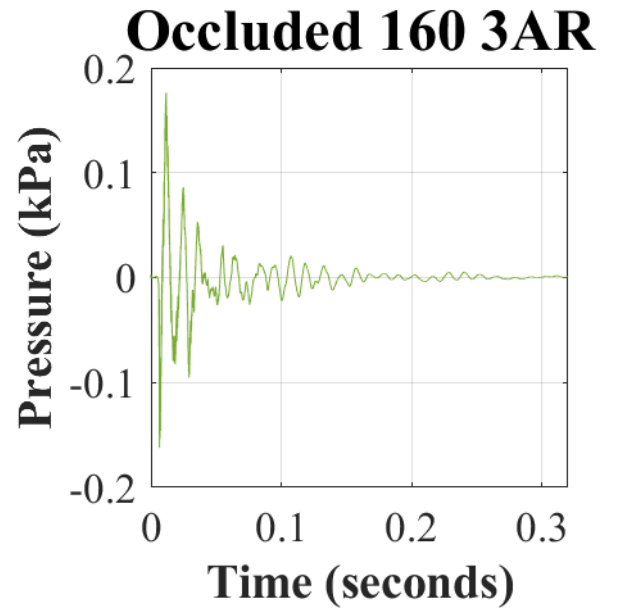
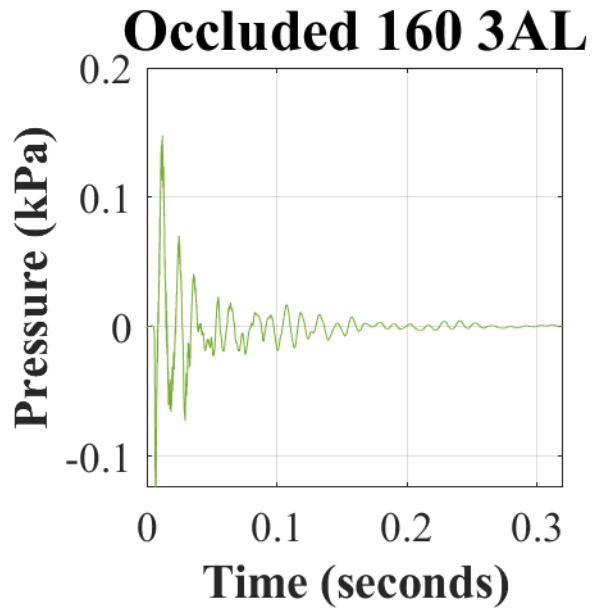
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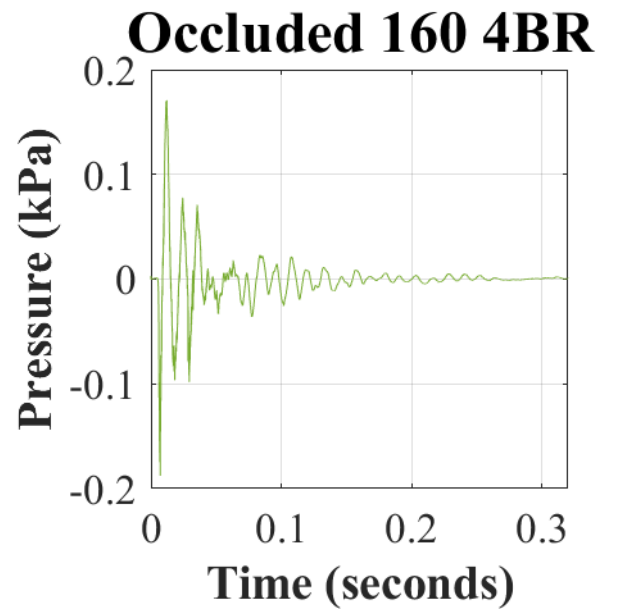
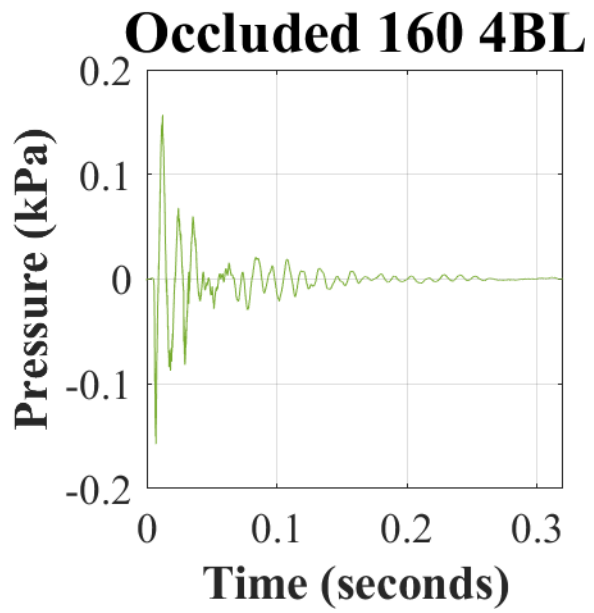
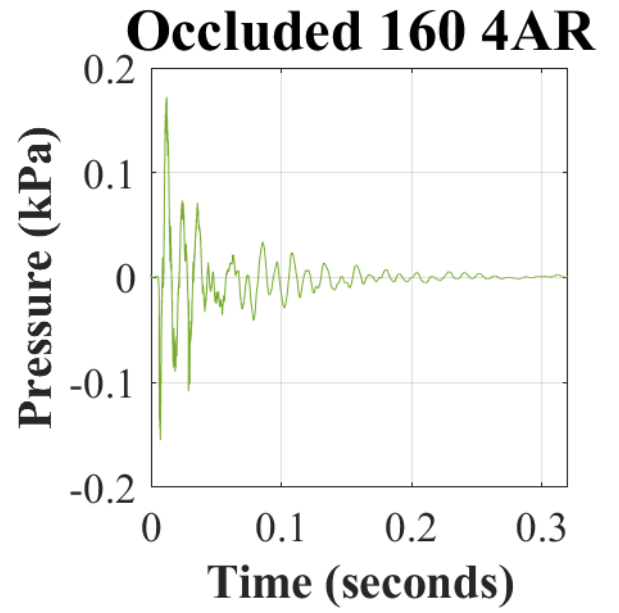
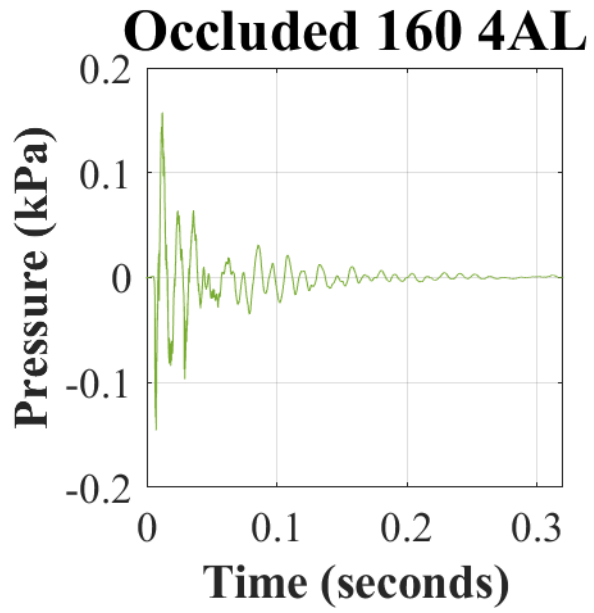
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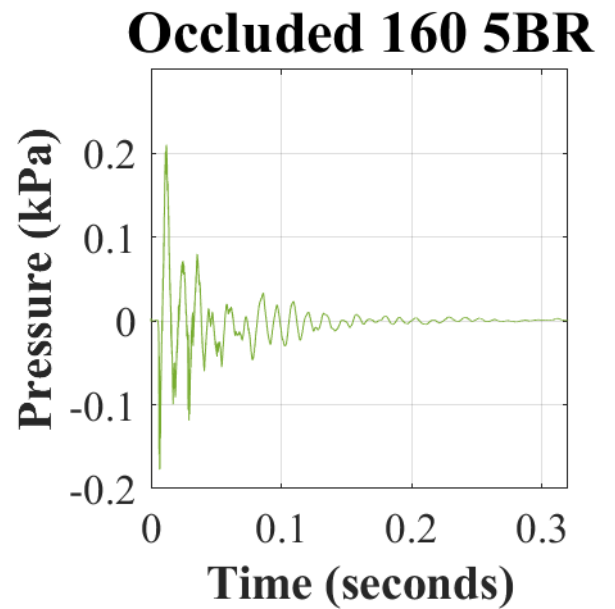
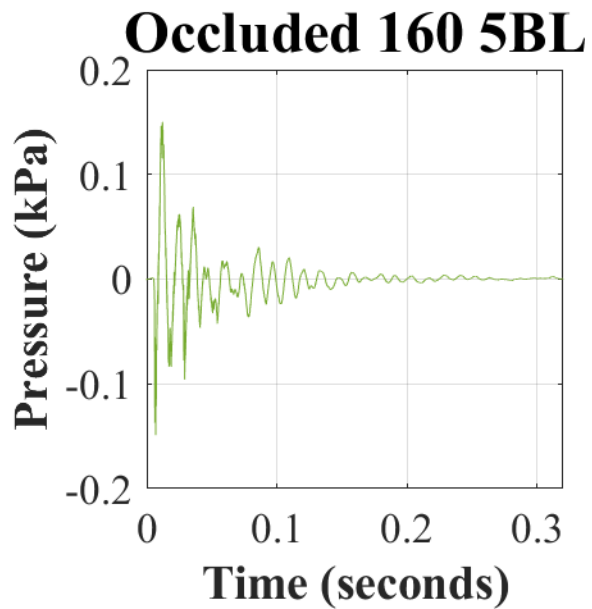
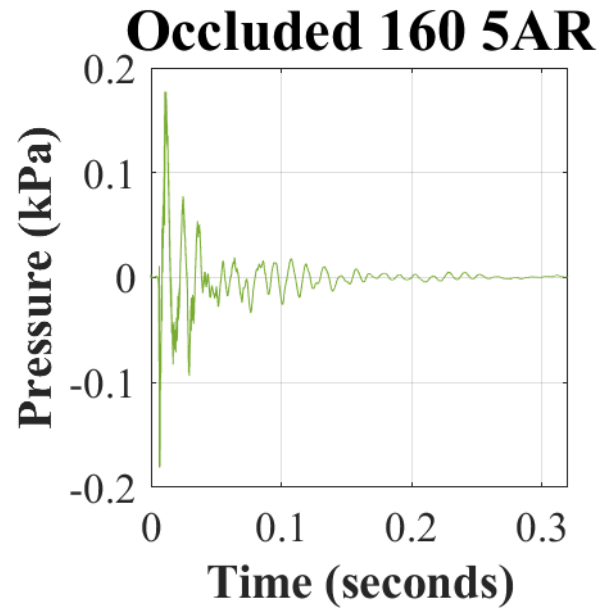
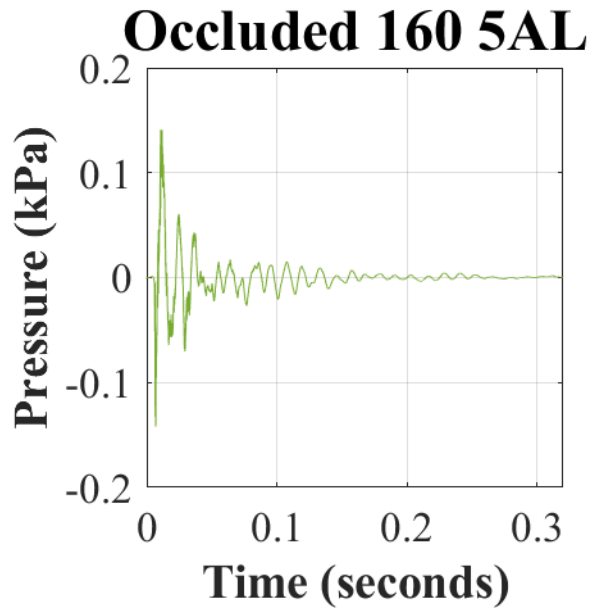
Appendix A. Recorded occluded (closed-ear) waveforms in response to 160 dBp with the CAE Gen 4.0 in the open mode.





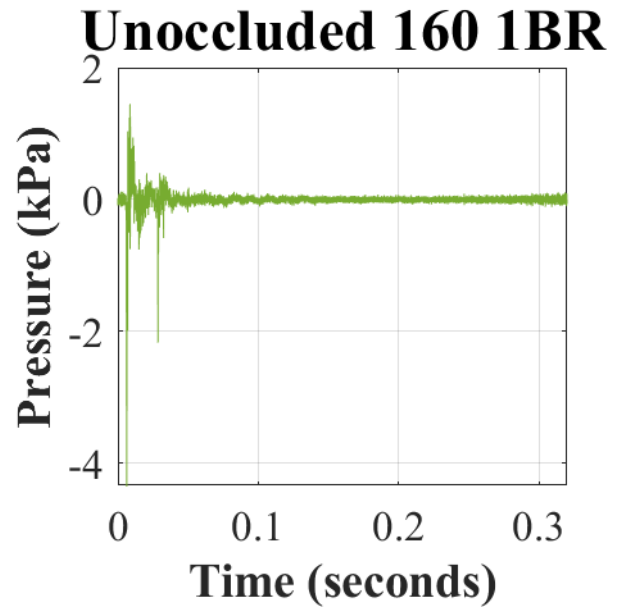
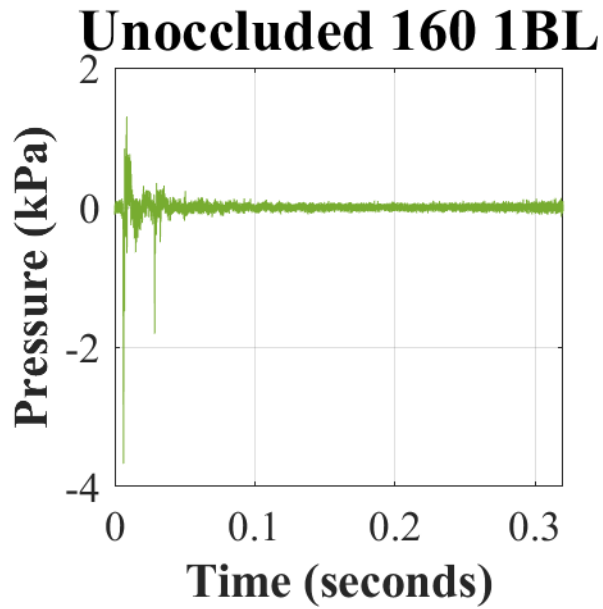
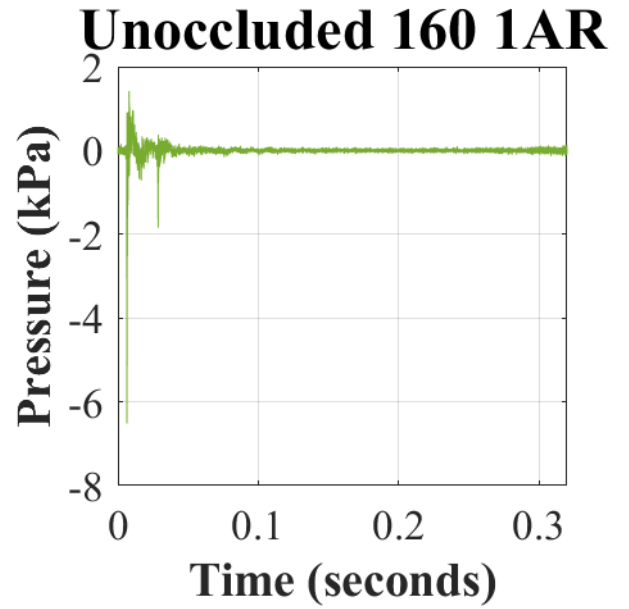
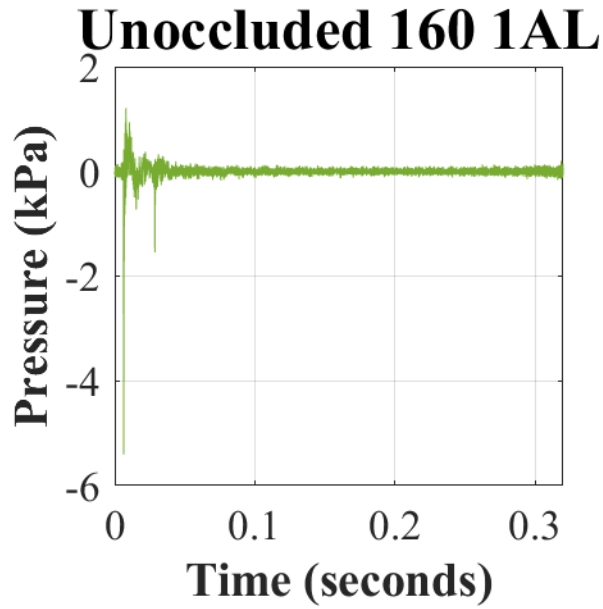


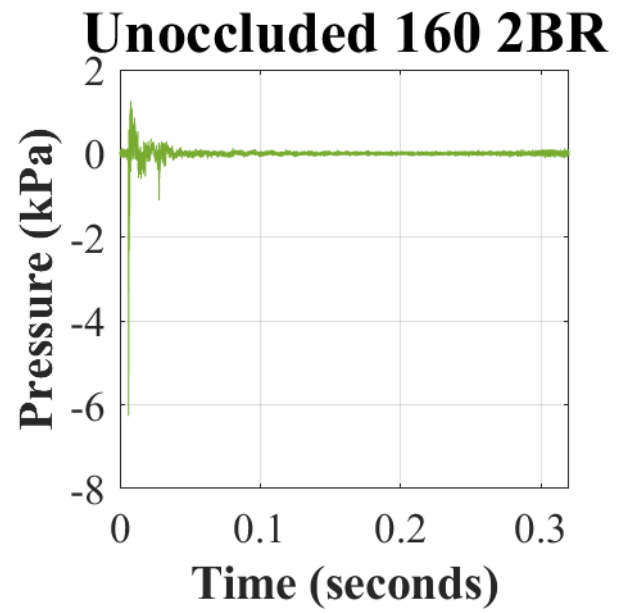
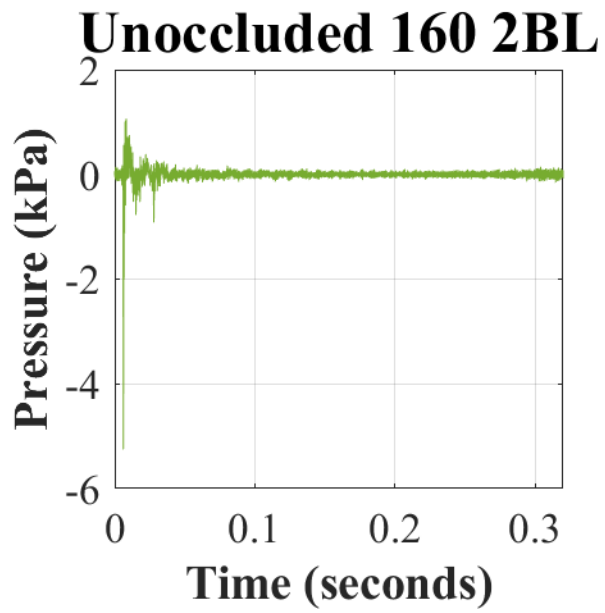
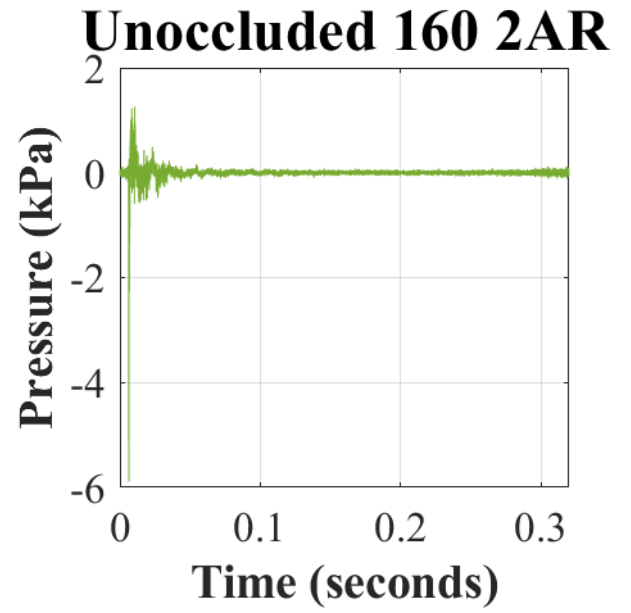
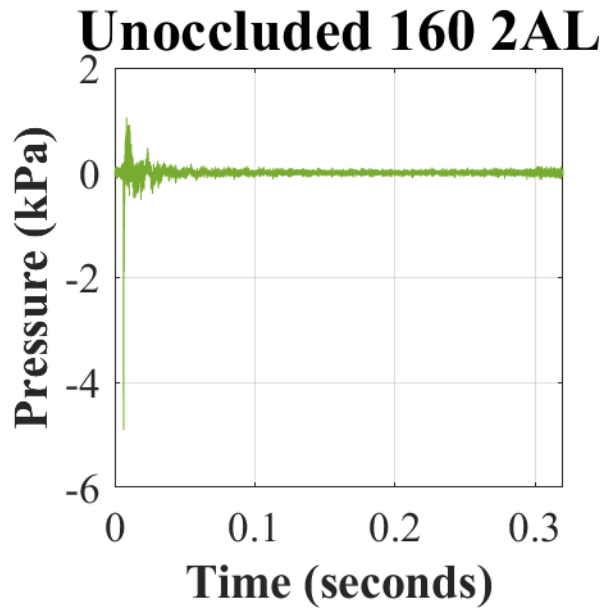


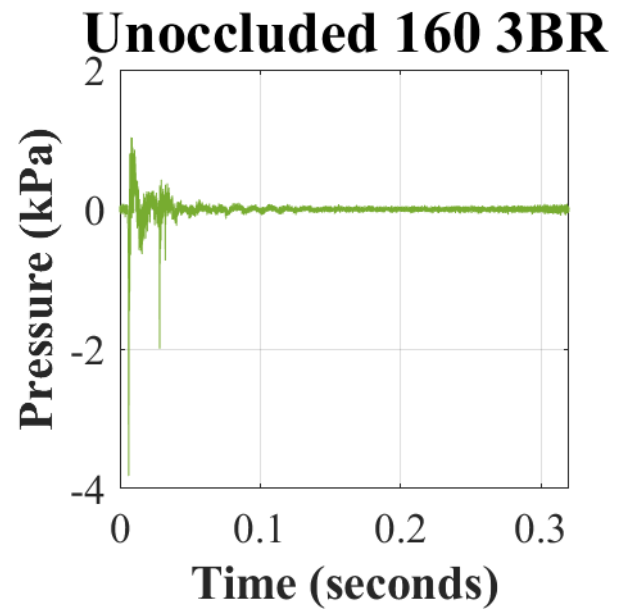
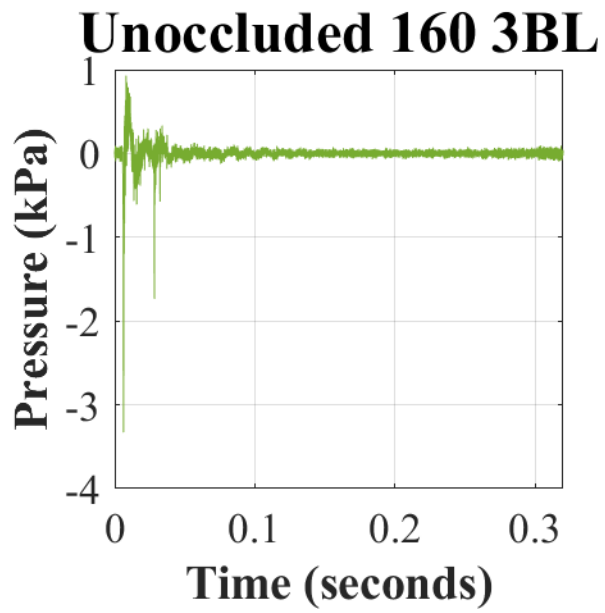
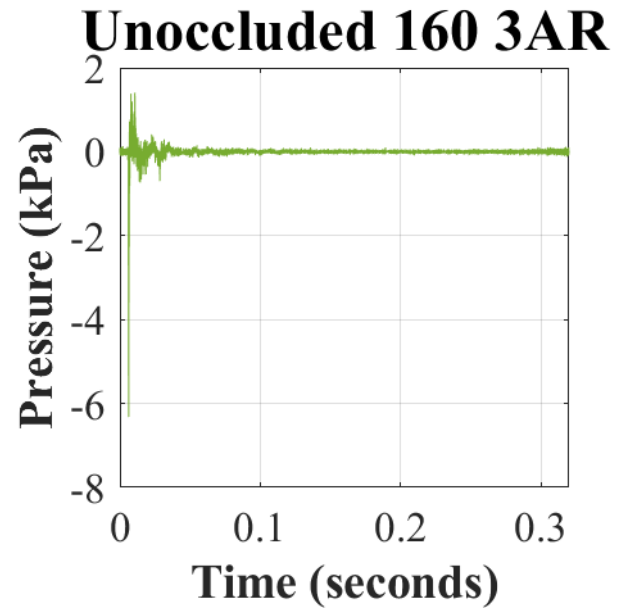
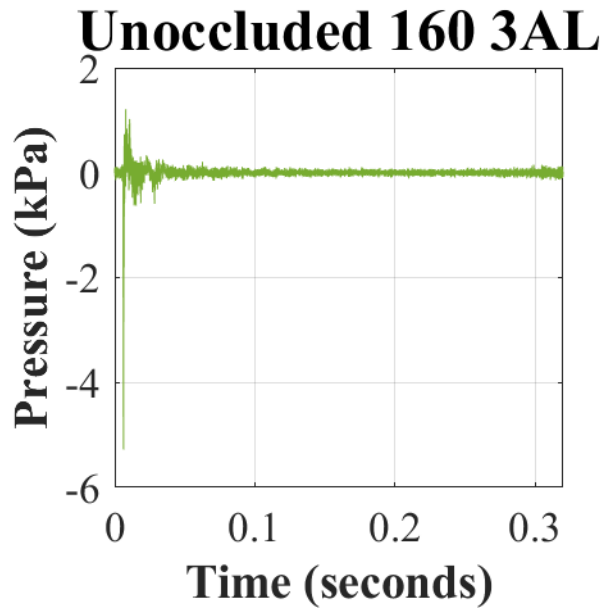


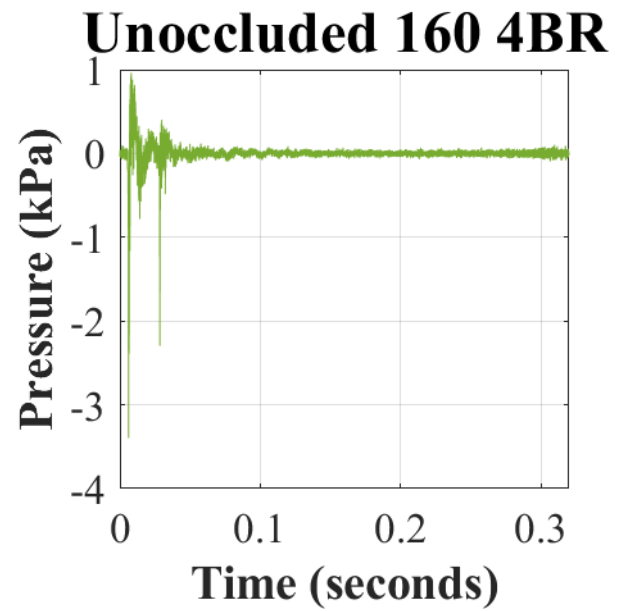
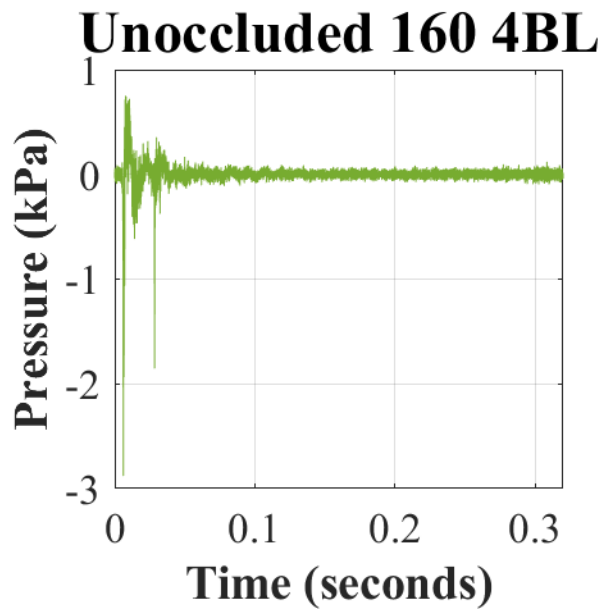
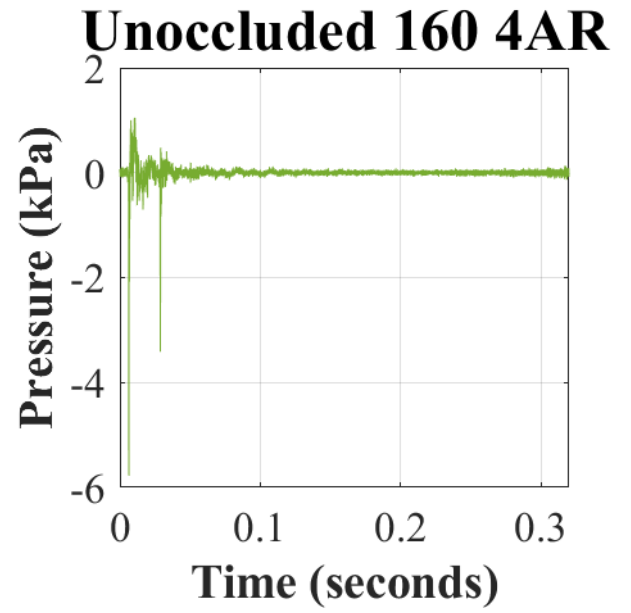
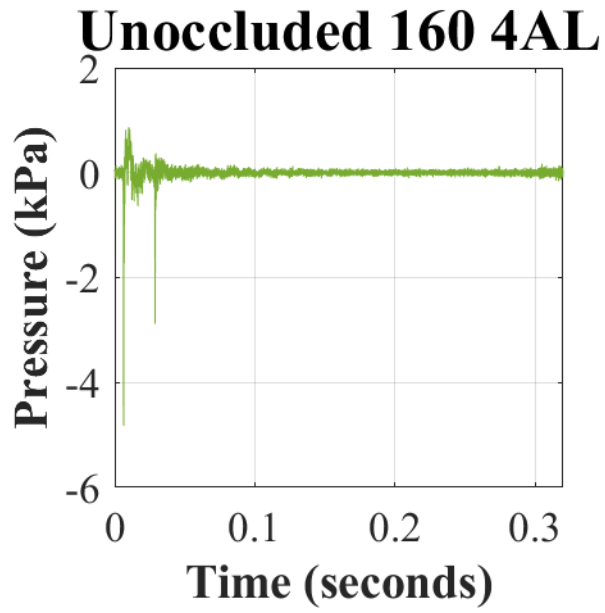
Note. The naming convention for all occluded waveforms is “Occluded LvL NnX”, where ‘Occluded’ is the test condition (i.e., ATF has HPD donned), ‘LvL’ is the nominal test level (i.e., 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or B) indicating 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).

