

# Naval Submarine Medical Research Laboratory

NSMRL/F1016,F2002/TM--2022-1395

March 24, 2022

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## **Impulse Assessment of the Enhanced Combat Helmet – Marine Corps with the ComTac™ V Headset and the Howard Leight™ MAX® Earplug**

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<b>1. REPORT DATE (DD-MM-YYYY)</b> 24-03-2022		<b>2. REPORT TYPE</b> Technical Memorandum		<b>3. DATES COVERED (From - To)</b> October 2021 - February 2022	
<b>4. TITLE AND SUBTITLE</b> Impulse Assessment of the Enhanced Combat Helmet – Marine Corps with the ComTac™ V Headset and the Howard Leight™ MAX® Earplug				<b>5a. CONTRACT NUMBER</b>	
				<b>5b. GRANT NUMBER</b>	
				<b>5c. PROGRAM ELEMENT NUMBER</b>	
<b>6. AUTHOR(S)</b> Alexa H. Kalias, AuD Derek W. Schwaller, BS Stephanie J. Karch, AuD, PhD Jeremy S. Federman, PhD				<b>5d. PROJECT NUMBER</b>	
				<b>5e. TASK NUMBER</b>	
				<b>5f. WORK UNIT NUMBER</b> F1016, F2002	
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b> Naval Submarine Medical Research Laboratory Box 900 Groton, CT 06349-5900				<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>  NSMRL/F1016,F2002/TM--2022-1395	
<b>9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b> Bureau of Medicine and Surgery      Office of Naval Research 7700 Arlington Blvd #5113              875 N Randolph St. Falls Church, VA 22042                  Arlington, VA 22217				<b>10. SPONSOR/MONITOR'S ACRONYM(S)</b> BUMED, ONR	
				<b>11. SPONSOR/MONITOR'S REPORT NUMBER(S)</b>	
<b>12. DISTRIBUTION/AVAILABILITY STATEMENT</b> DISTRIBUTION A. Approved for public release: distribution unlimited.					
<b>13. SUPPLEMENTARY NOTES</b>					
<b>14. ABSTRACT</b> This technical memorandum describes the IPIL testing conducted on a combined configuration that included the Gentex® Corporation Enhanced Combat Helmet – Marine Corps, the 3M™ PELTOR™ ComTac™ V Hearing Defender Headset, and the Howard Leight™ MAX® Earplug. Testing included two test modes for the ComTac™ V: passive and active. In all occluded conditions, the ECH-M, ComTac™ V, and Howard Leight™ MAX® were donned. Testing was completed in accordance with the ANSI standard S12.42-2010. All device samples were tested at the nominal levels of 150, 160, and 170 decibel peak (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 in both the passive and active test modes. These results suggest that the ComTac™ V, when functioning properly and fitted in combination with the ECH-M and Howard Leight™ MAX® earplugs can adequately protect against impulses below 180.0 dBp in both the passive and the active test modes.					
<b>15. SUBJECT TERMS</b> attenuation, impulse peak insertion loss, IPIL, blast, hearing protection device, HPD, active HPD, head worn device, combat helmet, headset, passive HPD, earplug					
<b>16. SECURITY CLASSIFICATION OF:</b>			<b>17. LIMITATION OF ABSTRACT</b>	<b>18. NUMBER OF PAGES</b>	<b>19a. NAME OF RESPONSIBLE PERSON</b>
<b>a. REPORT</b>	<b>b. ABSTRACT</b>	<b>c. THIS PAGE</b>			NAVSUBMEDRSCHLAB Commanding Officer
U	U	U	SAR	89	<b>19b. TELEPHONE NUMBER (Include area code)</b> 860-694-3263

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*This work was supported by the U.S. Navy Bureau of Medicine and Surgery funding work unit F1016 and the Office of Naval Research funding work unit F2002. The views expressed in this article are those of the authors and do not necessarily reflect the official policy or position of the Department of the Navy, Department of Defense, nor the U.S. Government. This work was prepared by employees of the U.S. Government as part of their official duties. Title 17 U.S.C. §105 provides that 'Copyright protection under this title is not available for any work of the United States Government.' Title 17 U.S.C. §101 defines a U.S. Government work as a work prepared by a military service member or employee of the U.S. Government as part of that person's official duties.*

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## **Acknowledgements**

The authors would like to thank Ms. Rachael Maten for assistance in the collection of resource materials. The authors would also like to thank Mr. Jake See for assistance in data collection.

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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 on a combined configuration that included the Gentex<sup>®</sup> Corporation Enhanced Combat Helmet – Marine Corps (ECH-M; Model: A14493-3A1A6, Model: A14493-3A0A6), the 3M<sup>™</sup> PELTOR<sup>™</sup> ComTac<sup>™</sup> V Hearing Defender Headset (ComTac<sup>™</sup> V; Model: MT20H682FB-09 CY), and the Honeywell Howard Leight<sup>™</sup> MAX<sup>®</sup> Single-Use Earplug (Howard Leight<sup>™</sup> MAX<sup>®</sup>; Model: MAX-1). Testing included two test modes for the ComTac<sup>™</sup> V: passive (i.e., turned OFF) and active (i.e., turned on and output level set to MAX). In all occluded conditions, the ECH-M, ComTac<sup>™</sup> V, and Howard Leight<sup>™</sup> MAX<sup>®</sup> were donned. Testing was completed 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 device samples were tested at the nominal levels of 150, 160, and 170 decibel peak (dB<sub>P</sub>, re: 20 μPa). A total of five samples (one helmet, one headset, and one set of earplugs) were fitted to an acoustic test fixture two times each for a total of 10 trials per test level in both the passive and active test modes. No samples of any product were rejected. The mean and standard deviation (SD) IPIL values at 150 dB<sub>P</sub> were 52.0 (2.7) dB SPL for the passive (i.e., OFF) mode, and 52.7 (3.2) dB SPL for the active (i.e., MAX) mode. Results obtained at the 160 dB<sub>P</sub> presentation level showed mean (SD) IPIL values of 55.5 (3.5) dB SPL for the passive mode, and 54.6 (3.8) dB SPL for the active mode. Results obtained at the 170 dB<sub>P</sub> presentation level showed mean (SD) IPIL values of 57.2 (3.6) dB SPL for the passive mode, and 57.5 (3.8) dB SPL for the active mode. These results suggest that the ComTac<sup>™</sup> V Hearing Defender Headset, when functioning properly and fitted in combination with the ECH-M and Howard Leight<sup>™</sup> MAX<sup>®</sup> earplugs can adequately protect (i.e., reduce exposure to less than 140 dB<sub>P</sub>) against impulses below 180.0 dB<sub>P</sub> in both the passive (OFF) and the active (on and set to MAX) test modes.

**Table 1.**

*ECH-M with ComTac<sup>™</sup> V and Howard Leight<sup>™</sup> MAX<sup>®</sup> mean (SD) IPIL value (in dB) for all test conditions.*

	<b>150 dB<sub>P</sub></b>	<b>160 dB<sub>P</sub></b>	<b>170 dB<sub>P</sub></b>
OFF	52.0 (2.7)	55.5 (3.5)	57.2 (3.6)
MAX	52.7 (3.2)	54.6 (3.8)	57.5 (3.8)

## Introduction

One of the helmets currently fielded for use by the U.S. Marine Corps (USMC) is the Gentex<sup>®</sup> Corporation Enhanced Combat Helmet – Marine Corps (ECH-M; Gentex Corporation, Carbondale, PA). The ECH-M is commercially available in size small, medium, large, extra-large, and extra-extra-large. The operator manual (Headquarters, Department of the Army, 2015) states that the ECH provides ballistic and impact protection. The reduced shell edge cut in front of the eyes and at the ears “provides an unobstructed field of view and increased ambient hearing capabilities” (p. 0002-1) to the Service Member, thereby allowing for maximum sensory and situational awareness while donned. While the ECH-M was not designed to serve as a hearing protection device (HPD), it can be worn in tandem with an HPD, such as an earmuff or earplug. The amount of protection provided to users when the ECH-M is worn in combination with both an earmuff and an earplug was tested.

The earmuff selected for the testing described herein was the 3M<sup>™</sup> PELTOR<sup>™</sup> ComTac<sup>™</sup> V Hearing Defender Headset (ComTac<sup>™</sup> V; 3M, St. Paul, MN), an active earmuff-style communications headset. The ComTac<sup>™</sup> V Hearing Defender has two ear-level, omni-directional microphones and a level dependent, electronic hearing protection signal processor powered by two AAA batteries. The signal processor function amplifies low level sounds (e.g., speech), and attenuates loud, continuous (e.g., vehicle engines, air compressors) and impulsive noises (e.g., weapon fire; 3M Personal Safety Division, n.d.). The headset is available as either a headband or neckband model, but can also be mounted on a helmet rail system when used with the 3M<sup>™</sup> PELTOR Accessory Rail Connector (ARC) attachment. The ComTac<sup>™</sup> V Hearing Defender Headset described herein is intended for face-to-face communications, and not radio communications.

The earplug selected was the Honeywell Howard Leight<sup>™</sup> MAX<sup>®</sup> Single-Use Earplug (Howard Leight<sup>™</sup> MAX<sup>®</sup>; Honeywell International Inc., Charlotte, NC). The Howard Leight<sup>™</sup> MAX<sup>®</sup> is an uncorded, passive, bell-shaped plug made of polyurethane foam intended for single use.

The Department of Defense Instruction 6055.12 (2019) “Hearing Conservation Program (HCP)” limits impulse noise exposure to 140 peak decibels (dBP). Therefore, should an impulse noise meet or exceed 140 dBP, hearing conservation efforts to prevent hearing loss resulting from occupational and operational illness and injury are mandated. One conservation measure used to reduce impulse noise hazards below the 140 dBP limit is HPDs.

To calculate whether an issued HPD or HPD combination will reduce the impulse noise exposure to below the 140 dBP limit, the impulse peak insertion loss (IPIL) value of the HPD is subtracted from the impulse noise level (Department of Defense, 2015). The IPIL value is the standard metric (ANSI/ASA S12.42) used to determine the amount of protection afforded by an HPD in response to impulse noise. At the time of this writing, the IPIL values of the ECH-M combined with the ComTac<sup>™</sup> V and the Howard Leight<sup>™</sup> MAX<sup>®</sup> at 150, 160, and 170 dBP were unknown. This report describes the methods used to determine the IPIL value for the ECH-M used in combination with the Howard Leight<sup>™</sup> MAX<sup>®</sup> and the ComTac<sup>™</sup> V Hearing Defender Headset in both the passive (i.e., OFF) and active (i.e., turned on and set to MAX) test

modes and reports the results. Specifically, both an overall device IPIL and ear-specific IPILs are reported for the tested nominal levels.

## Methods

### Facility

IPIL testing described herein was completed in the Naval Submarine Medical Research Laboratory (NSMRL) 1000 m<sup>3</sup> anechoic chamber in order to minimize any effects of sound reflections.

### Equipment

**Hardware.** NSMRL's 4 inch (in., 10.2 centimeters [cm]) shock tube (B/C Precision, Inc., Greendale, IN) generated all acoustic impulses. The shock tube pressure chamber is approximately 34 in. (86.4 cm) long, with an inner diameter of 4 in. (10.2 cm). A 64 in. (162.6 cm) 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. (11.4 cm) coupler. An industrial air compressor (ILA#1883054; Industrial Air Corporation, Memphis, TN) supplied pressurized air (900 kilopascal) to the shock tube.

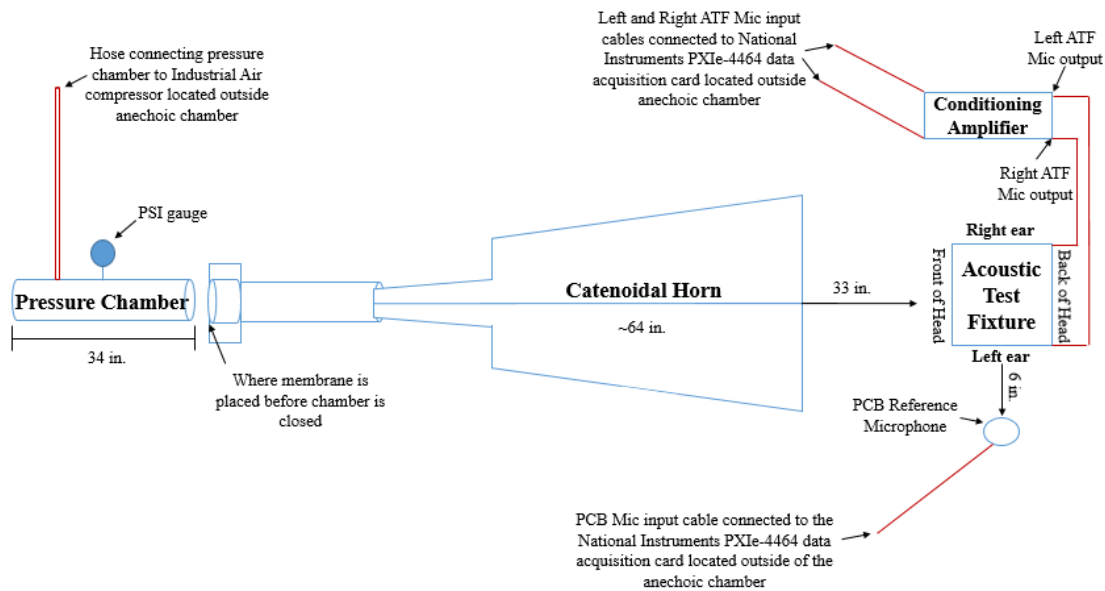
For each trial at 150 dBp, a 7 in. (17.8 cm) by 7 in. (17.8 cm) polyester sheet (SEVA Technical Services, Inc, Newport News, VA) was used as a membrane between the pressurized chamber and the catenoidal tube horn to enable pressurization of the air chamber. Each polyester sheet was 0.001 in. (1.0 mil, 25.4 micrometer [ $\mu\text{m}$ ]) thick. For each trial at 160 and 170 dBp, a 7 in. (17.8 cm) by 7 in. (17.8 cm) acetate sheet (Grafix Plastic, Maple Heights, OH) was used as the membrane. Each acetate sheet was 0.002 in. (2.0 mil, 50.8 micrometer [ $\mu\text{m}$ ]) thick.

All waveforms were recorded with an ANSI/ASA S12.42 (2010) compliant GRAS 45CB acoustic test fixture (ATF) with GRAS RA0045-S7 Ear Simulators (GRAS Sound and Vibration, Twinsburg, OH). 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. (15.2 cm) from the ATF left pinna. The reference, left ATF, and right ATF microphones were calibrated prior to data collection at 124 dB sound pressure level (SPL) using a 250 hertz (Hz) tone generator (Bruel & Kjaer, Marlborough, MA). A diagram depicting the aerial view of the NSMRL 4 in. (10.2 cm) shock tube and test system is presented in Figure 1.

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**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). In addition, it 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, right ATF, reference) 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.

Rather than using an ANSI/ASA S12.42-2010 compliant in-line analog external Bessel filter to filter impulses during data acquisition, anti-alias filtering was accomplished by an analog filter and a digital filter. First, an electronic analog anti-aliasing filter (corner frequency of 93.0 kHz [3 dB down]) was applied to all waveforms by the National Instruments data acquisition system during data collection. Then, a second digital Butterworth filter (6<sup>th</sup> order, low-pass, corner frequency of 20 kHz [3 dB down]) was applied to all recordings by the MATLAB post-processing script. This digital filter was used to mimic the effect of the ANSI/ASA S12.42-2010 standard required anti-aliasing Bessel 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 three 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 150, 160, and 170 dBP data (see Data Analysis below).

**Product Samples.** Five samples (See Figure 2 for example) of the helmet/HPD configuration were tested. Five large (NSN: NSN 8470-01-592-6208) ECH-M helmet systems (Part Numbers: A14493-3A1A6, A14493-3A0A6) with H-Nape chinstrap retention system (NSN: 8470-01-599-3210), five neckband versions of the ComTac™ V Hearing Defender Headset (Manufacturer Product Number: MT20H682FB-09 CY) with foam ear cushions, and five samples of the uncorded Honeywell Howard Leight™ MAX® Single-Use Earplugs (Manufacturer Product Number: MAX-1) were used. Each sample, consisting of one ECH-M helmet system, one ComTac™ V Hearing Defender, and 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.**

*Gentex® Corporation ECH-M Helmet, ComTac™ V Hearing Defender Headset, and Howard Leight™ MAX® Earplugs*



**Procedure**

Because the ComTac™ V employs active technology, it was tested in both the passive (OFF) and active (i.e., the headset turned on and the sound output level set at its maximum limit [MAX]) modes. Each HPD sample combination was fitted to the ATF twice, resulting in two trials (trials A and B) per sample combination, and 10 total trials per nominal level test condition (150, 160, and 170 dBp) for each HPD mode. ComTac™ V functionality and settings were confirmed via a listening check prior to each trial. No samples of any product were rejected.

To achieve an appropriate fit that would provide maximum attenuation, each sample was expertly fitted to the ATF following the instructions provided on the device packaging. The Howard Leight™ MAX® fitting guidelines stated that all samples be inspected for any wear, extreme hardness, or damage prior to use. Once inspected, each earplug was rolled down avoiding creases and inserted into the ear canal. Earplugs were given at least two minutes to fully expand in the ATF ear canal before a ComTac™ V

was fitted. The ComTac™ V manufacturer fitting guidelines stated that all samples should be inspected for any wear, cracks, or damage prior to use. Once inspected, earmuffs were placed over the ears to encompass the pinnae, and the neckband adjusted to just rest on the neck of the ATF. The helmet manufacturer fitting guidelines stated that all samples be inspected for any damage, blistering, loose material, or fraying prior to use. Each helmet was then placed on the ATF with the front brim approximately two fingers width above the eyes and the lower side edges sitting along the top of the ear canals. Once properly placed, the chinstrap was buckled and side straps were tightened to achieve a snug fit. If necessary, the nape strap was also adjusted until the ECH-M was stable on the ATF.

Testing at the 130 dBP nominal level was omitted, and the nominal level of 160 dBP was incorporated as impulses generated with the NSMRL 4 in. (10.2 cm) shock tube at levels below the nominal level of 150 dBP were found to be without a shock front. Measurement of IPIL at 160 dBP was added in order to provide accurate guidance for exposures between 150 and 170 dBP. At the measured levels described herein, all generated impulses had a shock front. As previously stated, the action level for the US Department of Defense (DoD) is 140 dBP for impulse noises. Therefore, IPIL values below 140 dBP are of marginal value to the DoD. Due to non-linear effects of HPDs on IPIL, it is best to use IPIL values measured close to the level of the predicted exposure (Department of Defense, 2015).

Impulse noises were presented to the ATF in the occluded (i.e., products donned) and unoccluded (i.e., without the products donned) test configurations. For all occluded measures, the products were fitted to the ATF in accordance with the specifications outlined in ANSI/ASA S12.42-2010. Each sample was exposed to two impulses at each tested nominal level in each test mode. 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 150 dBP (8.9 to 9.3 psi, 61 to 64 kilopascals [kPa]), 160 dBP (19.5 to 22.1 psi, 134 to 152 kPa), or 170 dBP impulses (28.5 to 29.5 psi, 197 to 203 kPa). The membrane was then punctured using a manual trigger, 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 dBP, six total calibration impulses (three pre-, three post-testing) were generated per nominal level (150, 160 dBP) in the unoccluded test configuration. Calibrations were not completed at the 170 dBP nominal level due to exposure limitations of the ATF microphones.

The clamping force of each ECH-M donned with each ComTac™ V earmuff sample was measured using Michael & Associates, Inc.'s Muff-type HPD Force Measurement System (S/N: 00001). Per ANSI/ASA S12.42-2010, each sample was fit to the measurement device, and left in place for two minutes before clamping force was recorded in pounds force (lbf). Clamping force was measured once post data collection for all five device samples (See Table 3.).

## Data Analysis

MATLAB (Natick, MA) was used to calculate the IPIL values at the 150, 160, and 170 dB nominal levels and to generate all waveform graphs (See Appendices A to R). 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 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 dB nominal level. Then, the difference of the maximum absolute values of the calculated and measured values was determined, 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 mean for each nominal level. 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 (SD) IPIL values for the ECH-M combined with the ComTac™ V and the Howard Leight™ MAX® were 52.0 (2.7) dB in the passive (i.e., OFF) test mode and 52.7 (3.2) dB in the active (i.e., MAX) test mode in response to the 150 dB nominal level impulse. At 160 dB, the calculated overall mean (SD) IPIL values were 55.5 (3.5) dB in the passive (i.e., OFF) mode and 54.6 (3.8) dB in the active (i.e., MAX) mode. At 170 dB, the calculated overall mean (SD) IPIL values were 57.2 (3.6) dB in the passive (i.e., OFF) mode and 57.5 (3.8) dB in the active (i.e., MAX) mode. Calculated IPIL values for all sample trials in the OFF mode ranged between 48.7 to 58.0 dB at 150 dB, between 49.6 to 64.8 dB at 160 dB, and 51.7 to 66.1 dB at 170 dB, while all tested sample trials in the MAX mode ranged between 48.2 to 59.2 dB at 150 dB, between 48.6 to 65.3 dB at 160 dB, and between 51.8 to 66.9 dB at 170 dB.

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**Table 2.**

*Mean (SD) IPIL values (in dB) for Tested ECH-M, ComTac™ V, and Howard Leight™ MAX® Sample Combinations.*

	150 dBP				160 dBP				170 dBP			
	OFF		MAX		OFF		MAX		OFF		MAX	
	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
HPD 1, Trial A	50.2	50.5	49.1	52.9	53.3	54.8	53.0	54.7	56.0	56.7	55.6	56.2
HPD 1, Trial B	51.8	48.7	51.9	48.2	54.5	51.8	53.2	50.1	55.4	52.1	55.2	51.9
HPD 2, Trial A	50.2	52.8	50.5	53.5	53.5	56.4	52.7	55.4	55.0	57.7	55.3	58.0
HPD 2, Trial B	50.0	52.2	50.7	52.2	53.0	55.9	50.9	53.4	55.7	57.9	55.9	58.1
HPD 3, Trial A	57.1	48.8	59.0	48.7	60.8	49.6	59.9	48.6	63.9	51.7	64.1	51.8
HPD 3, Trial B	54.9	49.5	57.0	51.1	59.0	53.3	56.9	51.2	61.3	55.1	61.9	56.1
HPD 4, Trial A	58.0	52.5	59.2	54.3	64.8	57.1	65.3	56.7	66.1	58.0	66.9	58.2
HPD 4, Trial B	54.7	50.2	54.9	50.4	57.2	52.7	56.9	51.9	58.7	53.6	59.4	54.2
HPD 5, Trial A	54.6	50.5	55.9	52.2	58.5	54.1	57.3	53.9	60.5	55.6	60.4	55.5
HPD 5, Trial B	53.1	50.5	52.6	49.5	56.7	53.6	57.1	53.8	58.2	54.4	59.1	55.2
<b>Ear Specific Mean (SD)</b>	53.5 (2.9)	50.6 (1.5)	54.1 (3.6)	51.3 (2.1)	57.1 (3.8)	53.9 (2.3)	56.3 (4.2)	53.0 (2.5)	59.1 (3.8)	55.3 (2.3)	59.4 (4.0)	55.5 (2.3)
<b>Level Overall Mean (SD)</b>	<b>52.0 (2.7) 52.7 (3.2)</b>				<b>55.5 (3.5) 54.6 (3.8)</b>				<b>57.2 (3.6) 57.5 (3.8)</b>			

As shown in Table 3, the measured clamping force of the ComTac™ V samples ranged from 2.2 to 2.4 lbf, with a mean (SD) of 2.3 (0.1) lbf.

**Table 3.**

*Mean (SD) Band Force (lbf) for Tested ComTac™ V Samples.*

	<b>Band Force</b>
HPD 1	2.3
HPD 2	2.2
HPD 3	2.2
HPD 4	2.3
HPD 5	2.4
<b>MEAN (SD)</b>	<b>2.3 (0.1)</b>

The waveforms for the passive (i.e., OFF) test mode for all trials of the ComTac™ V plus the ECH-M and Howard Leight™ MAX® are provided in Appendices A to I and are color-coded green. The waveforms for the active (i.e., MAX) test mode of the ComTac™ V plus the ECH-M and Howard Leight™ MAX® are provided in Appendices J to R and are color-coded orange.

## Discussion

As required by ANSI/ASA S12.42-2010 the ComTac™ V Hearing Defender was tested in both its passive and active modes. The ComTac™ V uses an external microphone, an amplifier, a signal limiting circuit, and an internal loudspeaker to pass low-level sounds through the HPD. According to the manufacturer, when a signal

exceeds 82 dB A-weighted (dBA), the limiting circuit automatically turns off the amplifier (3M Personal Safety Division, 2015). Once the amplifier is turned off, the headset acts as a passive HPD, attenuating all incoming noise above 82 dBA. Therefore, when the active technology is functional and the ear cups are fitted properly, it is anticipated that the passive (i.e., OFF) and active (i.e., MAX) test modes will perform similarly. One possible mode of failure could occur if the limiting circuit fails to turn off quickly enough. This would allow some portion of the impulse noise to be amplified and actively passed through the device. To test for this possibility, the ComTac™ V Hearing Defender Headset was tested both powered off and with the unit powered on and volume set to its maximum setting.

Results revealed overall mean IPILs across test modes (i.e., OFF, MAX) within 0.7 dB of each other for the 150 dB nominal test level, within 0.9 dB of each other for the 160 dB nominal test level, and within 0.3 dB of each other for the 170 dB nominal test level. Across ears, the individual trial mean IPIL values were found to vary as much as 9.3 dB at 150 dB, 15.2 dB at 160 dB, and 14.4 dB at 170 dB in the OFF test mode. All individual trial mean IPIL values varied as much as 11.0 dB at 150 dB, 16.7 dB at 160 dB, and 15.1 dB at 170 dB in the MAX test mode. These results may be explained by a combination of inherent variance within the impulse system, variability in passive (i.e., OFF) and active (i.e., MAX) attenuation, and/or variability in fit as a result of each product sample combination being fitted twice. Another potential source of variability causing the observed between ear difference could be a small deviation in the ATF's angle of incidence.

In addition, results consistency across the passive (i.e., OFF) and active (i.e., MAX) test modes could be explained by proper function of the active limiting circuit, or, alternatively, a ComTac™ V device complete failure (i.e., device complete failure would be equivalent to passive mode). Variance in the data could also be explained by intermittent function or digital signal processing algorithms contained in the active electronics. However, device complete failures were accounted for via a listening check before each test trial to confirm that the active electronics were functioning and set at the appropriate maximum sound output level. Further, based on the results obtained, there is little reason to conclude that the active limiting circuit was intermittent in any tested samples of the ComTac™ V. However, additional testing of the ComTac™ V's signal processing and subsequent effects on input and output signals was outside of the scope of this report.

It is important to note that these results do not guarantee similar performance of the tested products across all users and environments. Product performance may be impacted by factors such as variability in physical fit of the device, integrity of the acoustic seal around the ear, HPD configuration (e.g., single, double- or triple-configuration), and/or use with other head worn protective devices like that of eye protection.

## **Conclusions**

This report described the process for determining the mean impulse peak insertion loss (IPIL) values provided by the ECH-M worn with the ComTac™ V Hearing Defender Headset and the Howard Leight™ MAX® earplugs at the nominal

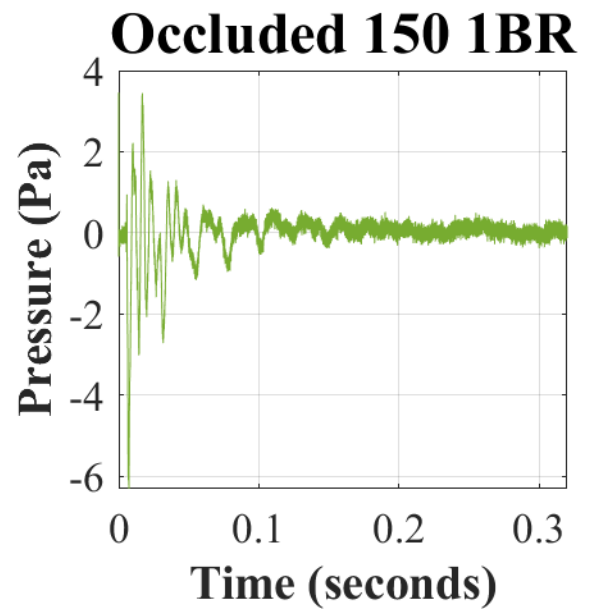
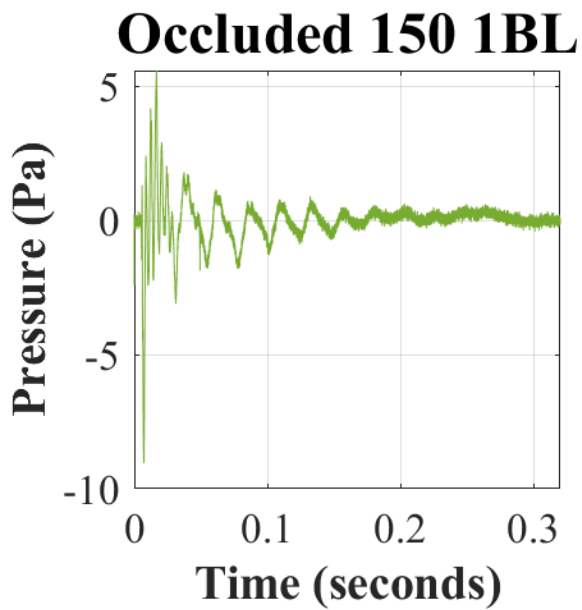
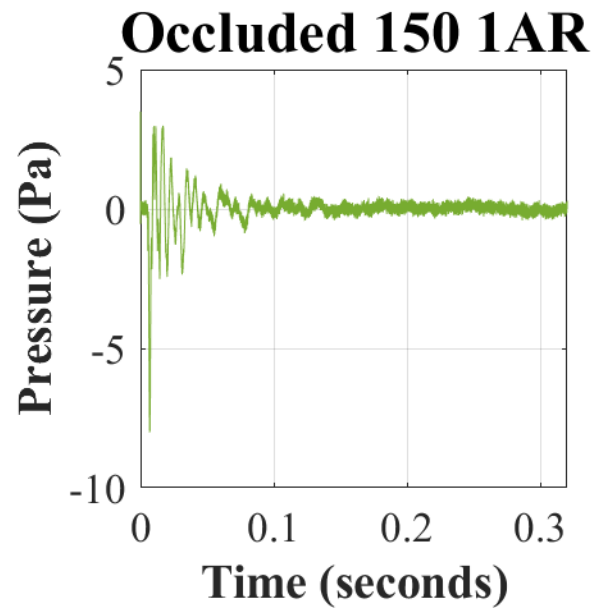
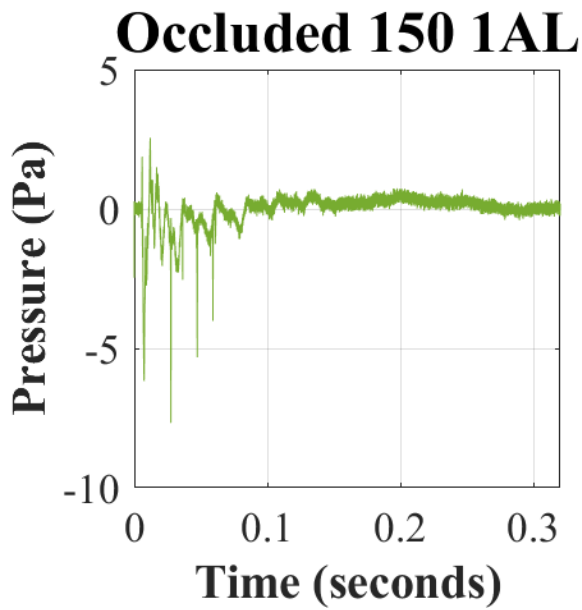
levels of 150, 160, and 170 dBP. The calculated overall mean (SD) IPIL values for the ECH-M, Howard Leight™ MAX®, and the ComTac™ V Hearing Defender Headset in the passive (OFF) mode were found to be 52.0 (2.7) dB at 150 dBP, 55.5 (3.5) dB at 160 dBP, and 57.2 (3.6) dB at 170 dBP. When the ECH-M and Howard Leight™ MAX® were worn with the ComTac™ V in the active mode (turned on, and output level set to MAX), the overall mean (SD) IPIL values were 52.7 (3.2) dB at 150 dBP, 54.6 (3.8) dB at 160 dBP, and 57.5 (3.8) dB at 170 dBP.

The results of testing suggest that, when properly fit and functional, the ComTac™ V worn in combination with the ECH-M and the Howard Leight™ MAX® can adequately protect (i.e., reduce the exposure level below 140 dBP) the user from impulses below 180.0 dBP in both the passive (i.e., OFF) and the active (i.e., MAX) test modes. This value is based on the 180 dBP limit of the applicability of IPIL values measured at 170 dBP in MIL-STD-1474E B.5.3.3 (Department of Defense, 2015).

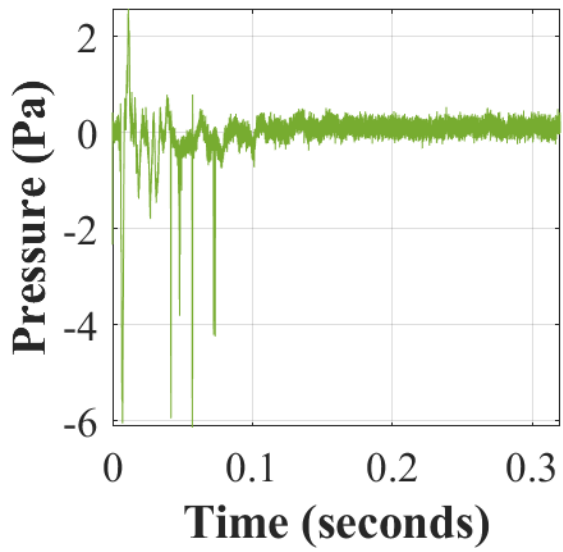
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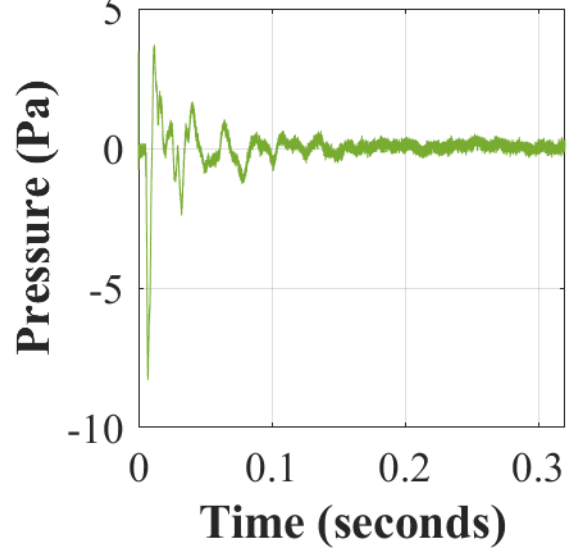
**Appendix A.** Recorded occluded (closed-ear) waveforms (in pascals [Pa]) over time (in seconds [s]) in response to 150 dBp with the ComTac™ V (OFF).



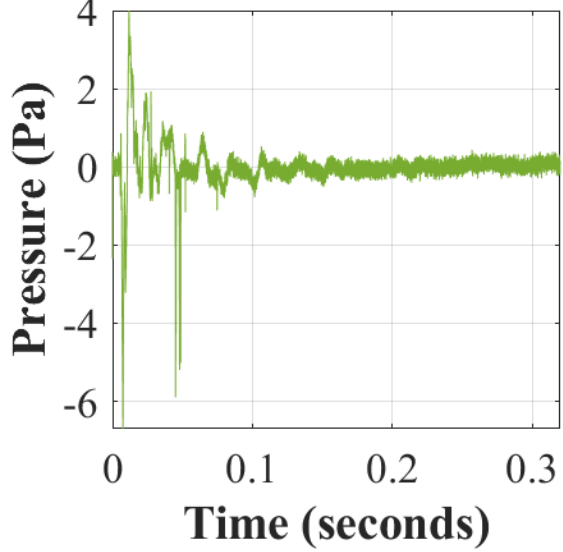
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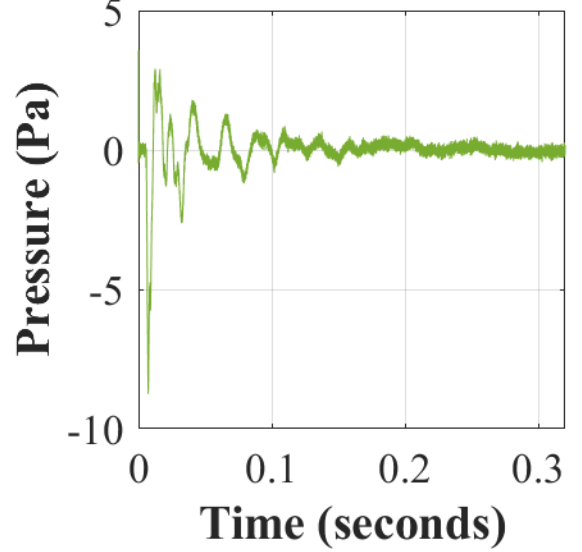
**Occluded 150 2AR**

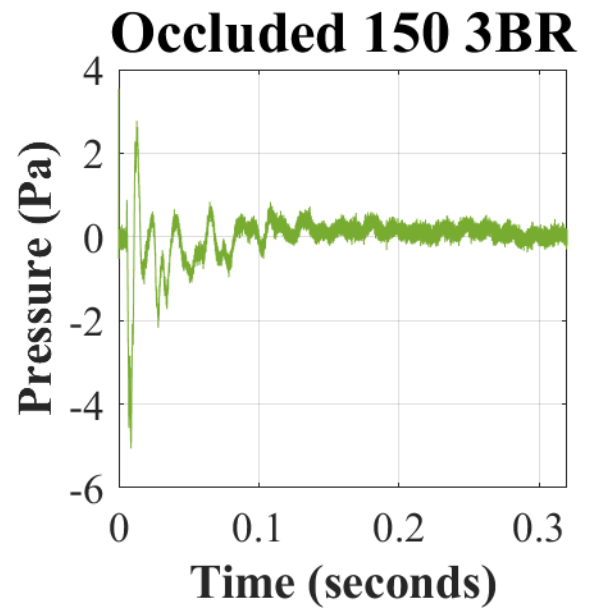
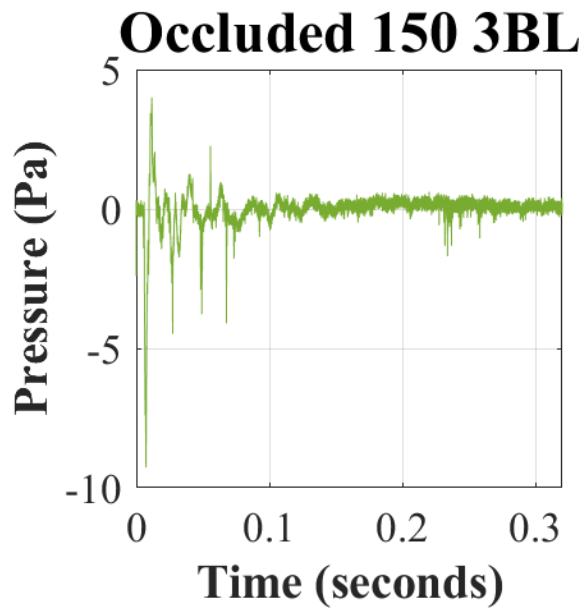
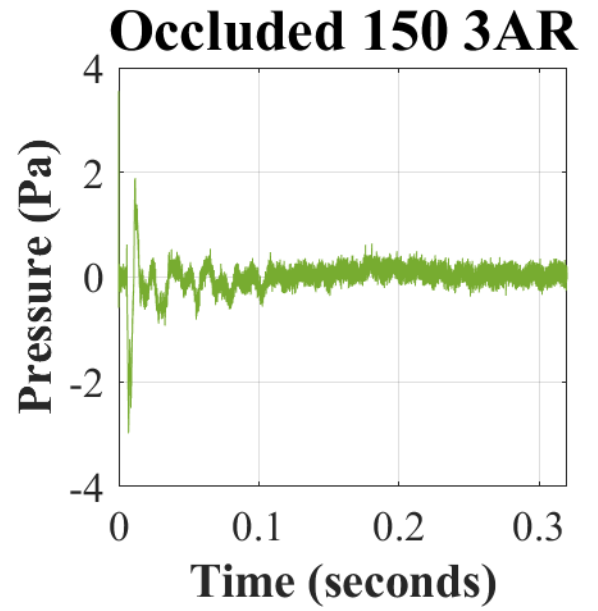
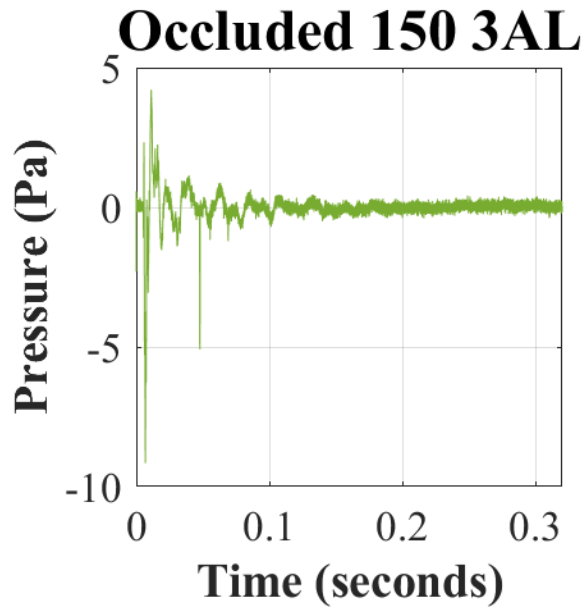


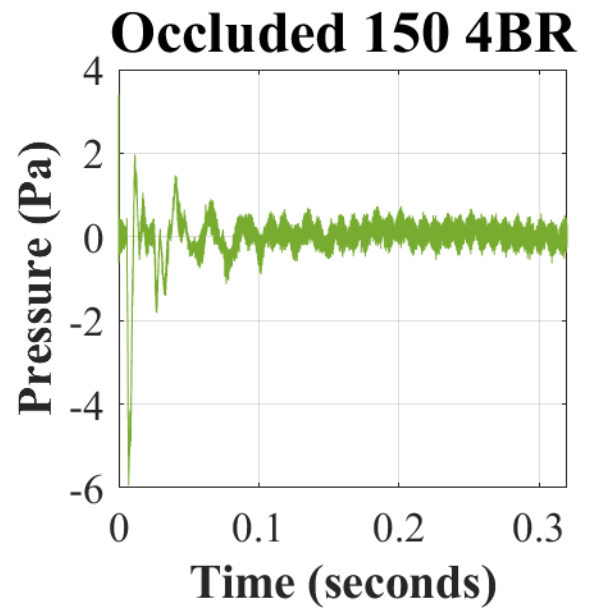
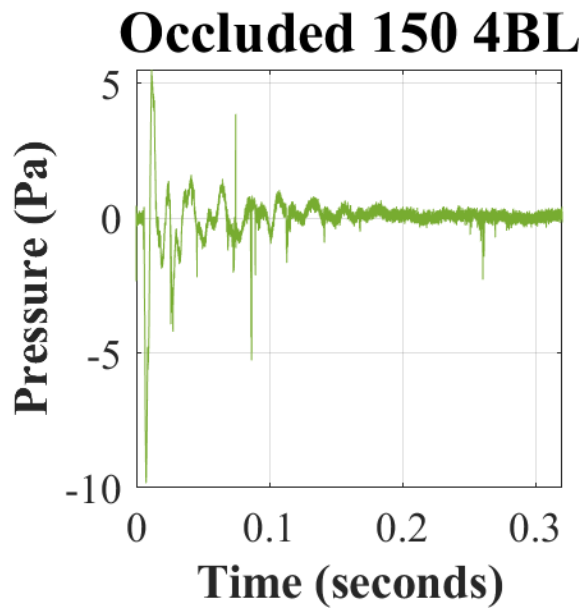
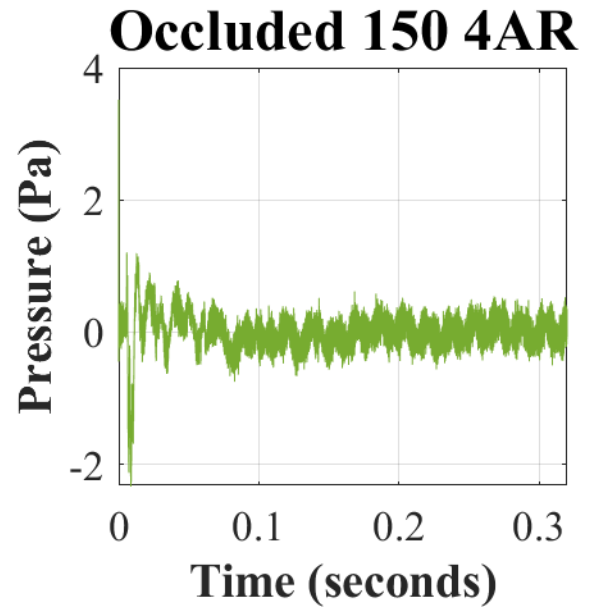
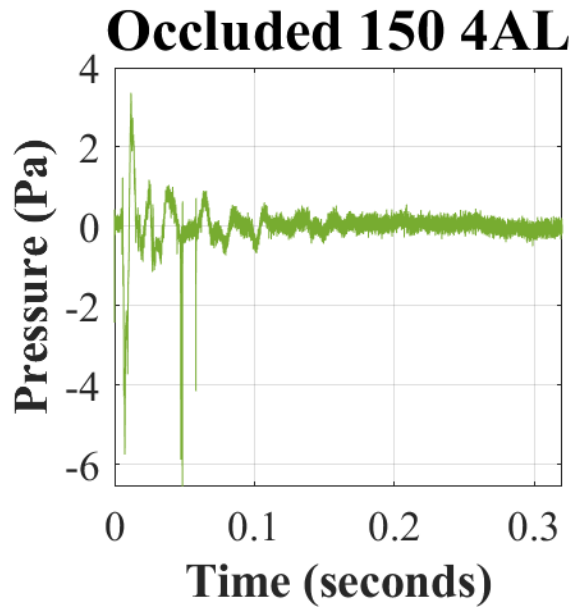
**Occluded 150 2BL**

