

# Naval Submarine Medical Research Laboratory

NSMRL/F1016/TM—2022-1378

February 18, 2022

---



## **Impulse Assessment of the Moldex® Battleplugs® Impulse Protection Earplug**

Alexa H. Kolias, AuD <sup>1,2</sup>

Jacob J. See, BS <sup>1,2</sup>

Derek W. Schwaller, BS <sup>1</sup>

Stephanie J. Karch, AuD, PhD <sup>1</sup>

Jeremy S. Federman, PhD <sup>1</sup>

<sup>1</sup> Naval Submarine Medical Research Laboratory, Groton, CT, United States

<sup>2</sup> Leidos, Inc., Reston, VA, United States

**Approved and Released by:**  
**K. K. Shobe, CAPT, MSC, USN**  
**Commanding Officer**  
**NAVSUBMEDRSCHLAB**

---

**DISTRIBUTION A. Approved for public release: distribution unlimited**

.

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |             |                                        |                                                                        |  |                                                                          |                                                           |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|----------------------------------------|------------------------------------------------------------------------|--|--------------------------------------------------------------------------|-----------------------------------------------------------|
| <b>REPORT DOCUMENTATION PAGE</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |             |                                        |                                                                        |  | <i>Form Approved<br/>OMB No. 0704-0188</i>                               |                                                           |
| The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to the Department of Defense, Executive Services and Communications Directorate (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.                                                                                                                                                                                                                                                                                                                                                                                                                           |             |                                        |                                                                        |  |                                                                          |                                                           |
| <b>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |             |                                        |                                                                        |  |                                                                          |                                                           |
| 1. REPORT DATE (DD-MM-YYYY)<br>18-02-2022                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |             | 2. REPORT TYPE<br>Technical Memorandum |                                                                        |  | 3. DATES COVERED (From - To)<br>October 2021 - January 2022              |                                                           |
| 4. TITLE AND SUBTITLE<br>Impulse Assessment of the Moldex® Battleplugs® Impulse Protection Earplug                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |             |                                        |                                                                        |  | 5a. CONTRACT NUMBER                                                      |                                                           |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |             |                                        |                                                                        |  | 5b. GRANT NUMBER                                                         |                                                           |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |             |                                        |                                                                        |  | 5c. PROGRAM ELEMENT NUMBER                                               |                                                           |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |             |                                        |                                                                        |  | 5d. PROJECT NUMBER                                                       |                                                           |
| 6. AUTHOR(S)<br>Alexa H. Kolias, AuD<br>Jacob J. See, BS<br>Derek W. Schwaller, BS<br>Stephanie J. Karch, AuD, PhD<br>Jeremy S. Federman, PhD                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |             |                                        |                                                                        |  | 5e. TASK NUMBER                                                          |                                                           |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |             |                                        |                                                                        |  | 5f. WORK UNIT NUMBER<br>F1016                                            |                                                           |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |             |                                        |                                                                        |  |                                                                          |                                                           |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>Naval Submarine Medical Research Laboratory<br>Box 900<br>Groton, CT 06349-5900                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |             |                                        |                                                                        |  | 8. PERFORMING ORGANIZATION<br>REPORT NUMBER<br>NSMRL/F1016/TM--2022-1378 |                                                           |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)<br>Bureau of Medicine and Surgery<br>7700 Arlington Blvd #5113<br>Falls Church, VA 22042                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |             |                                        |                                                                        |  | 10. SPONSOR/MONITOR'S ACRONYM(S)<br>BUMED                                |                                                           |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |             |                                        |                                                                        |  | 11. SPONSOR/MONITOR'S REPORT<br>NUMBER(S)                                |                                                           |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |             |                                        |                                                                        |  |                                                                          |                                                           |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT<br>DISTRIBUTION A. Approved for public release: distribution unlimited.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |             |                                        |                                                                        |  |                                                                          |                                                           |
| 13. SUPPLEMENTARY NOTES                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |             |                                        |                                                                        |  |                                                                          |                                                           |
| 14. ABSTRACT<br>The impulse peak insertion loss (IPIL) is the standard measure of attenuation provided by hearing protection devices (HPDs) in response to an impulsive noise. This technical memorandum describes the IPIL testing conducted and the calculated mean IPIL values for the Moldex® Battleplugs® Impulse Protection Earplug. Testing included two test modes: cap open (i.e., unfiltered) and cap closed (i.e., filtered). 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 cap open and cap closed modes. Results of the testing revealed overall higher mean IPIL values when the Battleplugs® earplug was in the closed mode compared to the open mode at all nominal test levels. These results suggest that, when properly fit and functional, the Battleplugs® can adequately protect (i.e., reduce exposure to less than 140 dBp) against impulses below 173.6 dBp in the cap open mode, and 178.3 dBp in the cap closed mode. |             |                                        |                                                                        |  |                                                                          |                                                           |
| 15. SUBJECT TERMS<br>attenuation, impulse peak insertion loss, IPIL, blast, hearing protection device, HPD, earplug, passive earplug                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |             |                                        |                                                                        |  |                                                                          |                                                           |
| 16. SECURITY CLASSIFICATION OF:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |             |                                        | 17. LIMITATION OF<br>ABSTRACT                                          |  | 18. NUMBER<br>OF<br>PAGES                                                |                                                           |
| a. REPORT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | b. ABSTRACT | c. THIS PAGE                           | SAR                                                                    |  | 87                                                                       |                                                           |
| U                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | U           | U                                      | 19a. NAME OF RESPONSIBLE PERSON<br>NAVSUBMEDRSCHLAB Commanding Officer |  |                                                                          |                                                           |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |             |                                        |                                                                        |  |                                                                          | 19b. TELEPHONE NUMBER (Include area code)<br>860-694-3263 |

[THIS PAGE INTENTIONALLY LEFT BLANK]

# Impulse Assessment of the Moldex® Battleplugs® Impulse Protection Earplug

Alexa H. Kolas, AuD <sup>1, 2</sup>  
Jacob J. See, BS <sup>1, 2</sup>  
Derek W. Schwaller, BS <sup>1</sup>  
Stephanie J. Karch, AuD, PhD <sup>1</sup>  
Jeremy S. Federman, PhD <sup>1</sup>

<sup>1</sup> Naval Submarine Medical Research Laboratory, Groton, CT, United States

<sup>2</sup> Leidos, Inc., Reston, VA, United States

## Naval Submarine Medical Research Laboratory

Approved and Released by:

SHOBE.KATHARINE.2518280  
KRAUSE.1242518280

Digitally signed by  
SHOBE.KATHARINE.KRAUSE.124  
2518280  
Date: 2022.02.21 10:38:19 -05'00'

CAPT K. K. Shobe, MSC, USN  
Commanding Officer  
Naval Submarine Medical Research Laboratory  
Submarine Base New London Box 900  
Groton, CT 06349-5900

*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.*

---

DISTRIBUTION A. Approved for public release: distribution unlimited.

[THIS PAGE INTENTIONALLY LEFT BLANK]

### **Acknowledgements**

The authors would like to thank Ms. Rachael Maten for assistance in the collection of resource materials.

## CONTENTS

|                         |     |
|-------------------------|-----|
| ACKNOWLEDGEMENTS.....   | iii |
| EXECUTIVE SUMMARY ..... | 1   |
| INTRODUCTION .....      | 2   |
| METHODS .....           | 2   |
| RESULTS .....           | 7   |
| DISCUSSION .....        | 8   |
| CONCLUSIONS.....        | 8   |
| REFERENCES .....        | 9   |
| APPENDIX A.....         | 10  |
| APPENDIX B .....        | 15  |
| APPENDIX C .....        | 20  |
| APPENDIX D.....         | 25  |
| APPENDIX E .....        | 30  |
| APPENDIX F.....         | 35  |
| APPENDIX G.....         | 40  |
| APPENDIX H.....         | 43  |
| APPENDIX I .....        | 46  |
| APPENDIX J .....        | 49  |
| APPENDIX K.....         | 54  |
| APPENDIX L .....        | 59  |
| APPENDIX M .....        | 64  |
| APPENDIX N.....         | 69  |
| APPENDIX O.....         | 74  |
| APPENDIX P.....         | 79  |
| APPENDIX Q.....         | 82  |
| APPENDIX R.....         | 85  |

## Executive Summary

The impulse peak insertion loss (IPIL) is the standard measure of attenuation provided by hearing protection devices (HPDs) in response to an impulsive noise. This technical memorandum describes the IPIL testing conducted and the calculated mean IPIL values for the Moldex® Battleplugs® Impulse Protection Earplug (Battleplugs®; Model: 6498). Testing included two test modes: cap open (i.e., filtered signal) and cap closed (i.e., unfiltered signal). 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 were fitted to an acoustic test fixture two times each for a total of 10 trials per test level in both the cap open and cap closed modes. No samples of the HPD were rejected. Results of the testing revealed overall higher mean IPIL values when the Battleplugs® earplug was in the cap closed mode compared to the cap open mode at all nominal test levels. The mean and standard deviation (SD) IPIL values were 26.3 (1.6) dB SPL at 150 dB<sub>P</sub>, 30.7 (1.2) dB SPL at 160 dB<sub>P</sub>, and 33.6 (0.7) dB SPL at 170 dB<sub>P</sub> in the cap open mode, and 36.7 (0.9) dB SPL at 150 dB<sub>P</sub>, 37.8 (1.3) dB SPL at 160 dB<sub>P</sub>, and 38.3 (0.7) dB SPL at 170 dB<sub>P</sub> in the cap closed mode (see Table 1). These results suggest that, when properly fit and functional, the Battleplugs® can adequately protect (i.e., reduce exposure to less than 140 dB<sub>P</sub>) against impulses below 173.6 dB<sub>P</sub> in the cap open mode, and below 178.3 dB<sub>P</sub> in the cap closed mode.

**Table 1.**

*Battleplugs® mean (SD) IPIL value (in dB) for all test conditions.*

|            | 150 dB <sub>P</sub> | 160 dB <sub>P</sub> | 170 dB <sub>P</sub> |
|------------|---------------------|---------------------|---------------------|
| Cap Open   | 26.3 (1.6)          | 30.7 (1.2)          | 33.6 (0.7)          |
| Cap Closed | 36.7 (0.9)          | 37.8 (1.3)          | 38.3 (0.7)          |

## Introduction

The corded Moldex<sup>®</sup> Battleplugs<sup>®</sup> Impulse Protection Earplug (Battleplugs<sup>®</sup>; Moldex-Metric Inc., Culver City, CA) is a dual-mode, triple-flange earplug that is available in four sizes: x-small, small, medium and large. The dual mode function of the Battleplugs<sup>®</sup> allows the user to manually select a cap open (i.e., filtered) or cap closed (i.e., unfiltered) mode. Per the manufacturer, the open cap allows for communication while maintaining protection from impulse noise (e.g., gunfire), whereas the closed cap provides continuous and impulse noise protection (Moldex-Metric Inc, n.d.). In order to reuse, the Battleplugs<sup>®</sup> should be cleaned according to manufacturer instructions (Moldex-Metric Inc, n.d.).

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 the user’s noise hazard below the 140 dBP limit is the use of hearing protection devices (HPDs; e.g., earplug or earmuff).

To calculate whether the issued HPD will reduce the impulse noise exposure 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 value of the Battleplugs<sup>®</sup> at 150, 160, and 170 dBP was unknown. This report describes the methods and results used to determine the IPIL value for the Moldex<sup>®</sup> Battleplugs<sup>®</sup> Impulse Protection Earplug in the cap open and cap closed modes. In addition to reporting an overall device IPIL, 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

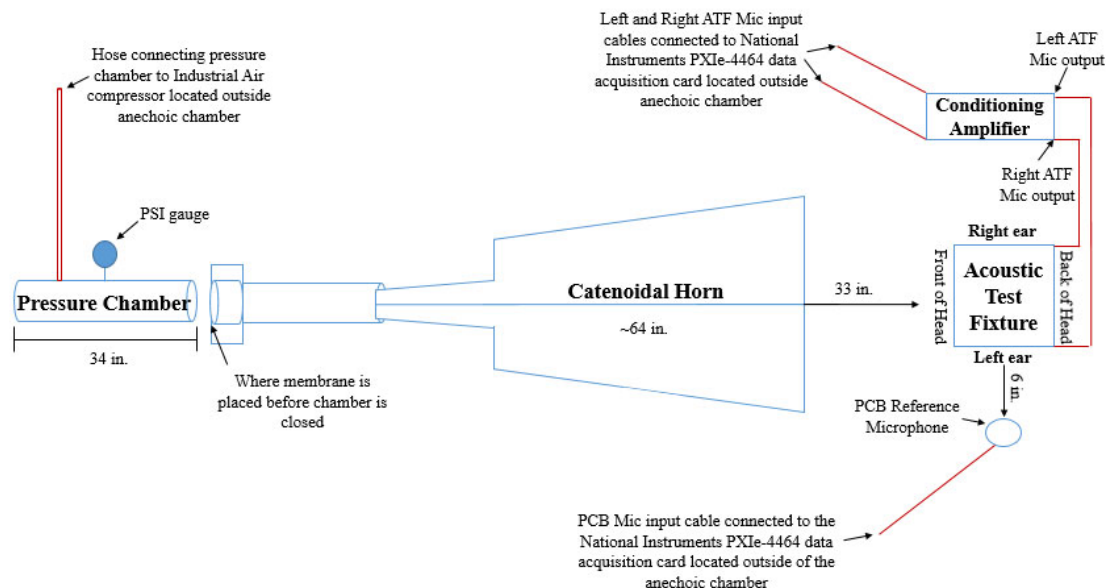
the pressurized chamber and the catenoidal tube horn to enable pressurization of the air chamber. Each polyester sheet was 0.001 in. (1.0 mil, 25.4 micrometer [ $\mu\text{m}$ ]) thick. For each trial at 160 and 170 dB, a 7 in. (17.8 cm) by 7 in. (17.8 cm) acetate sheet (Grafix Plastic, Maple Heights,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

All waveforms were recorded with the ANSI/ASA S12.42 (2010) compliant GRAS 45CB acoustic test fixture (ATF) along with GRAS RA0045-S7 Ear Simulators (GRAS Sound and Vibration, Twinsburg, OH). 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  $0^\circ$  elevation and  $0^\circ$  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 microphone, the left ATF microphone, and the right ATF microphone were calibrated prior to data collection at 124 dB sound pressure level (SPL) using a 250 hertz (Hz) tone. A diagram depicting the aerial view of the NSMRL 4 in. (10.2 cm) shock tube and test system is presented in Figure 1.

**Figure 1.**

*Diagram of the NSMRL Acoustic Shock Tube and ATF.*



**Data Acquisition System.** The data acquisition system (NI chassis PXIe-1071 with NI PXIe-4460 and NI PXIe-4464; National Instruments Corp., Austin, TX) was controlled by a standalone laptop computer running project specific software (LabVIEW; National Instruments Corp., Austin, TX). The data acquisition system was connected to the laptop using an MXI cord and host interface card (NI PXIe-8360). The software controlled the acquisition of waveforms from the three source microphones (left ATF microphone, right ATF microphone, and a reference microphone) at a sampling rate of 204.8 k Samples/second during each impulse recording. Pre-trigger

settings were 1024 samples per 0.005 seconds, with a trigger level of 110 dB SPL. Each recording was 0.3 seconds in duration.

Rather than using an ANSI/ASA S12.42-2010 standardized in-line analog external Bessel filter (6<sup>th</sup> order, corner frequency 20.0 kHz [3 dB down]) to filter impulses during data acquisition, anti-alias filtering was accomplished by an analog filter and a digital filter. 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. A second digital Butterworth filter (6th 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. These deviations were made due to equipment and software limitations.

The custom-written software program saved all recorded waveforms as files (\*.tdms), which were exported and converted to data files using an additional custom software programming script. The script compiled the reference PCB microphone, left ATF microphone, and right ATF microphone channels into a file (\*.mat) that saved variables for input to analysis script (MATLAB) similar to the script provided in Annex H of the ANSI/ASA S12.42-2010 standard. Minor alterations were made to the analysis script in order to accept 150 dBP, 160 dBP, and 170 dBP data (see Data Analysis below).

**Hearing Protection Device Samples.** Five samples (See Figures 2 and 3 for examples) of the Moldex<sup>®</sup> Battleplugs<sup>®</sup> Impulse Protection Earplugs (Manufacturer Product Number: 6498) were tested in accordance with ANSI/ASA S12.42-2010. All samples were medium size. Each sample, consisting of one set of two earplugs, was randomly assigned a number 1 through 5. Each earplug in the sampled set was labeled 'L' for left or 'R' for right to indicate which ATF ear they were to be inserted for all trials.

[THIS SPACE INTENTIONALLY LEFT BLANK]

**Figure 2.**

*Photograph of a Battleplugs® (Cap Open) Earplug Sample.*



**Figure 3.**

*Photograph of a Battleplugs® (Cap Closed) Earplug Sample.*



### **Procedure**

Two HPD modes (i.e., cap open [filtered], cap closed [unfiltered]) were tested for each of the five samples of the Battleplugs®. Each HPD sample (left and right earplug pair) was fitted to the ATF twice, resulting in two trials (trials A and B) per sample, and 10 total trials per nominal level test condition (150, 160, and 170 dBP) for each HPD mode (i.e., cap open, cap closed). No samples of the HPD were rejected. To achieve an appropriate fit that would provide maximum attenuation, each sample was

expertly fitted to the ATF in accordance with instructions on the device packaging. The manufacturer fitting guidelines stated that all samples be inspected for any wear, cracks, or damage prior to use. Once inspected, the filter cap was placed in the open or closed position and the earplug was inserted into the ATF ear canal. Appropriate fit of each earplug was confirmed by pulling gently on the earplug to confirm it did not easily come out of the canal.

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 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., HPD inserted) and unoccluded (i.e., without the HPD inserted) test configurations. For all occluded measures, the earplugs were fitted on the ATF in accordance with the specifications outlined in ANSI/ASA S12.42-2010. Each HPD sample was exposed to two impulses at each tested nominal level in each test 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 (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 (i.e., without HPD) test configuration. Calibrations were not completed at the 170 dBP nominal level due to exposure limitations of the ATF right and left microphones.

## **Data Analysis**

MATLAB (Natick, MA) was used to calculate IPIL values at the 150, 160, and 170 dBP 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 dBP nominal levels. The mean transfer function for each ear at each level was then calculated, and the first elements of the transfer functions were 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 150 and 160 dBP nominal level. The difference of the maximum absolute values of

the calculated values and the measured values was then calculated, converted to dB SPL, and displayed.

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

## Results

At all nominal test levels, greater IPILs were obtained when the earplug filter cap was closed (i.e., unfiltered) compared to when it was open (i.e., filtered). As shown in Table 2, the overall mean (SD) IPIL value in the cap open mode was 26.3 (1.6) dB for the 150 dBP test condition, 30.7 (1.2) dB for the 160 dBP test condition, and 33.6 (0.7) dB for the 170 dBP test condition. The overall mean (SD) IPIL value in the cap closed mode was 36.7 (0.9) dB for the 150 dBP test condition, 37.8 (1.3) dB for the 160 dBP test condition, and 38.3 (0.7) dB for the 170 dBP test condition. Calculated IPIL values for all individual sample trials in the cap open mode ranged between 23.5 and 29.2 dB at 150 dBP, between 28.8 and 33.0 dB at 160 dBP, and between 31.9 and 34.9 dB at 170 dBP, while all tested sample trials in the cap closed mode ranged between 35.2 and 38.6 dB at 150 dBP, between 35.9 to 40.1 dB at 160 dBP, and between 37.0 to 39.4 dB at 170 dBP.

**Table 2.**

*Mean (SD) IPIL values (in dB) for Tested Battleplugs® Samples.*

|                                | 150 dBP    |            |            |            | 160 dBP    |            |            |            | 170 dBP    |            |            |            |
|--------------------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
|                                | Open       |            | Closed     |            | Open       |            | Closed     |            | Open       |            | Closed     |            |
|                                | Right      | Left       | Right      | Left       | Right      | Left       | Right      | Left       | Right      | Left       | Right      | Left       |
| HPD 1, Trial A                 | 24.6       | 24.7       | 35.2       | 36.2       | 31.2       | 31.4       | 36.2       | 36.7       | 33.4       | 33.7       | 37.0       | 38.0       |
| HPD 1, Trial B                 | 27.1       | 26.7       | 36.0       | 36.7       | 29.5       | 29.8       | 35.9       | 37.0       | 34.2       | 34.1       | 37.0       | 38.3       |
| HPD 2, Trial A                 | 26.5       | 28.0       | 36.1       | 36.3       | 28.8       | 30.1       | 36.7       | 37.3       | 32.8       | 34.4       | 37.6       | 38.3       |
| HPD 2, Trial B                 | 28.6       | 29.2       | 36.0       | 36.9       | 31.0       | 32.7       | 38.0       | 37.9       | 33.0       | 34.3       | 38.3       | 38.4       |
| HPD 3, Trial A                 | 26.4       | 27.4       | 36.6       | 36.8       | 30.6       | 32.0       | 39.7       | 39.8       | 33.8       | 34.9       | 38.2       | 39.1       |
| HPD 3, Trial B                 | 26.2       | 27.5       | 38.1       | 36.8       | 30.4       | 31.7       | 40.1       | 39.8       | 33.5       | 34.6       | 39.4       | 39.3       |
| HPD 4, Trial A                 | 24.7       | 25.3       | 36.4       | 36.5       | 29.1       | 29.8       | 37.8       | 37.9       | 31.9       | 32.8       | 37.8       | 38.2       |
| HPD 4, Trial B                 | 23.5       | 24.2       | 36.9       | 35.7       | 30.9       | 31.9       | 38.2       | 37.1       | 33.9       | 33.8       | 38.9       | 38.0       |
| HPD 5, Trial A                 | 25.0       | 25.7       | 38.3       | 36.4       | 31.7       | 33.0       | 39.0       | 37.0       | 32.9       | 33.5       | 37.3       | 38.6       |
| HPD 5, Trial B                 | 27.3       | 28.3       | 38.6       | 37.4       | 29.1       | 30.0       | 37.0       | 36.2       | 33.0       | 33.9       | 39.1       | 38.3       |
| <b>Ear Specific Mean (SD)</b>  | 26.0 (1.5) | 26.7 (1.7) | 36.8 (1.1) | 36.6 (0.5) | 30.2 (1.0) | 31.2 (1.2) | 37.9 (1.4) | 37.7 (1.2) | 33.2 (0.7) | 34.0 (0.6) | 38.1 (0.9) | 38.5 (0.4) |
| <b>Level Overall Mean (SD)</b> | 26.3 (1.6) |            | 36.7 (0.9) |            | 30.7 (1.2) |            | 37.8 (1.3) |            | 33.6 (0.7) |            | 38.3 (0.7) |            |

The waveforms for all trials with the Battleplugs® filter cap open are provided in Appendices A to I and are color-coded green. The waveforms for all trials with the Battleplugs® filter cap closed are provided in Appendices J to R and are color-coded orange.

## **Discussion**

Results showed greater IPIL values when the Battleplugs® earplug was in the cap closed mode compared to the cap open mode at all nominal test levels (i.e., 150, 160, and 170 dBP). The overall mean IPIL value for the Battleplugs® in the cap open mode was 26.3 dB at 150 dBP, 30.7 dB at 160 dBP, and 33.6 dB at 170 dBP. The overall mean IPIL value for the Battleplugs® in the cap closed mode was 36.7 dB at 150 dBP, 37.8 dB at 160 dBP, and 38.3 dB at 170 dBP. Across ears, the individual trial mean IPIL values were found to vary as much as 5.7 dB at 150 dBP, 4.2 dB at 160 dBP, and 3.0 dB at 170 dBP in the cap open mode, and 3.4 dB at 150 dBP, 4.2 dB at 160 dBP, and 2.4 dB at 170 dBP in the cap closed mode. This may be due to a combination of inherent variance within the impulse system and/or variability in fit as a result of each HPD sample being fitted twice.

It is important to note that these results do not guarantee similar Battleplugs® product performance across all users and environments. Product performance may be impacted by factors such as variability in physical fit of the device and HPD configuration (e.g., single, double- or triple- configuration).

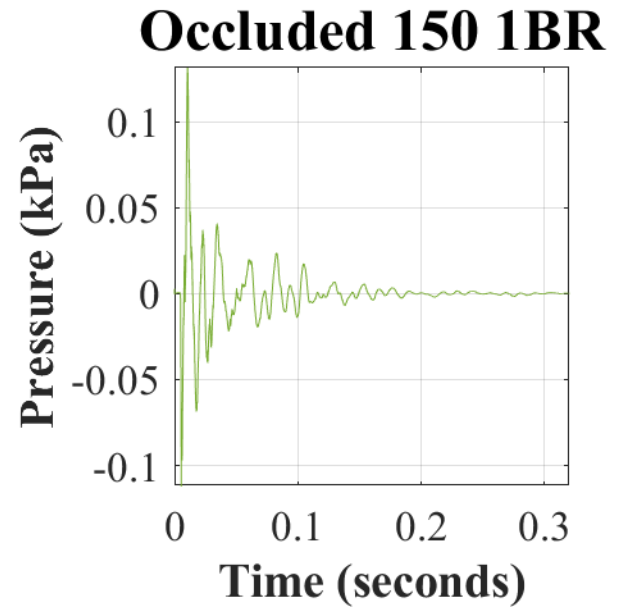
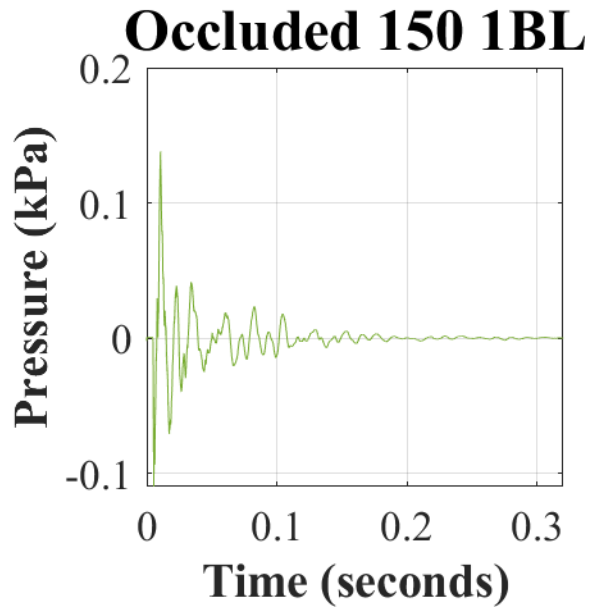
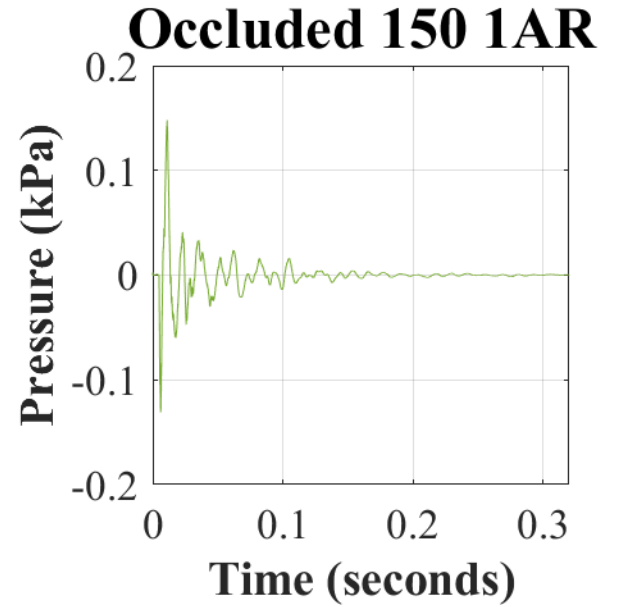
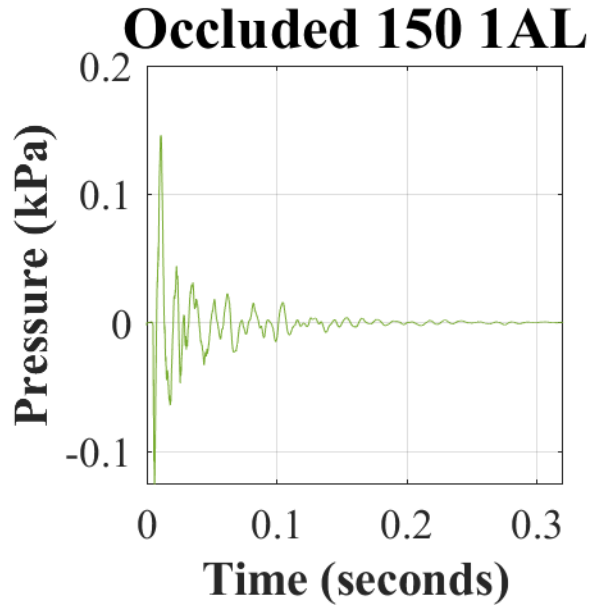
## **Conclusions**

This report described the process for determining the mean impulse peak insertion loss (IPIL) values provided by the Moldex® Battleplugs® Impulse Protection Earplug (Battleplugs®) at 150, 160, and 170 dBP nominal levels in both the cap open (i.e., filtered) and cap closed (i.e., unfiltered) modes. The calculated overall mean (SD) IPIL values for the Battleplugs® in the cap open mode were found to be 26.3 (1.6) dB at 150 dBP, 30.7 (1.2) dB at 160 dBP, and 33.6 (0.7) dB at 170 dBP. The calculated overall mean (SD) IPIL values for the Battleplugs® in the cap closed mode were found to be 36.7 (0.9) dB at 150 dBP, 37.8 (1.3) dB at 160 dBP, and 38.3 (0.7) dB at 170 dBP. The results of testing suggest that, when properly fit and functional, the Battleplugs® can adequately protect (i.e., reduce the exposure below 140 dBP) the user from impulses below 173.6 dBP in the cap open mode, and 178.3 dBP in the cap closed mode.

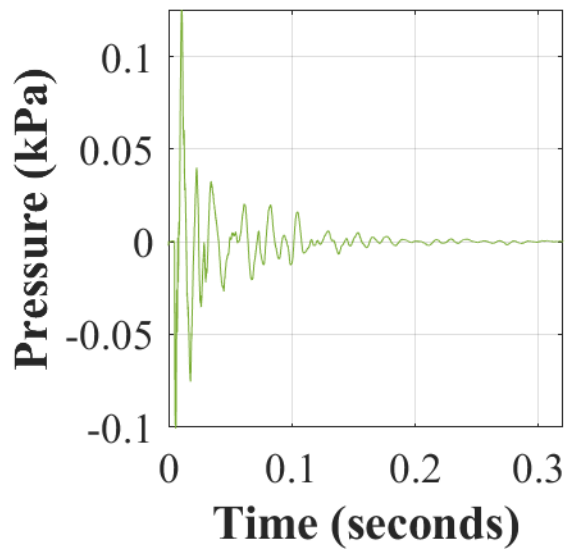
## References

- American National Standards Institute, Inc. (2010). *ANSI 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*. Acoustical Society of America.
- Department of Defense (2015). *MIL-STD-1474E Department of Defense Design Criteria Standard Noise Limits*. Department of Defense.
- Moldex-Metric Inc (n.d.). *Moldex Tactical Products Battleplugs®*. Culver City, CA: Moldex-Metric Inc.
- Moldex-Metric Inc (n.d.). *Battleplugs®: Fitting/Usage Instructions*. Culver City, CA: Moldex-Metric Inc.
- Office of the Under Secretary of Defense for Personnel and Readiness (2019). *DoD Instruction 6055.12 Hearing Conservation Program (HCP)*. Department of Defense.

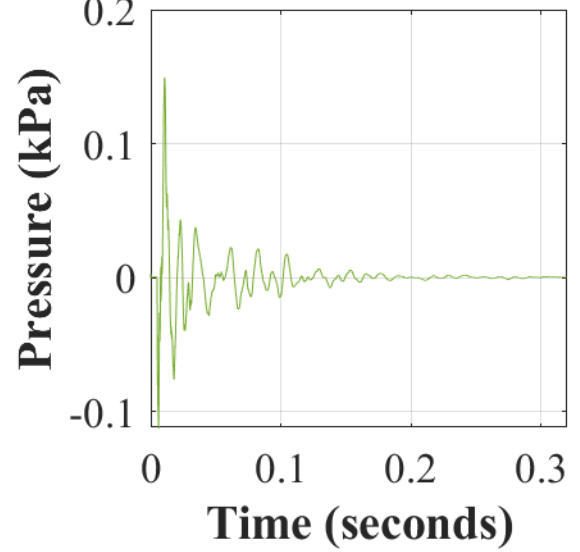
**Appendix A.** Recorded occluded (closed-ear) waveforms (in kilopascals [kPa]) over time (in seconds [s]) in response to 150 dBp with the Battleplugs® in the cap open mode.