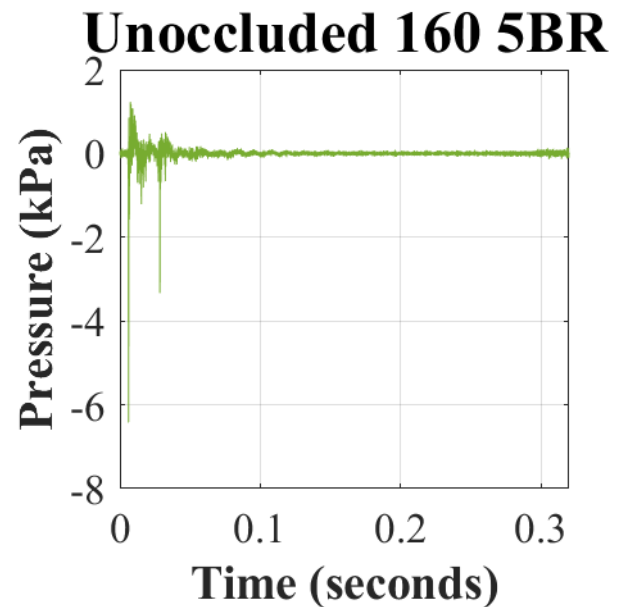
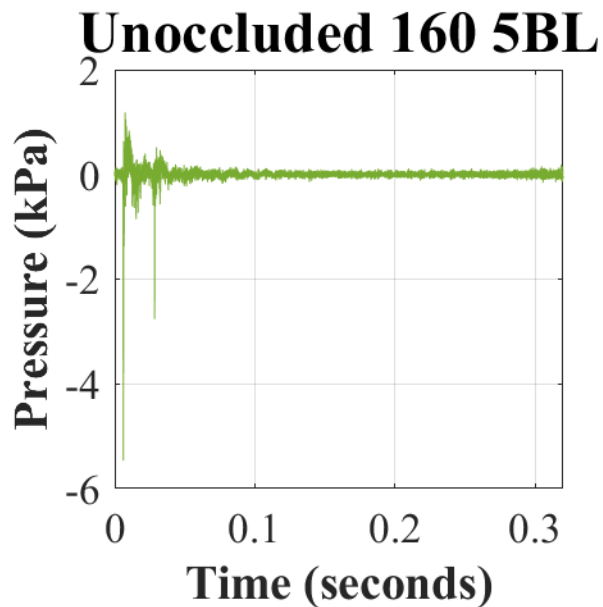
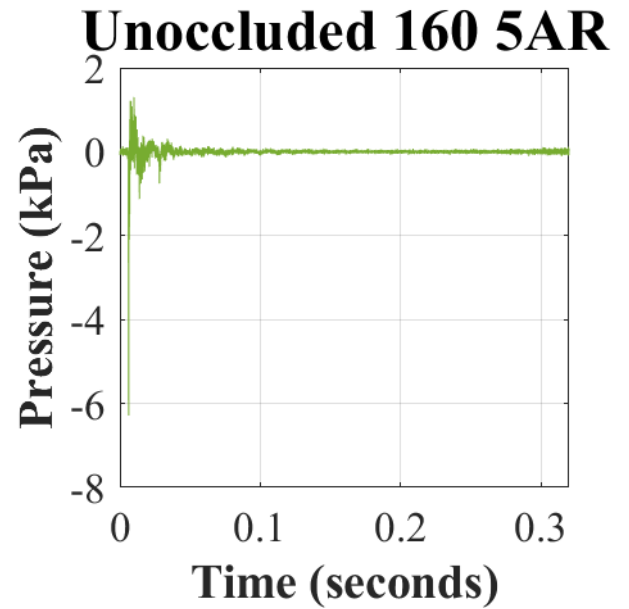
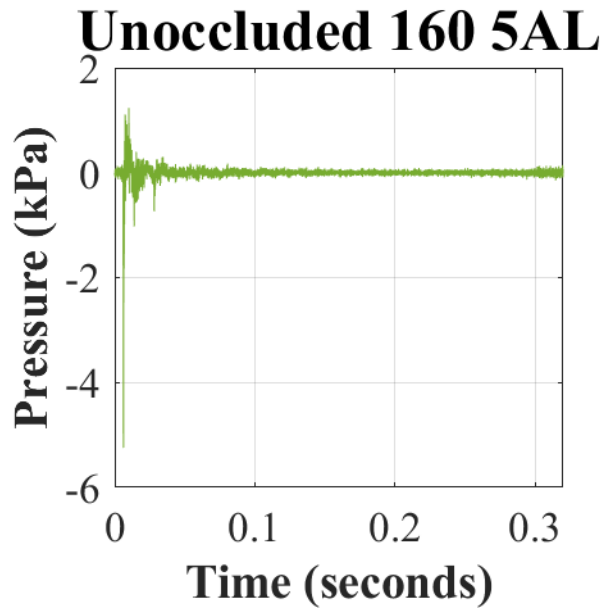
Appendix B. Estimated unoccluded (open-ear) waveforms in response to 160 dBp with the CAE Gen 4.0 earplugs in the open mode.







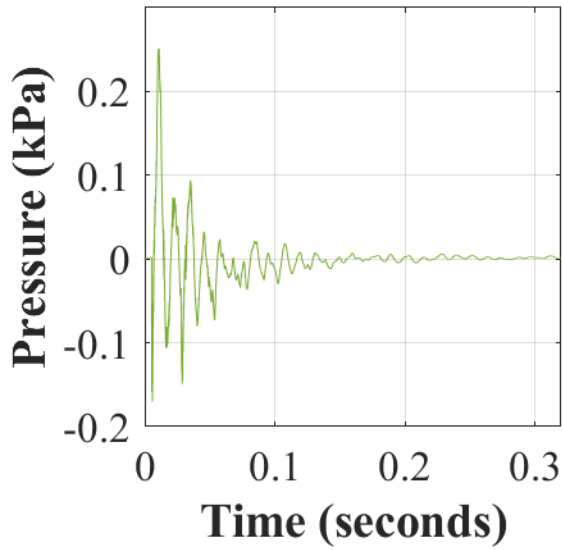




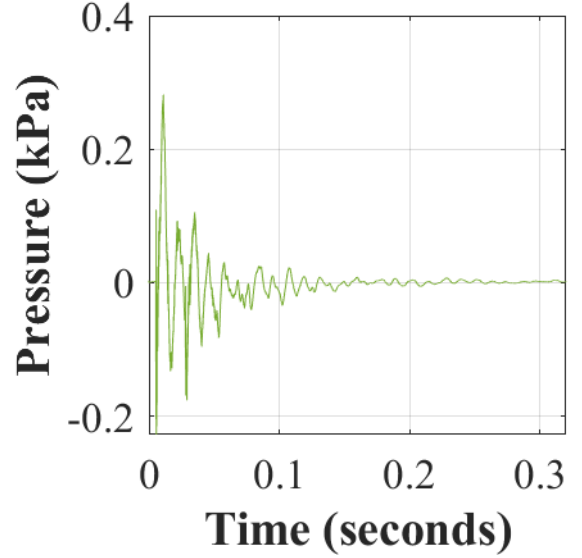
Note. The naming convention for all occluded waveforms is “Occluded LvL NnX”, where ‘Unoccluded’ is the test condition (i.e., ATF has HPD doffed), ‘LvL’ is the nominal test level (i.e., 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or B) indicating 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 CAE Gen 4.0 in the open mode.