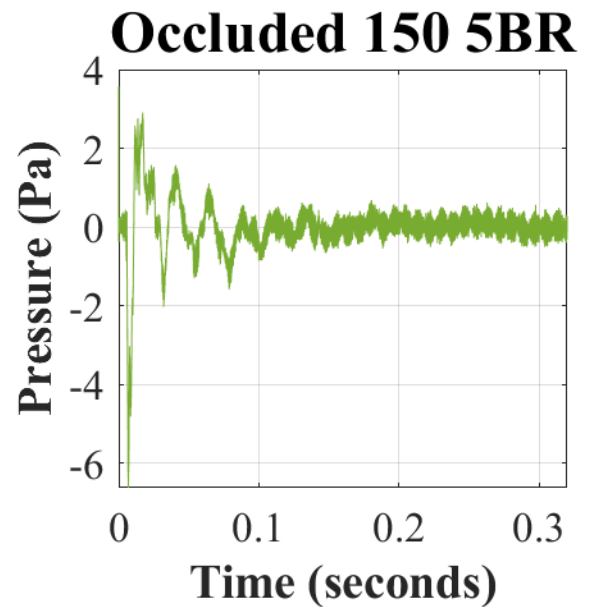
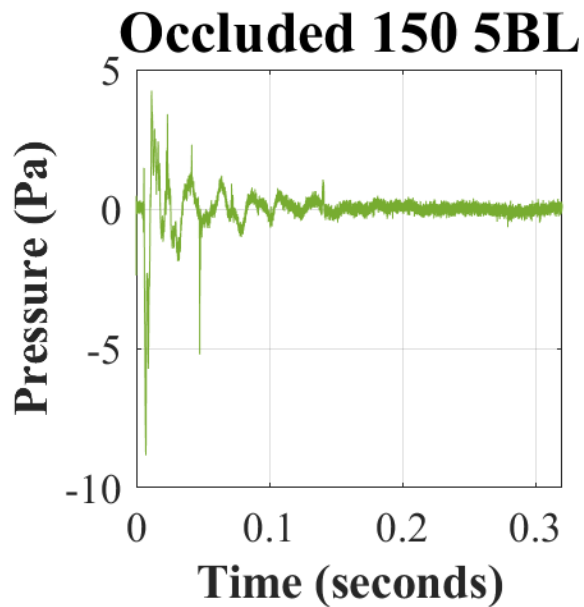
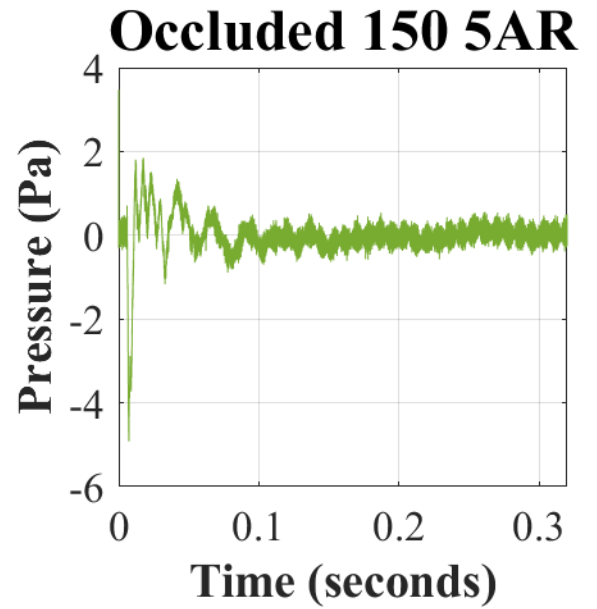
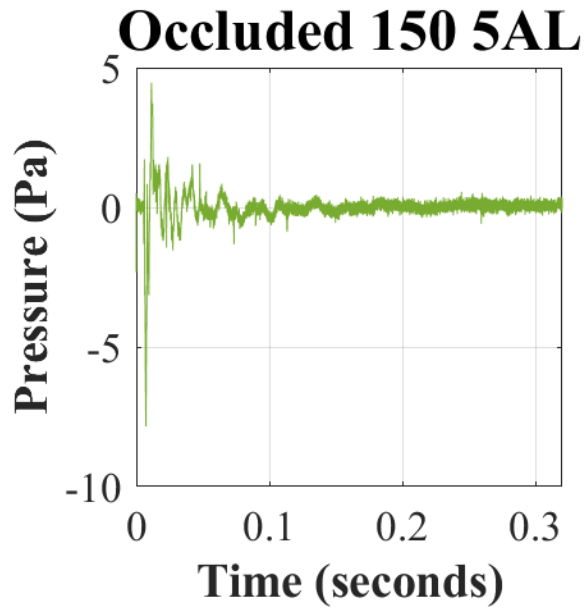


**Occluded 150 2BR**



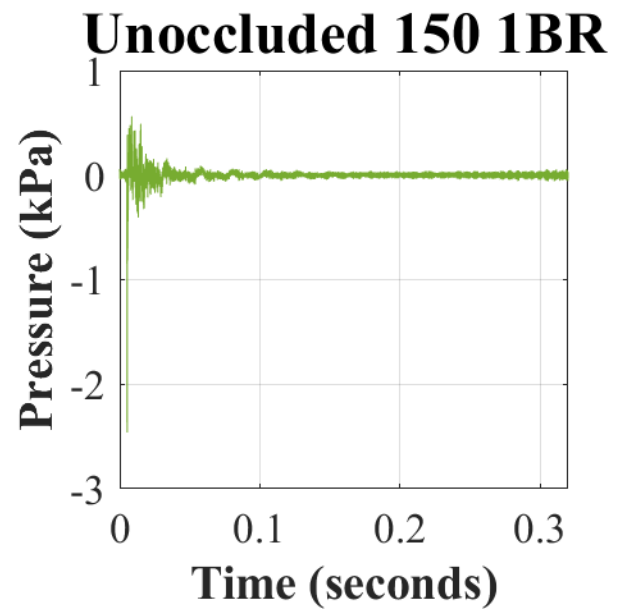
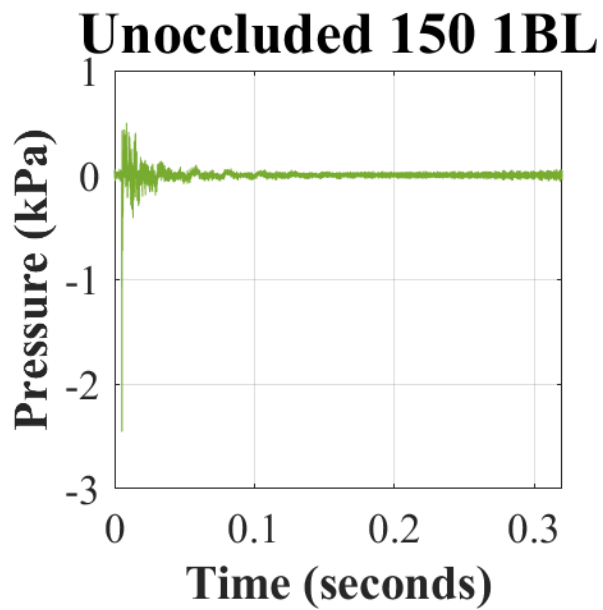
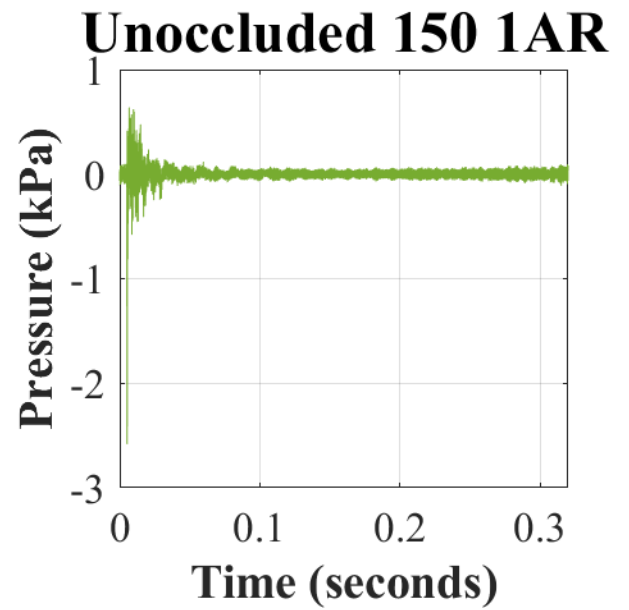
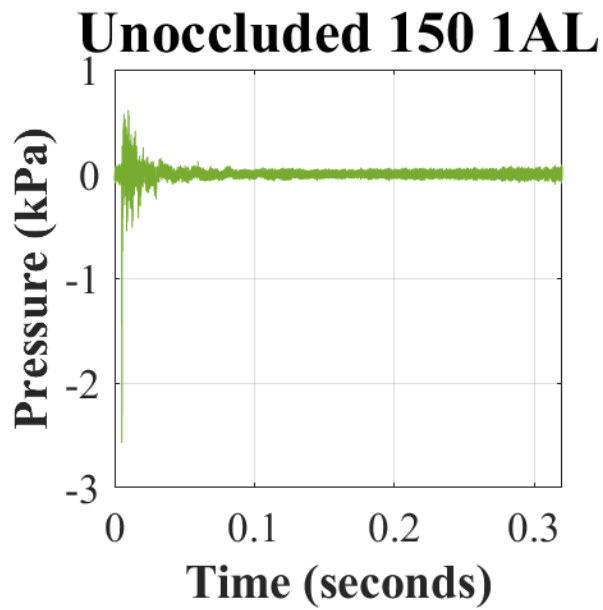


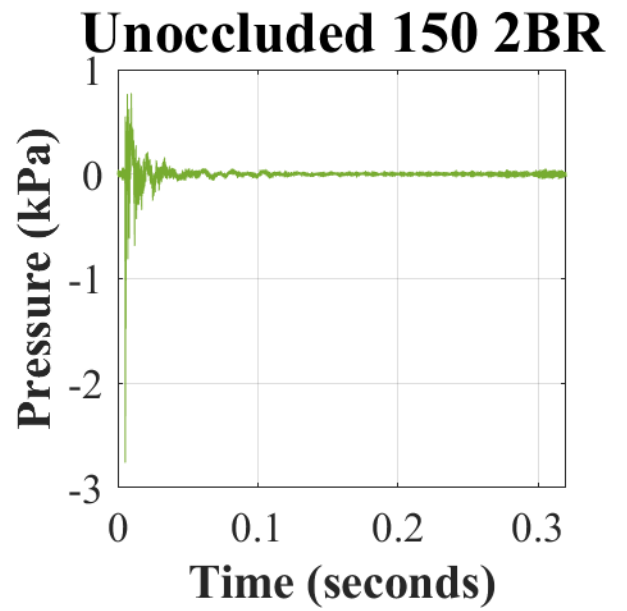
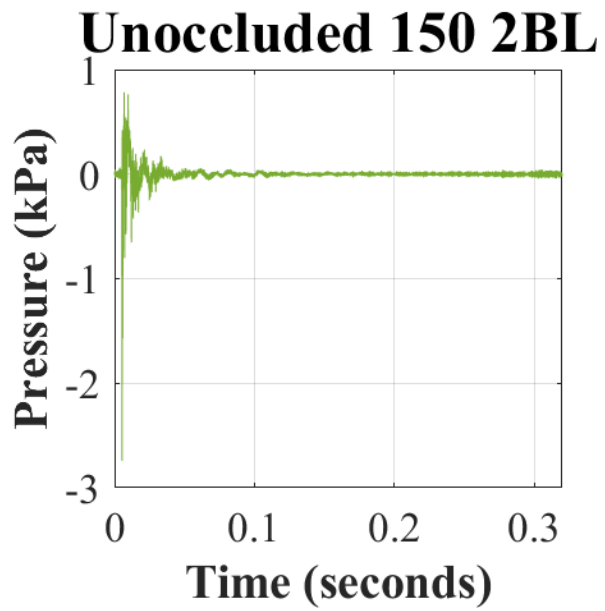
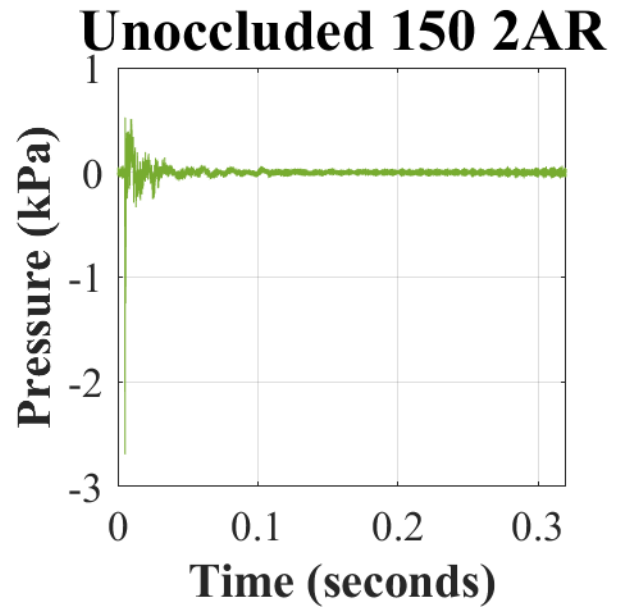
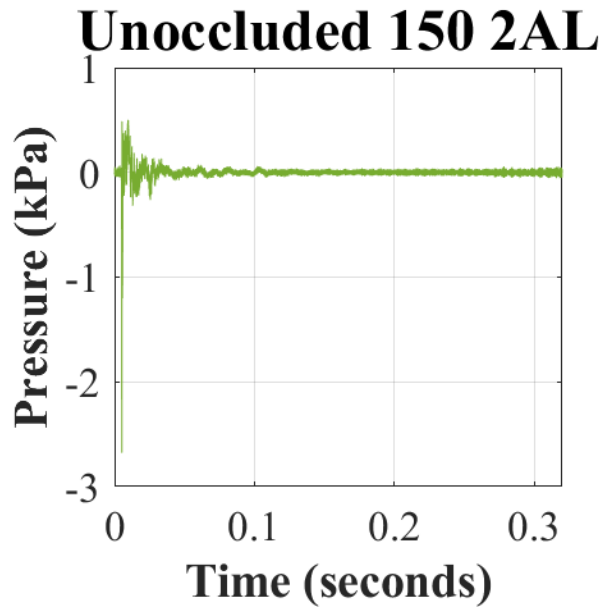


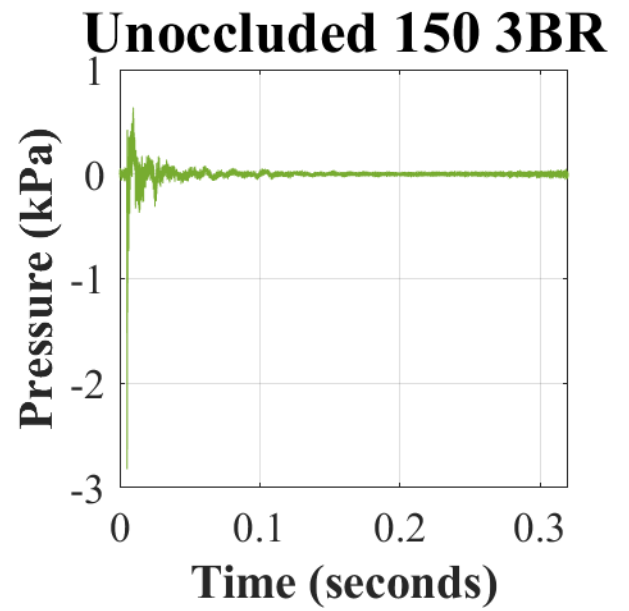
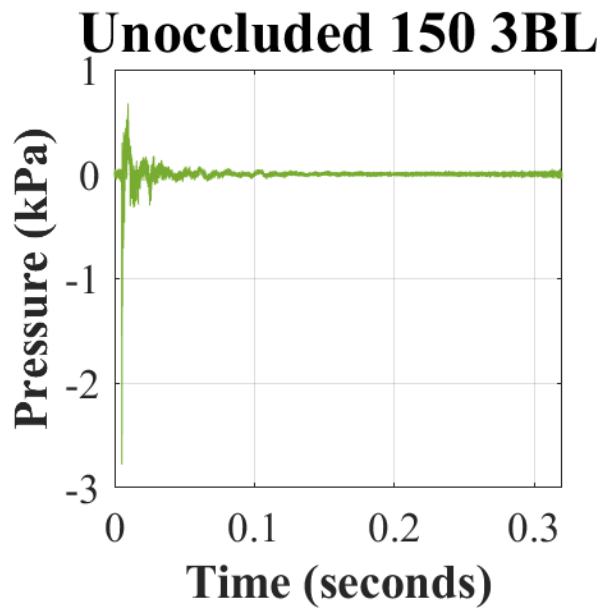
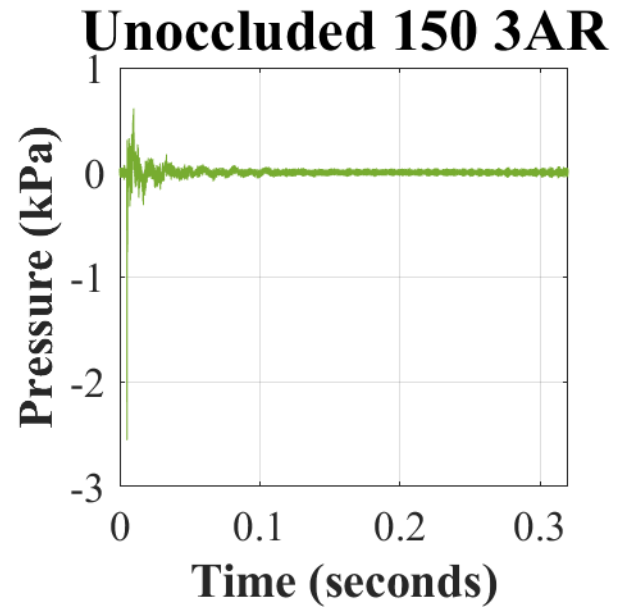
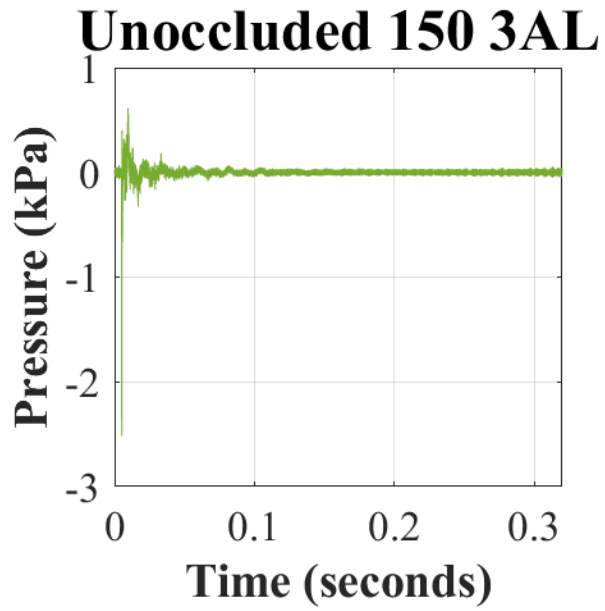


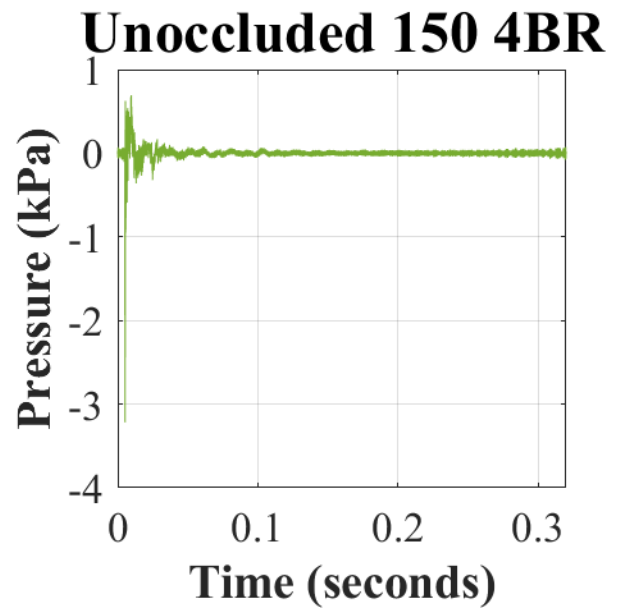
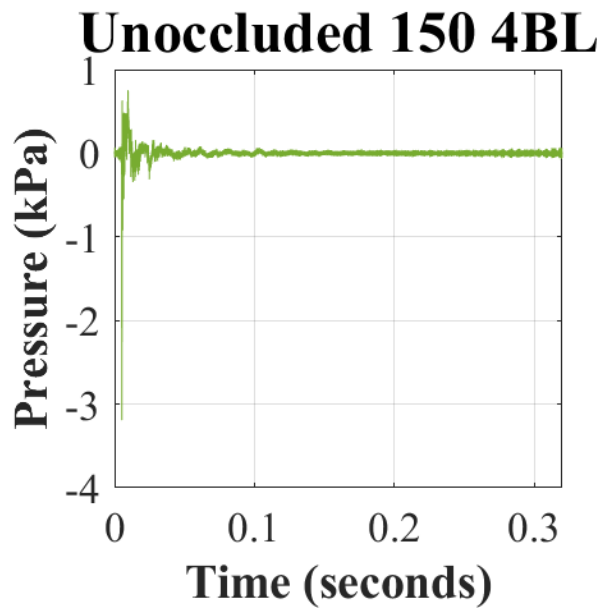
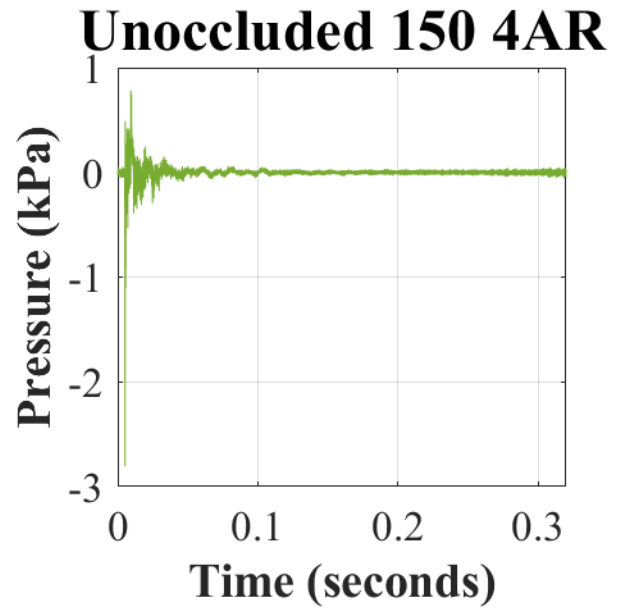
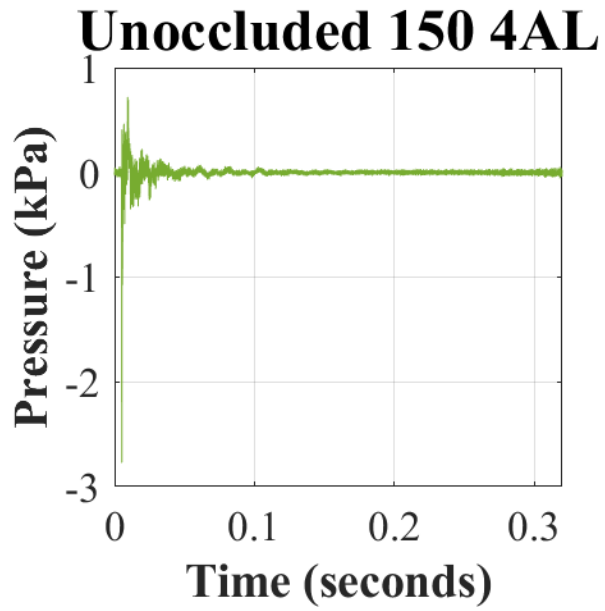
Note. The naming convention for all occluded waveforms is “Occluded LvL NnX”, where ‘Occluded’ is the test condition (i.e., ATF has the HPD donned), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or 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).

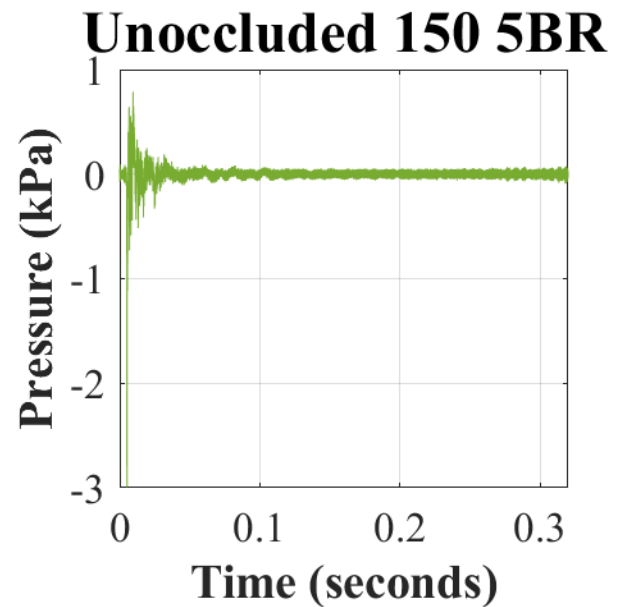
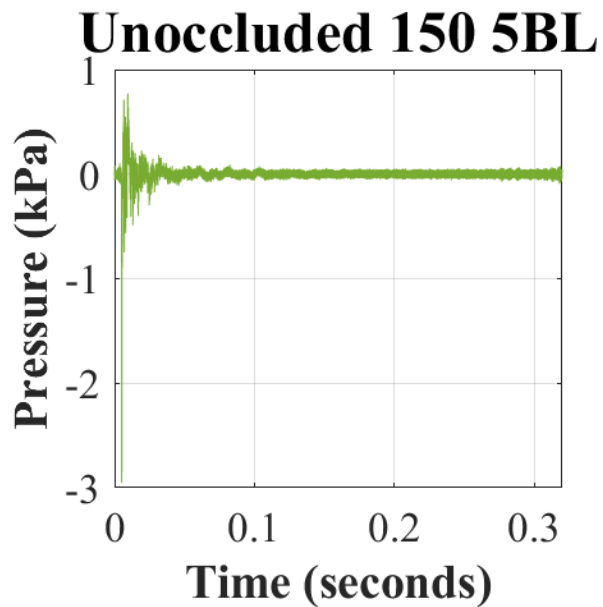
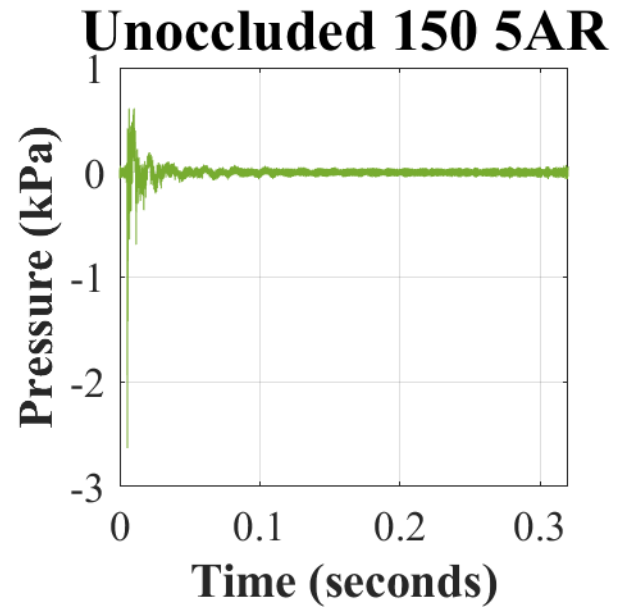
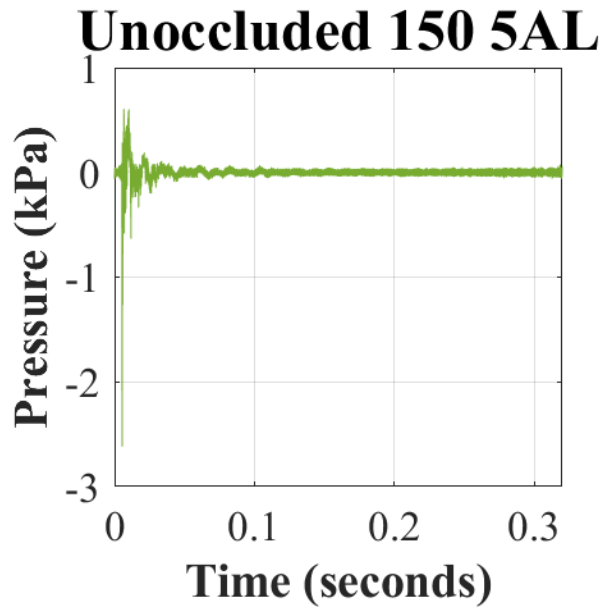
**Appendix B.** Estimated unoccluded (open-ear) waveforms (in kilopascals [kPa]) over time (in seconds [s]) in response to 150 dBp with the ComTac™ V (OFF).





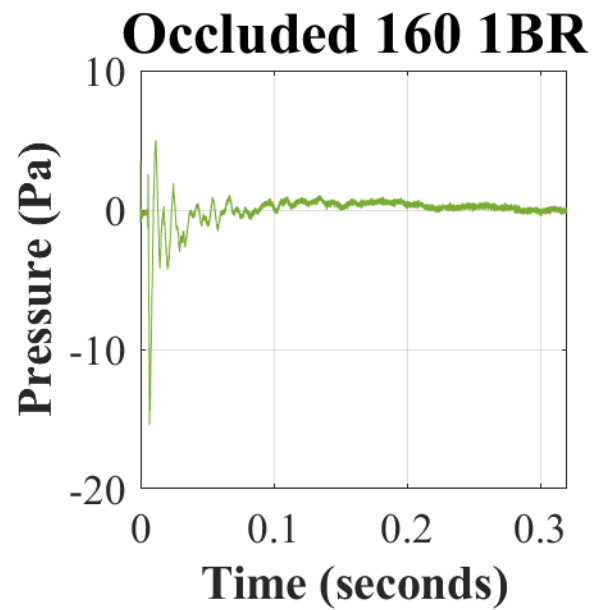
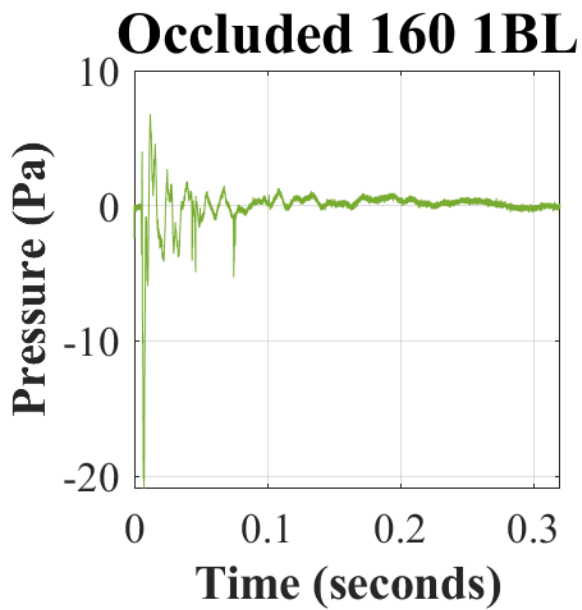
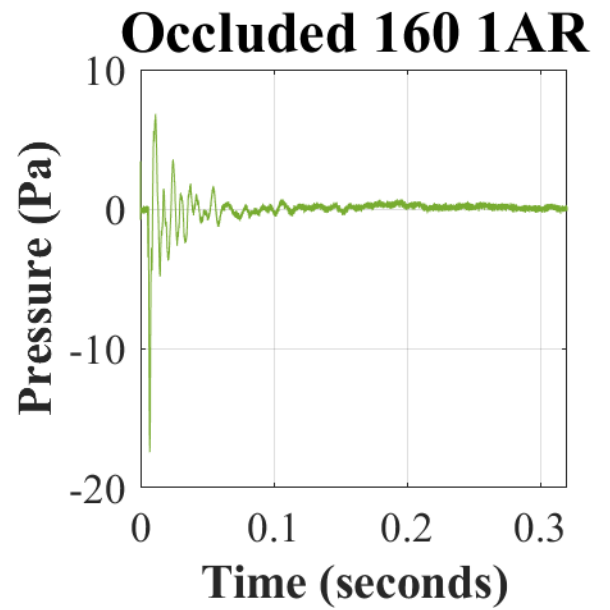
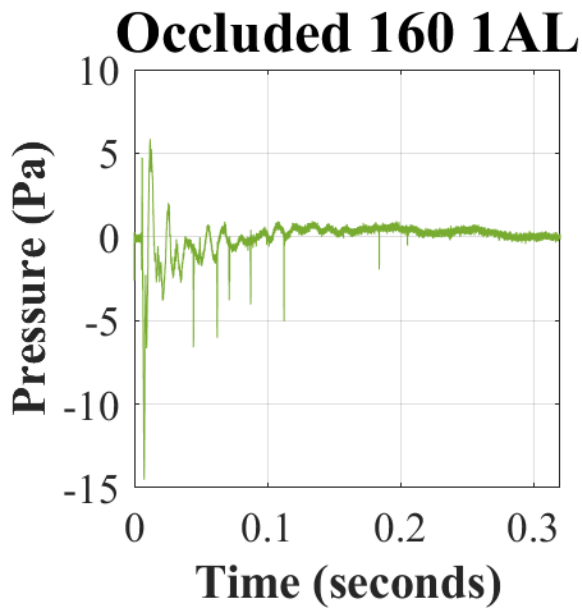


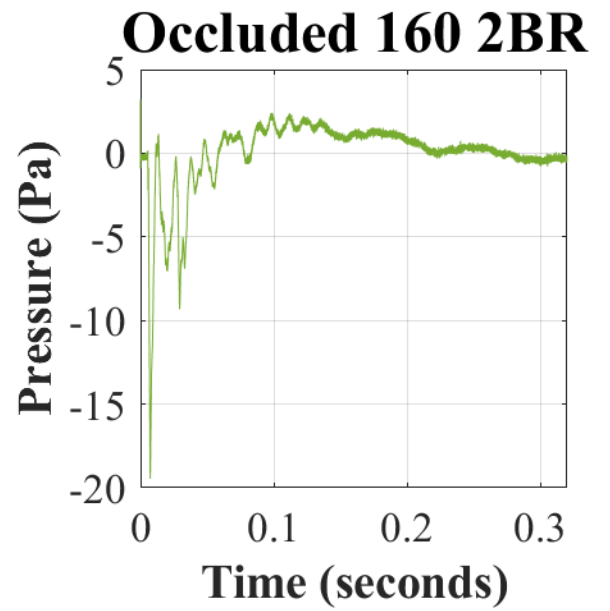
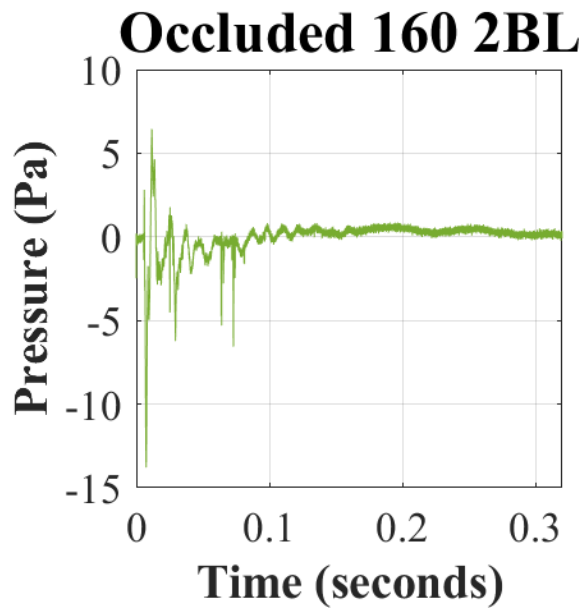
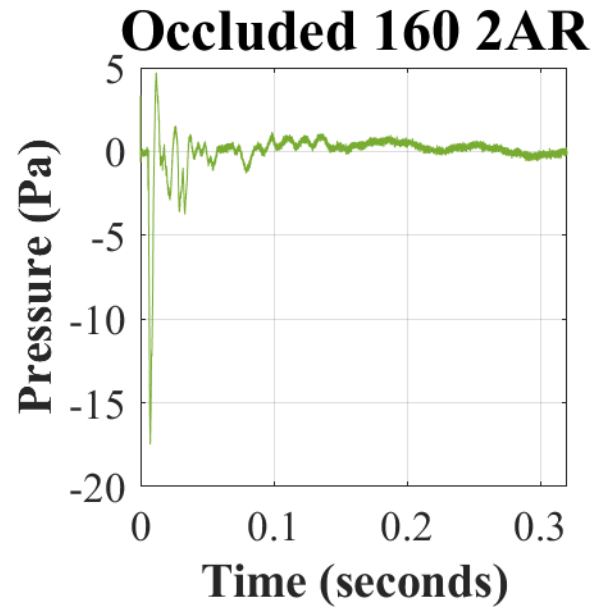
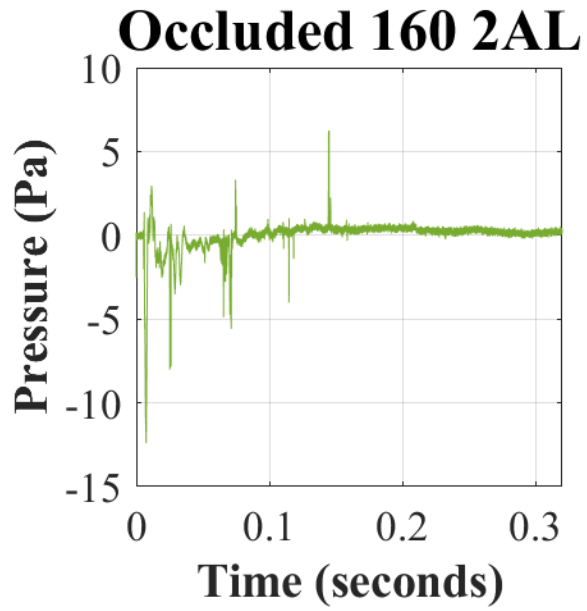


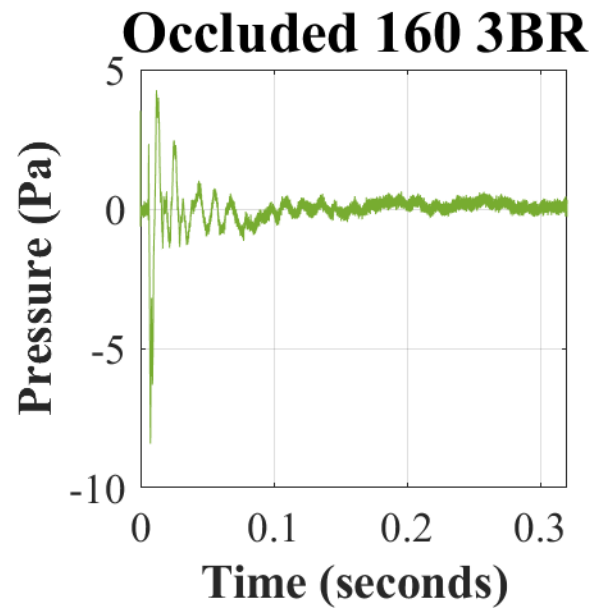
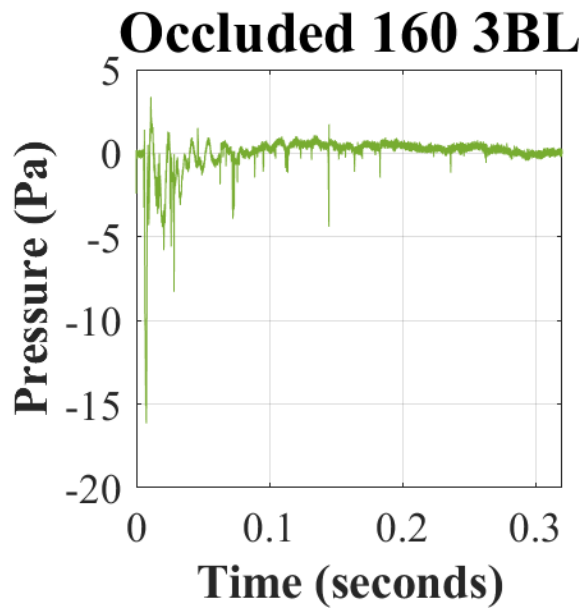
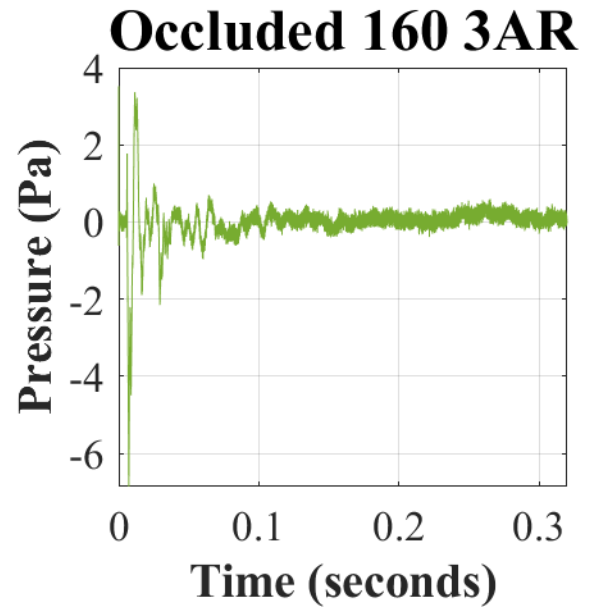
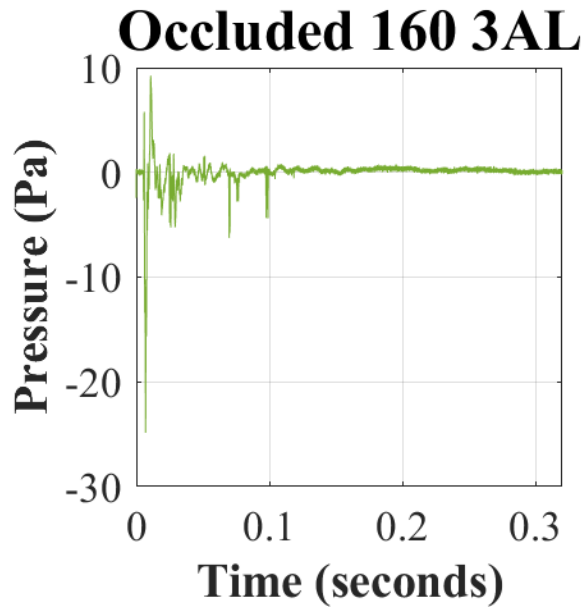


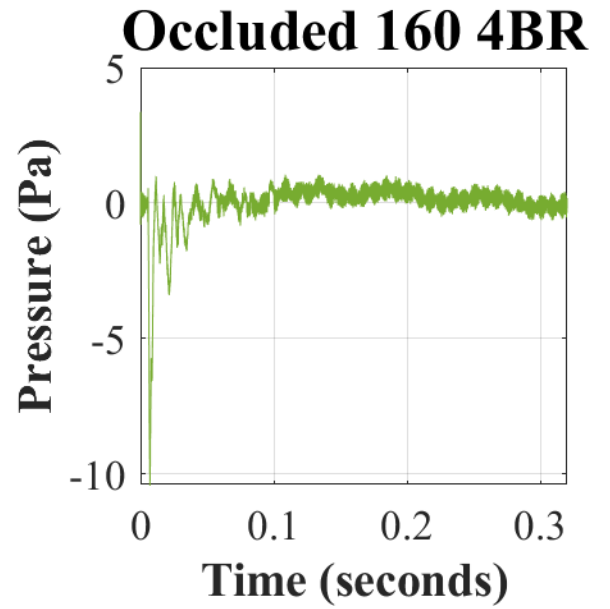
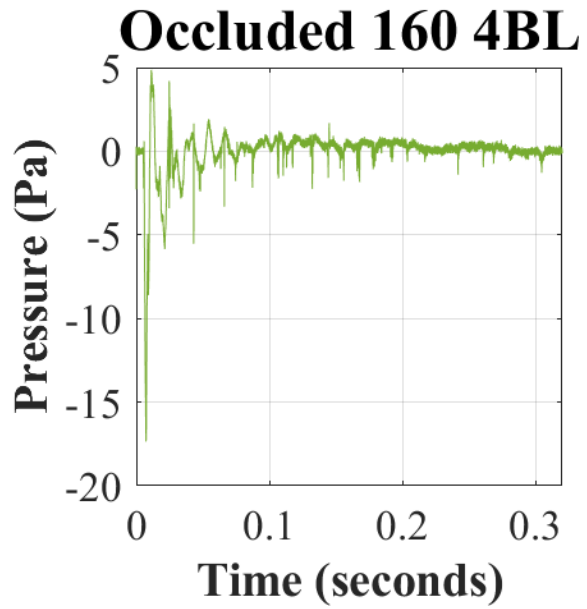
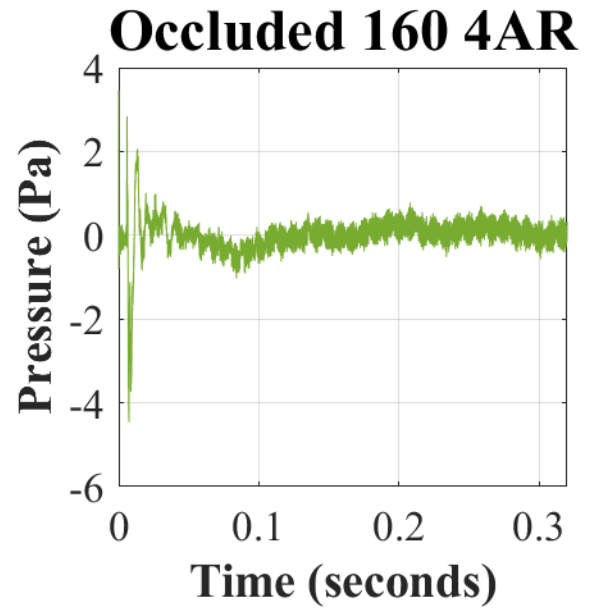
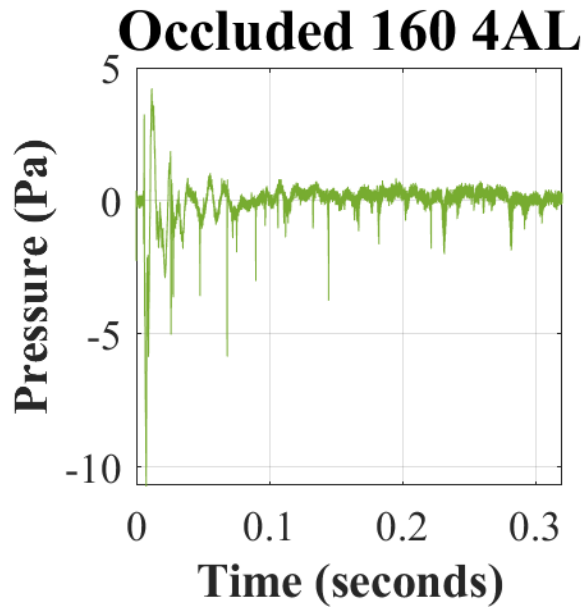
Note. The naming convention for all unoccluded waveforms is “Unoccluded LvL NnX”, where ‘Unoccluded’ is the test condition (i.e., ATF has the HPD doffed), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dB), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., 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).