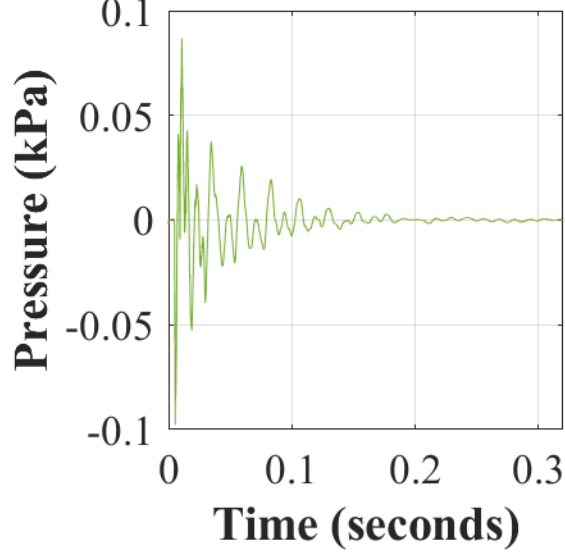
**Occluded 150 2AL**



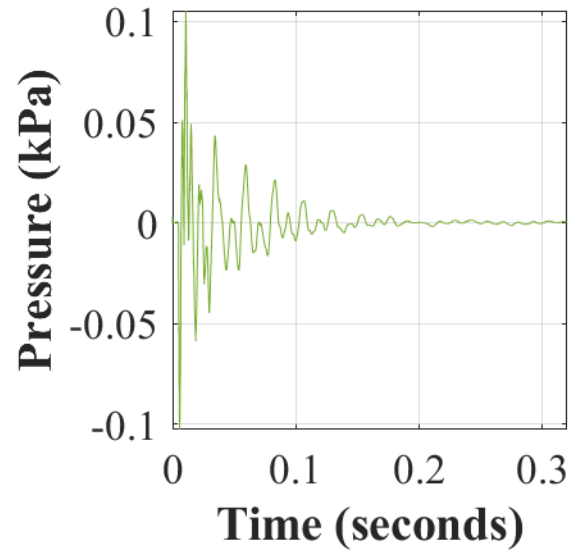
**Occluded 150 2AR**



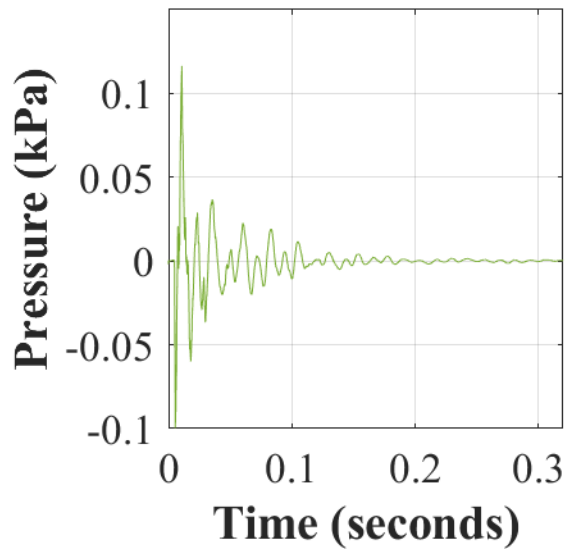
**Occluded 150 2BL**



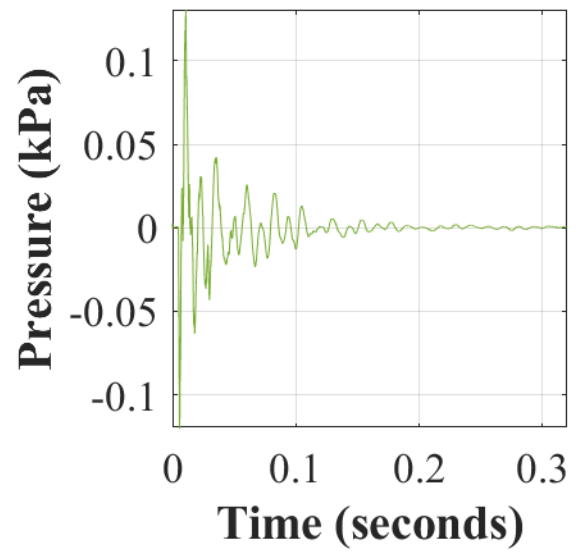
**Occluded 150 2BR**



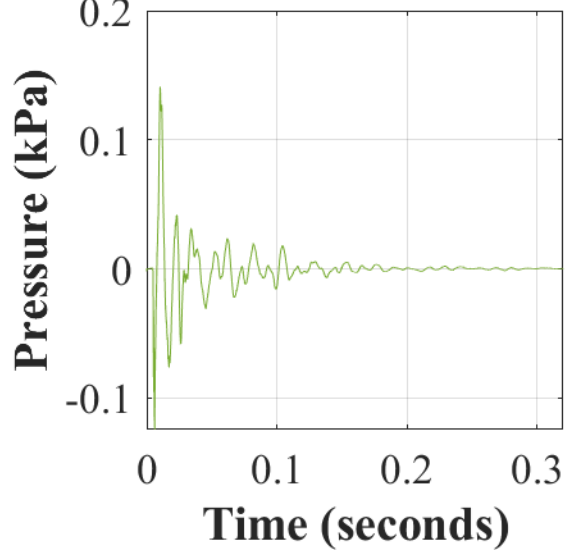
**Occluded 150 3AL**



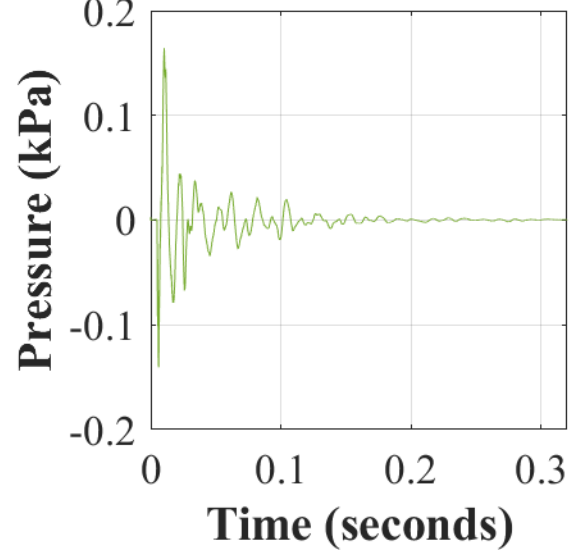
**Occluded 150 3AR**



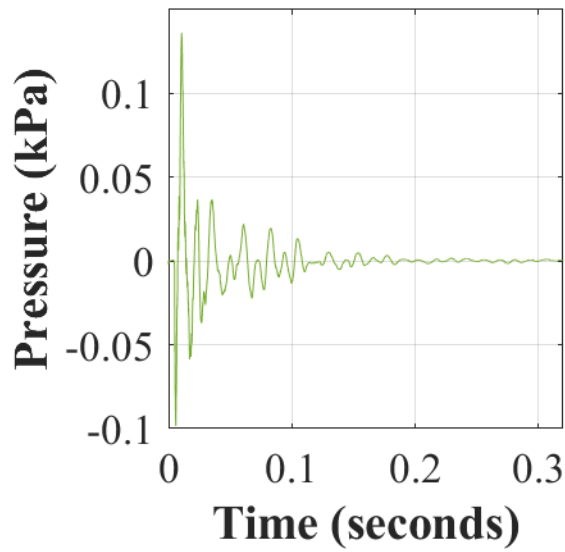
**Occluded 150 3BL**



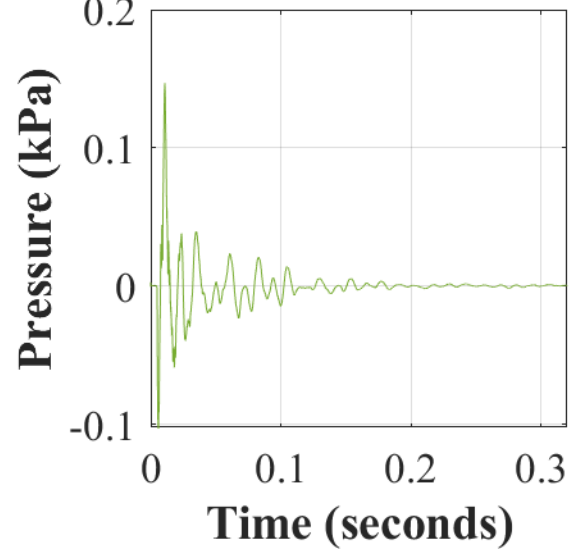
**Occluded 150 3BR**



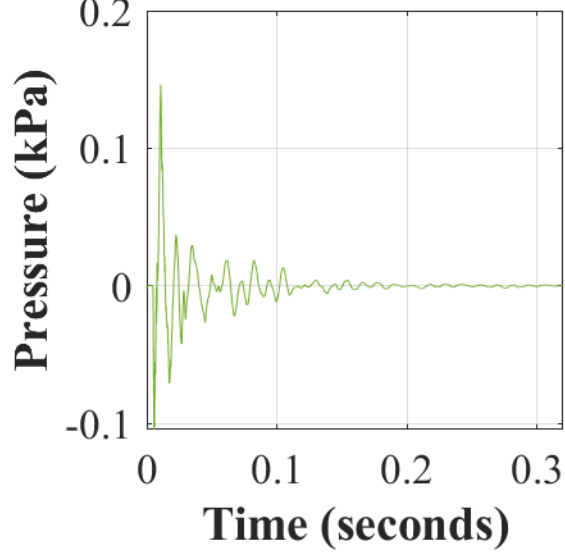
**Occluded 150 4AL**



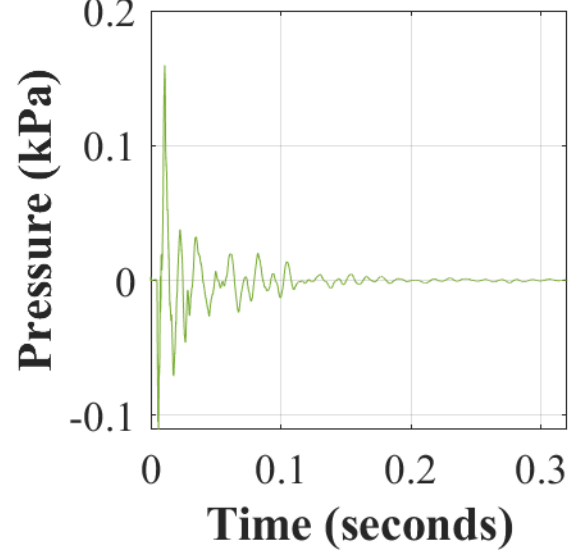
**Occluded 150 4AR**

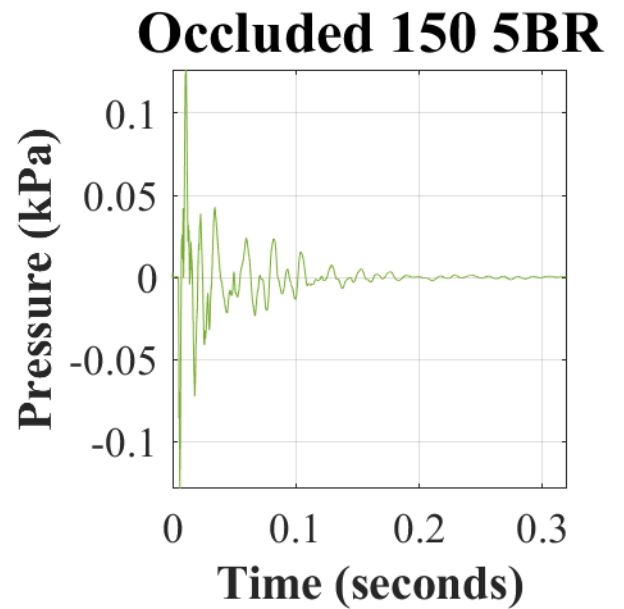
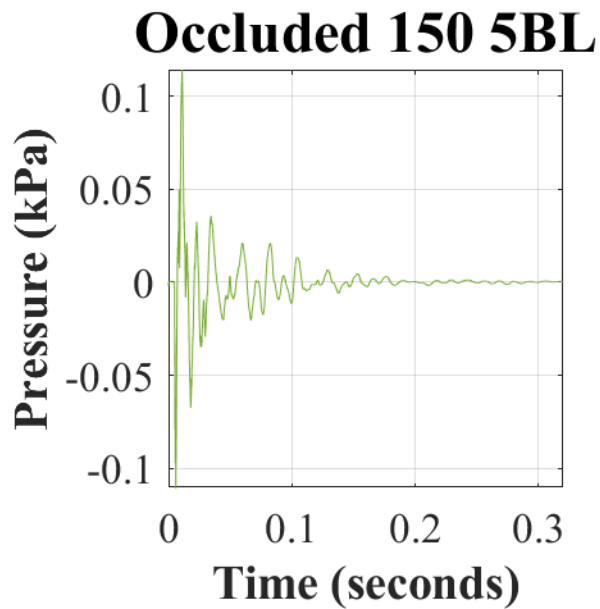
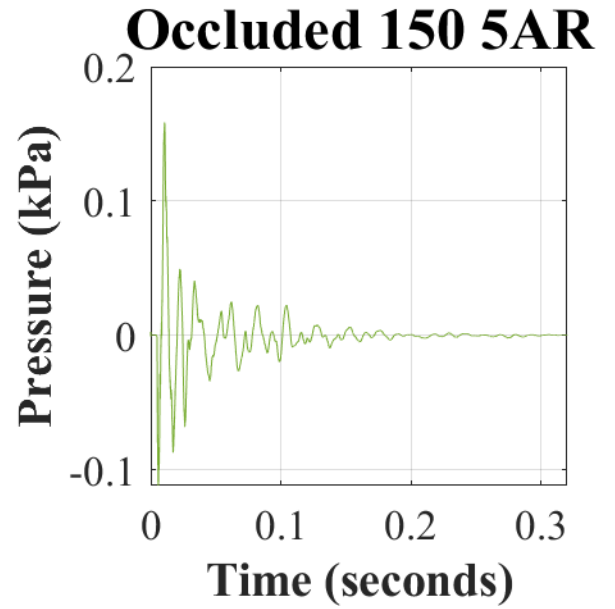
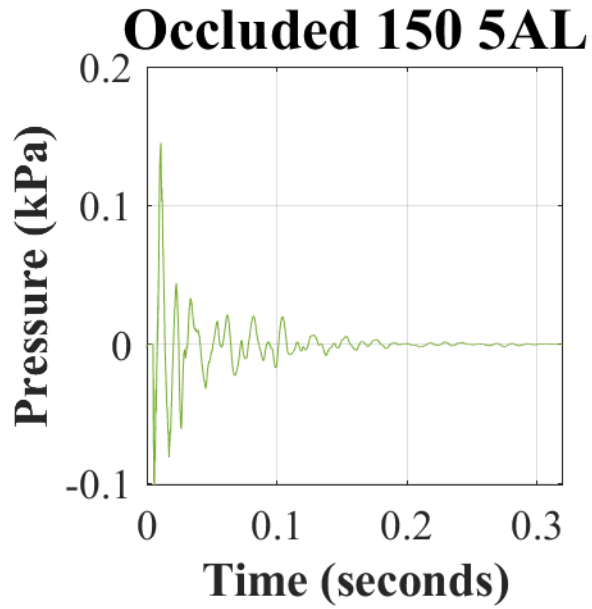


**Occluded 150 4BL**



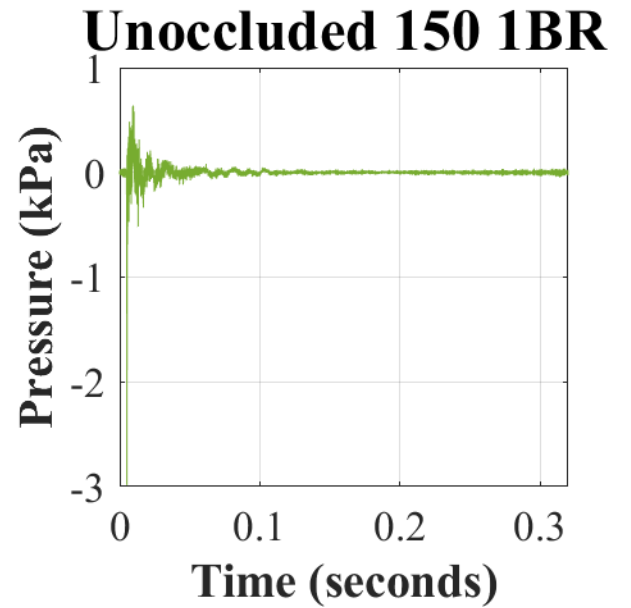
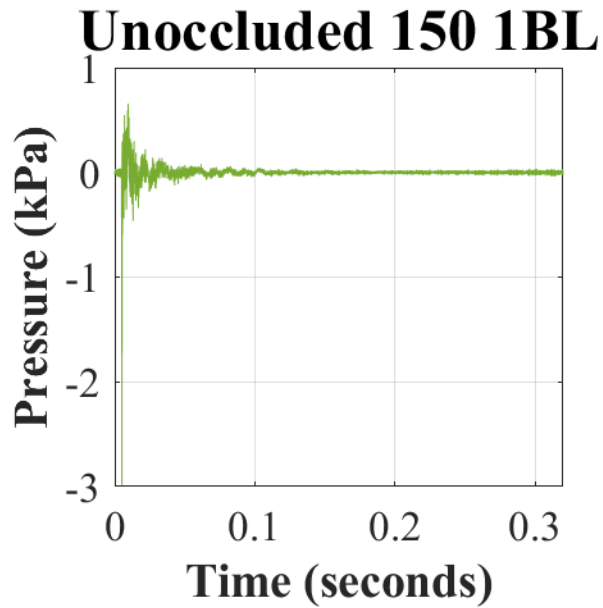
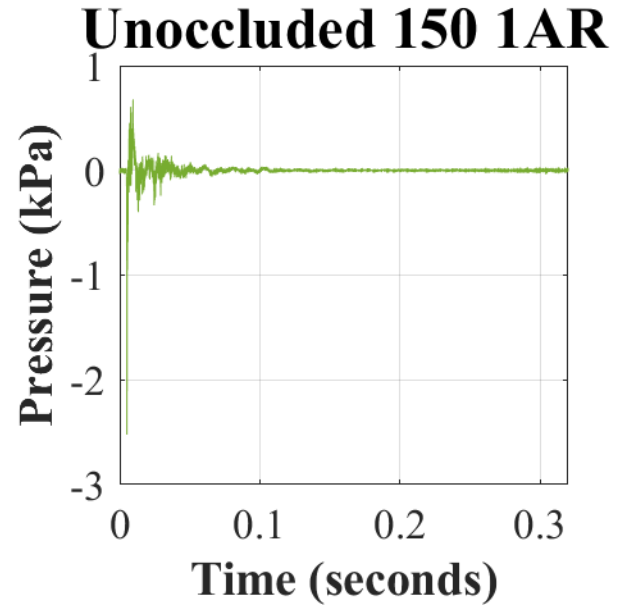
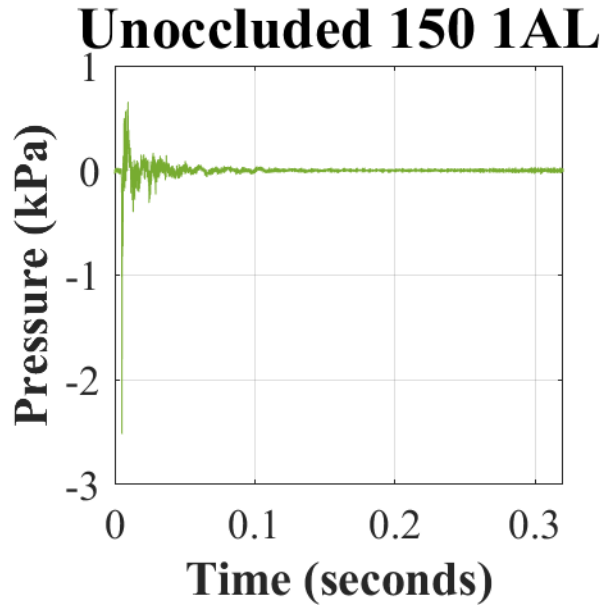
**Occluded 150 4BR**

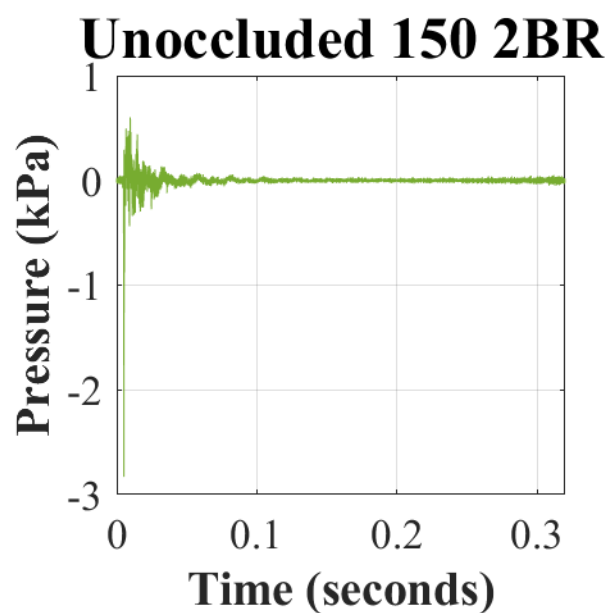
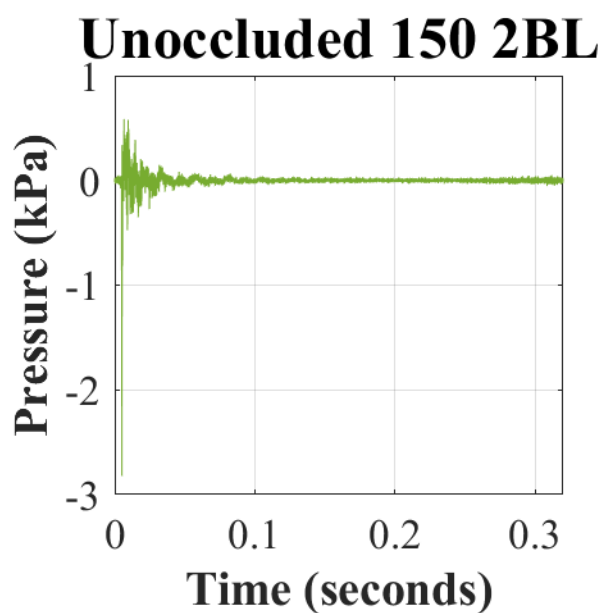
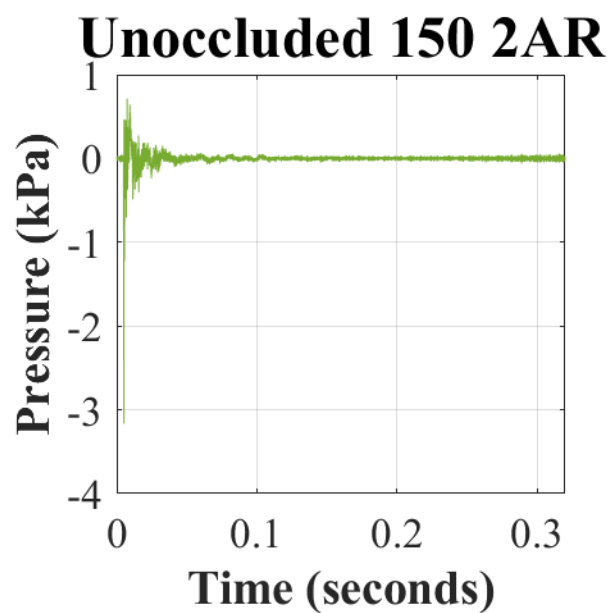
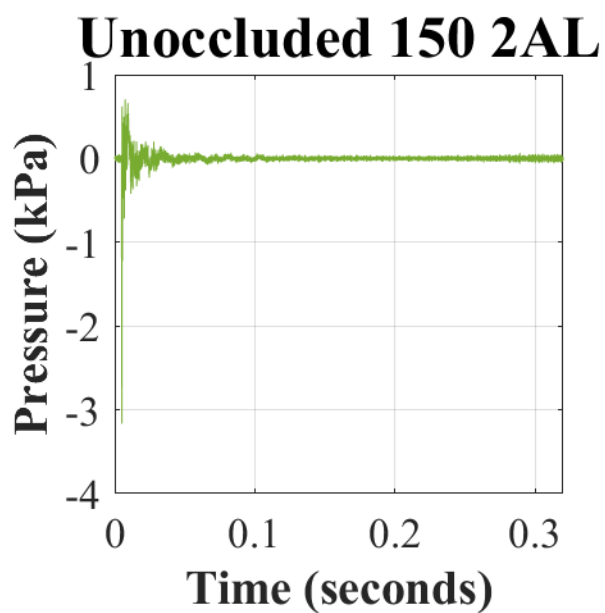


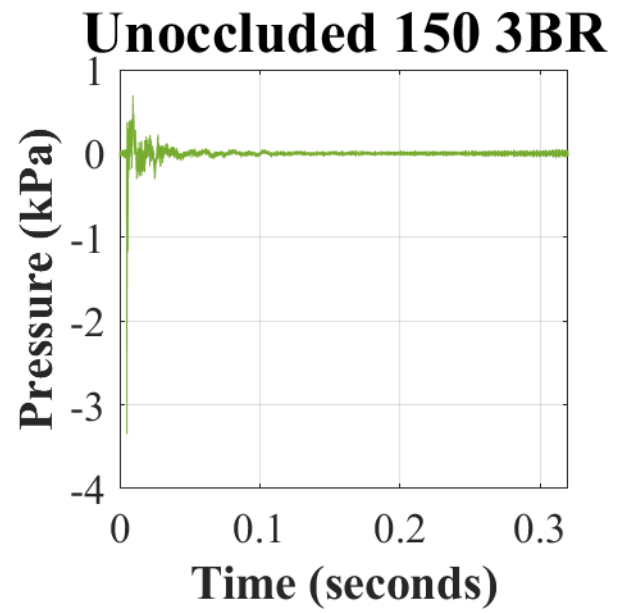
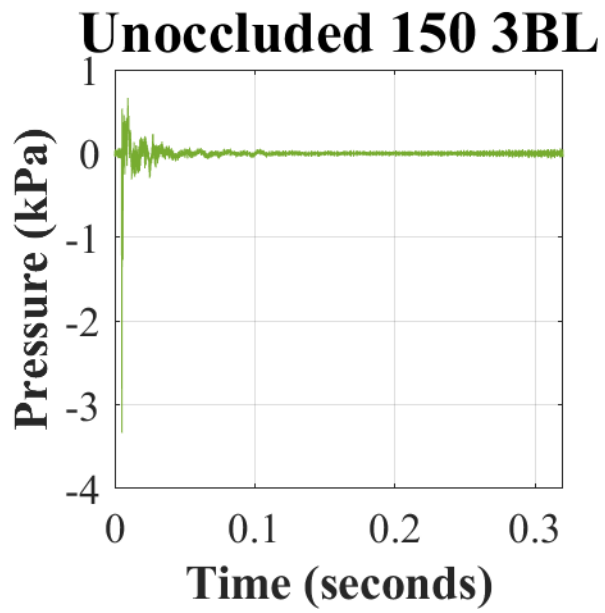
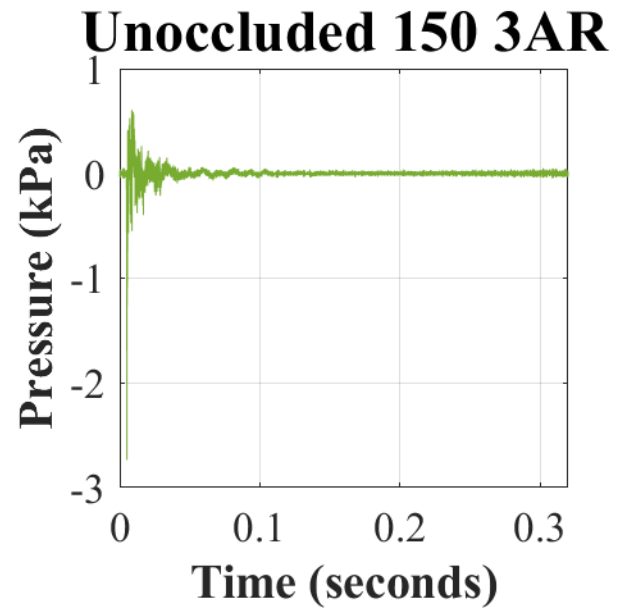
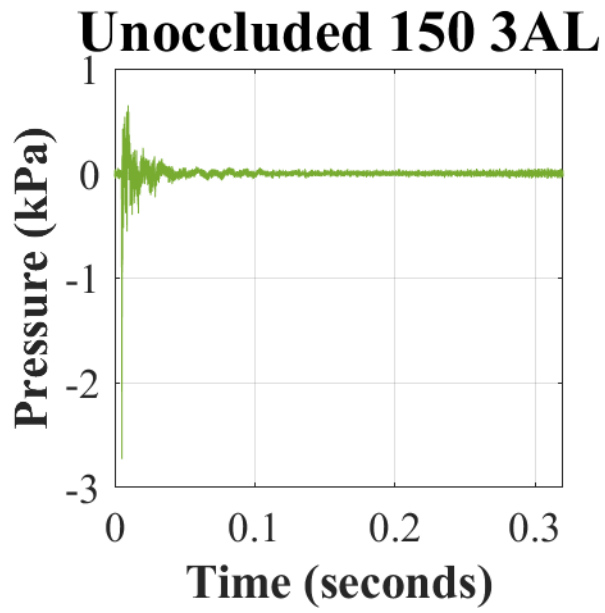


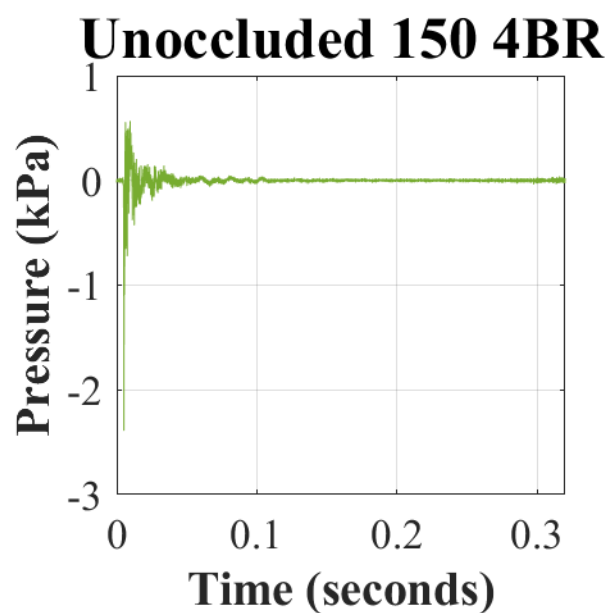
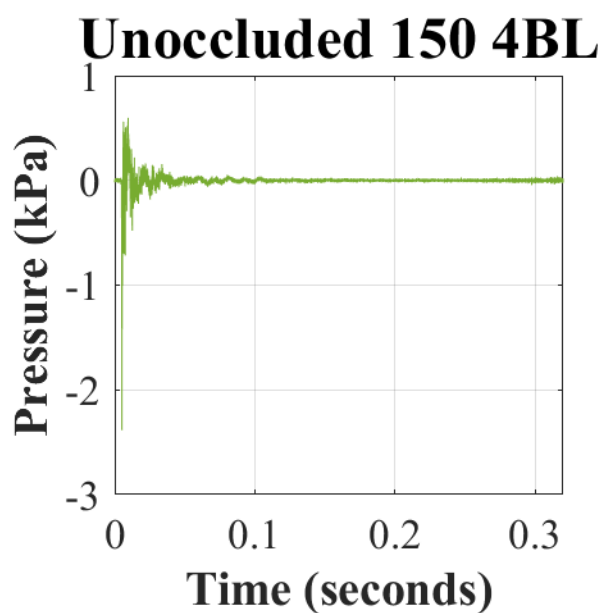
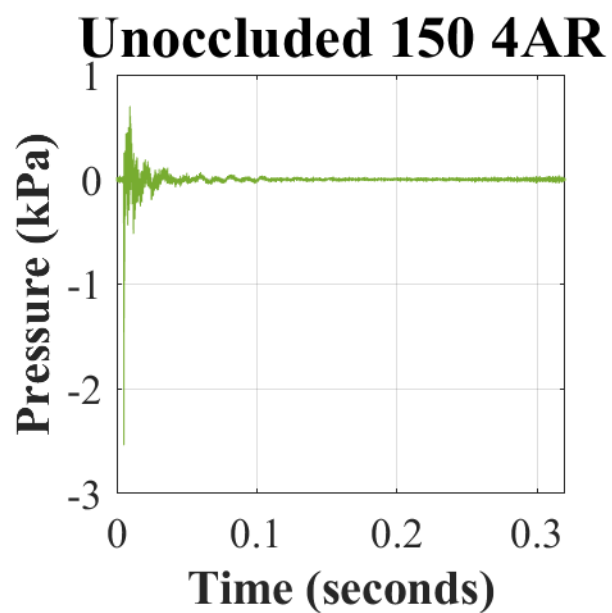
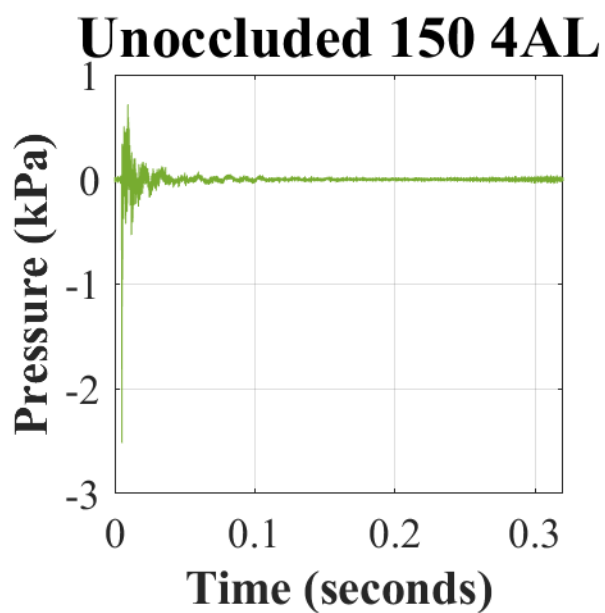
Note. The naming convention for all occluded waveforms is “Occluded LvL NnX”, where ‘Occluded’ is the test condition (i.e., ATF has the HPD donned), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or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

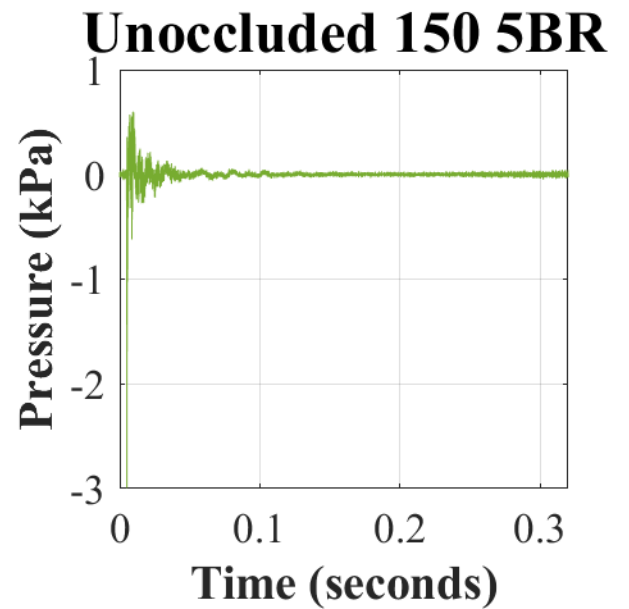
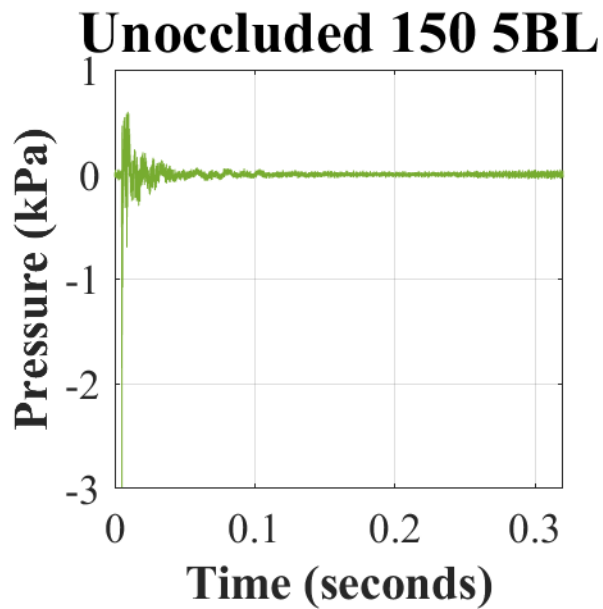
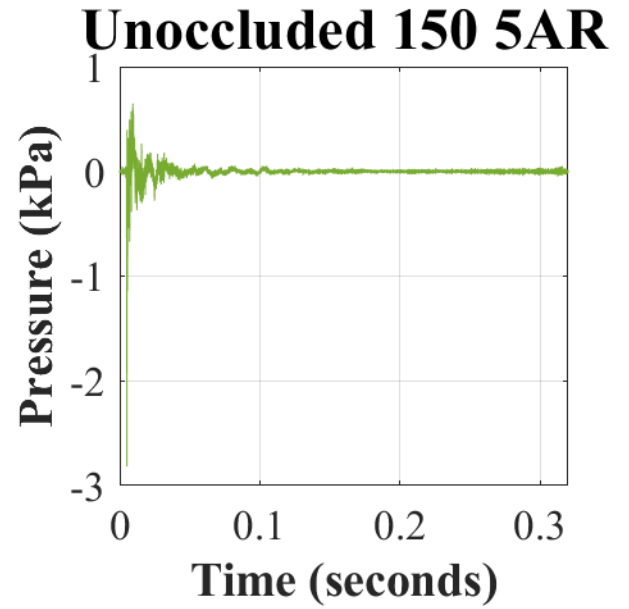
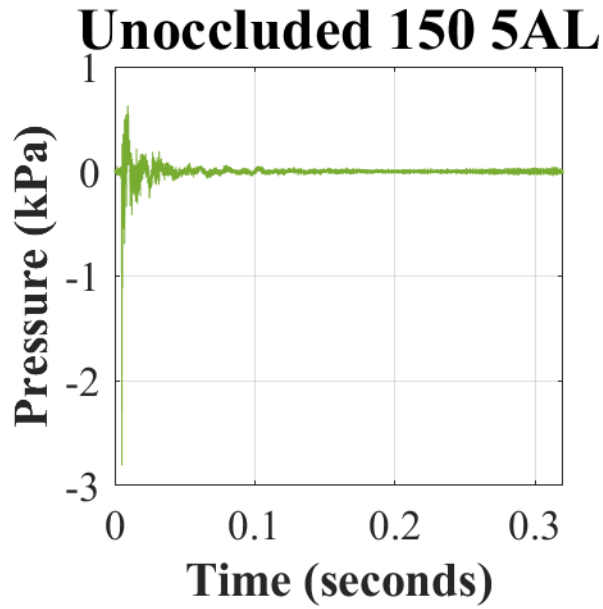
**Appendix B.** Estimated unoccluded (open-ear) waveforms (in kilopascals [kPa]) over time (in seconds [s]) in response to 150 dBp with the Battleplugs® in the cap open mode.