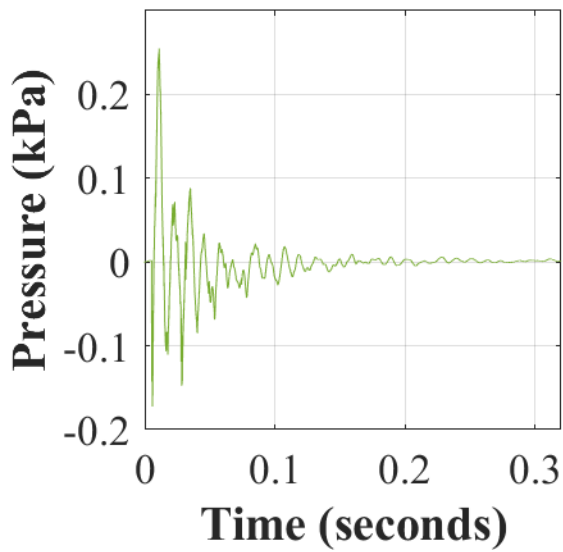
Occluded 170 1AL



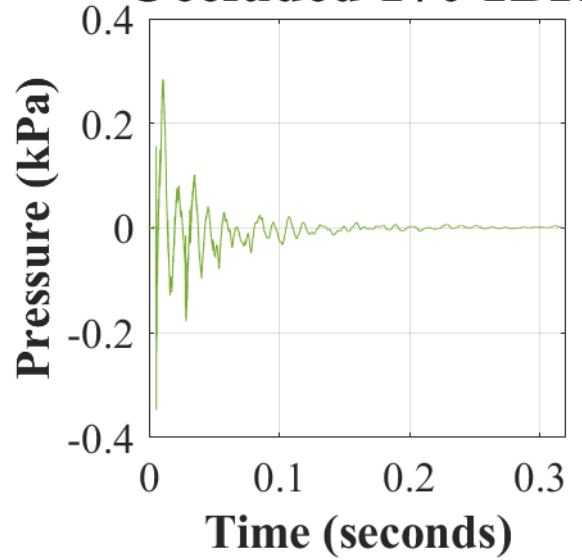
Occluded 170 1AR



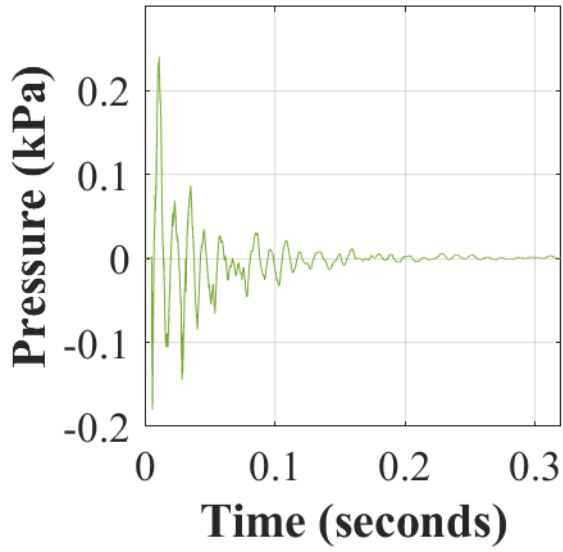
Occluded 170 1BL



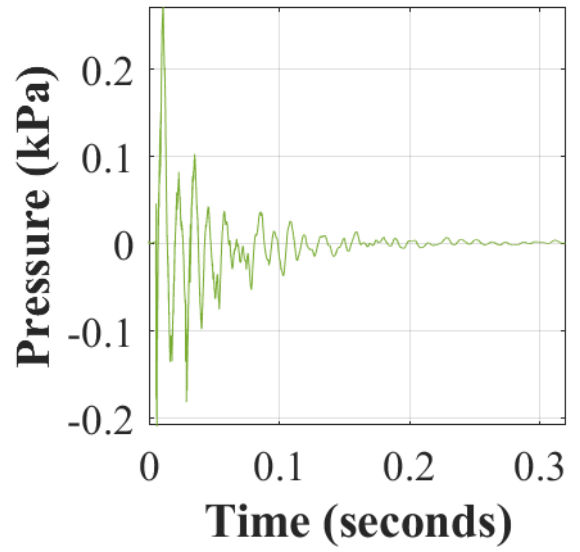
Occluded 170 1BR



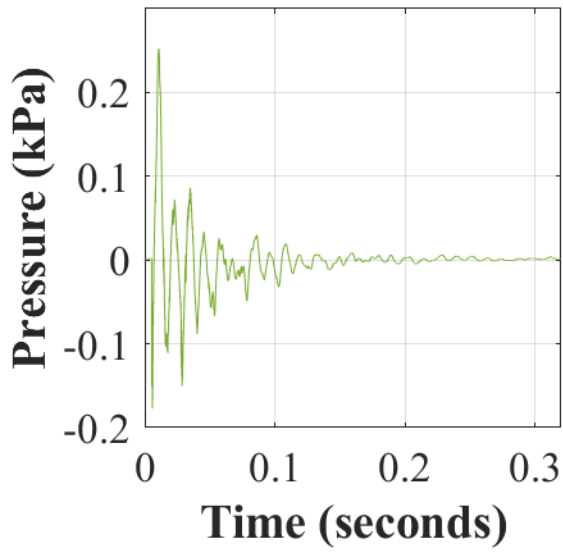
Occluded 170 2AL



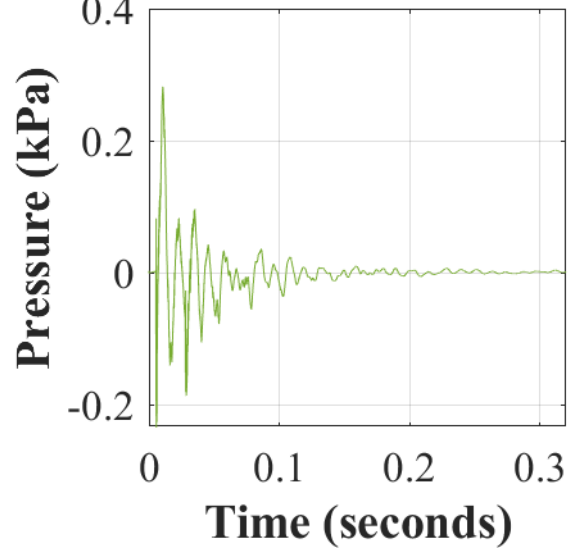
Occluded 170 2AR



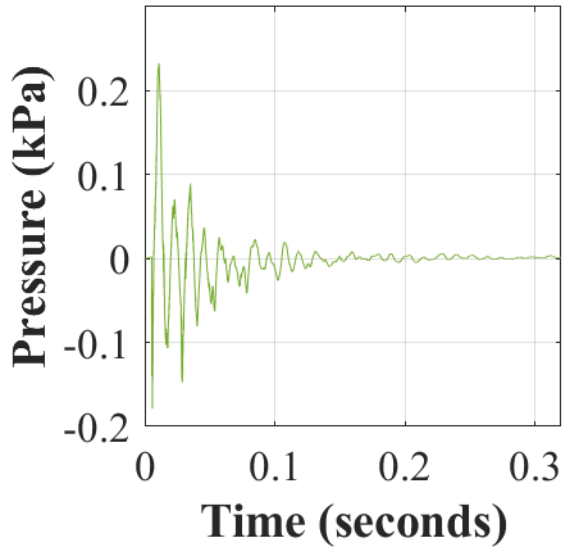
Occluded 170 2BL



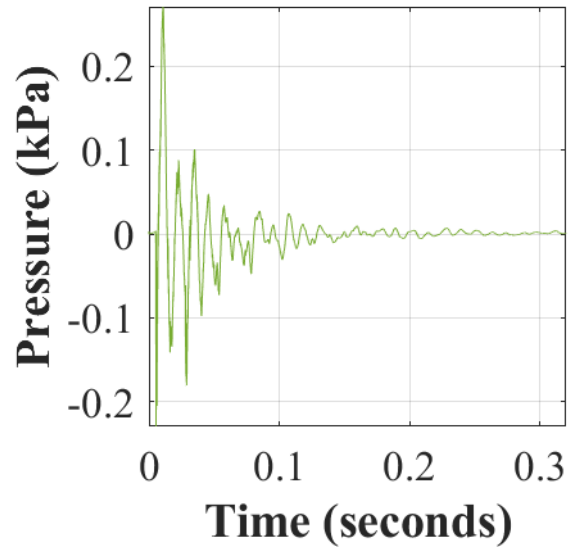
Occluded 170 2BR



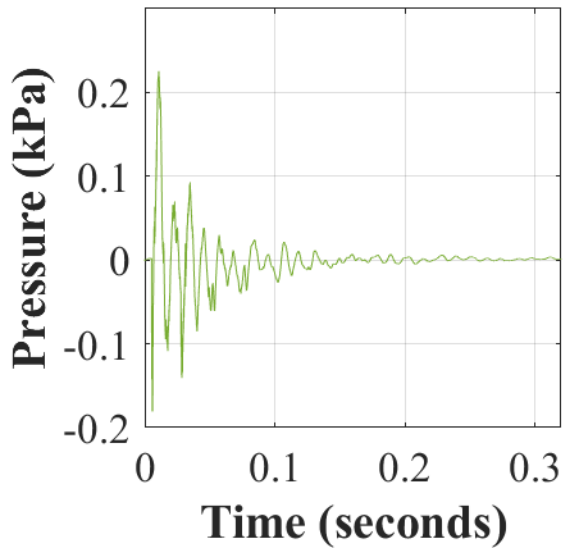
Occluded 170 3AL



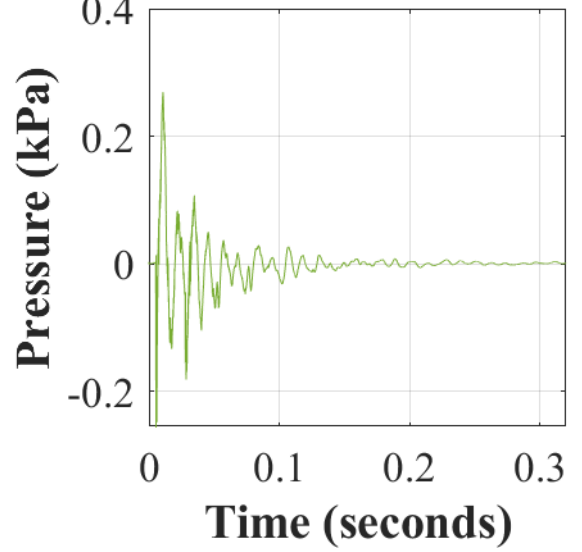
Occluded 170 3AR



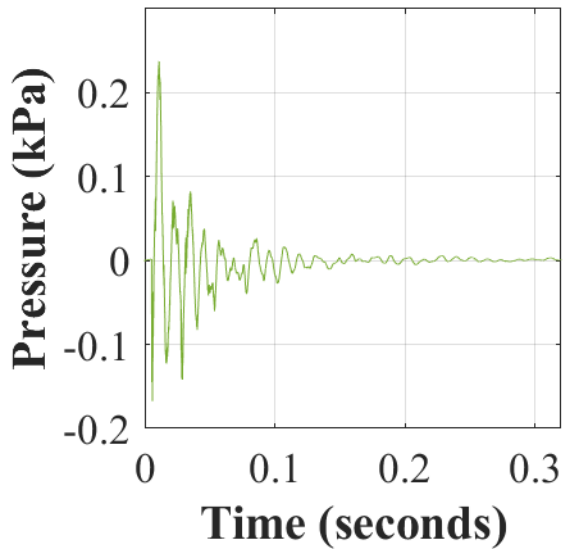
Occluded 170 3BL



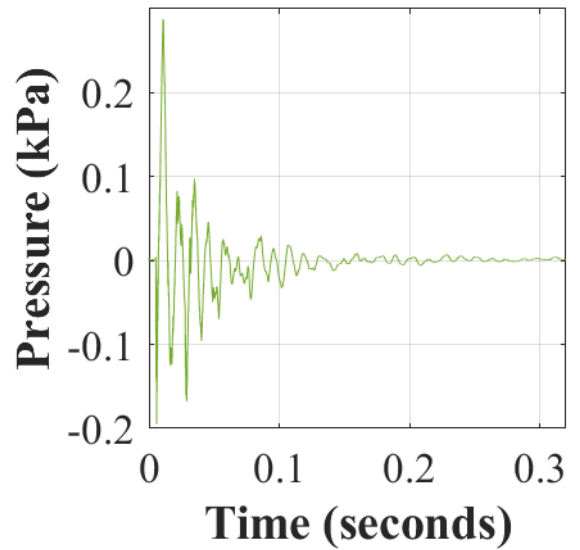
Occluded 170 3BR



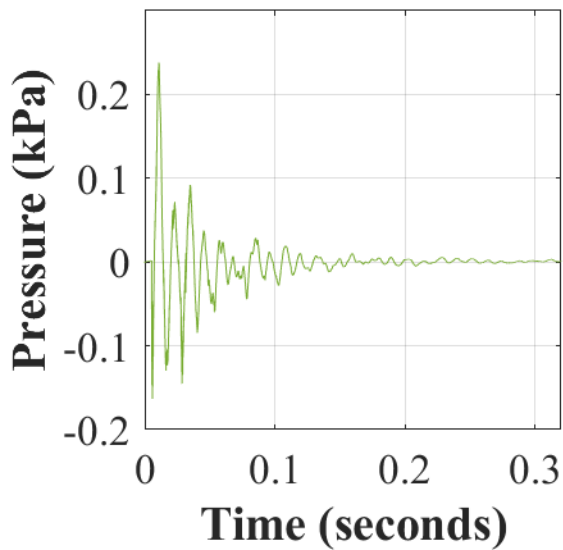
Occluded 170 4AL



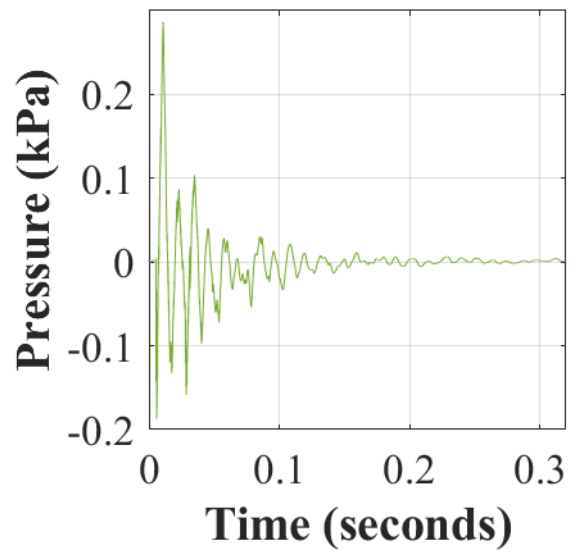
Occluded 170 4AR



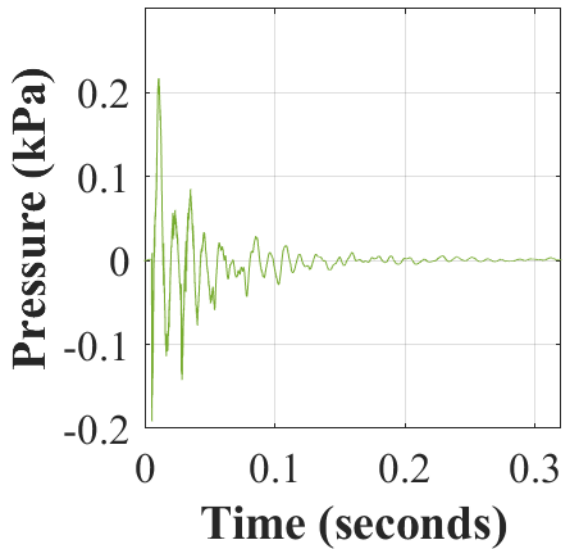
Occluded 170 4BL



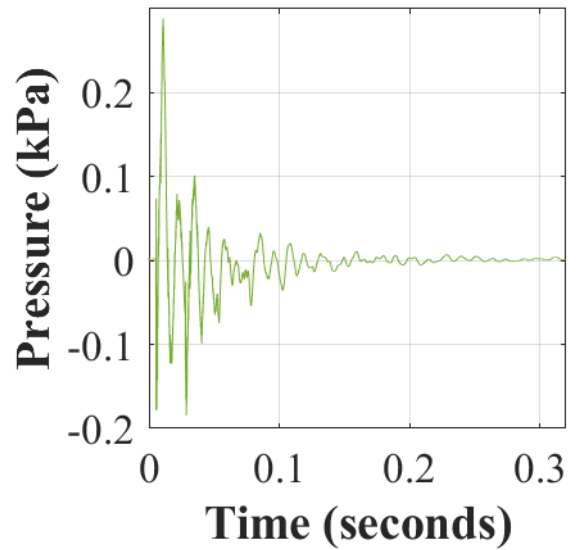
Occluded 170 4BR



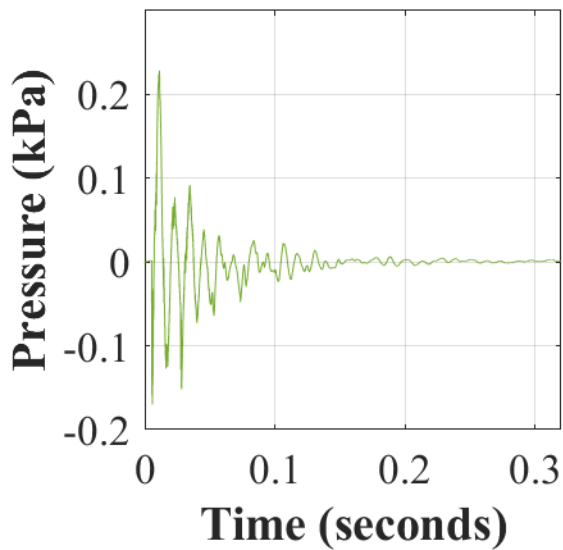
Occluded 170 5AL



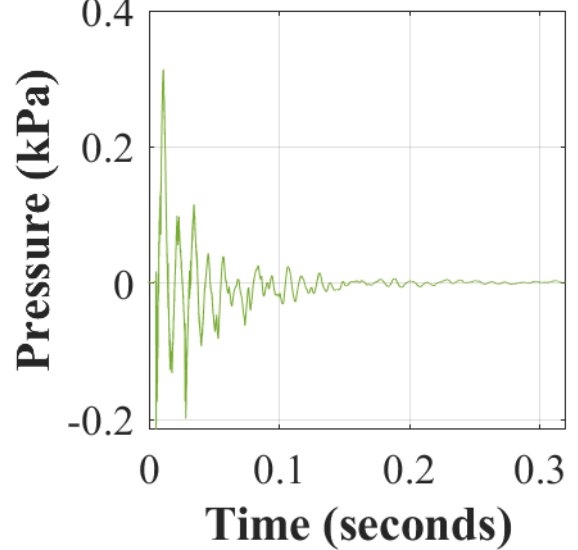
Occluded 170 5AR



Occluded 170 5BL

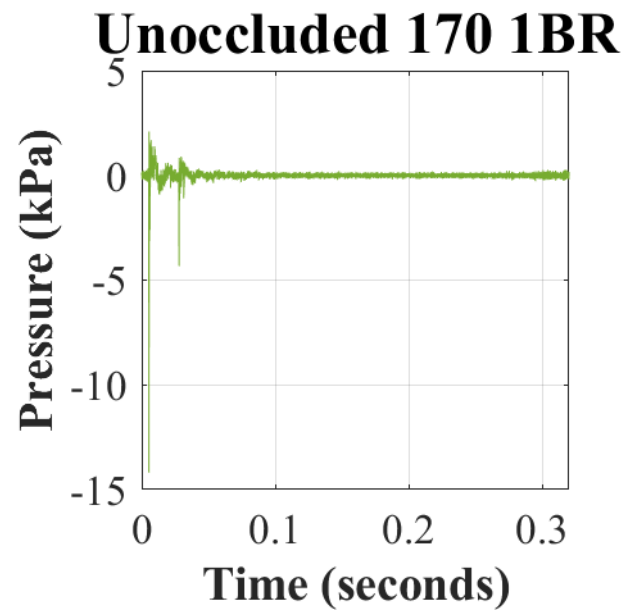
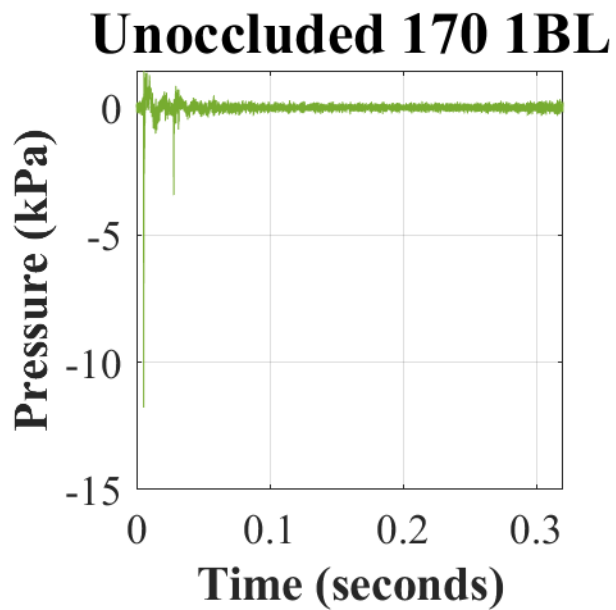
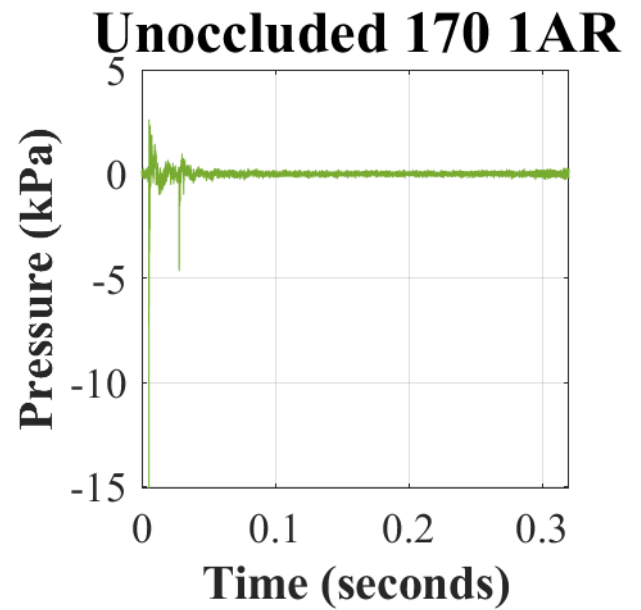
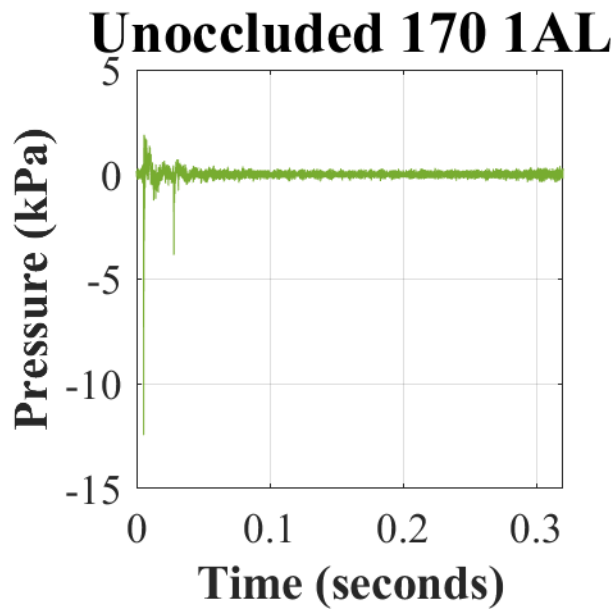


Occluded 170 5BR

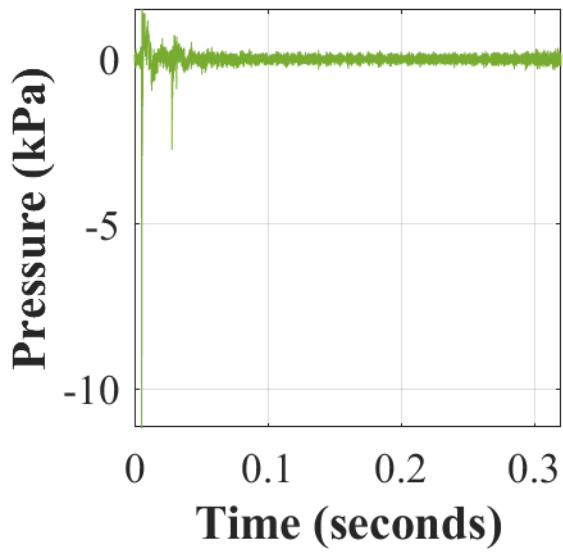


Note. The naming convention for all occluded waveforms is “Occluded LvL NnX”, where ‘Occluded’ is the test condition (i.e., ATF has HPD donned), ‘LvL’ is the nominal test level (i.e., 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or B) indicating 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).

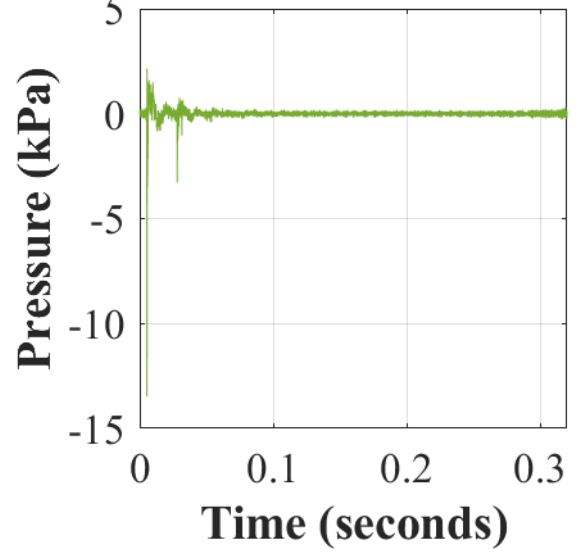
Appendix D. Estimated unoccluded (open-ear) waveforms in response to 170 dBp with the CAE Gen 4.0 earplugs in the open mode.



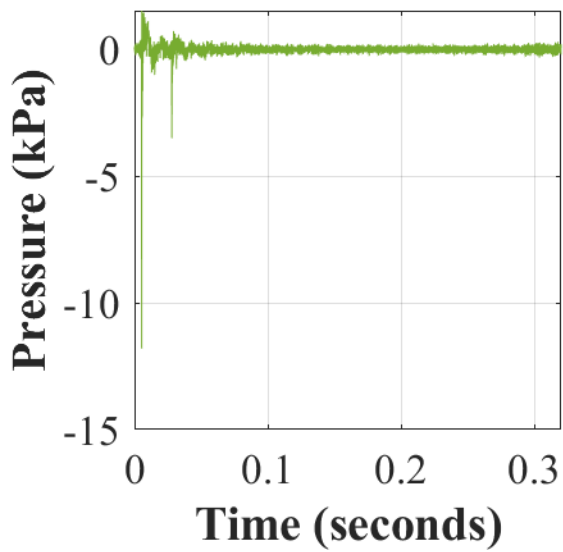
Unoccluded 170 2AL



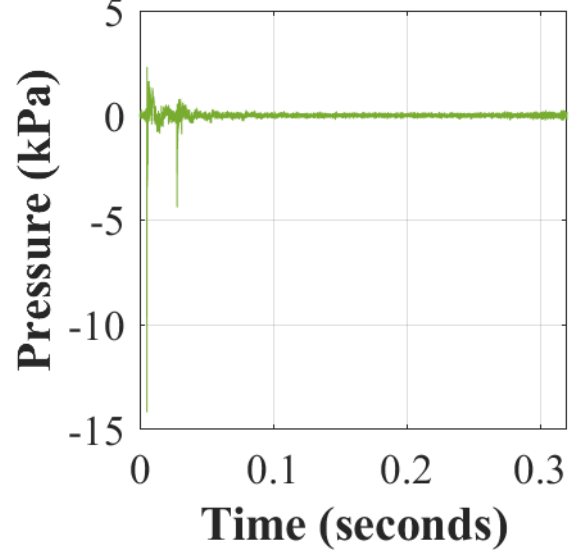
Unoccluded 170 2AR

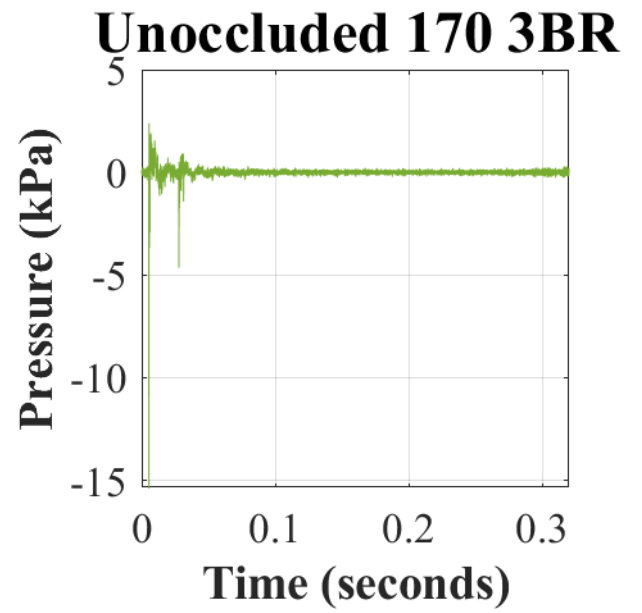
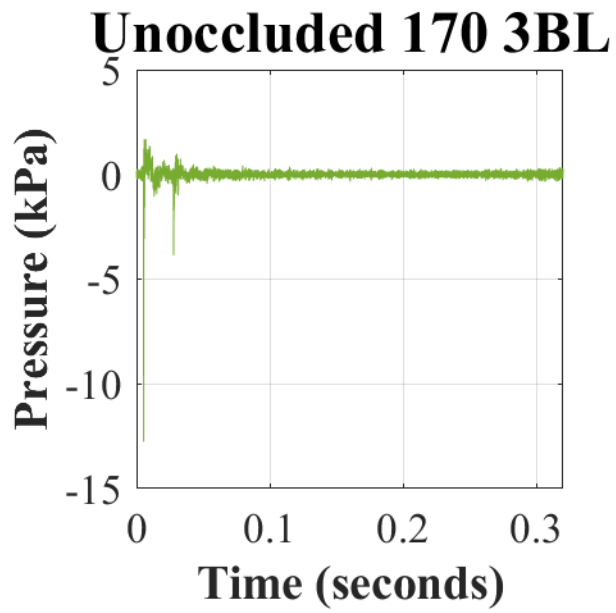
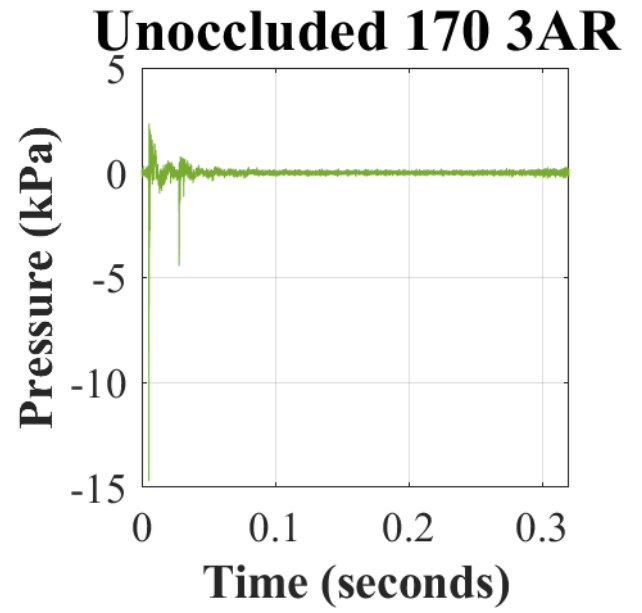
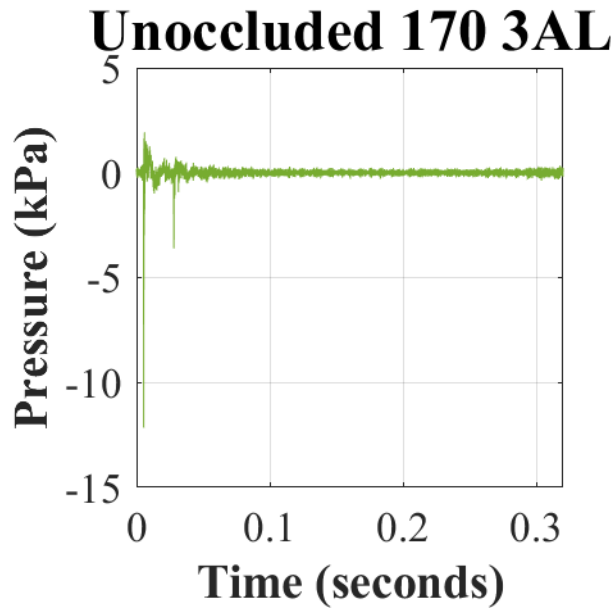


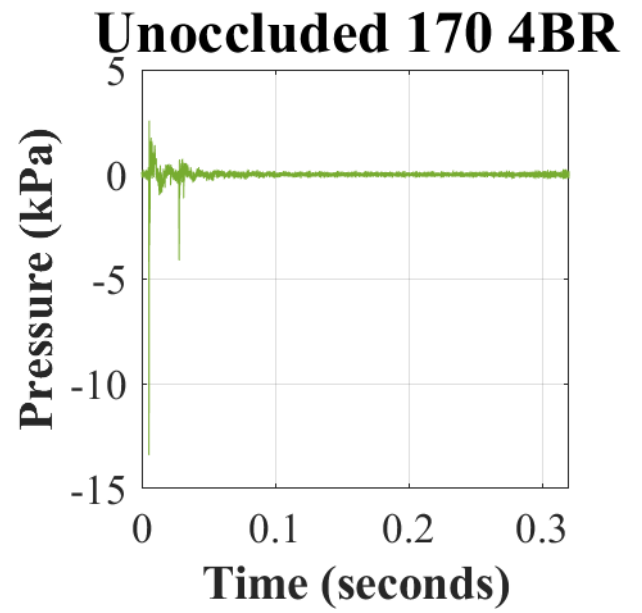
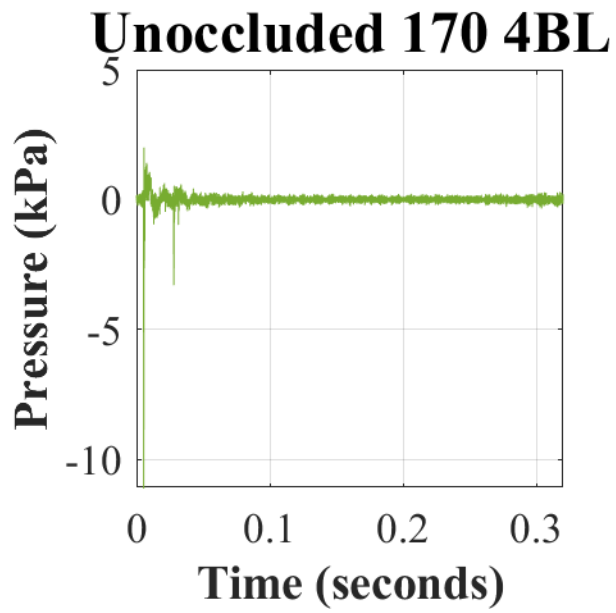
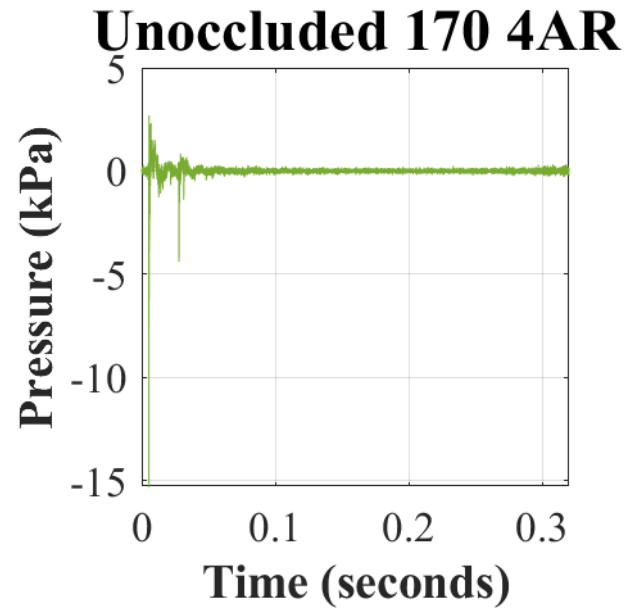
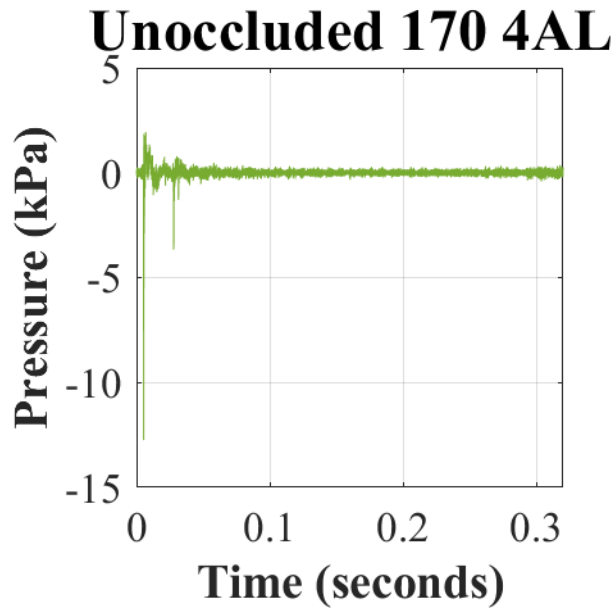
Unoccluded 170 2BL

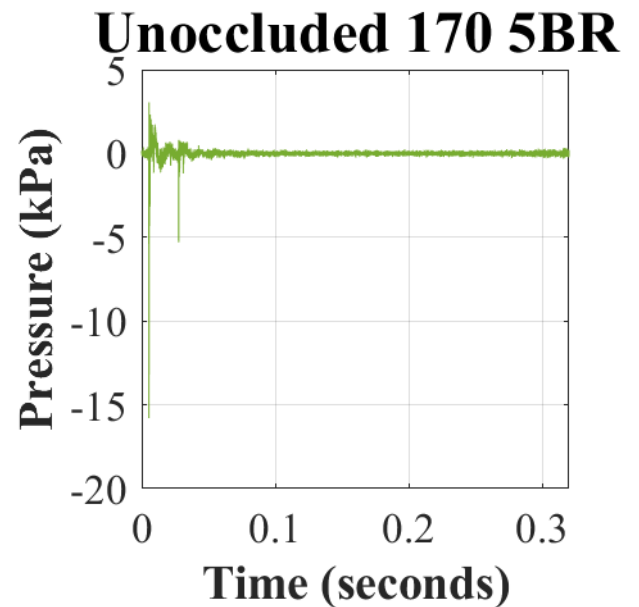
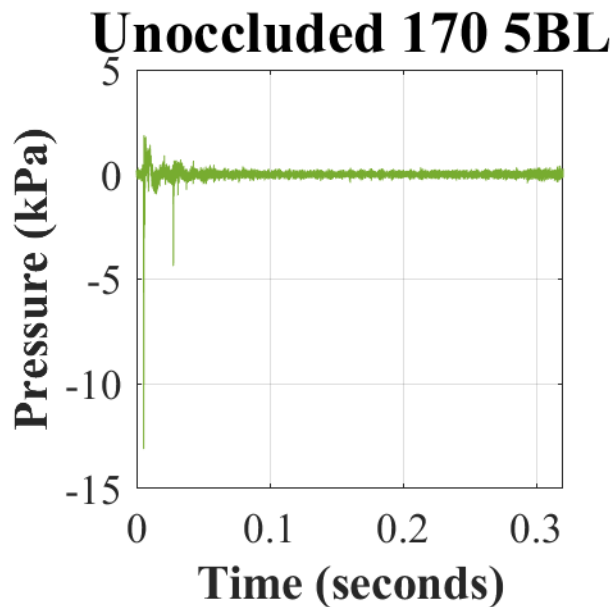
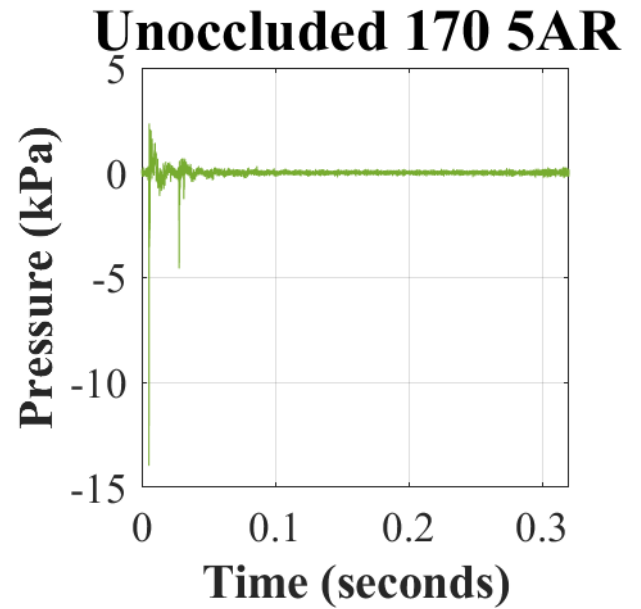
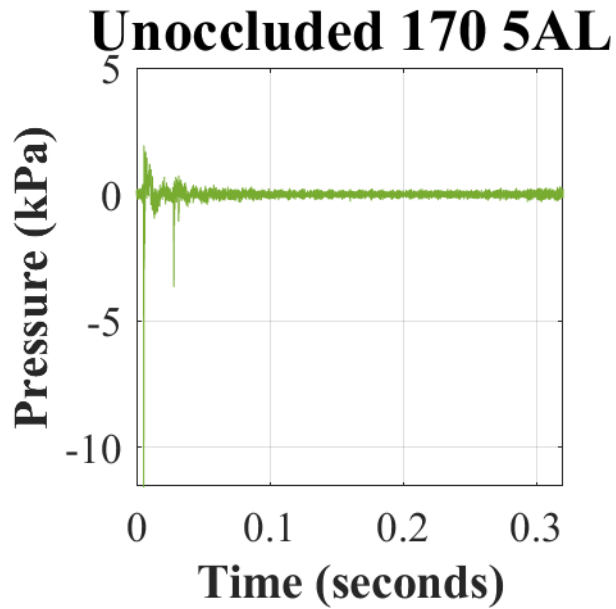


Unoccluded 170 2BR



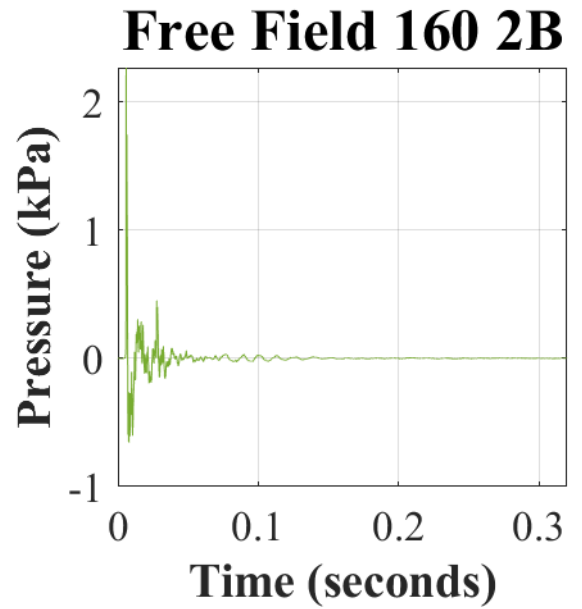
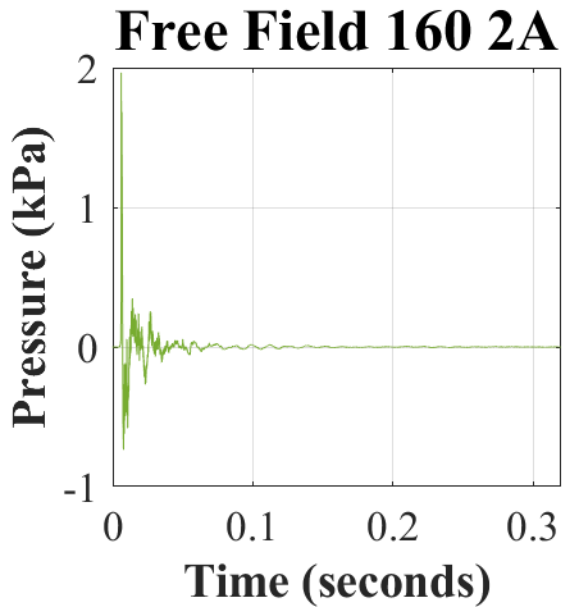
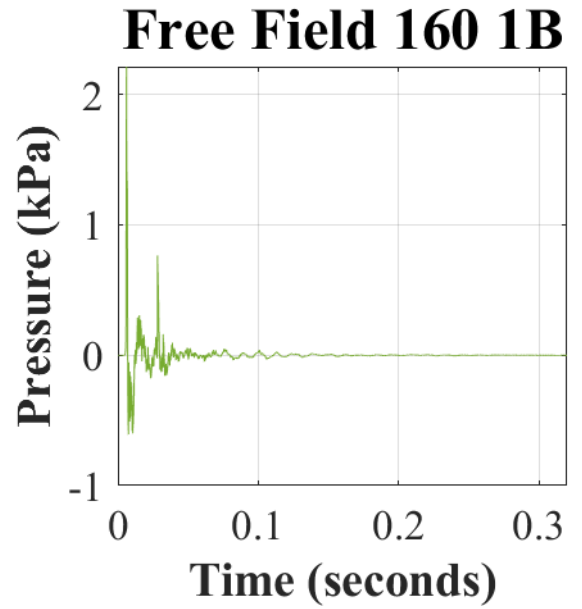
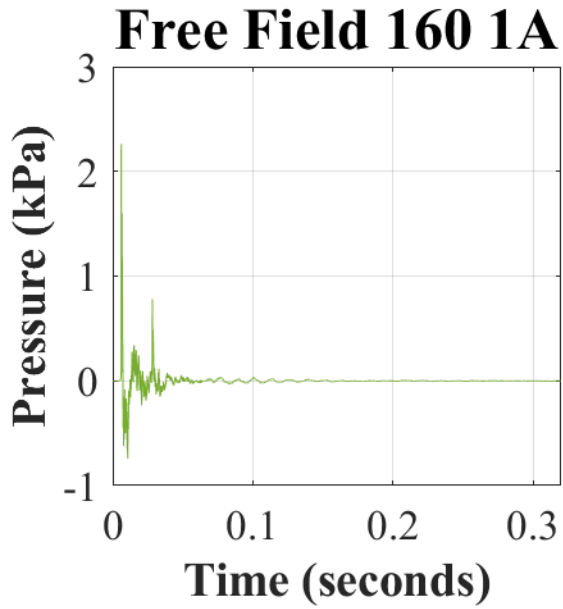




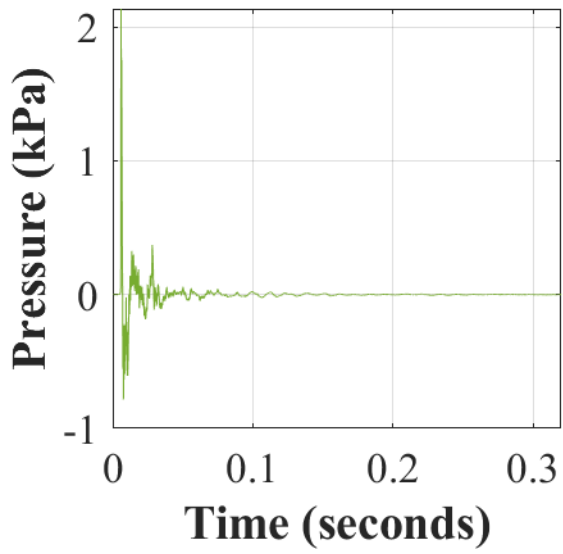


Note. The naming convention for all occluded waveforms is “Occluded LvL NnX”, where ‘Unoccluded’ is the test condition (i.e., ATF has HPD donned), ‘LvL’ is the nominal test level (i.e., 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or B) indicating 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).