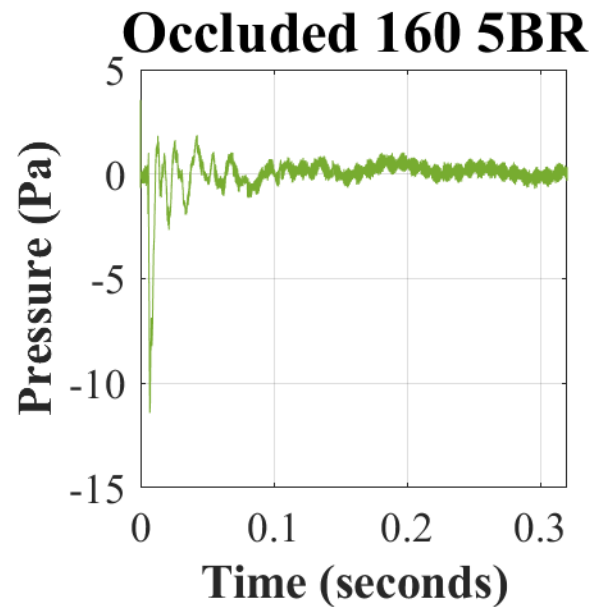
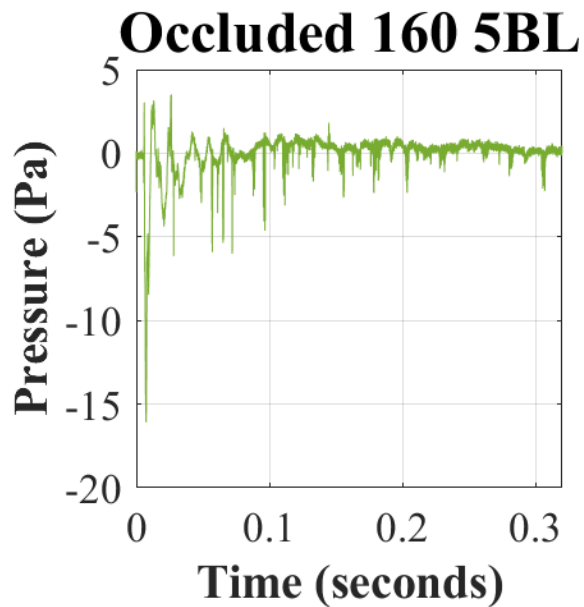
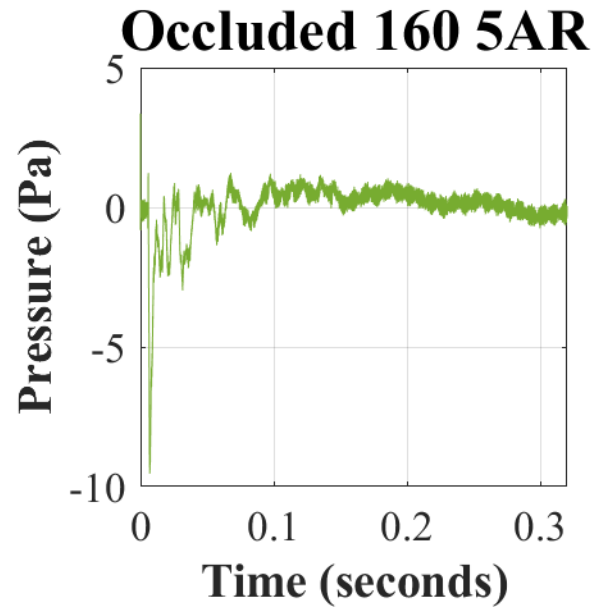
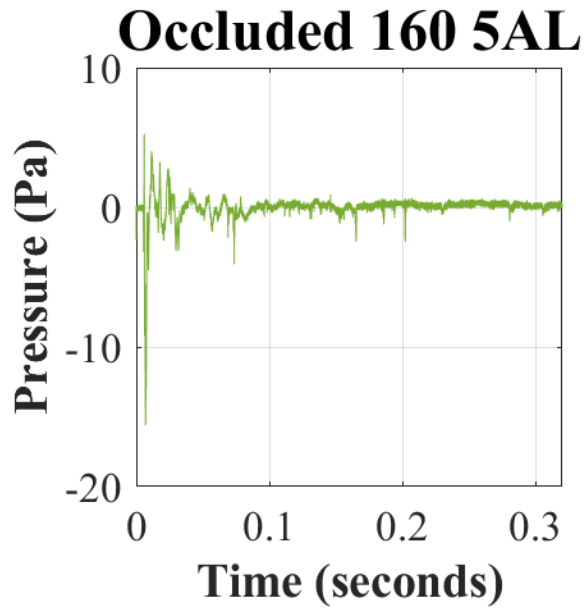
**Appendix C.** Recorded occluded (closed-ear) waveforms (in pascals [Pa]) over time (in seconds [s]) in response to 160 dBp with the ComTac™ V (OFF).





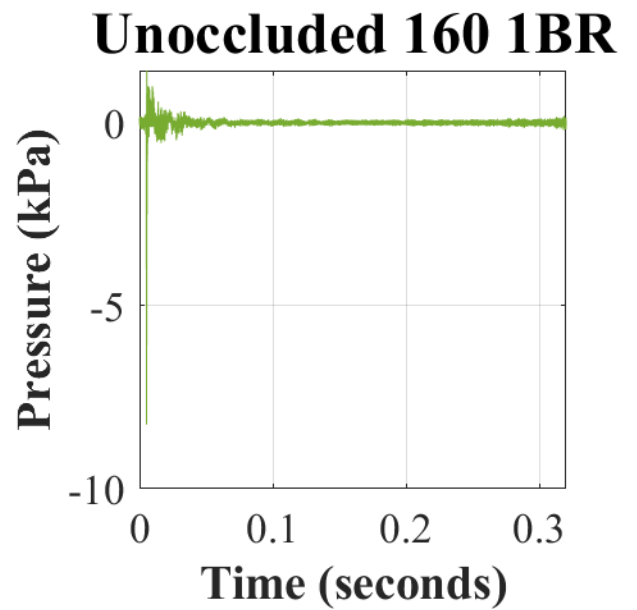
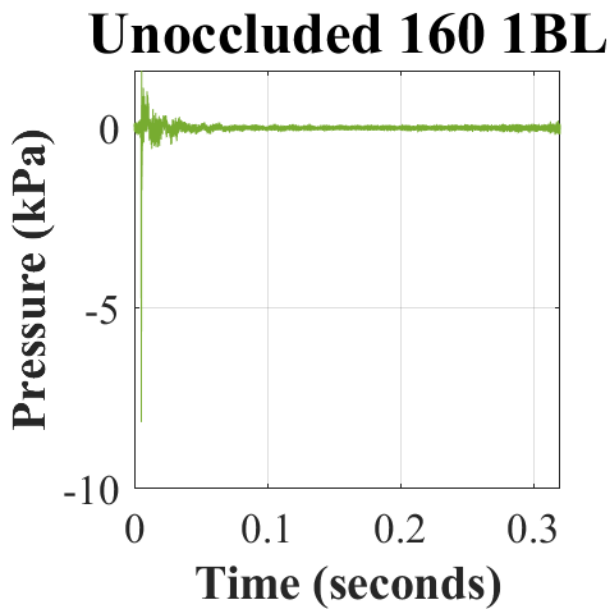
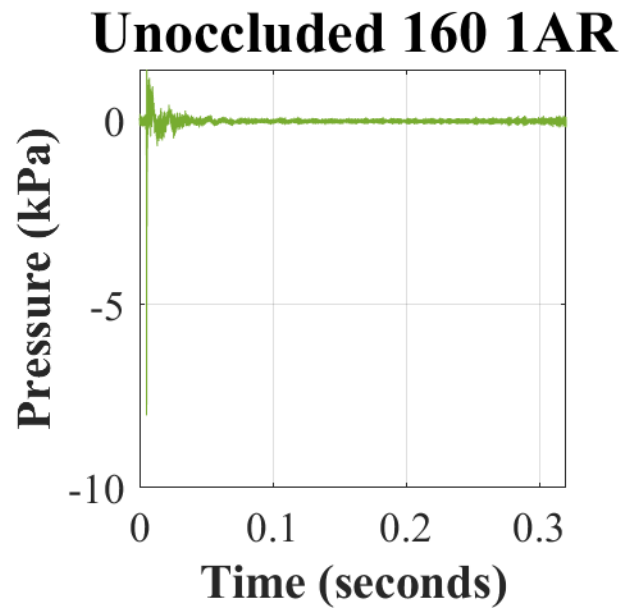
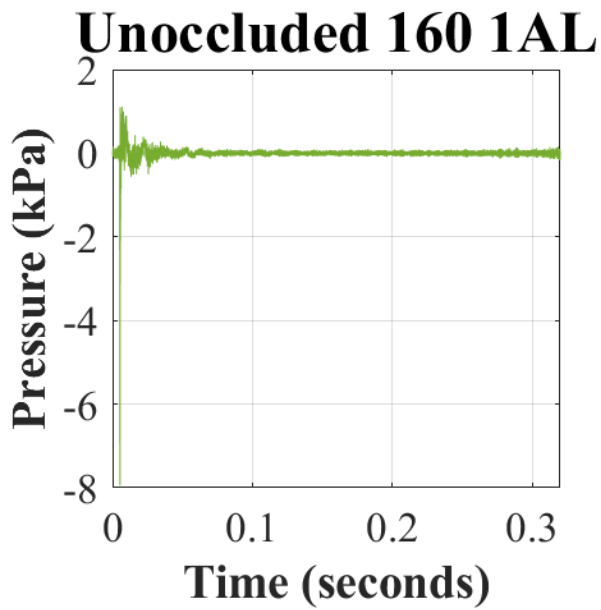




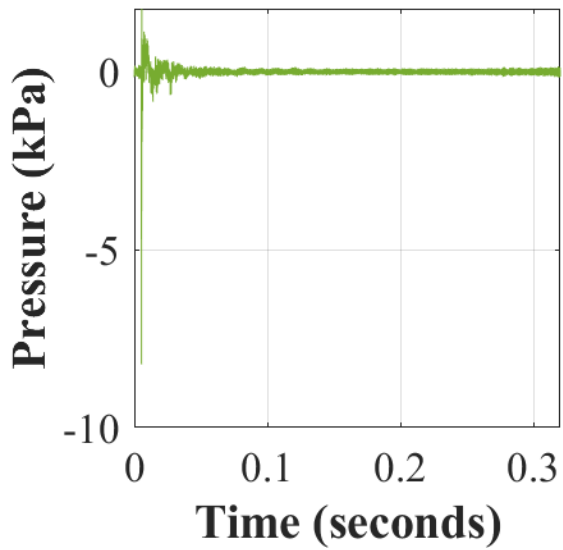


Note. The naming convention for all occluded waveforms is “Occluded LvL NnX”, where ‘Occluded’ is the test condition (i.e., ATF has the HPD donned), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or 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).

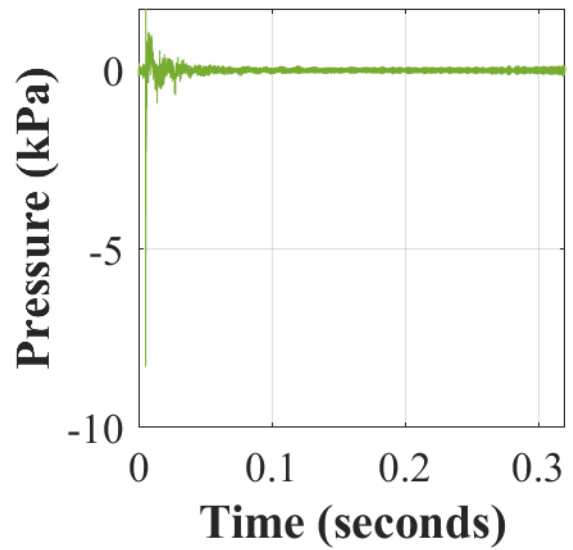
**Appendix D.** Estimated unoccluded (open-ear) waveforms (in kilopascals [kPa]) over time (in seconds [s]) in response to 160 dBp with the ComTac™ V (OFF).



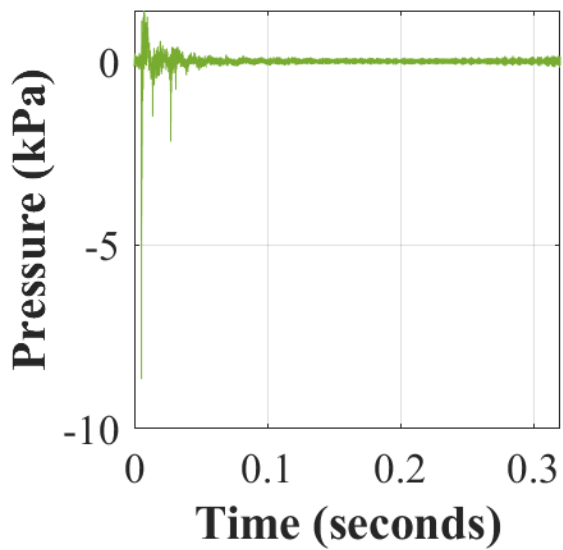
**Unoccluded 160 2AL**



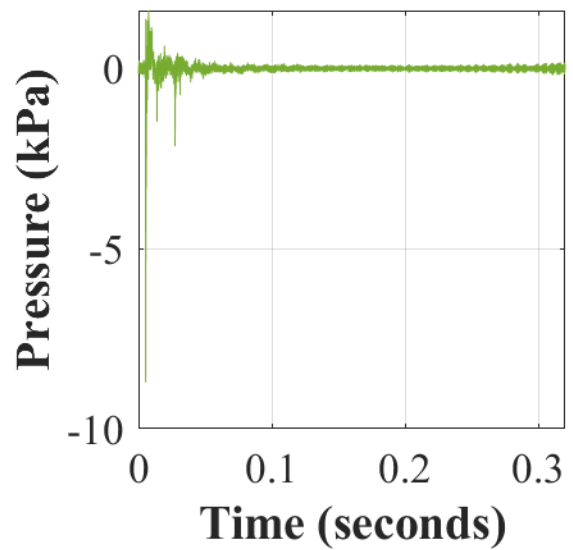
**Unoccluded 160 2AR**

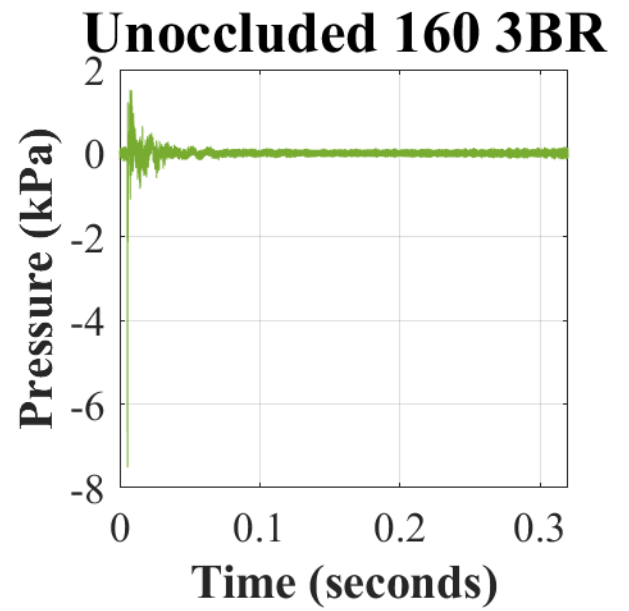
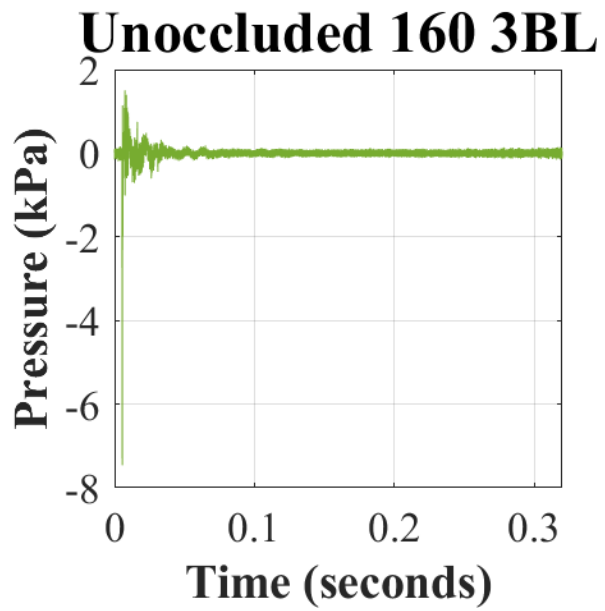
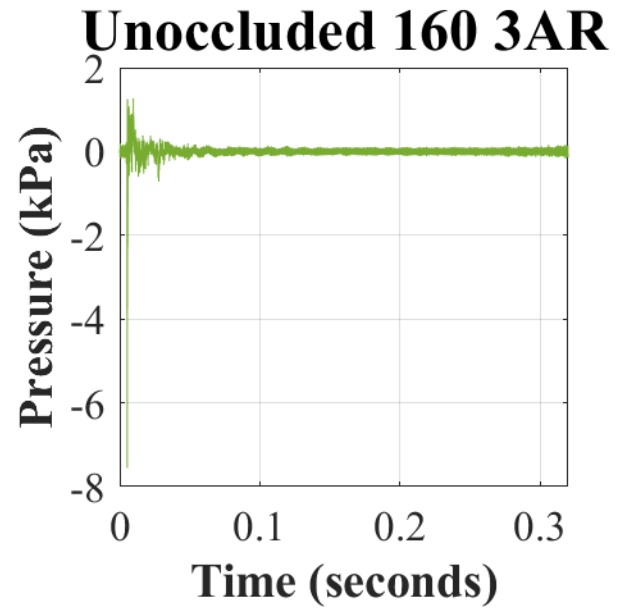
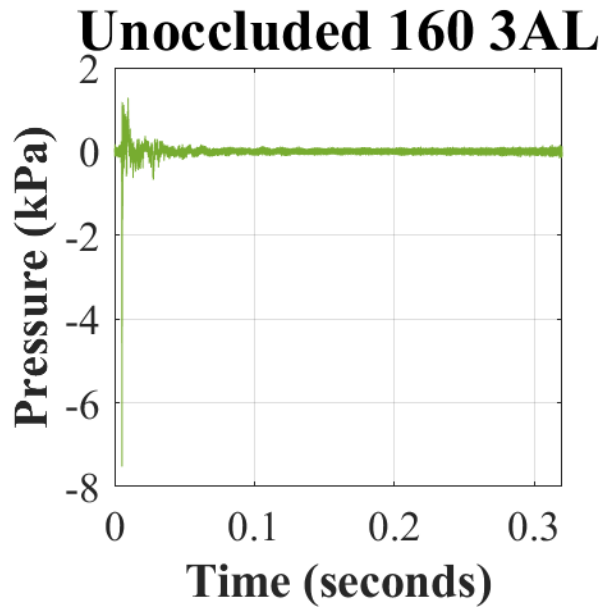


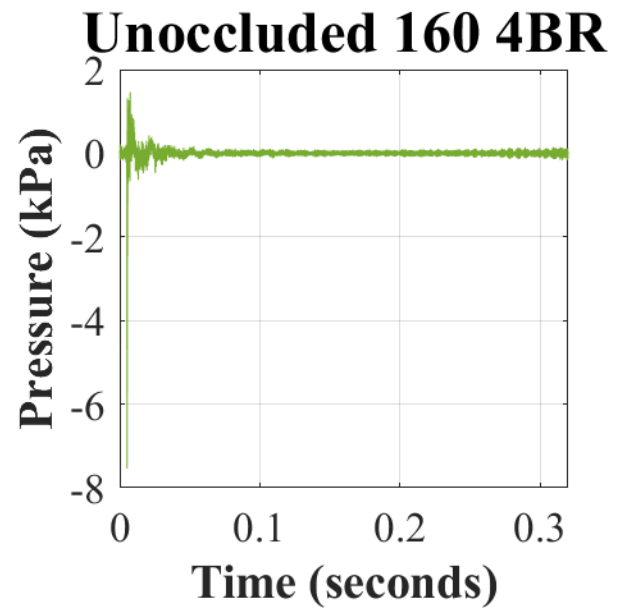
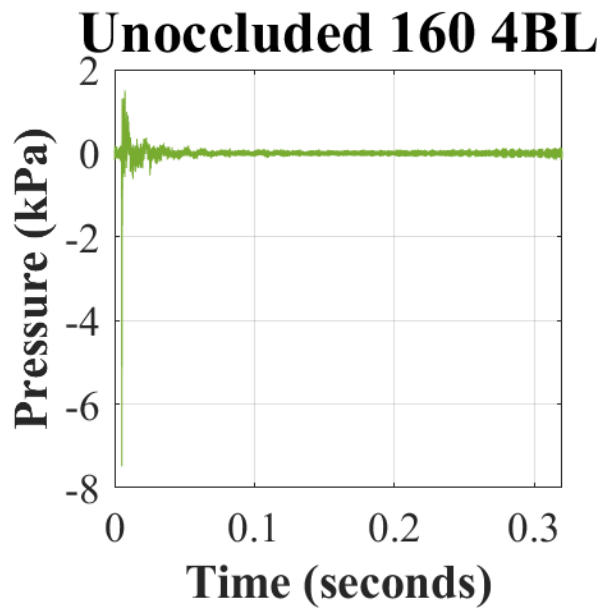
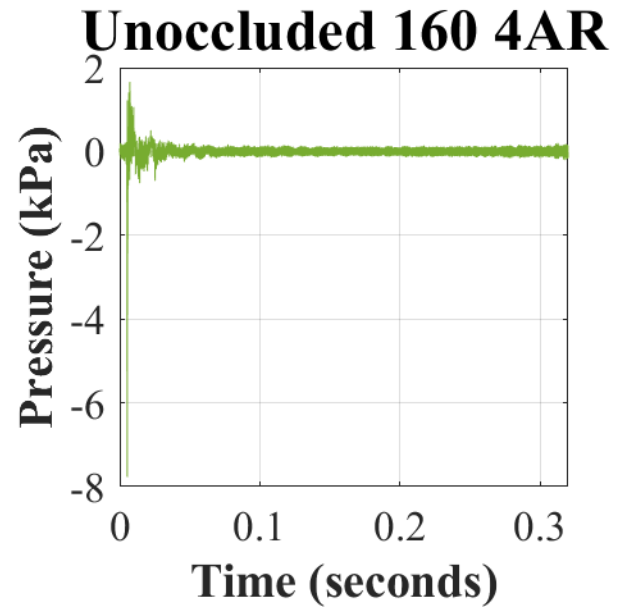
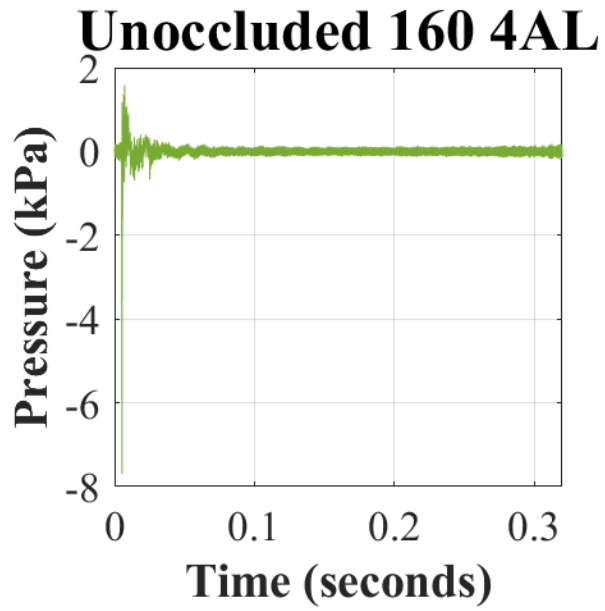
**Unoccluded 160 2BL**

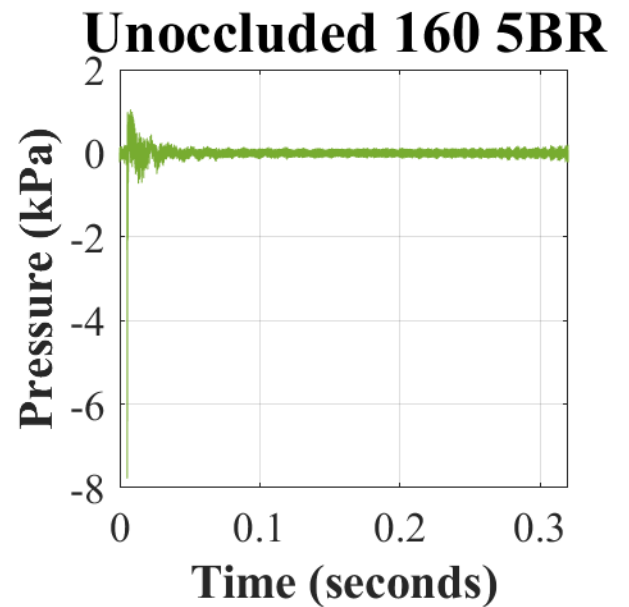
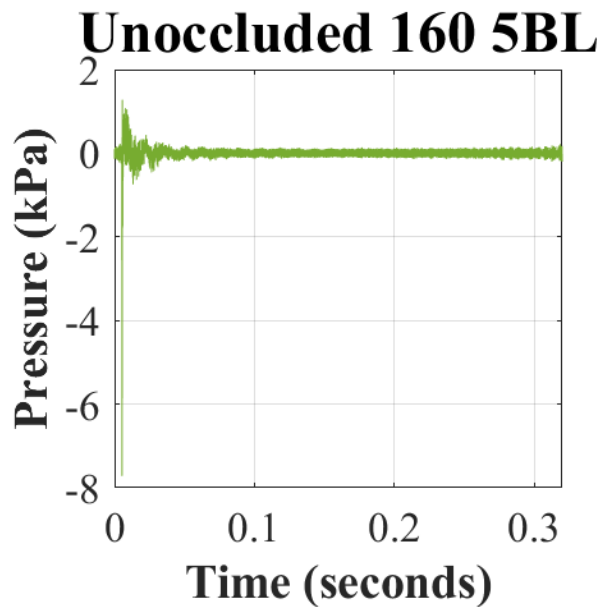
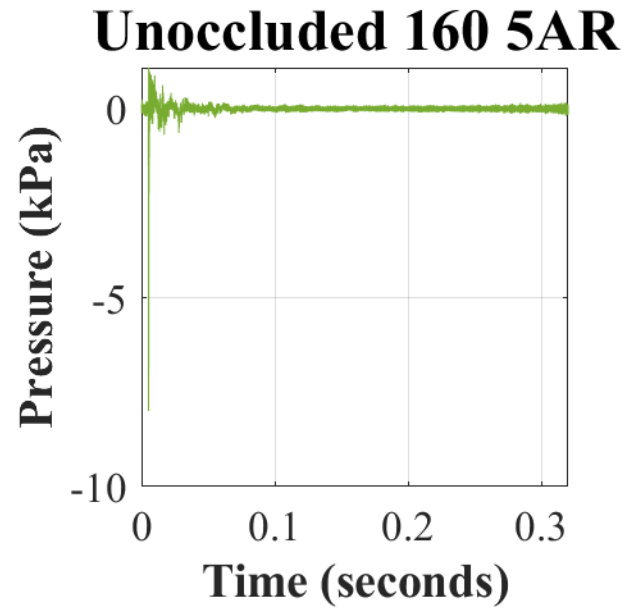
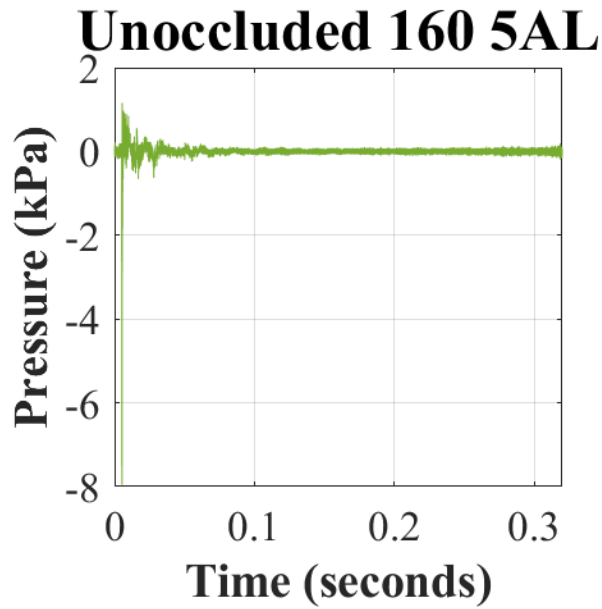


**Unoccluded 160 2BR**



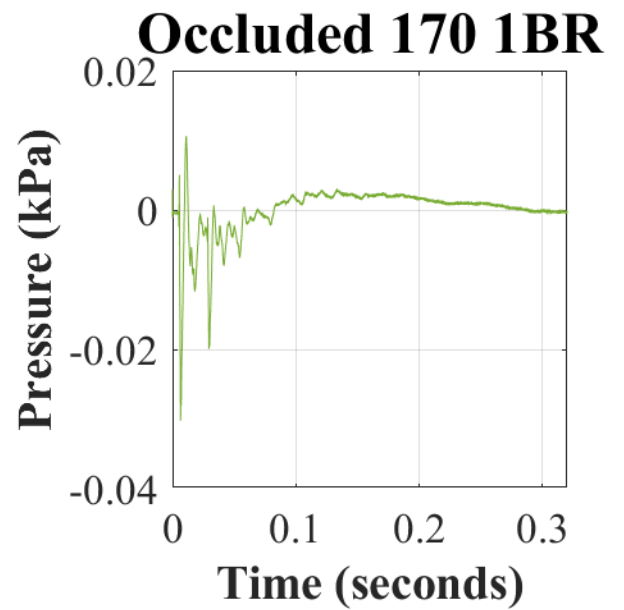
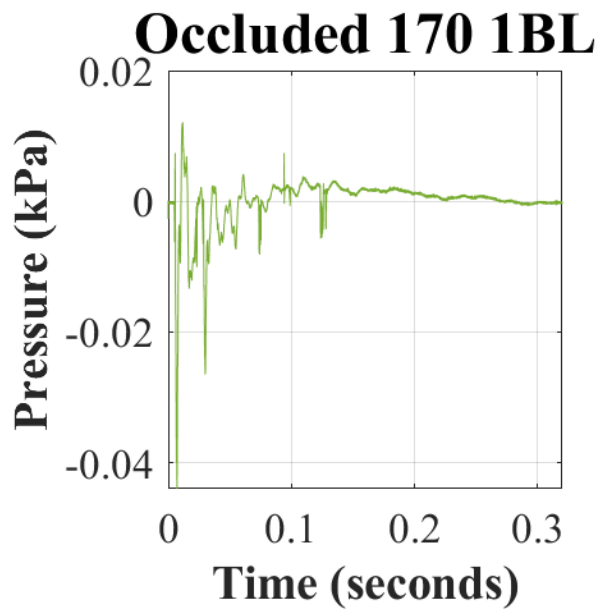
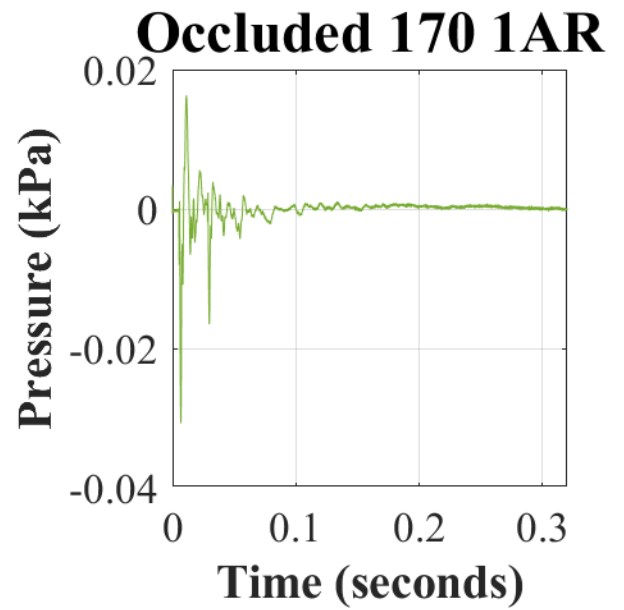
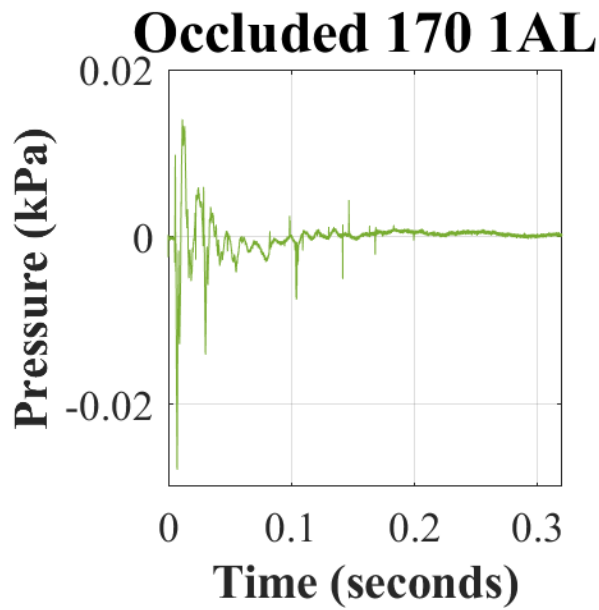


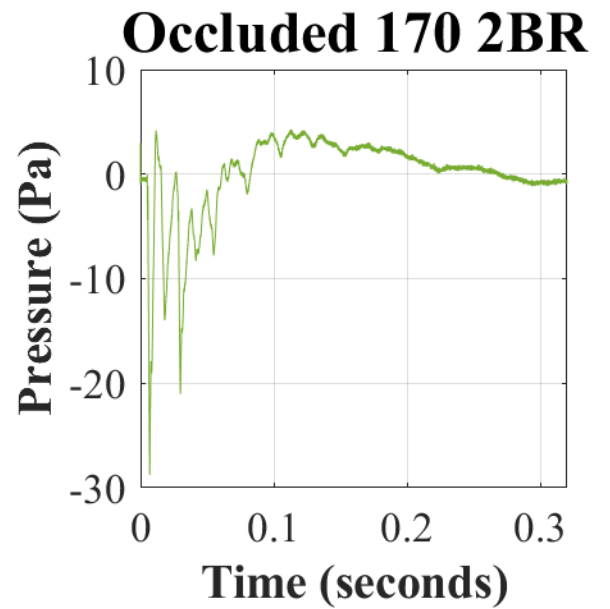
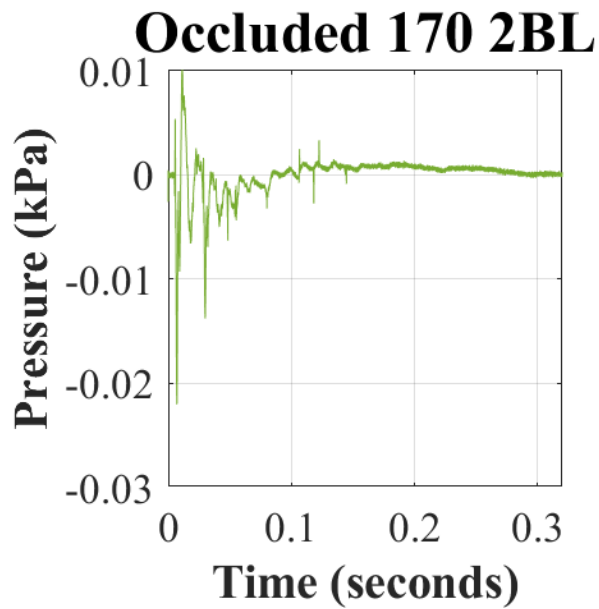
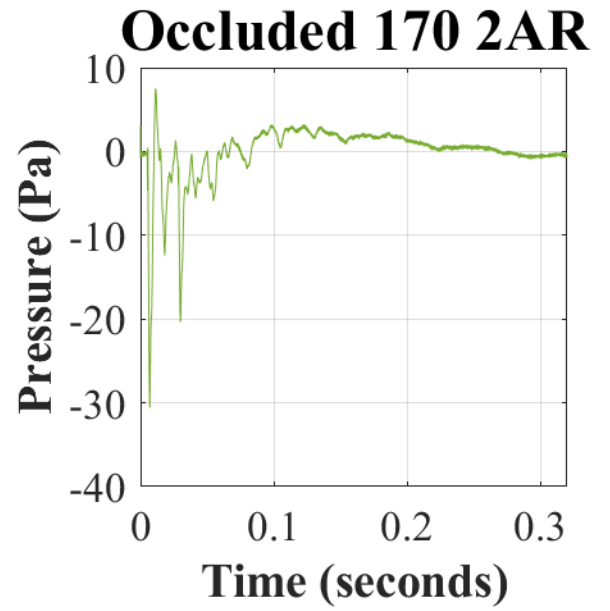
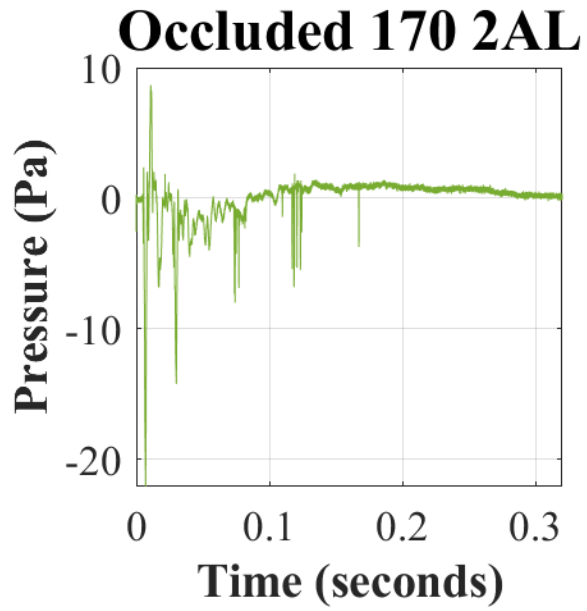


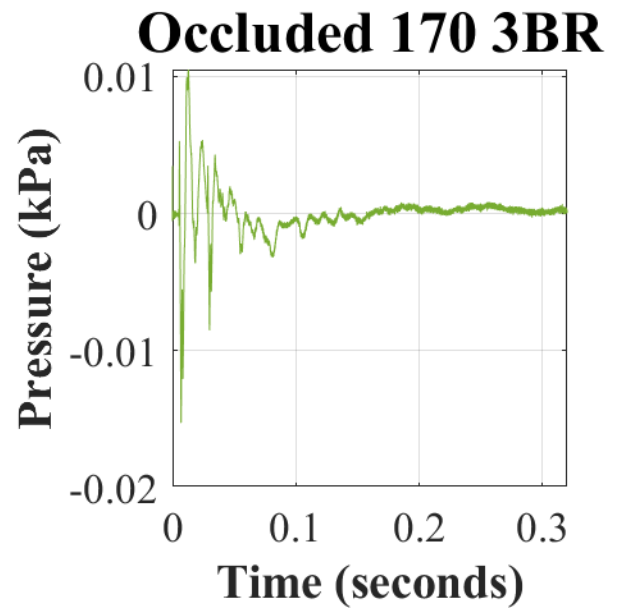
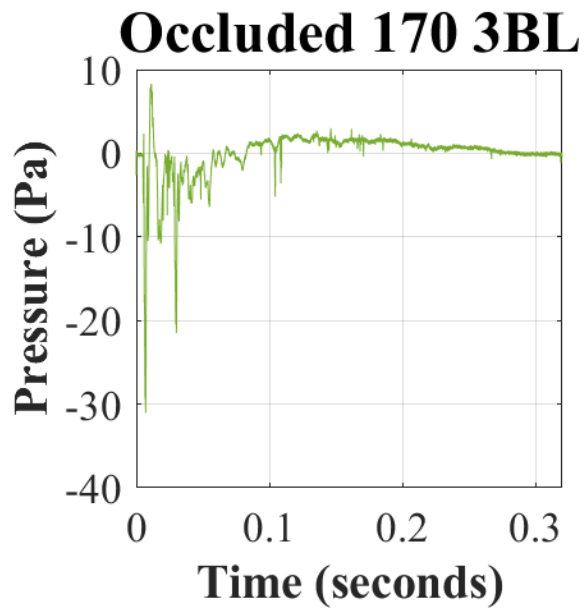
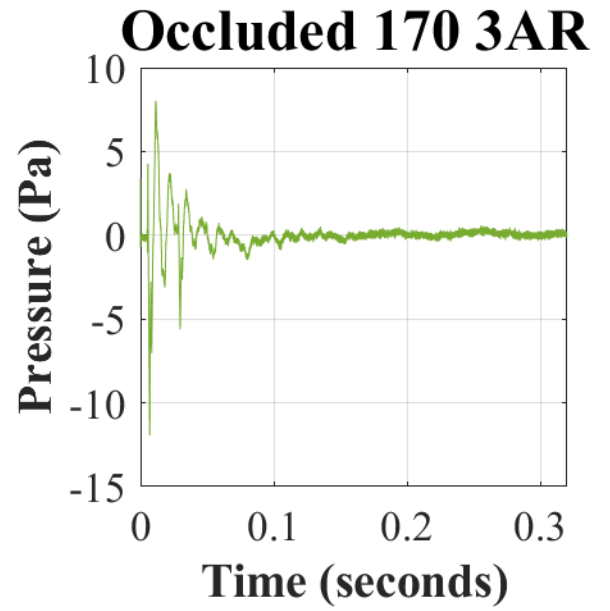
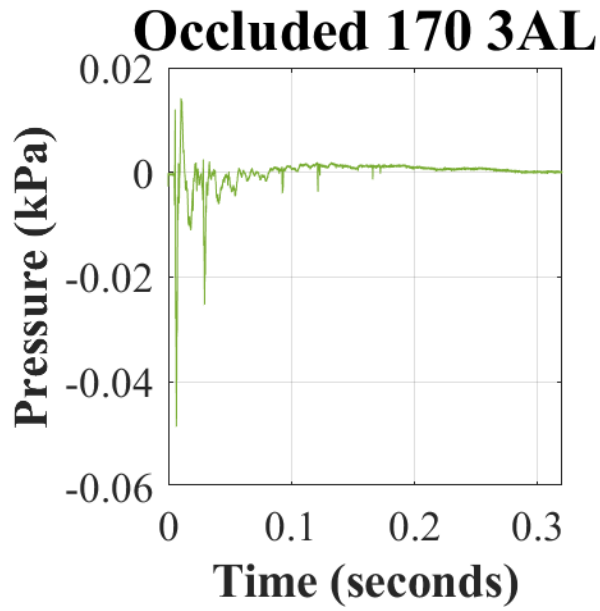


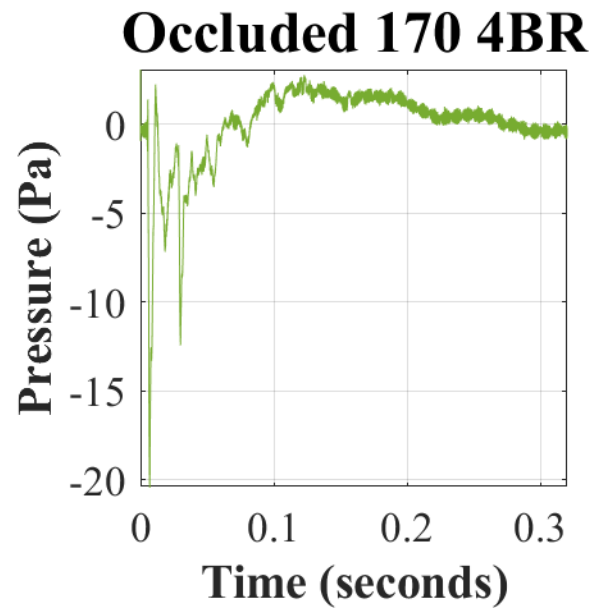
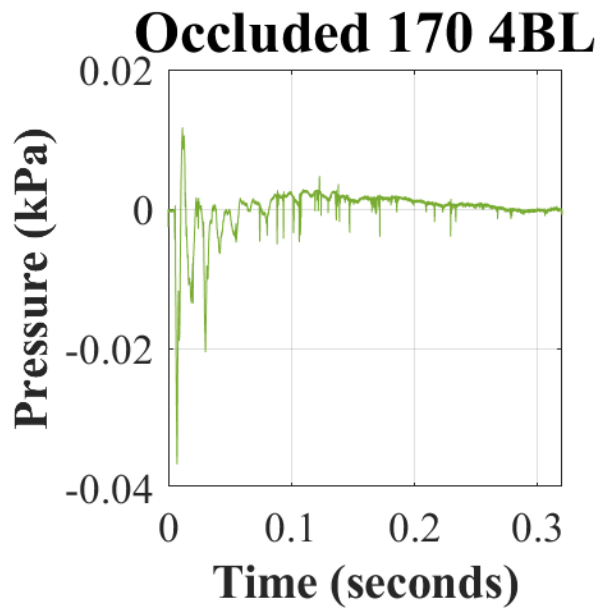
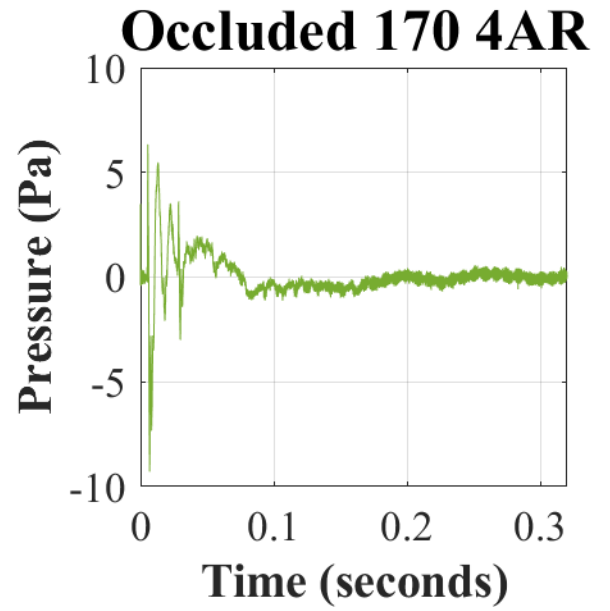
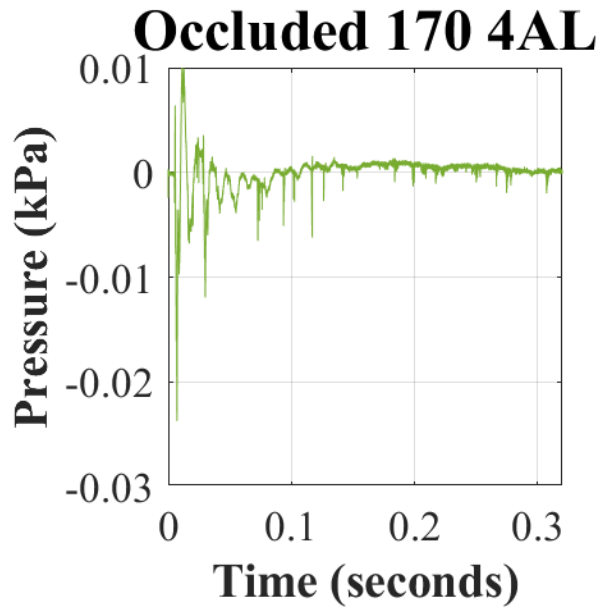
Note. The naming convention for all unoccluded waveforms is “Unoccluded LvL NnX”, where ‘Unoccluded’ is the test condition (i.e., ATF has the HPD doffed), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dB), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., 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).