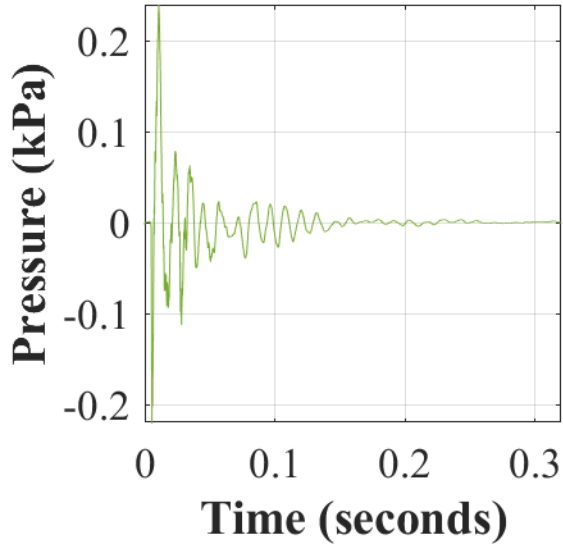




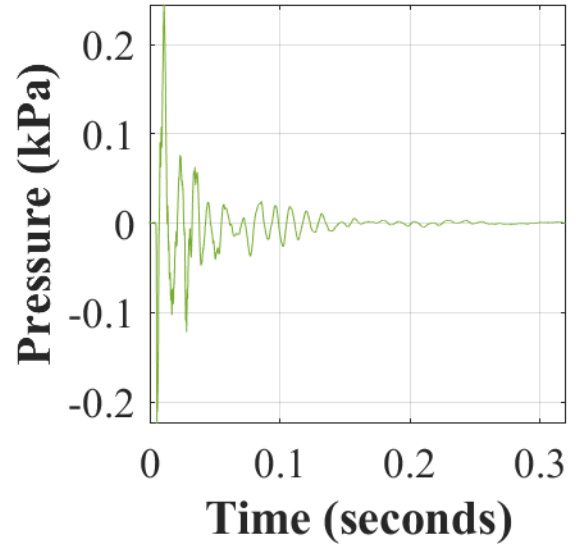
Note. The naming convention for all unoccluded waveforms is “Unoccluded LvL NnX”, where ‘Unoccluded’ is the test condition (i.e., ATF has the HPD doffed), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., 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 C.** Recorded occluded (closed-ear) waveforms (in kilopascals [kPa]) over time (in seconds [s]) in response to 160 dBp with the Battleplugs® in the cap open mode.

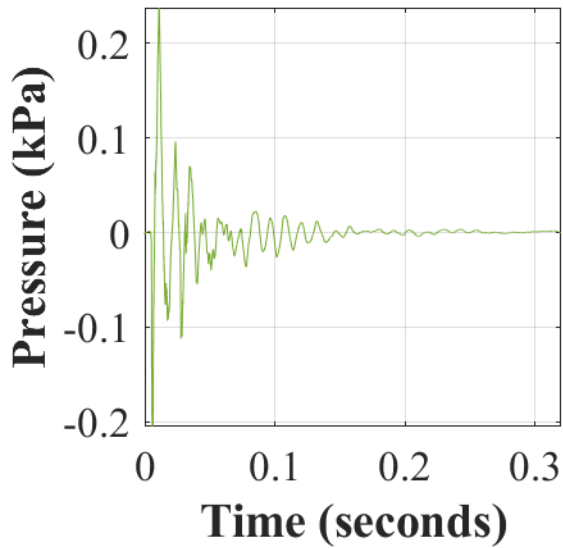
**Occluded 160 1AL**



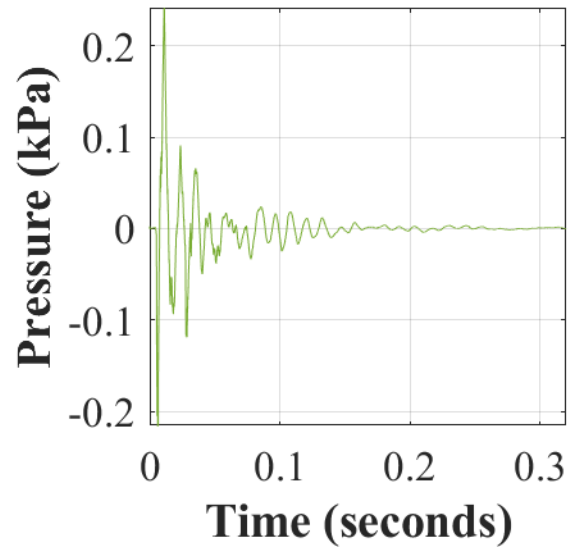
**Occluded 160 1AR**



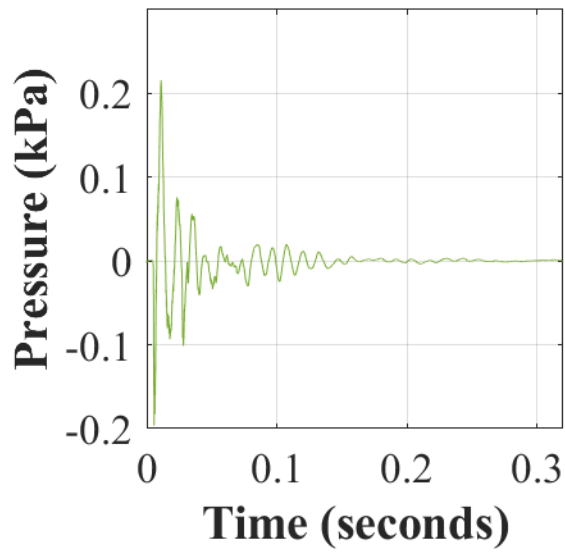
**Occluded 160 1BL**



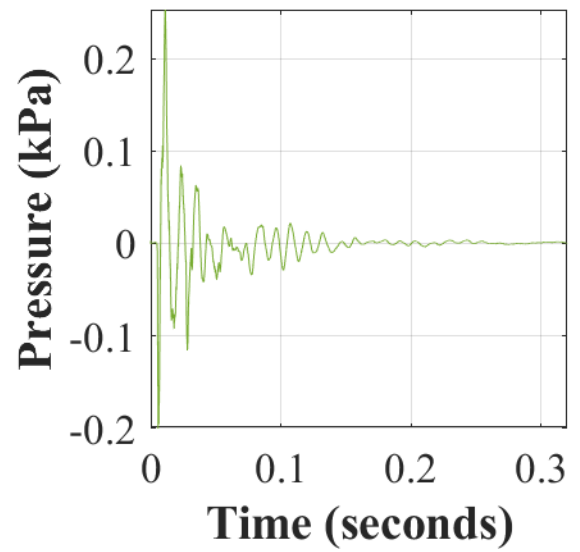
**Occluded 160 1BR**



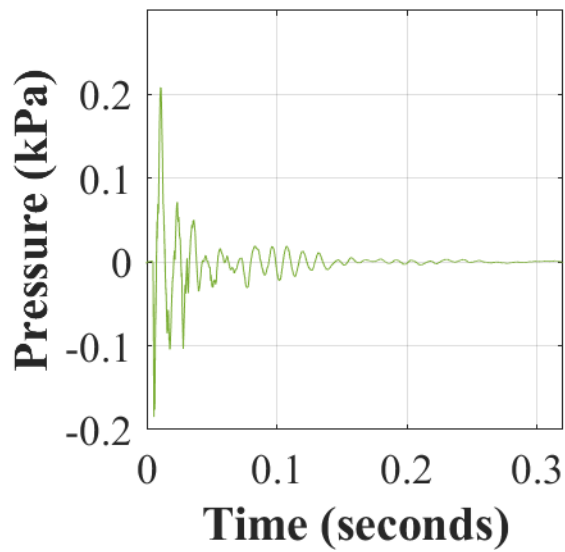
**Occluded 160 2AL**



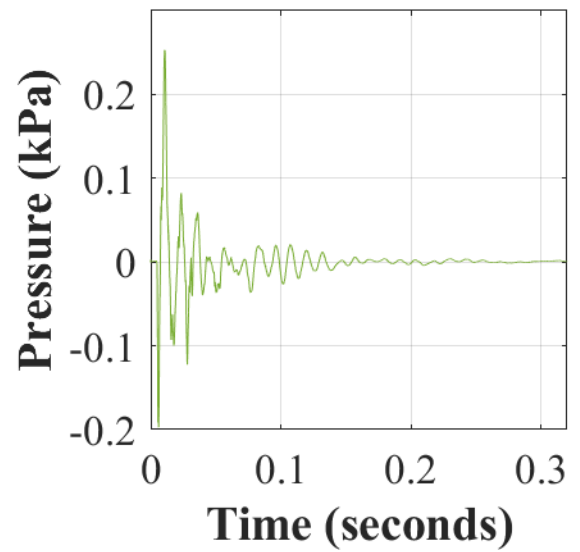
**Occluded 160 2AR**



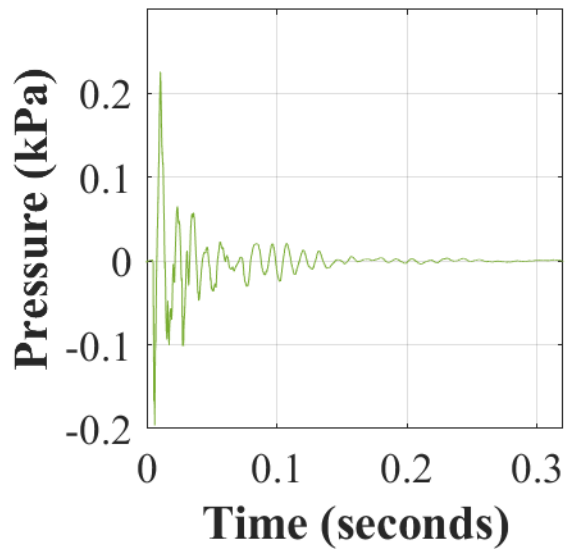
**Occluded 160 2BL**



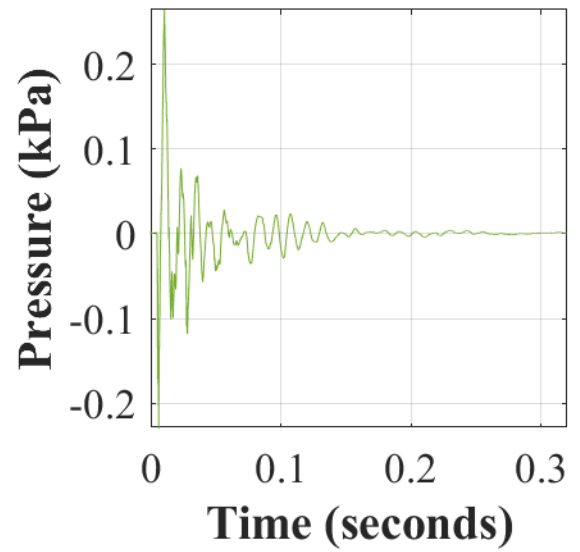
**Occluded 160 2BR**



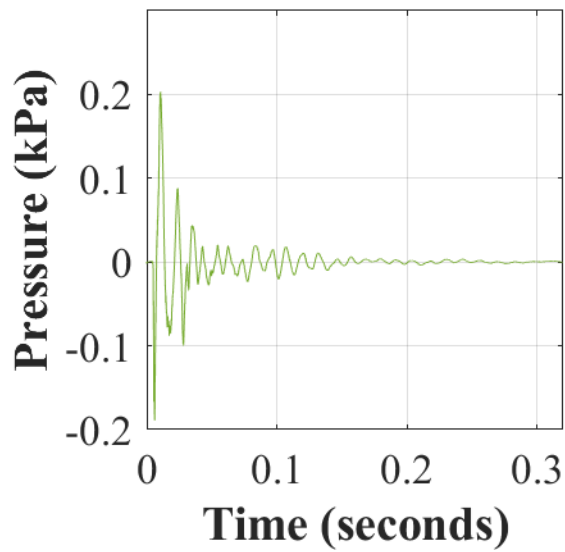
**Occluded 160 3AL**



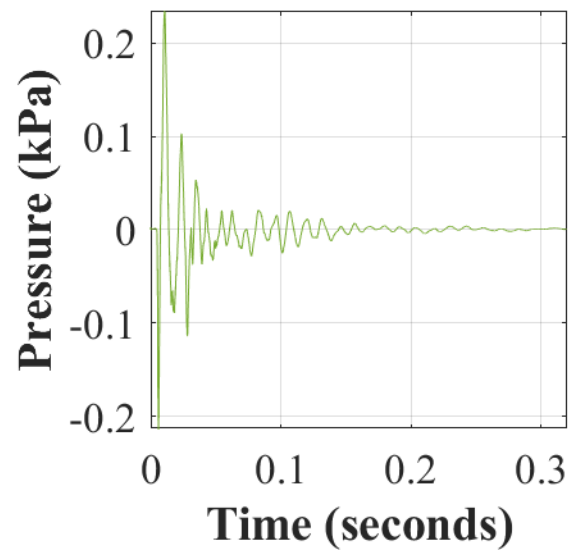
**Occluded 160 3AR**



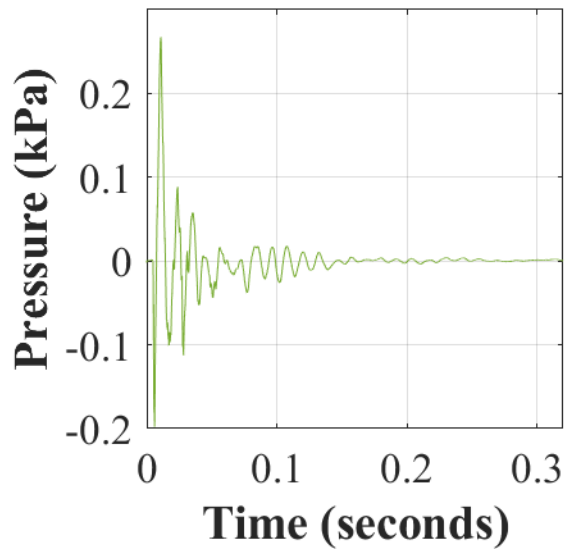
**Occluded 160 3BL**



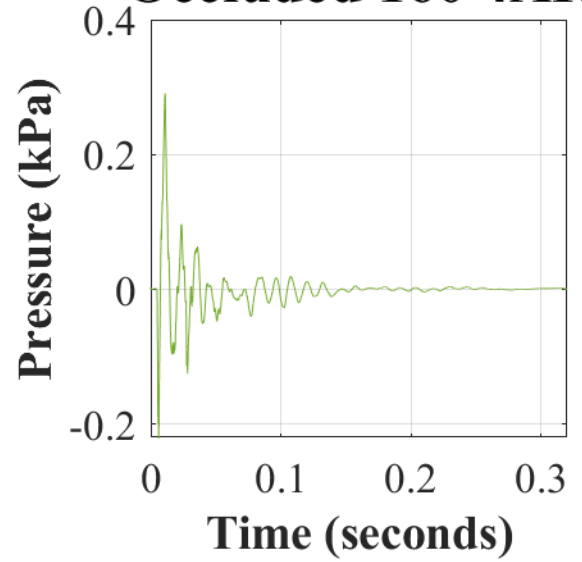
**Occluded 160 3BR**



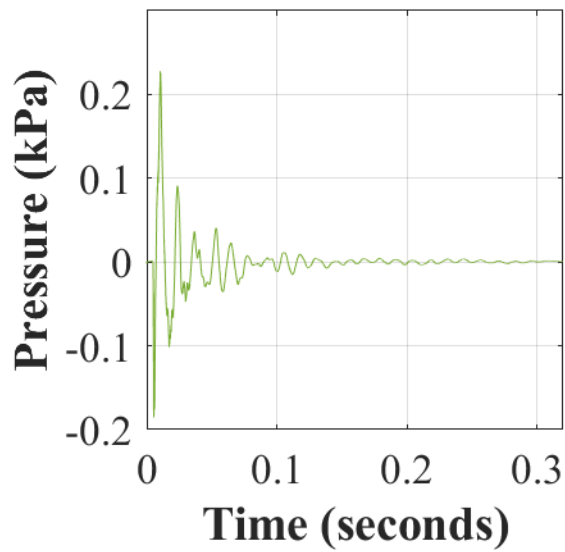
**Occluded 160 4AL**



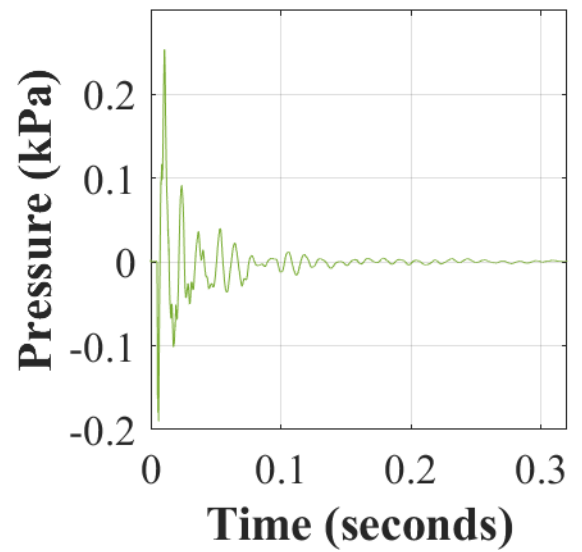
**Occluded 160 4AR**



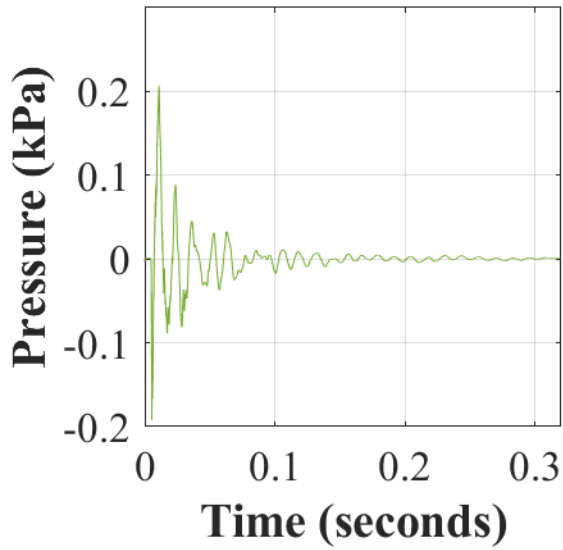
**Occluded 160 4BL**



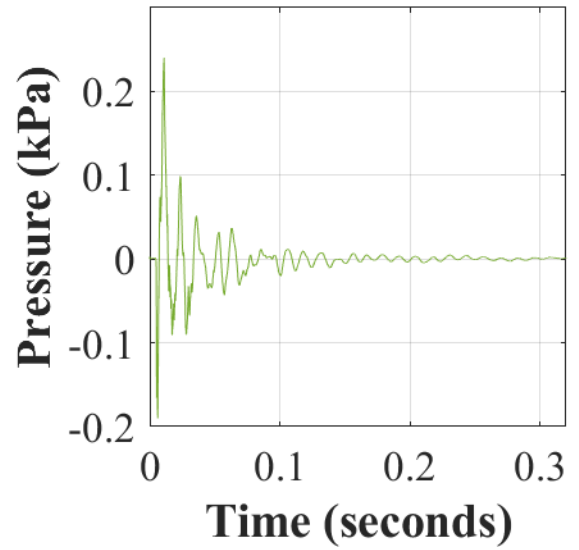
**Occluded 160 4BR**



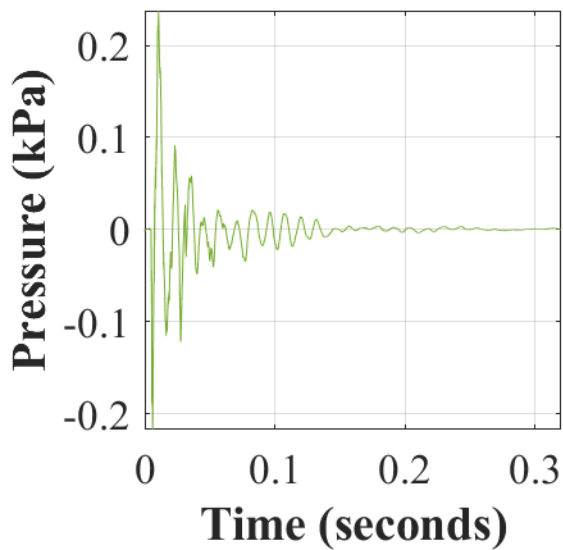
**Occluded 160 5AL**



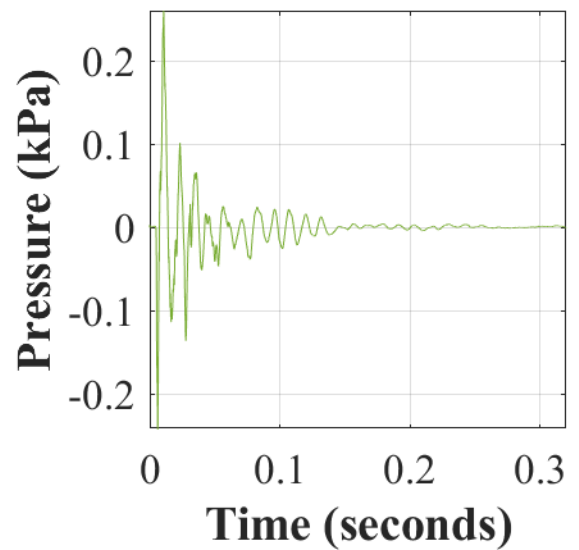
**Occluded 160 5AR**



**Occluded 160 5BL**

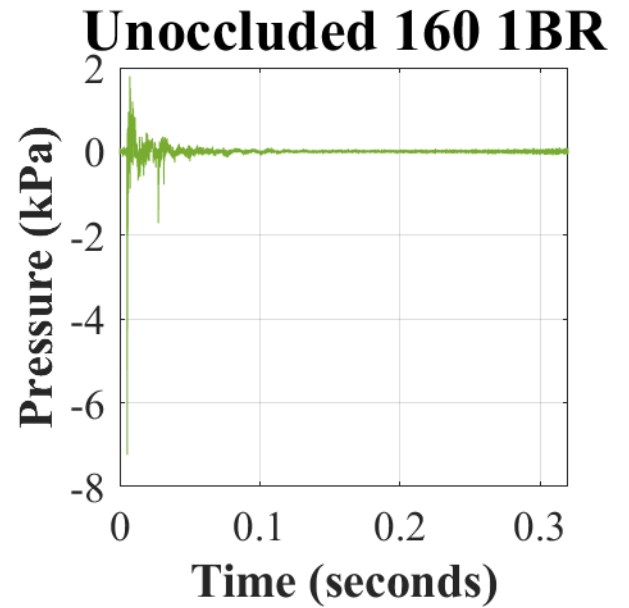
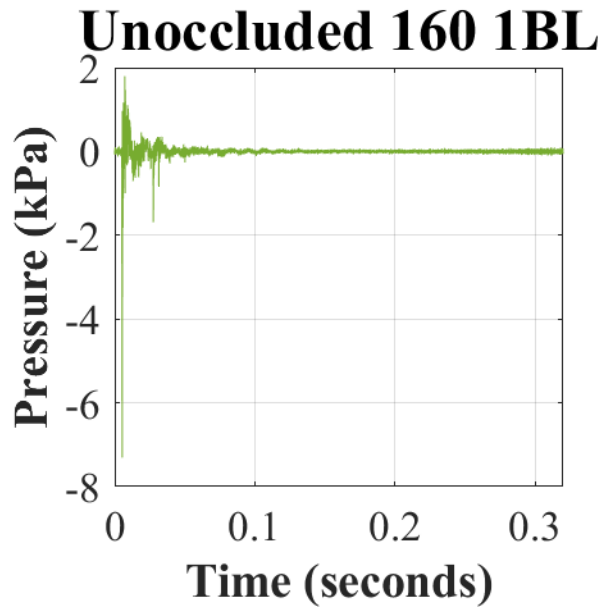
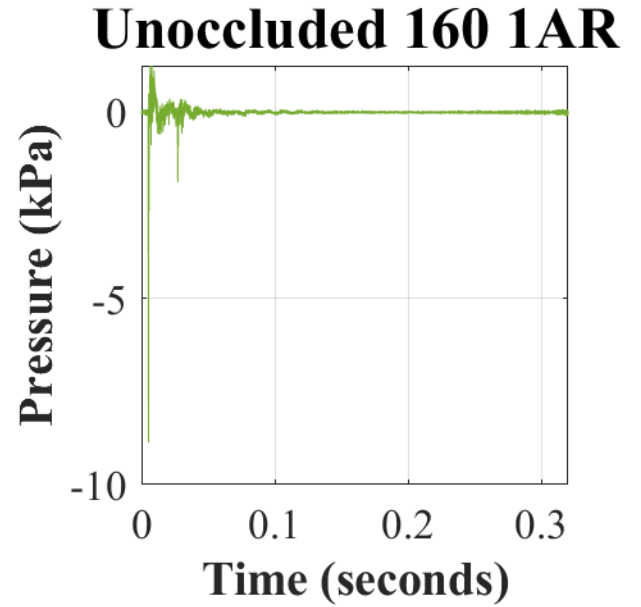
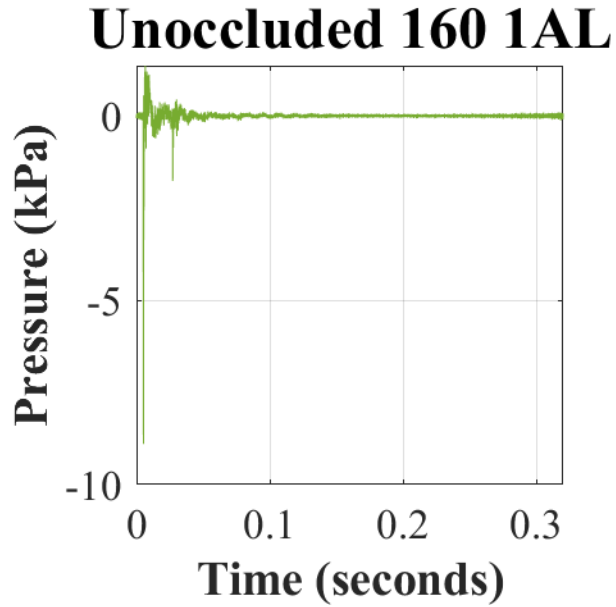


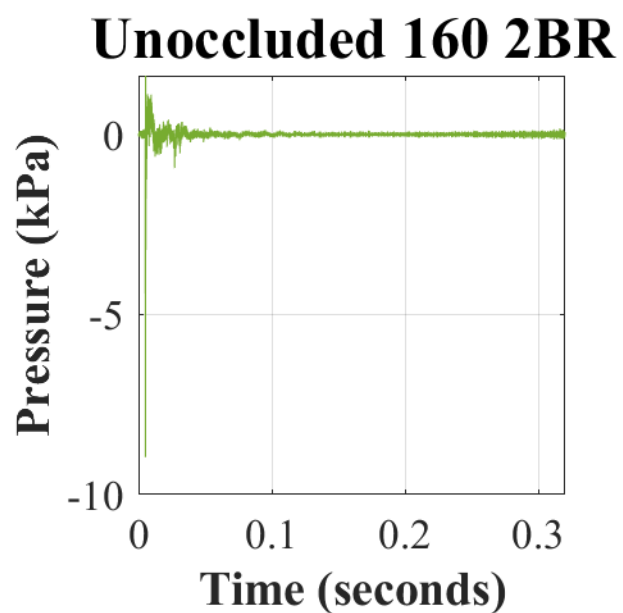
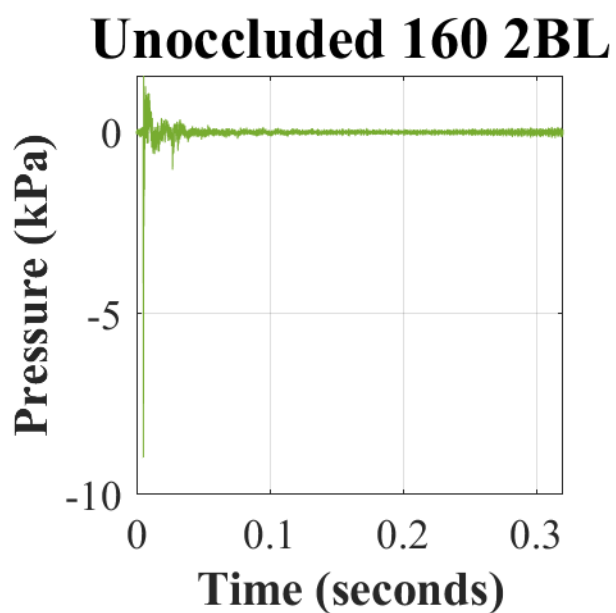
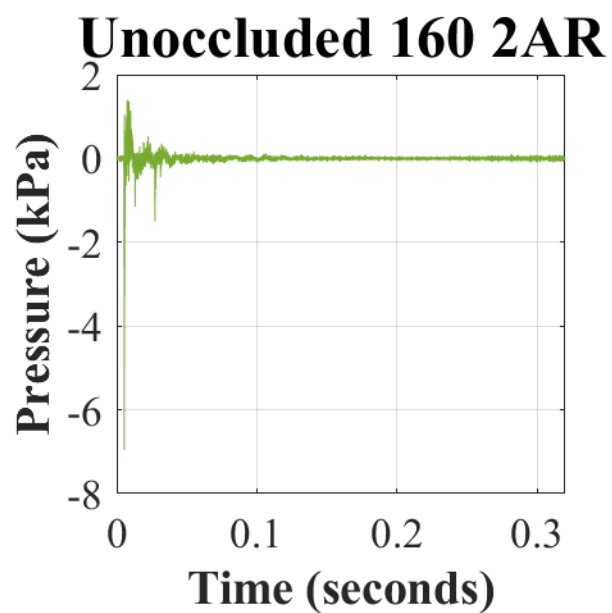
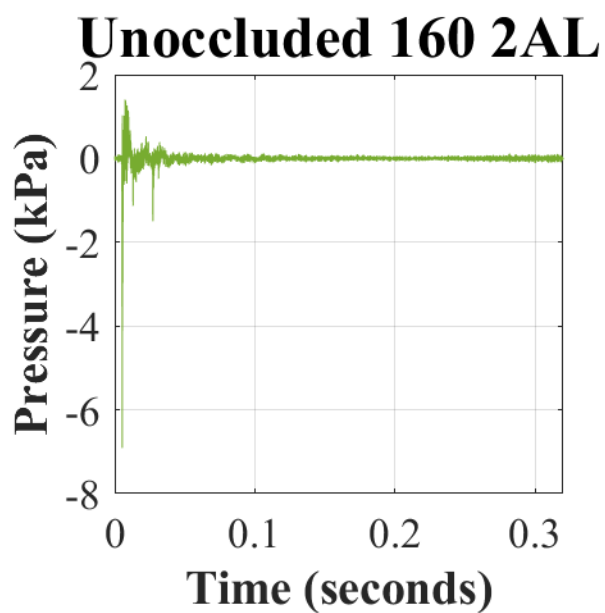
**Occluded 160 5BR**