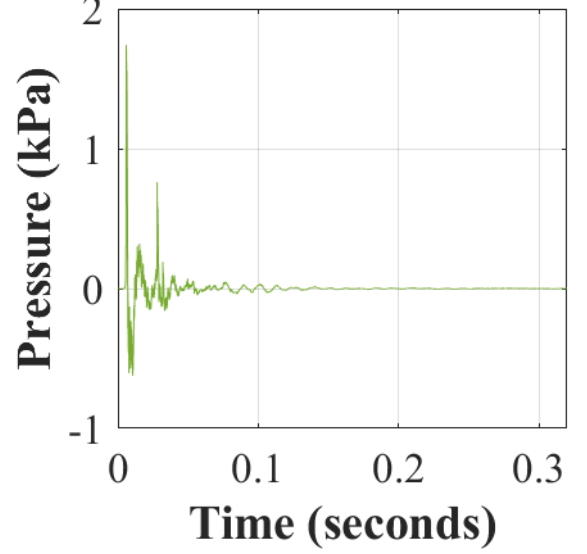
Appendix E. Recorded waveform of the impulse measured with the free-field probe at 160 dBp and the CAE Gen 4.0 earplugs in the open mode.



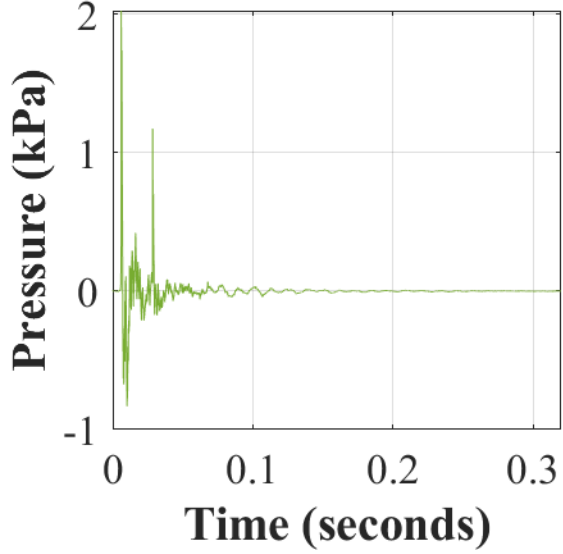
Free Field 160 3A



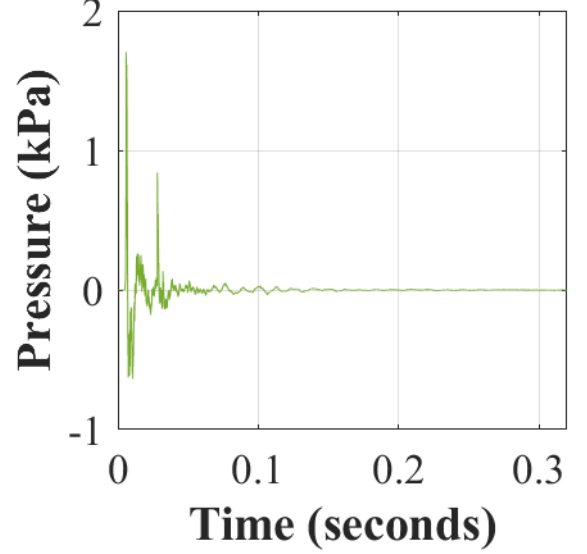
Free Field 160 3B

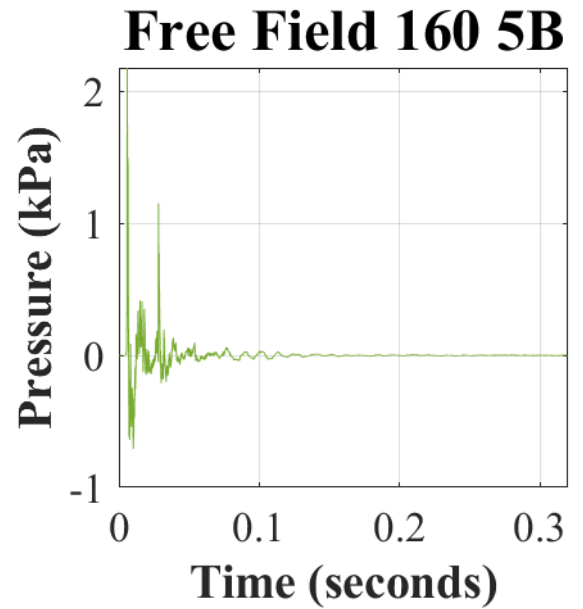
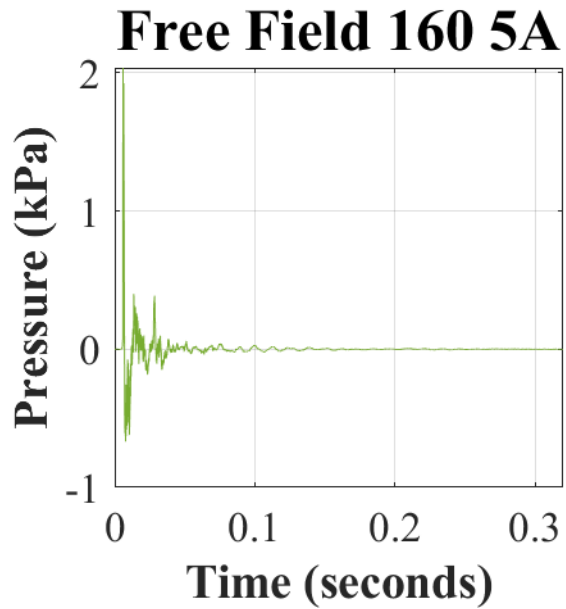


Free Field 160 4A



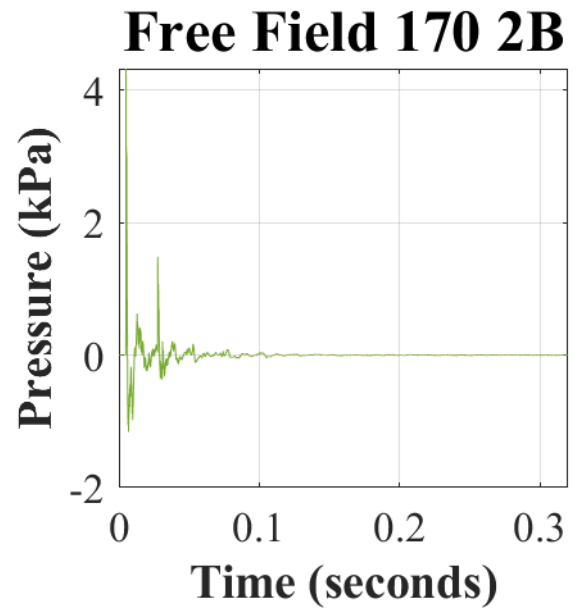
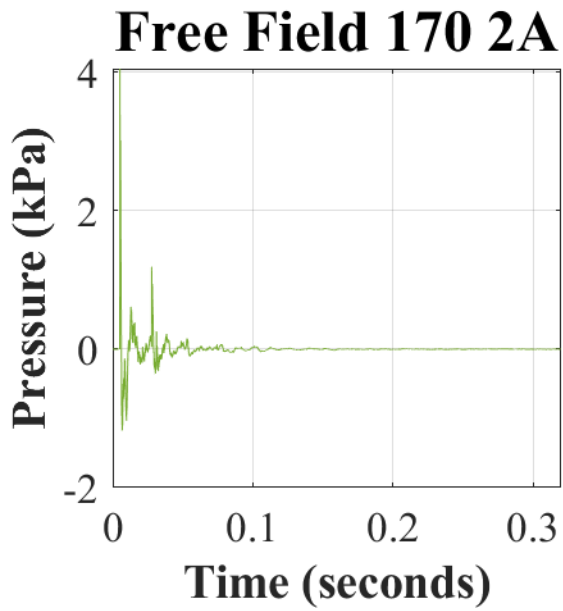
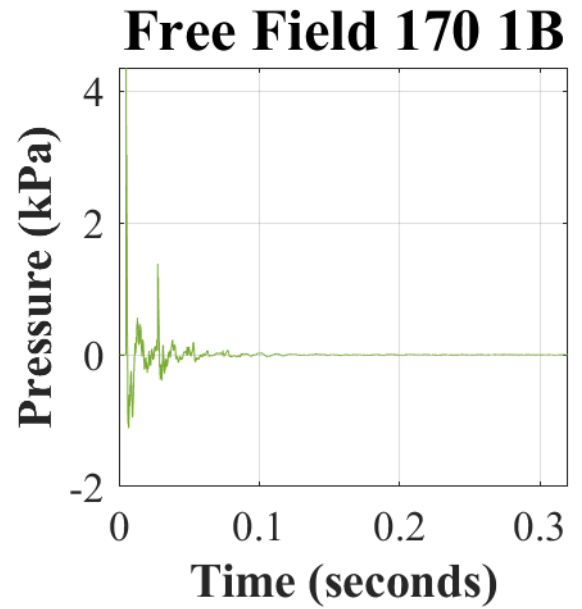
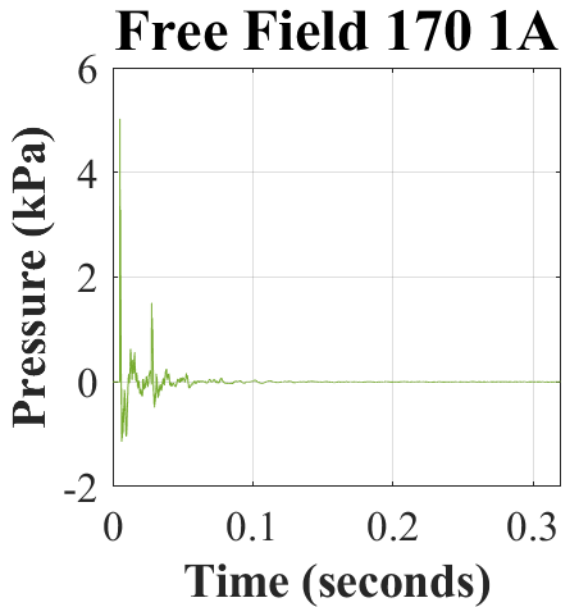
Free Field 160 4B

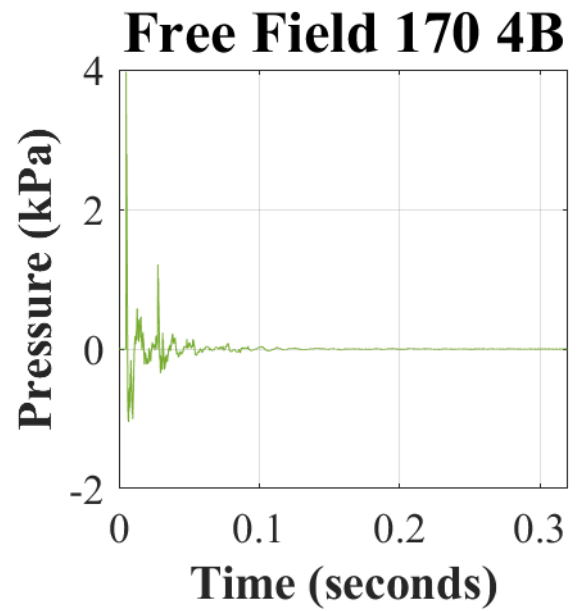
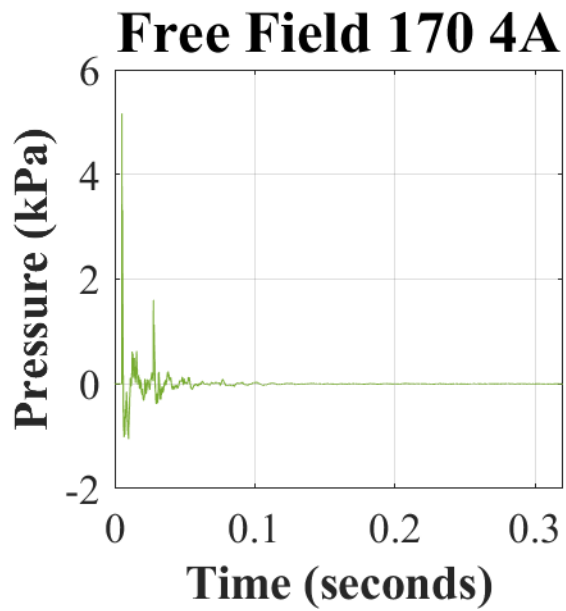
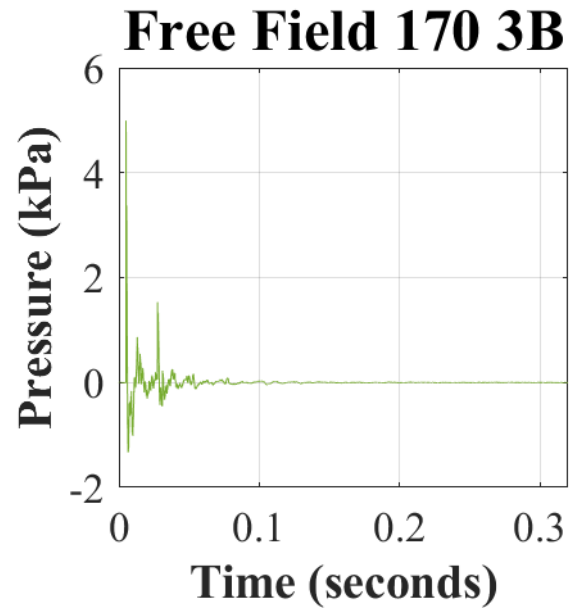
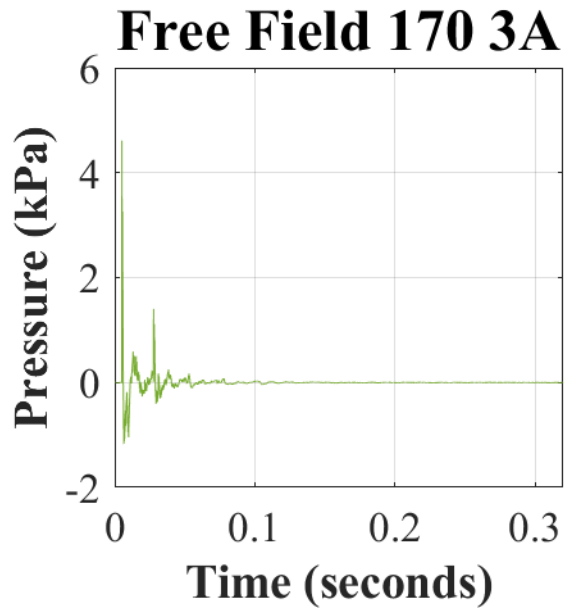


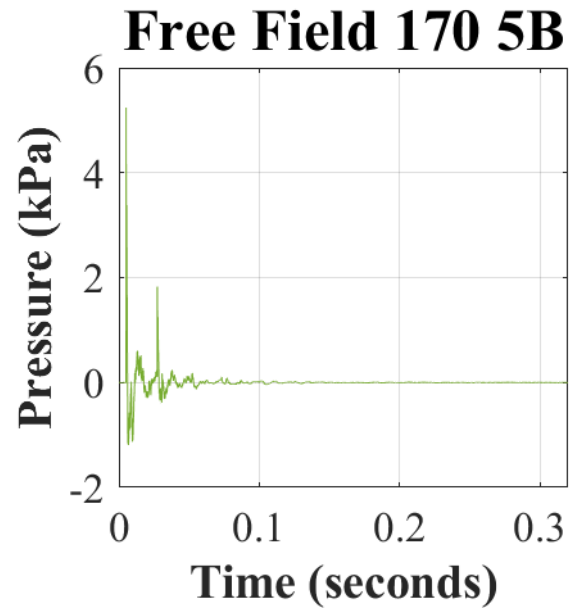
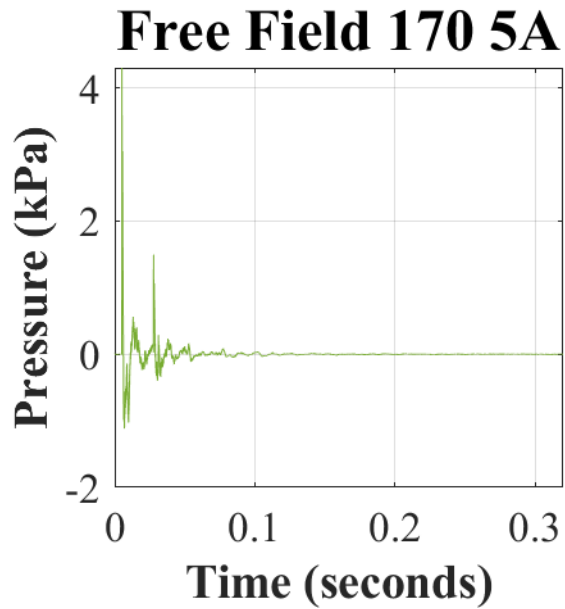


Note. The naming convention for all free-field waveforms is “Free Field LvL Nn”, where ‘Free Field’ indicates that the recording was obtained using the PCB reference microphone, ‘LvL’ is the nominal test level (170 dBp), ‘N’ is the device sample number (1 to 5), and ‘n’ is the device trial (i.e., A or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

Appendix F. Recorded waveform of the impulse measured with the free-field probe at 170 dBp and the CAE Gen 4.0 earplugs in the open mode.

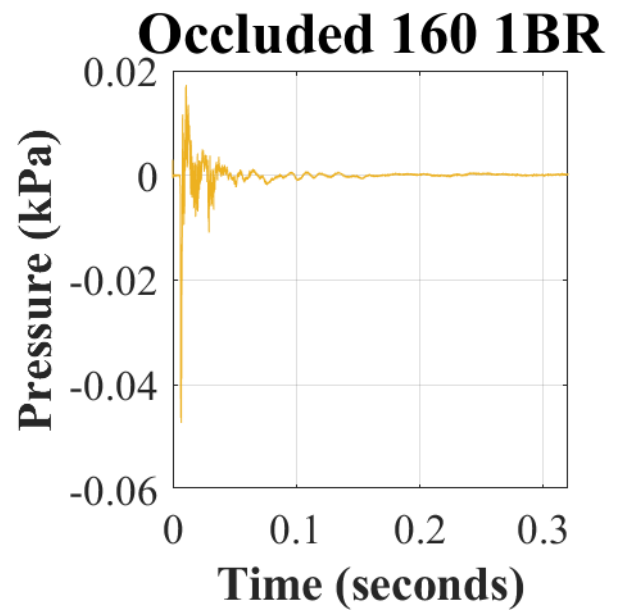
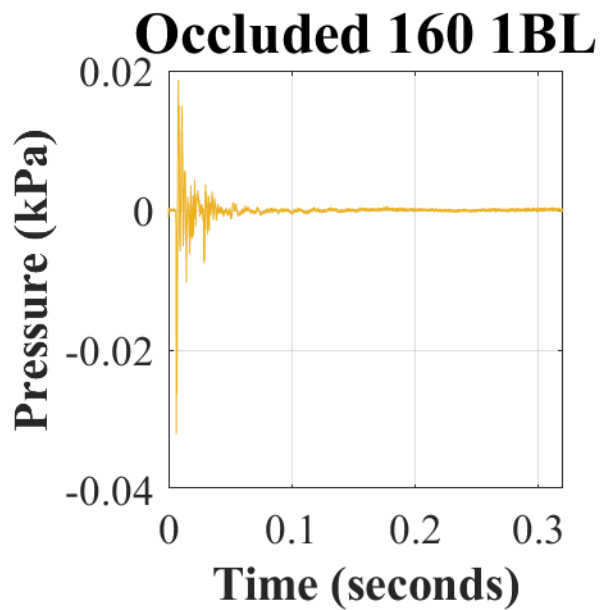
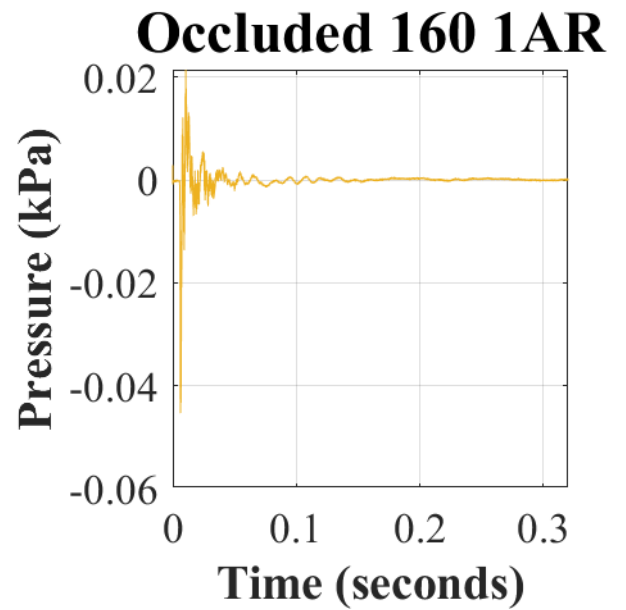
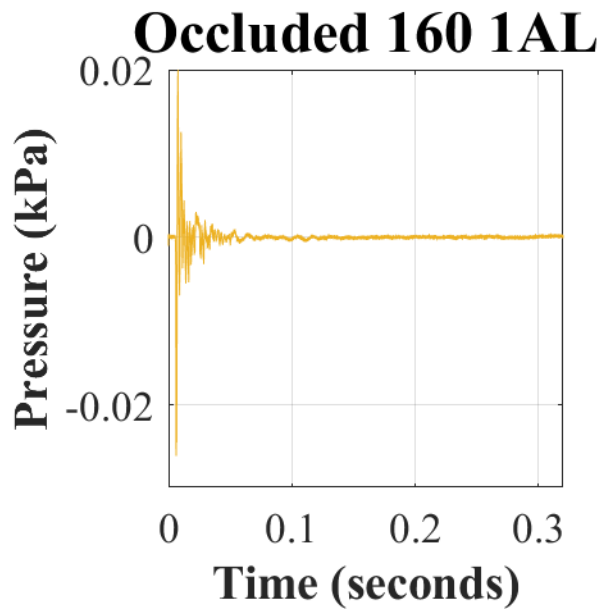


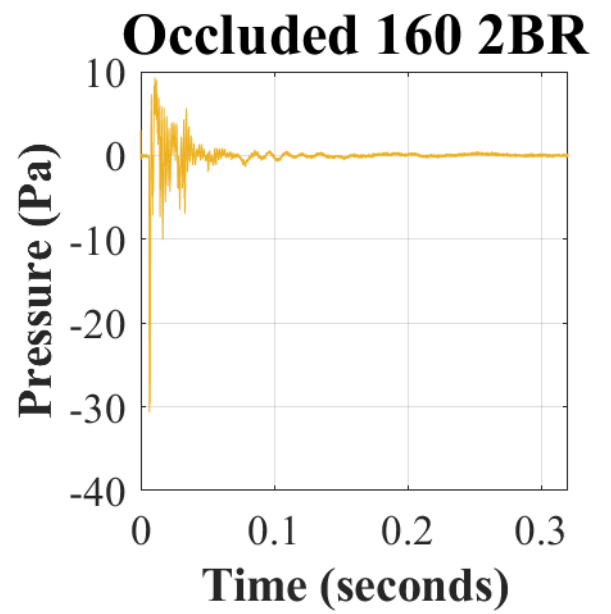
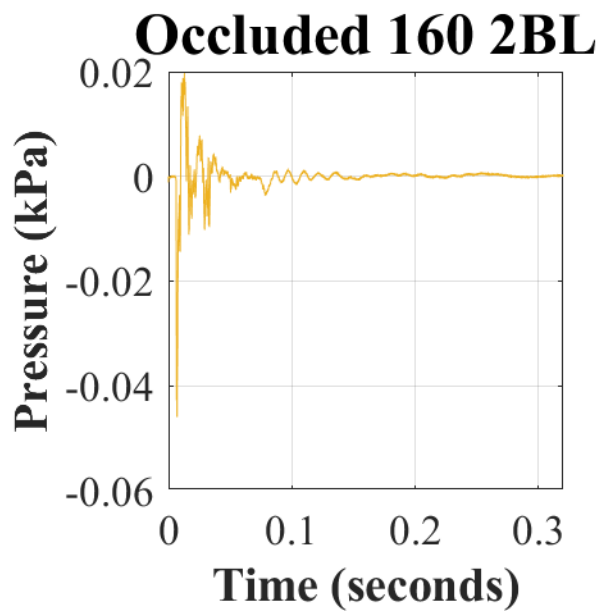
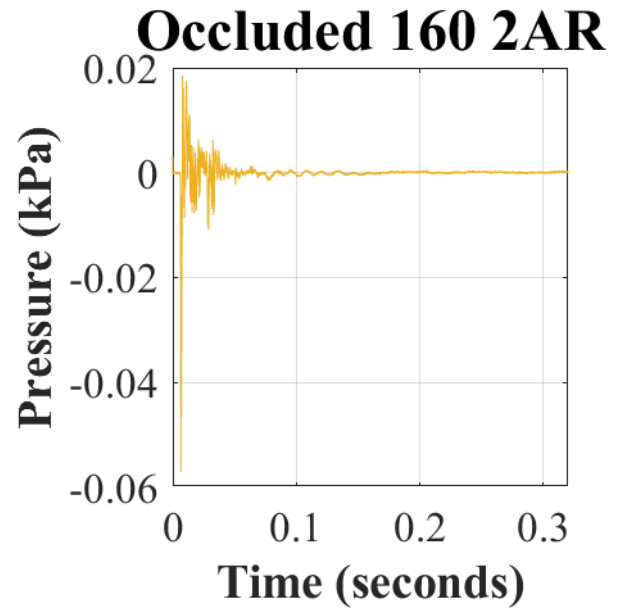
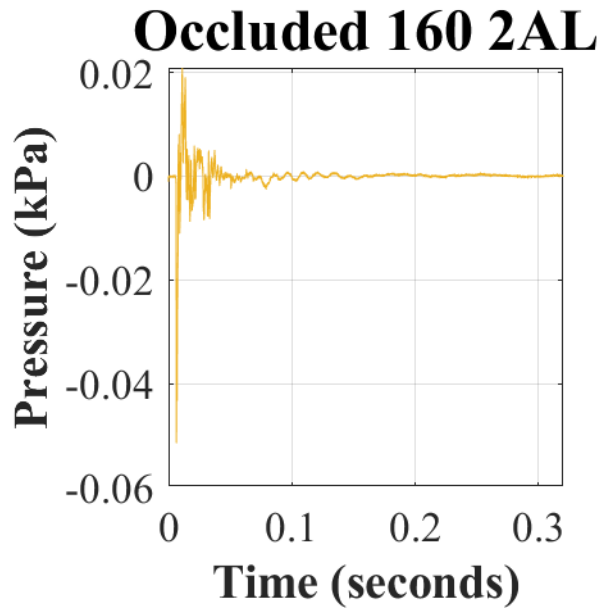