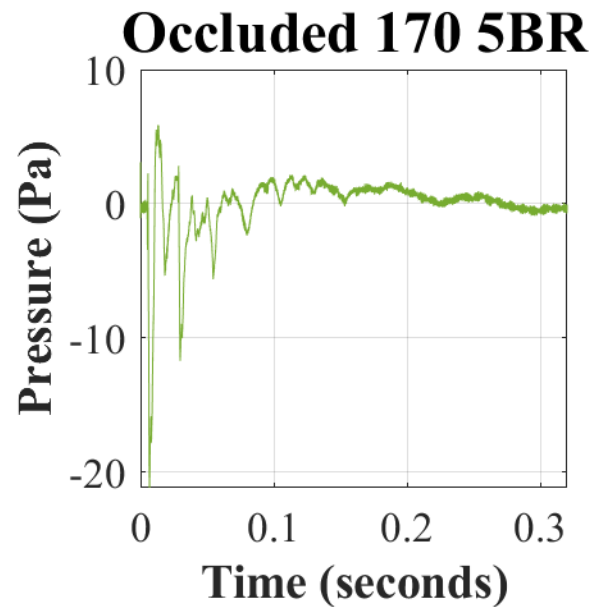
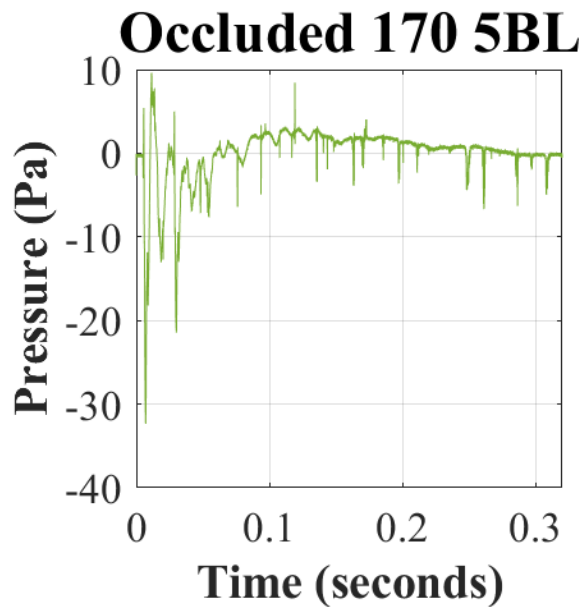
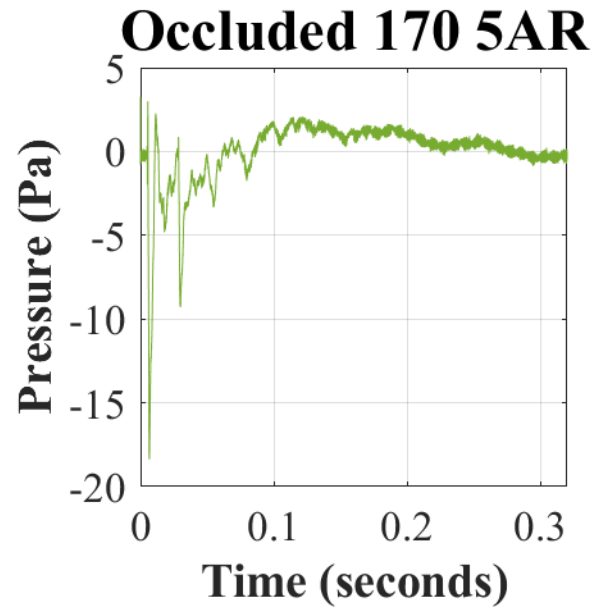
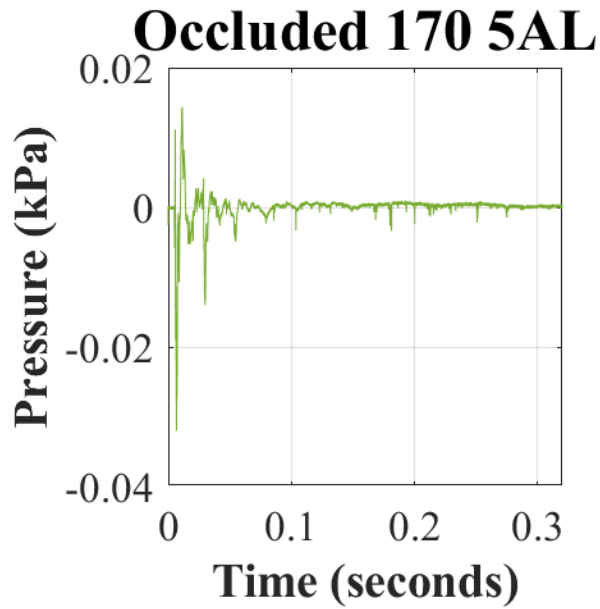
**Appendix E.** Recorded occluded (closed-ear) waveforms (in pascals [Pa] or kilopascals [kPa]) over time (in seconds [s]) in response to 170 dBp with the ComTac™ V (OFF).





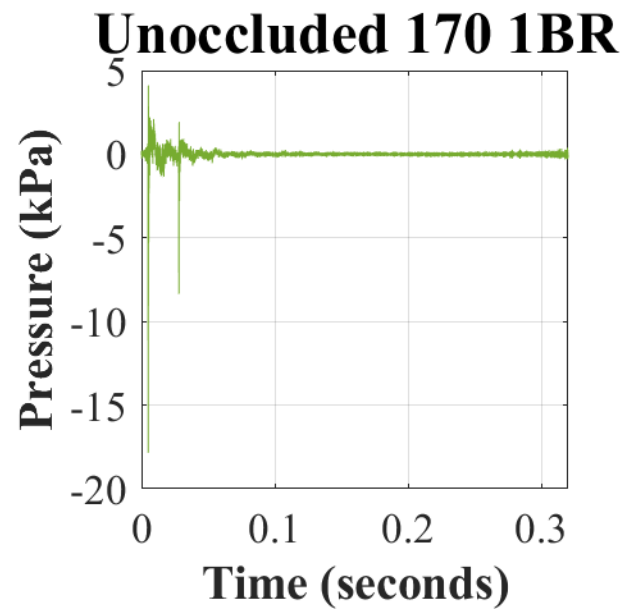
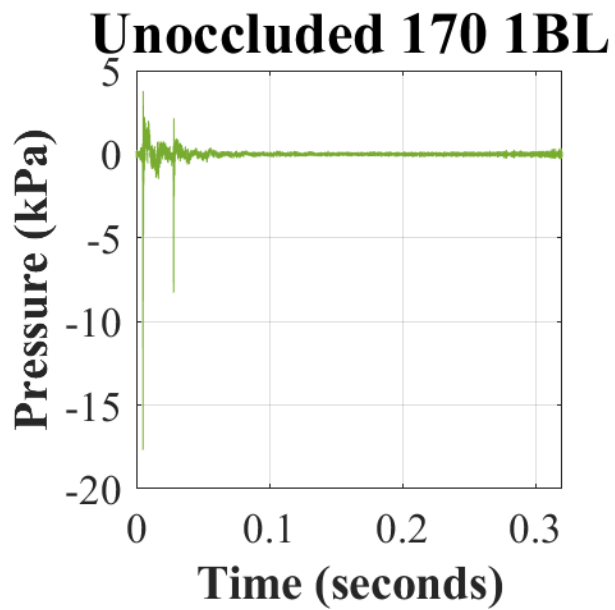
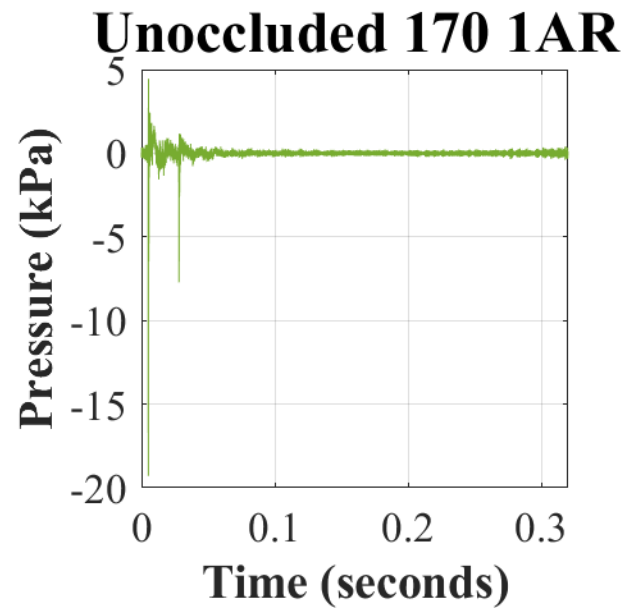
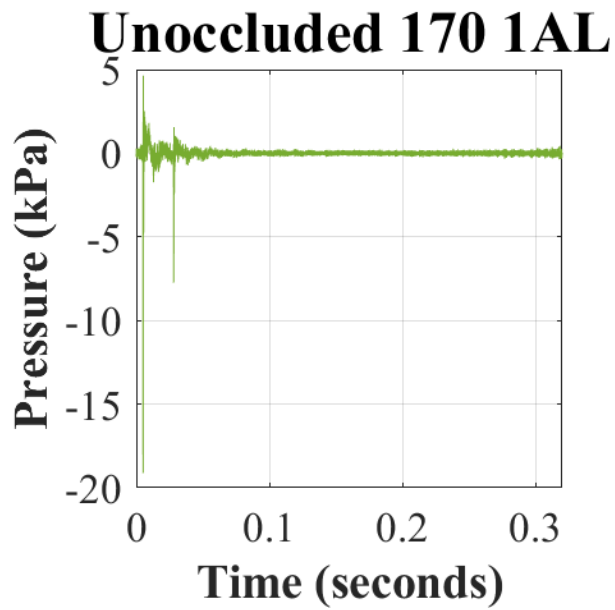


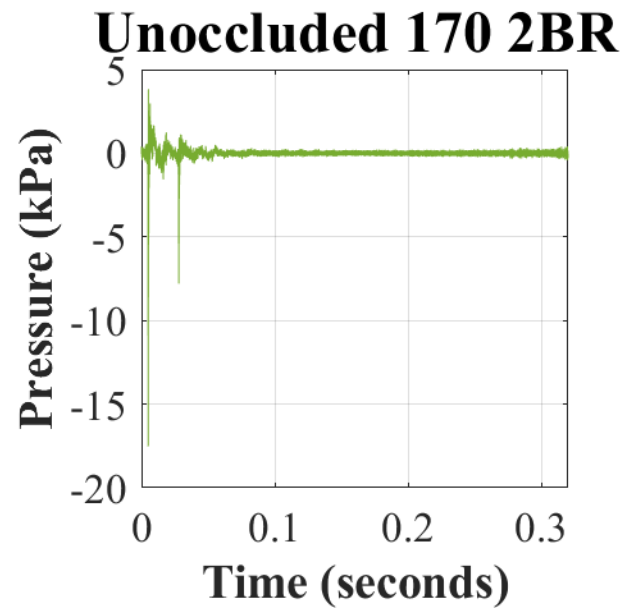
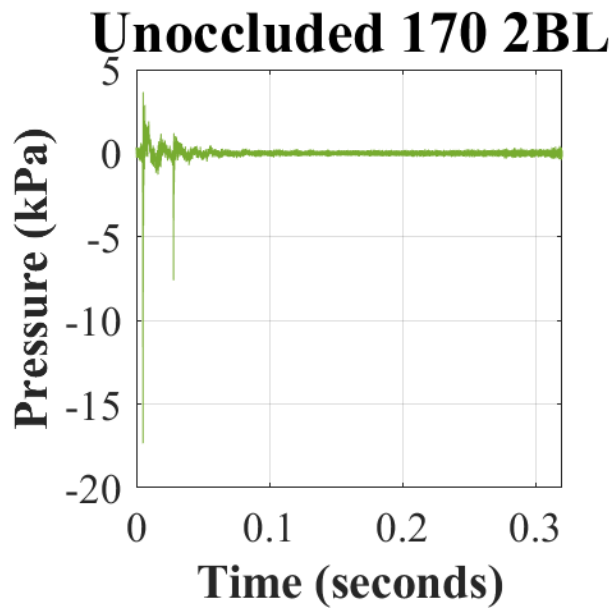
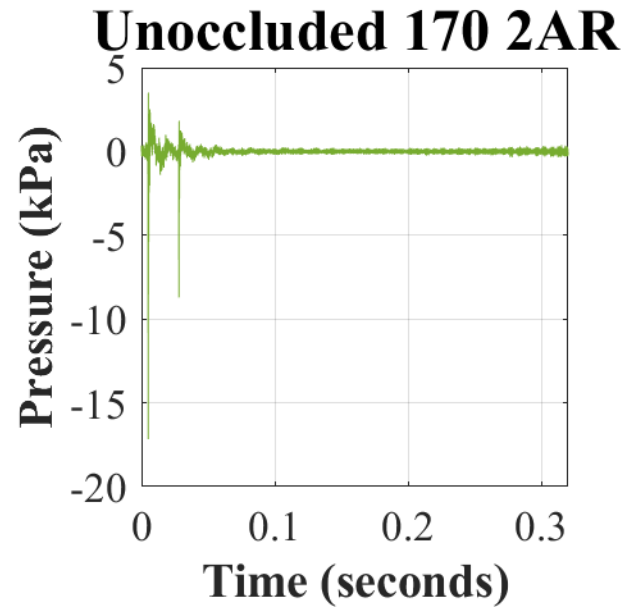
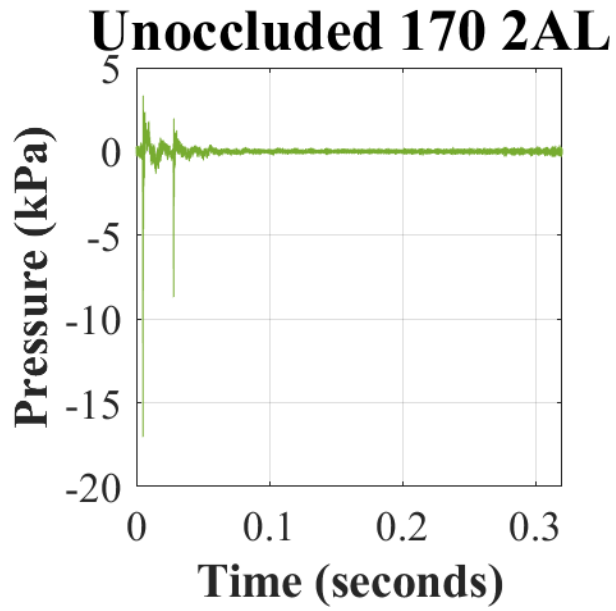


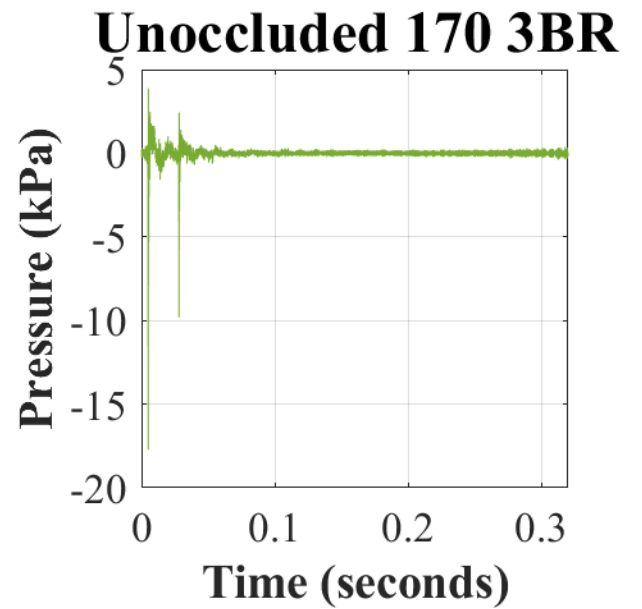
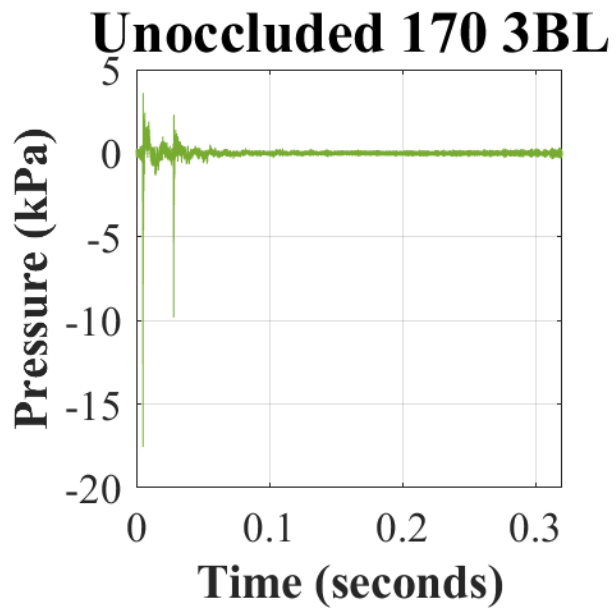
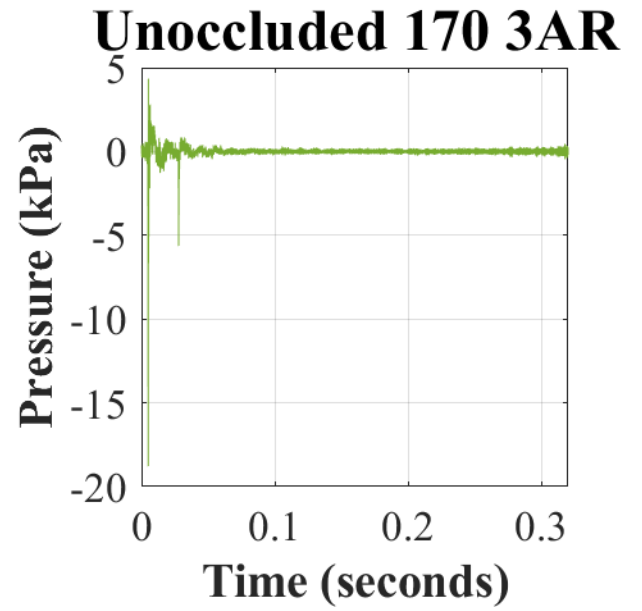
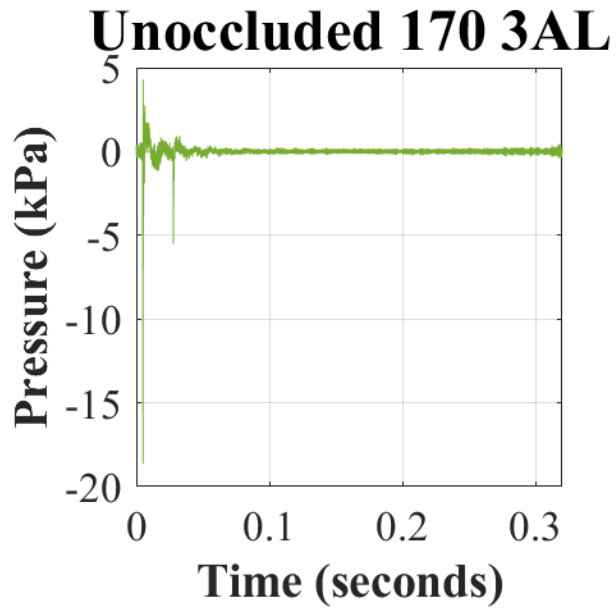


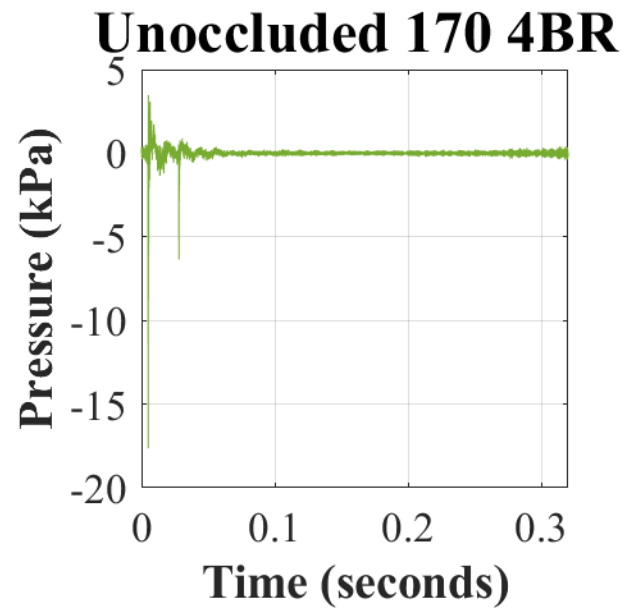
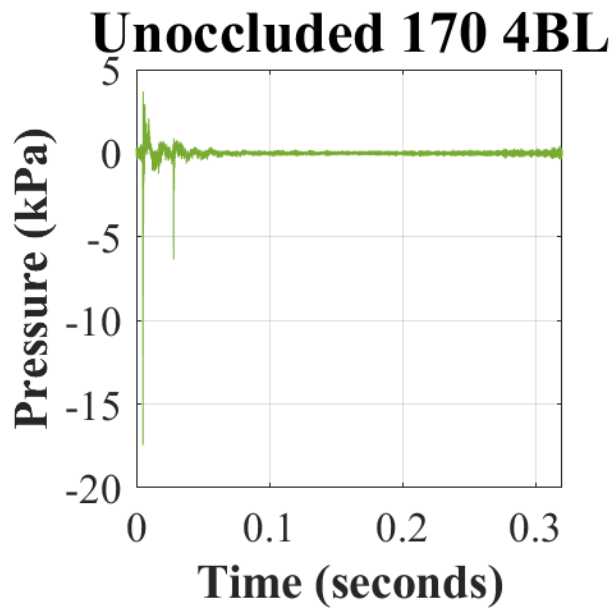
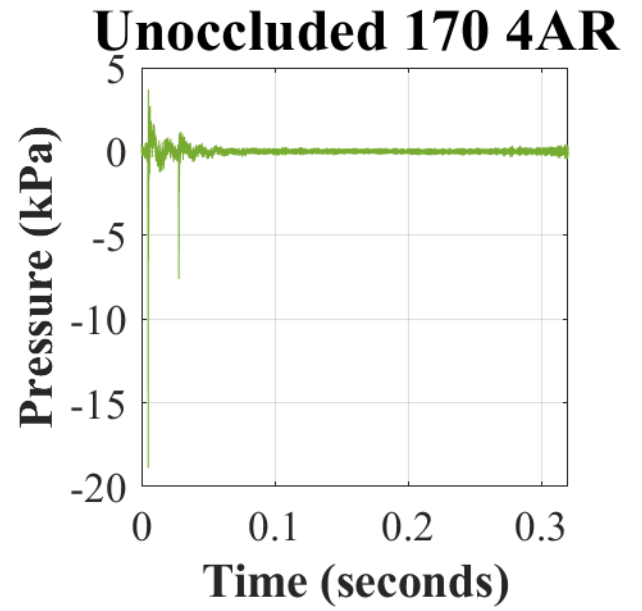
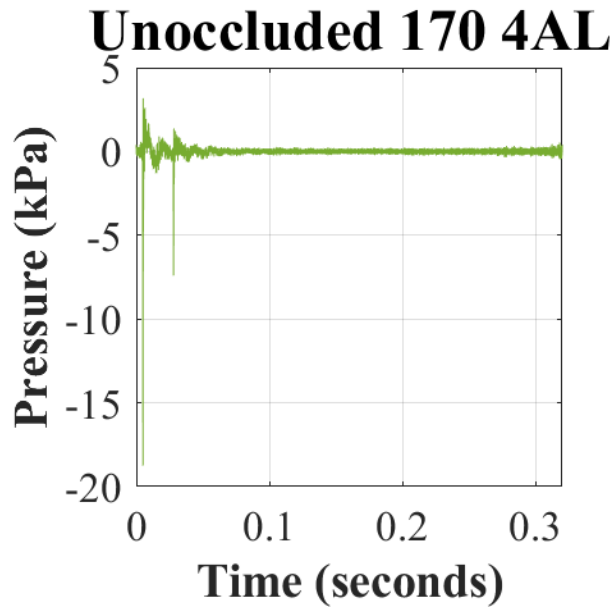
Note. The naming convention for all occluded waveforms is “Occluded LvL NnX”, where ‘Occluded’ is the test condition (i.e., ATF has the HPD donned), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or 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).

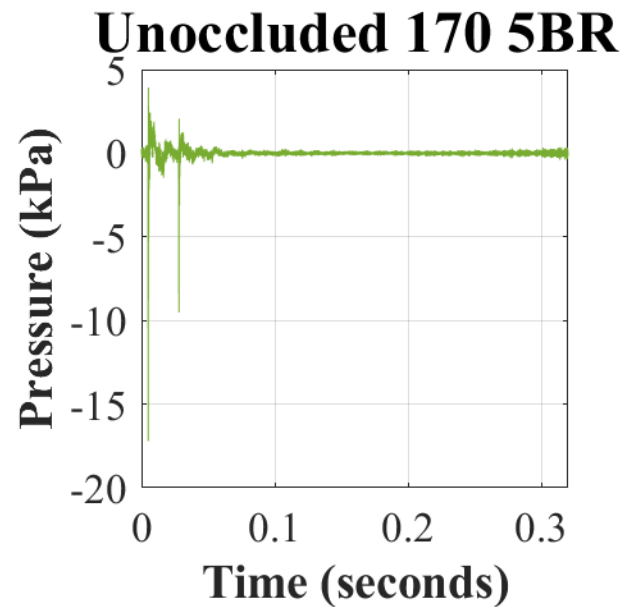
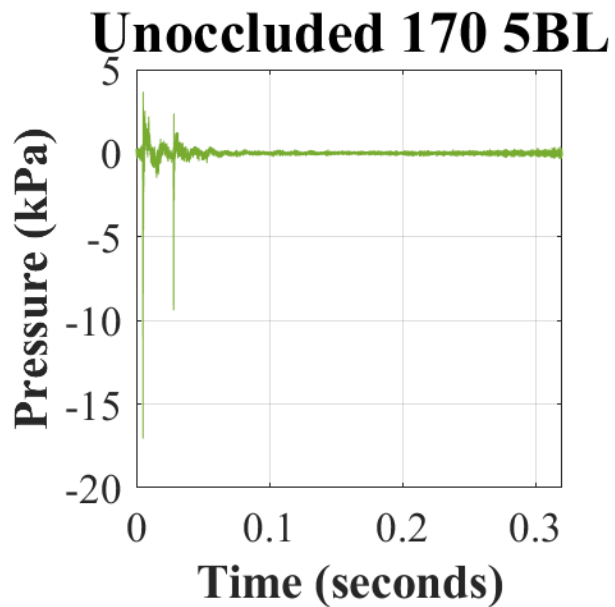
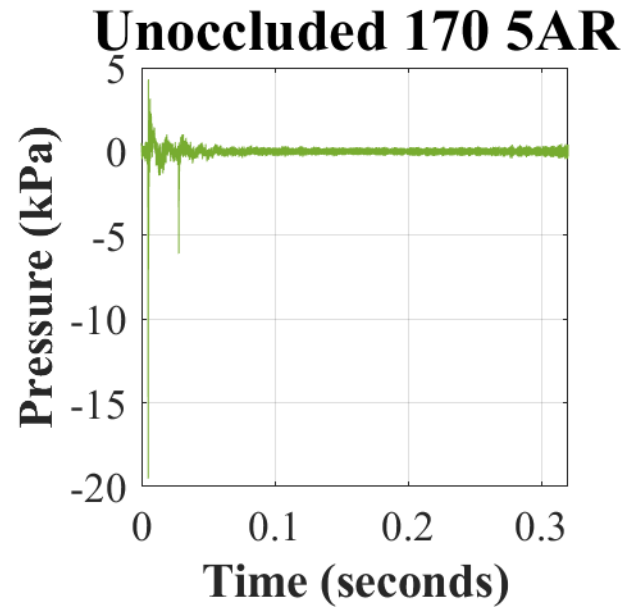
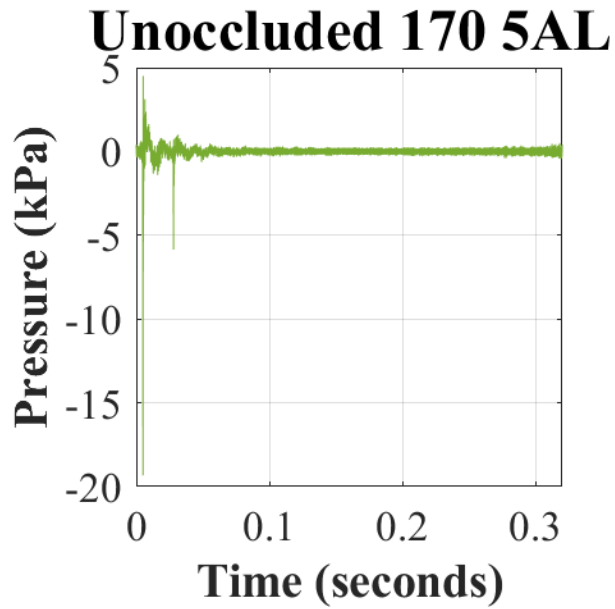
**Appendix F.** Estimated unoccluded (open-ear) waveforms (in kilopascals [kPa]) over time (in seconds [s]) in response to 170 dBp with the ComTac™ V (OFF).







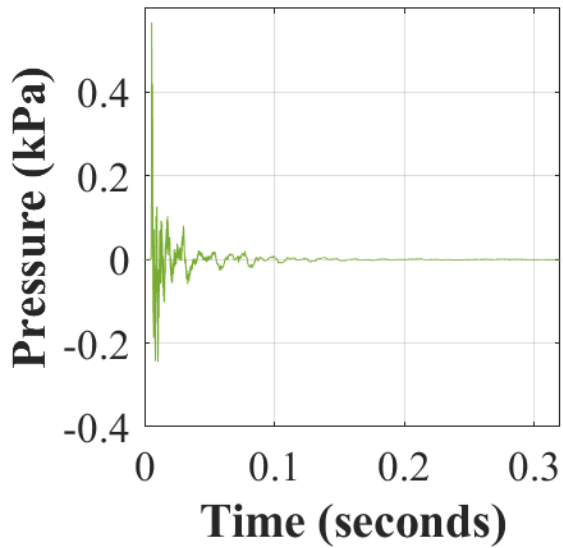




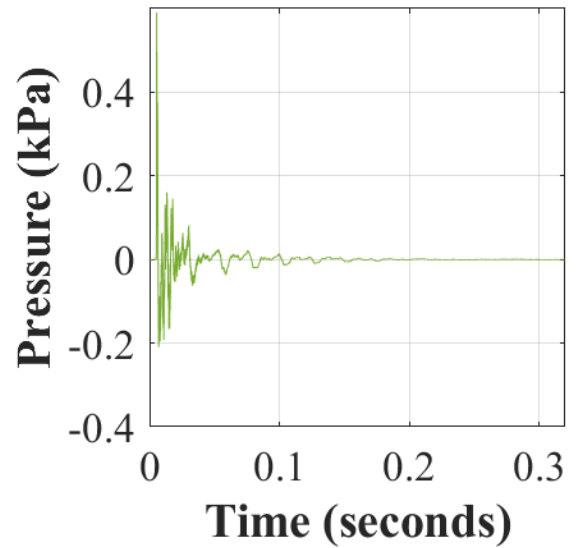
Note. The naming convention for all unoccluded waveforms is “Unoccluded LvL NnX”, where ‘Unoccluded’ is the test condition (i.e., ATF has the HPD doffed), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dB), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., 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 G.** Recorded waveform (in kilopascals [kPa]) over time (in seconds [s]) of the impulse measured with the free-field probe at 150 dBp and the ComTac™ V (OFF) donned.

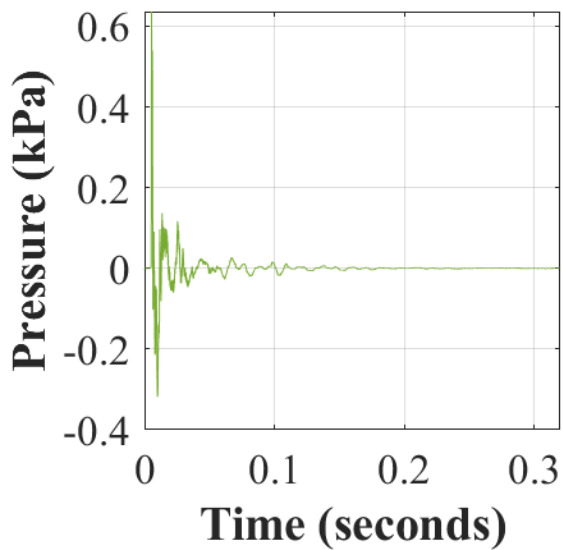
**Free Field 150 1A**



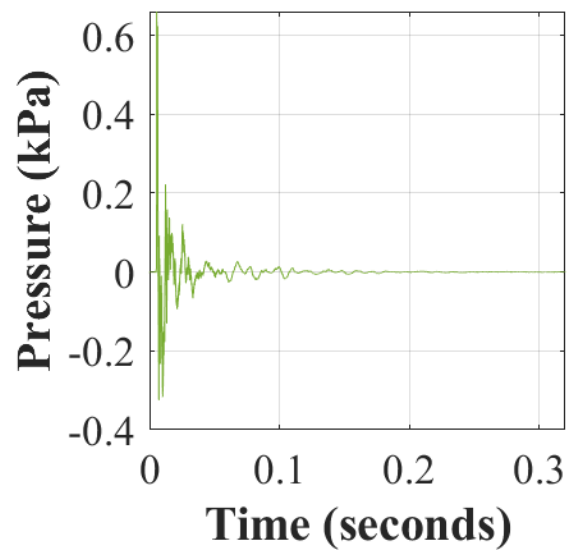
**Free Field 150 1B**



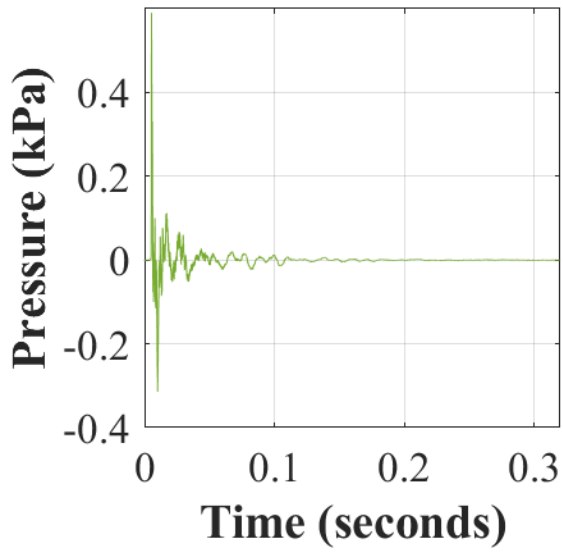
**Free Field 150 2A**



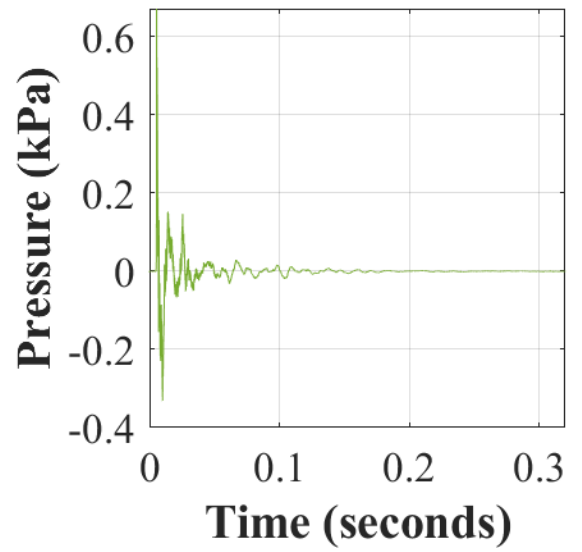
**Free Field 150 2B**



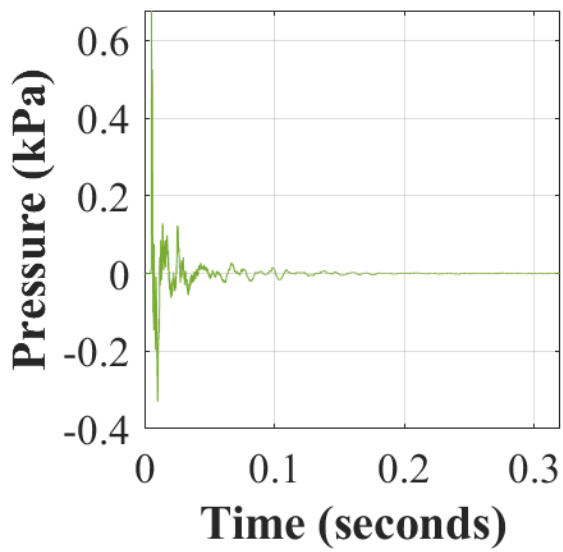
**Free Field 150 3A**



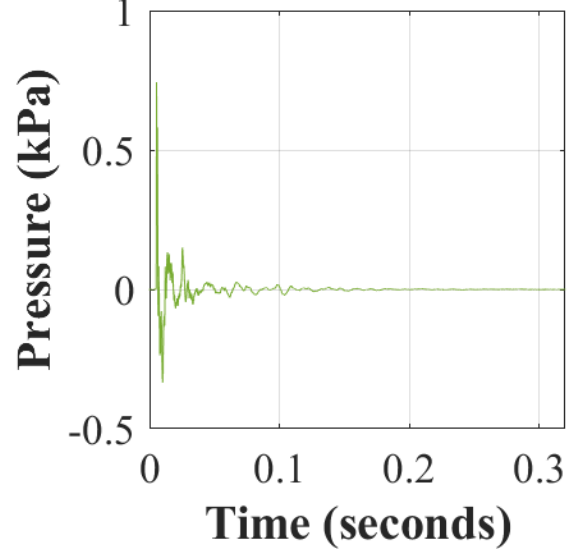
**Free Field 150 3B**

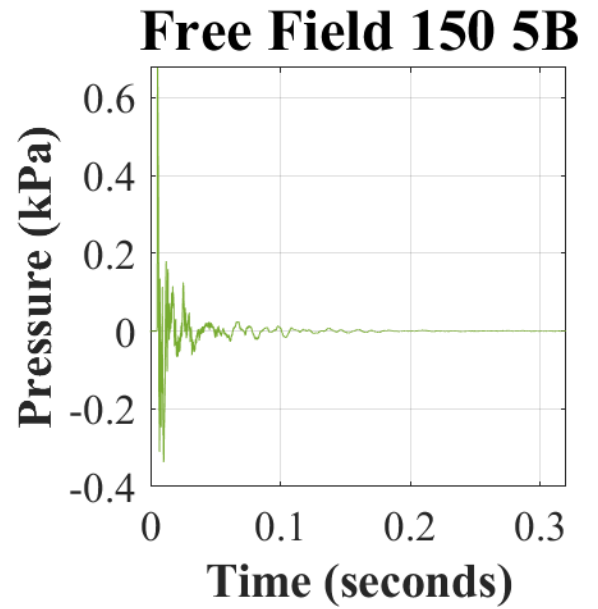
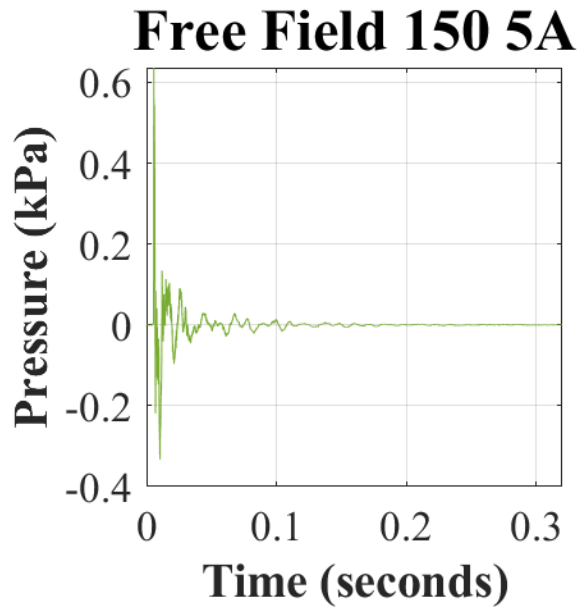


**Free Field 150 4A**



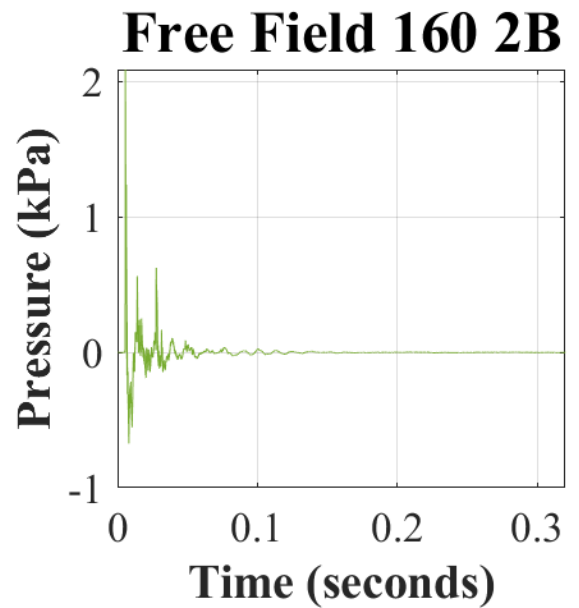
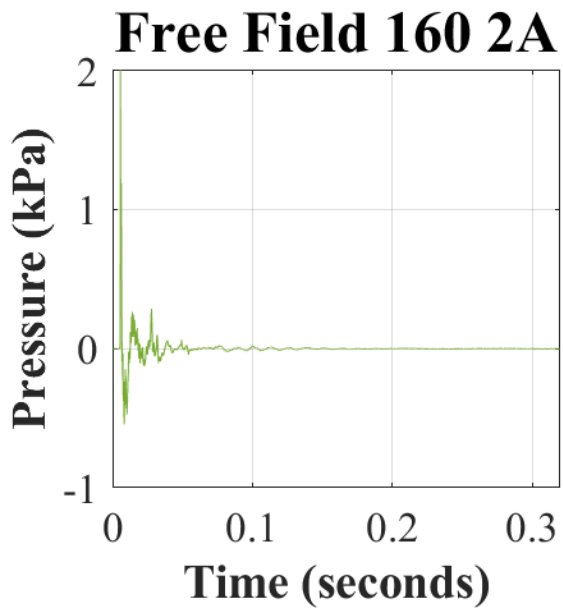
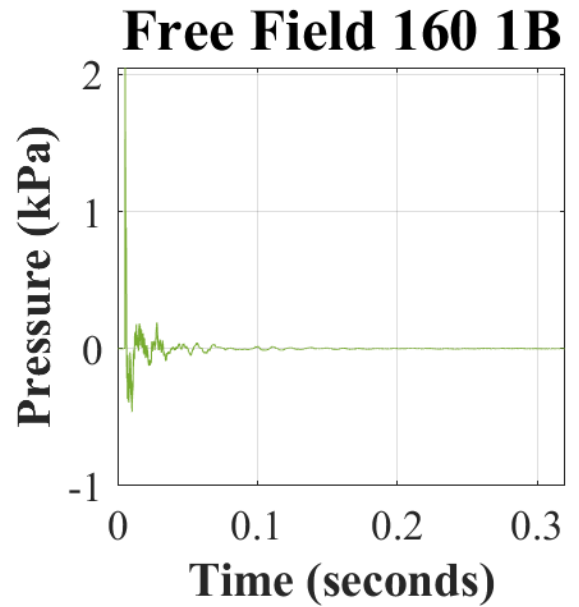
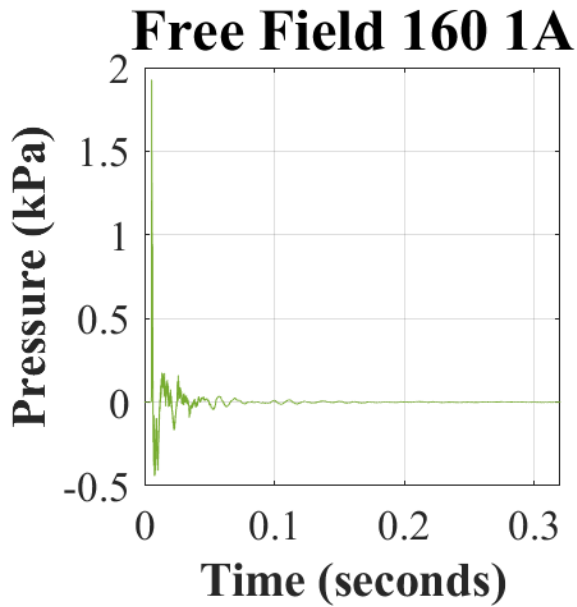
**Free Field 150 4B**

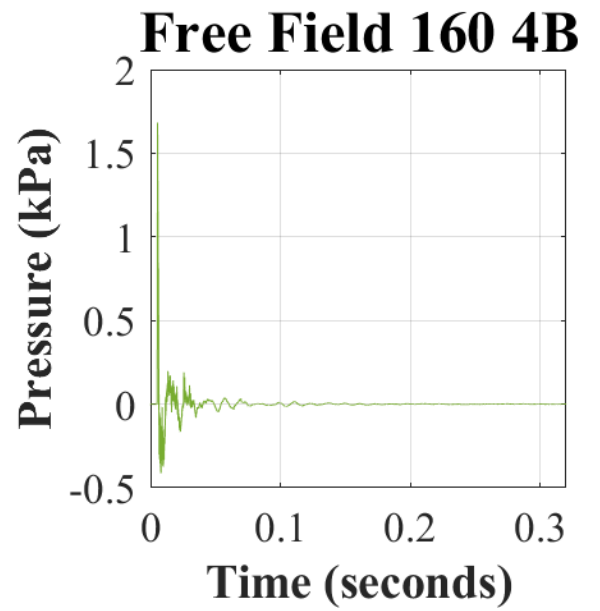
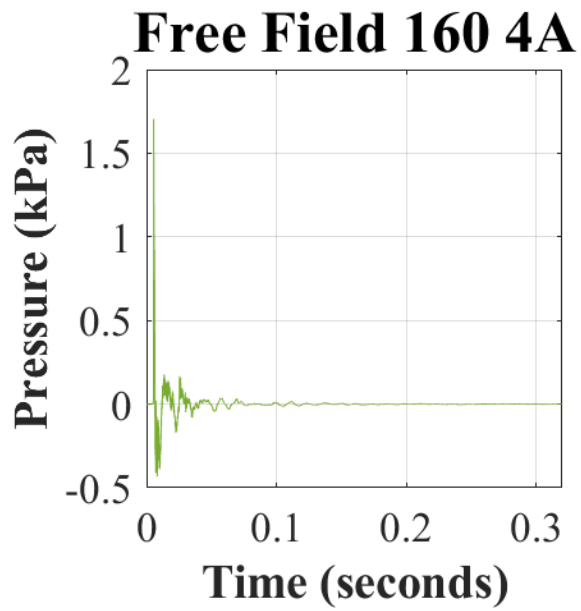
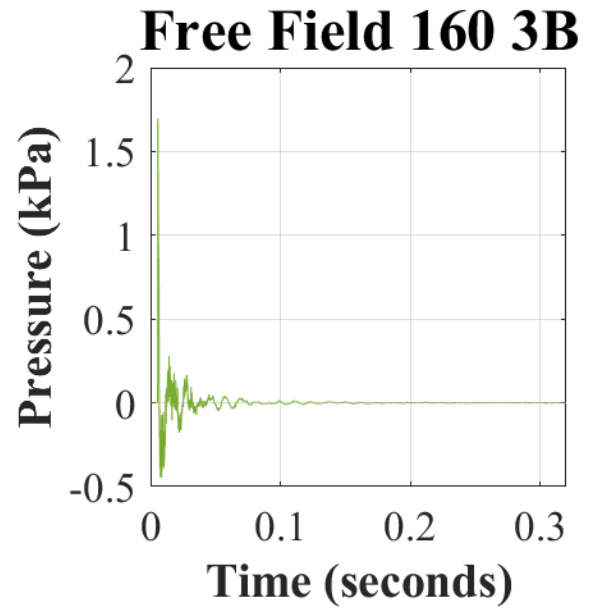
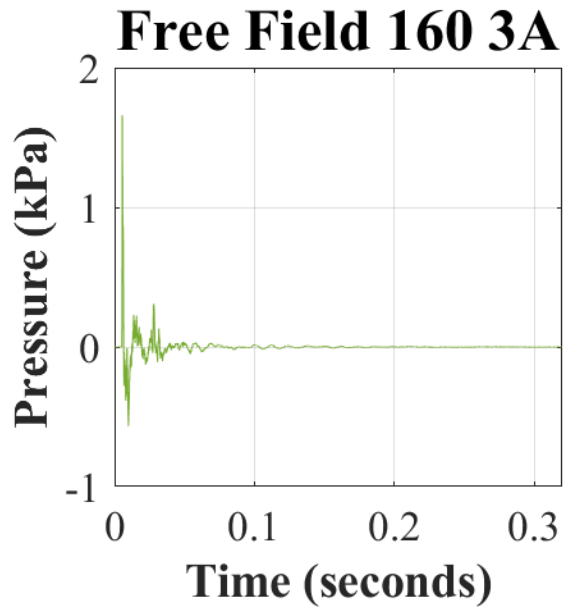


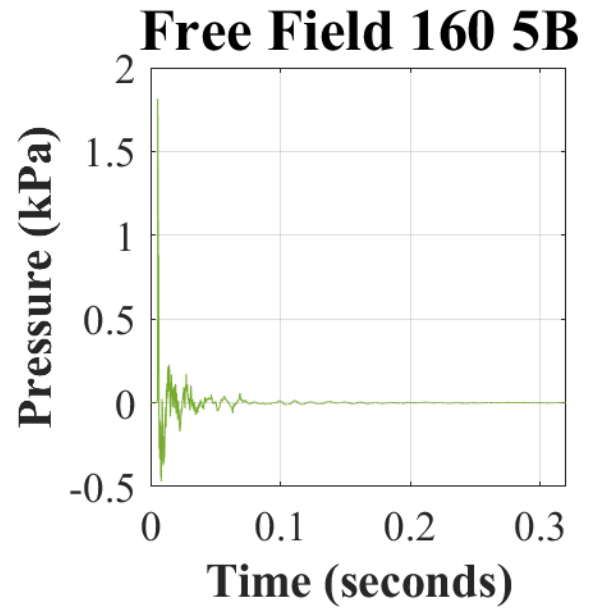
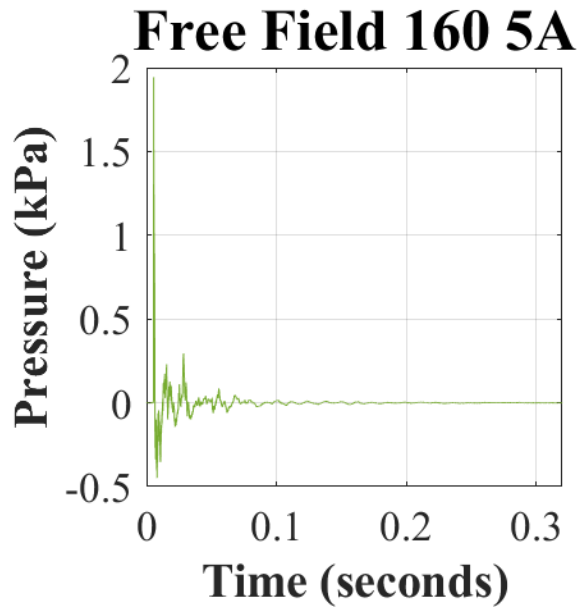


Note. The naming convention for all free-field waveforms is “Free Field LvL Nn”, where ‘Free Field’ indicates that the recording was obtained using the PCB reference microphone, ‘LvL’ is the nominal test level (150 dBp), ‘N’ is the device sample number (1 to 5), and ‘n’ is the device trial (i.e., A or B).