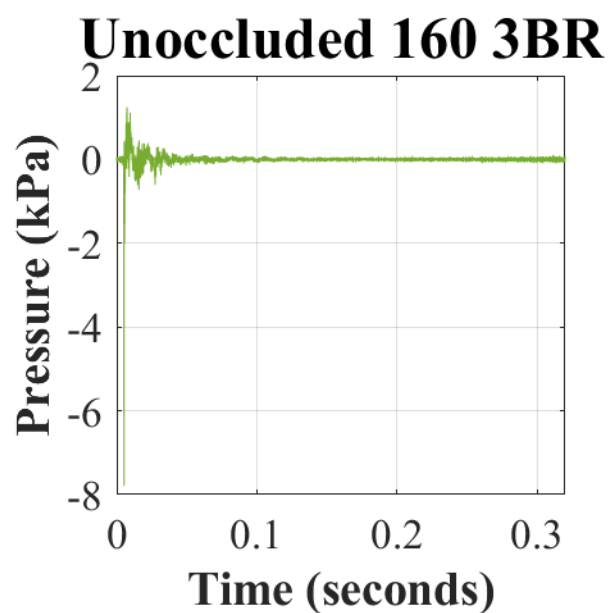
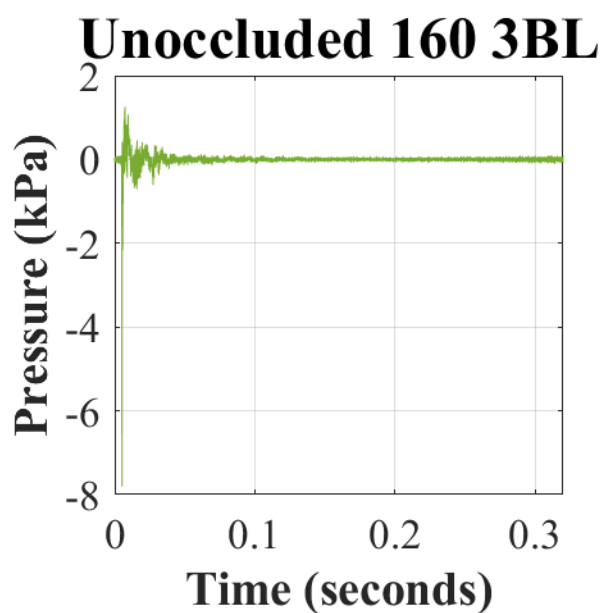
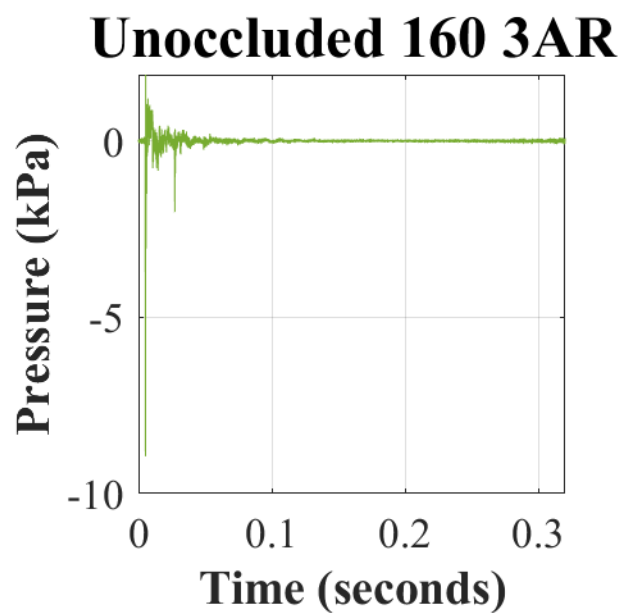
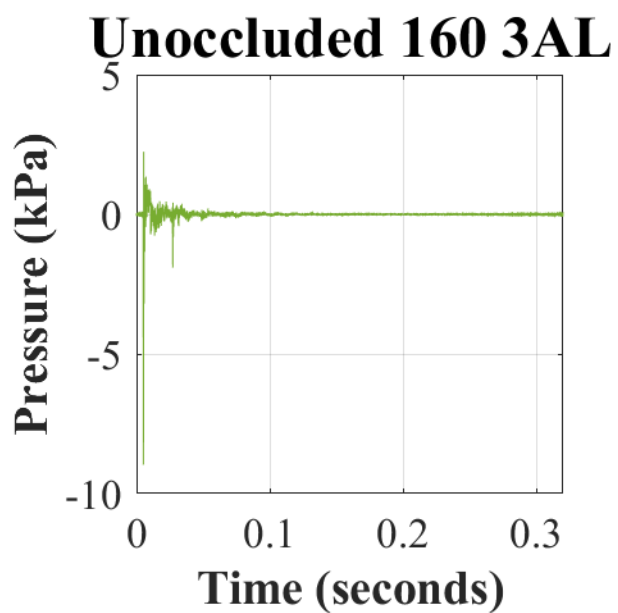


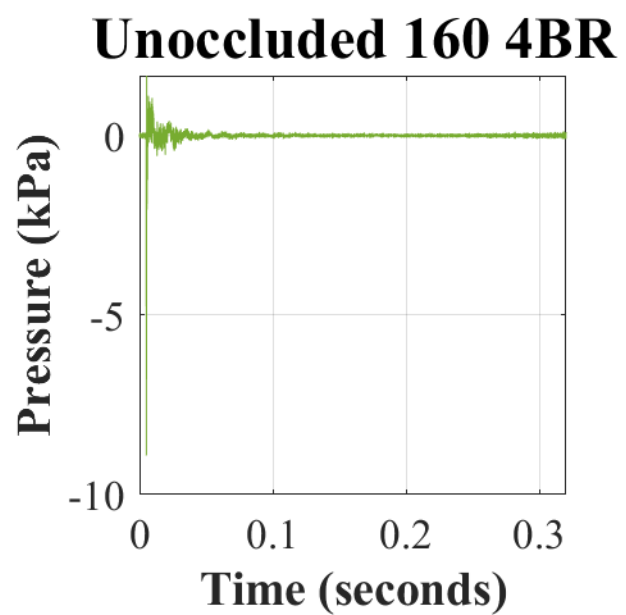
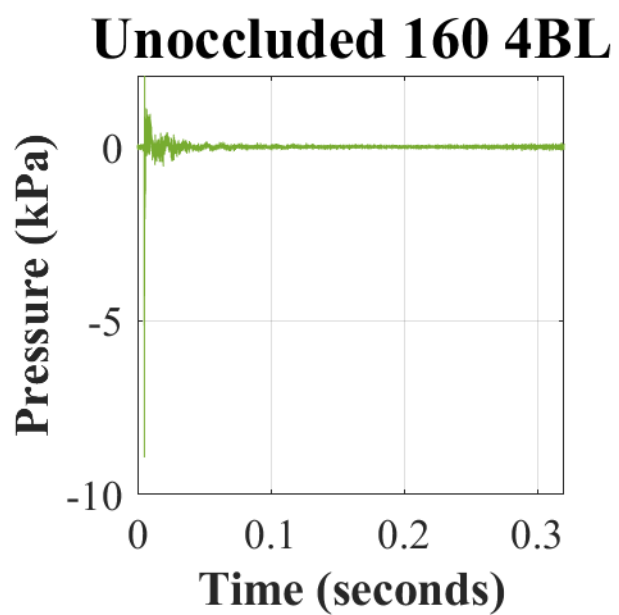
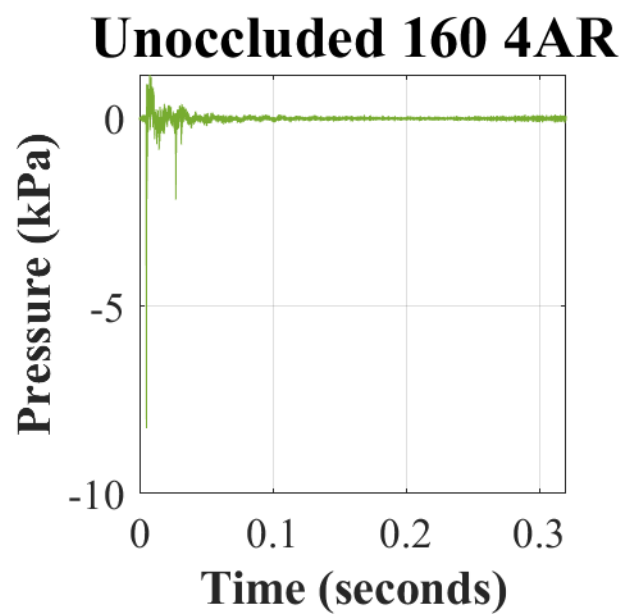
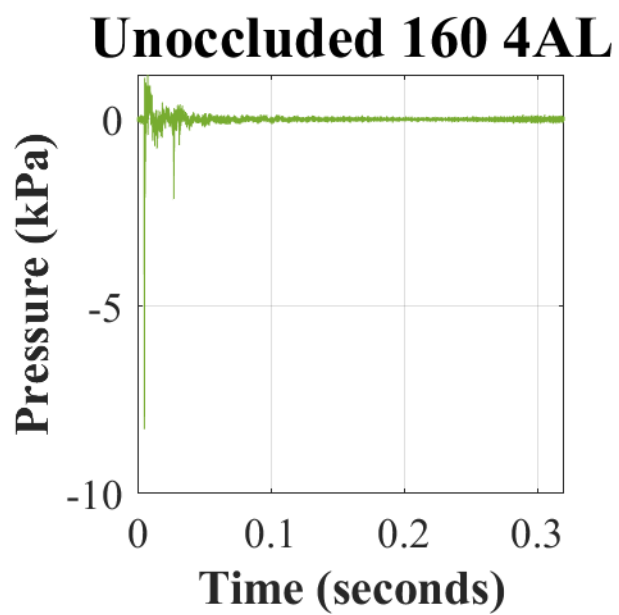
Note. The naming convention for all occluded waveforms is “Occluded LvL NnX”, where ‘Occluded’ is the test condition (i.e., ATF has the HPD donned), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or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

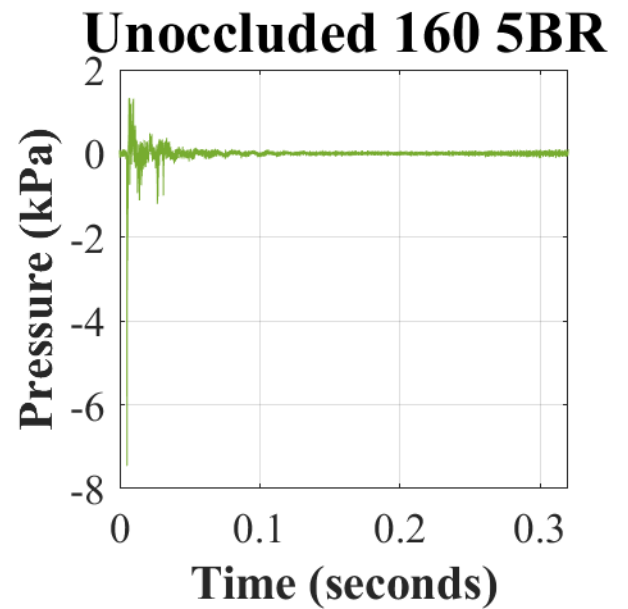
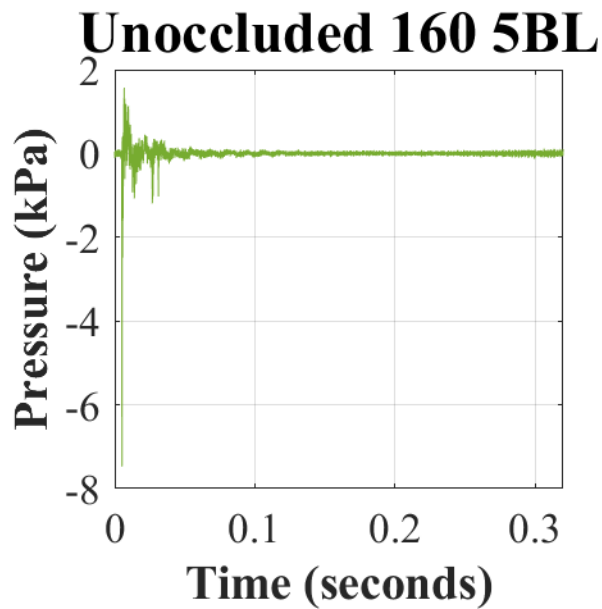
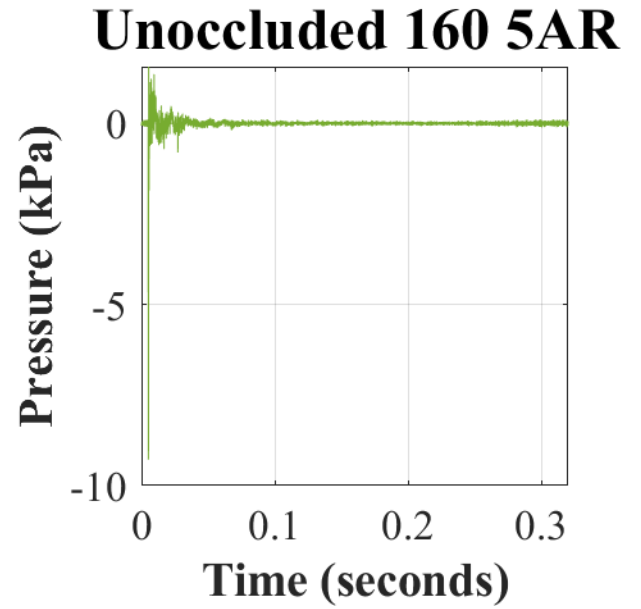
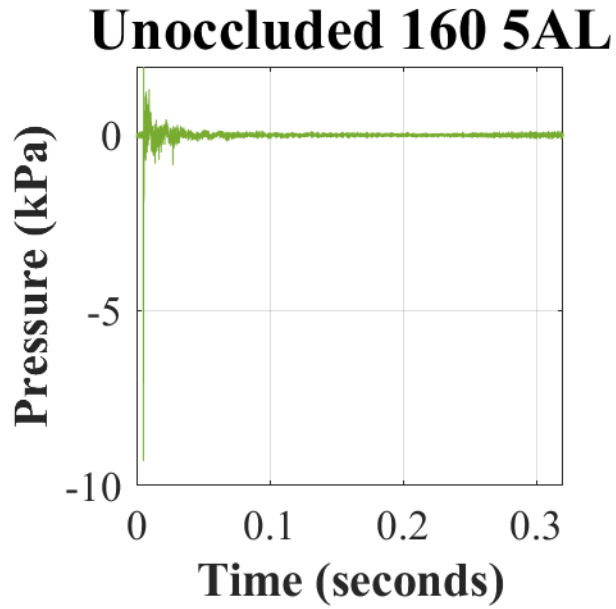
**Appendix D.** Estimated unoccluded (open-ear) waveforms (in kilopascals [kPa]) over time (in seconds [s]) in response to 160 dBp with the Battleplugs® in the cap open mode.





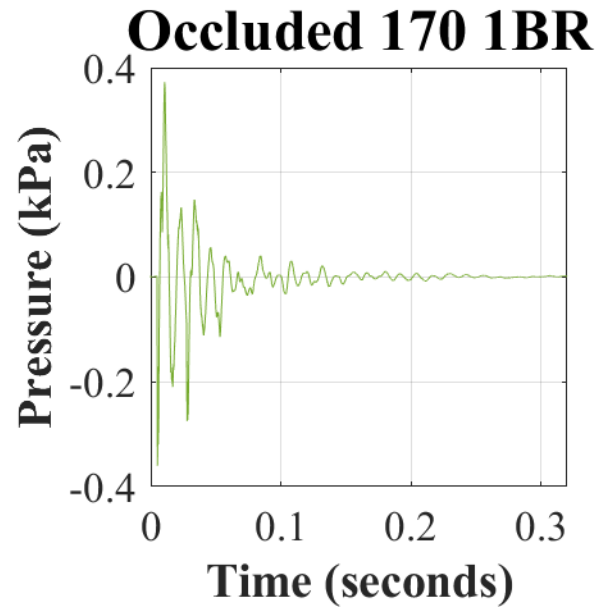
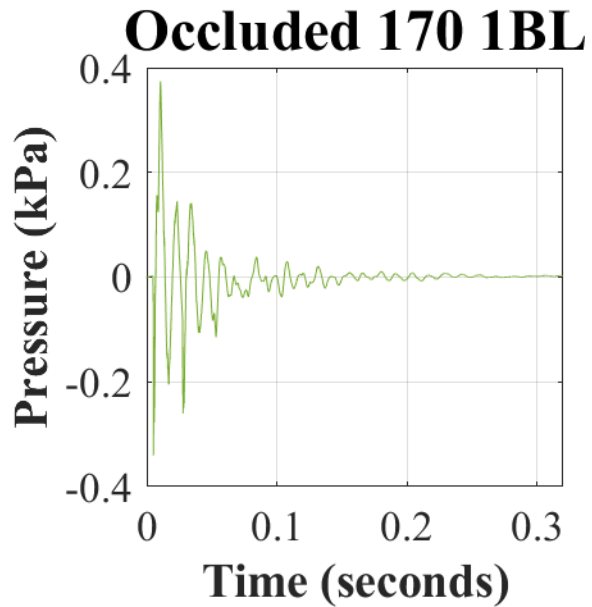
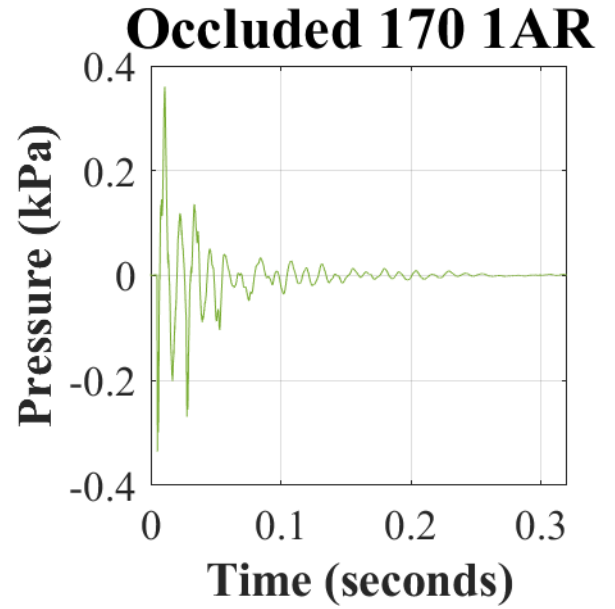
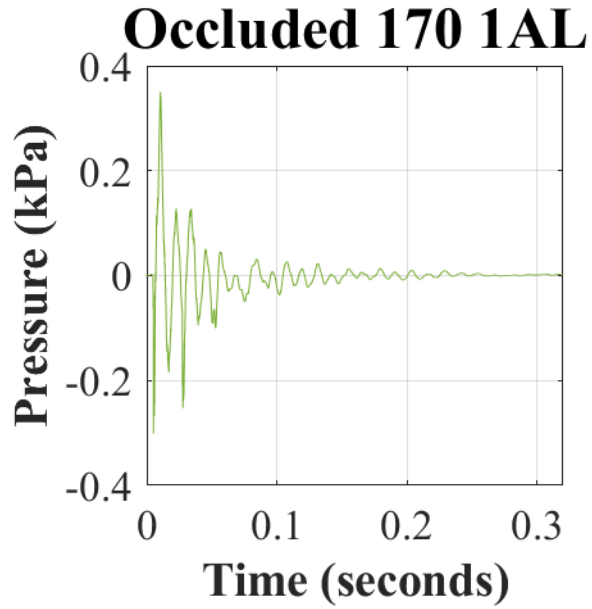


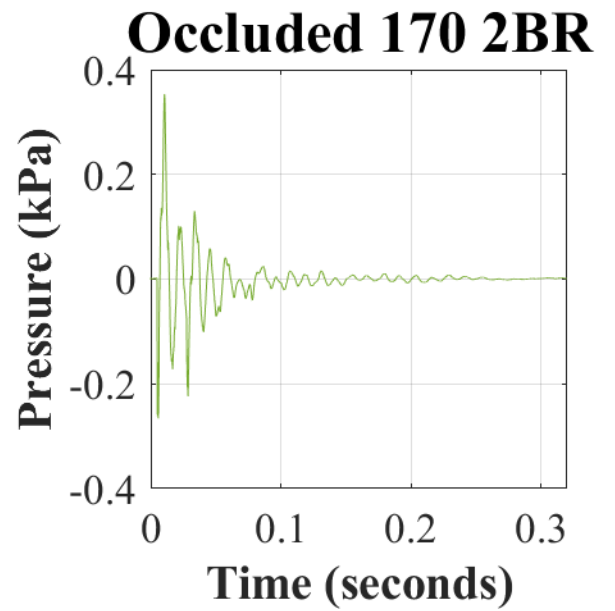
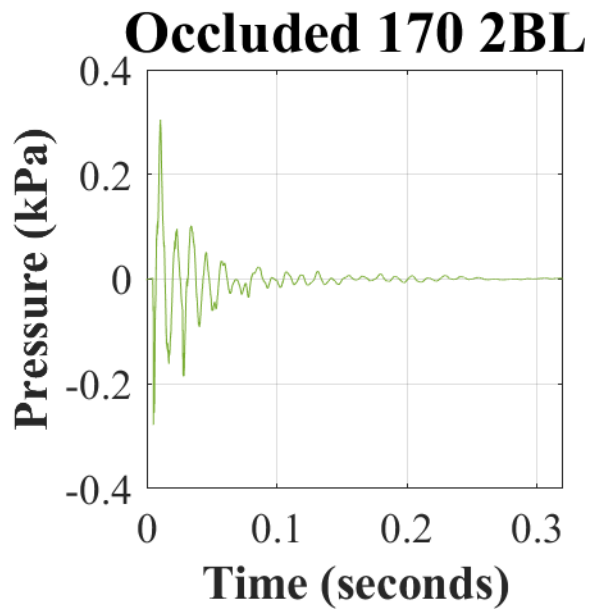
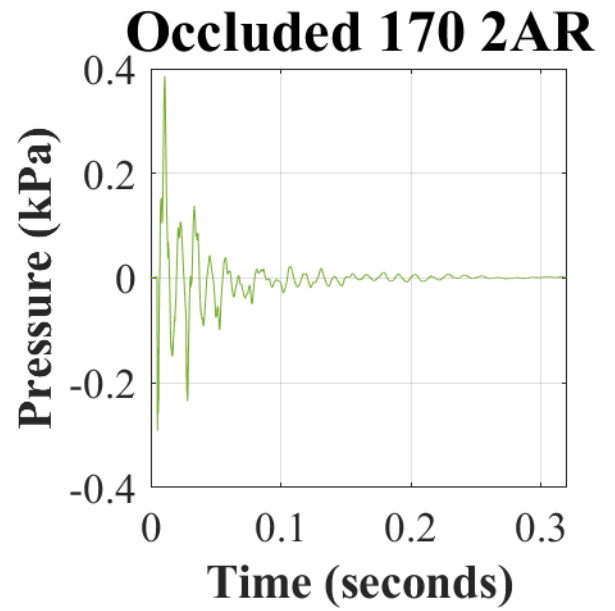
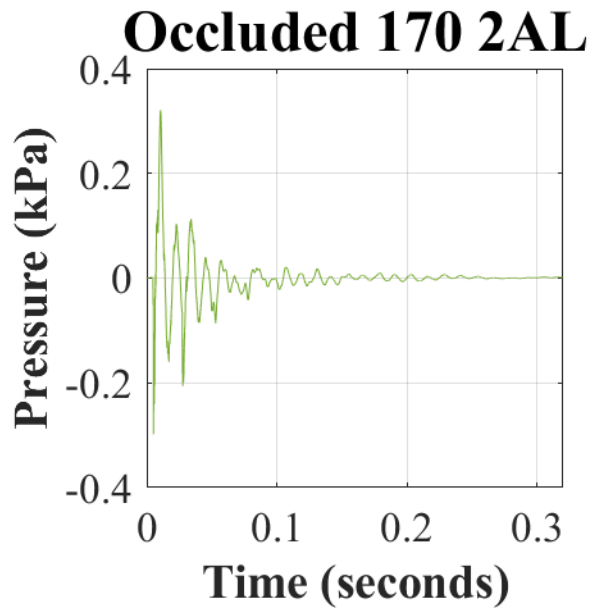


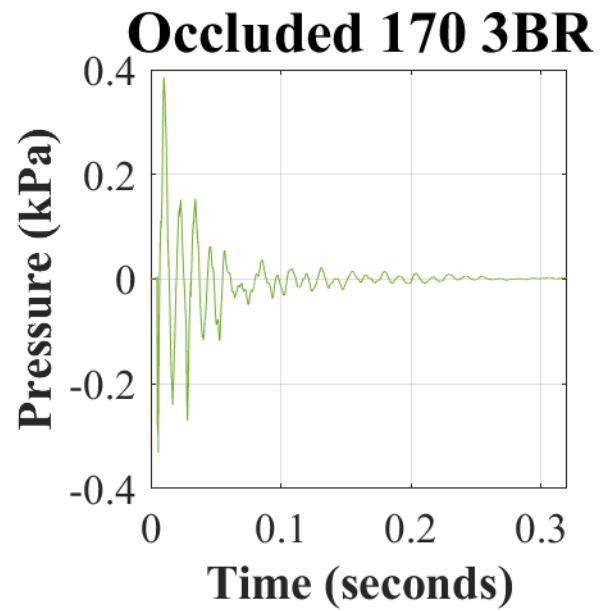
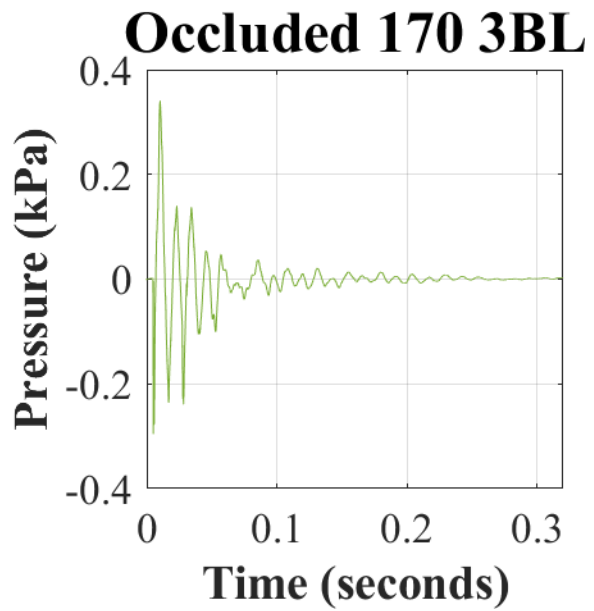
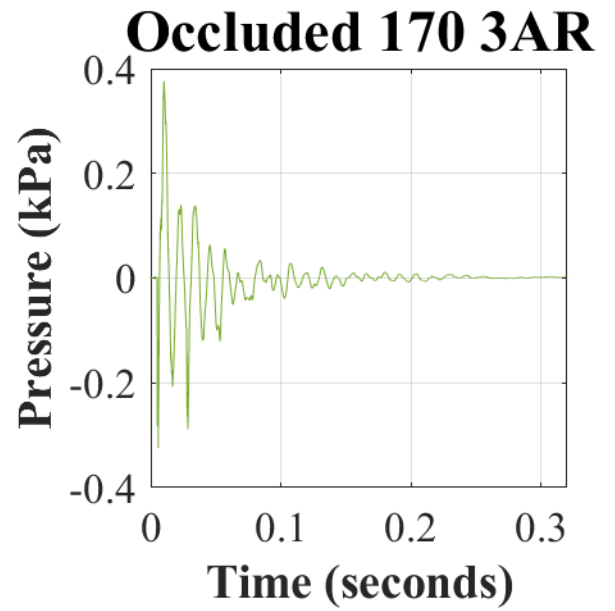
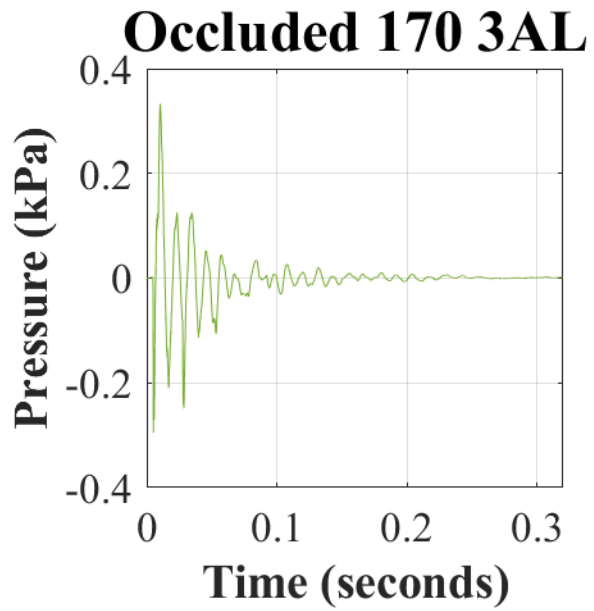


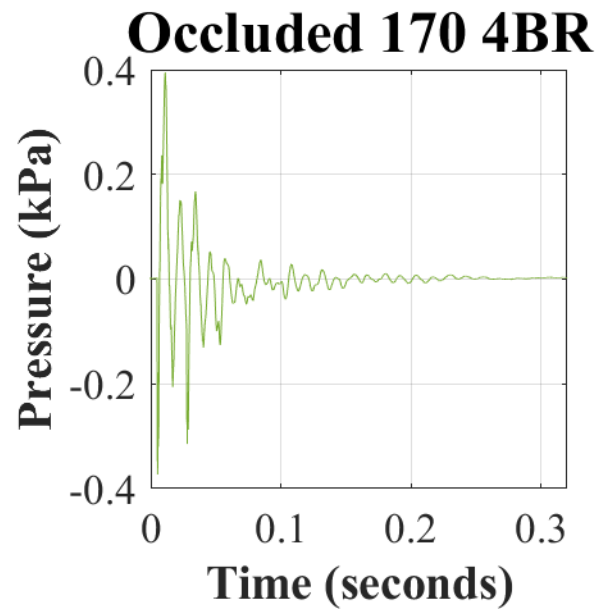
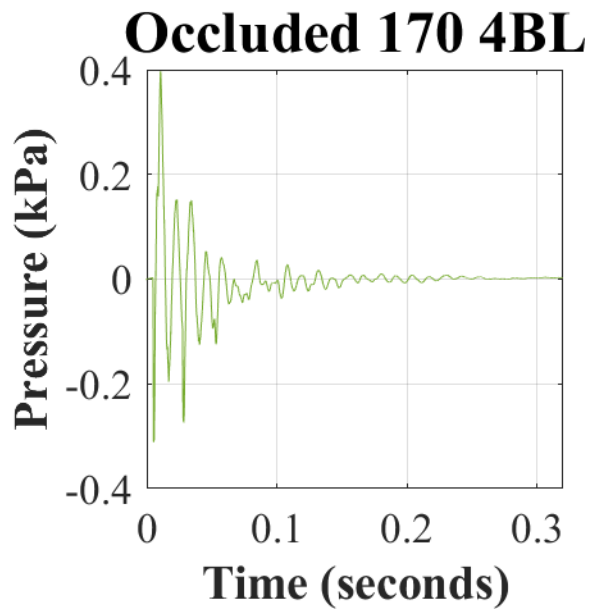
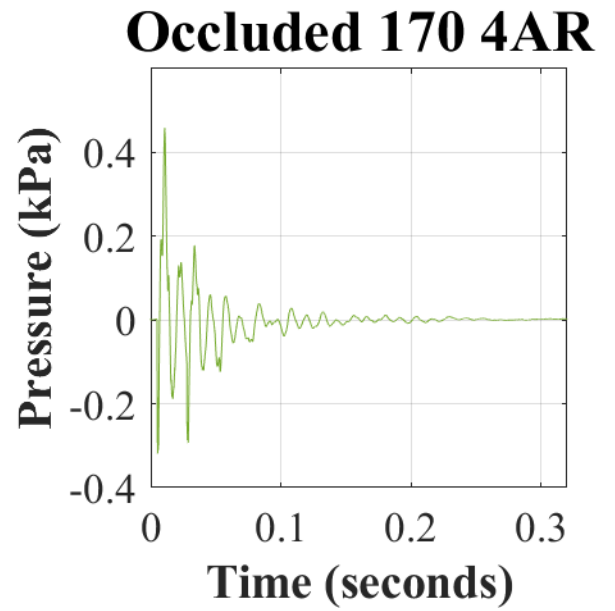
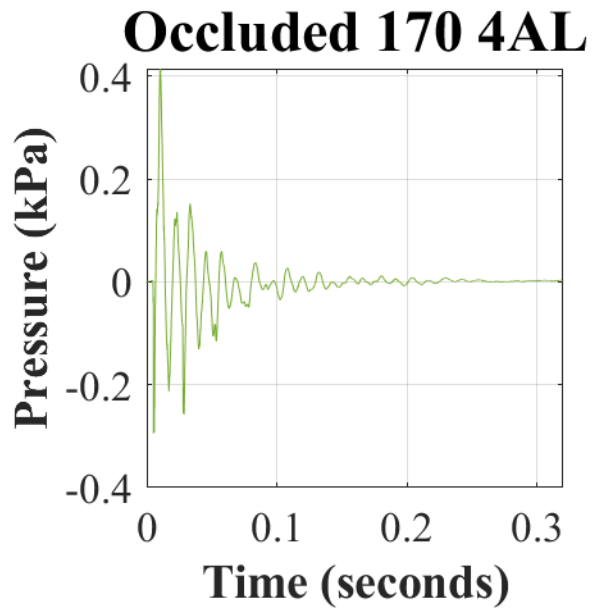
Note. The naming convention for all unoccluded waveforms is “Unoccluded LvL NnX”, where ‘Unoccluded’ is the test condition (i.e., ATF has the HPD doffed), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dBP), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e.,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

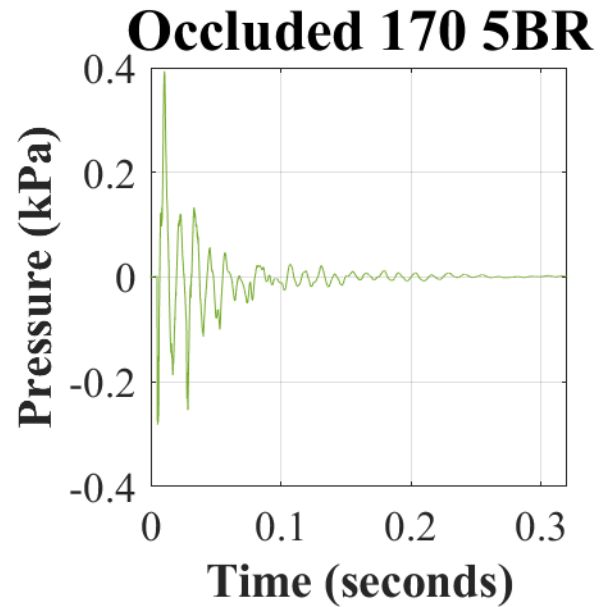
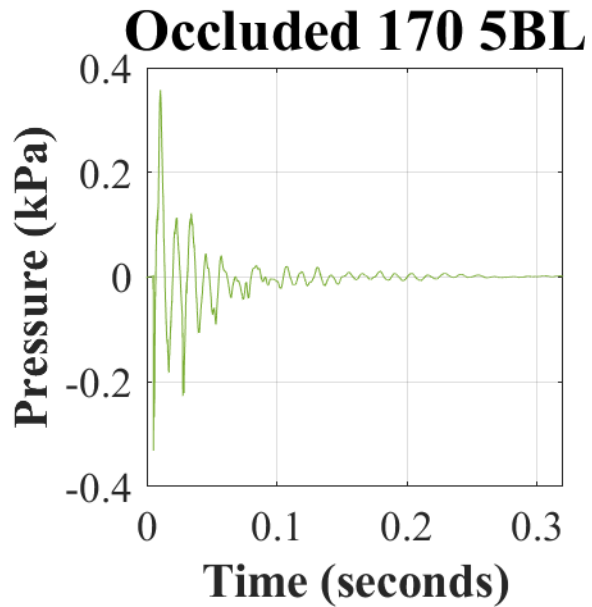
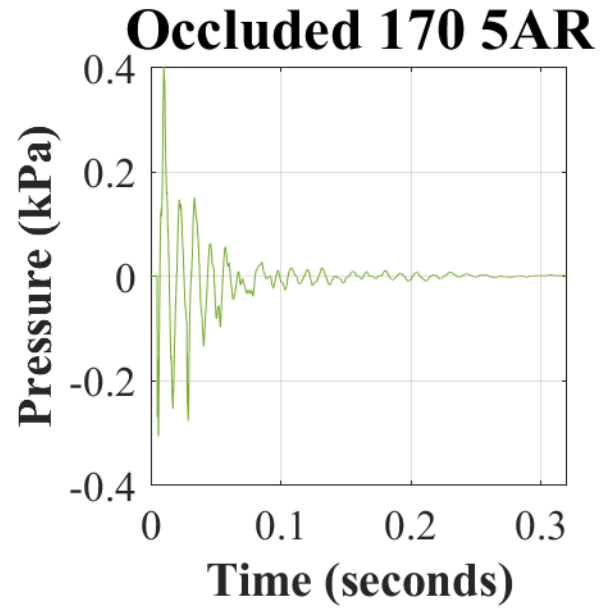
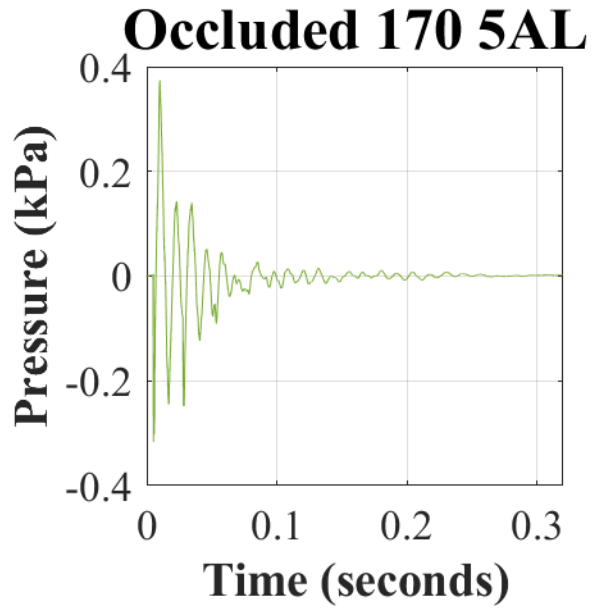
**Appendix E.** Recorded occluded (closed-ear) waveforms (in kilopascals [kPa]) over time (in seconds [s]) in response to 170 dBp with the Battleplugs® in the cap open mode.