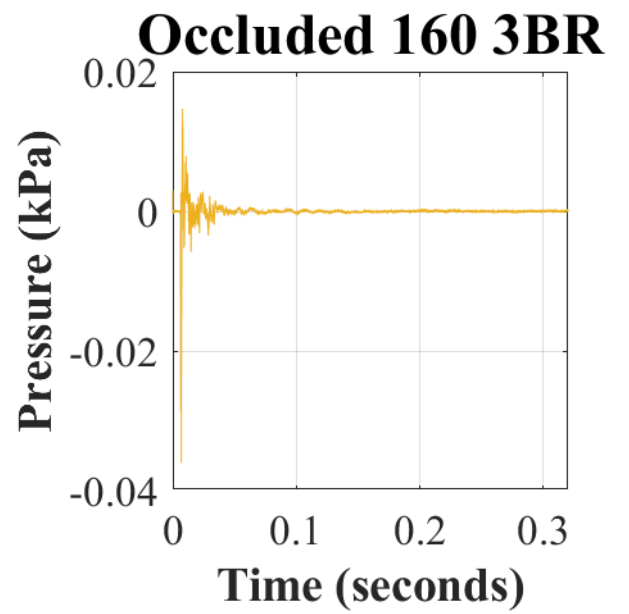
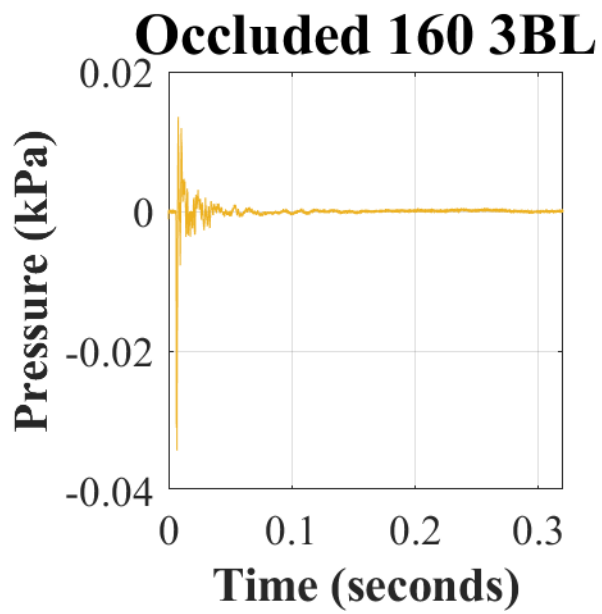
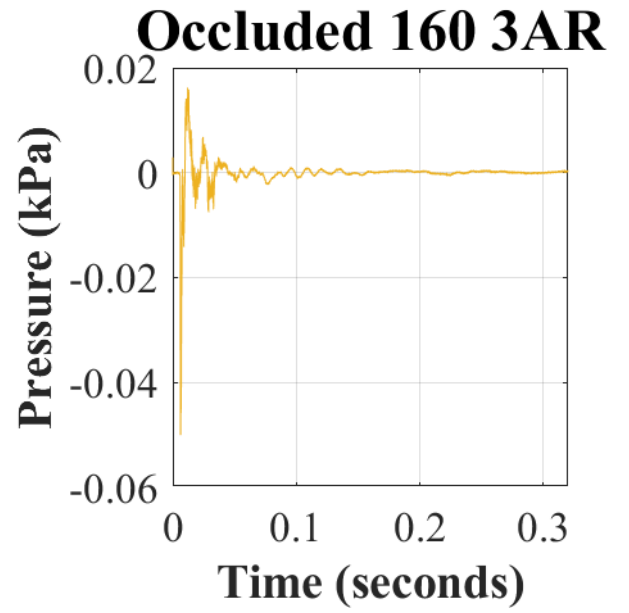
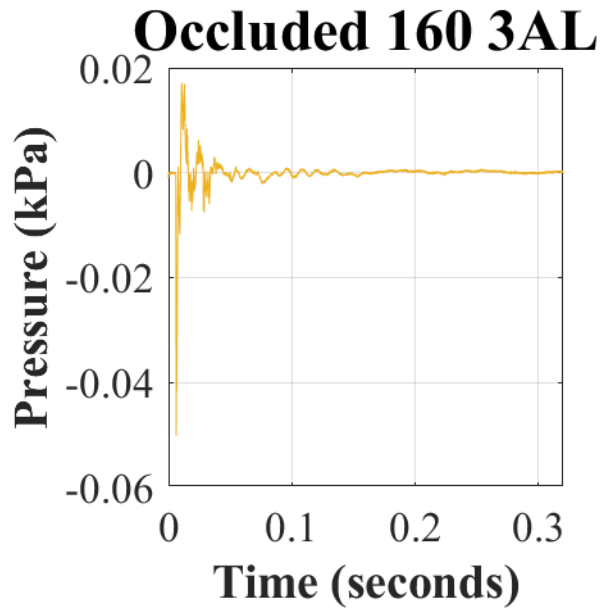


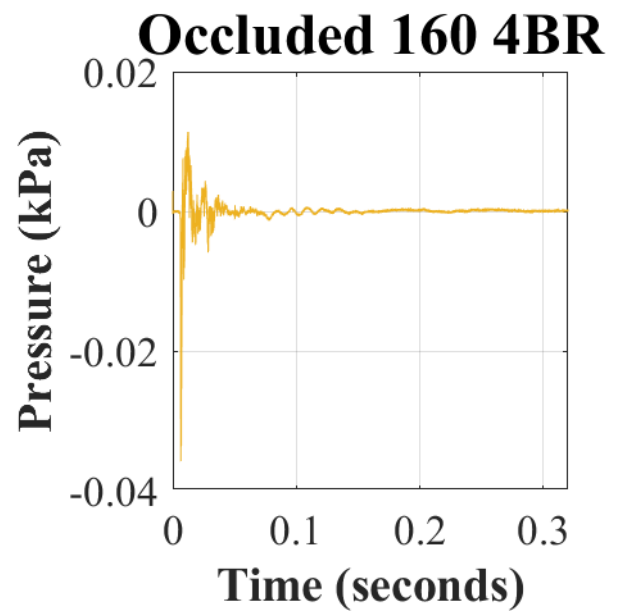
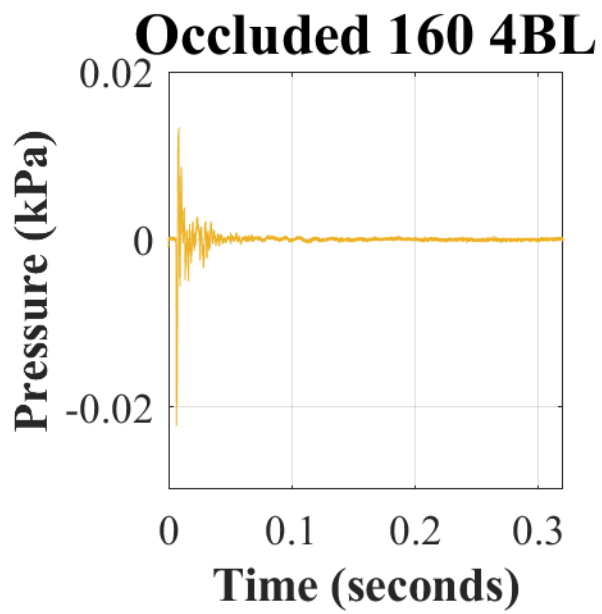
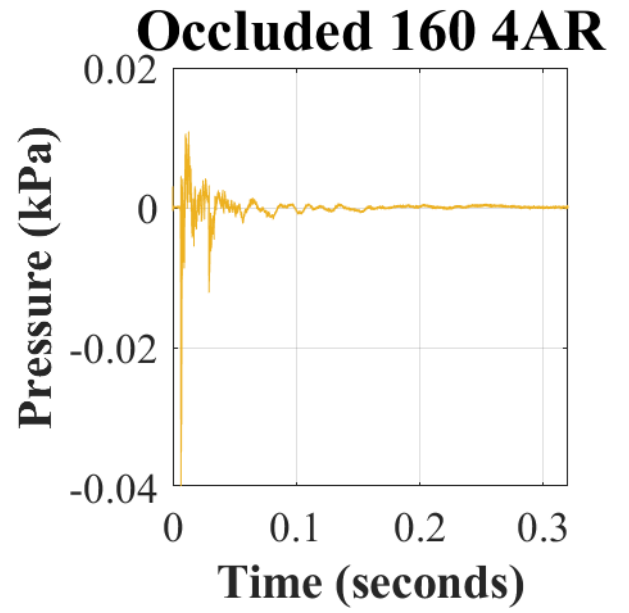
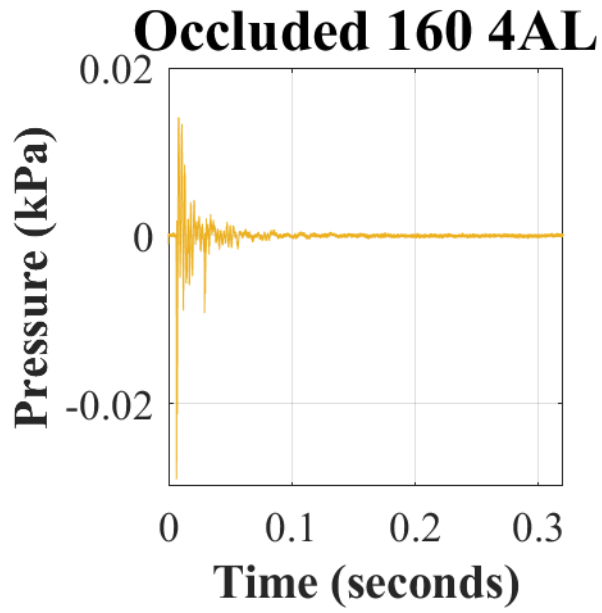
Note. The naming convention for all free-field waveforms is “Free Field LvL Nn”, where ‘Free Field’ indicates that the recording was obtained using the PCB reference microphone, ‘LvL’ is the nominal test level (170 dBp), ‘N’ is the device sample number (1 to 5), and ‘n’ is the device trial (i.e., A or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

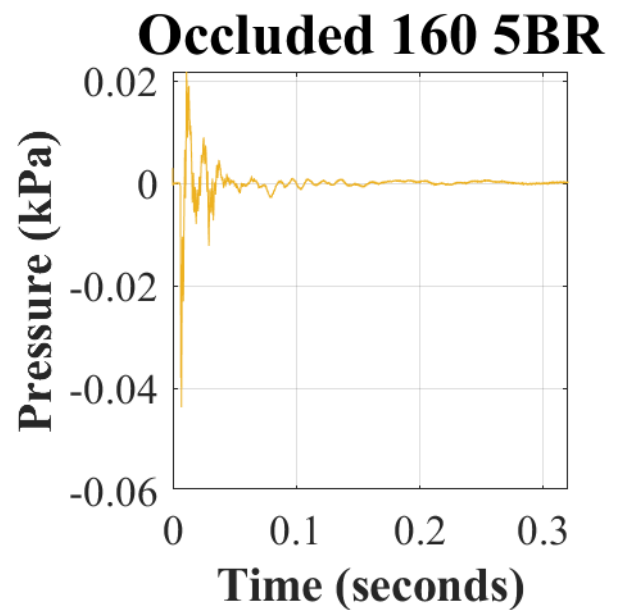
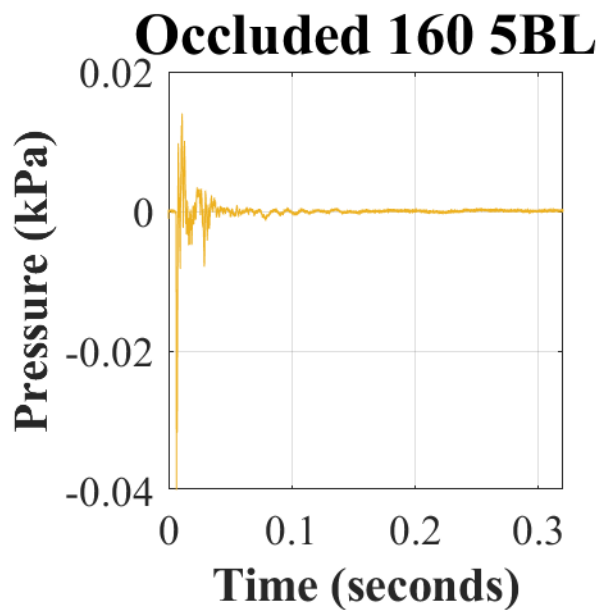
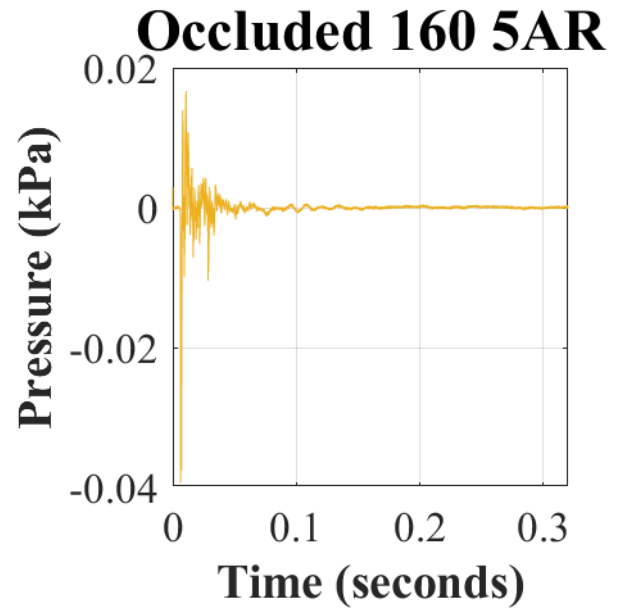
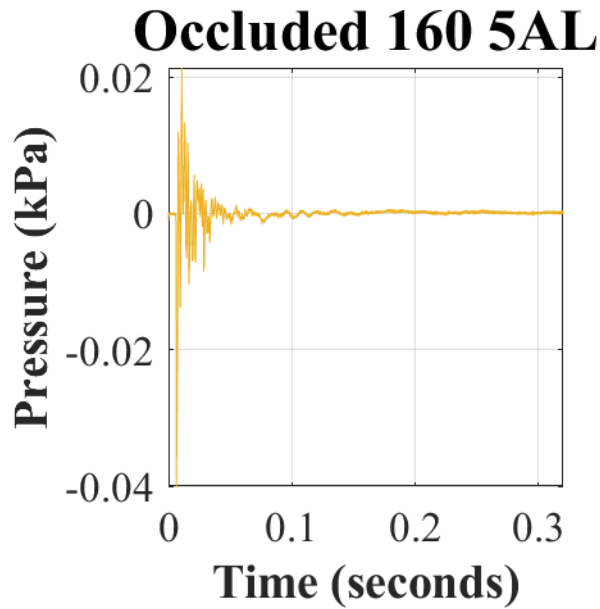
Appendix G. Recorded occluded (closed-ear) waveforms in response to 160 dBp with the CAE Gen 4.0 in the closed mode.





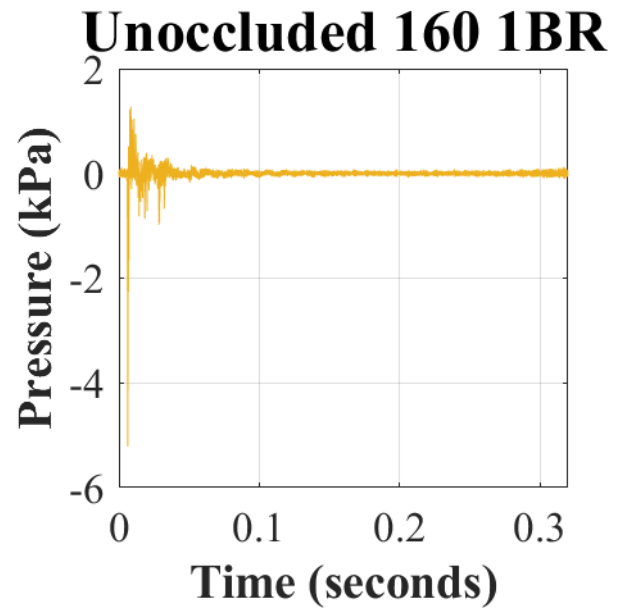
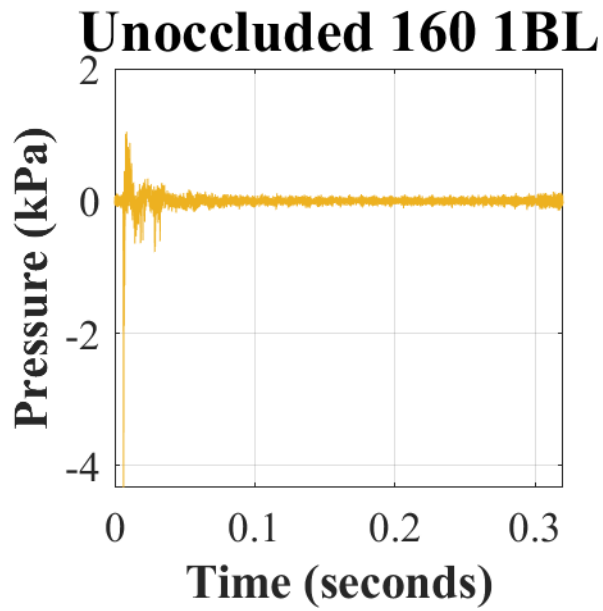
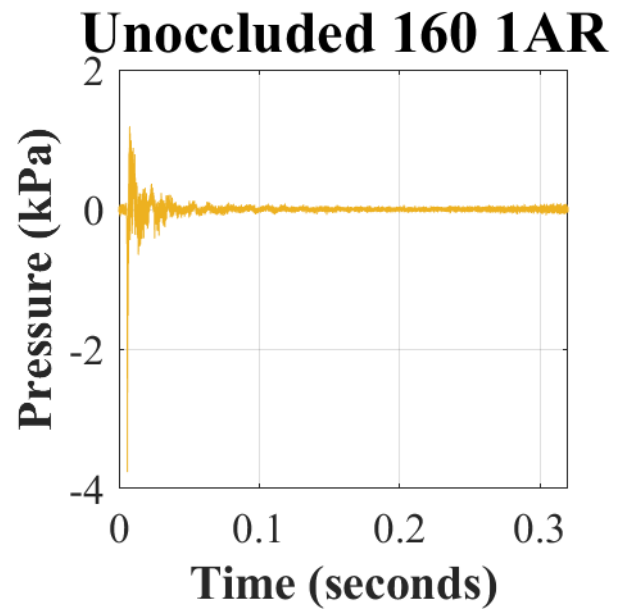
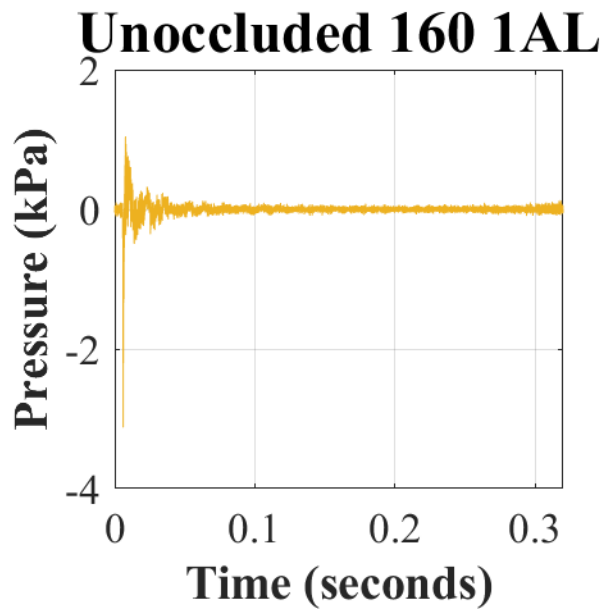


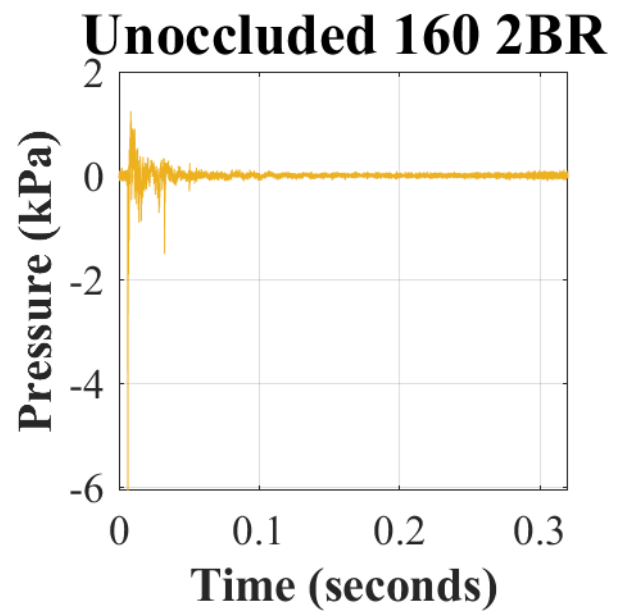
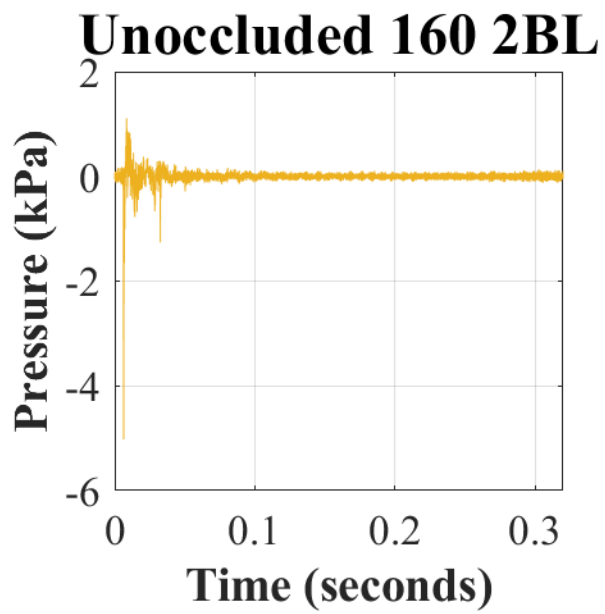
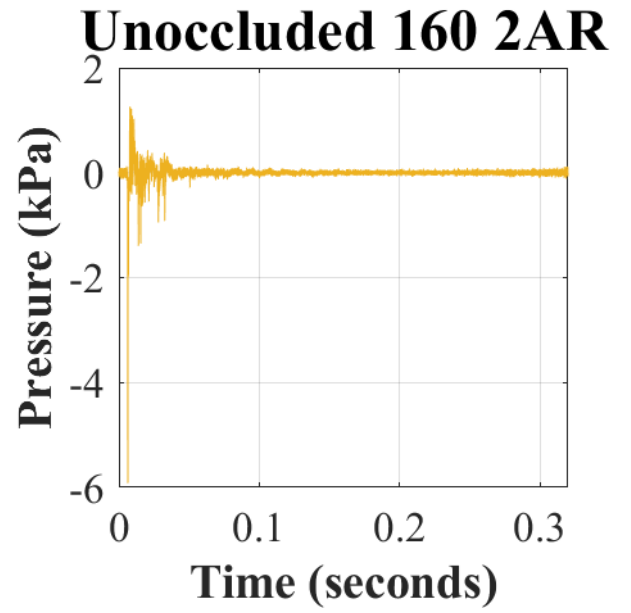
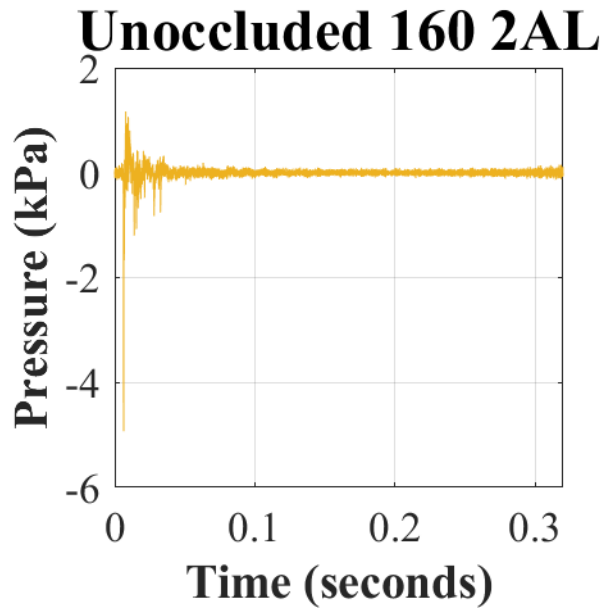