**Appendix H.** Recorded waveform (in kilopascals [kPa]) over time (in seconds [s]) of the impulse measured with the free-field probe at 160 dBp and the ComTac™ V (OFF) donned.

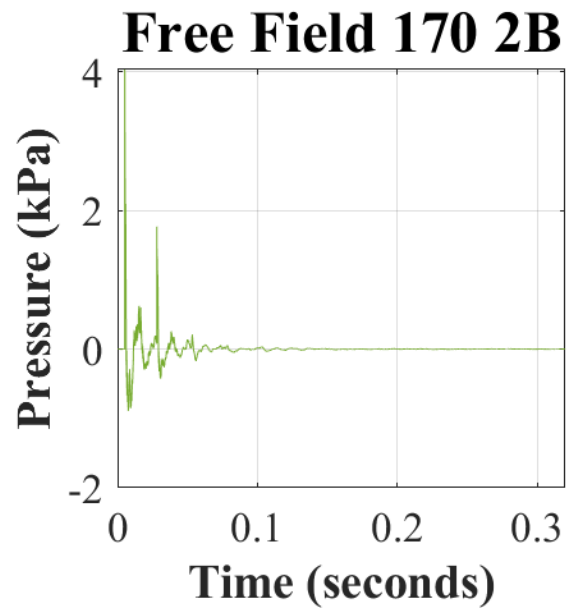
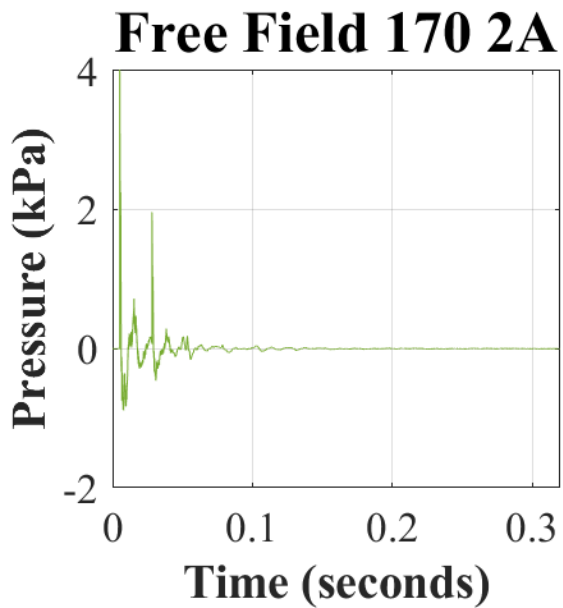
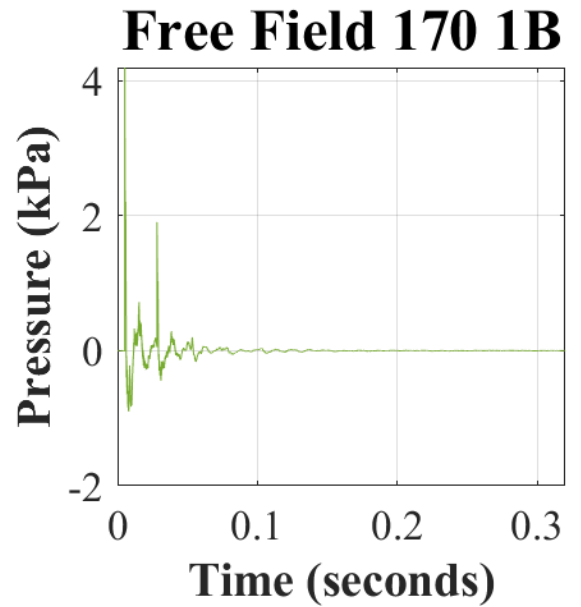
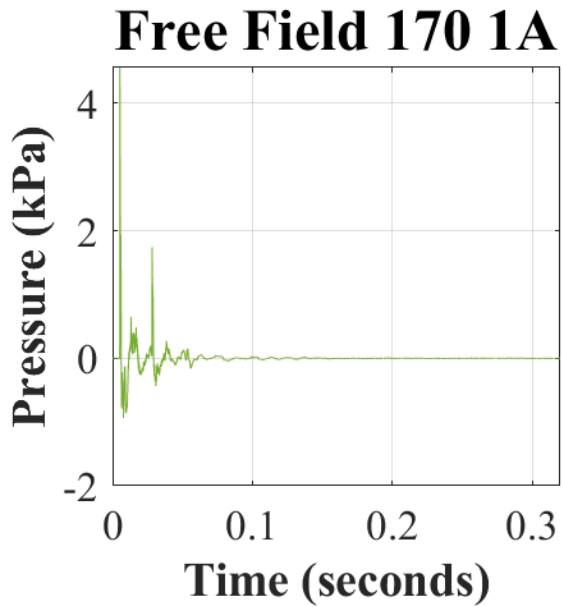




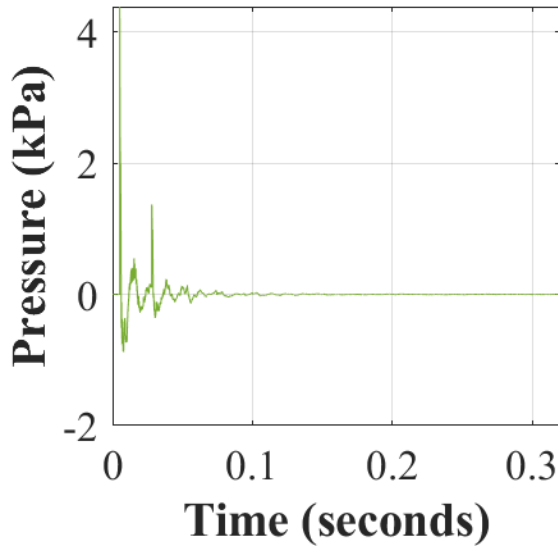


Note. The naming convention for all free-field waveforms is “Free Field LvL Nn”, where ‘Free Field’ indicates that the recording was obtained using the PCB reference microphone, ‘LvL’ is the nominal test level (160 dB), ‘N’ is the device sample number (1 to 5), and ‘n’ is the device trial (i.e., A or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

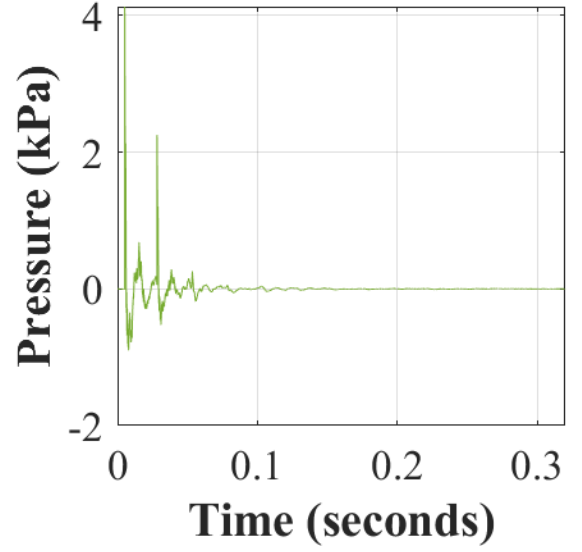
**Appendix I.** Recorded waveform (in kilopascals [kPa]) over time (in seconds [s]) of the impulse measured with the free-field probe at 170 dBp and the ComTac™ V (OFF) donned.



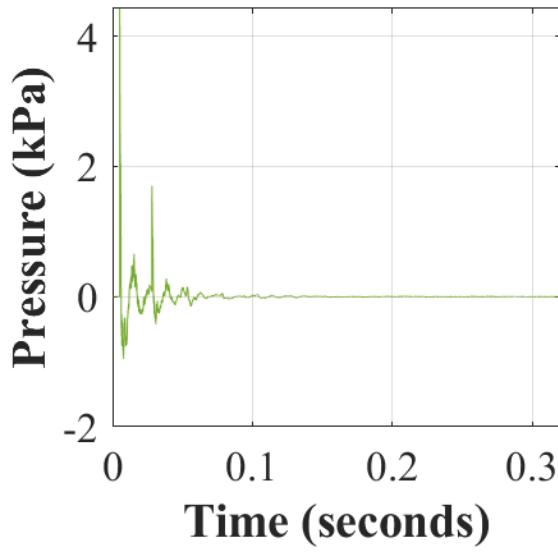
**Free Field 170 3A**



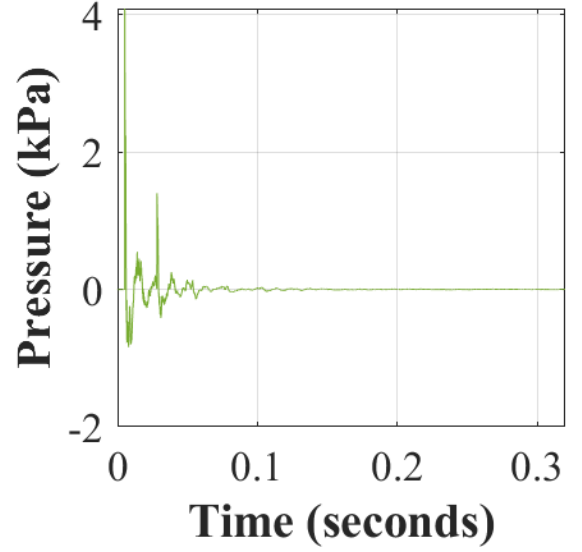
**Free Field 170 3B**

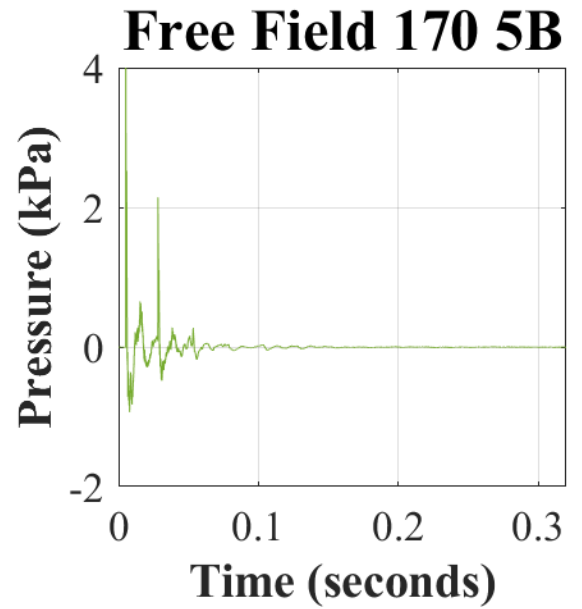
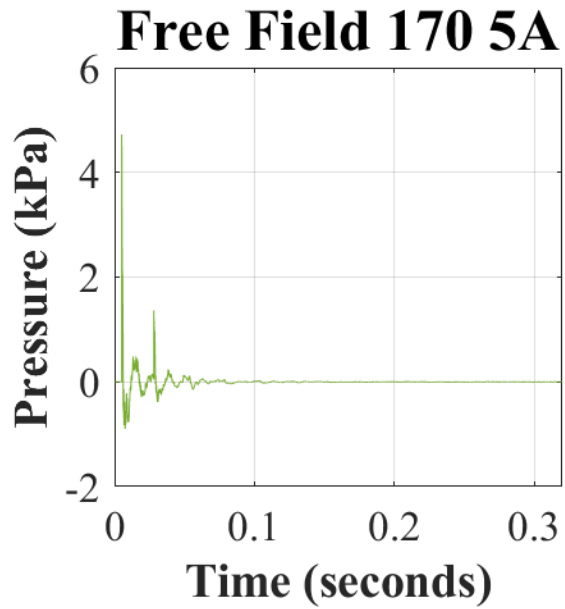


**Free Field 170 4A**



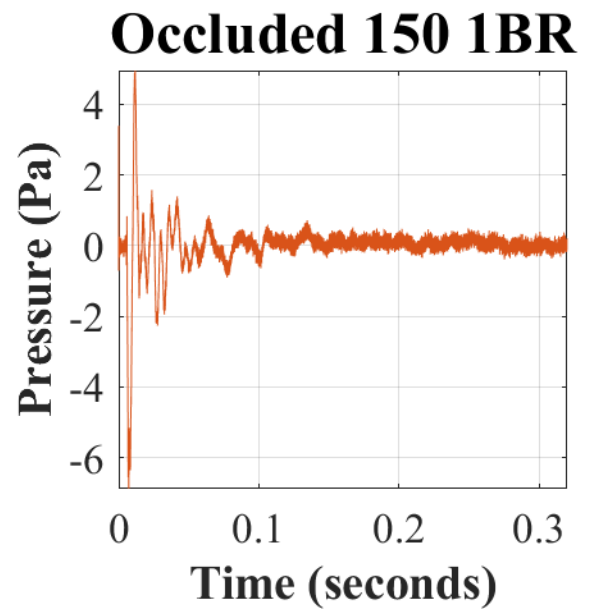
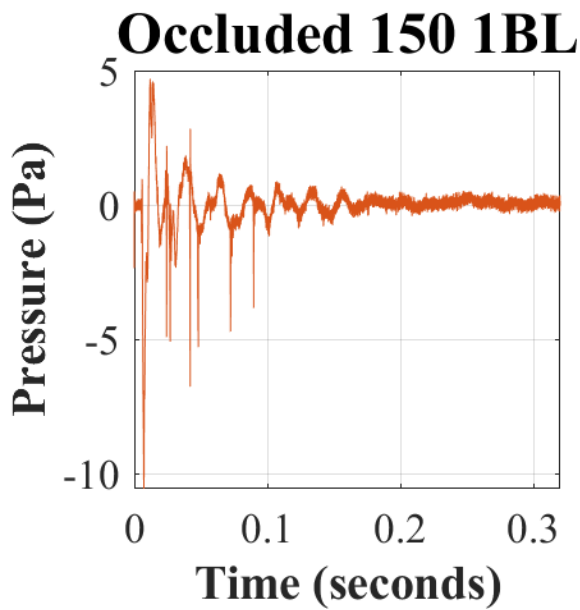
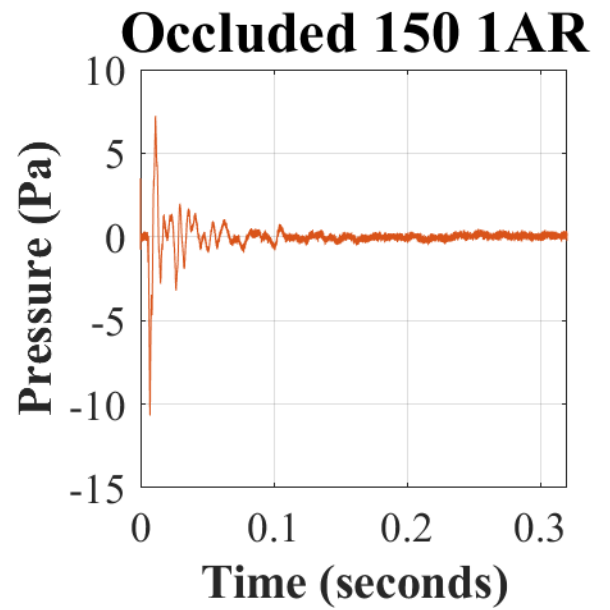
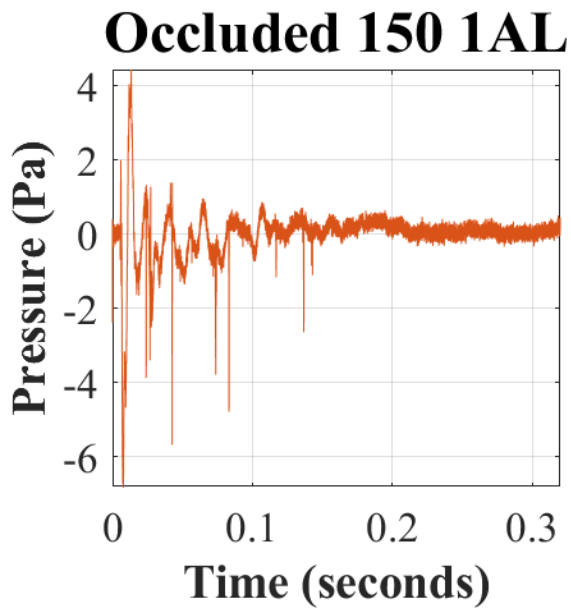
**Free Field 170 4B**



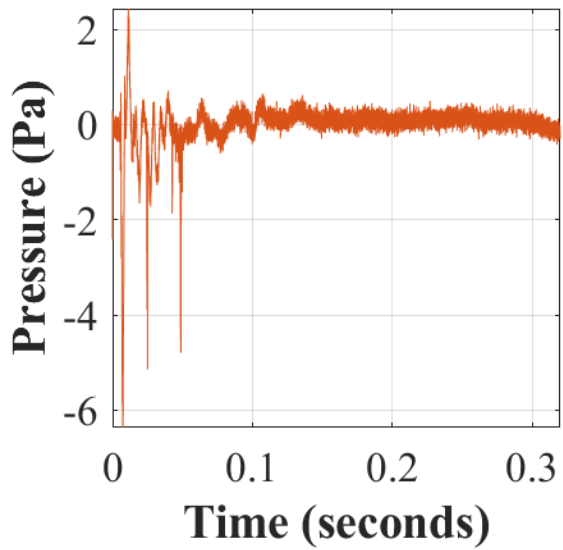


Note. The naming convention for all free-field waveforms is “Free Field LvL Nn”, where ‘Free Field’ indicates that the recording was obtained using the PCB reference microphone, ‘LvL’ is the nominal test level (170 dBp), ‘N’ is the device sample number (1 to 5), and ‘n’ is the device trial (i.e., A or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

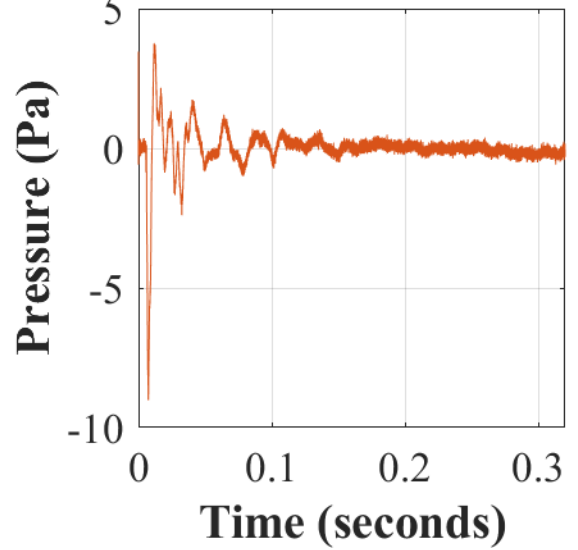
**Appendix J.** Recorded occluded (closed-ear) waveforms (in pascals [Pa]) over time (in seconds [s]) in response to 150 dBp with the ComTac™ V (MAX).



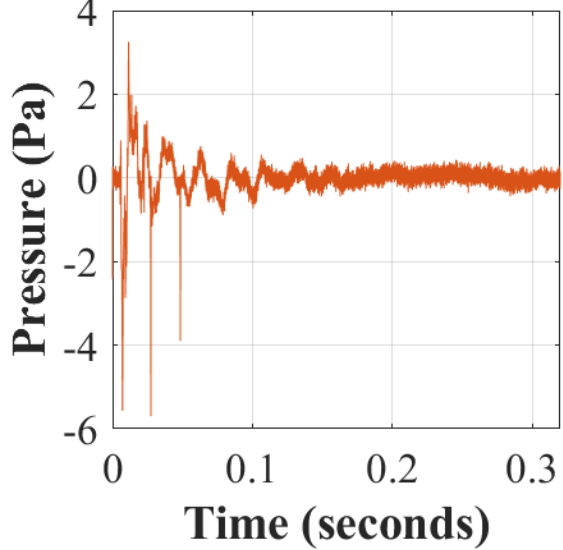
**Occluded 150 2AL**



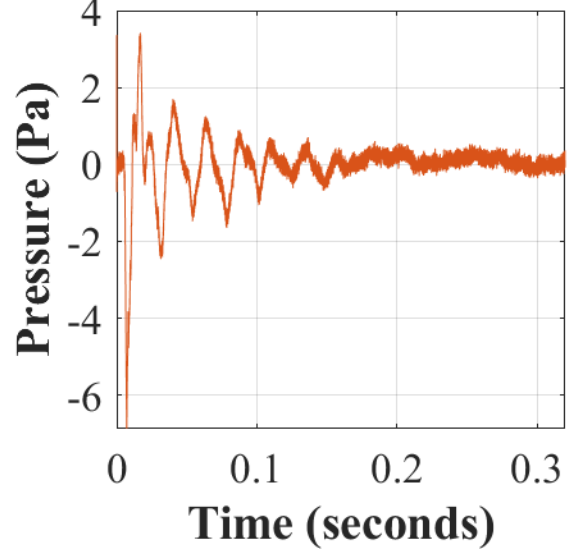
**Occluded 150 2AR**

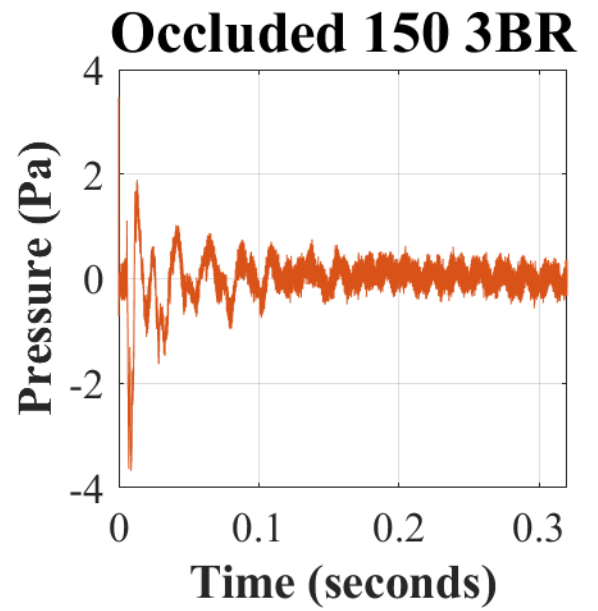
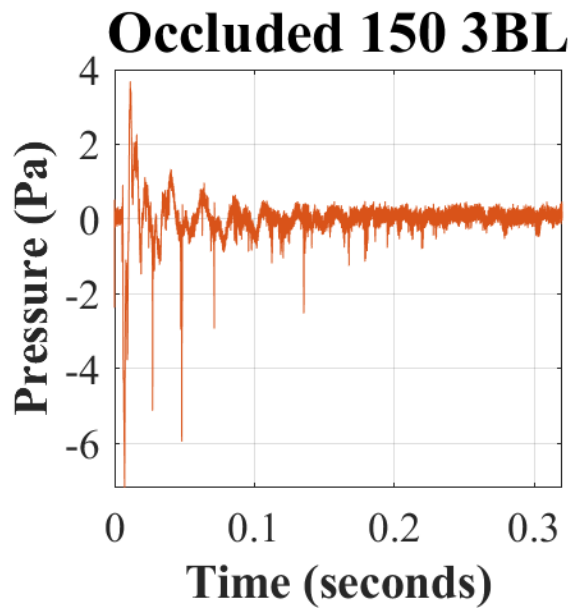
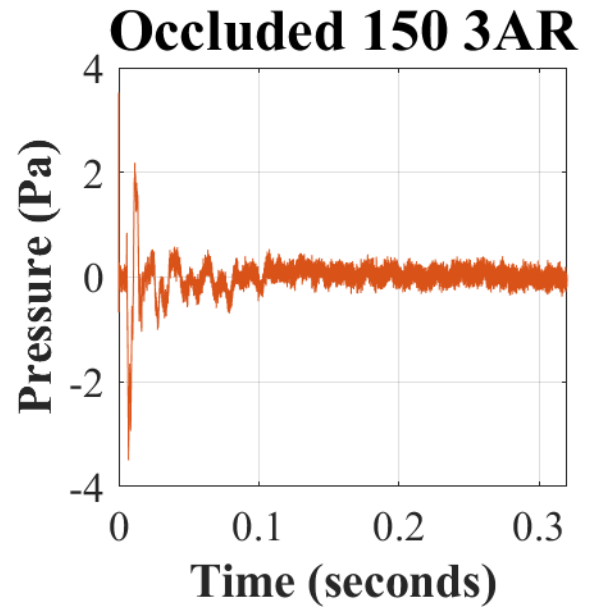
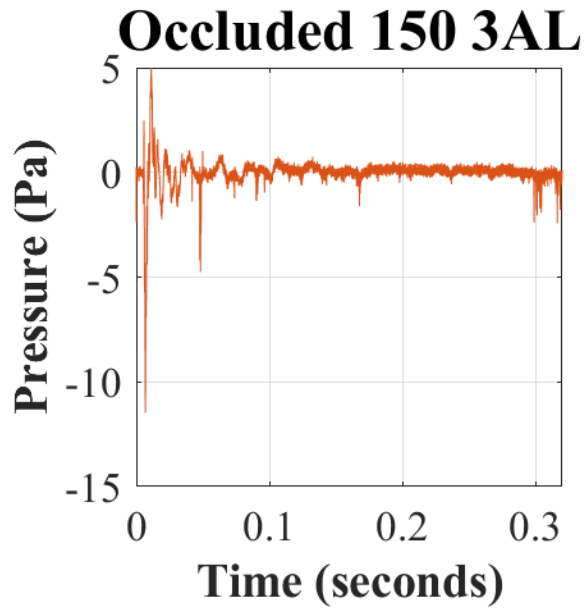


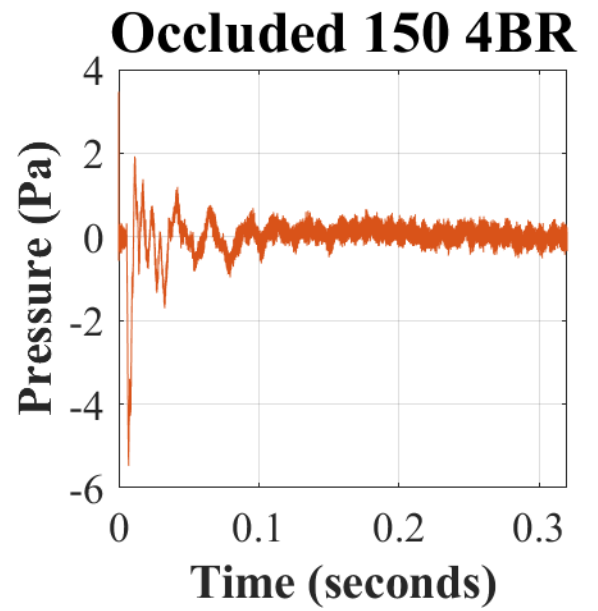
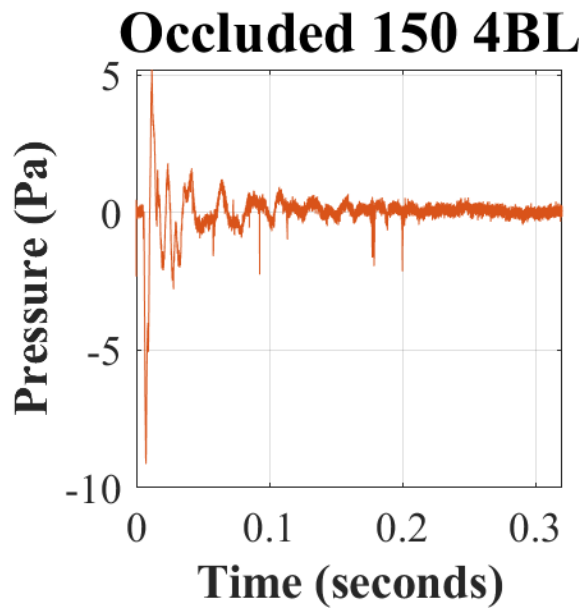
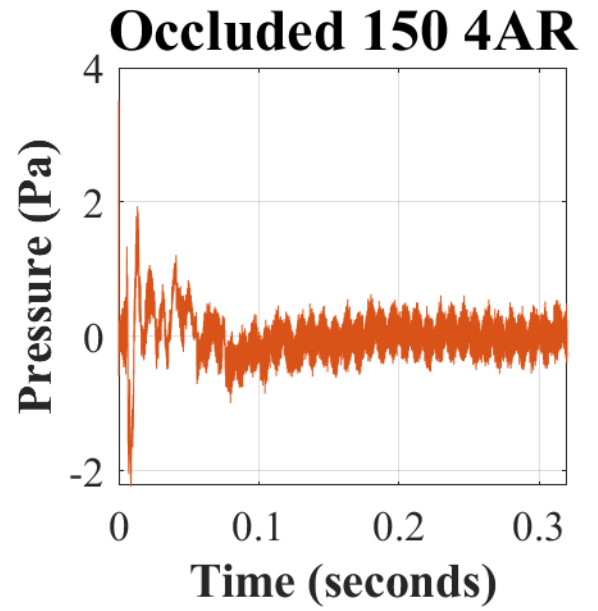
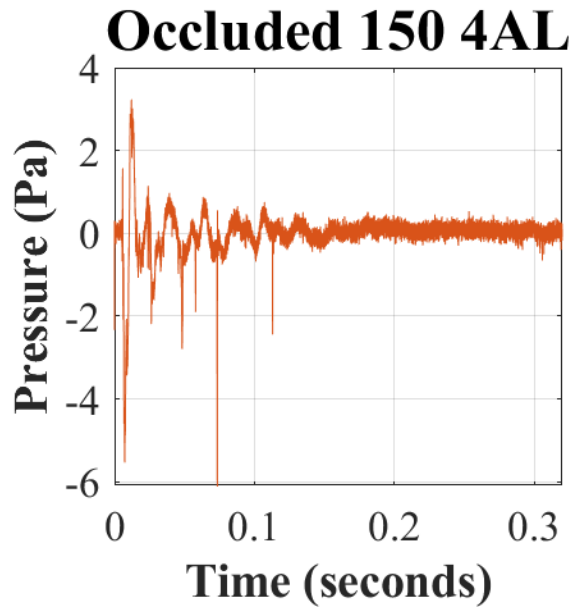
**Occluded 150 2BL**

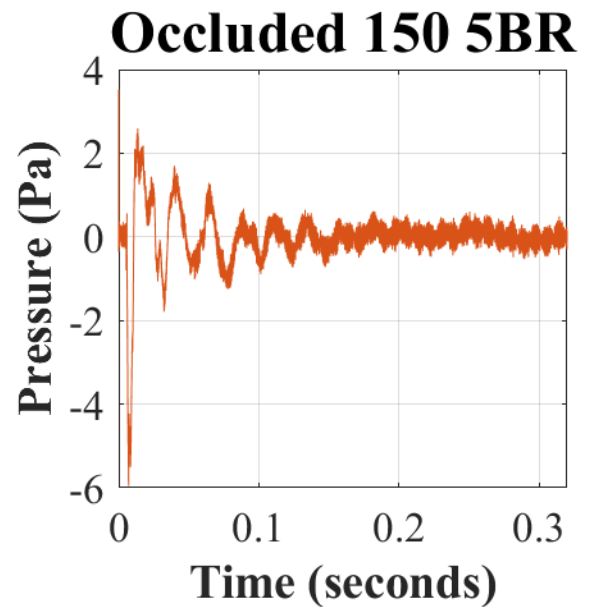
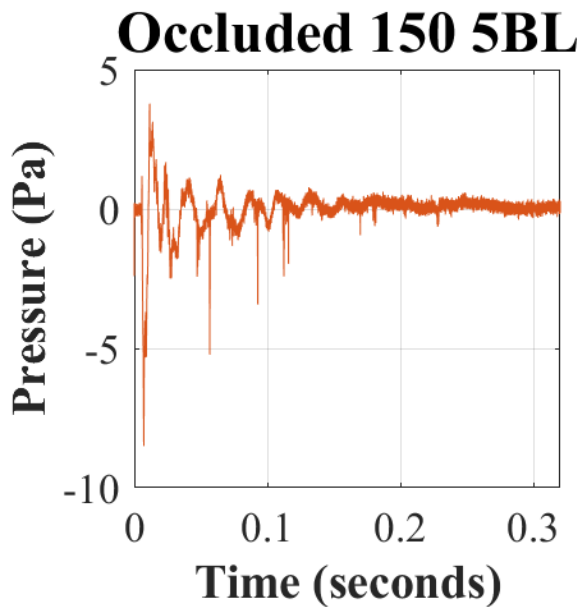
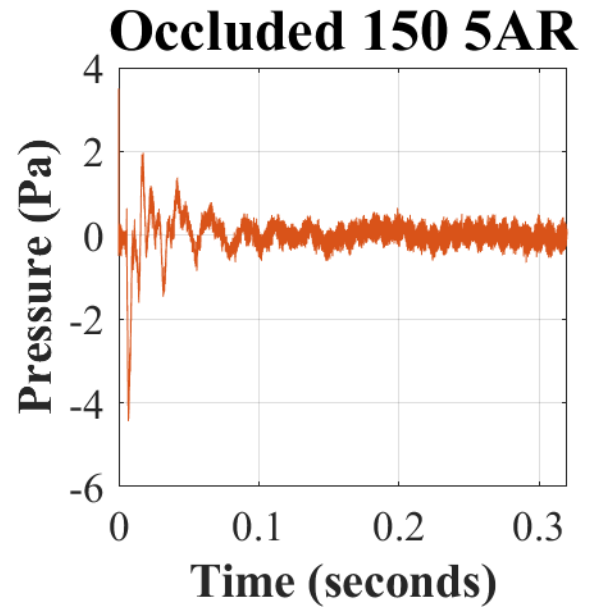
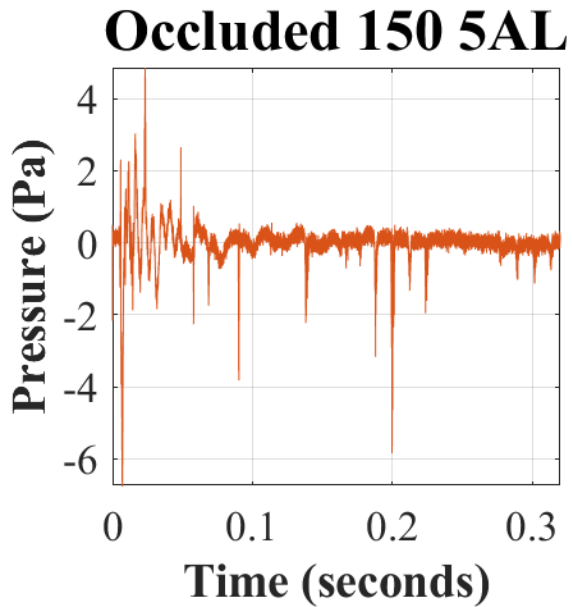


**Occluded 150 2BR**



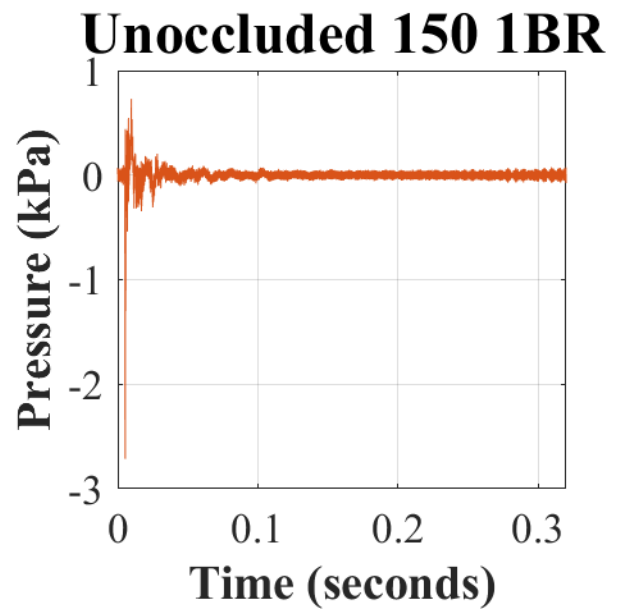
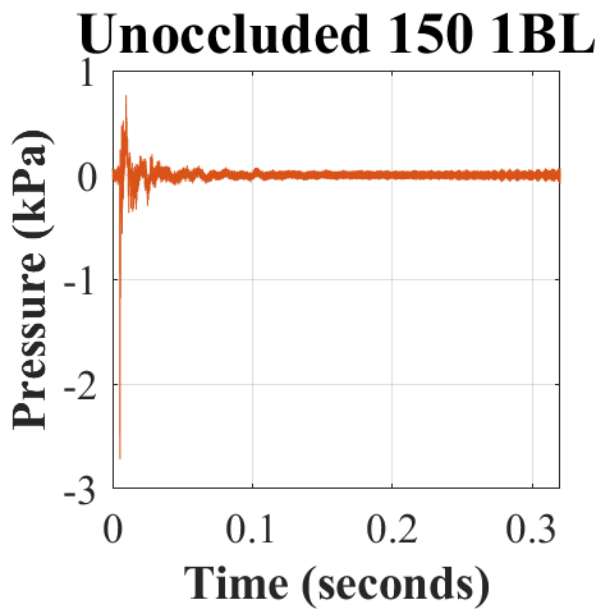
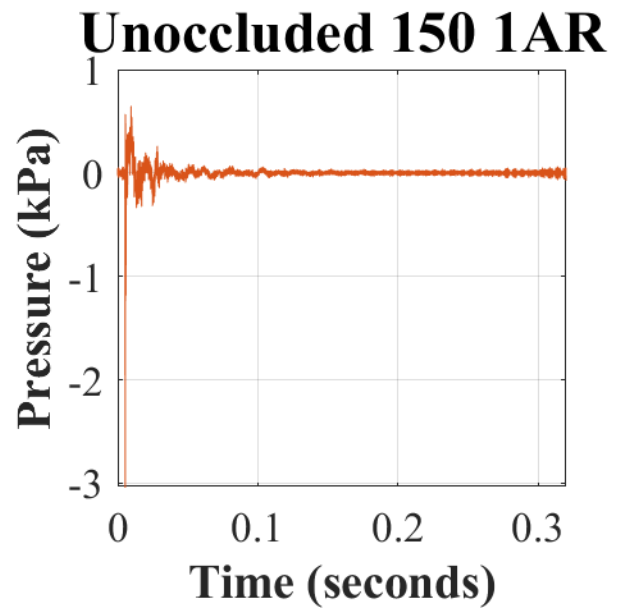
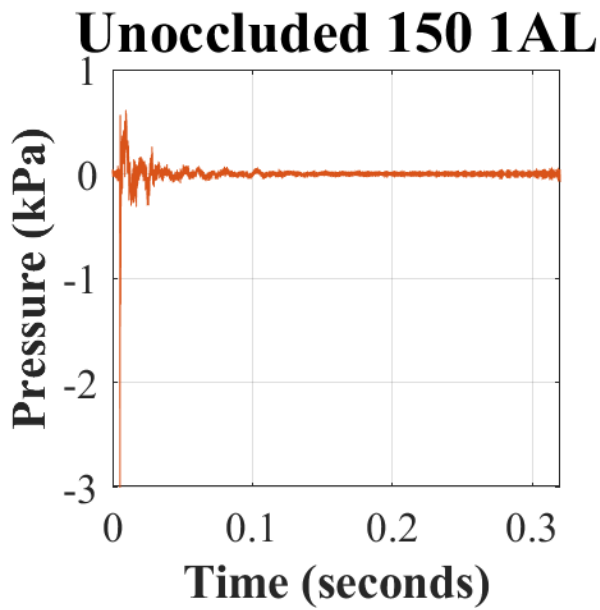


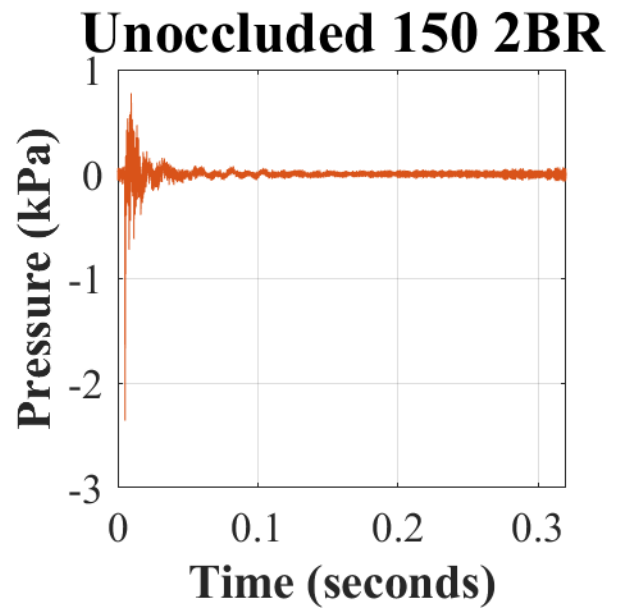
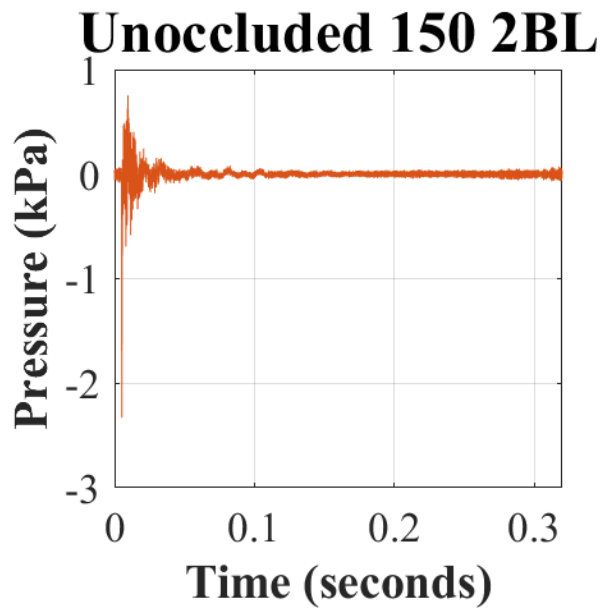
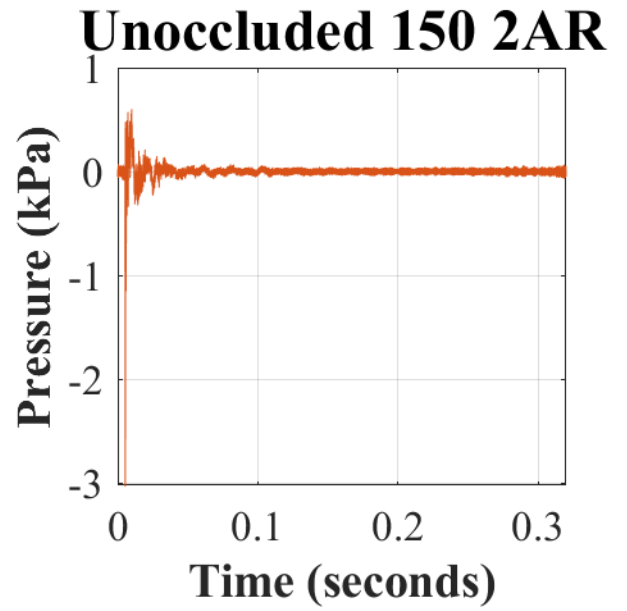
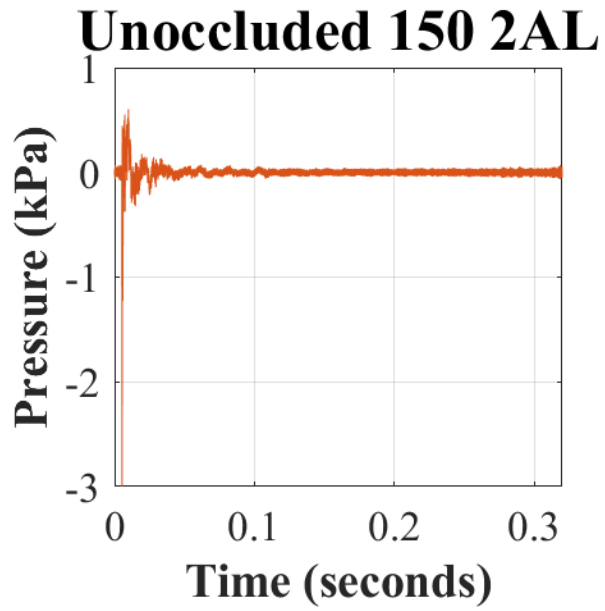