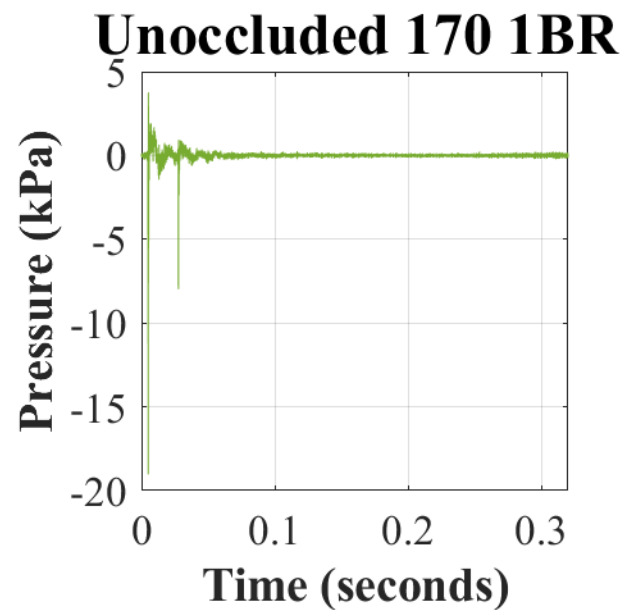
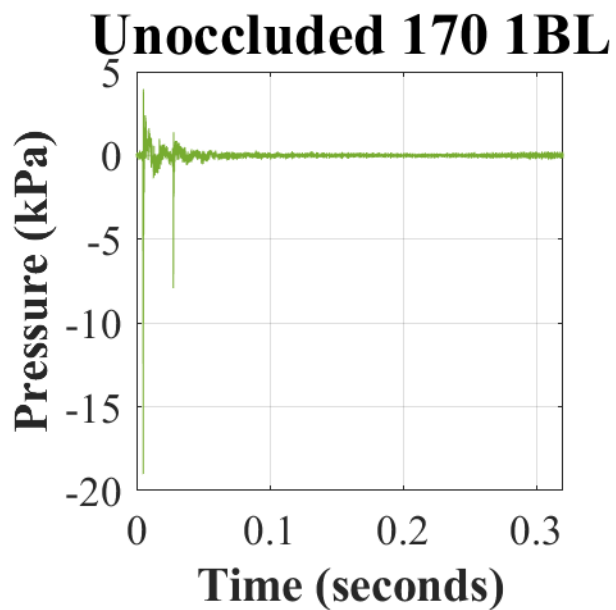
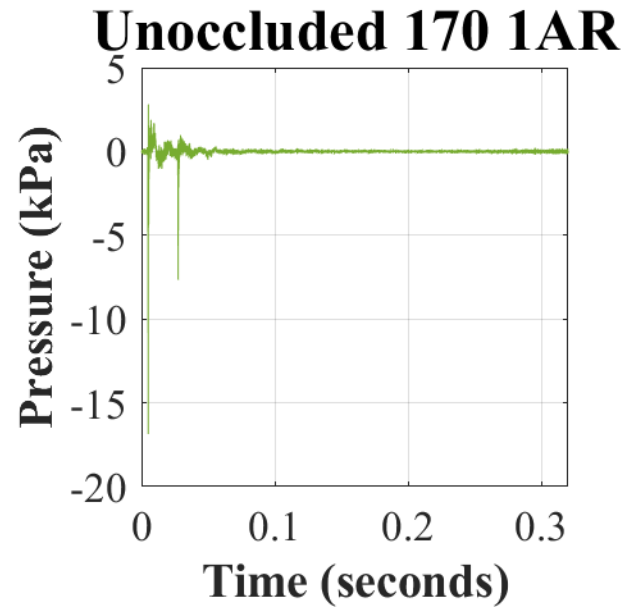
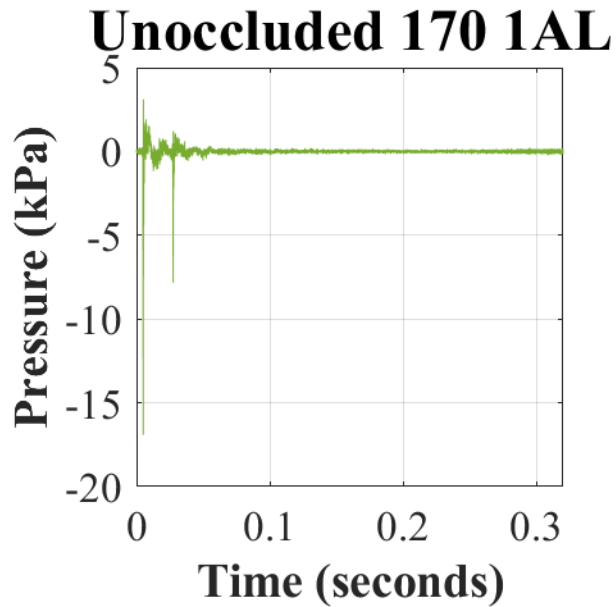


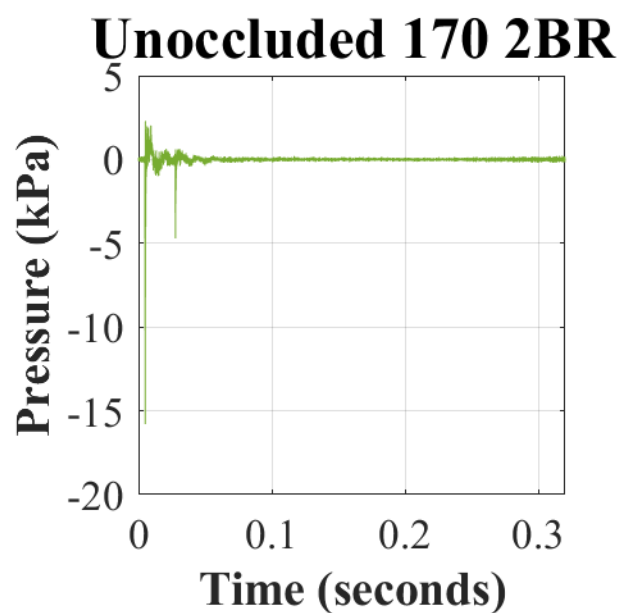
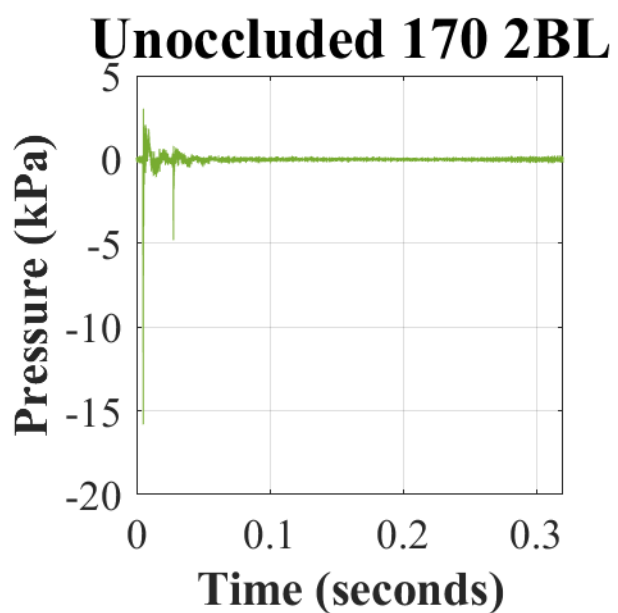
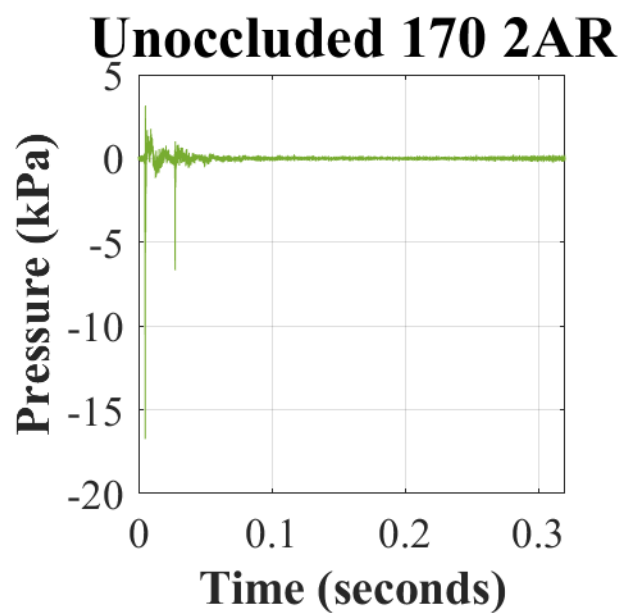
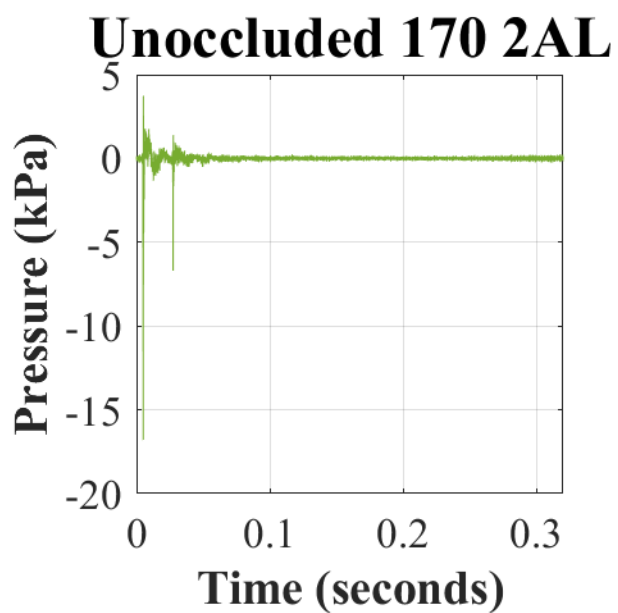


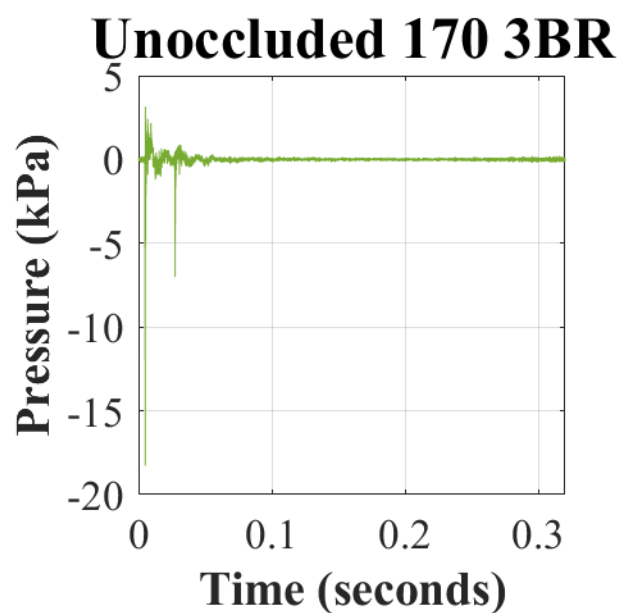
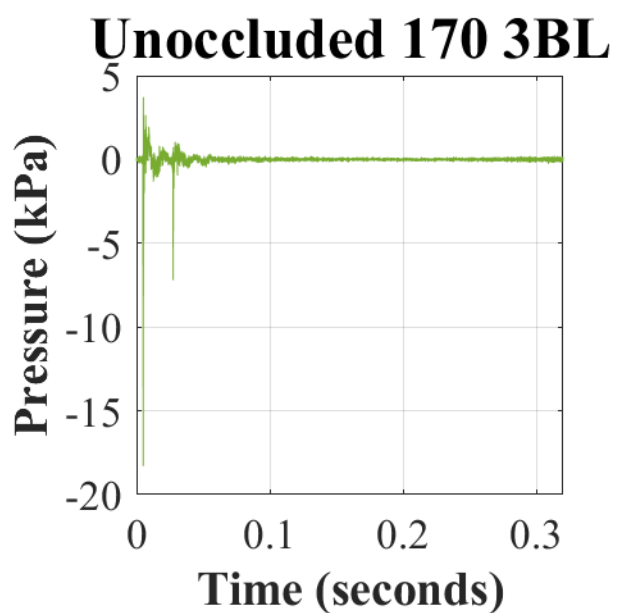
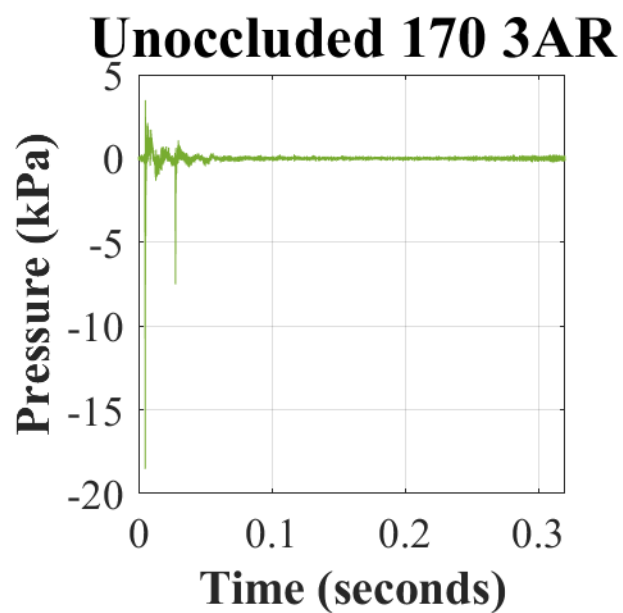
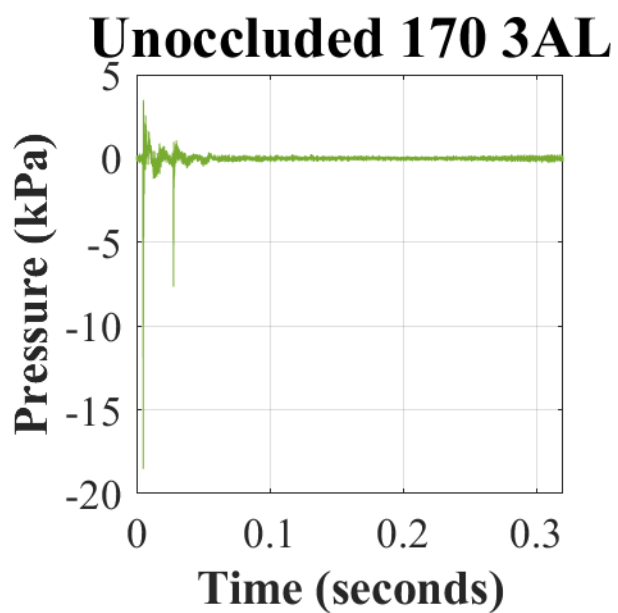


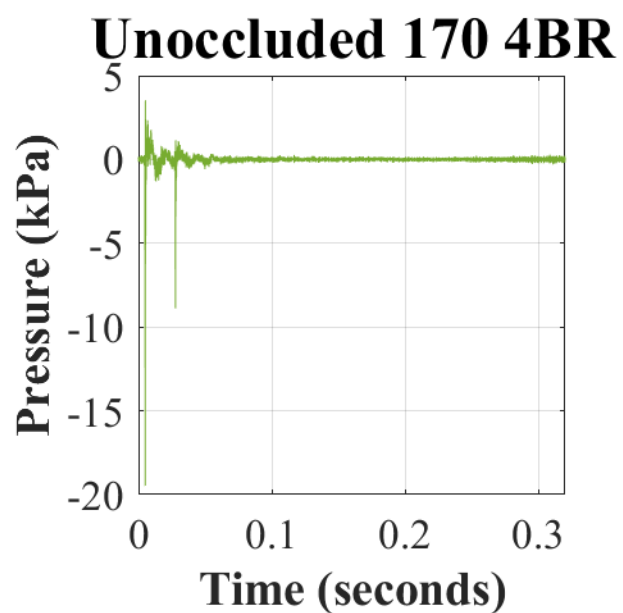
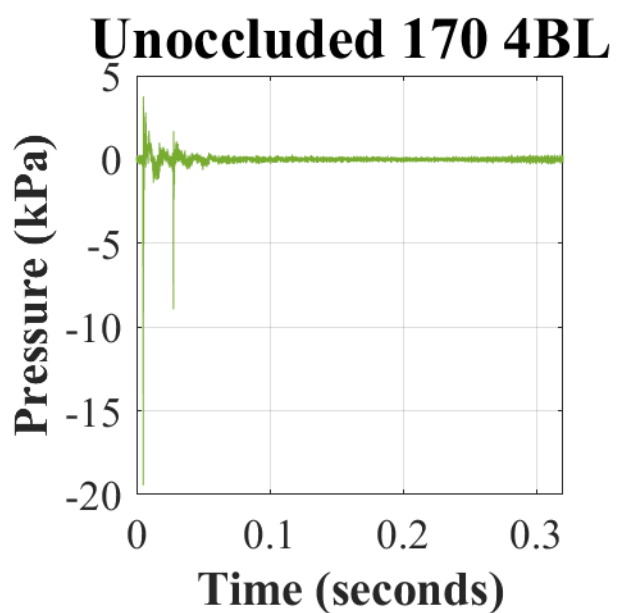
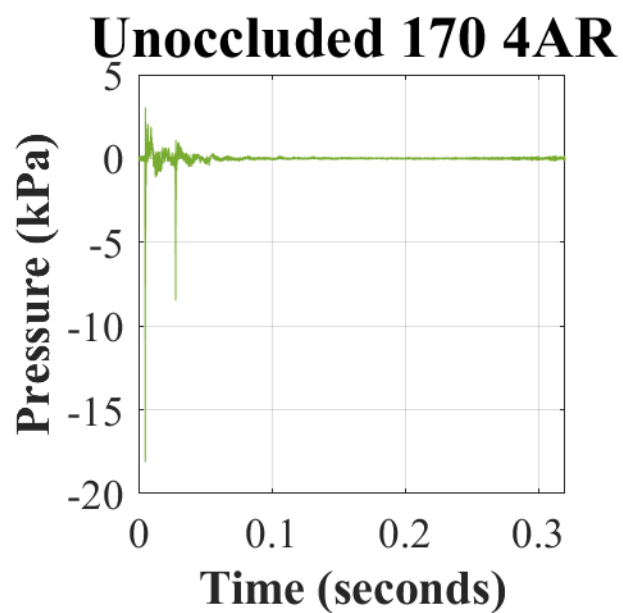
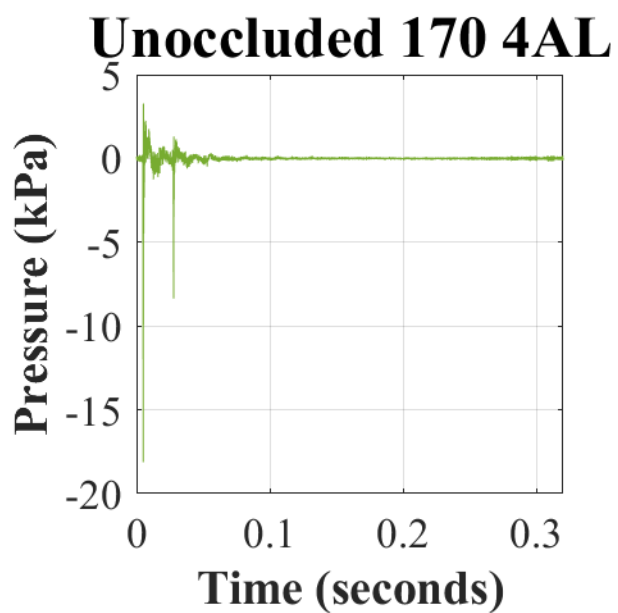
Note. The naming convention for all occluded waveforms is “Occluded LvL NnX”, where ‘Occluded’ is the test condition (i.e., ATF has the HPD donned), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or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

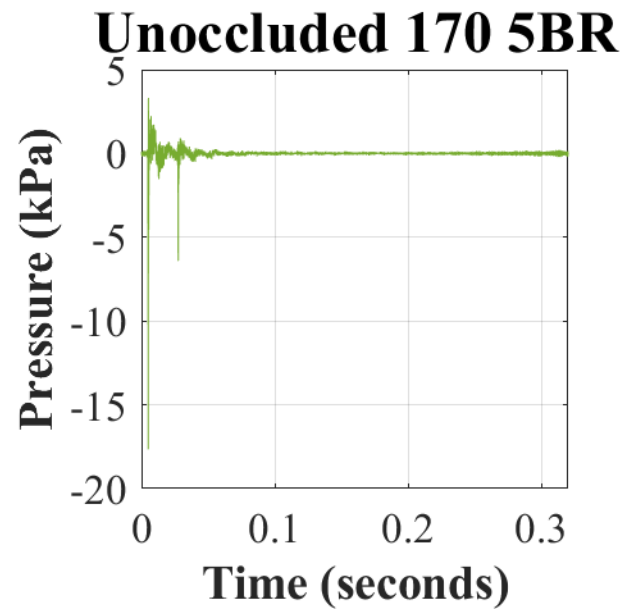
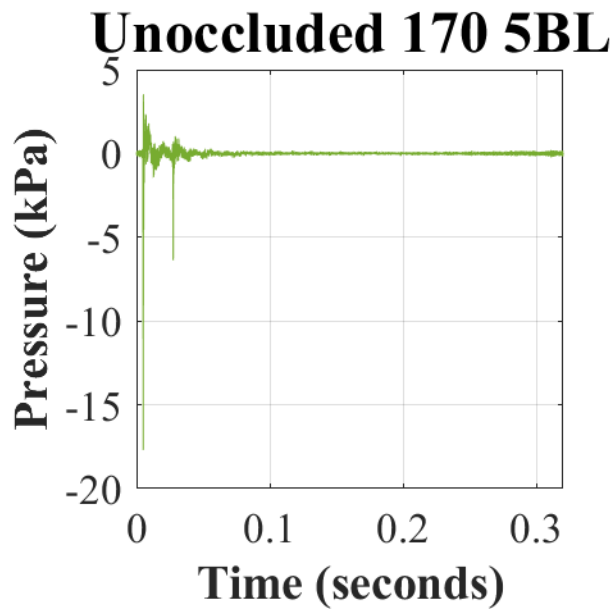
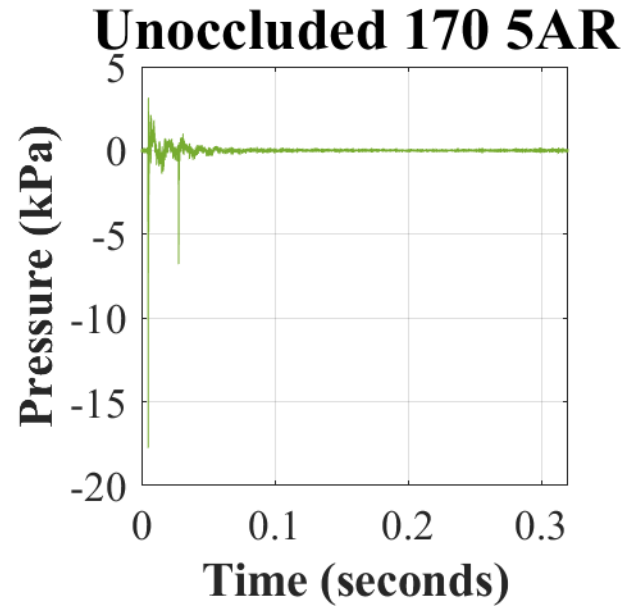
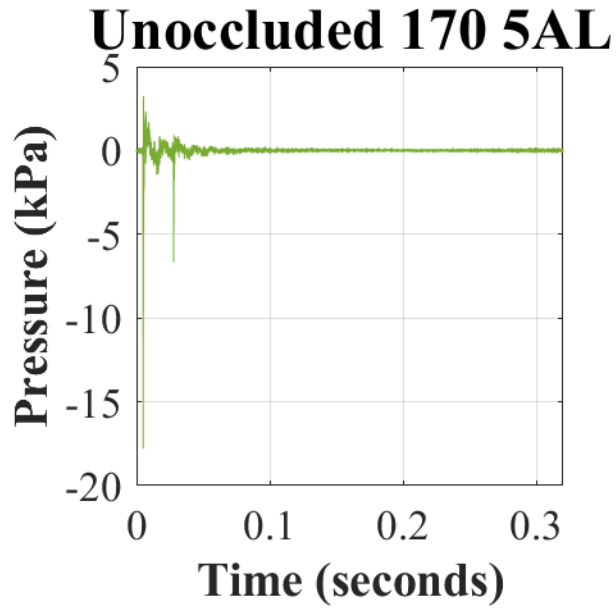
**Appendix F.** Estimated unoccluded (open-ear) waveforms (in kilopascals [kPa]) over time (in seconds [s]) in response to 170 dBp with the Battleplugs® in the cap open mode.





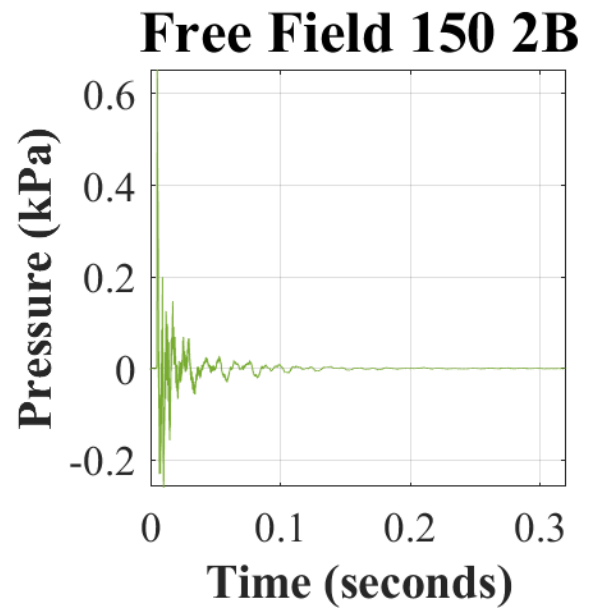
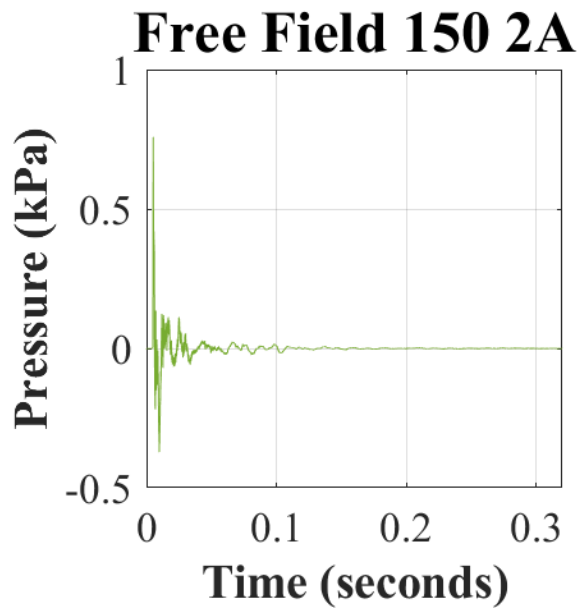
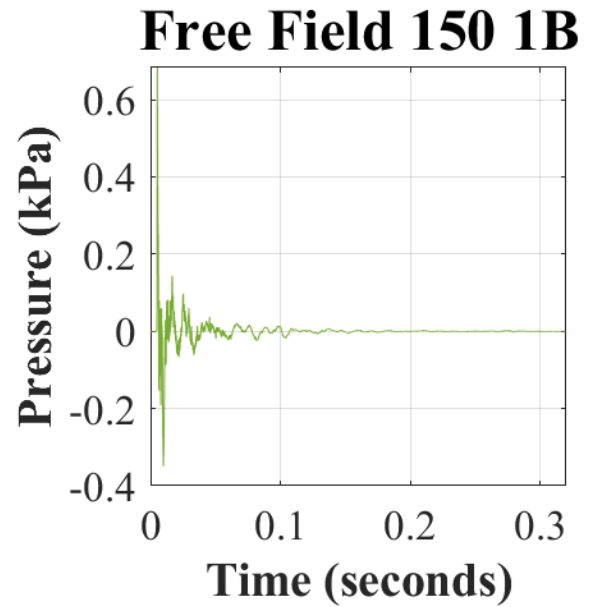
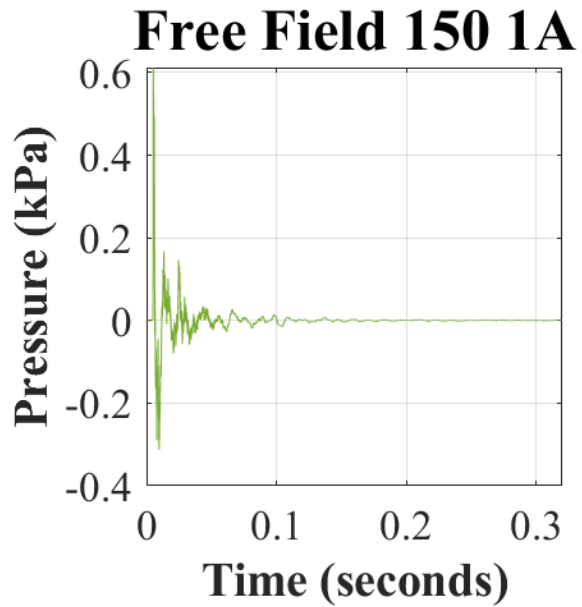




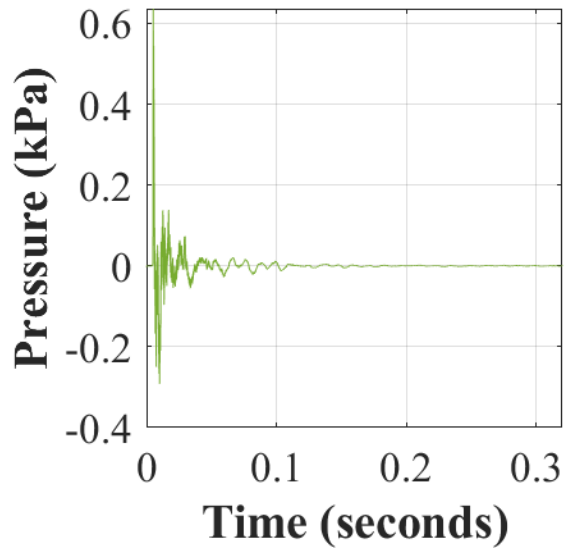


Note. The naming convention for all unoccluded waveforms is “Unoccluded LvL NnX”, where ‘Unoccluded’ is the test condition (i.e., ATF has the HPD doffed), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e.,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

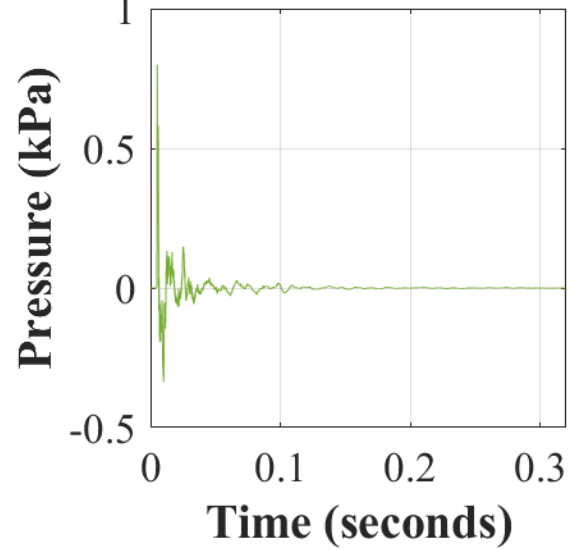
**Appendix G.** Recorded waveform (in kilopascals [kPa]) over time (in seconds [s]) of the impulse measured with the free-field probe at 150 dBp and the Battleplugs<sup>®</sup> donned in the cap open mode.