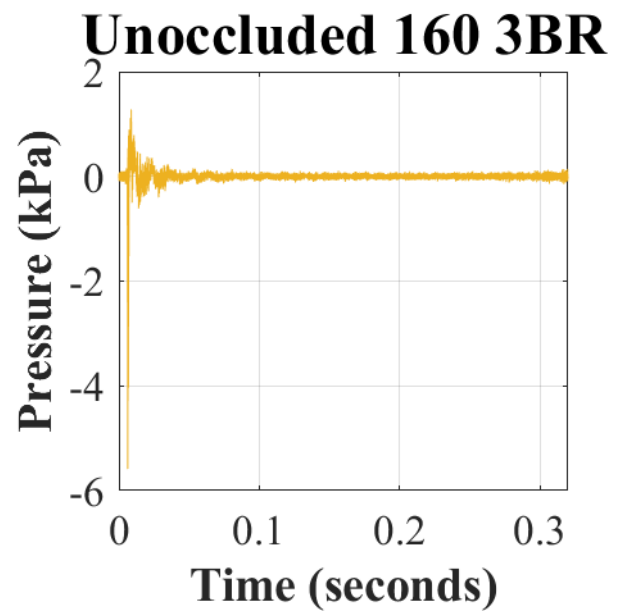
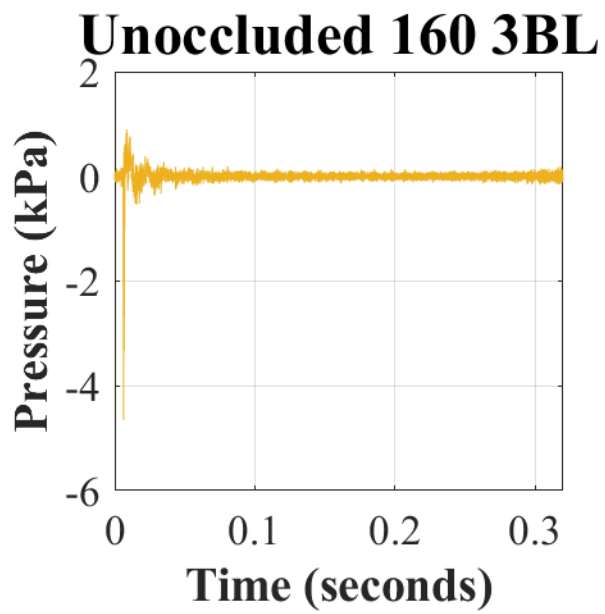
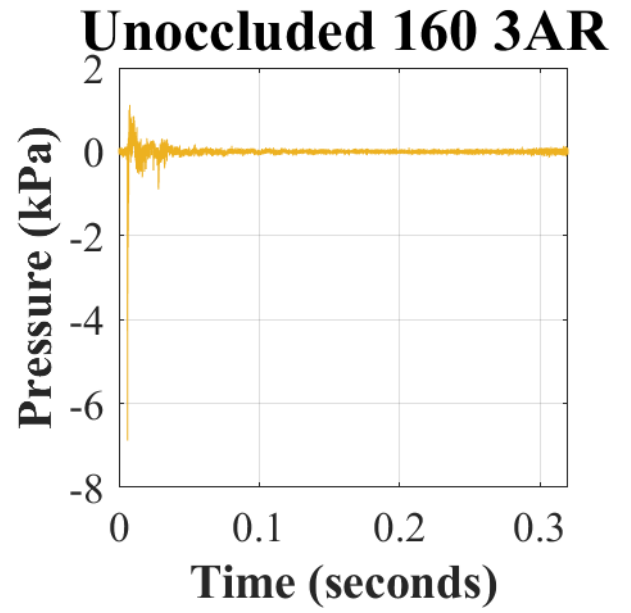
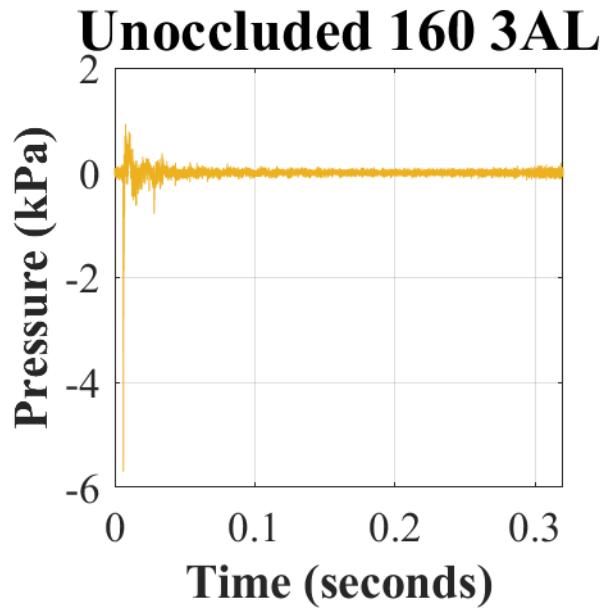


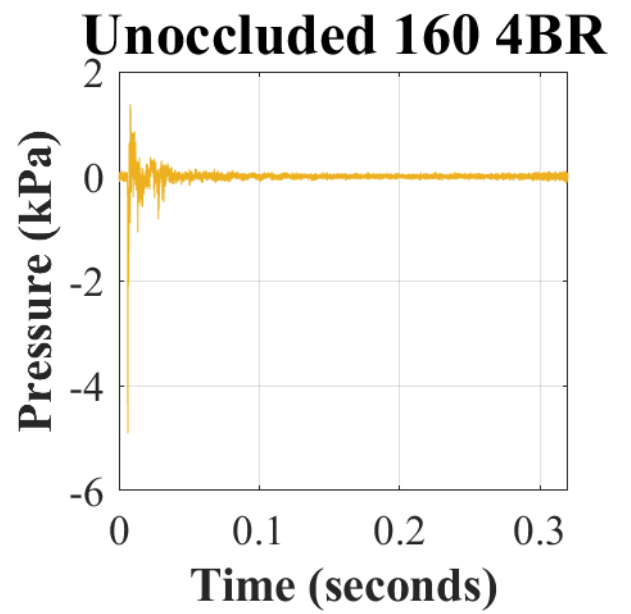
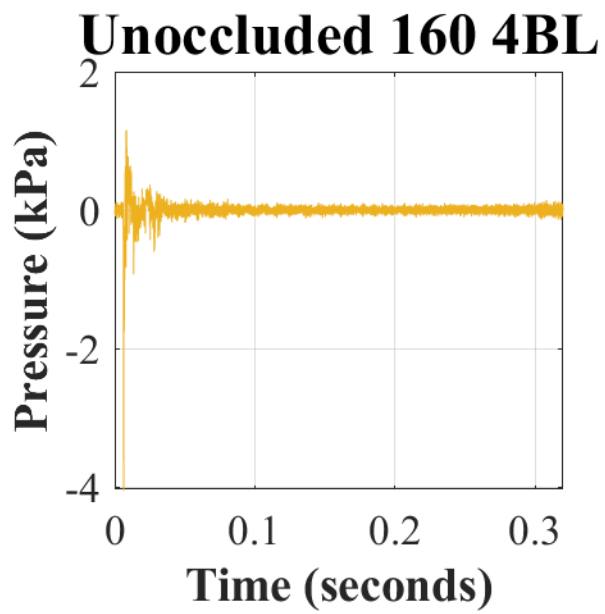
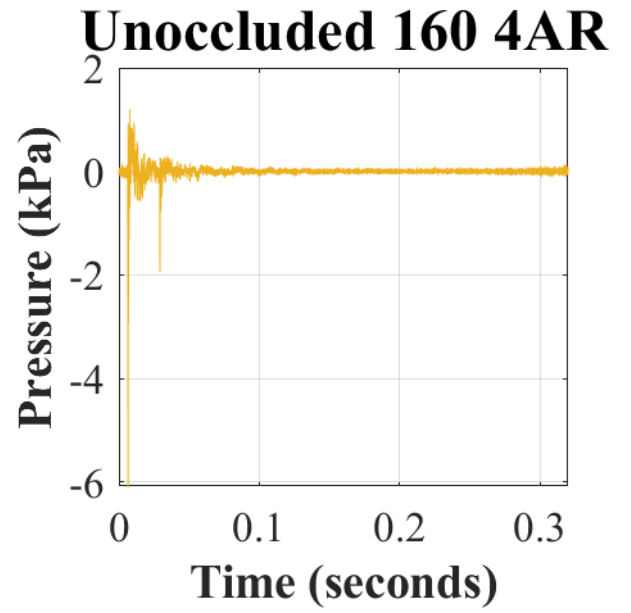
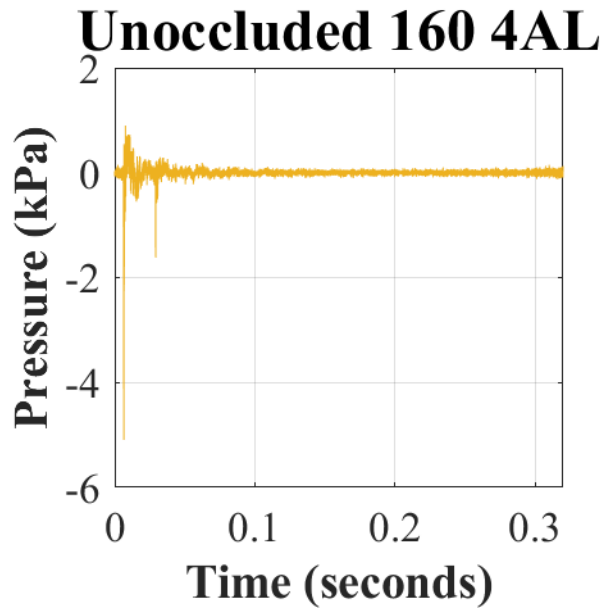
Note. The naming convention for all occluded waveforms is “Occluded LvL NnX”, where ‘Occluded’ is the test condition (i.e., ATF has HPD doffed), ‘LvL’ is the nominal test level (i.e., 160 or 170 dBP), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or B) indicating 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).

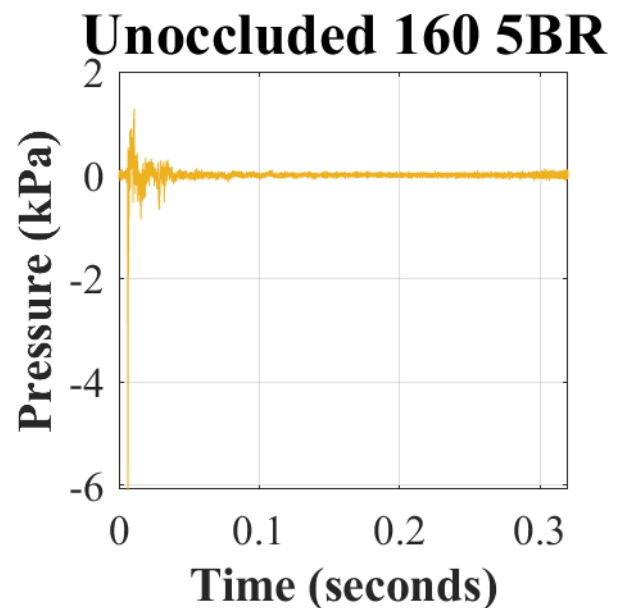
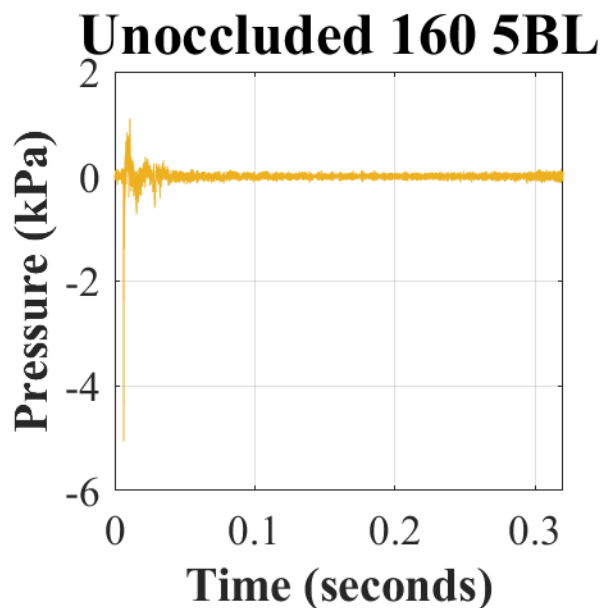
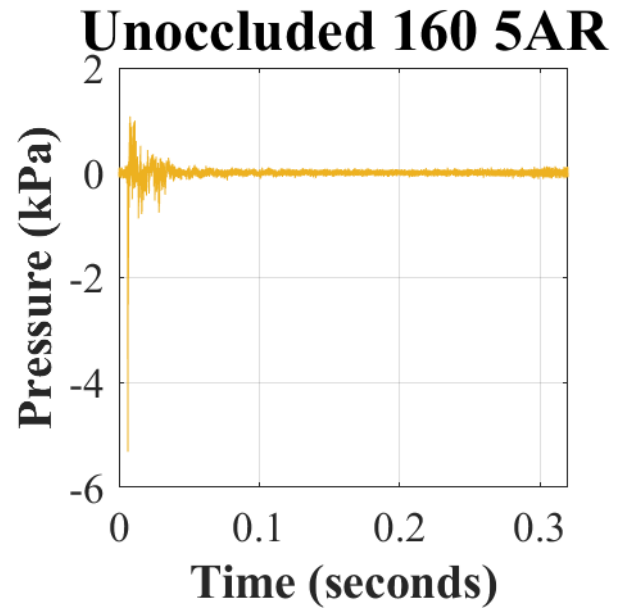
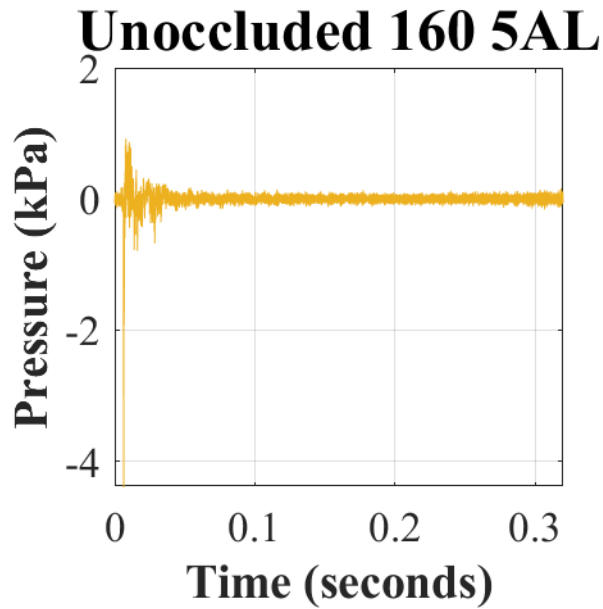
Appendix H. Estimated unoccluded (open-ear) waveforms in response to 160 dBp with the CAE Gen 4.0 earplugs in closed mode.





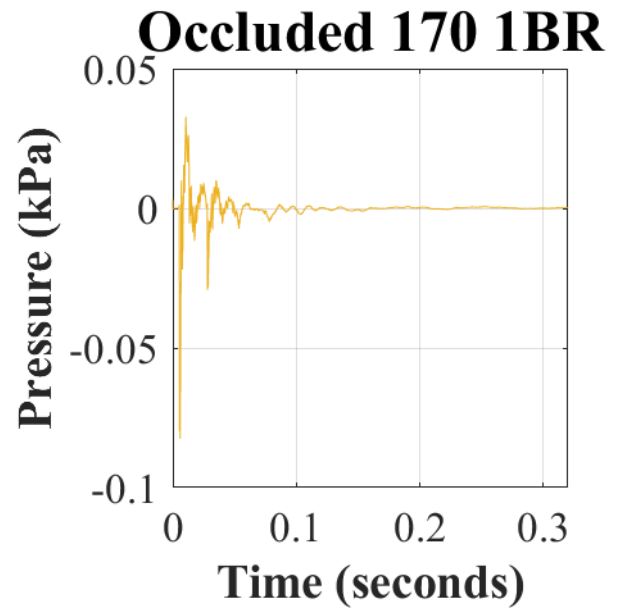
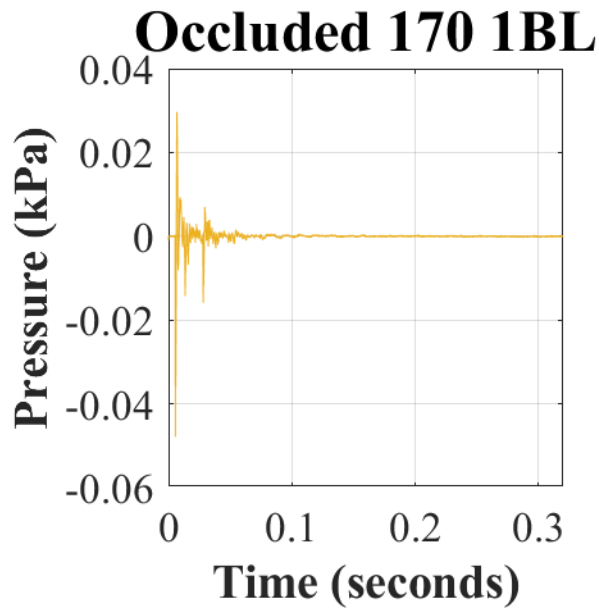
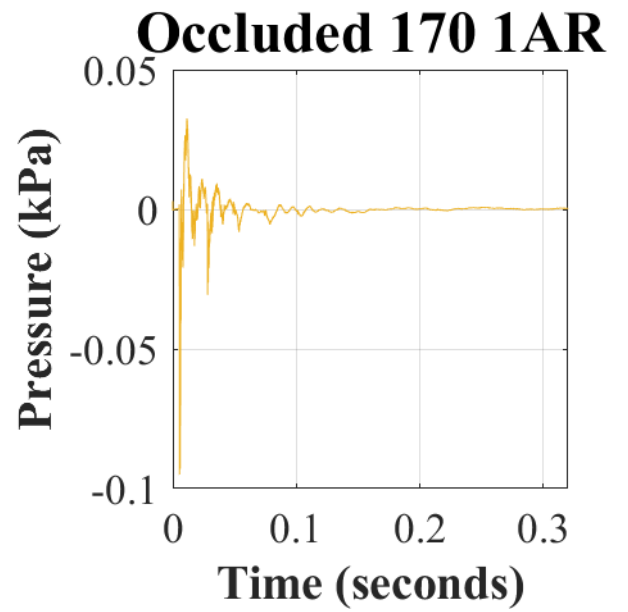
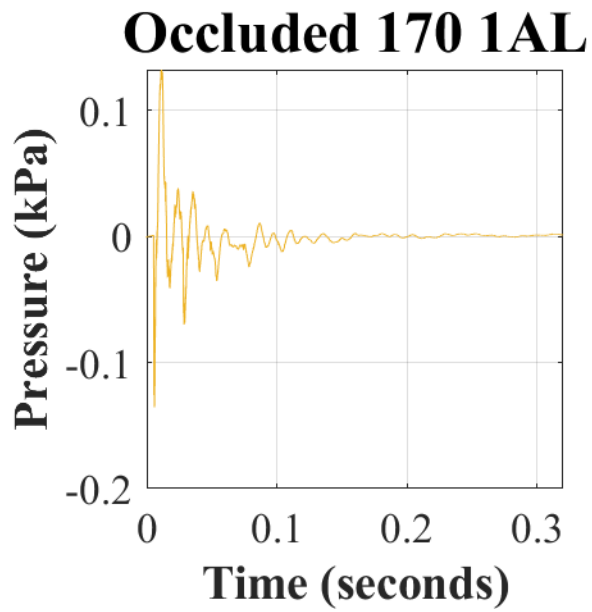


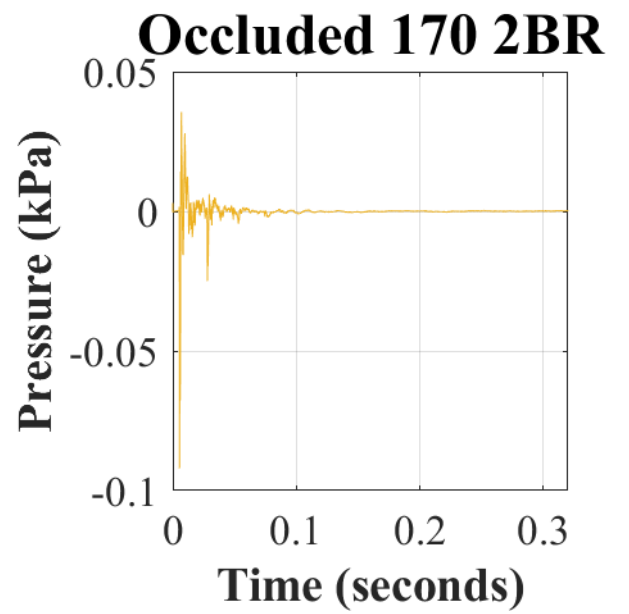
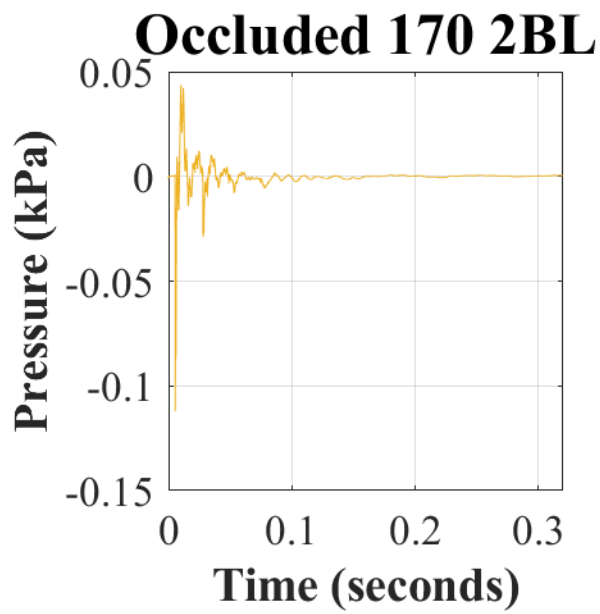
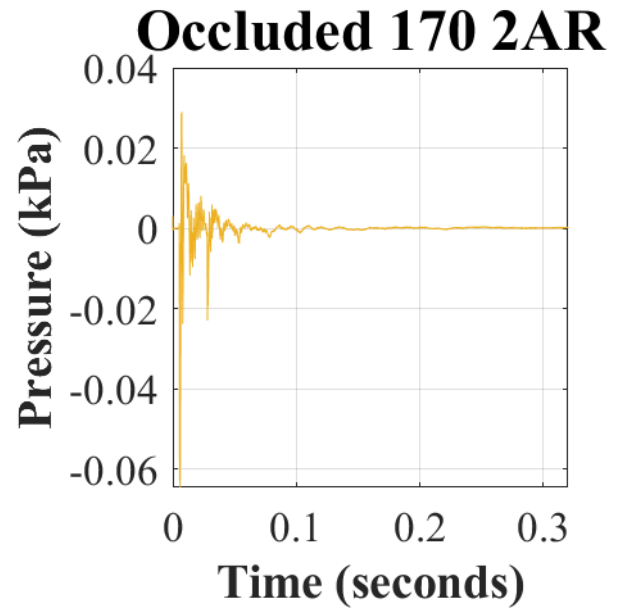
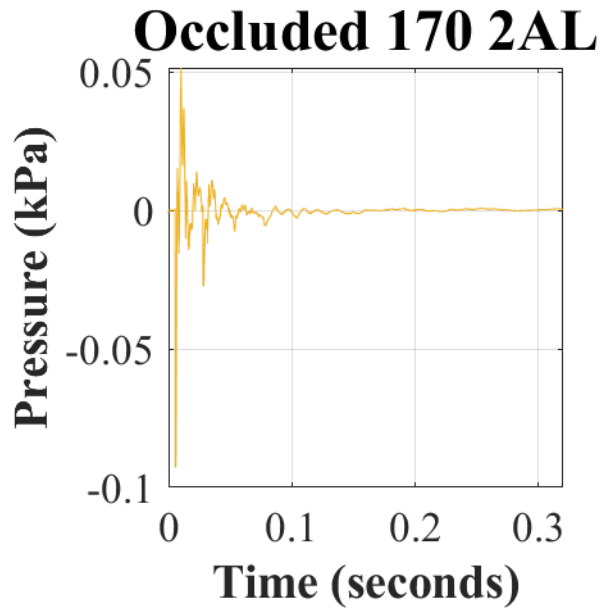




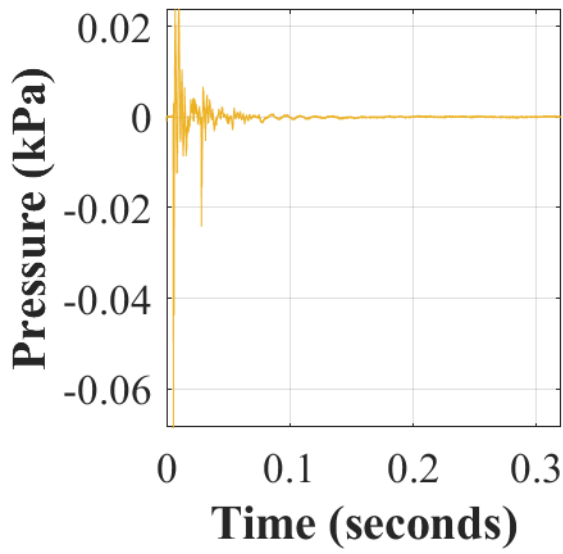
Note. The naming convention for all occluded waveforms is “Occluded LvL NnX”, where ‘Unoccluded’ is the test condition (i.e., ATF has HPD donned), ‘LvL’ is the nominal test level (i.e., 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or B) indicating 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 I. Recorded occluded (closed-ear) waveforms in response to 170 dBp with the CAE Gen 4.0 in the closed mode.

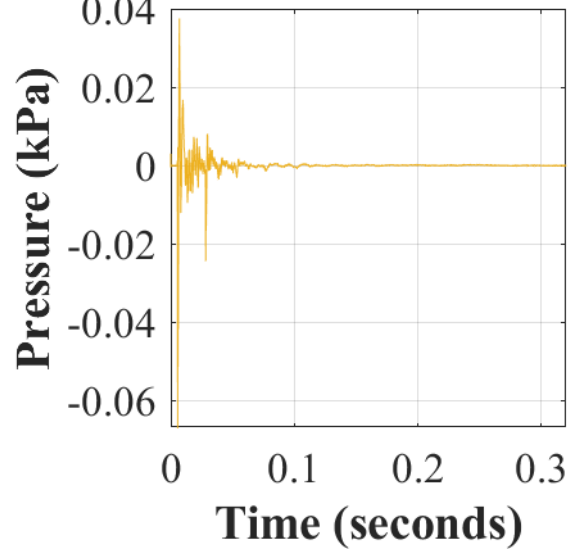




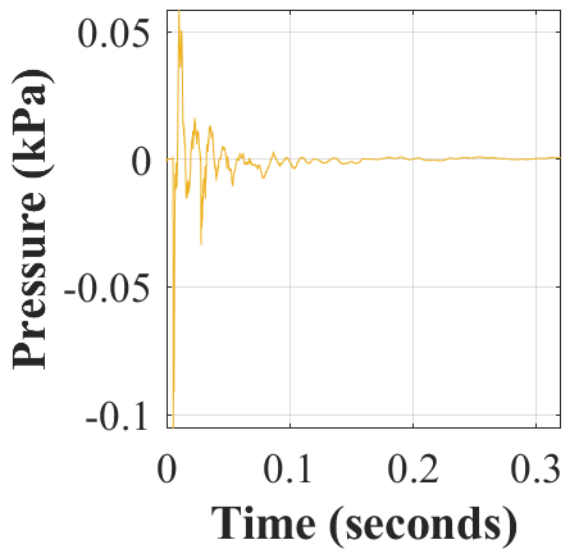
Occluded 170 3AL



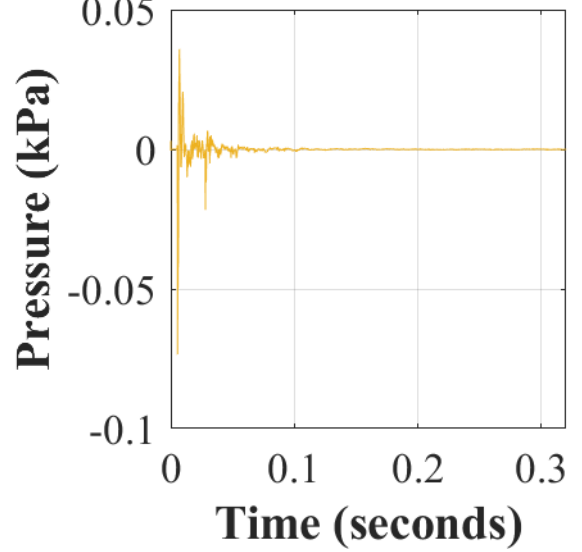
Occluded 170 3AR

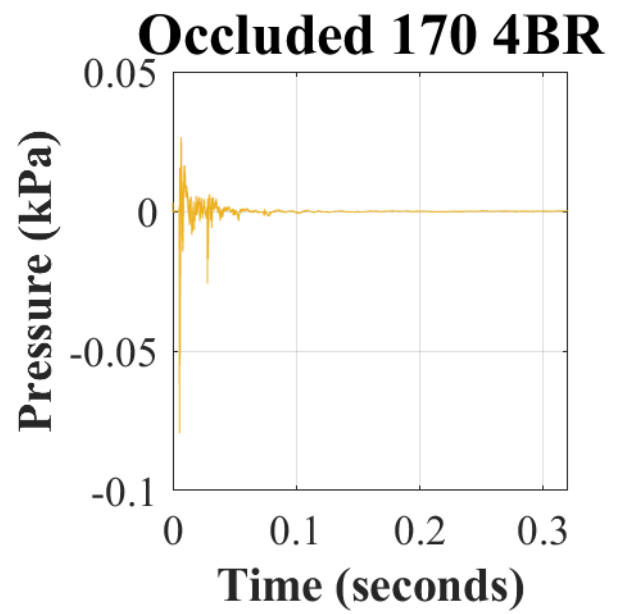
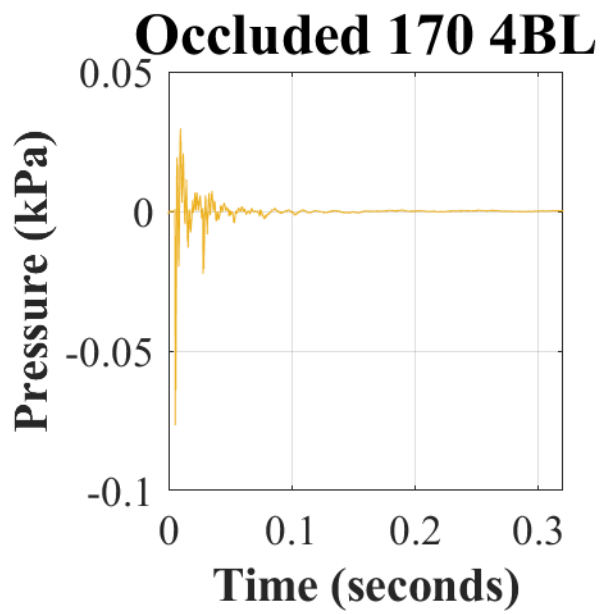
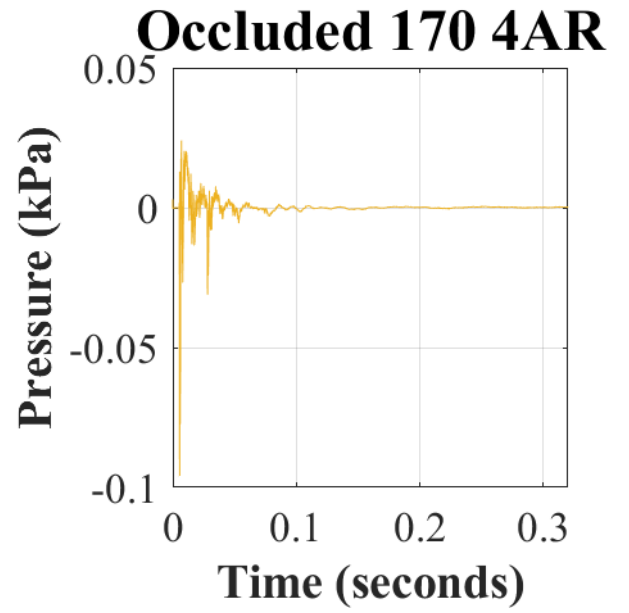
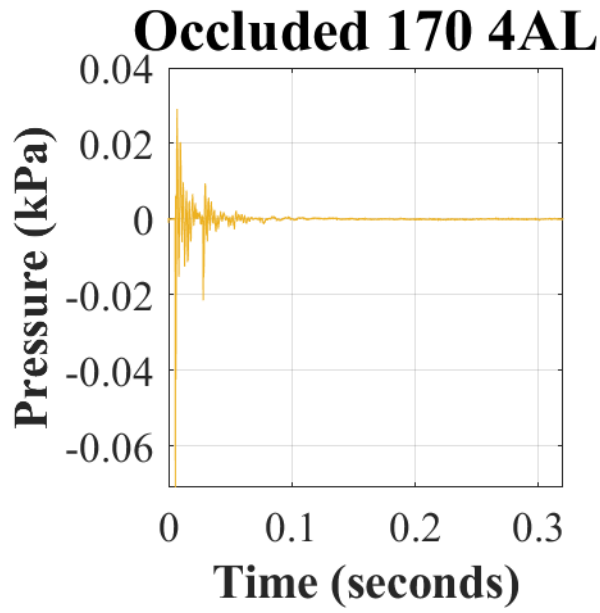