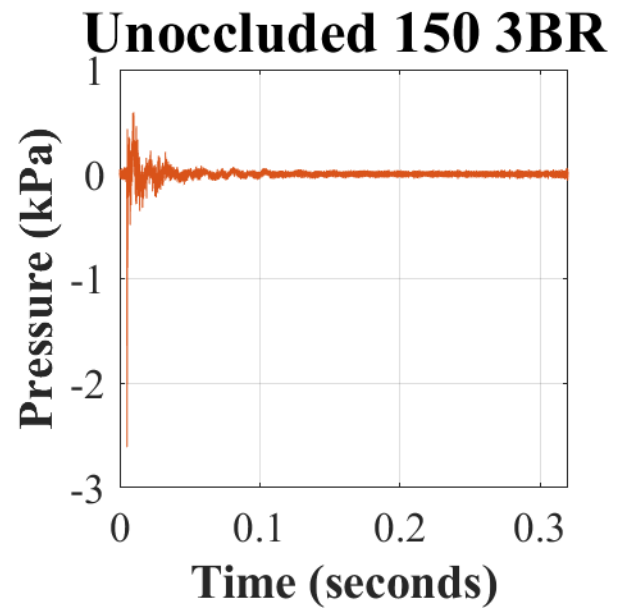
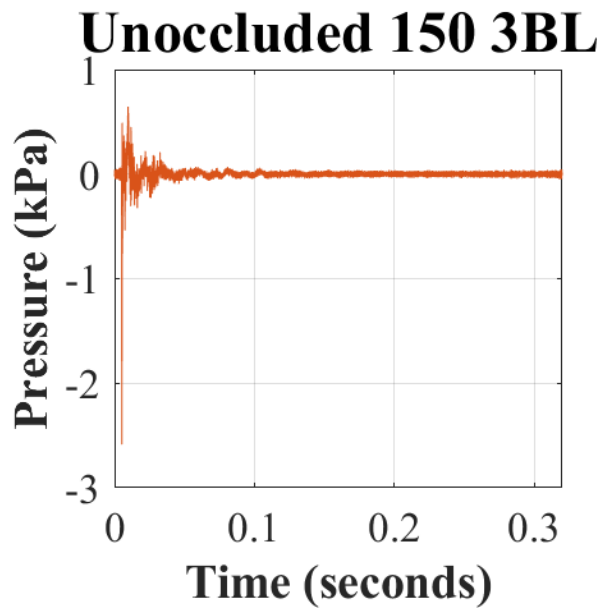
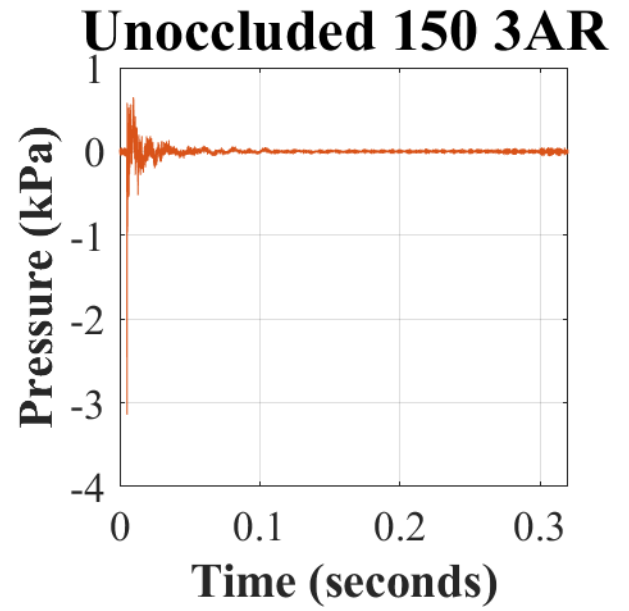
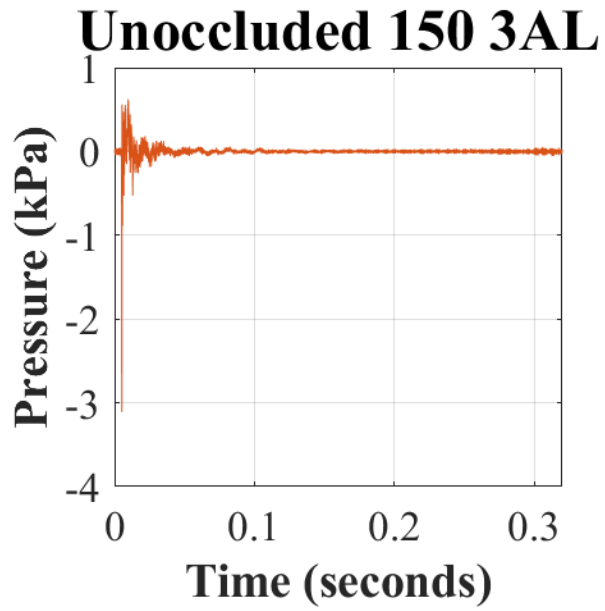


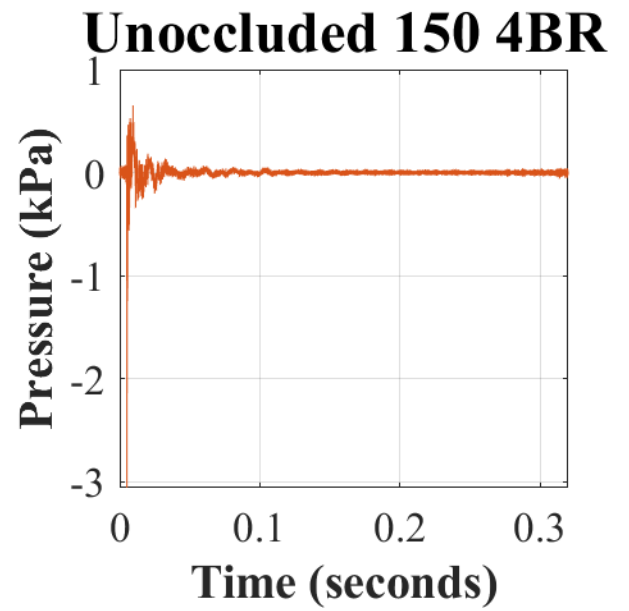
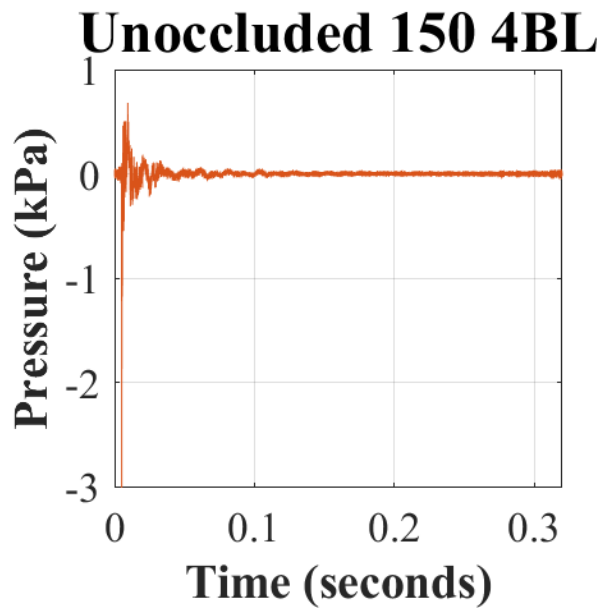
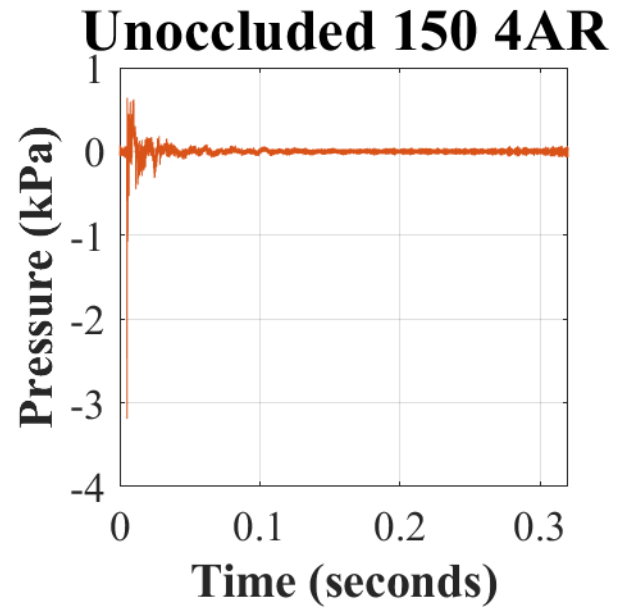
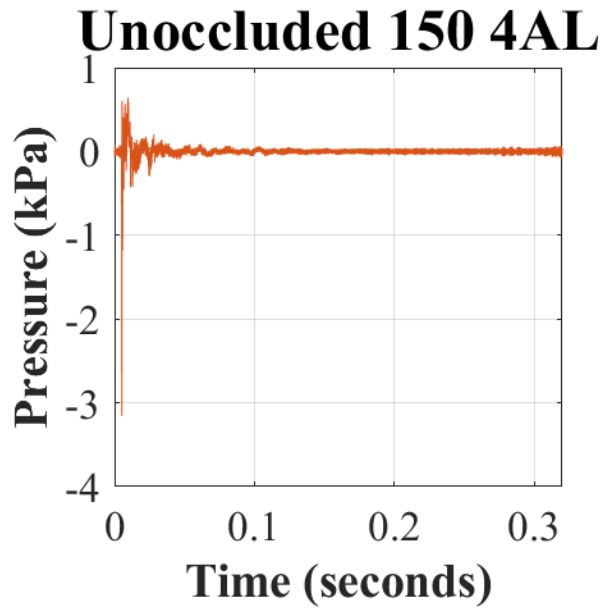
Note. The naming convention for all occluded waveforms is “Occluded LvL NnX”, where ‘Occluded’ is the test condition (i.e., ATF has the HPD donned), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or 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).

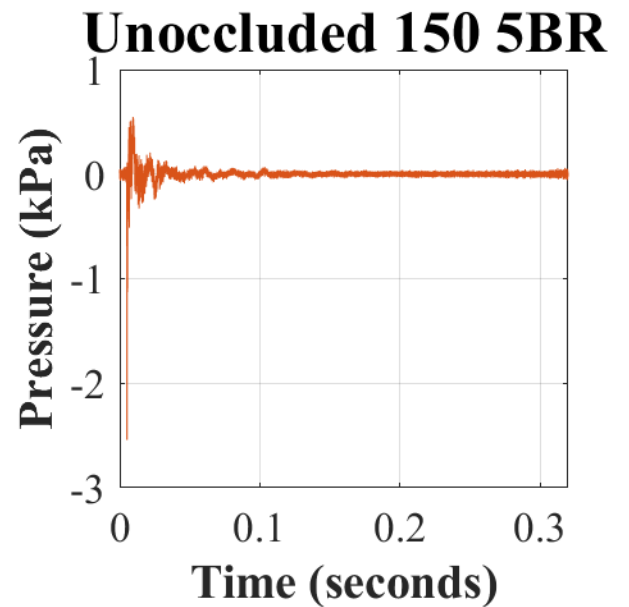
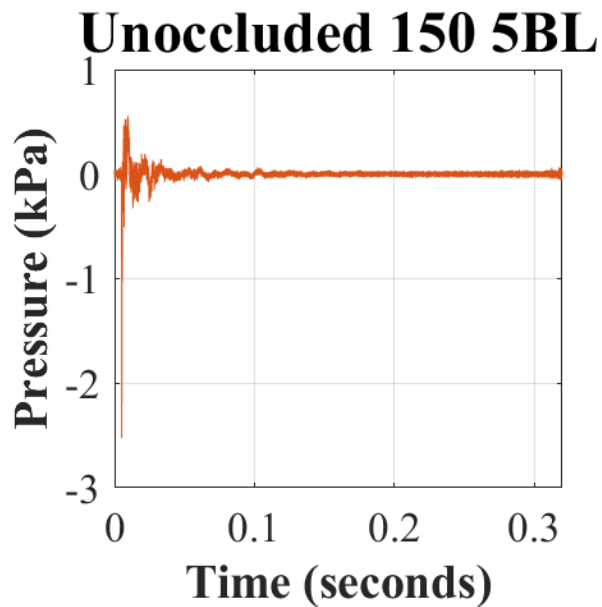
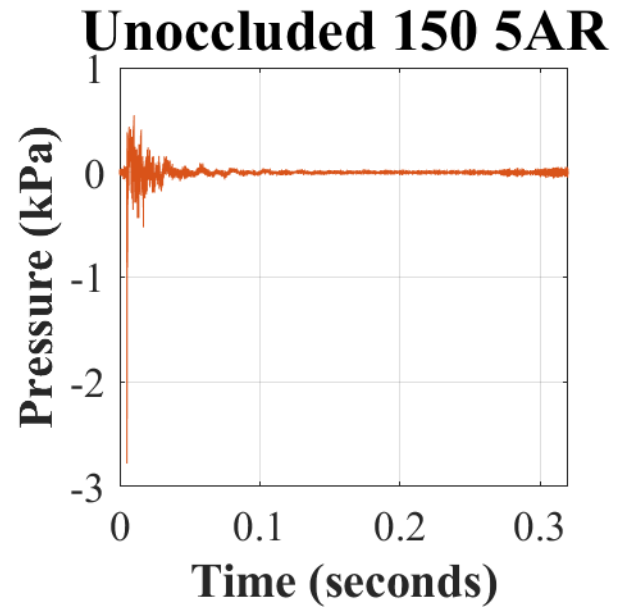
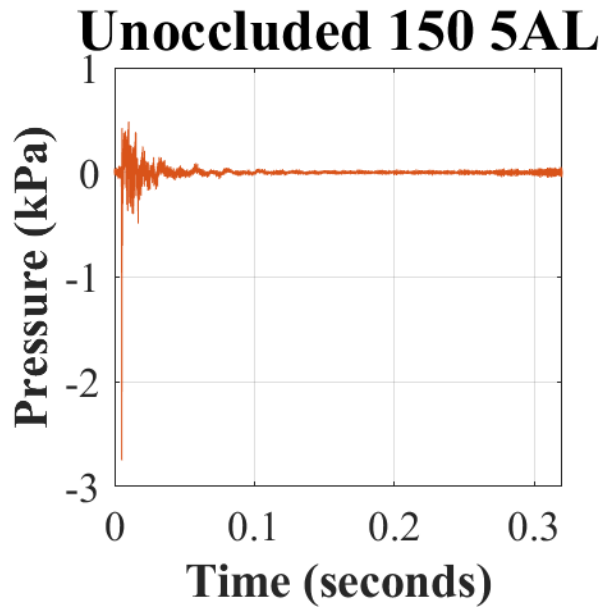
**Appendix K.** Estimated unoccluded (open-ear) waveforms (in kilopascals [kPa]) over time (in seconds [s]) in response to 150 dBp with the ComTac™ V (MAX).





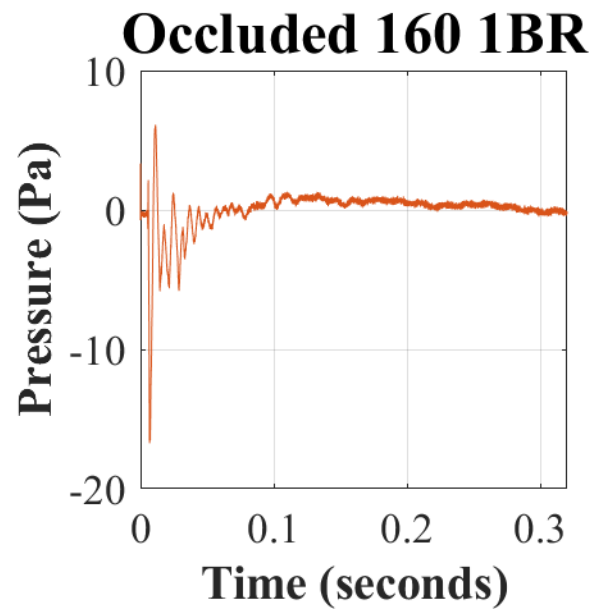
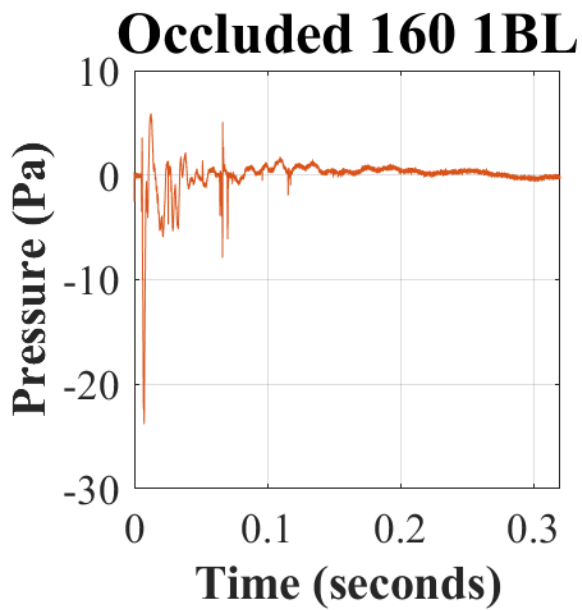
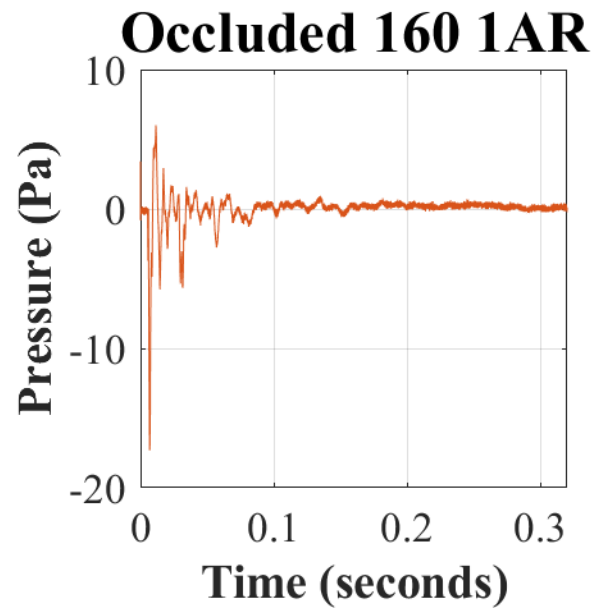
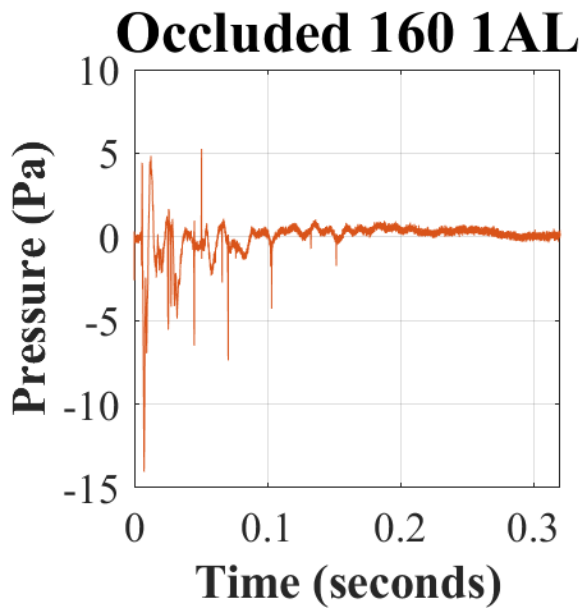


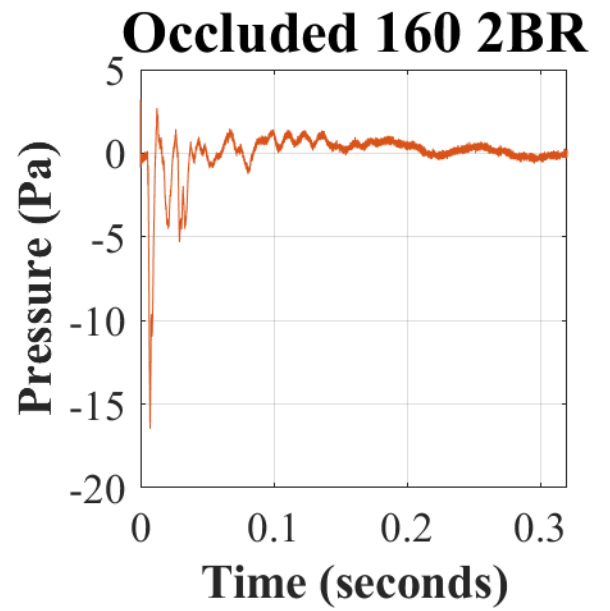
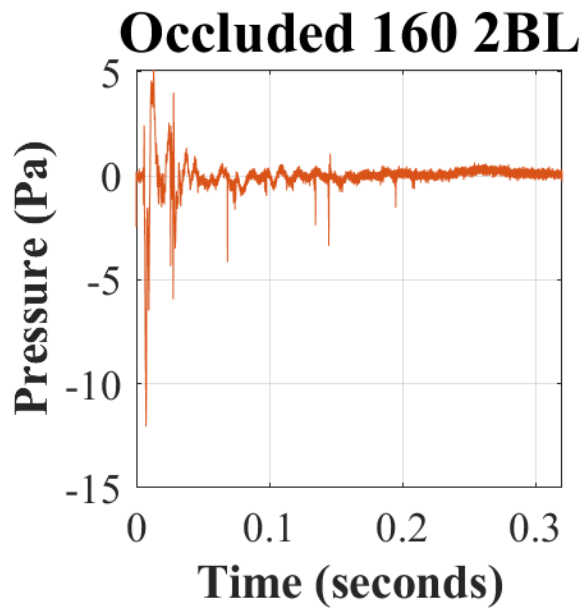
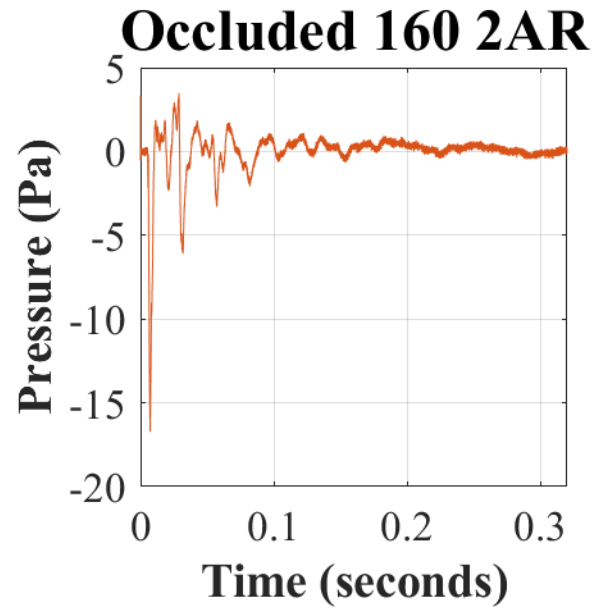
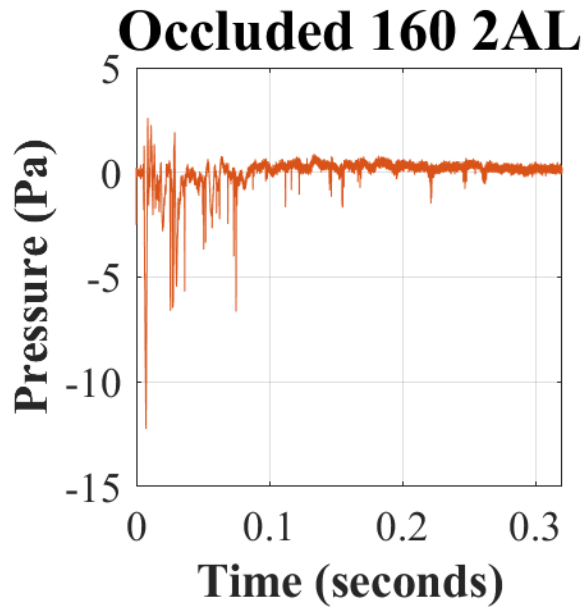


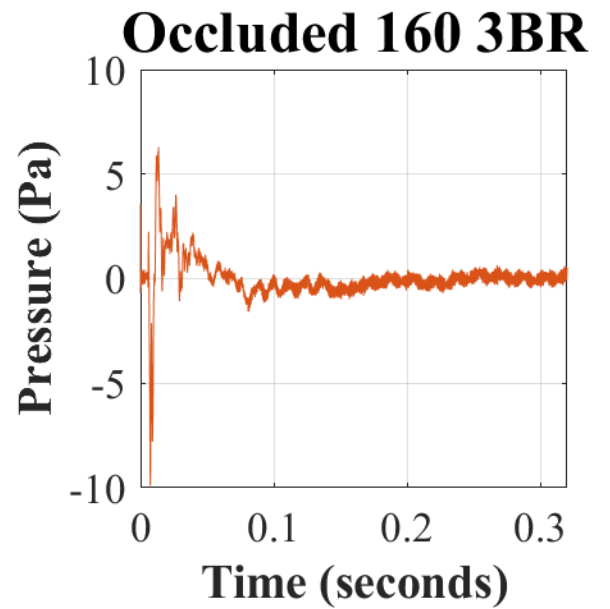
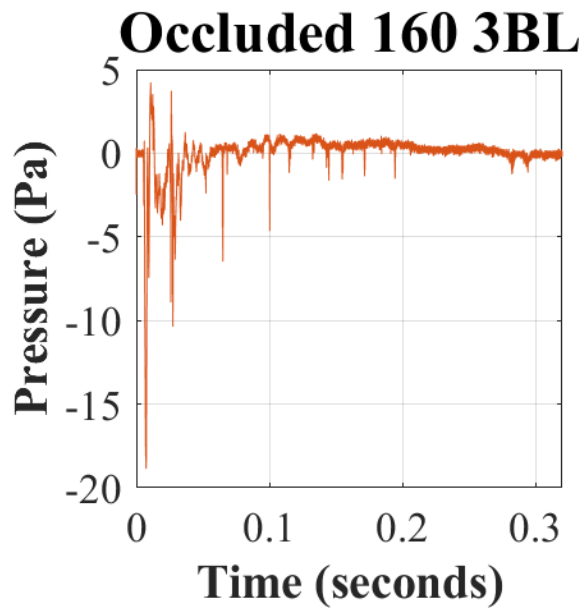
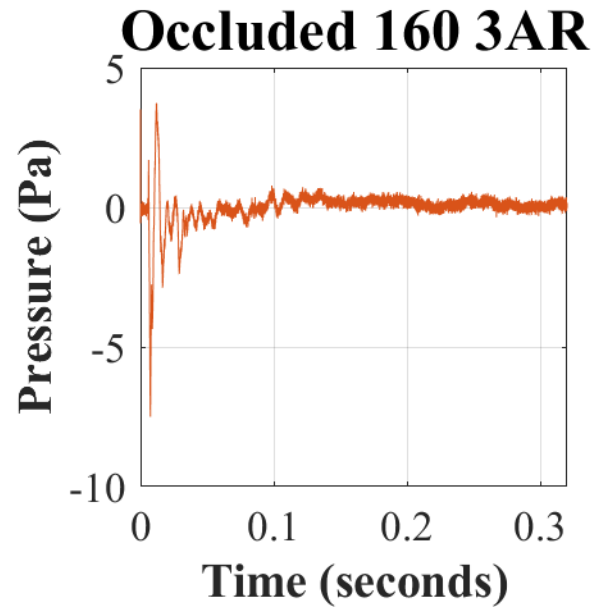
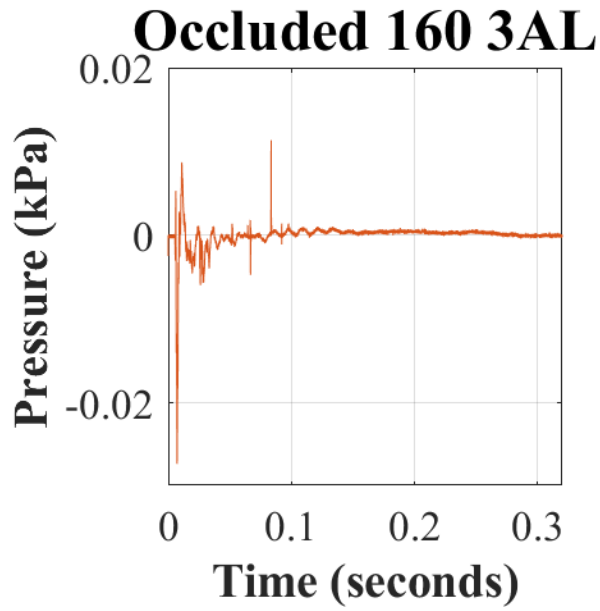


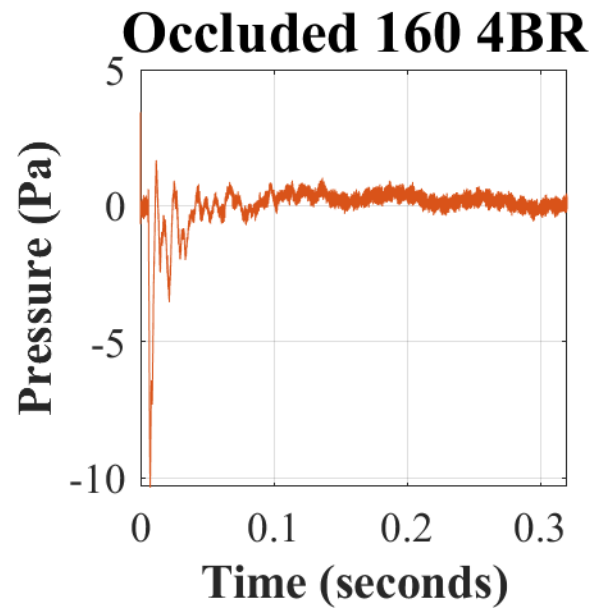
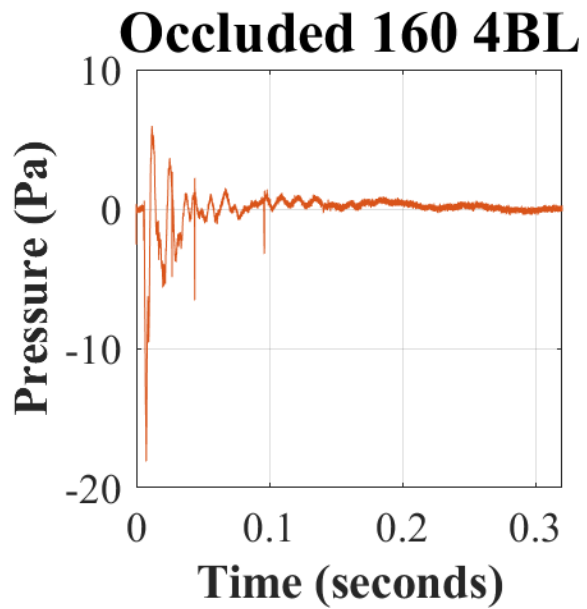
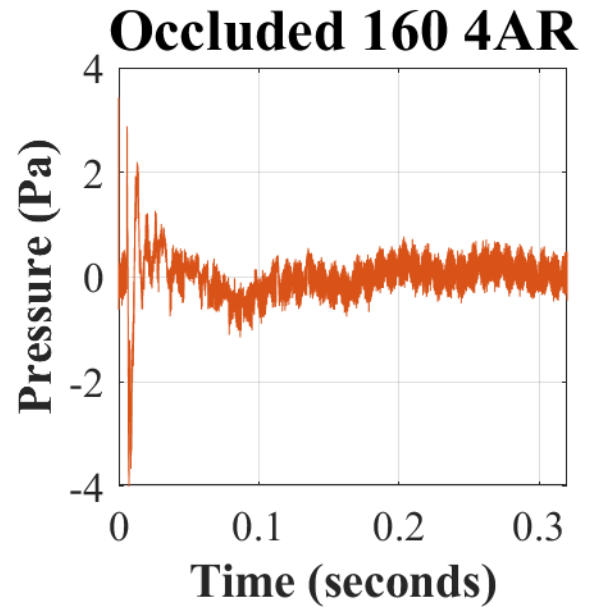
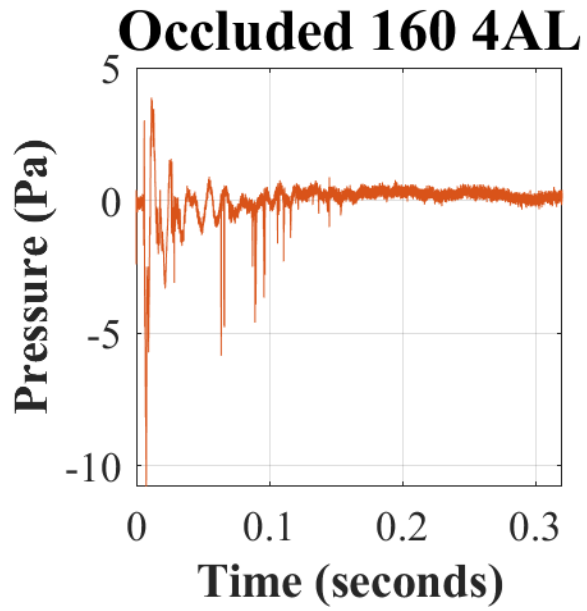
Note. The naming convention for all unoccluded waveforms is “Unoccluded LvL NnX”, where ‘Unoccluded’ is the test condition (i.e., ATF has the HPD doffed), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., 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).

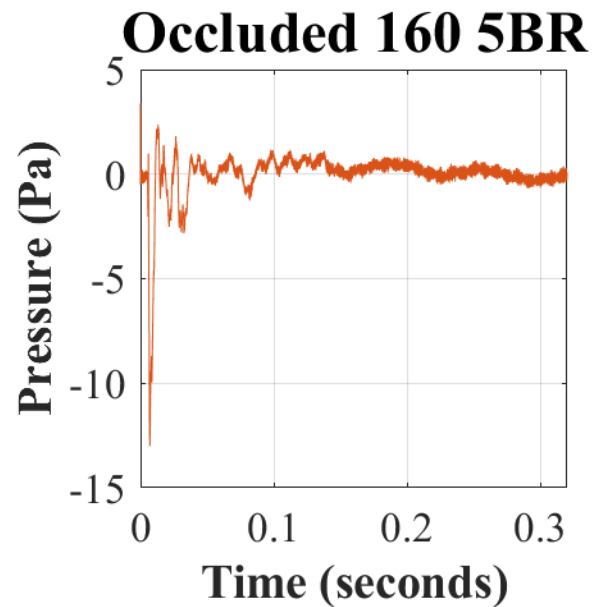
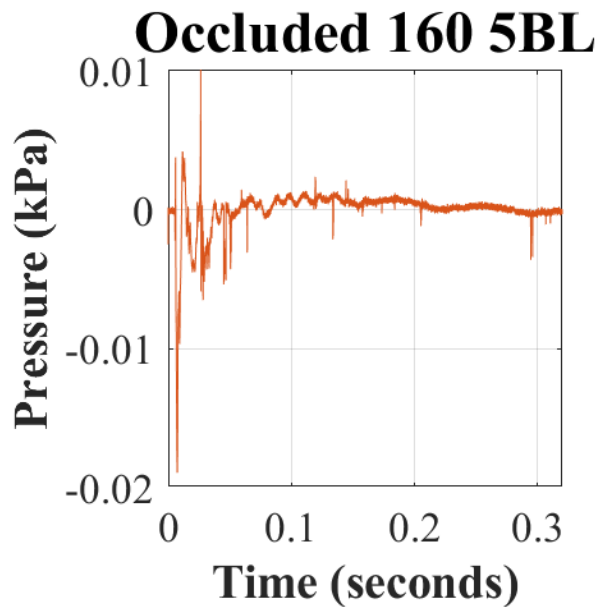
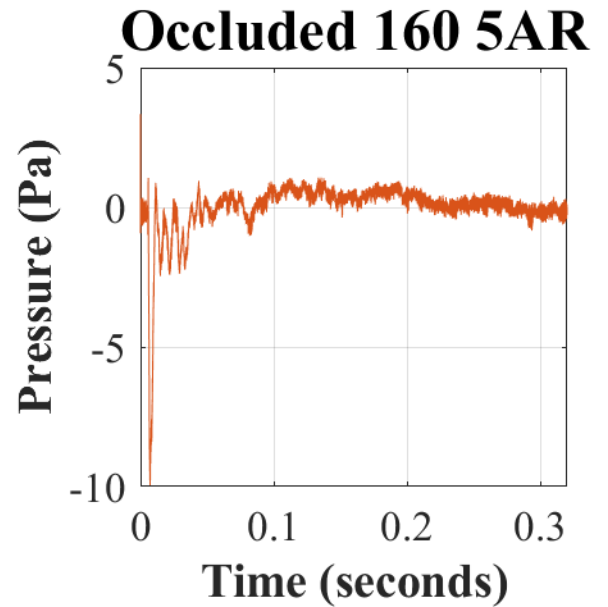
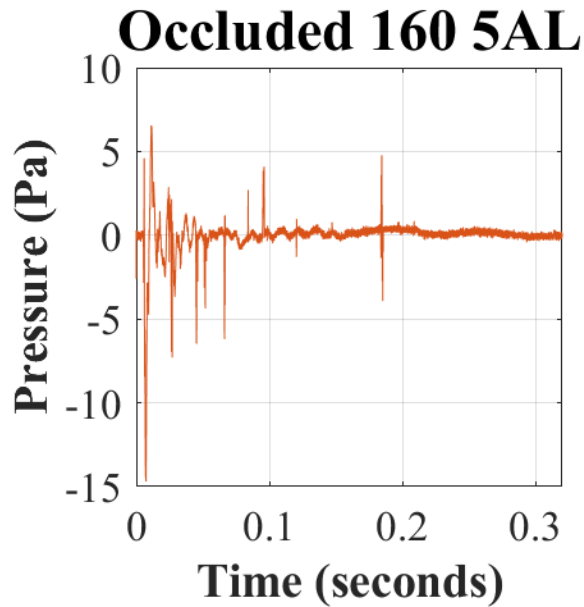
**Appendix L.** Recorded occluded (closed-ear) waveforms (in pascals [Pa] or kilopascals [kPa]) over time (in seconds [s]) in response to 160 dBp with the ComTac™ V (MAX).





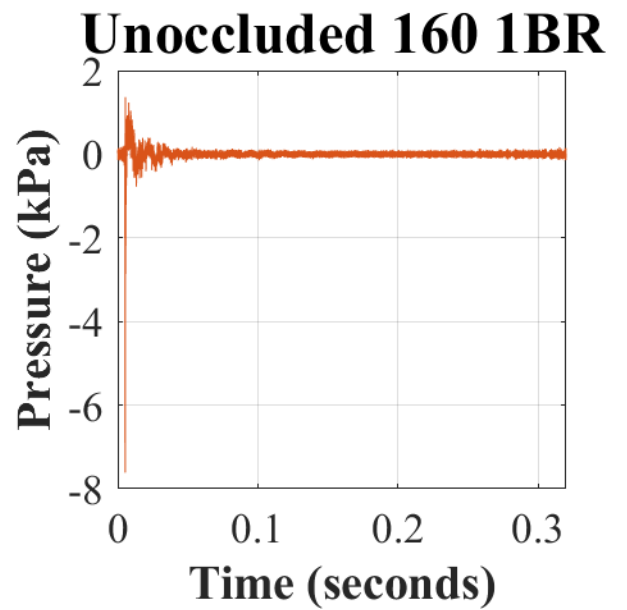
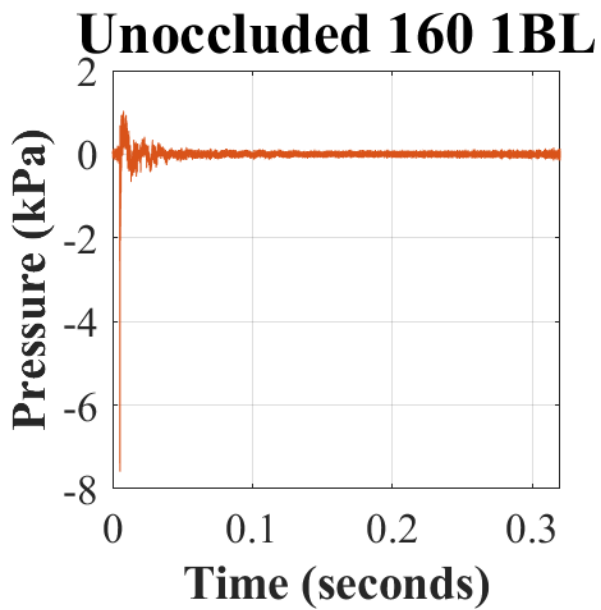
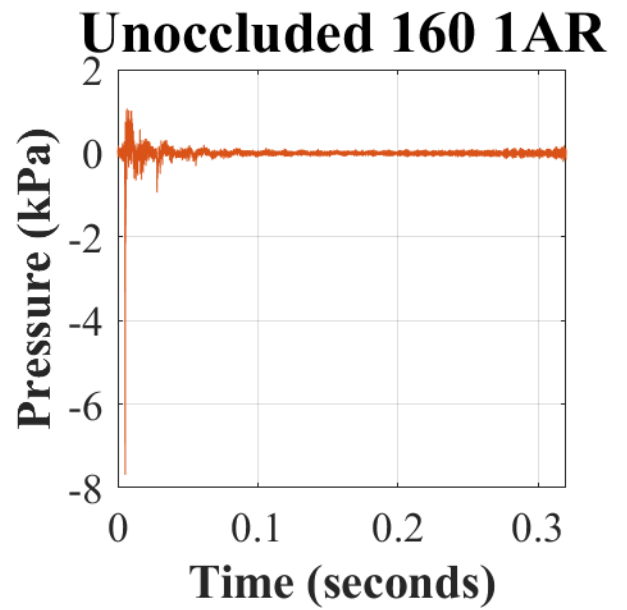
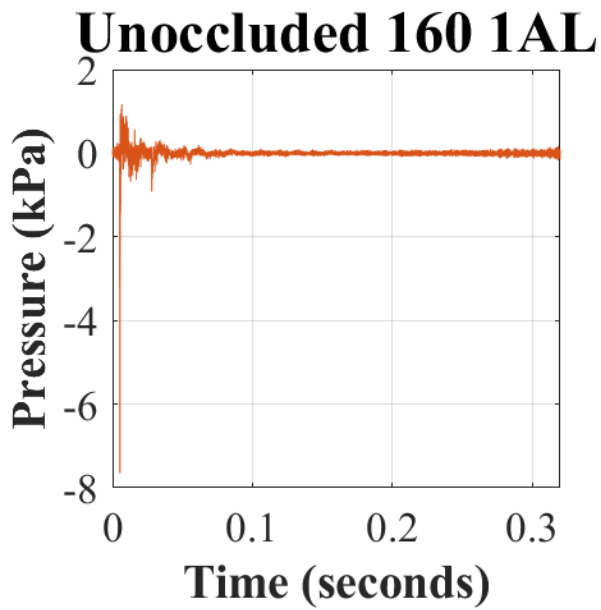


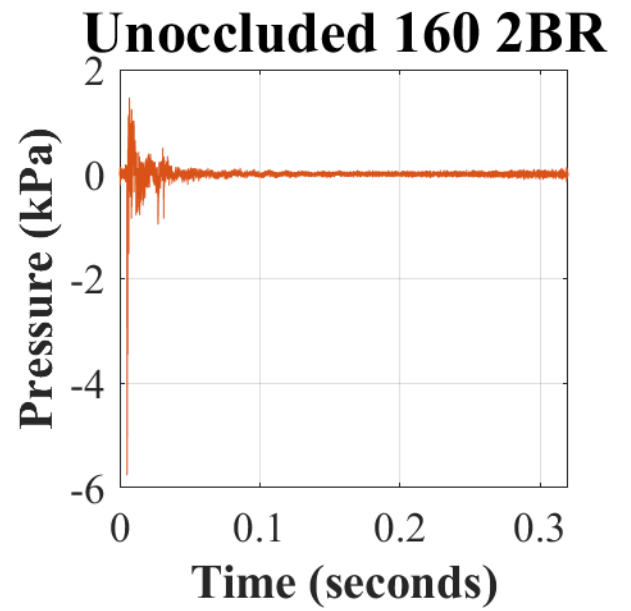
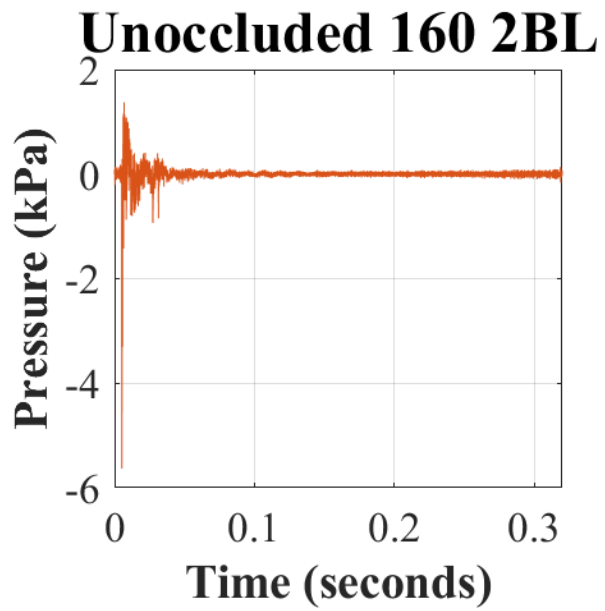
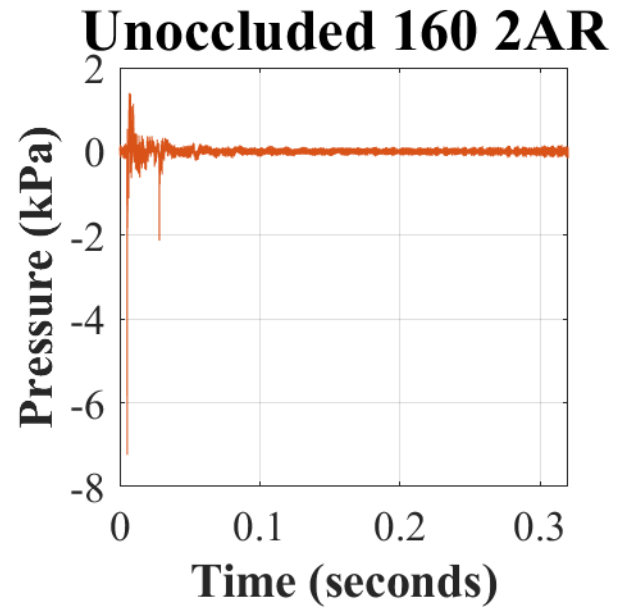
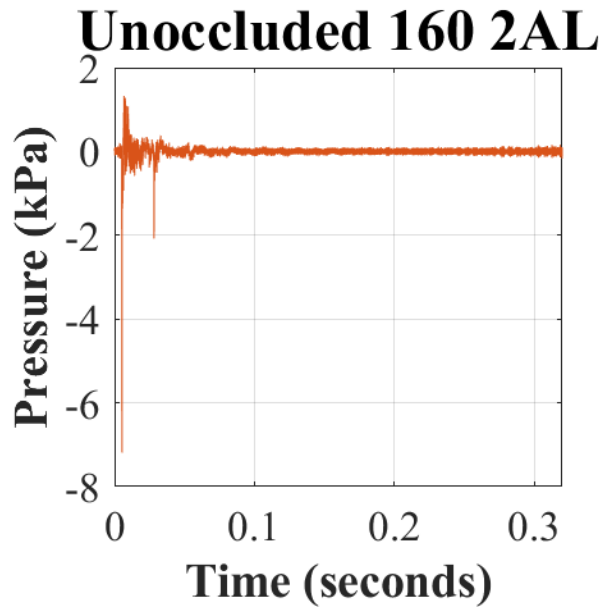