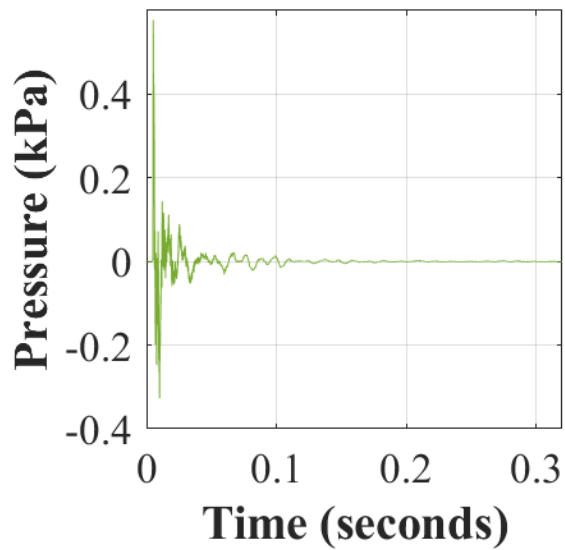
**Free Field 150 3A**



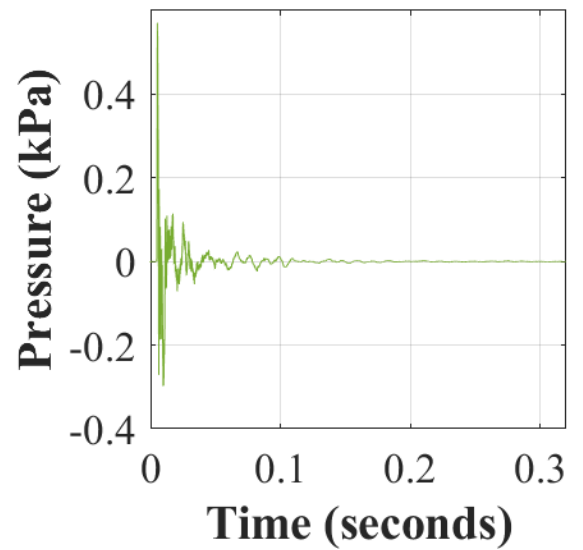
**Free Field 150 3B**

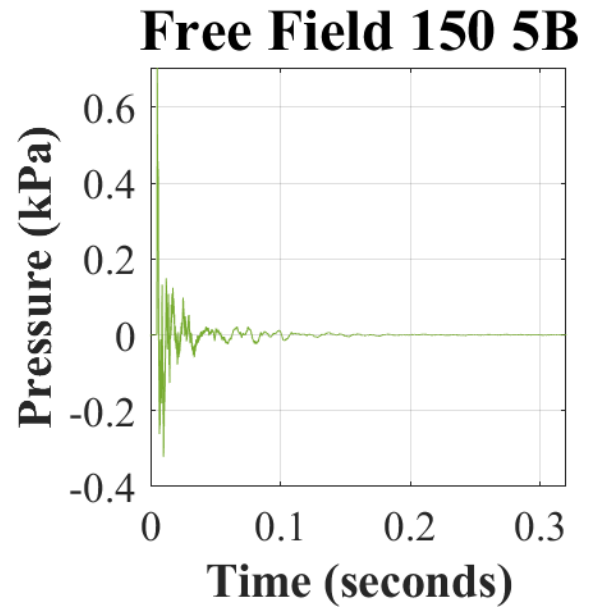
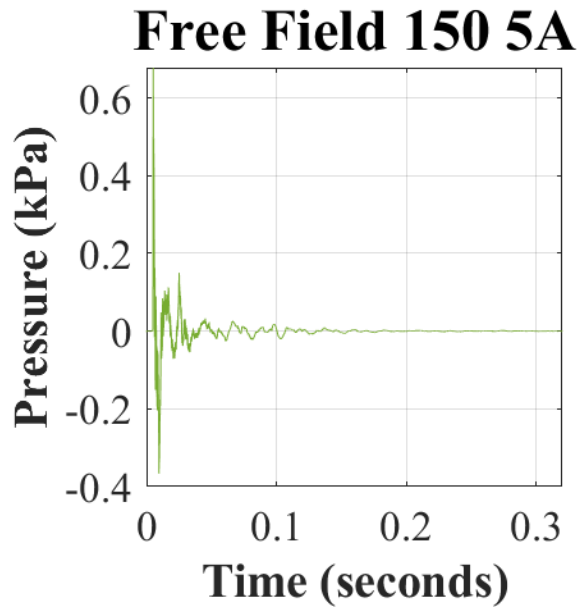


**Free Field 150 4A**



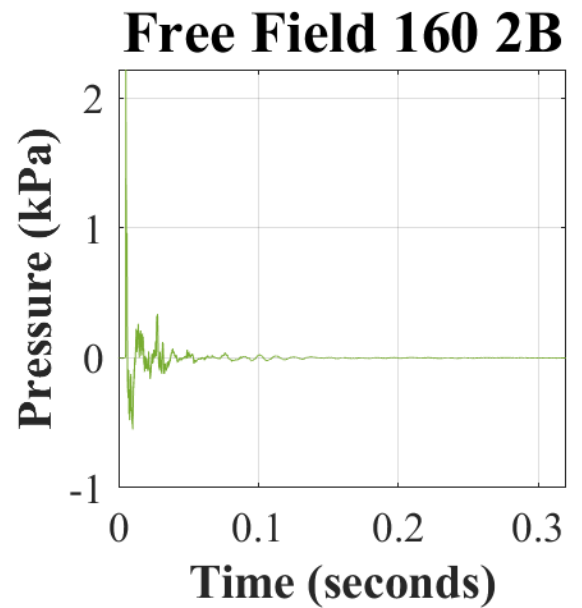
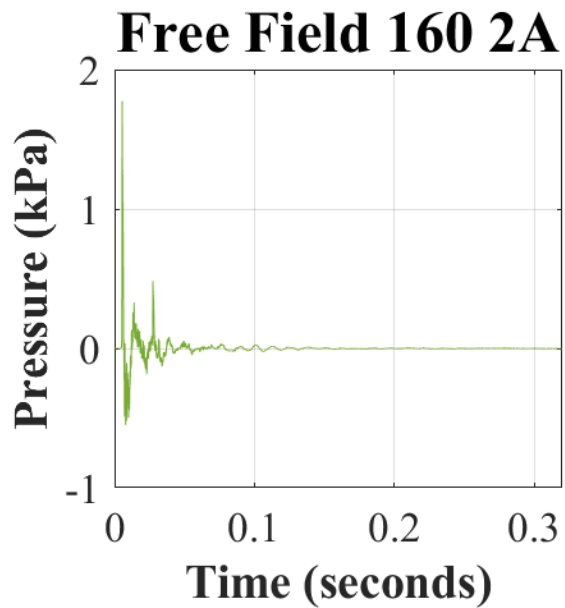
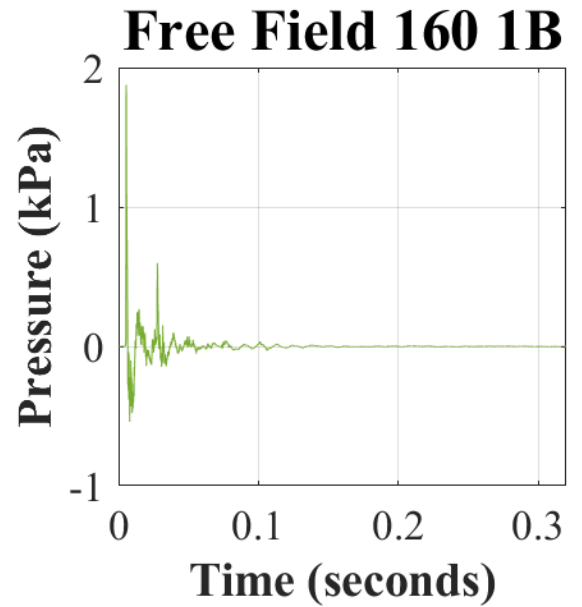
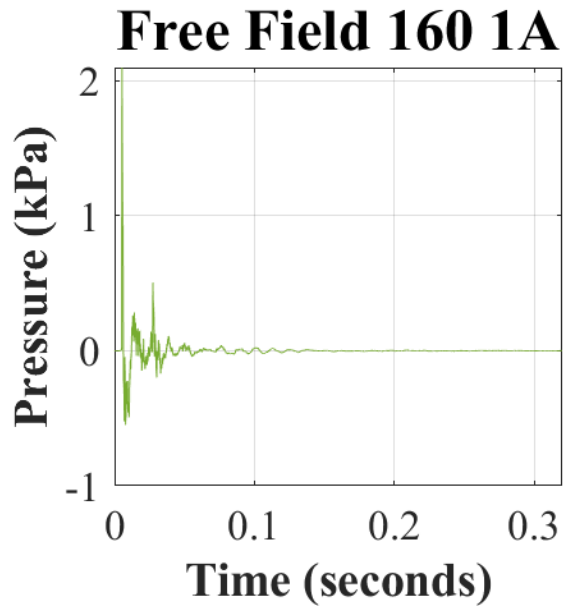
**Free Field 150 4B**

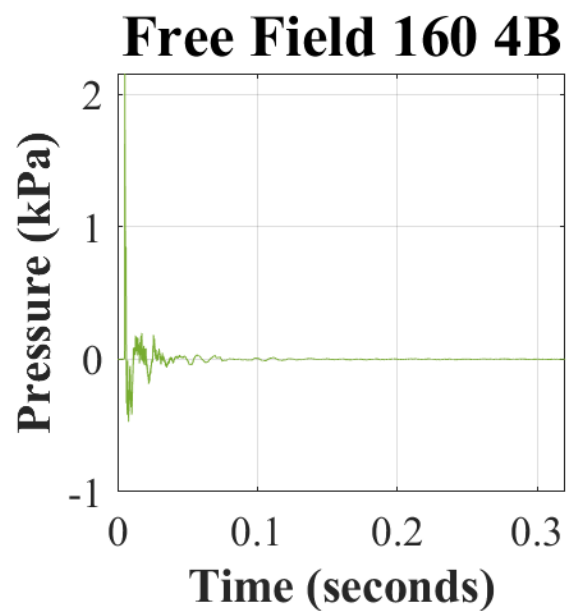
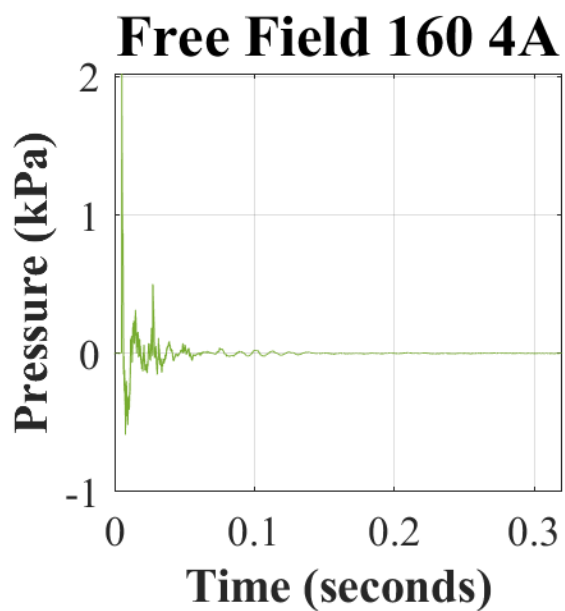
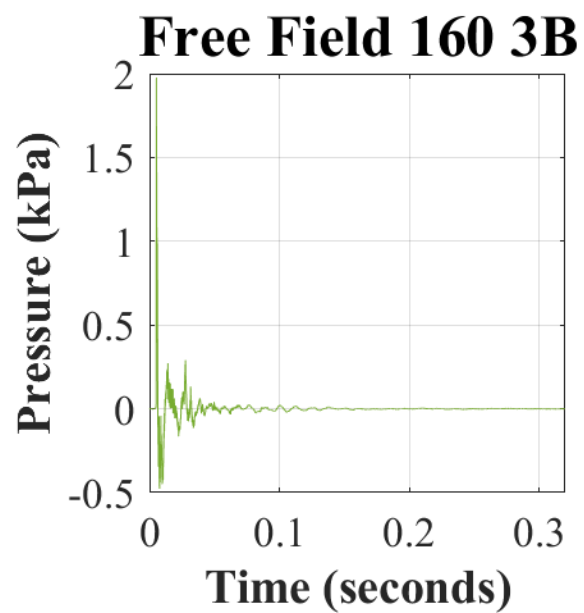
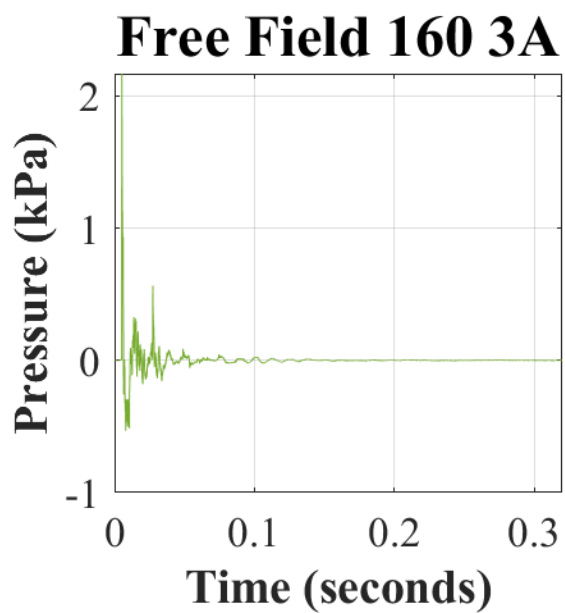


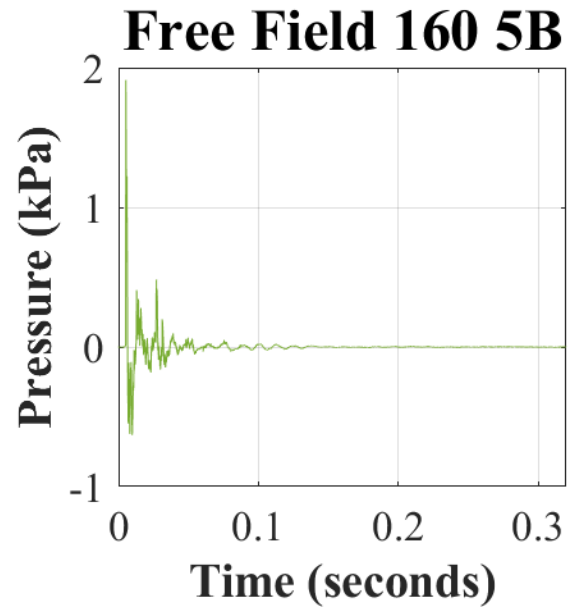
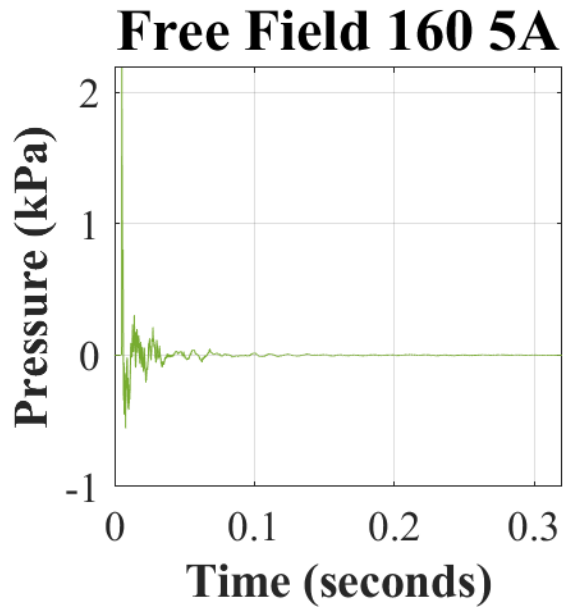


Note. The naming convention for all free-field waveforms is “Free Field LvL Nn”, where ‘Free Field’ indicates that the recording was obtained using the PCB reference microphone, ‘LvL’ is the nominal test level (150 dBP), ‘N’ is the device sample number (1 to 5), and ‘n’ is the device trial (i.e., A or 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 Battleplugs<sup>®</sup> donned in the cap open mode.

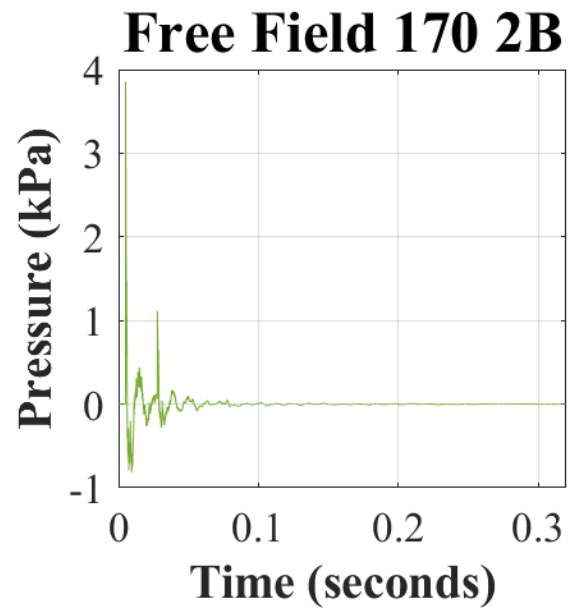
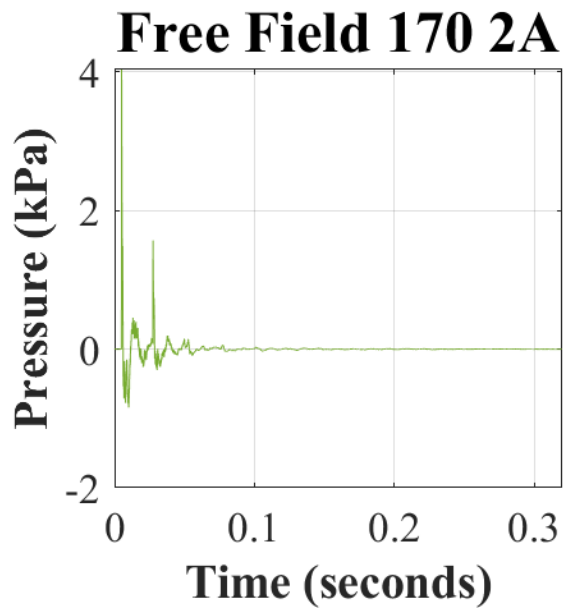
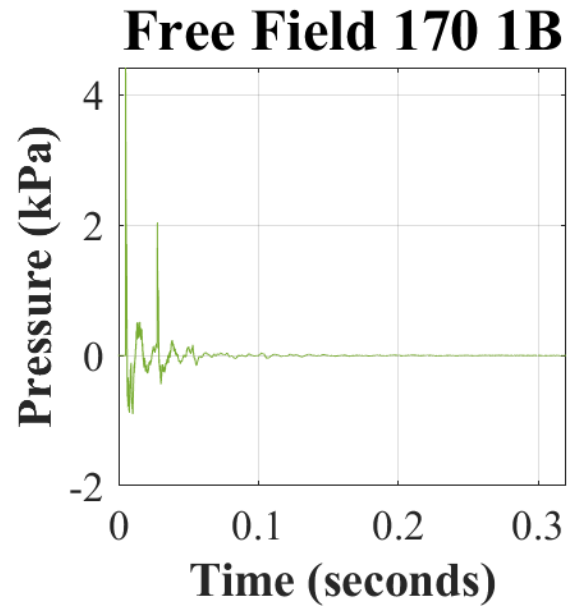
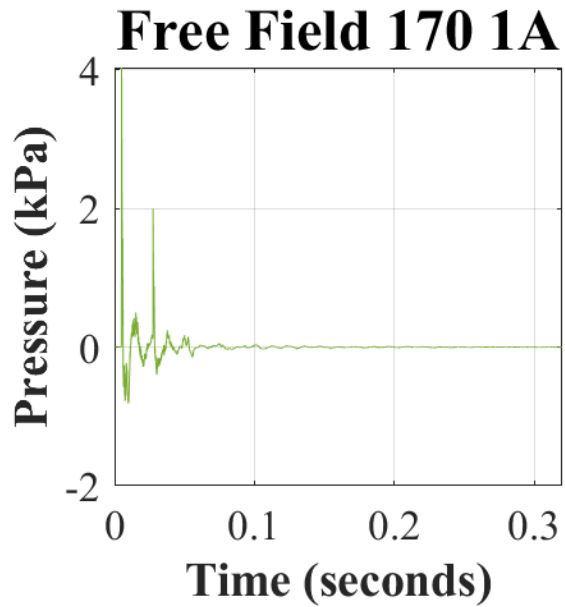


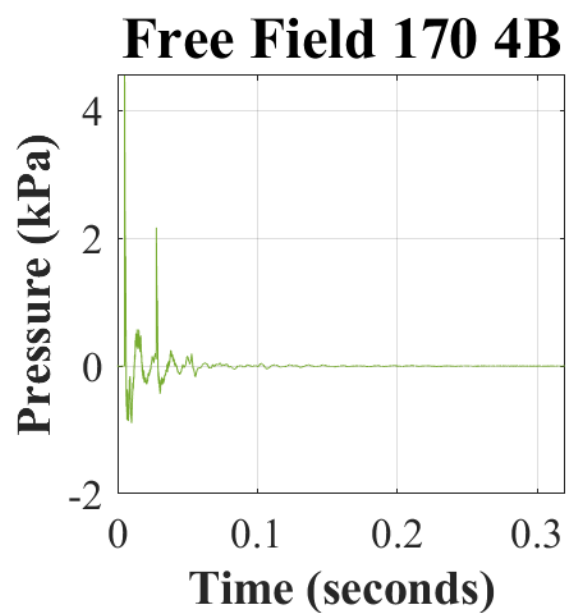
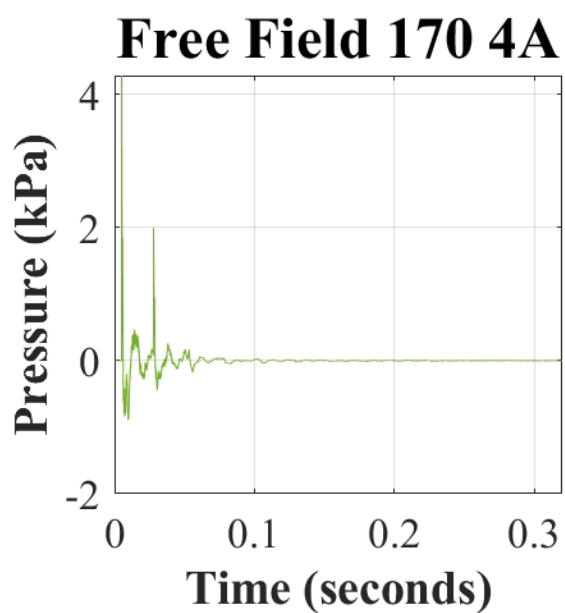
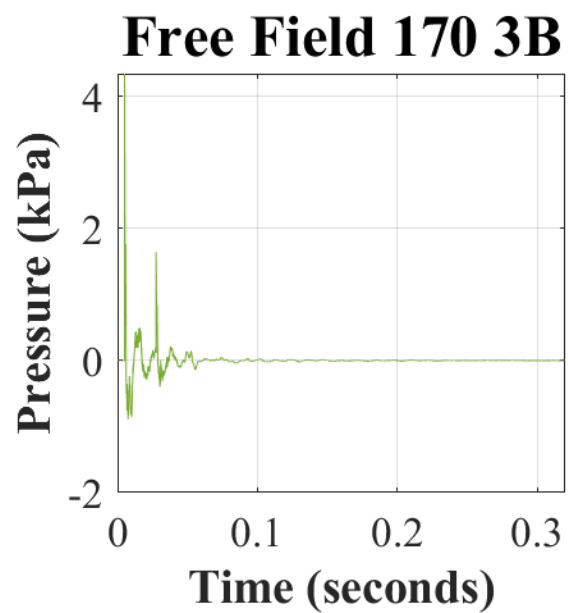
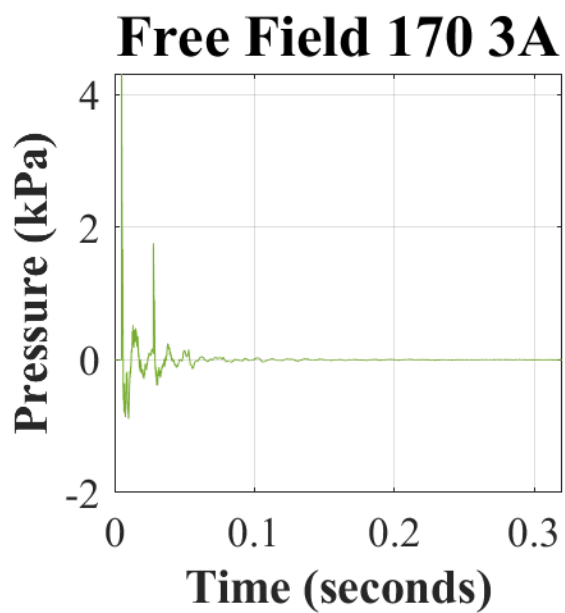


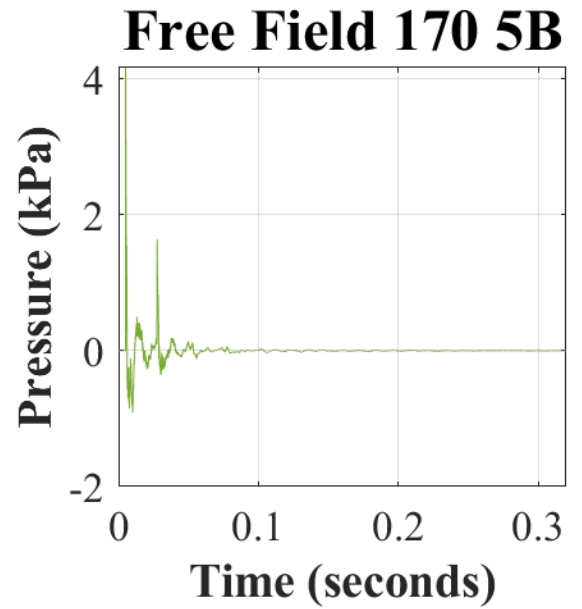
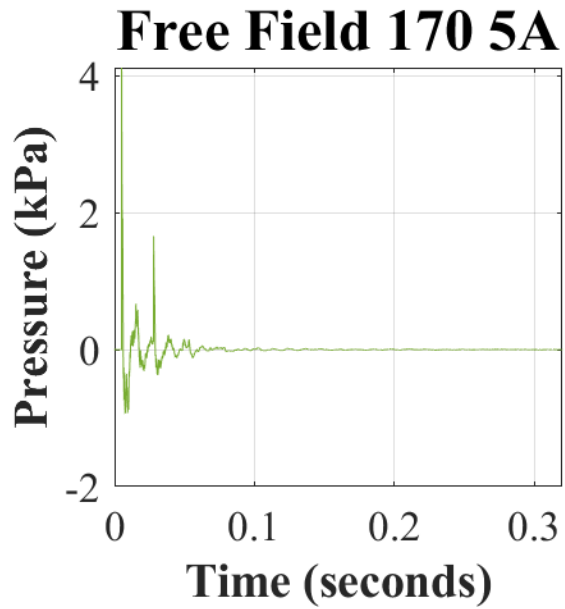


Note. The naming convention for all free-field waveforms is “Free Field LvL Nn”, where ‘Free Field’ indicates that the recording was obtained using the PCB reference microphone, ‘LvL’ is the nominal test level (160 dBp), ‘N’ is the device sample number (1 to 5), and ‘n’ is the device trial (i.e., A or 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 Battleplugs<sup>®</sup> donned in the cap open mode.

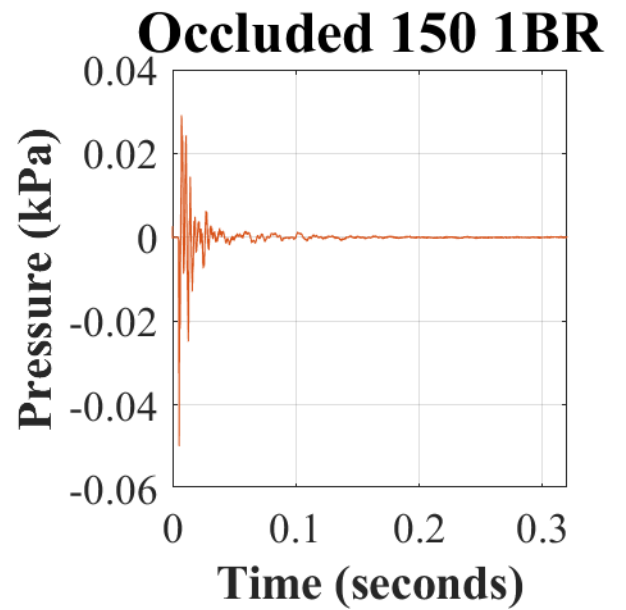
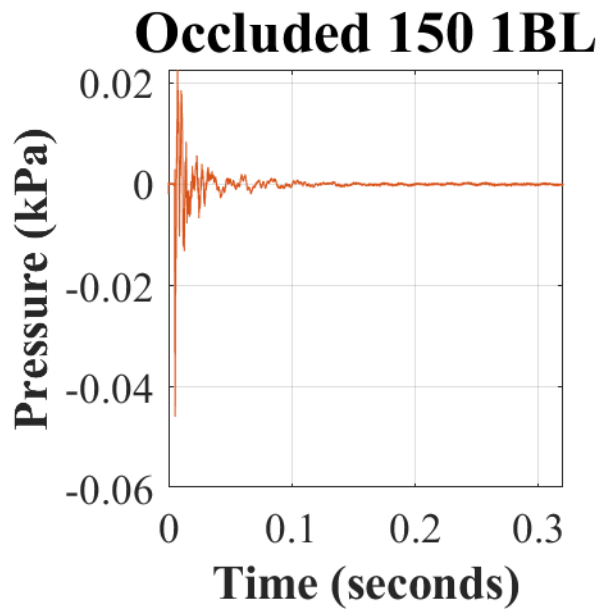
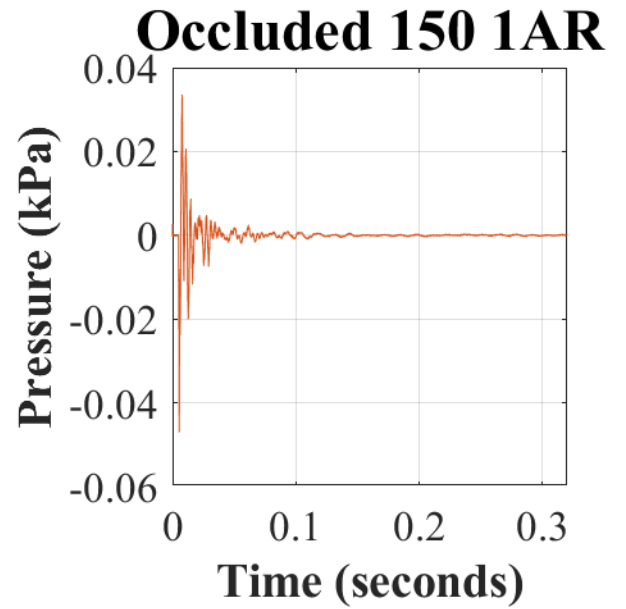
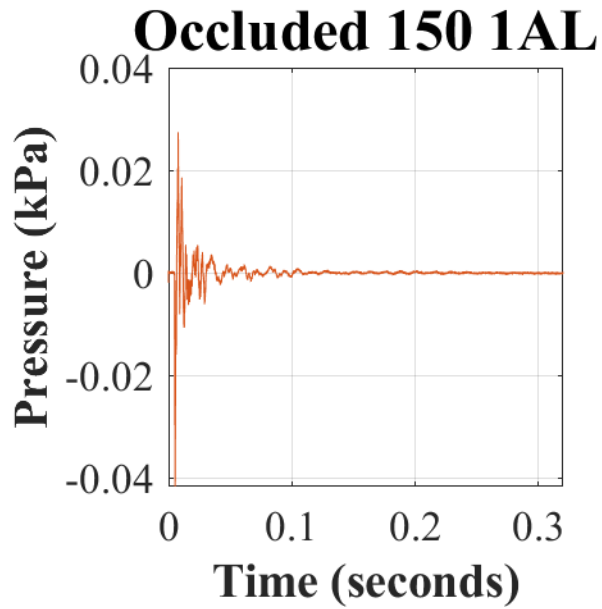