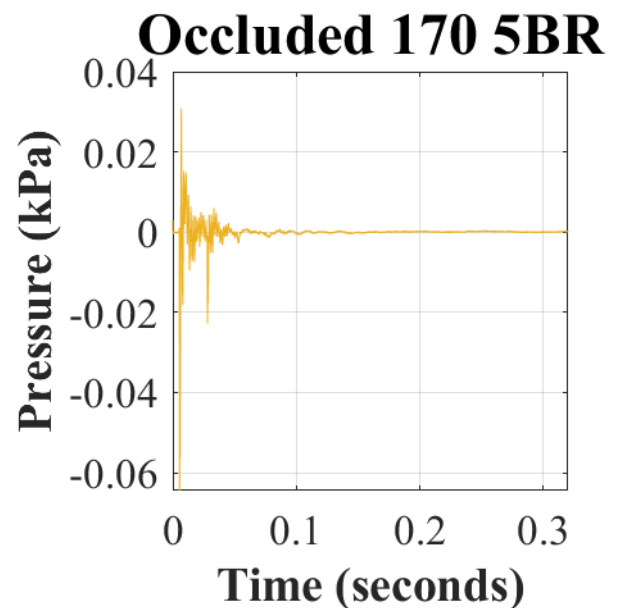
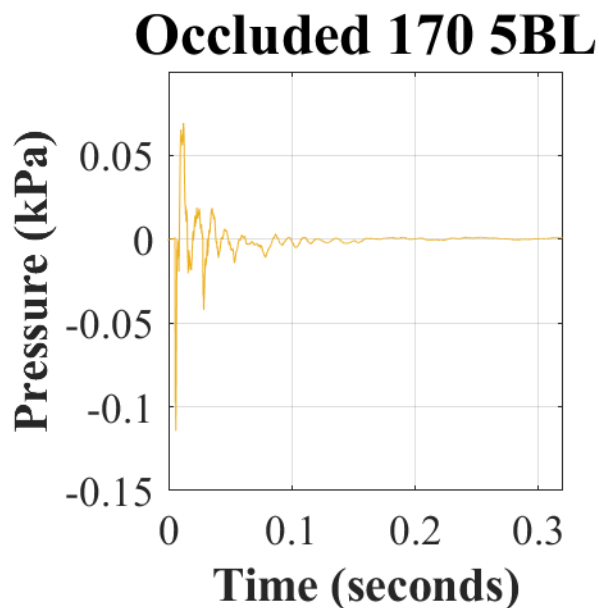
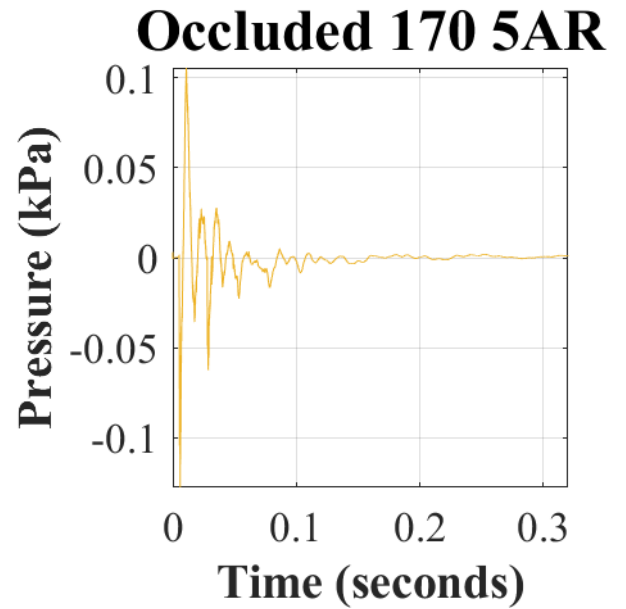
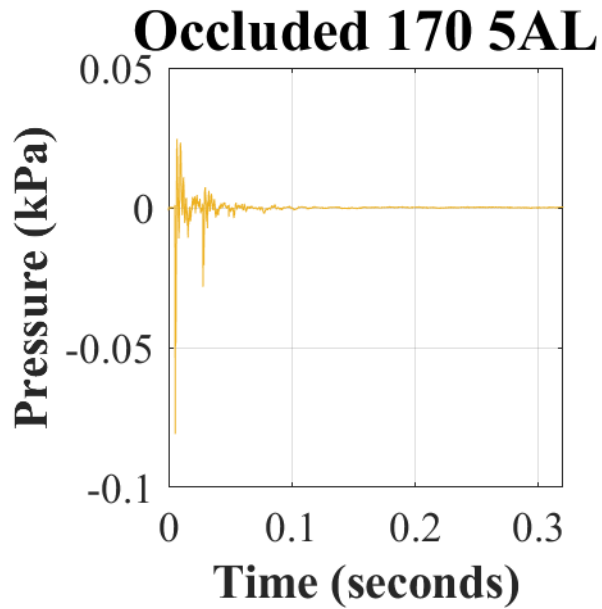
Occluded 170 3BL



Occluded 170 3BR

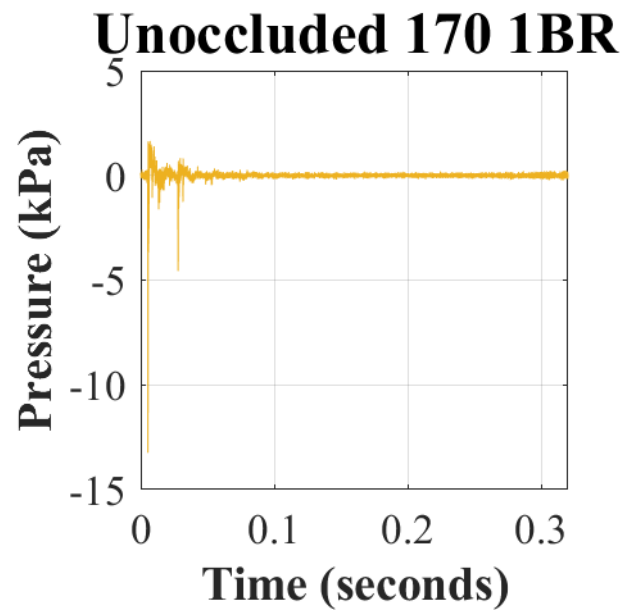
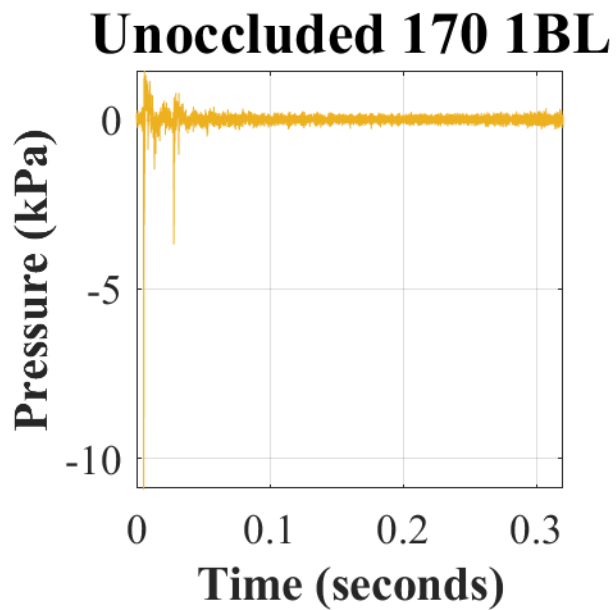
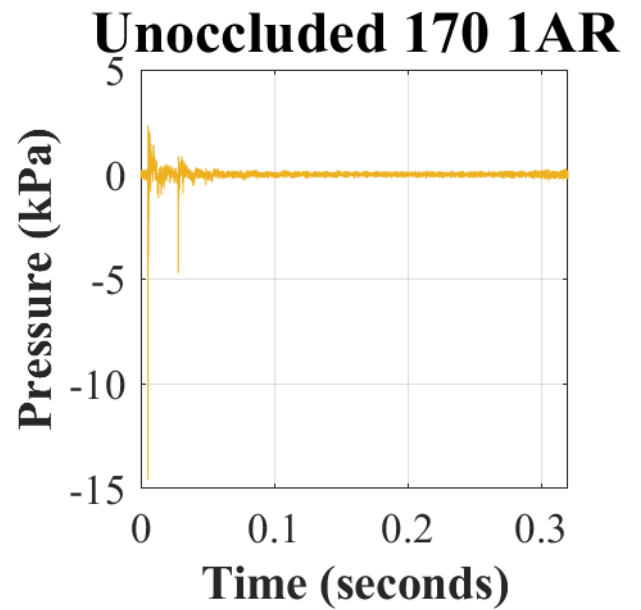
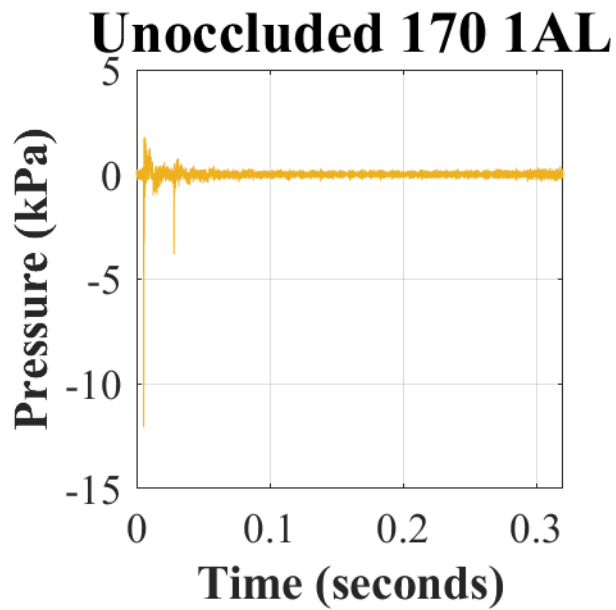


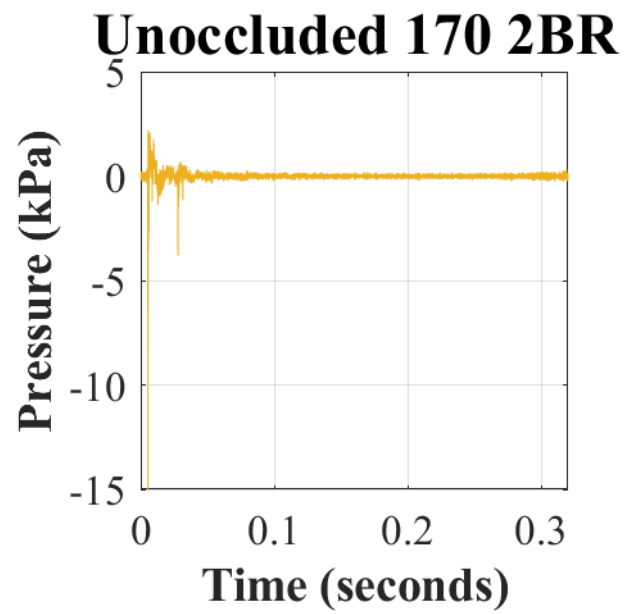
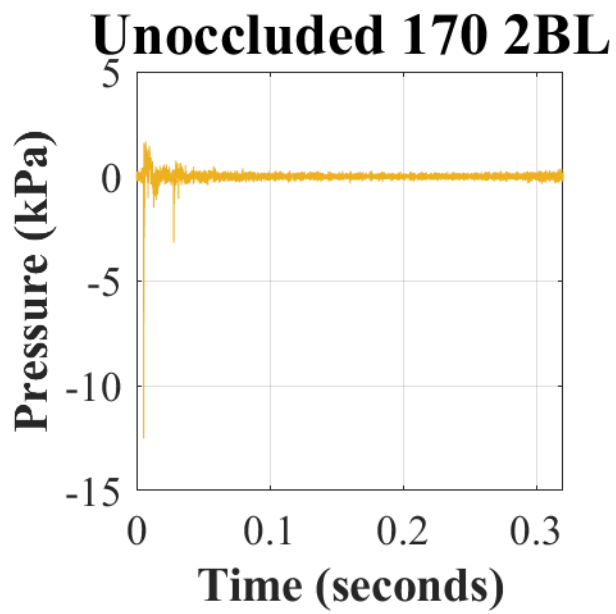
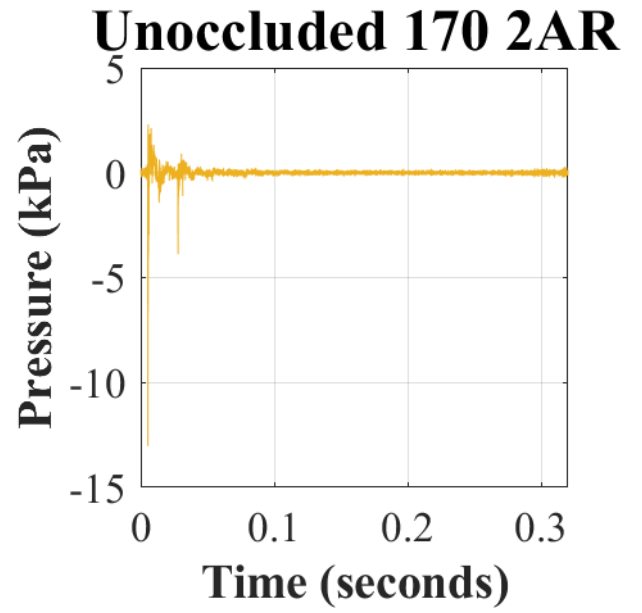
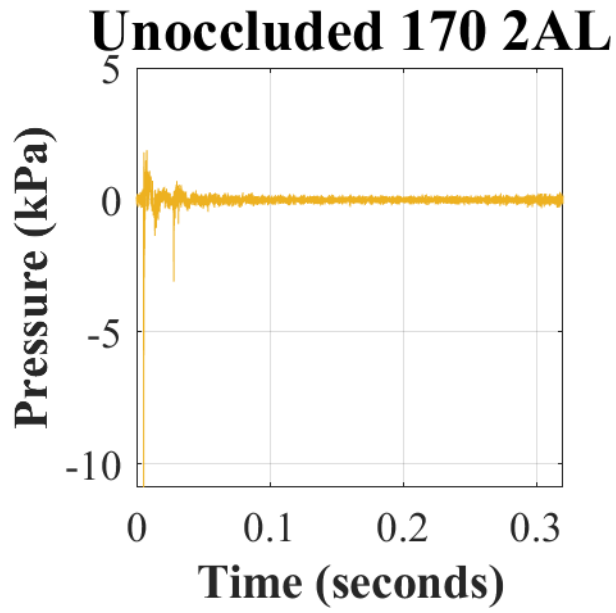


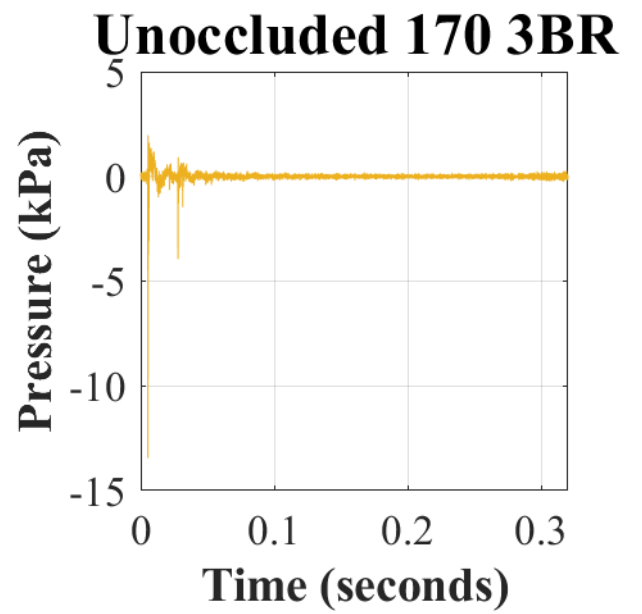
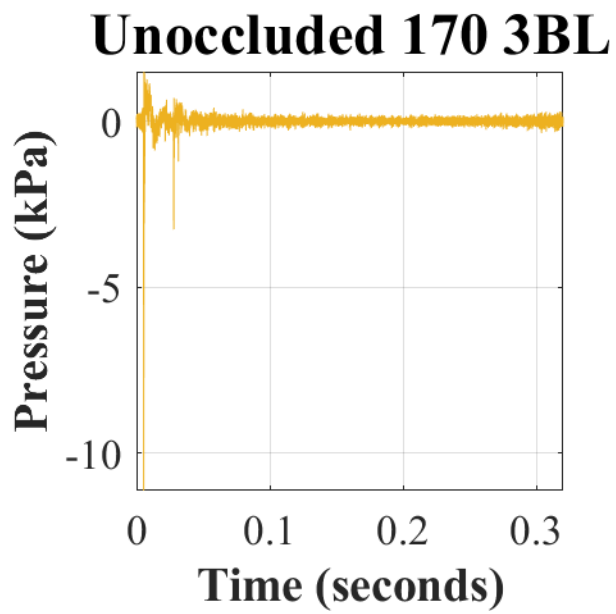
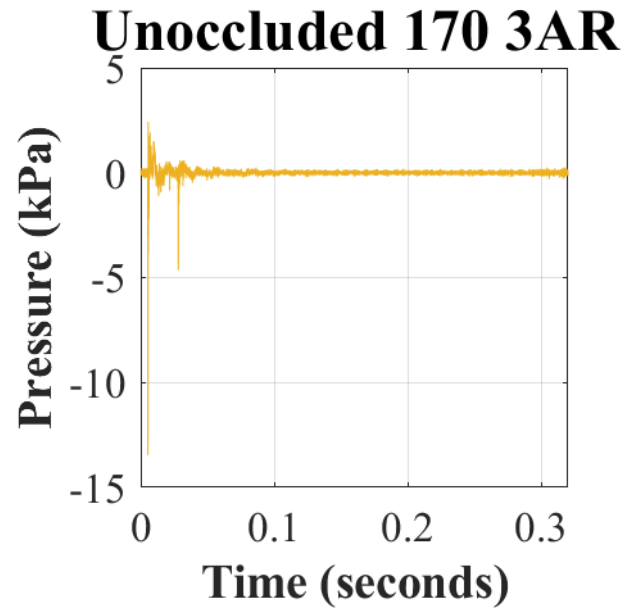
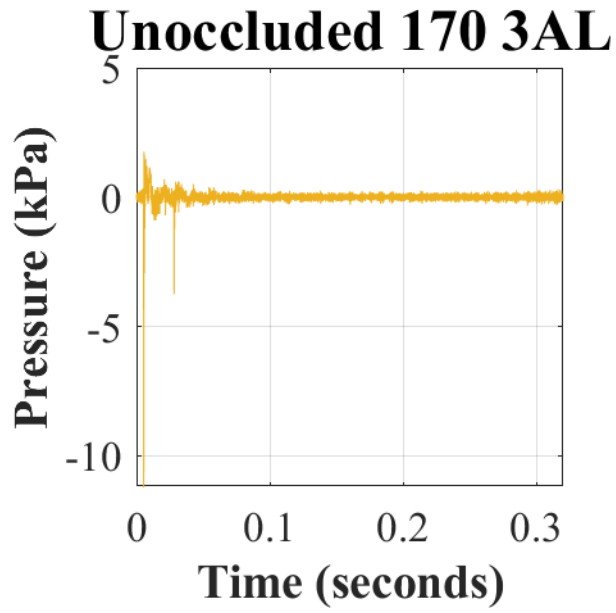


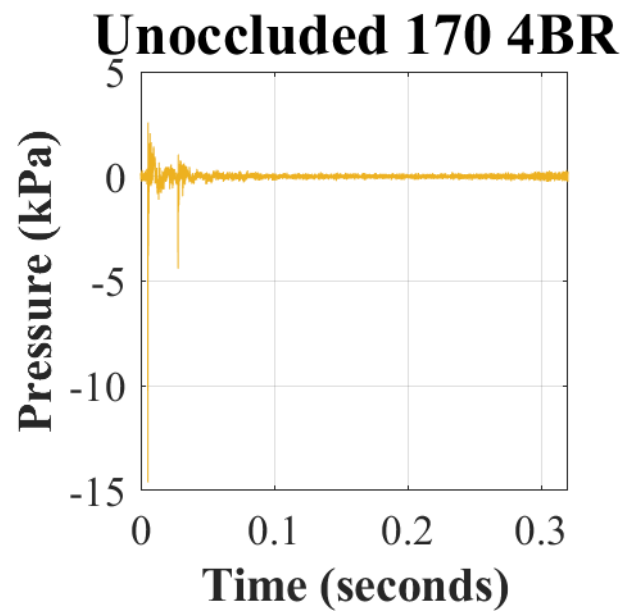
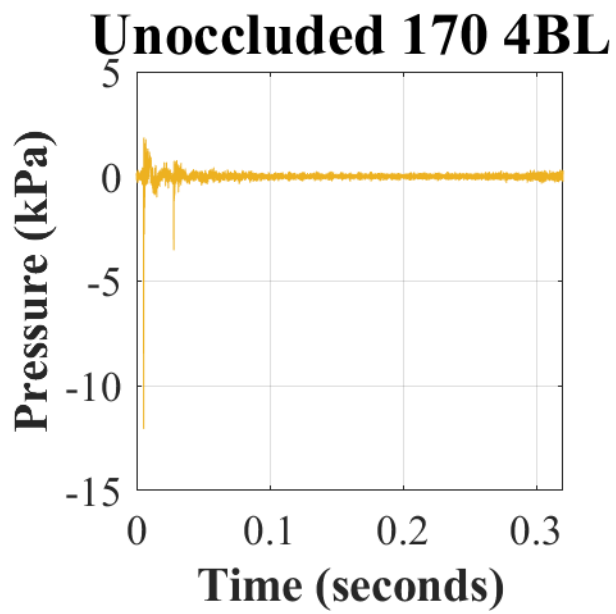
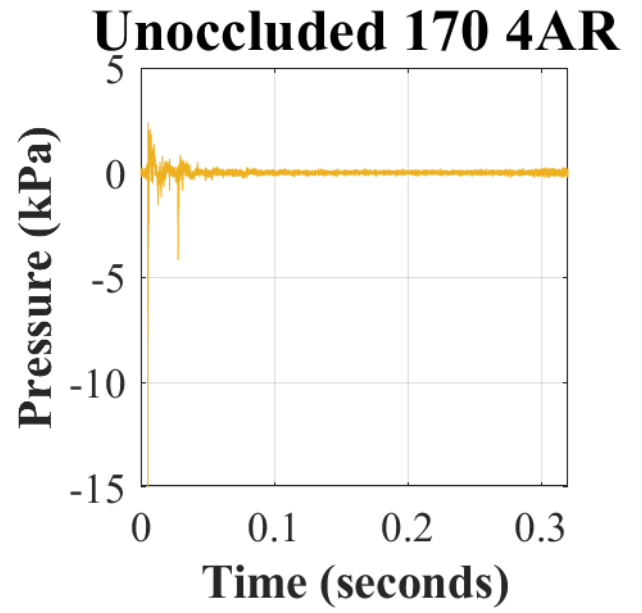
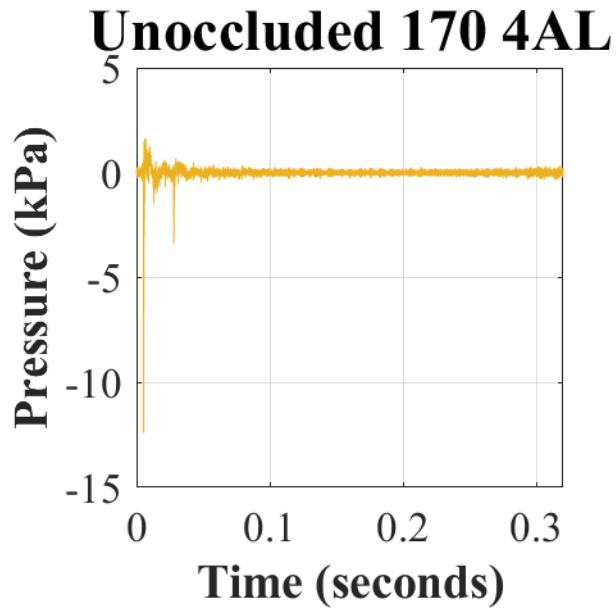
Note. The naming convention for all occluded waveforms is “Occluded LvL NnX”, where ‘Occluded’ is the test condition (i.e., ATF has HPD donned), ‘LvL’ is the nominal test level (i.e., 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or B) indicating 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).