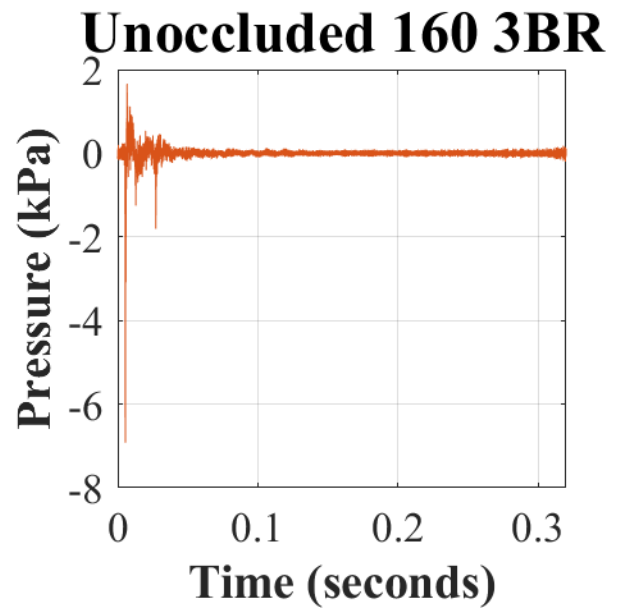
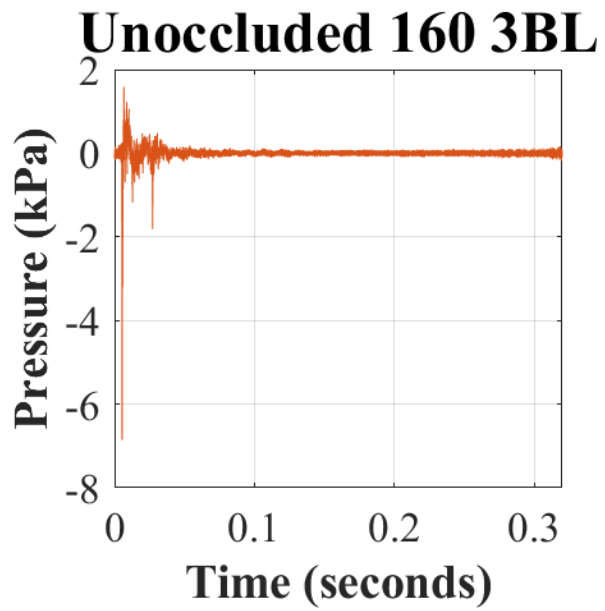
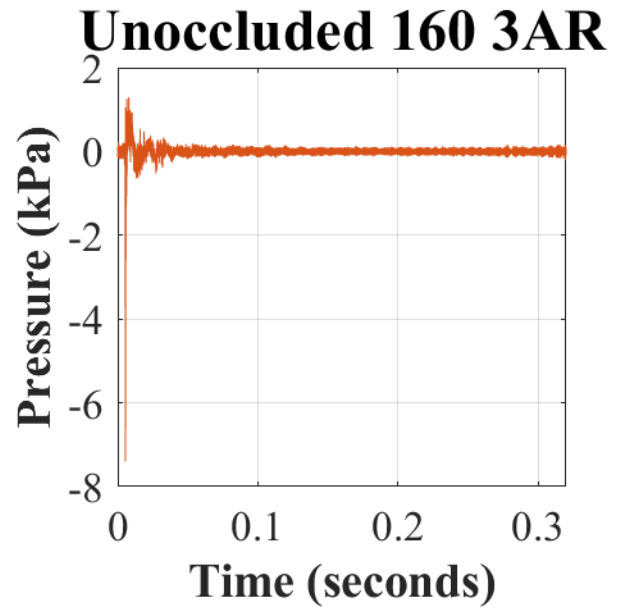
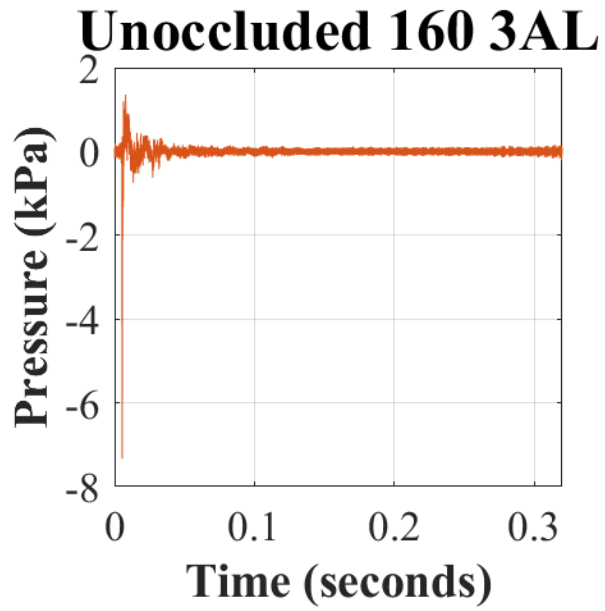


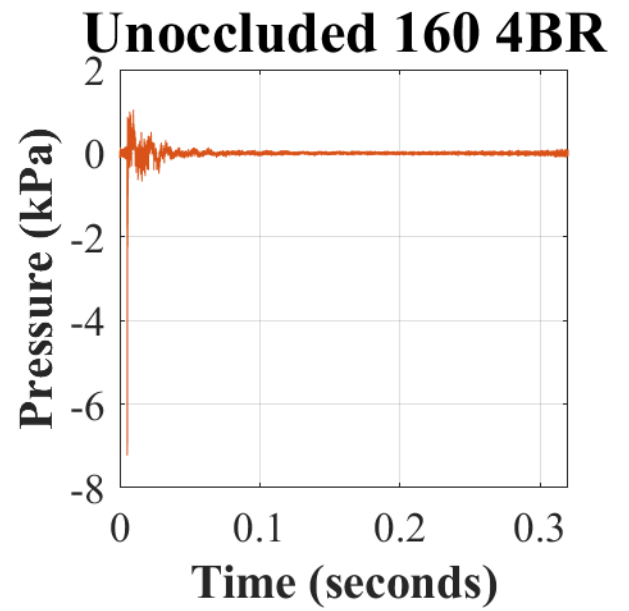
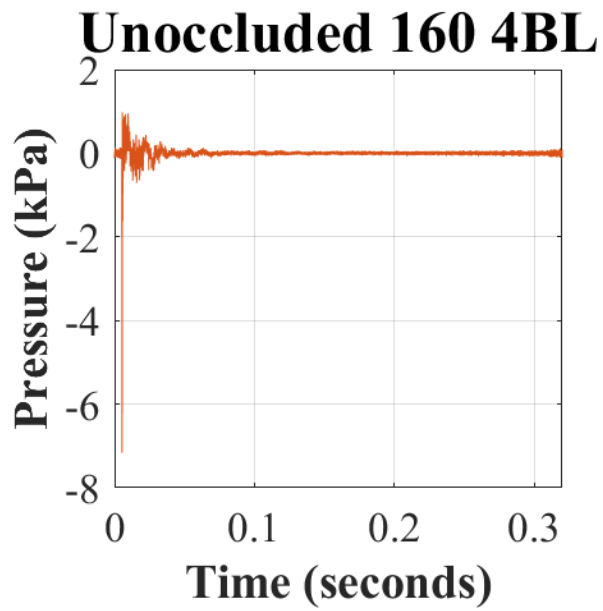
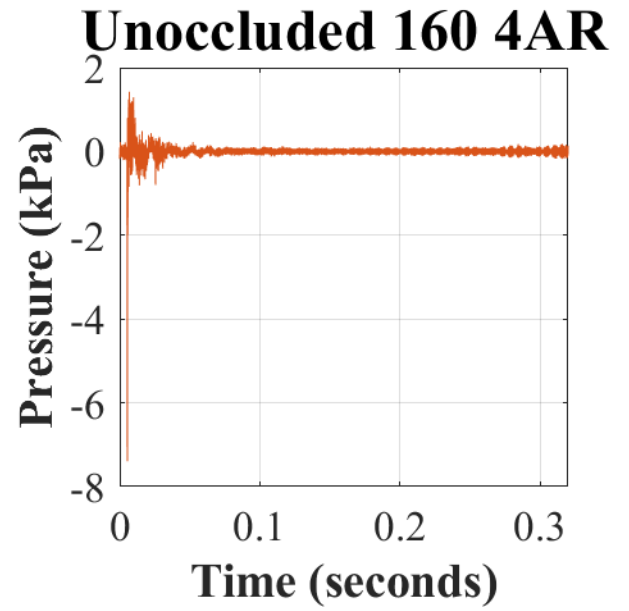
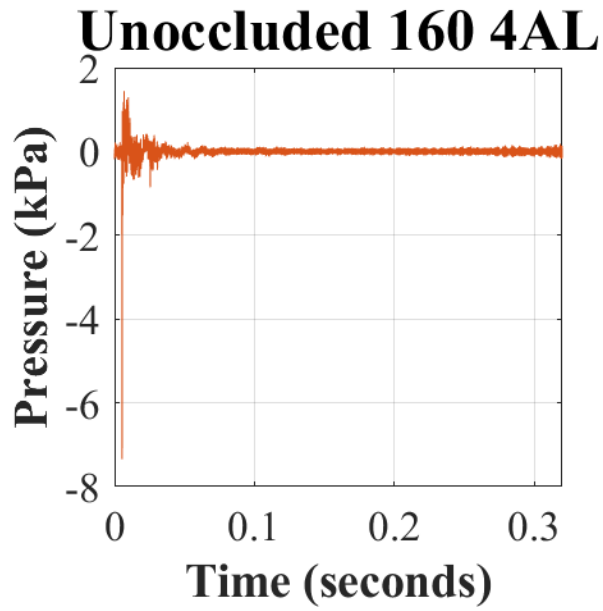
Note. The naming convention for all occluded waveforms is “Occluded LvL NnX”, where ‘Occluded’ is the test condition (i.e., ATF has the HPD donned), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or 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).

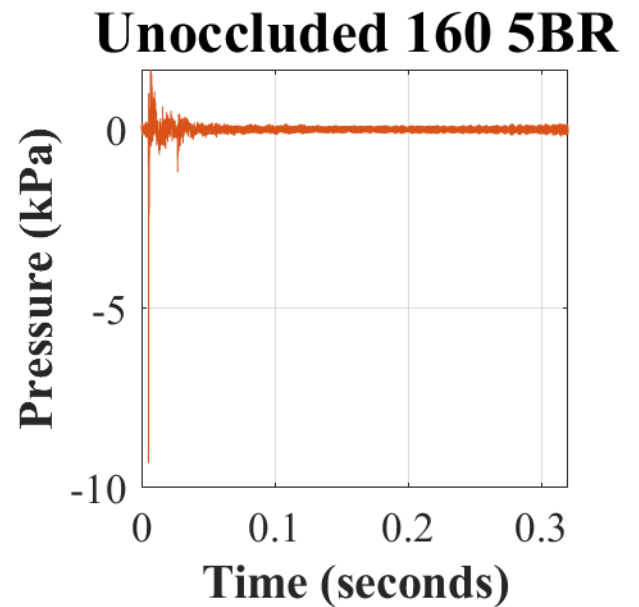
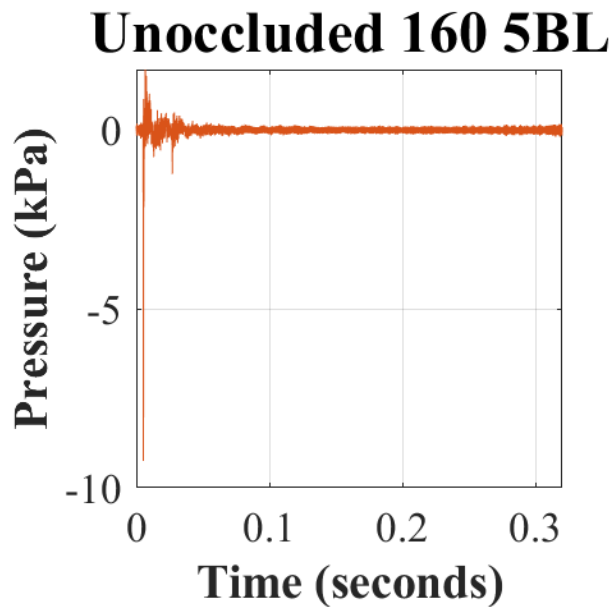
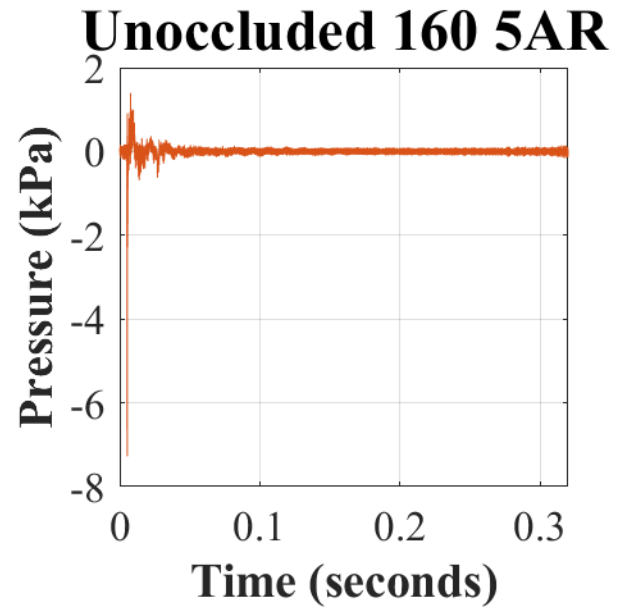
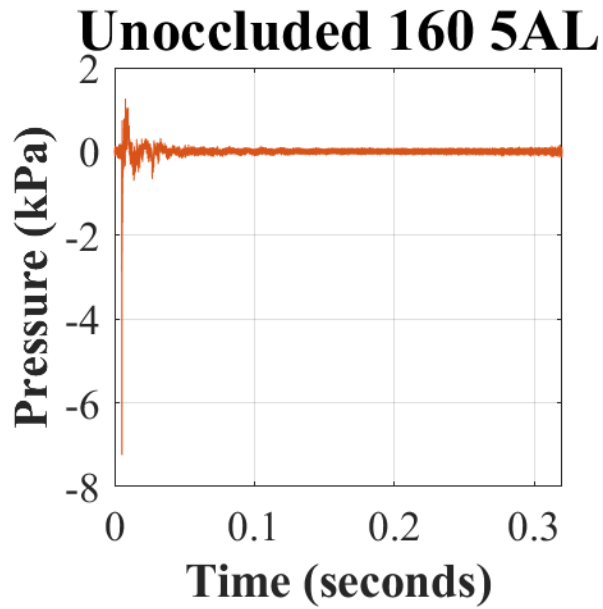
**Appendix M.** Estimated unoccluded (open-ear) waveforms (in kilopascals [kPa]) over time (in seconds [s]) in response to 160 dBp with the ComTac™ V (MAX).





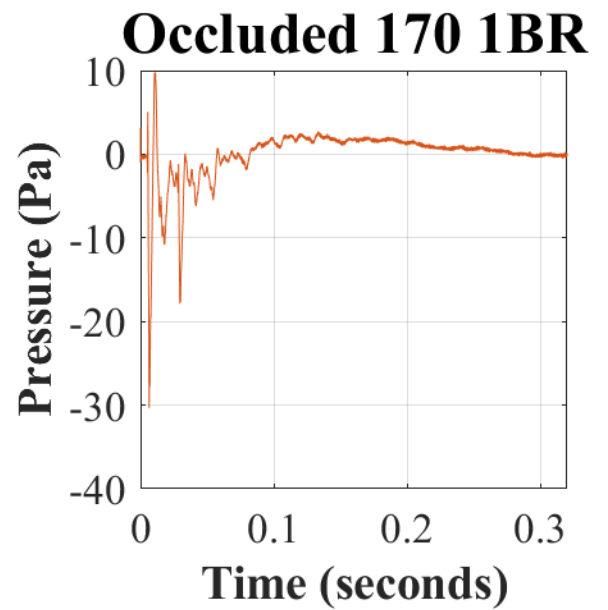
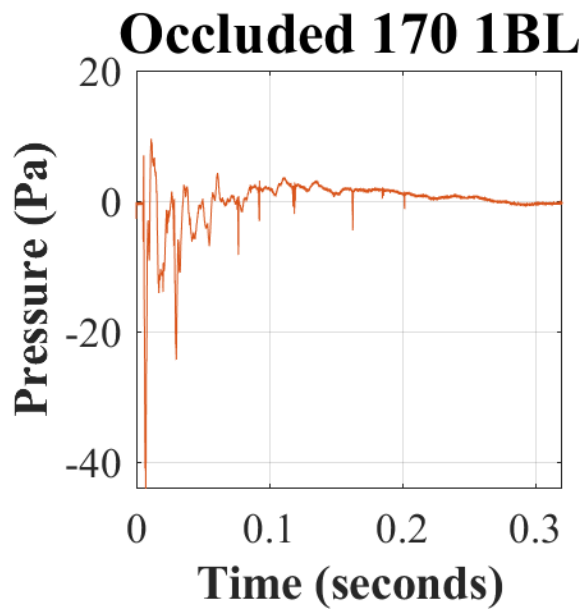
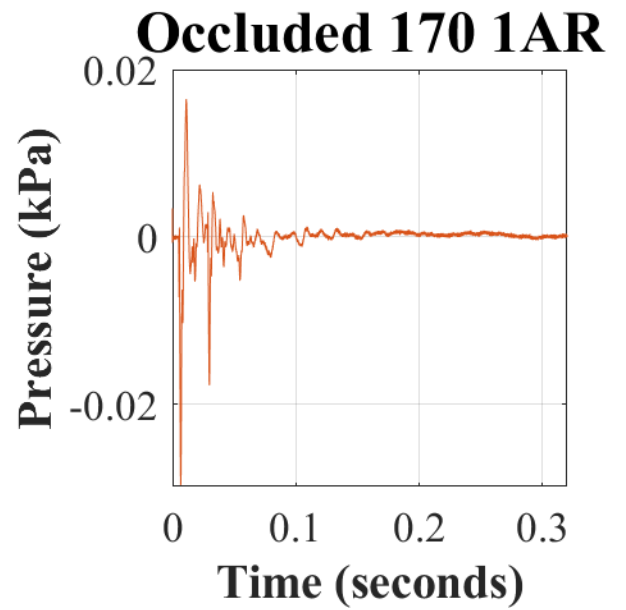
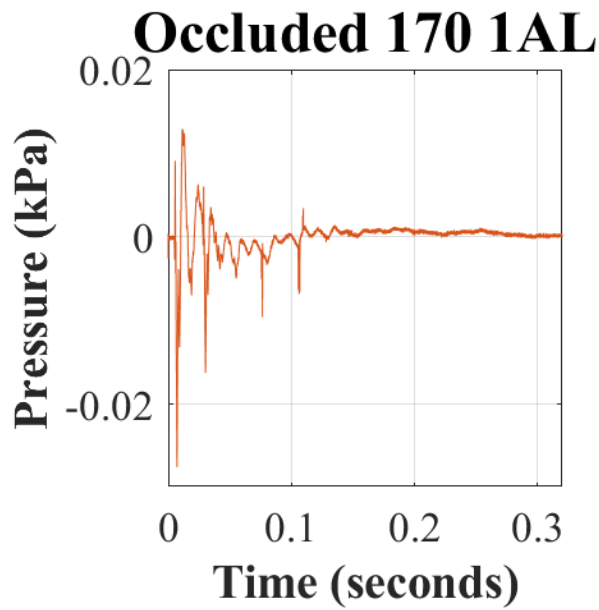


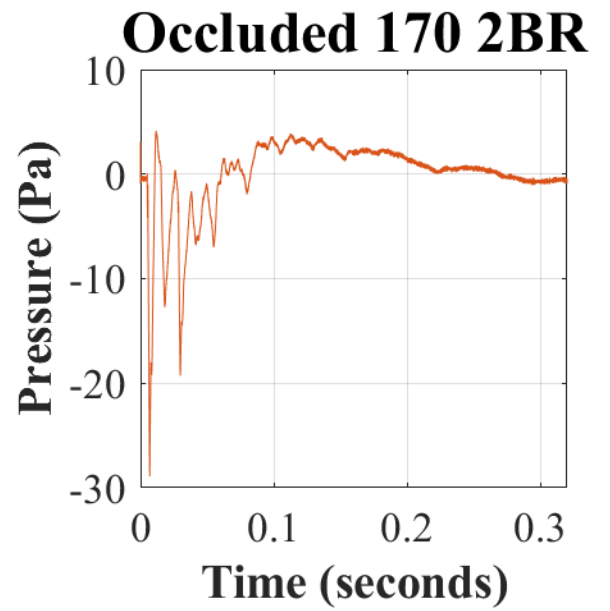
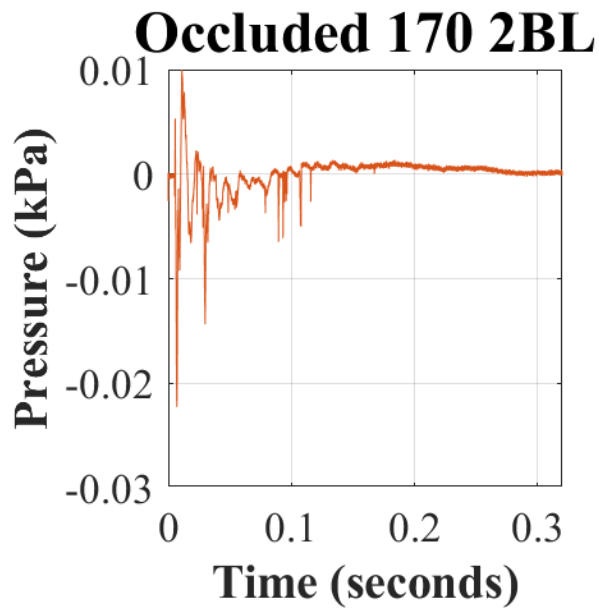
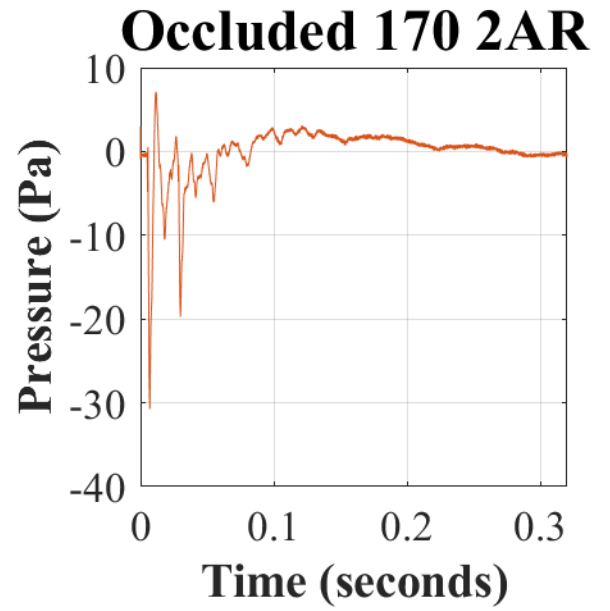
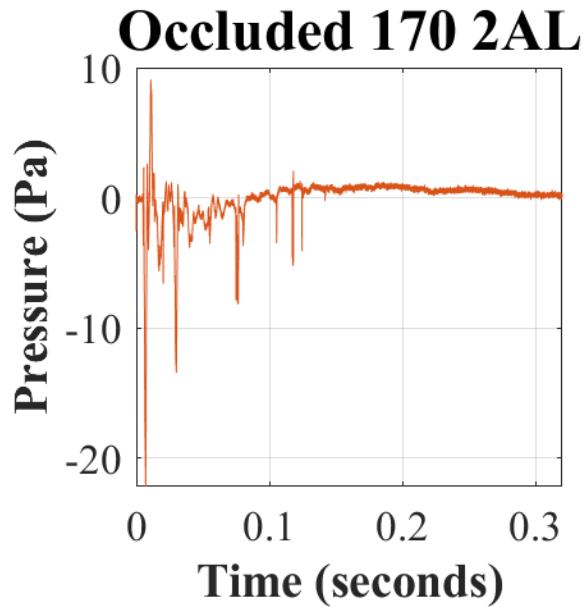


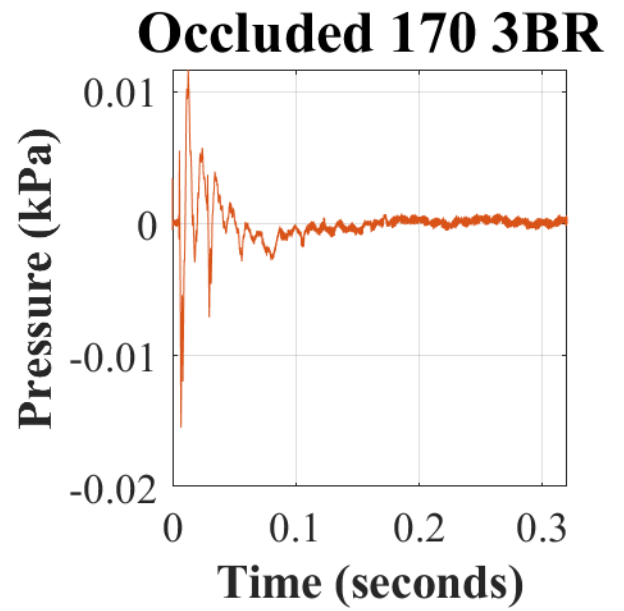
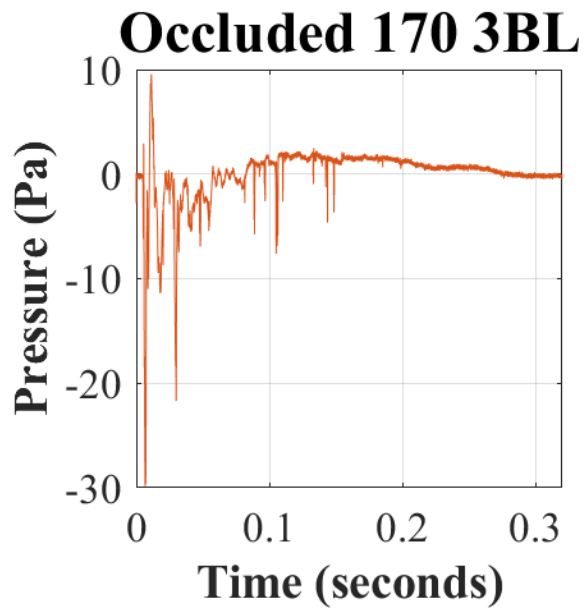
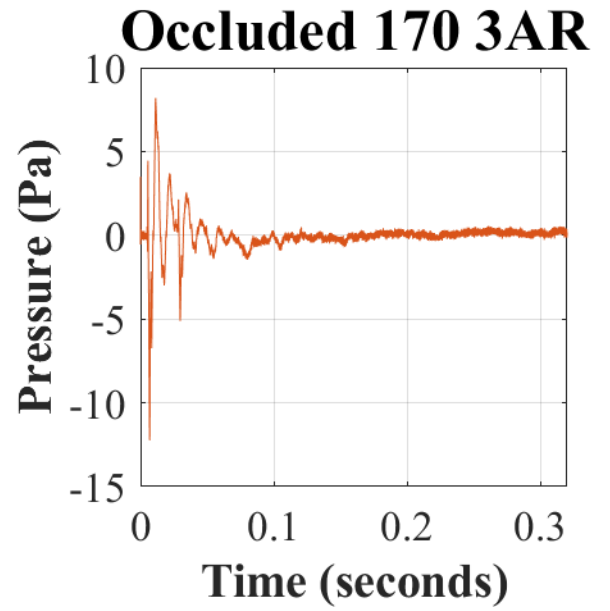
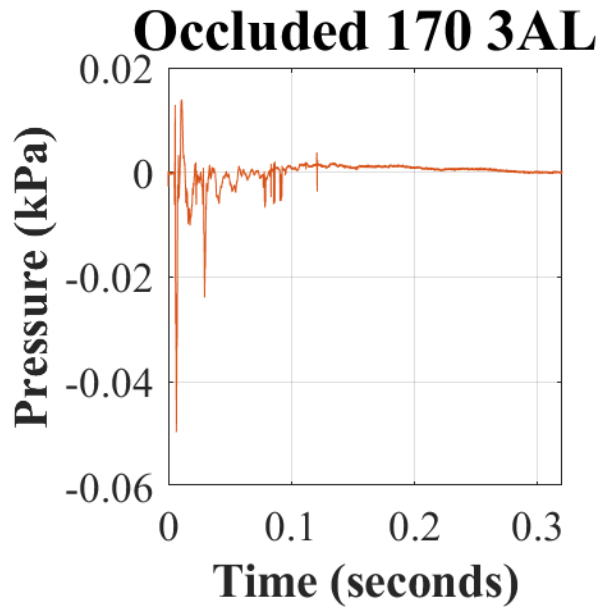


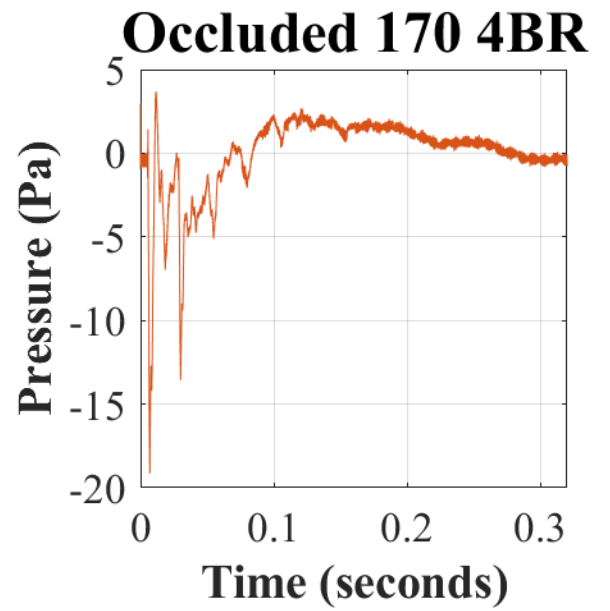
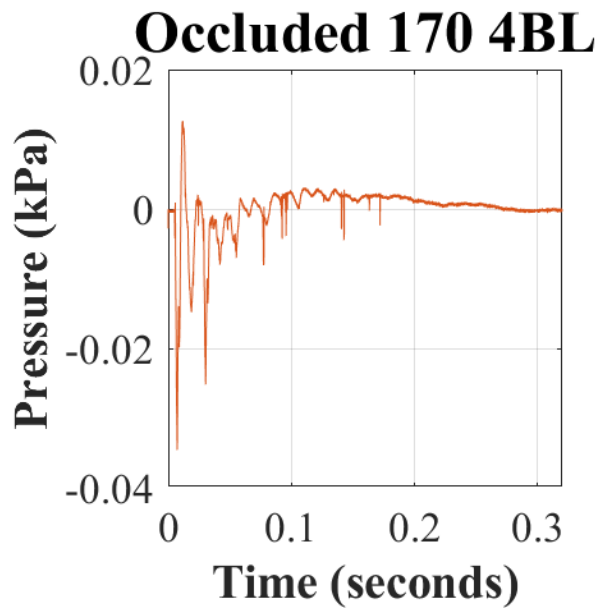
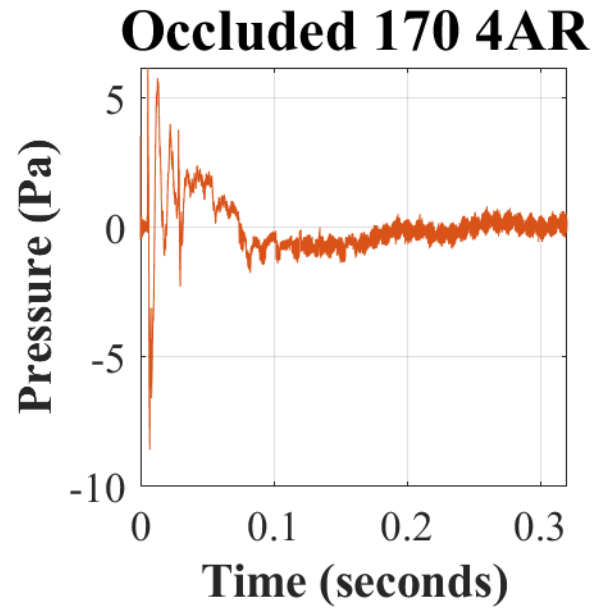
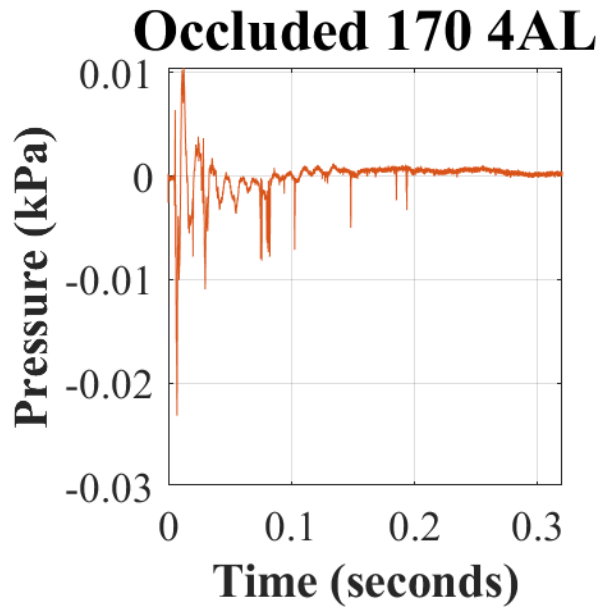
Note. The naming convention for all unoccluded waveforms is “Unoccluded LvL NnX”, where ‘Unoccluded’ is the test condition (i.e., ATF has the HPD doffed), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dB), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., 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).

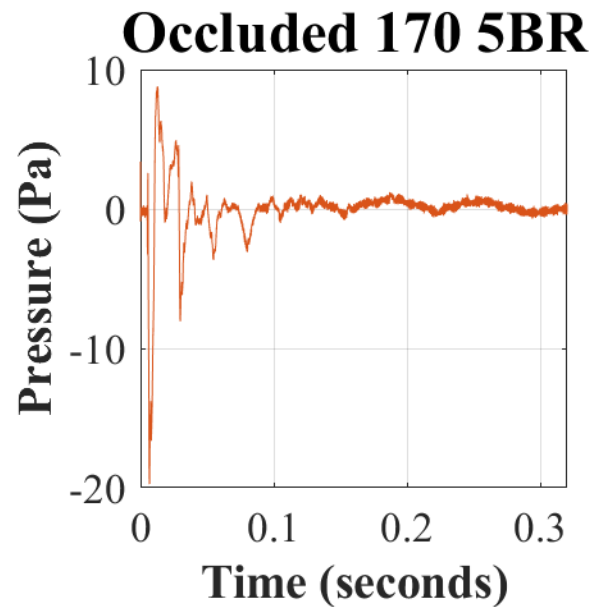
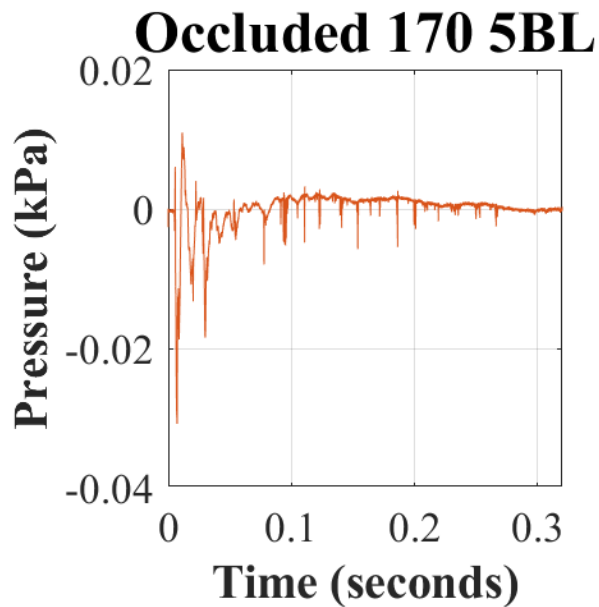
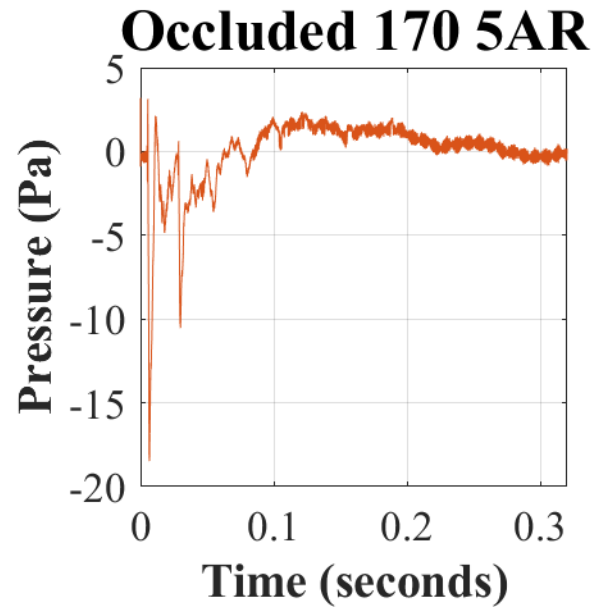
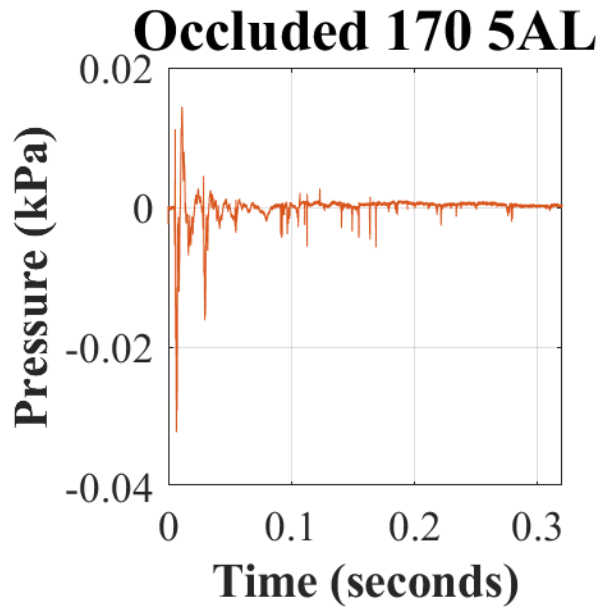
**Appendix N.** Recorded occluded (closed-ear) waveforms (in pascals [Pa] or kilopascals [kPa]) over time (in seconds [s]) in response to 170 dBp with the ComTac™ V (MAX).





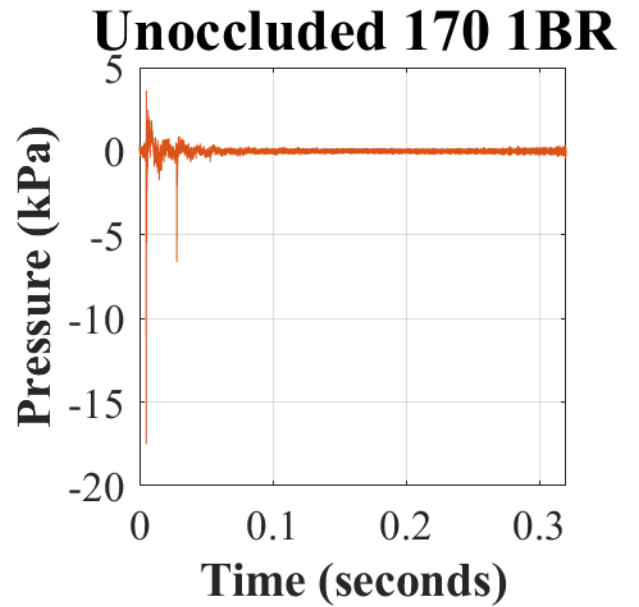
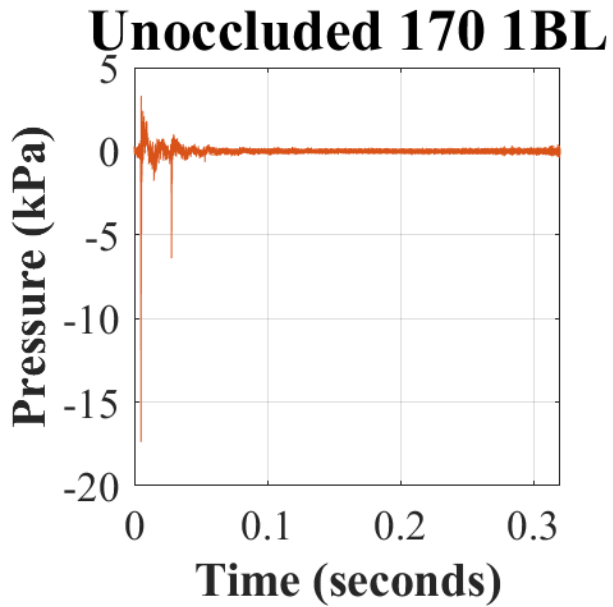
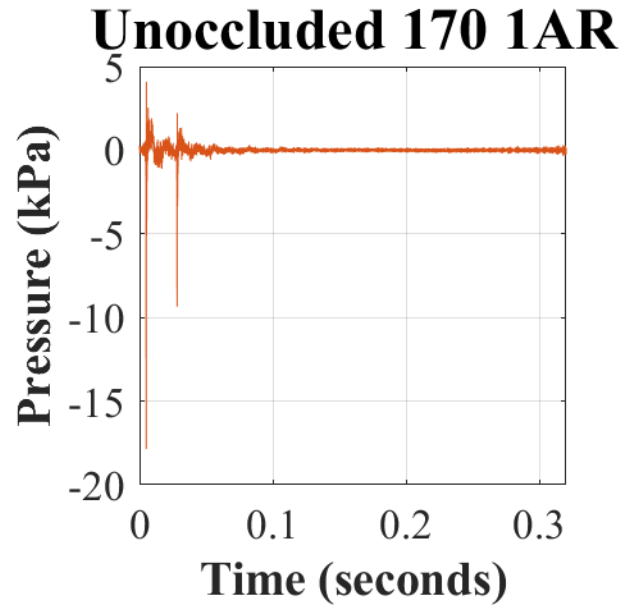
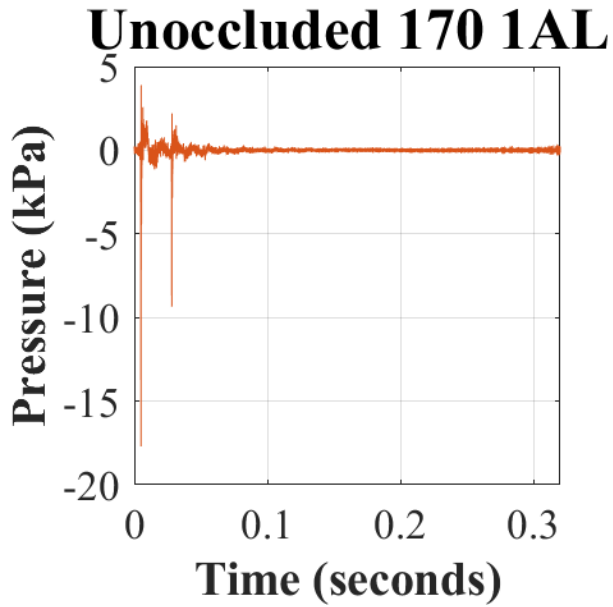


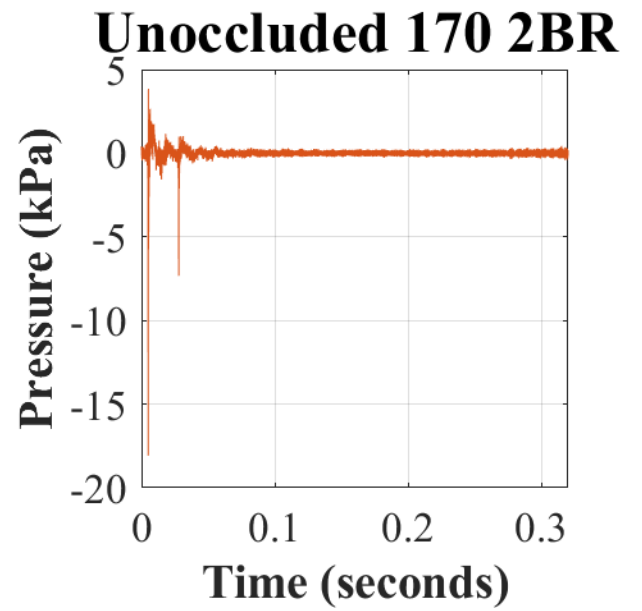
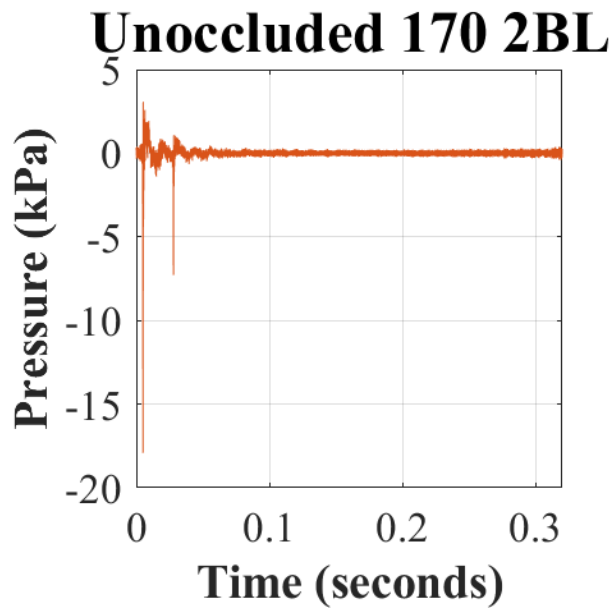
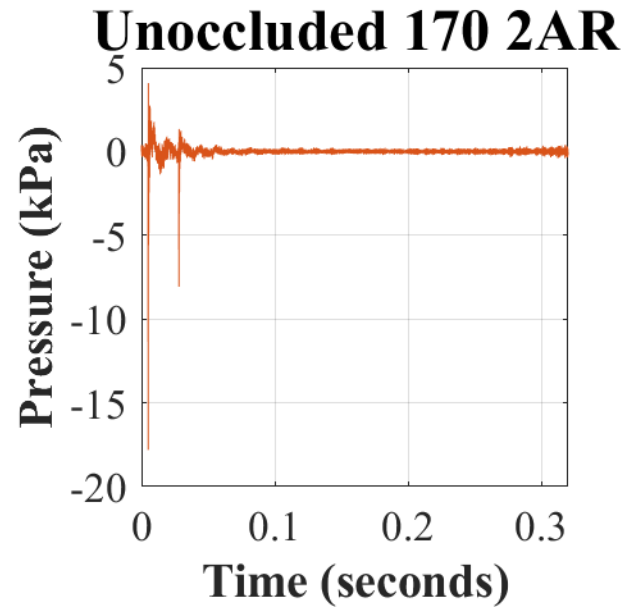
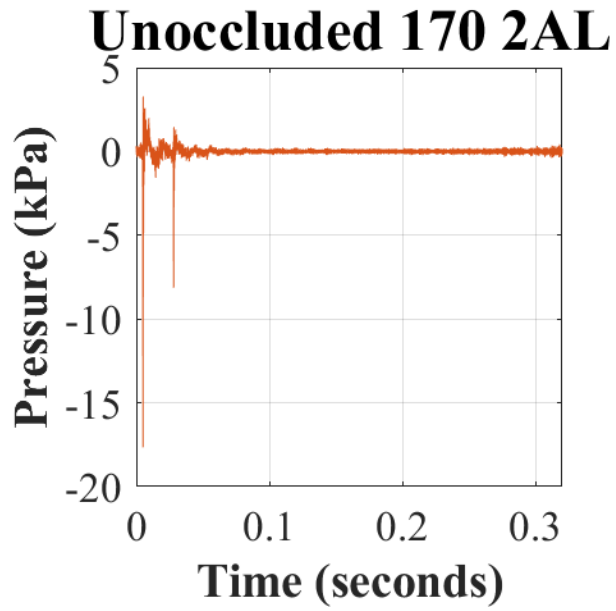