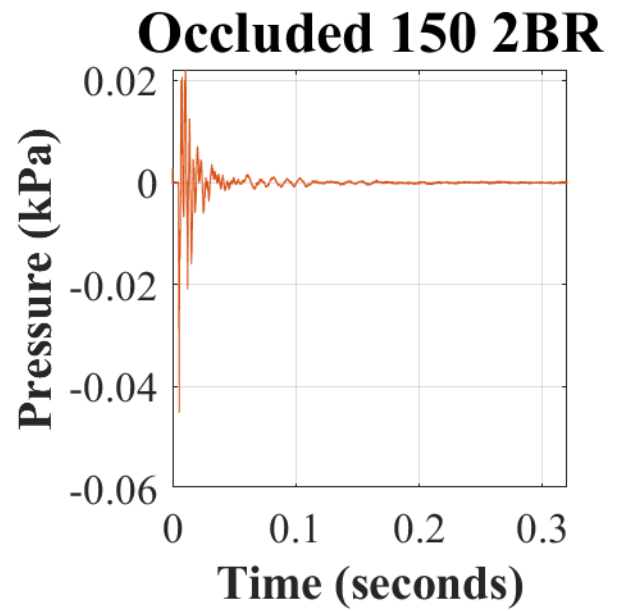
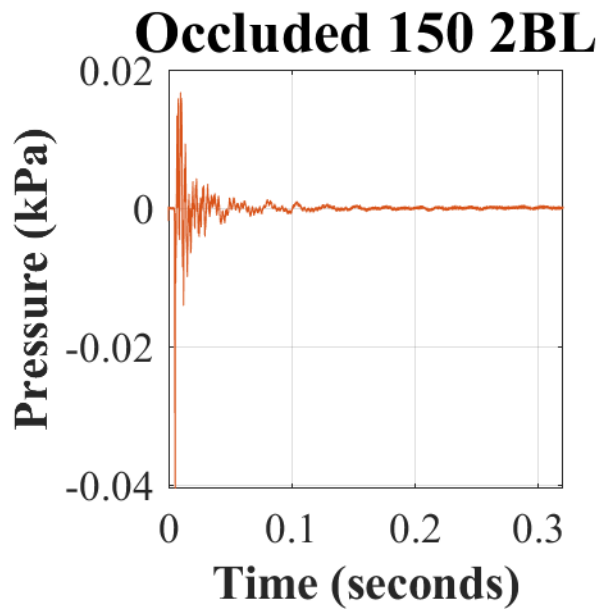
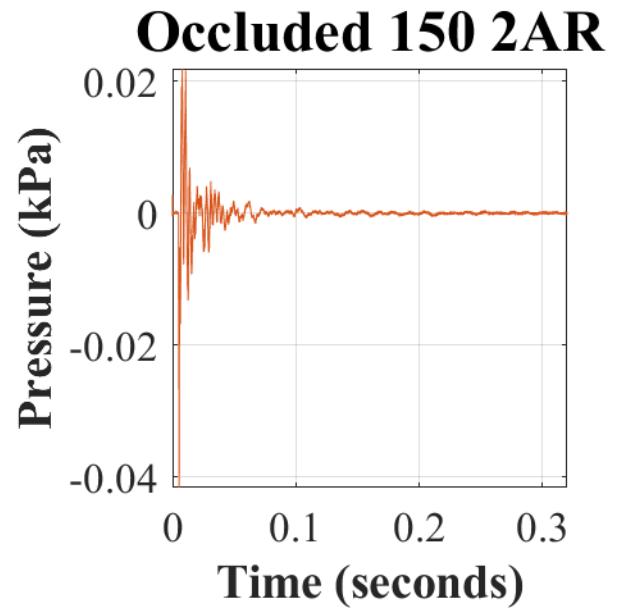
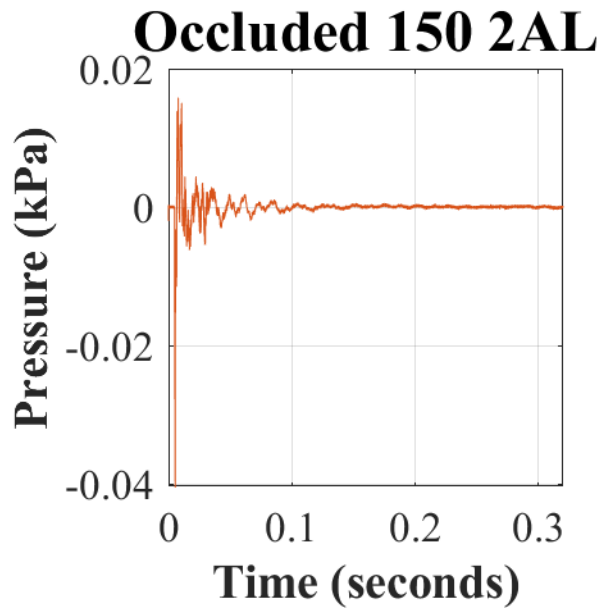


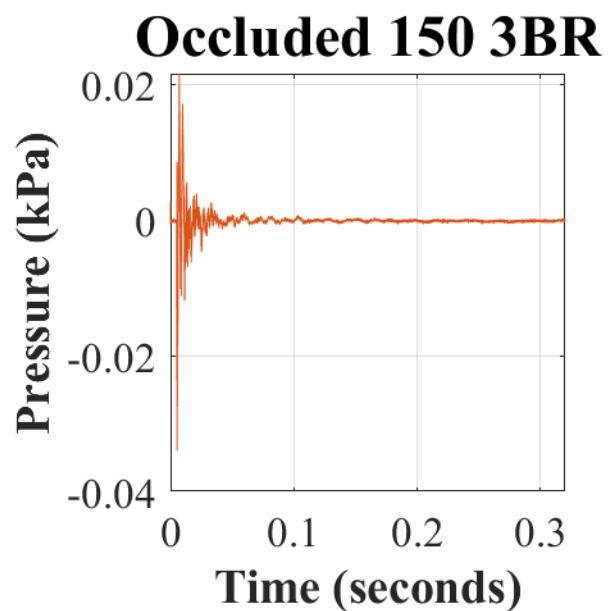
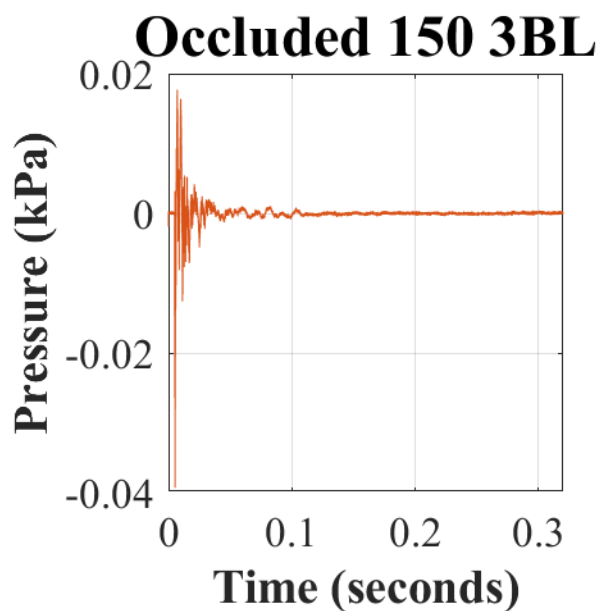
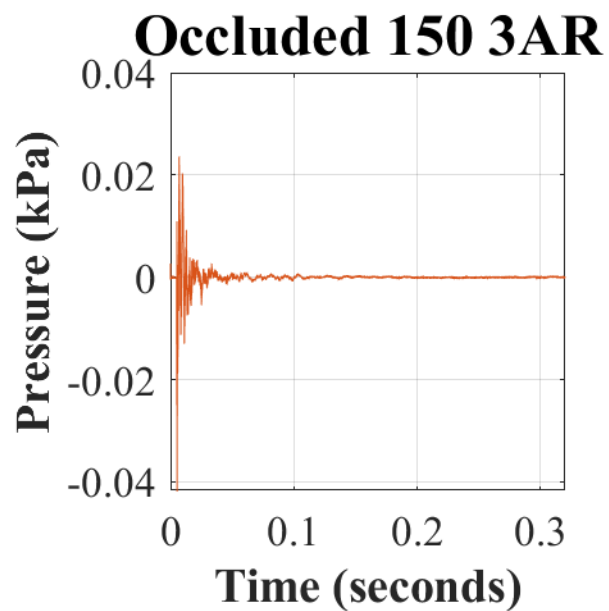
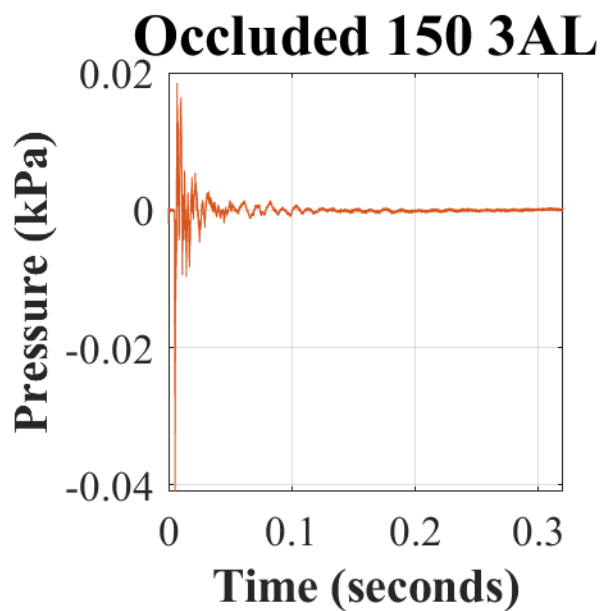


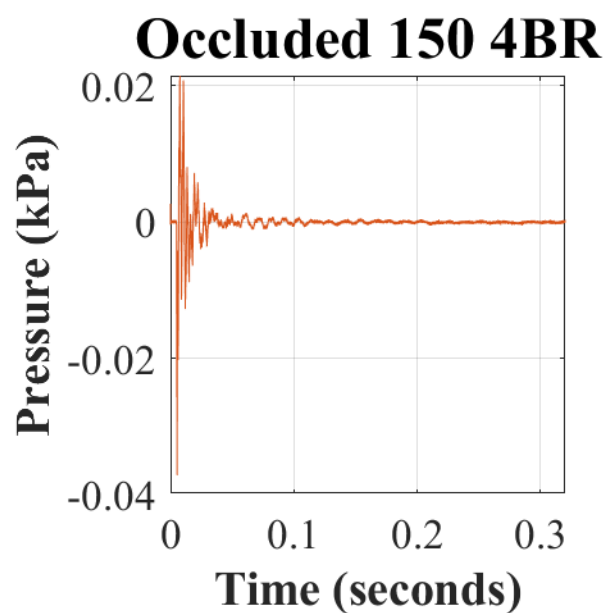
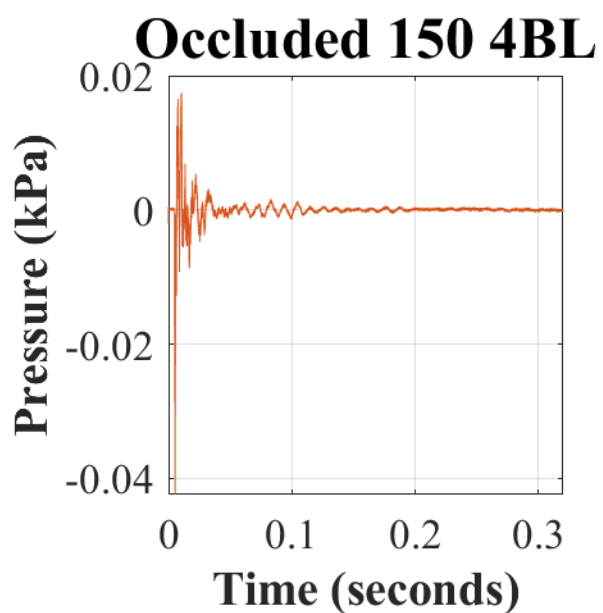
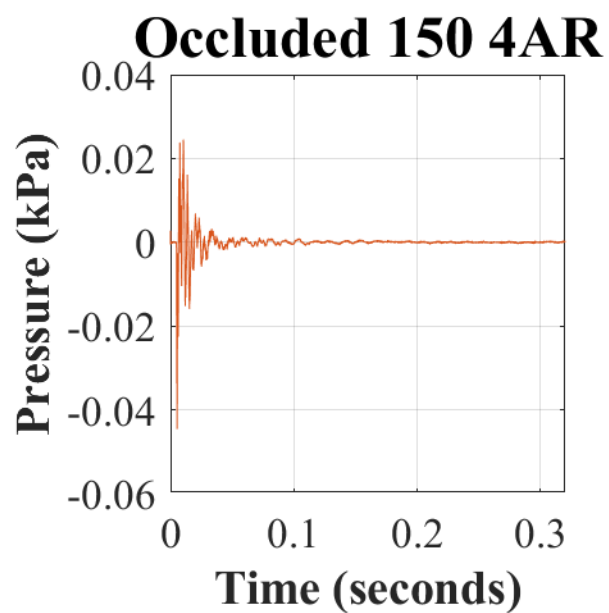
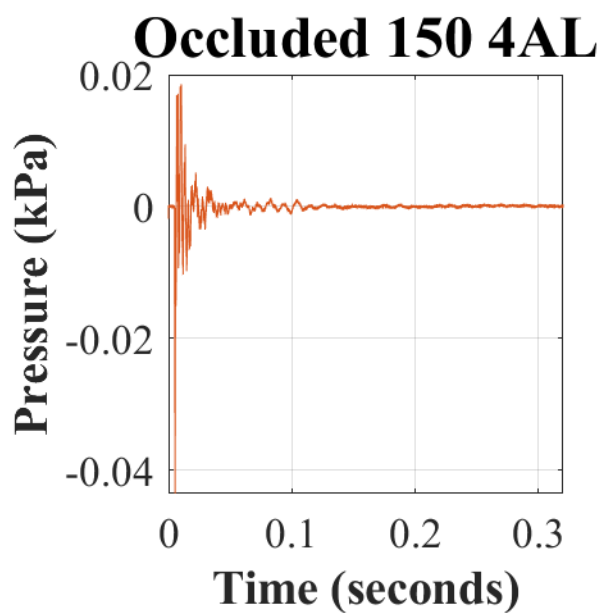
Note. The naming convention for all free-field waveforms is “Free Field LvL Nn”, where ‘Free Field’ indicates that the recording was obtained using the PCB reference microphone, ‘LvL’ is the nominal test level (170 dBp), ‘N’ is the device sample number (1 to 5), and ‘n’ is the device trial (i.e., A or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

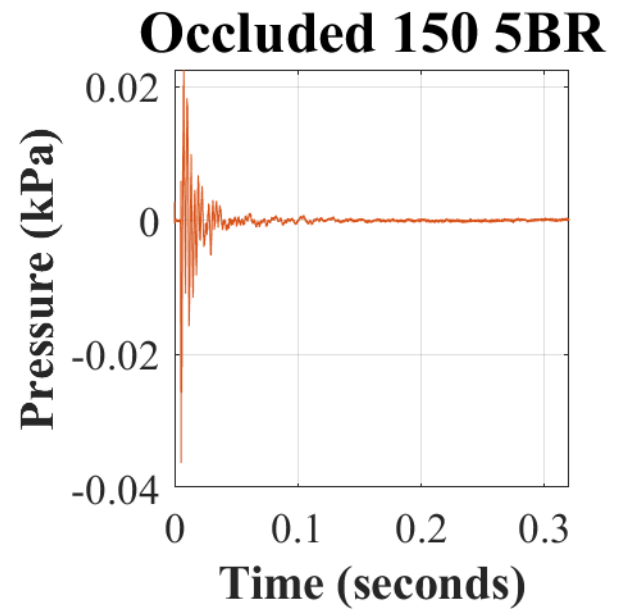
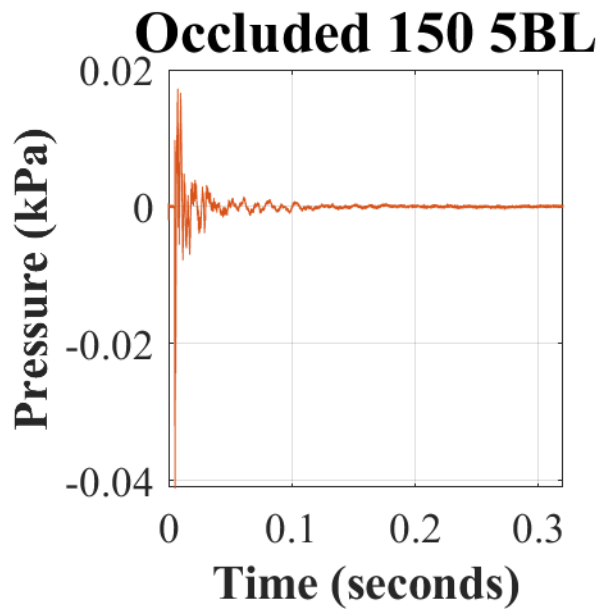
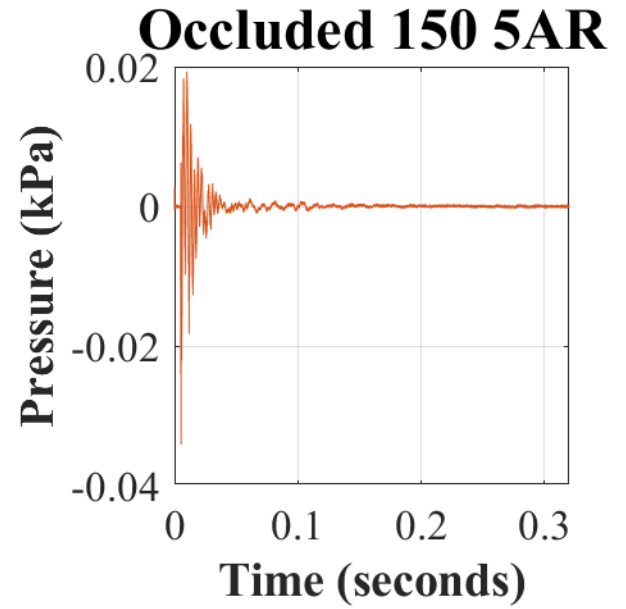
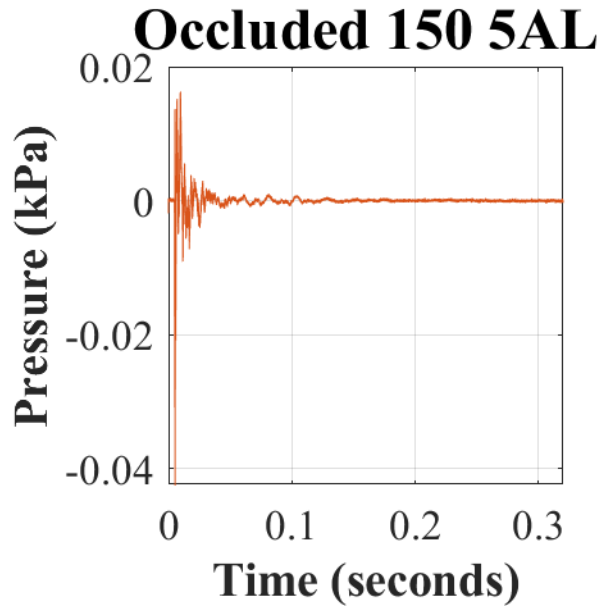
**Appendix J.** Recorded occluded (closed-ear) waveforms (in kilopascals [kPa]) over time (in seconds [s]) in response to 150 dBp with the Battleplugs® in the cap closed mode.





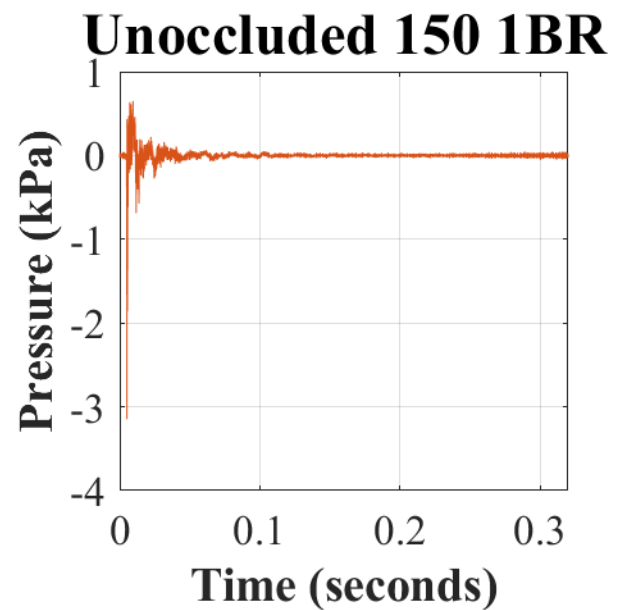
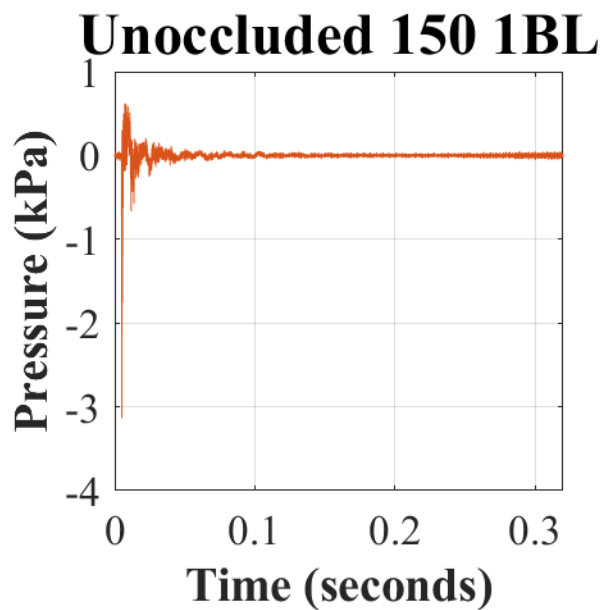
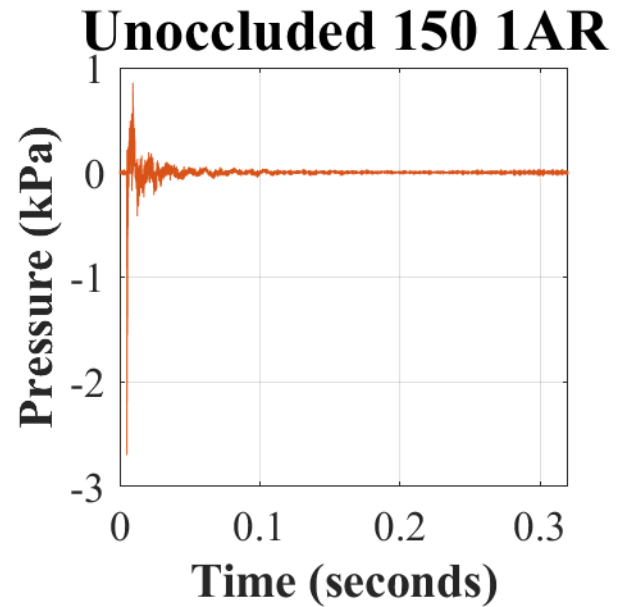
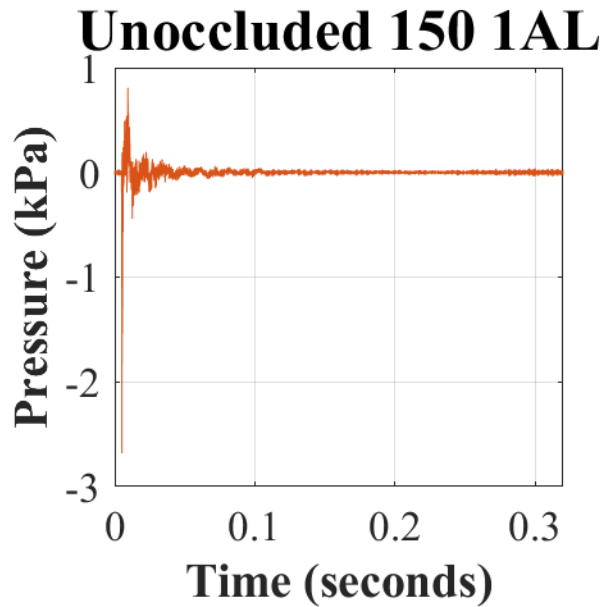


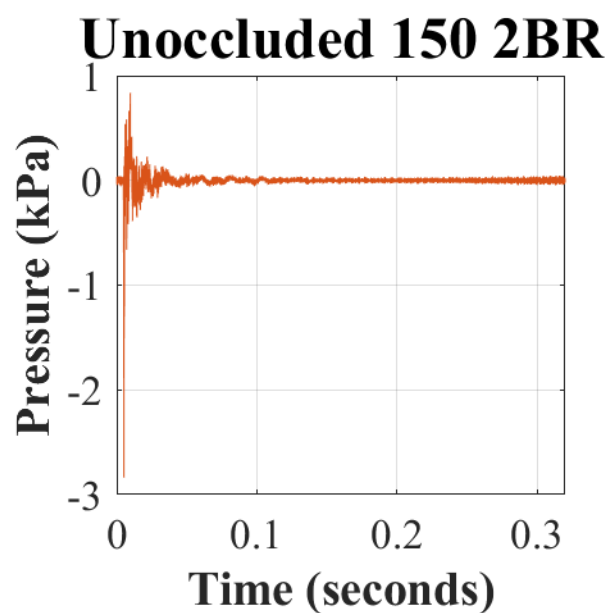
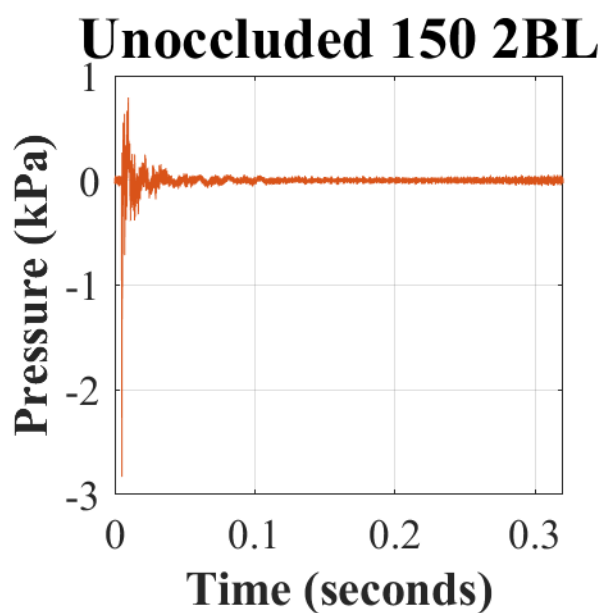
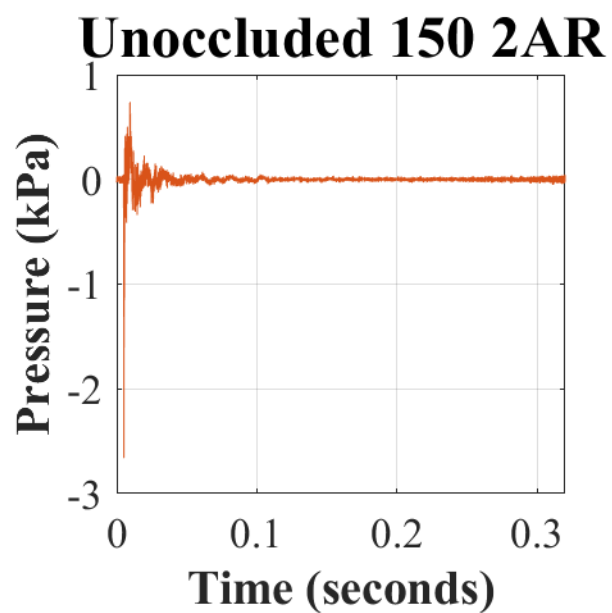
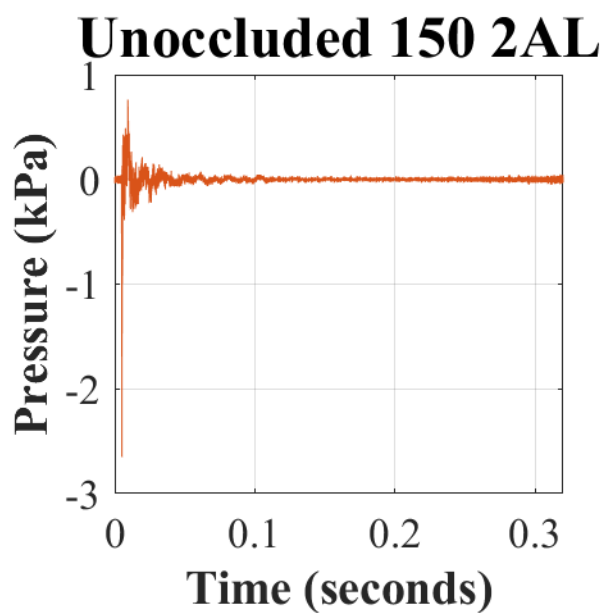


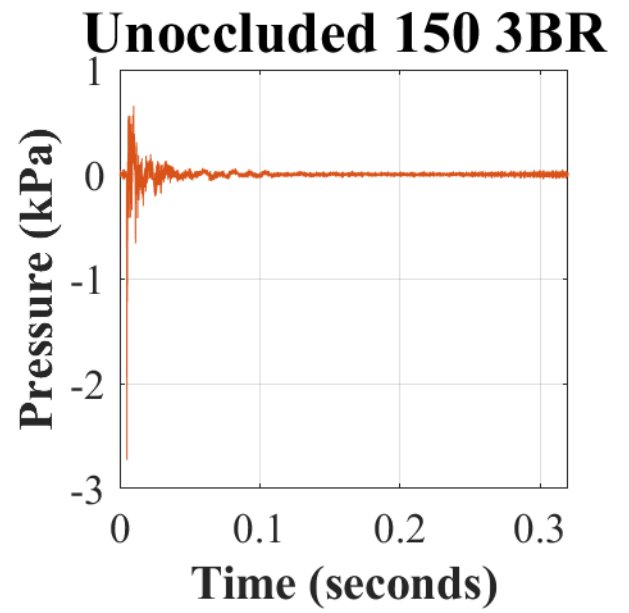
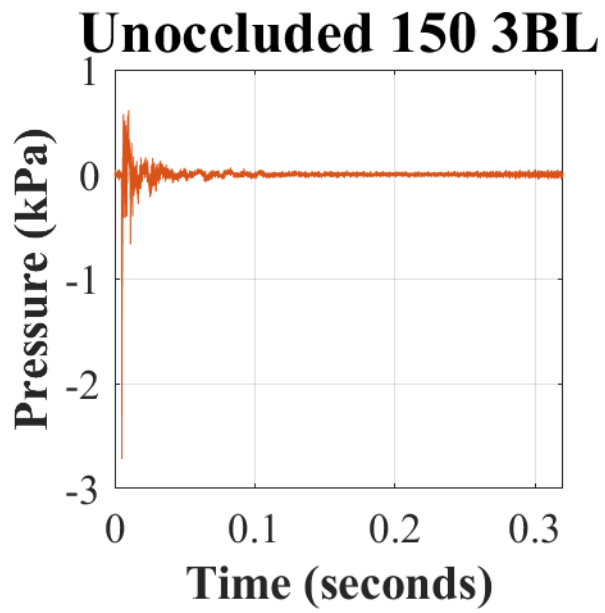
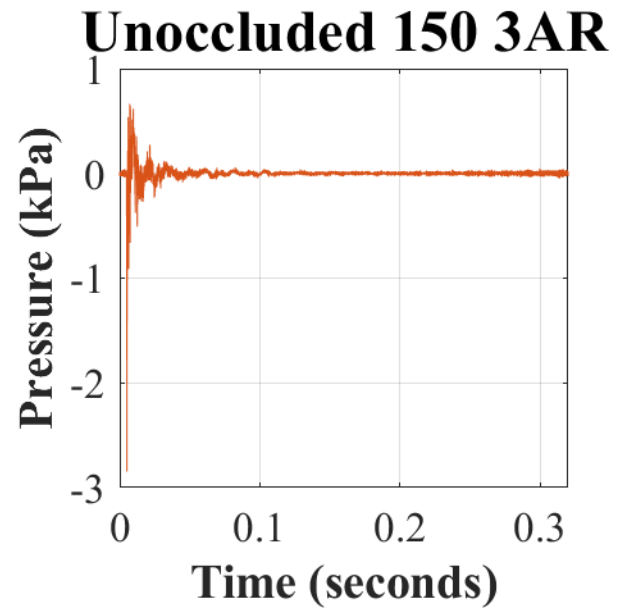
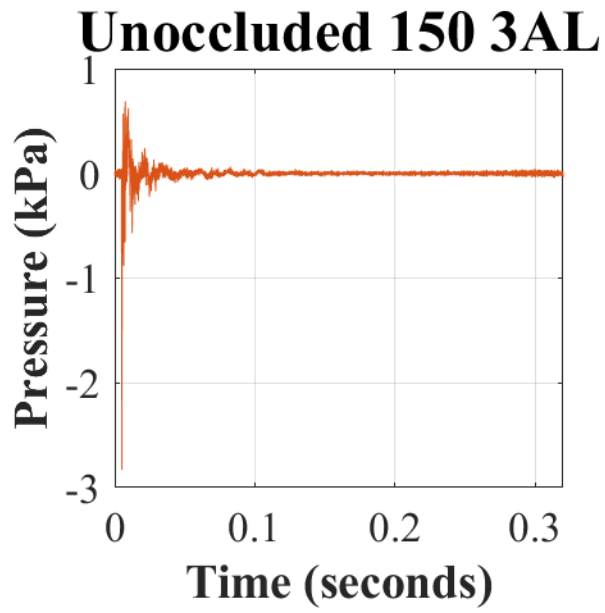