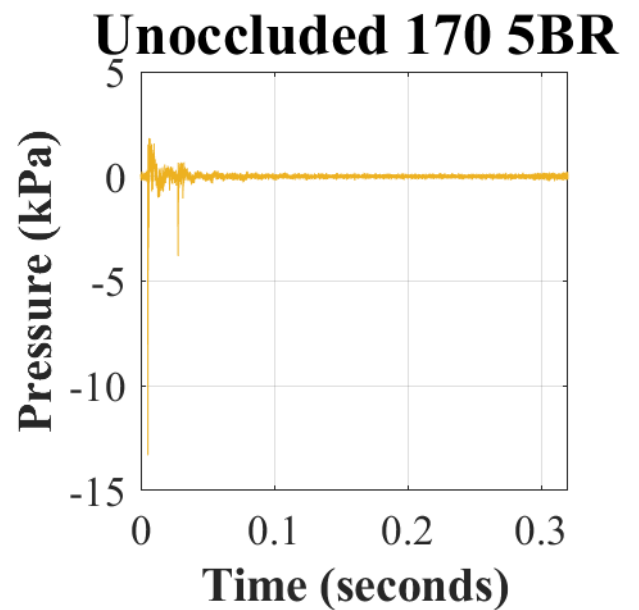
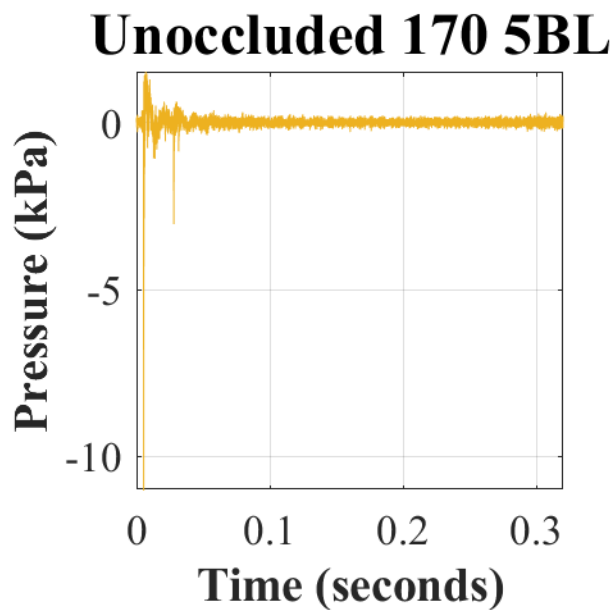
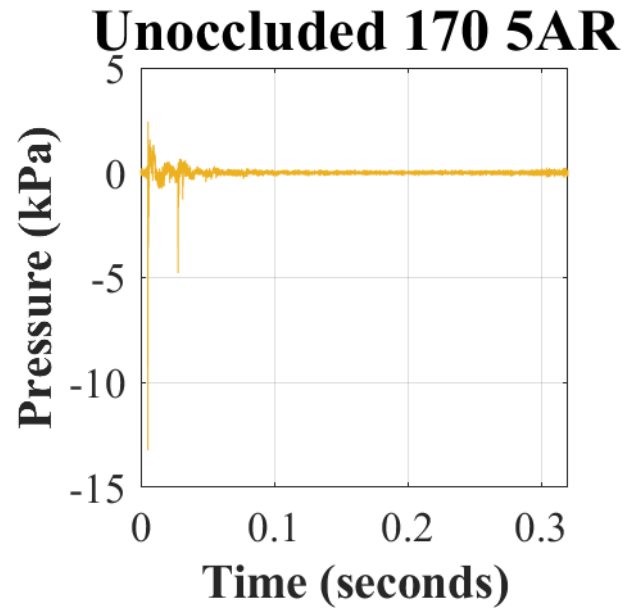
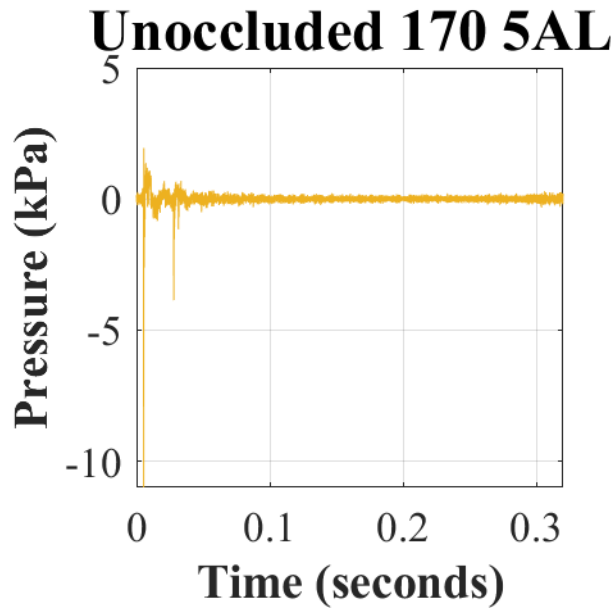
Appendix J. Estimated unoccluded (open-ear) waveforms in response to 170 dBp with the CAE Gen 4.0 earplugs in the closed mode.





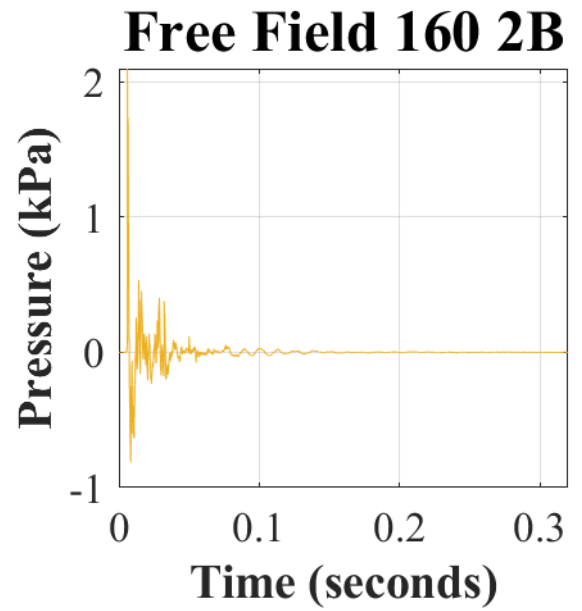
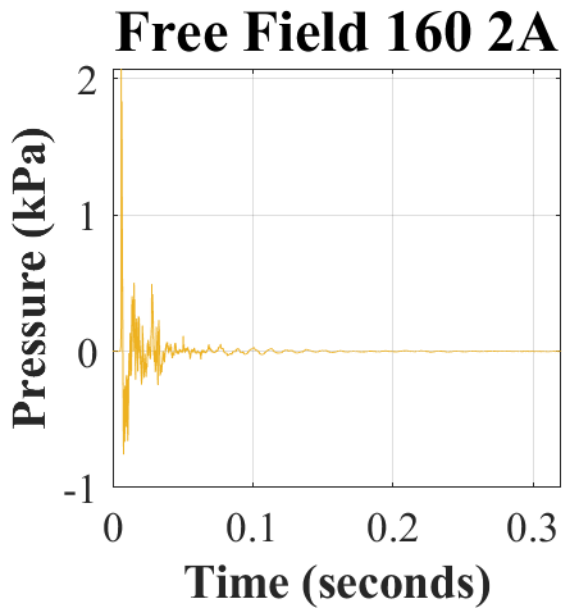
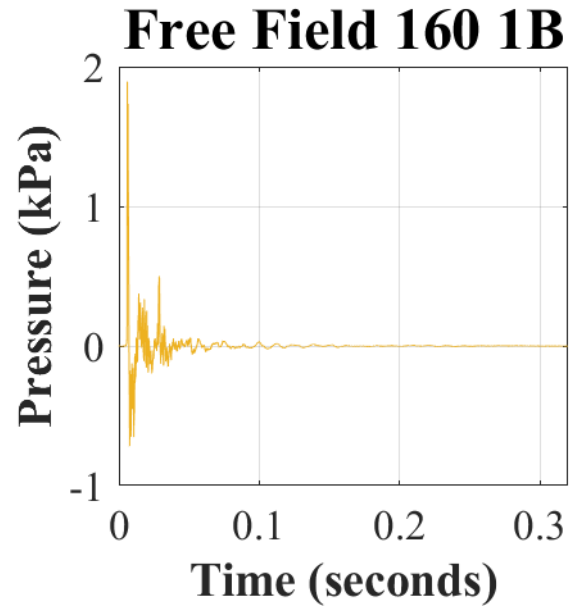
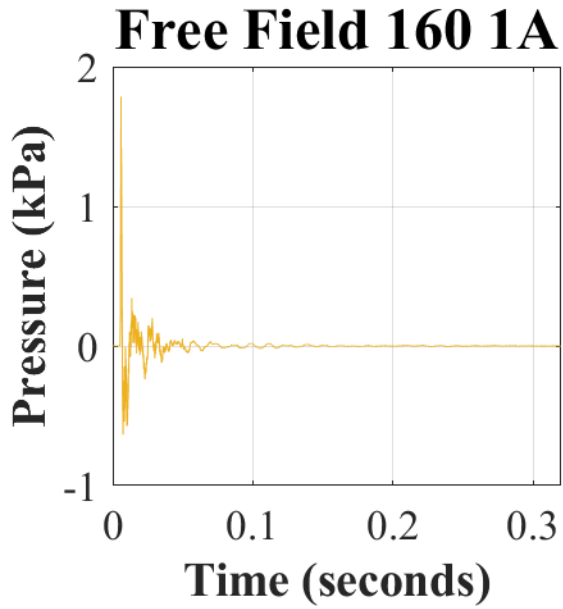


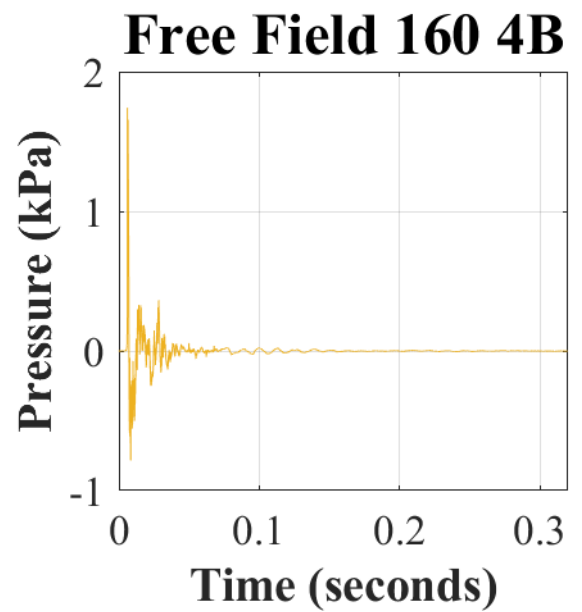
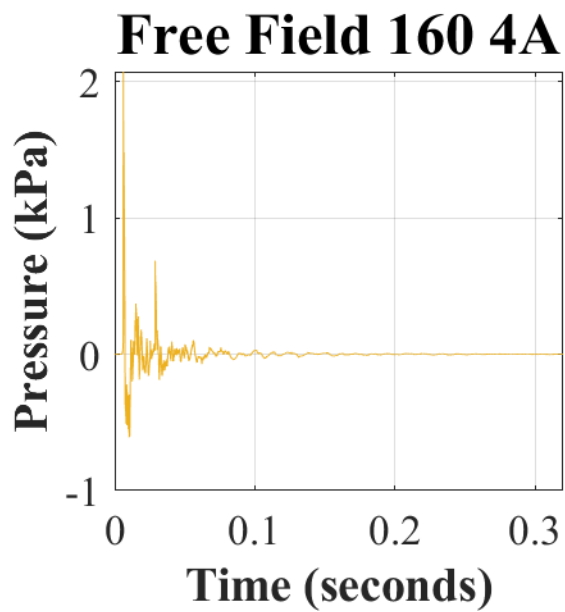
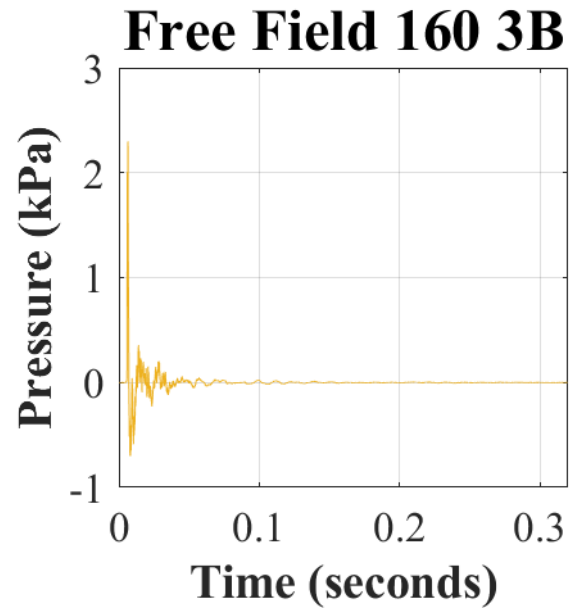
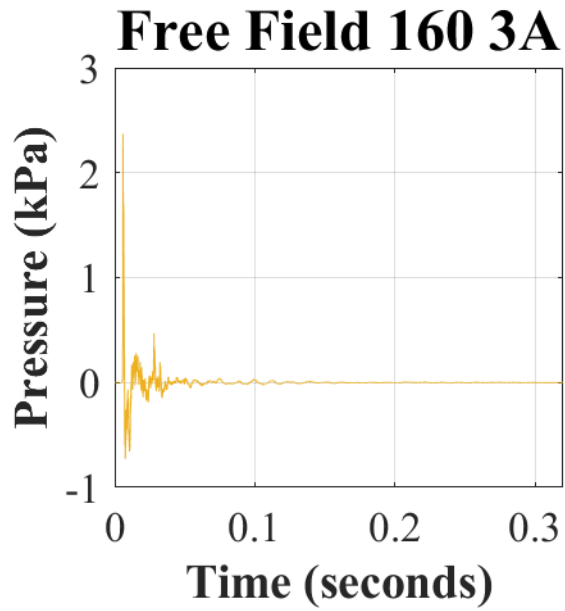


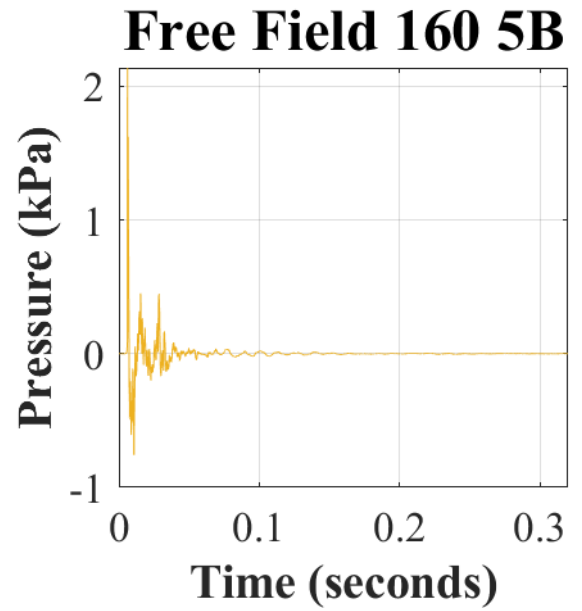
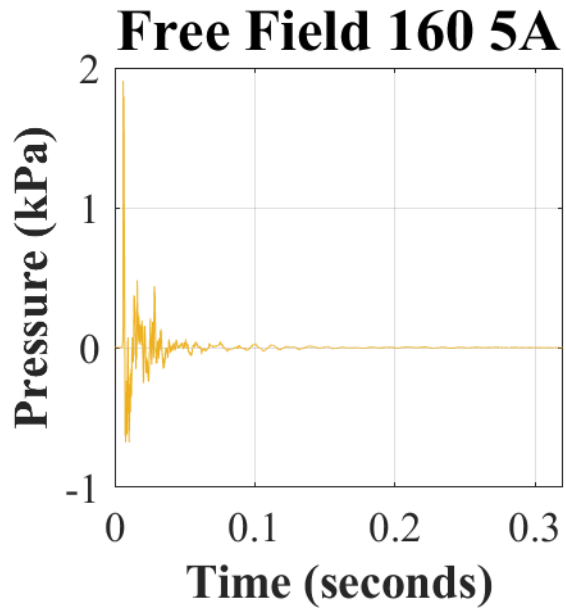


Note. The naming convention for all occluded waveforms is “Occluded LvL NnX”, where ‘Unoccluded’ is the test condition (i.e., ATF has HPD donned), ‘LvL’ is the nominal test level (i.e., 160 or 170 dBP), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or B) indicating 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 K. Recorded waveform of the impulse measured with the free-field probe at 160 dBp and the CAE Gen 4.0 earplugs in the closed mode.

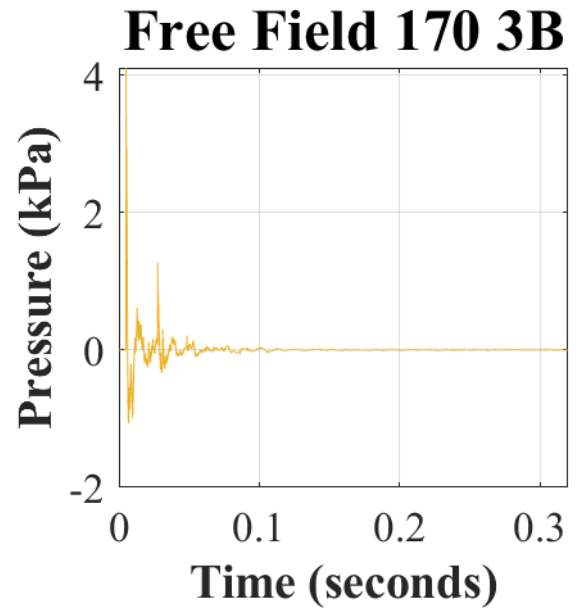
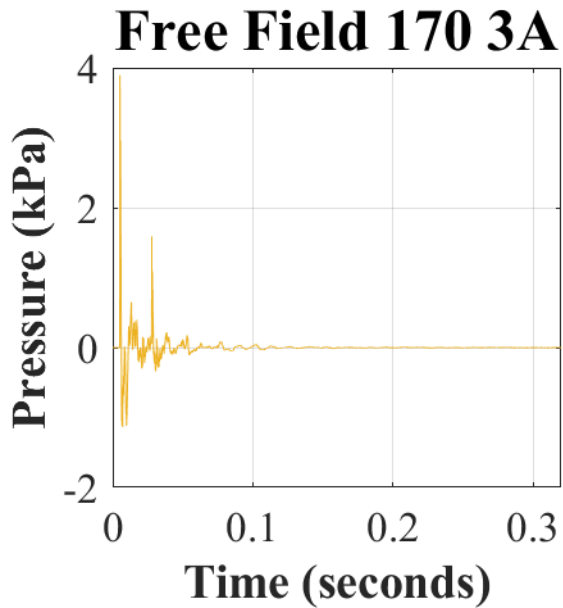
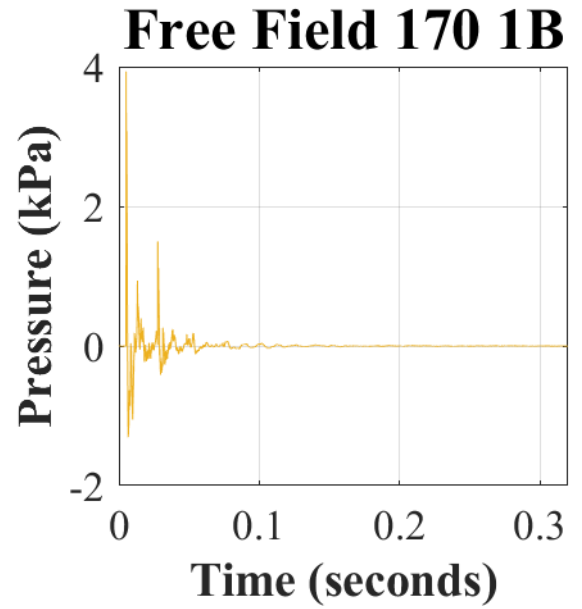
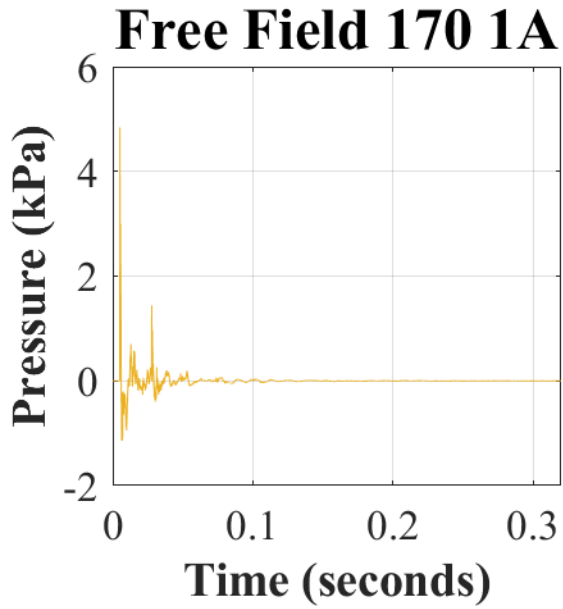


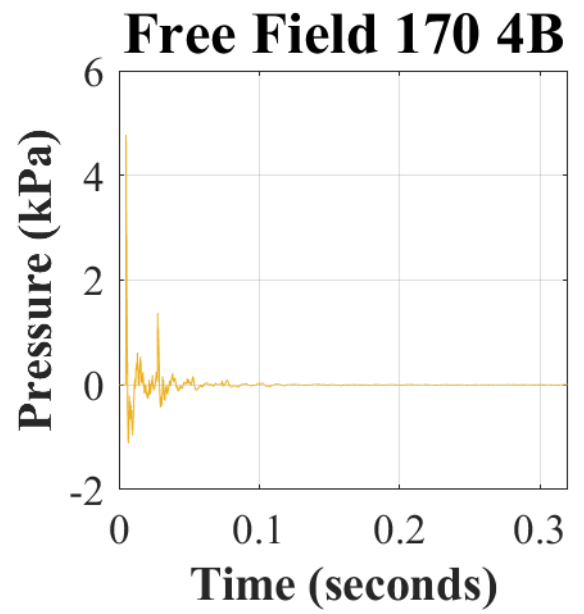
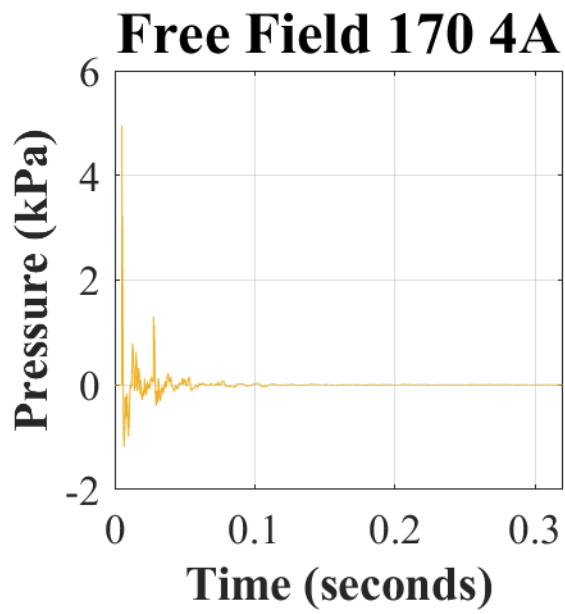
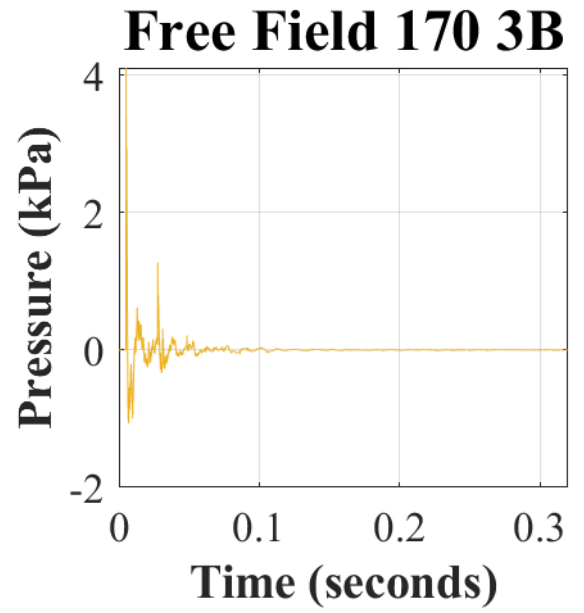
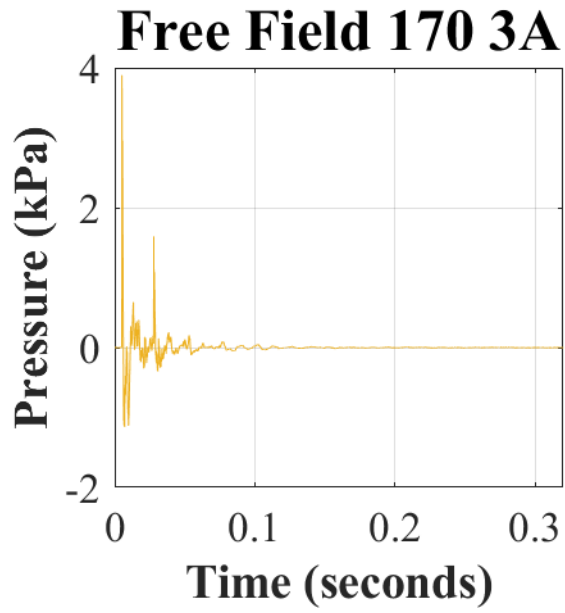


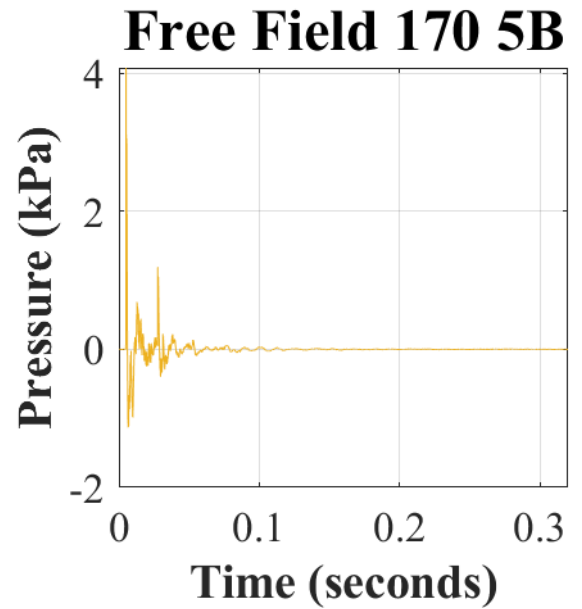
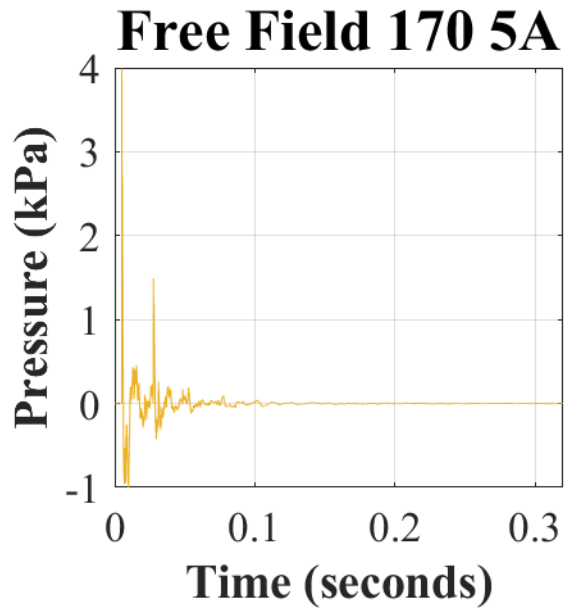


Note. The naming convention for all free-field waveforms is “Free Field LvL Nn”, where ‘Free Field’ indicates that the recording was obtained using the PCB reference microphone, ‘LvL’ is the nominal test level (160 dB), ‘N’ is the device sample number (1 to 5), and ‘n’ is the device trial (i.e., A or B).

Appendix L. Recorded waveform of the impulse measured with the free-field probe at 170 dBp and the CAE Gen 4.0 earplugs in the closed mode.







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).