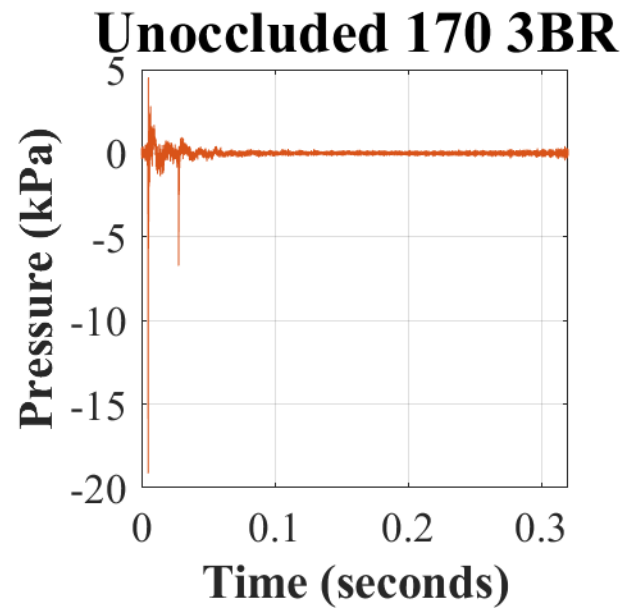
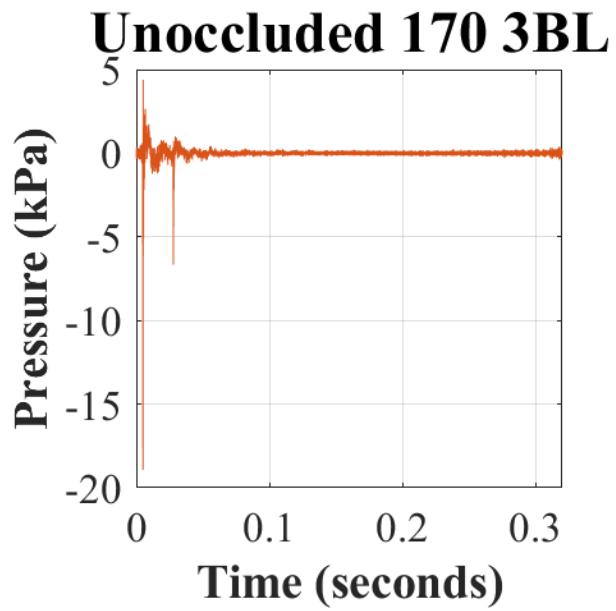
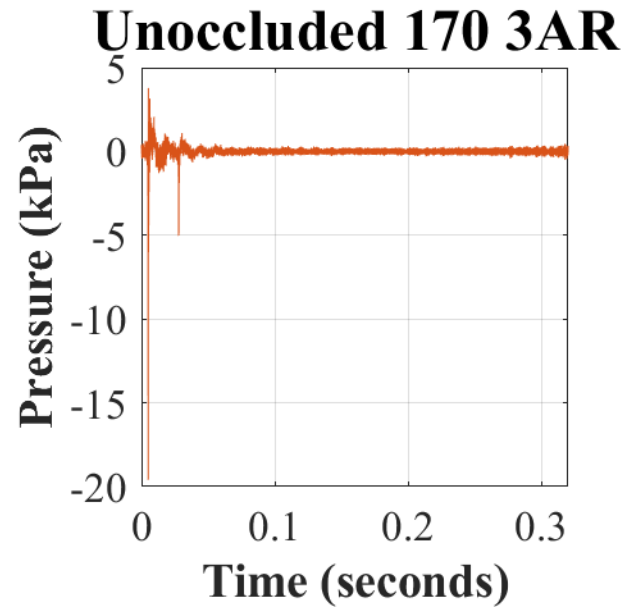
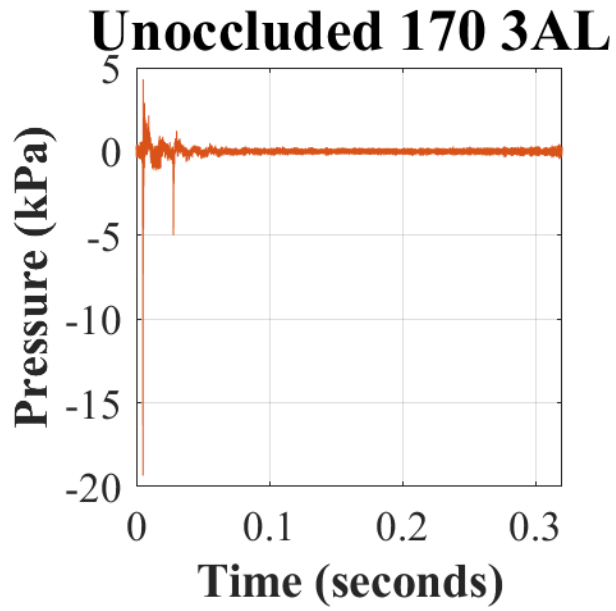


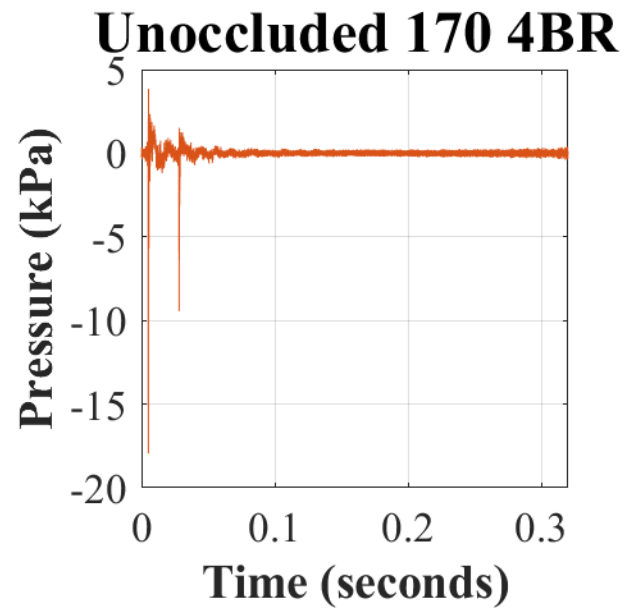
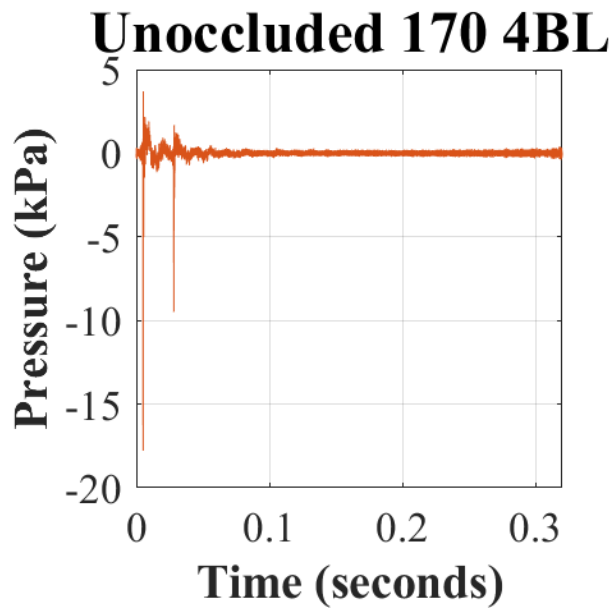
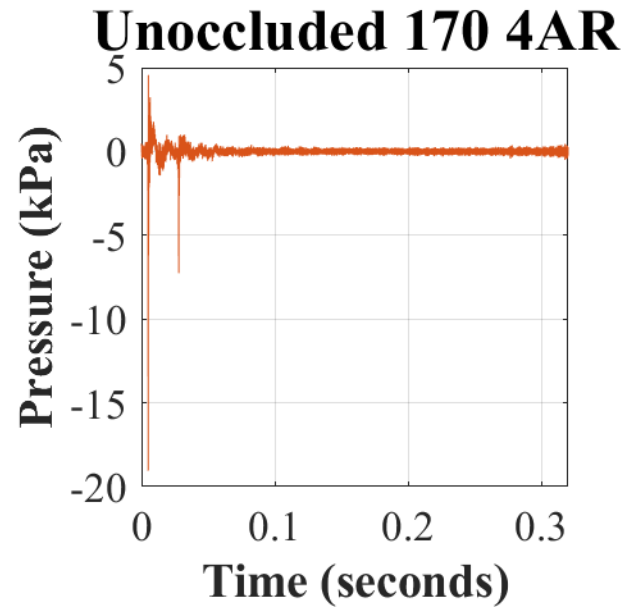
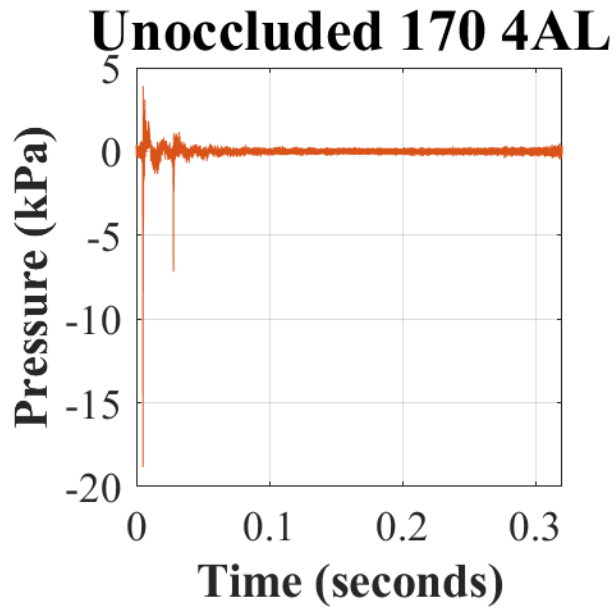
Note. The naming convention for all occluded waveforms is “Occluded LvL NnX”, where ‘Occluded’ is the test condition (i.e., ATF has the HPD donned), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or 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).

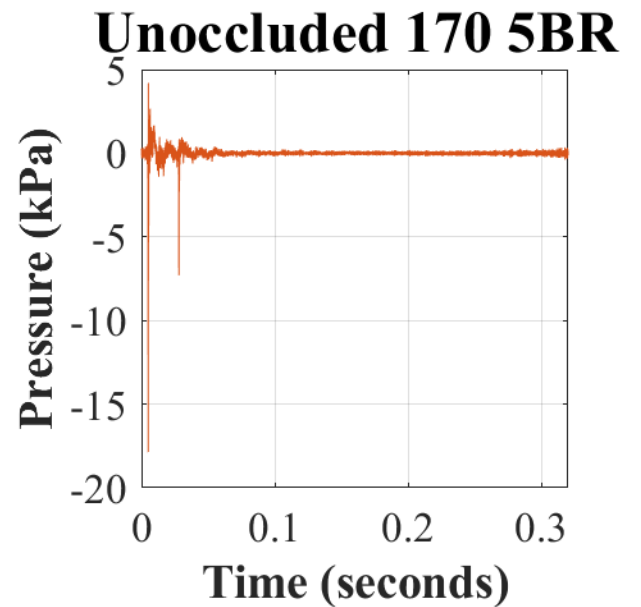
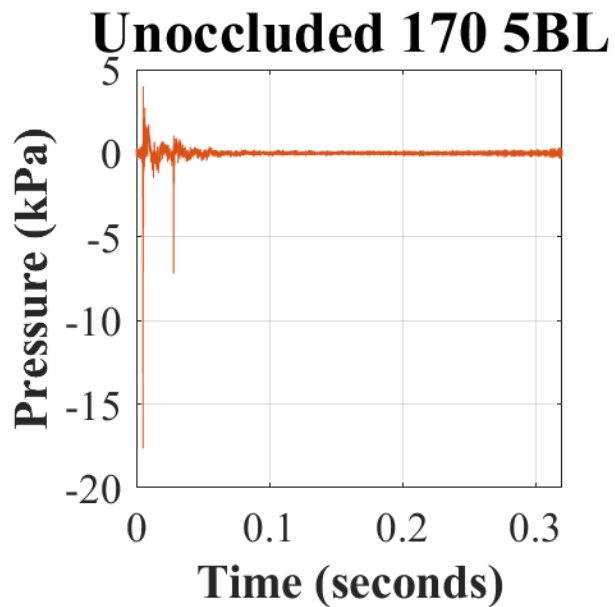
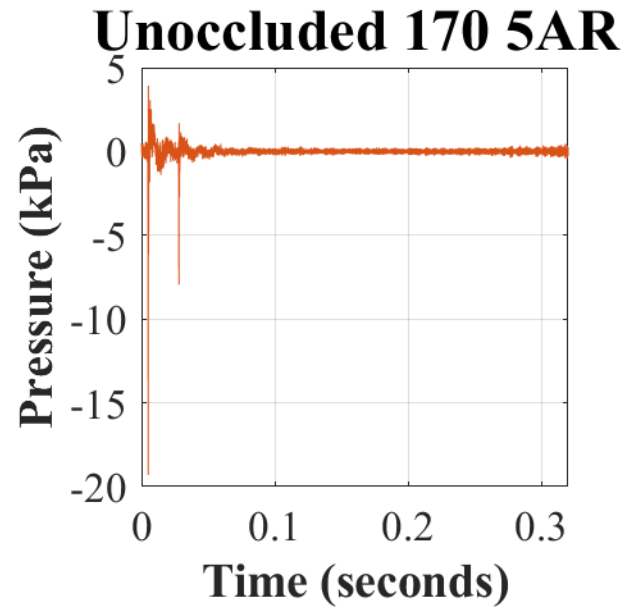
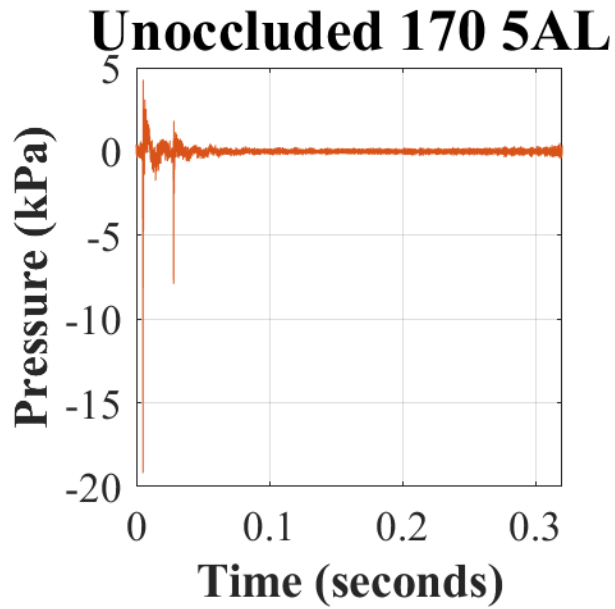
**Appendix O.** Estimated unoccluded (open-ear) waveforms (in kilopascals [kPa]) over time (in seconds [s]) in response to 170 dBp with the ComTac™ V (MAX).





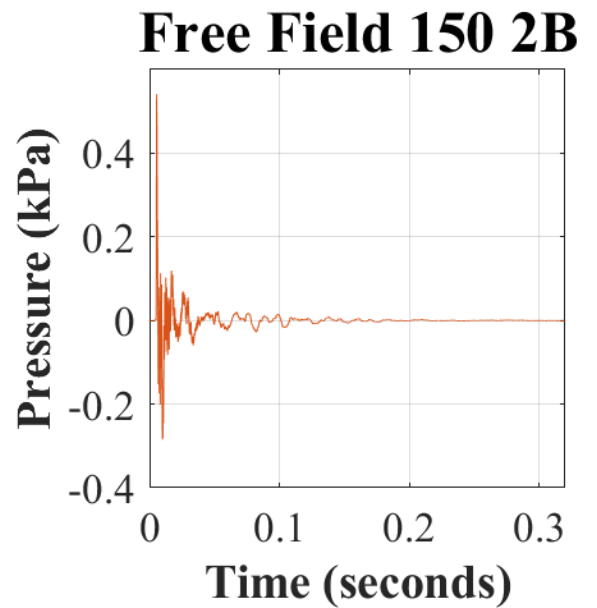
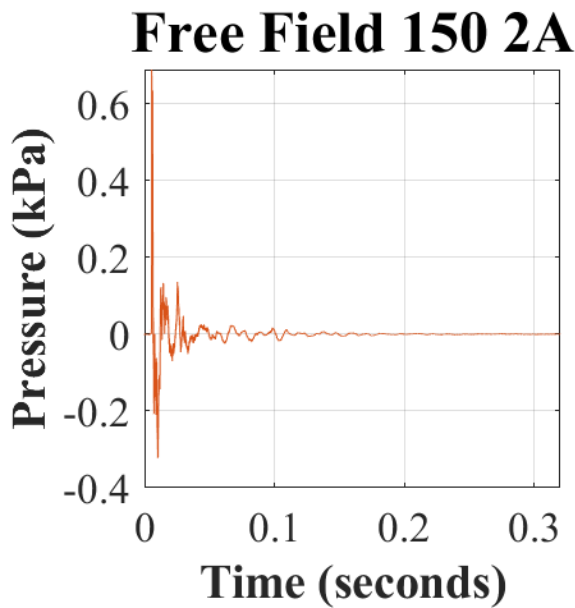
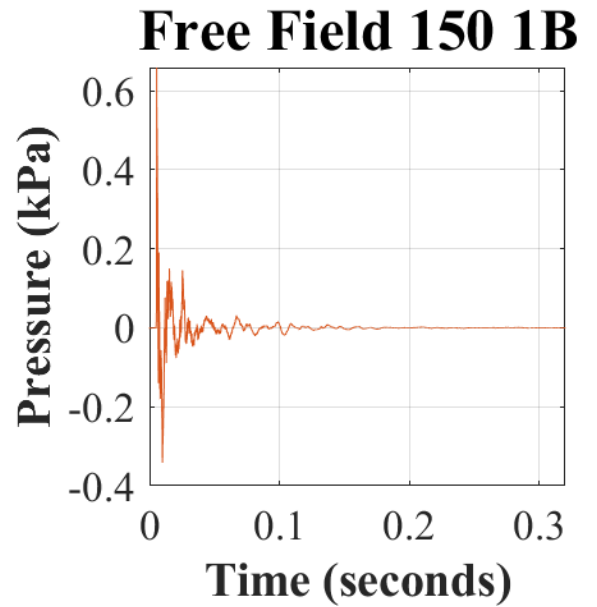
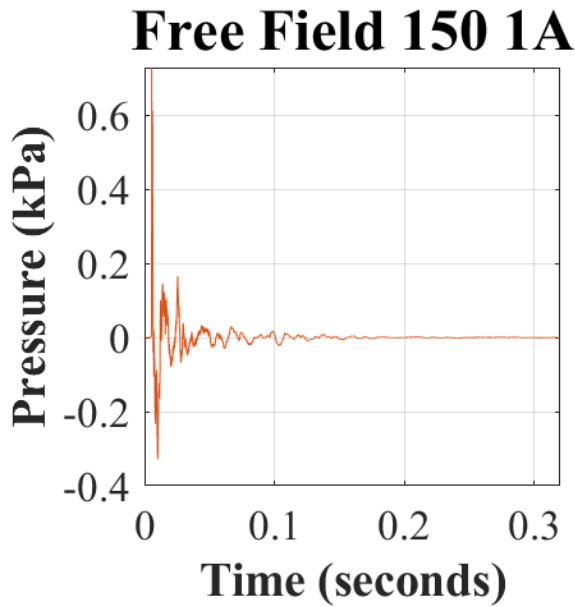




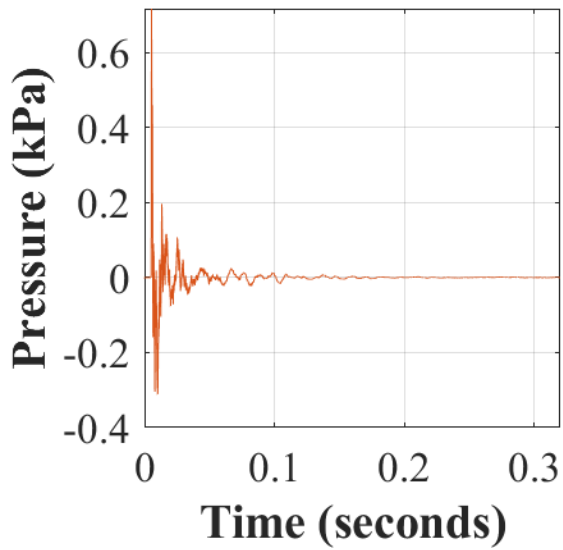


Note. The naming convention for all unoccluded waveforms is “Unoccluded LvL NnX”, where ‘Unoccluded’ is the test condition (i.e., ATF has the HPD doffed), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dB), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., 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).

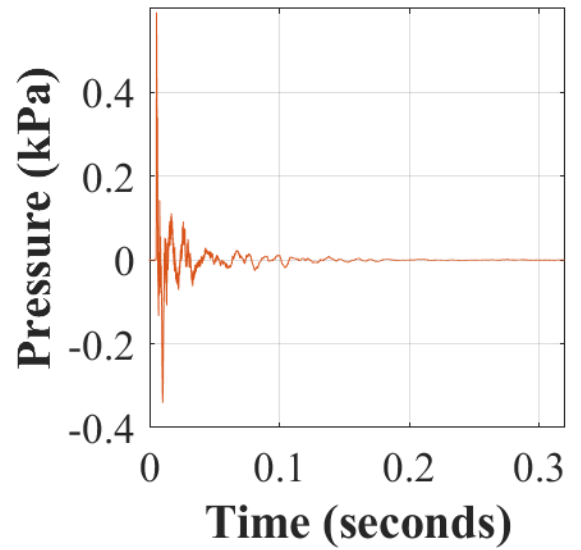
**Appendix P.** Recorded waveform (in kilopascals [kPa]) over time (in seconds [s]) of the impulse measured with the free-field probe at 150 dBp and the ComTac™ V (MAX) donned.



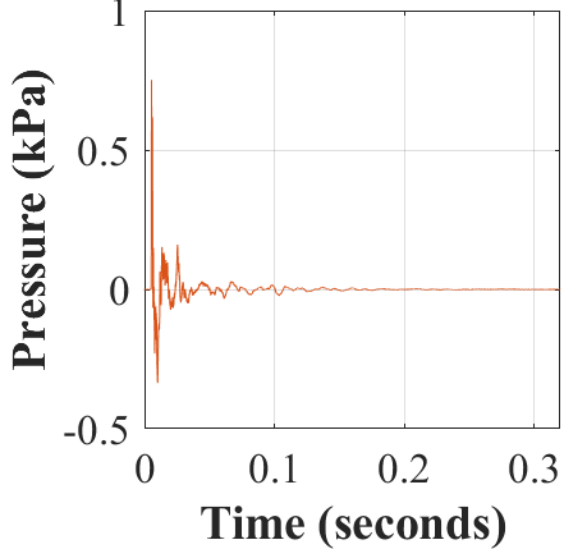
**Free Field 150 3A**



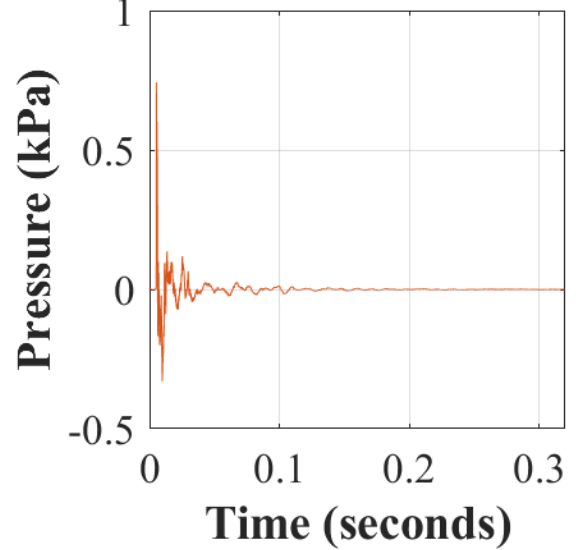
**Free Field 150 3B**

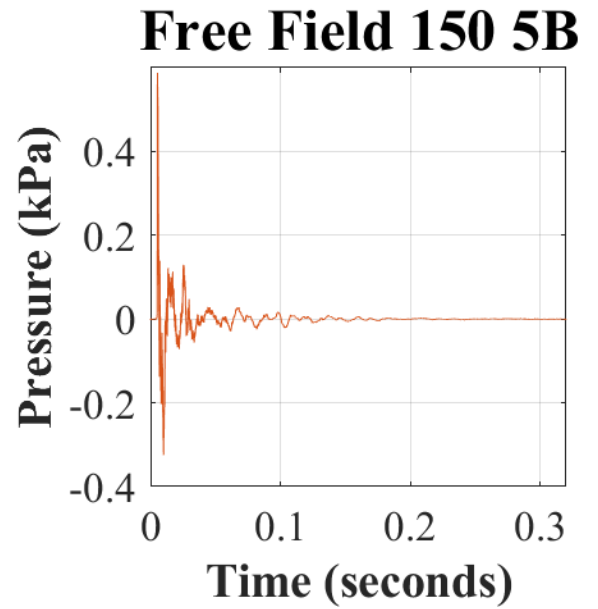
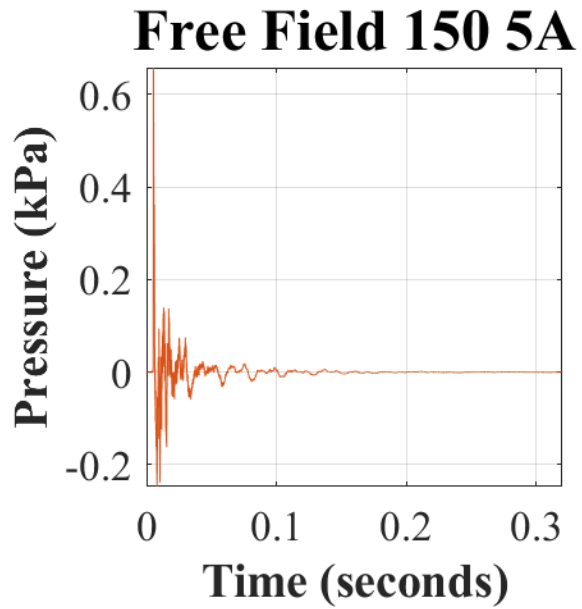


**Free Field 150 4A**



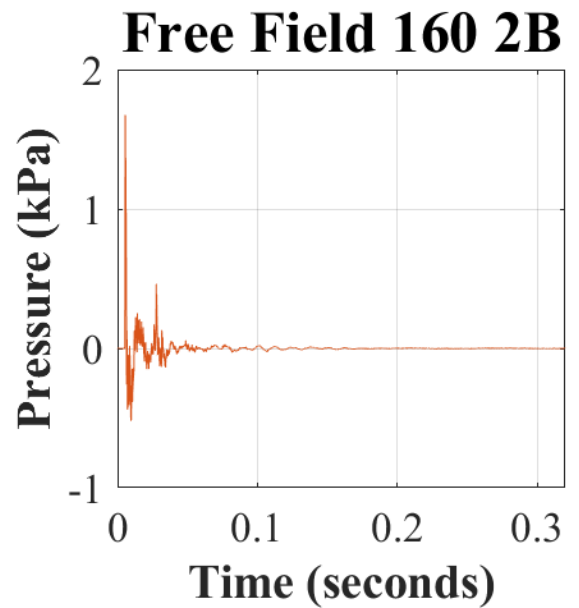
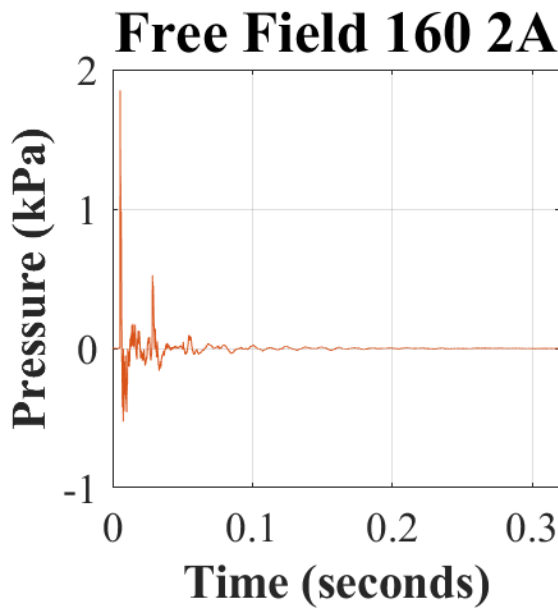
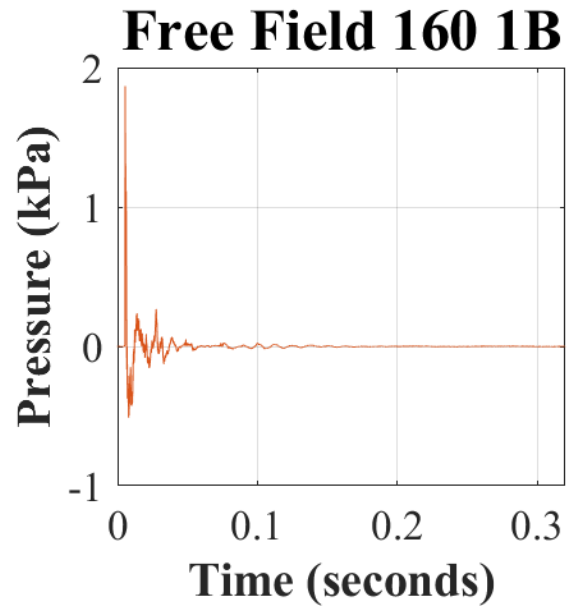
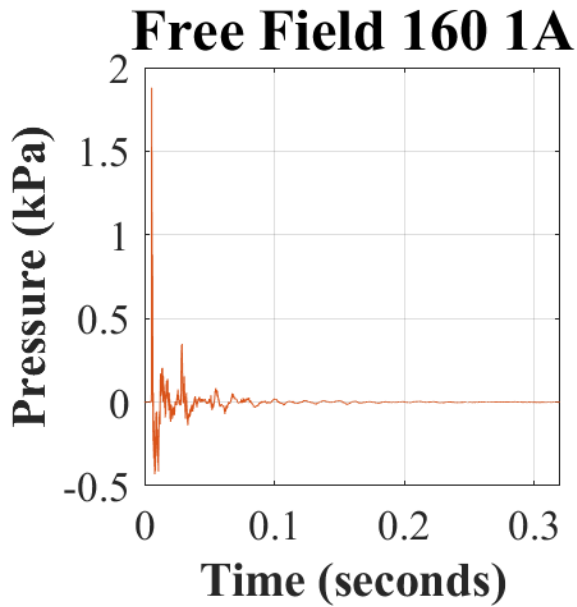
**Free Field 150 4B**

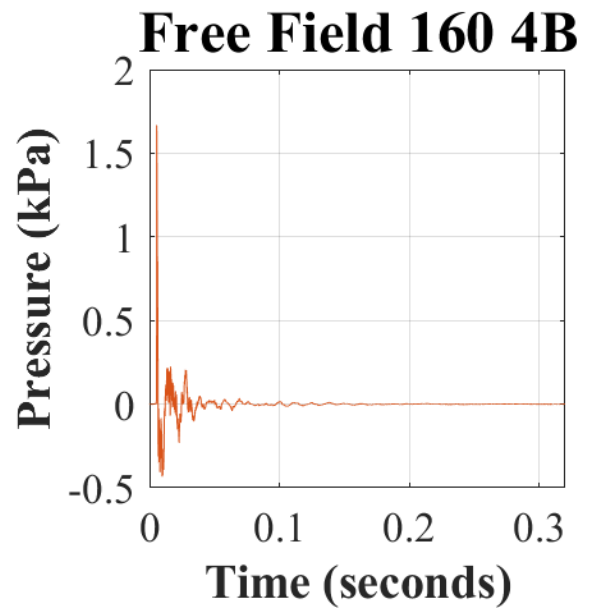
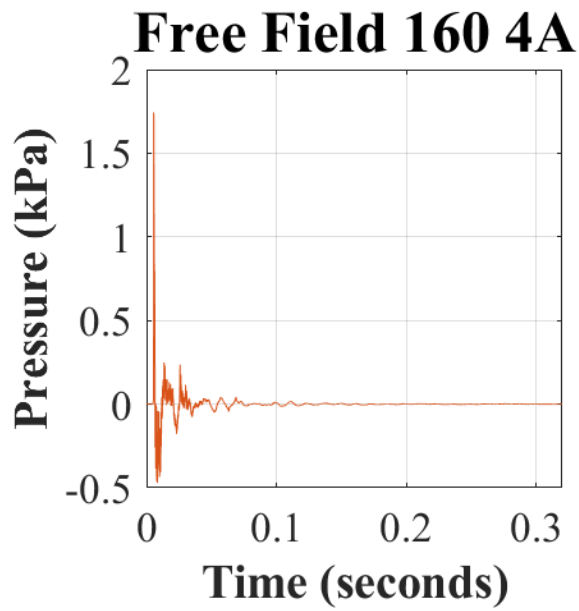
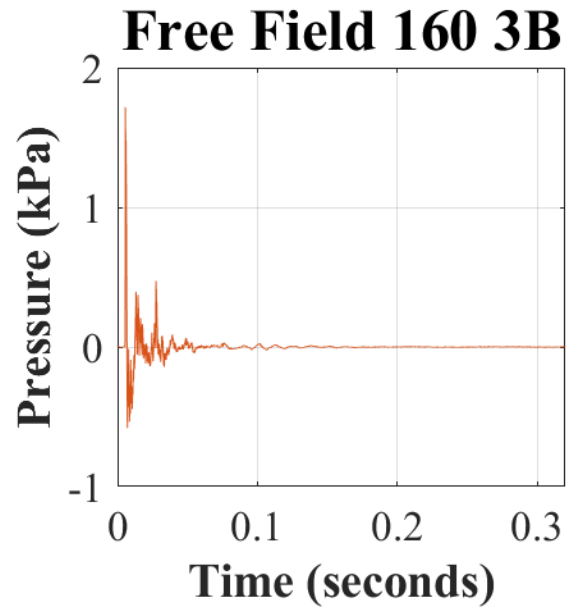
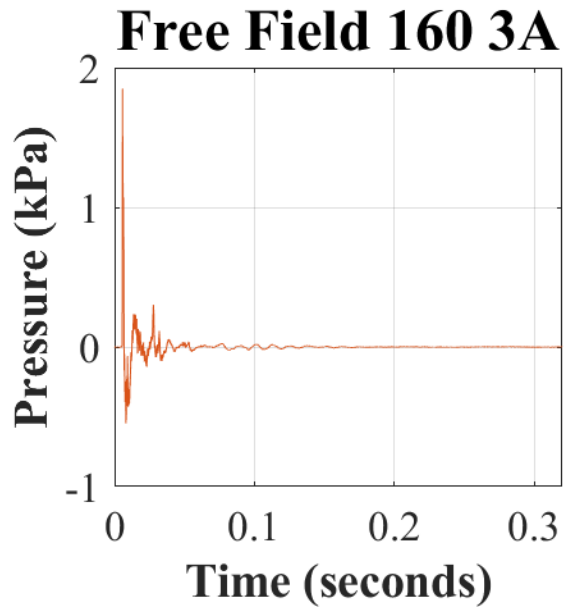


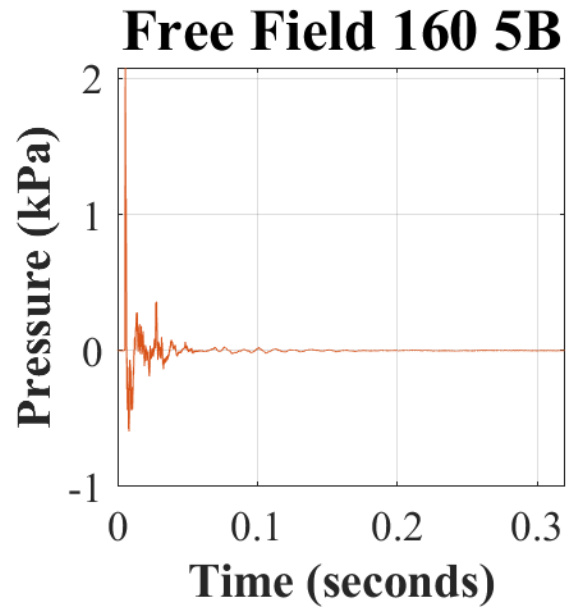
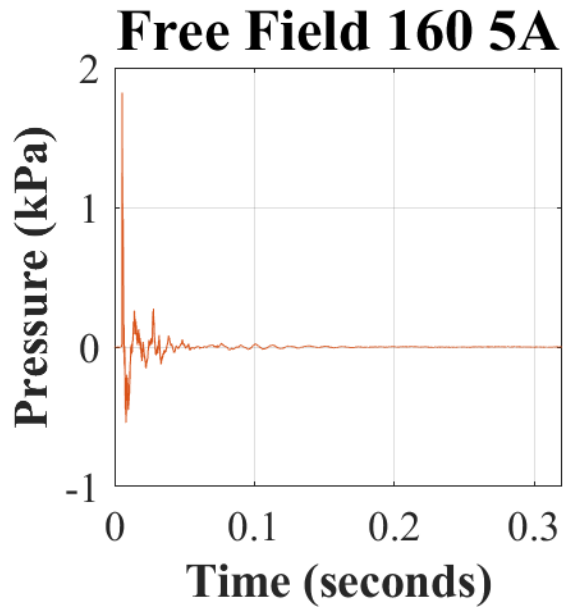


Note. The naming convention for all free-field waveforms is “Free Field LvL Nn”, where ‘Free Field’ indicates that the recording was obtained using the PCB reference microphone, ‘LvL’ is the nominal test level (150 dBp), ‘N’ is the device sample number (1 to 5), and ‘n’ is the device trial (i.e., A or B).

**Appendix Q.** Recorded waveform (in kilopascals [kPa]) over time (in seconds [s]) of the impulse measured with the free-field probe at 160 dBp and the ComTac™ V (MAX) donned.

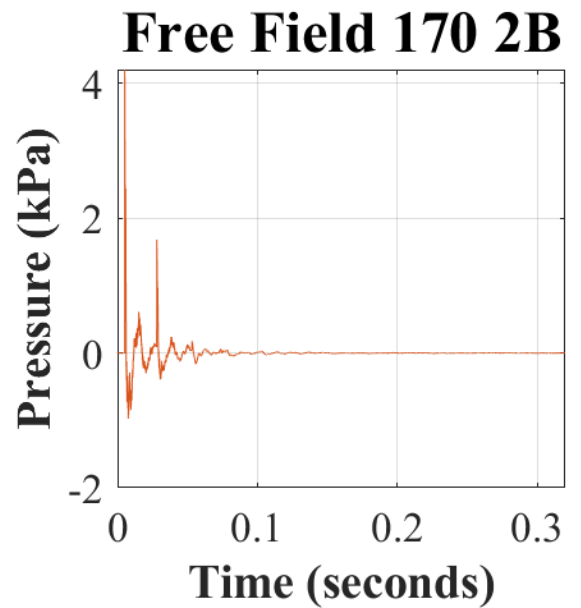
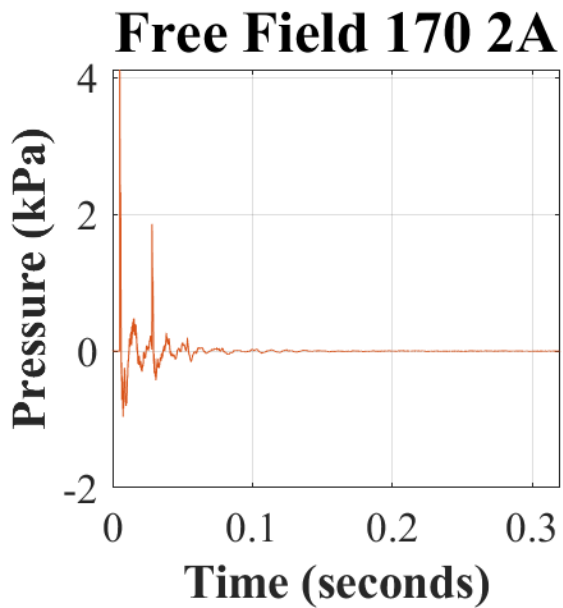
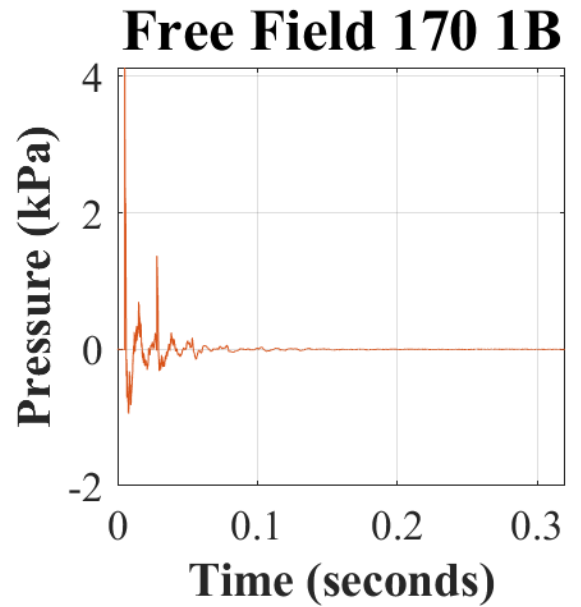
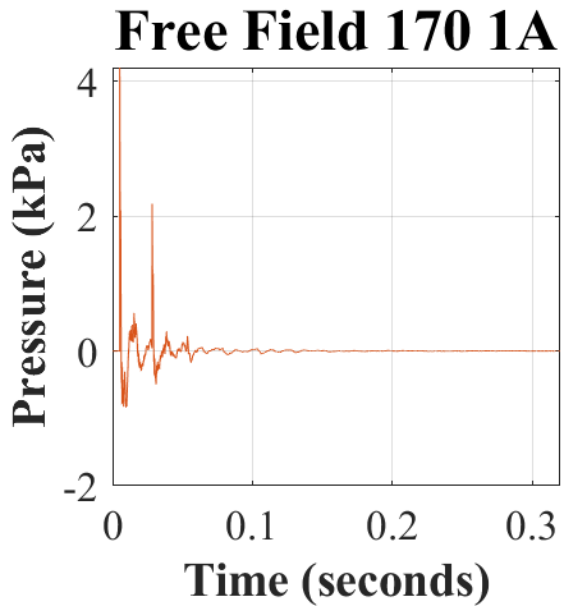


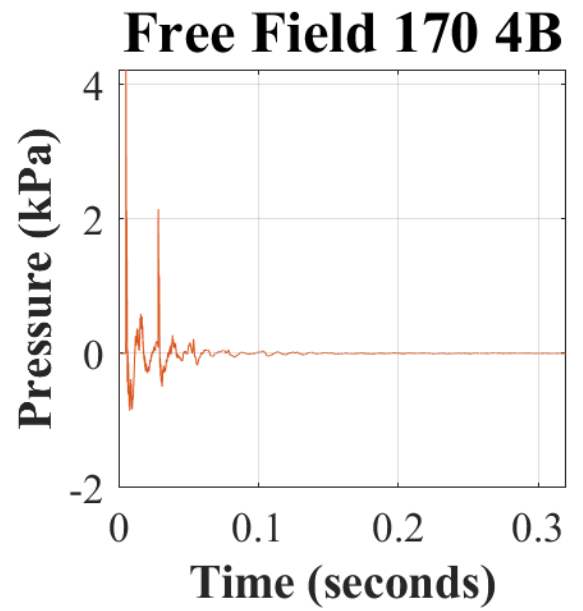
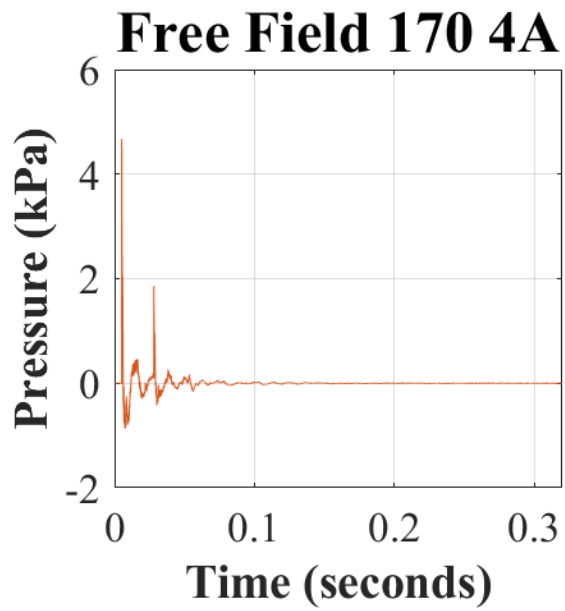
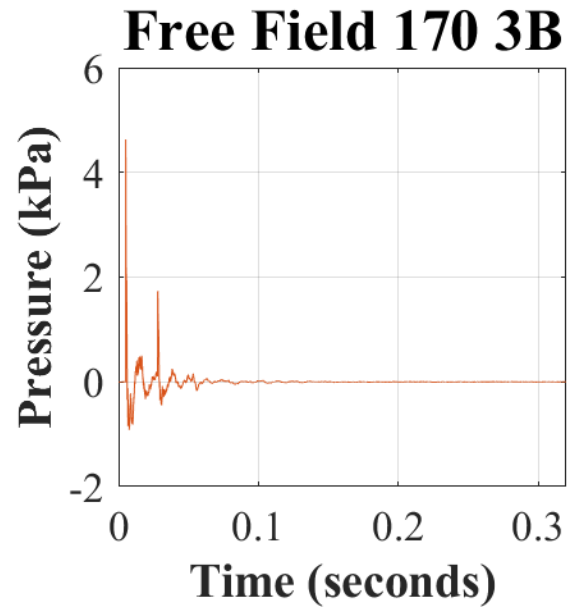
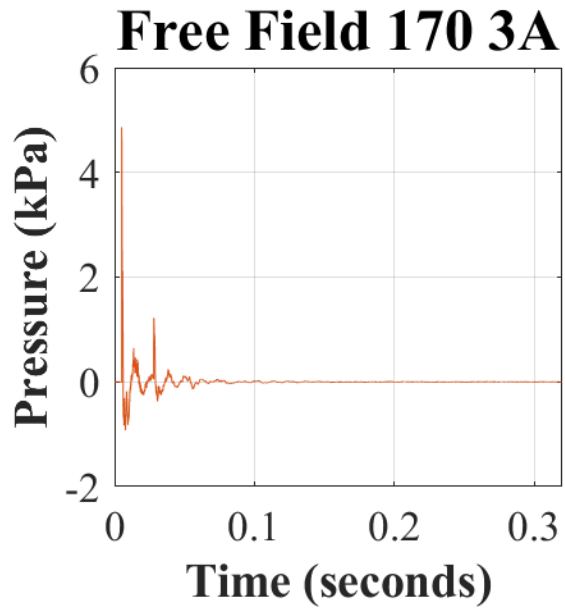


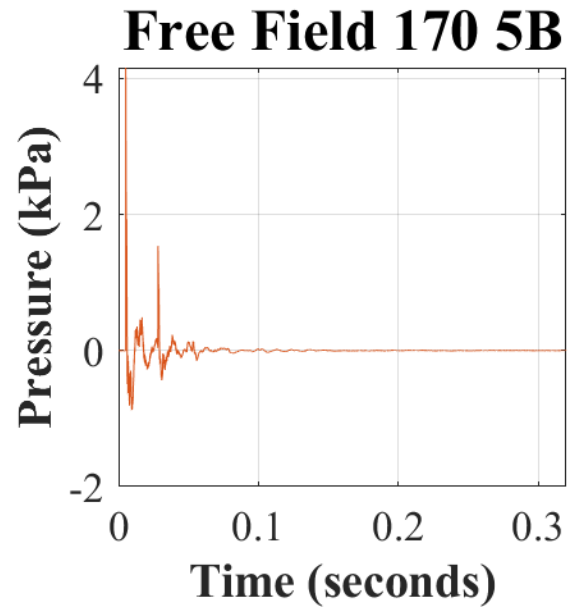
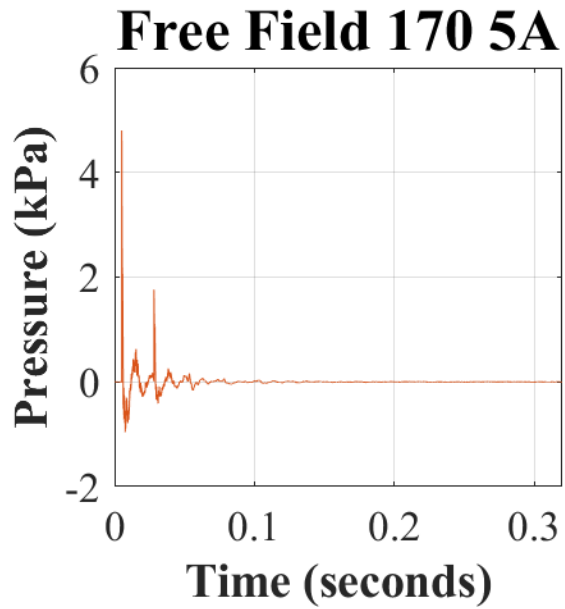


Note. The naming convention for all free-field waveforms is “Free Field LvL Nn”, where ‘Free Field’ indicates that the recording was obtained using the PCB reference microphone, ‘LvL’ is the nominal test level (160 dB), ‘N’ is the device sample number (1 to 5), and ‘n’ is the device trial (i.e., A or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

**Appendix R.** Recorded waveform (in kilopascals [kPa]) over time (in seconds [s]) of the impulse measured with the free-field probe at 170 dBp and the ComTac™ V (MAX) 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).