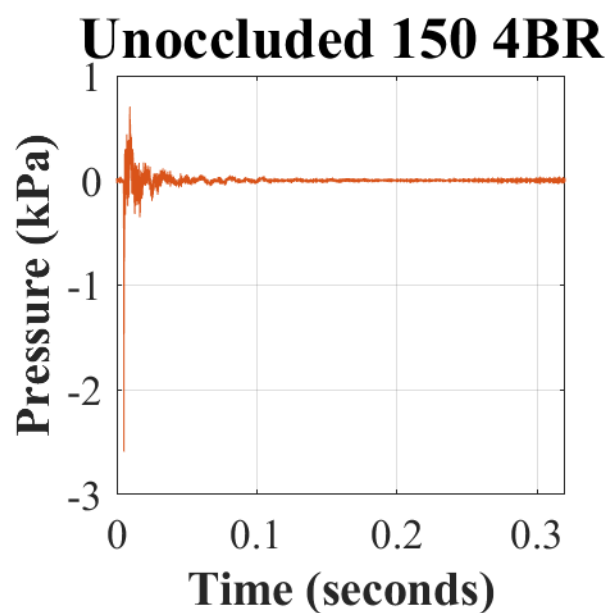
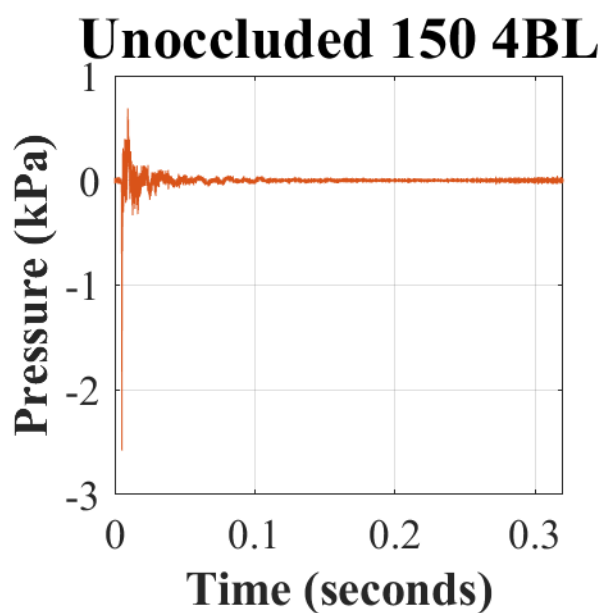
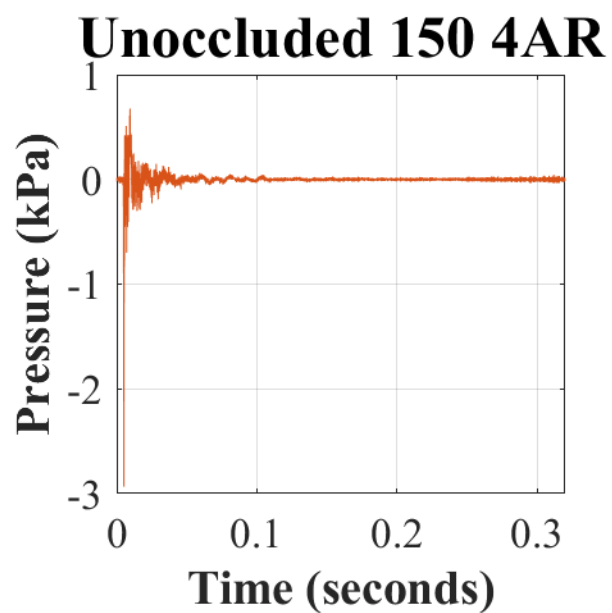
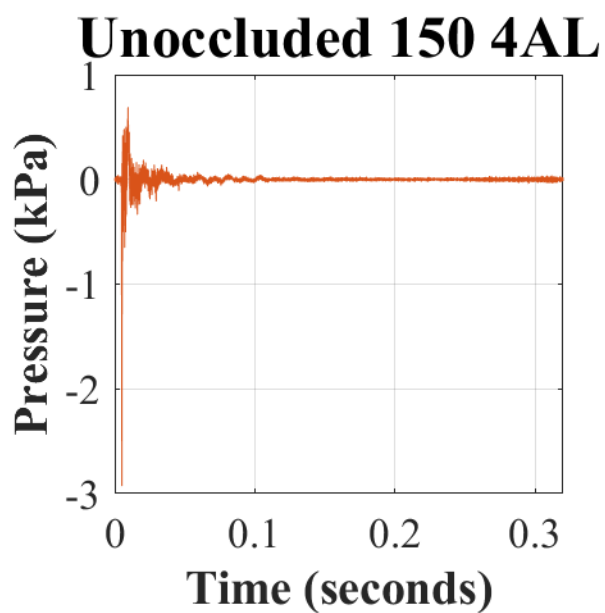
Note. The naming convention for all occluded waveforms is “Occluded LvL NnX”, where ‘Occluded’ is the test condition (i.e., ATF has the HPD donned), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or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

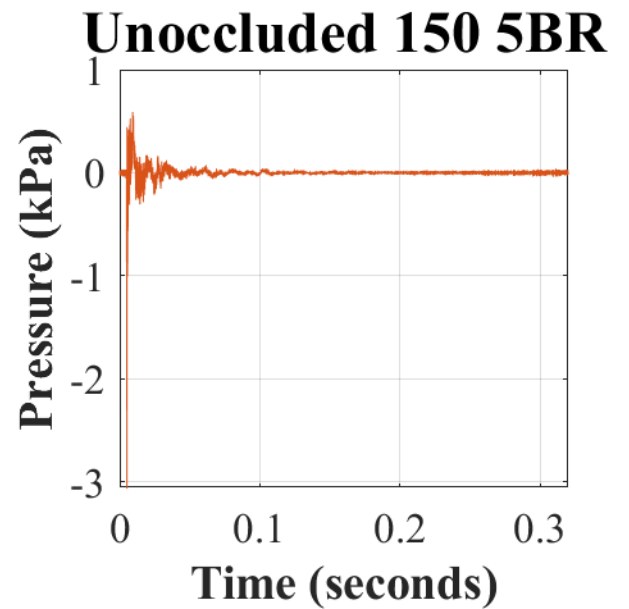
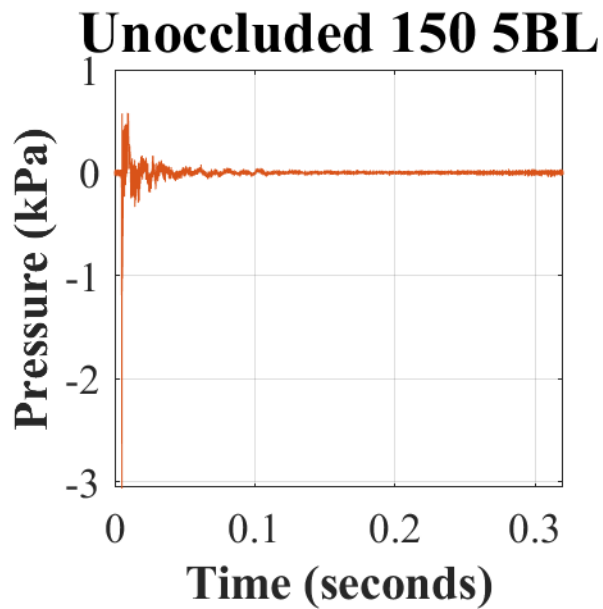
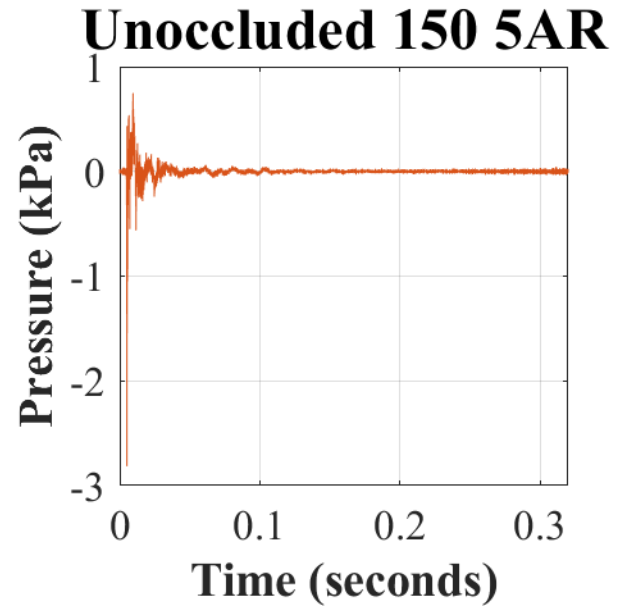
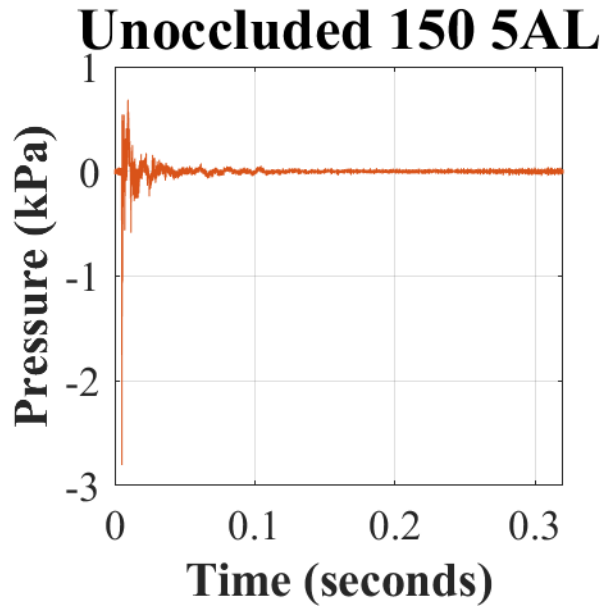
**Appendix K.** Estimated unoccluded (open-ear) waveforms (in kilopascals [kPa]) over time (in seconds [s]) in response to 150 dBp with the Battleplugs® in the cap closed mode.







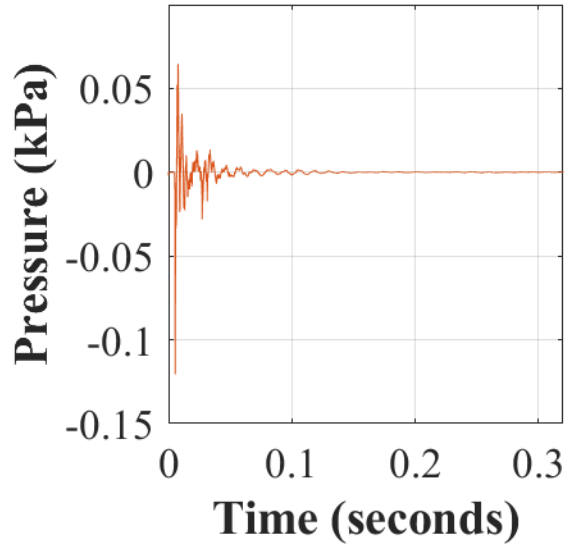




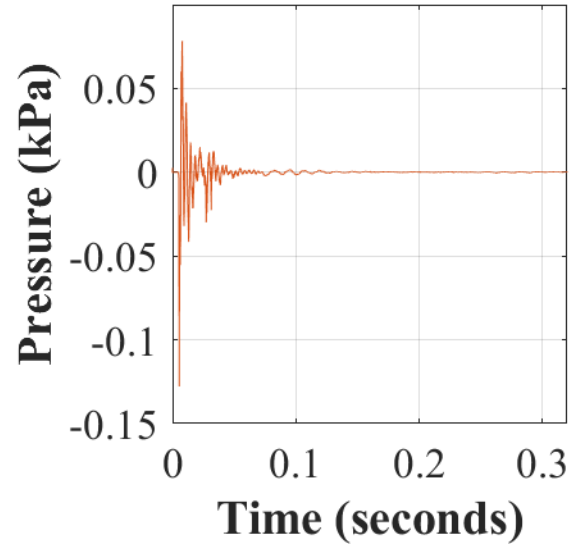
Note. The naming convention for all unoccluded waveforms is “Unoccluded LvL NnX”, where ‘Unoccluded’ is the test condition (i.e., ATF has the HPD doffed), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., 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 kilopascals [kPa]) over time (in seconds [s]) in response to 160 dBp with the Battleplugs® in the cap closed mode.

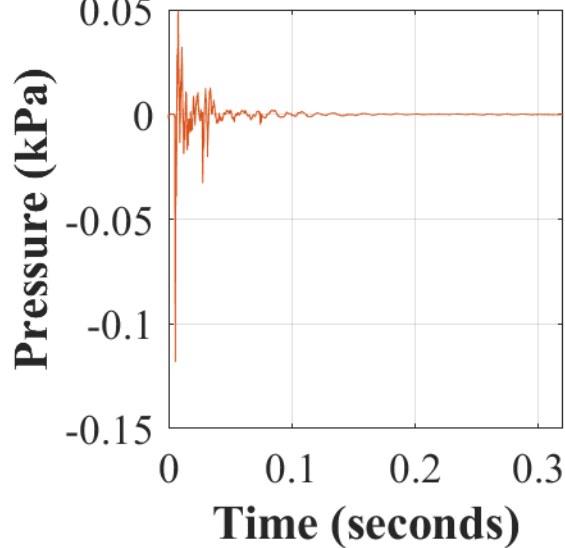
**Occluded 160 1AL**



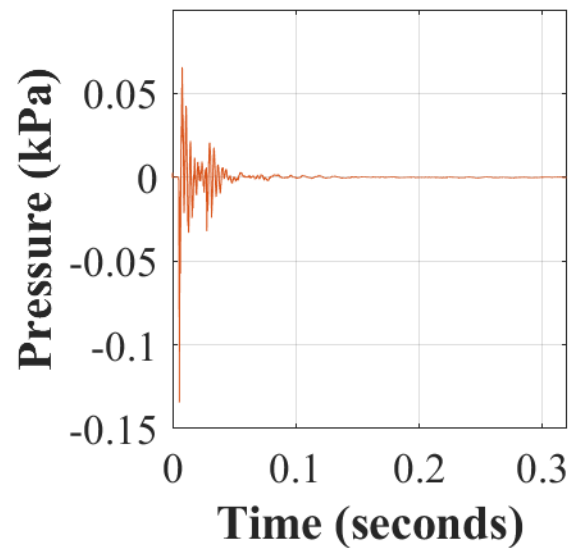
**Occluded 160 1AR**



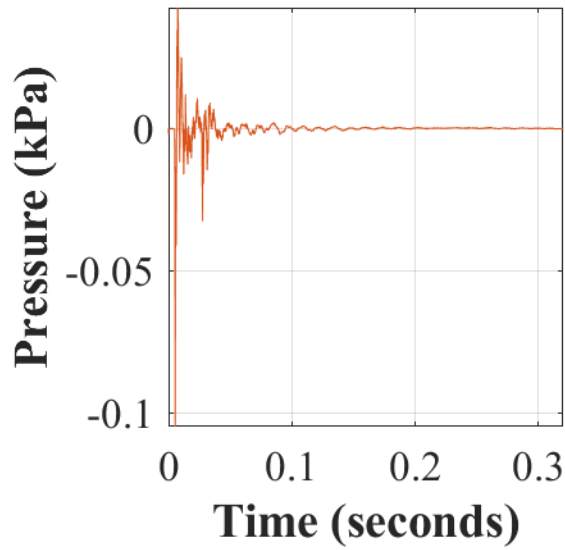
**Occluded 160 1BL**



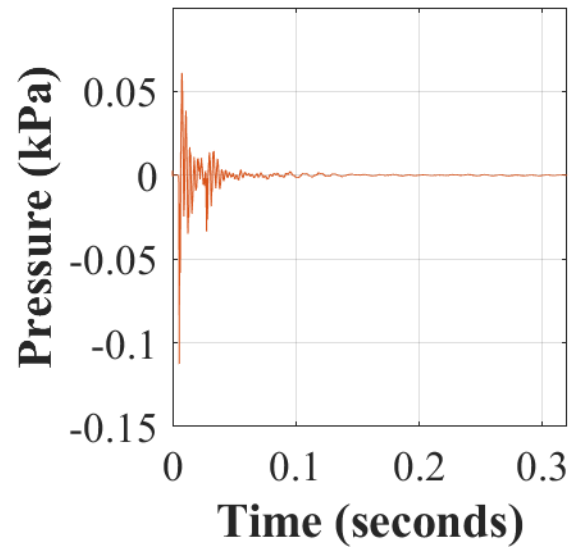
**Occluded 160 1BR**



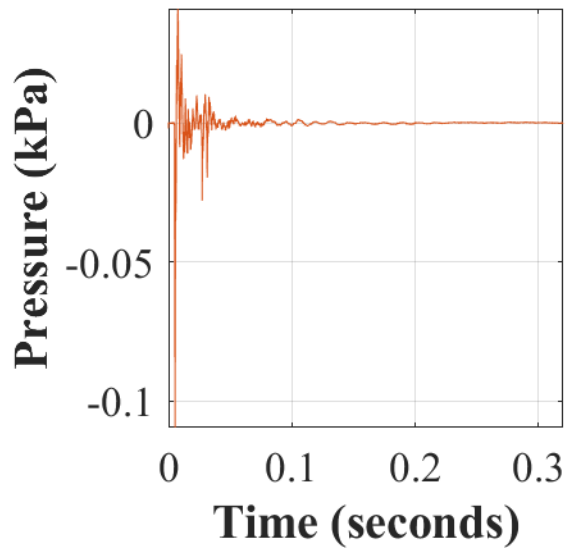
**Occluded 160 2AL**



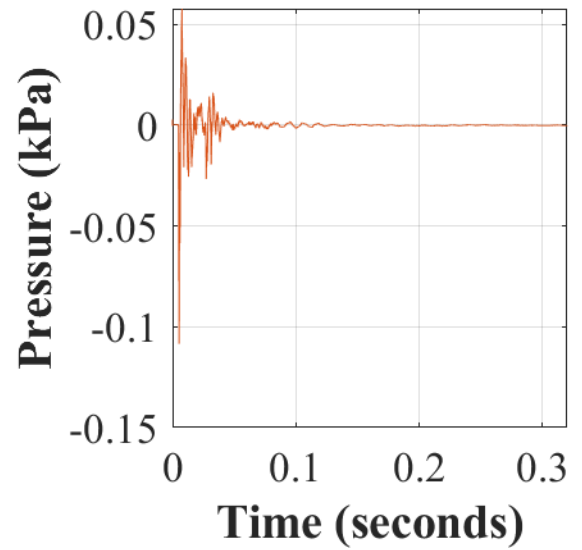
**Occluded 160 2AR**

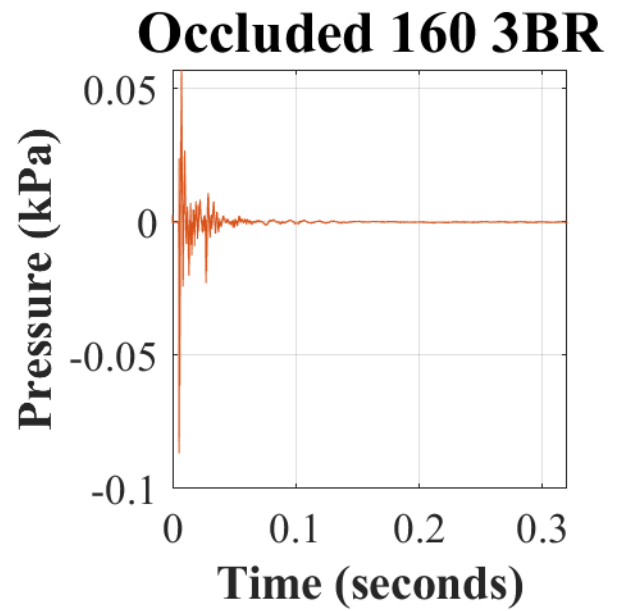
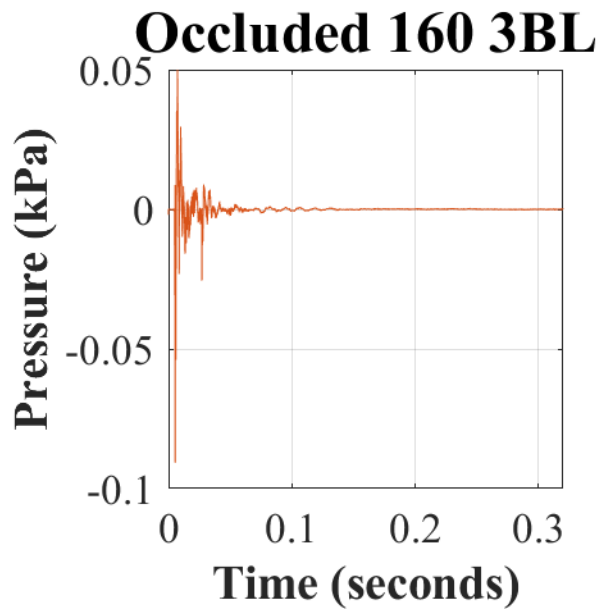
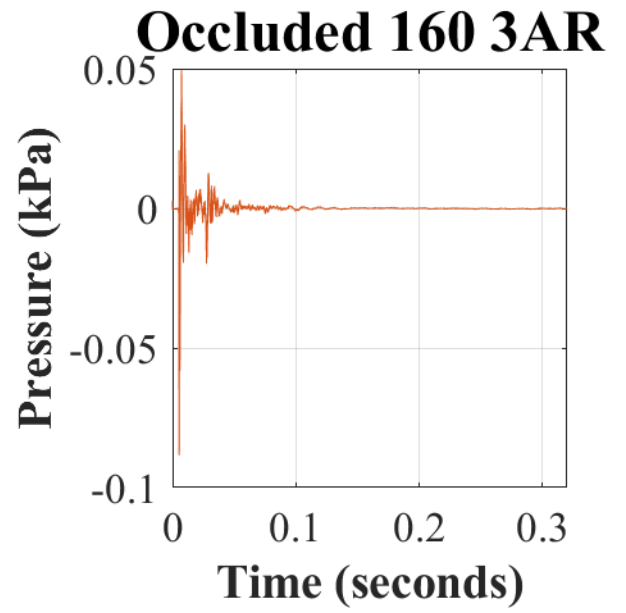
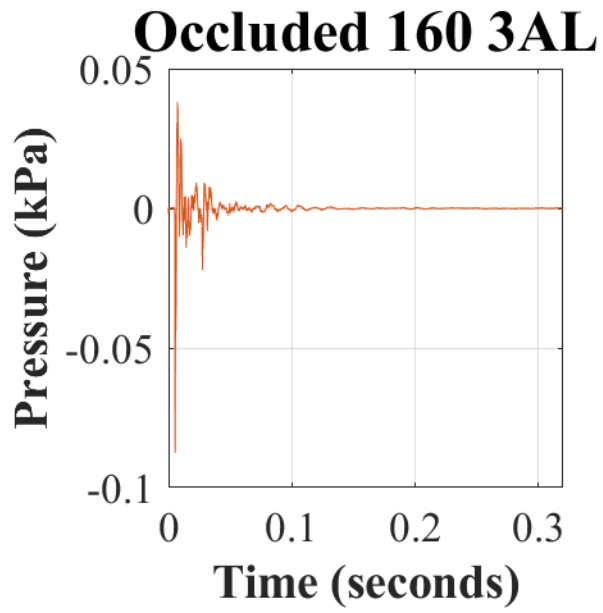


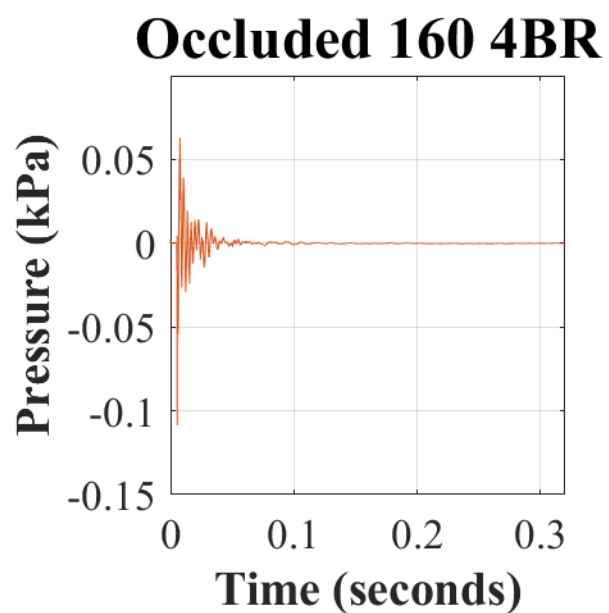
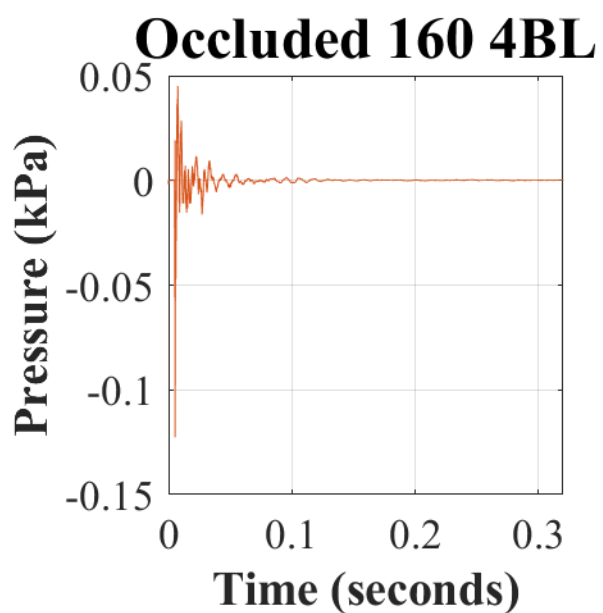
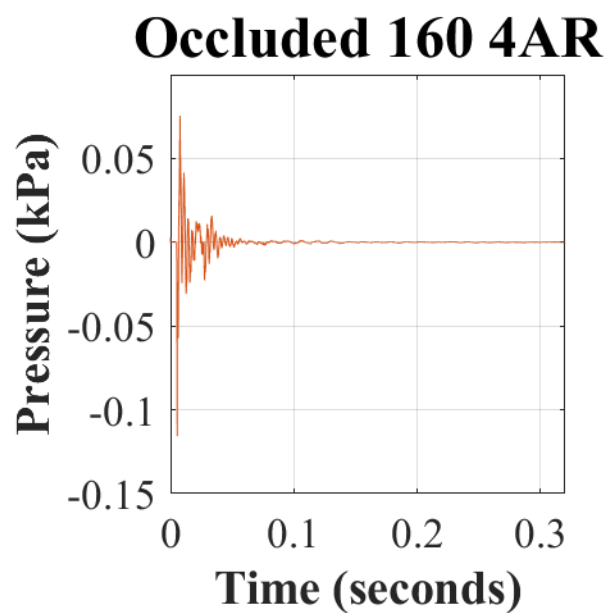
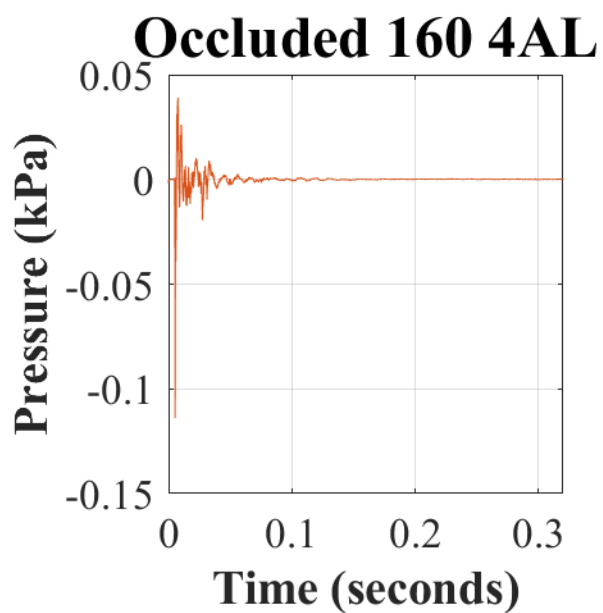
**Occluded 160 2BL**

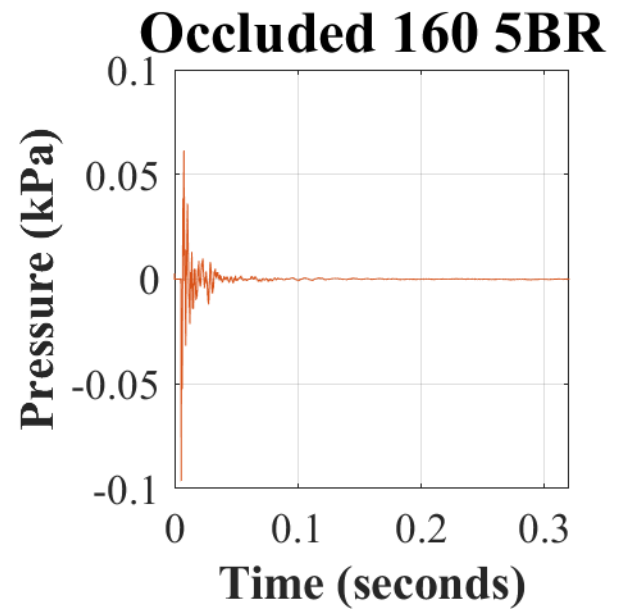
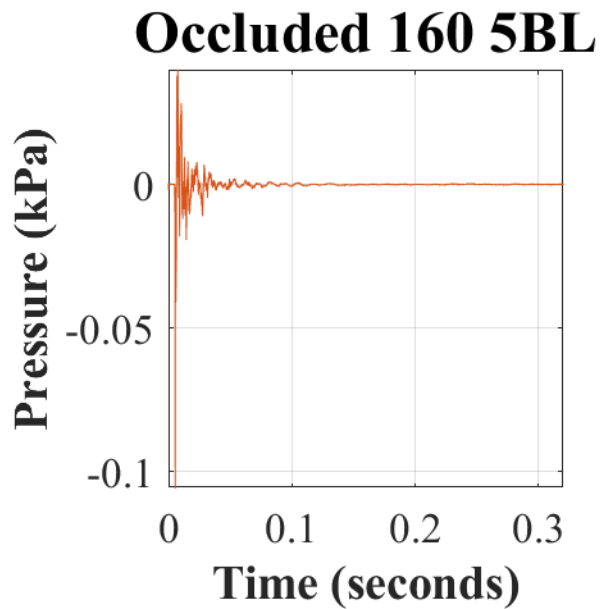
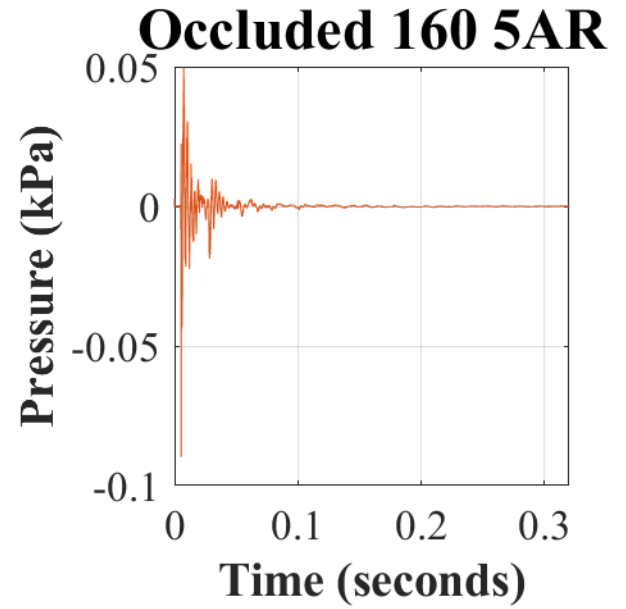
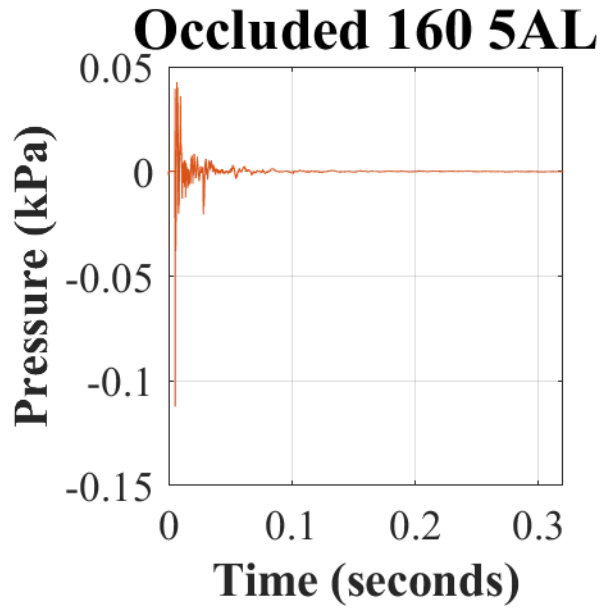


**Occluded 160 2BR**



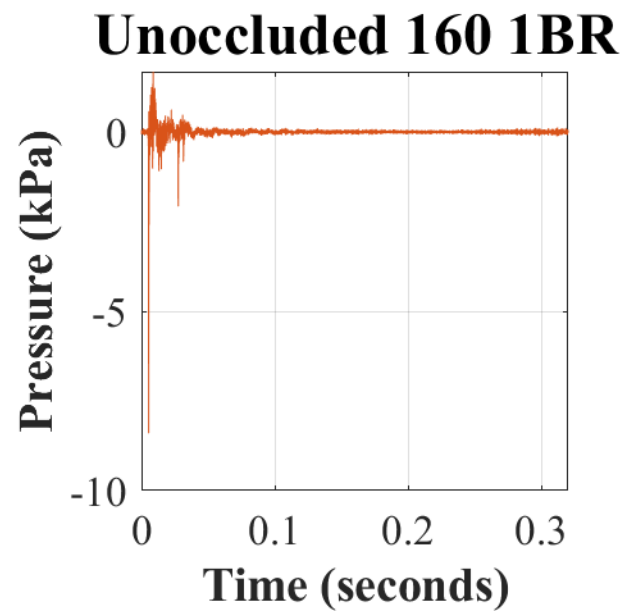
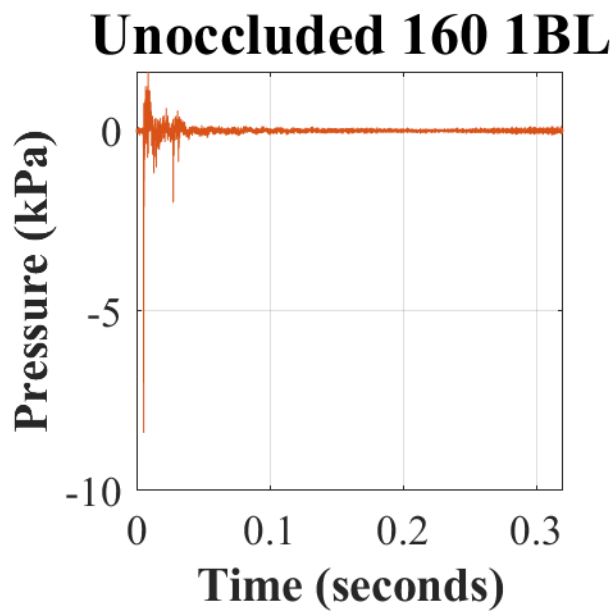
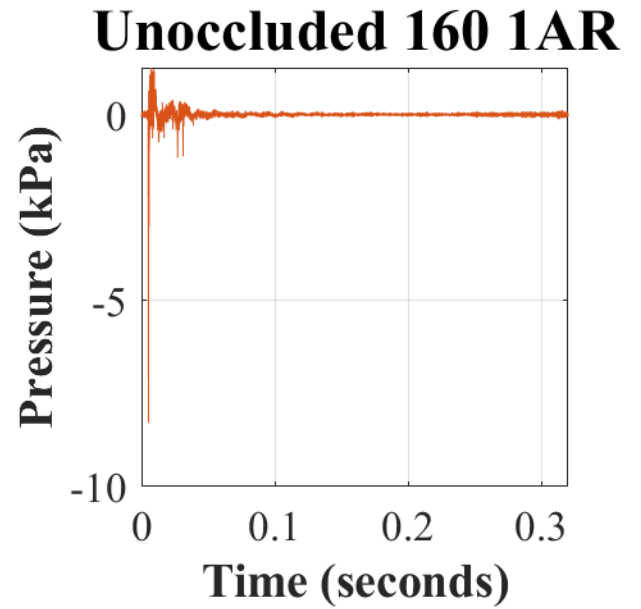
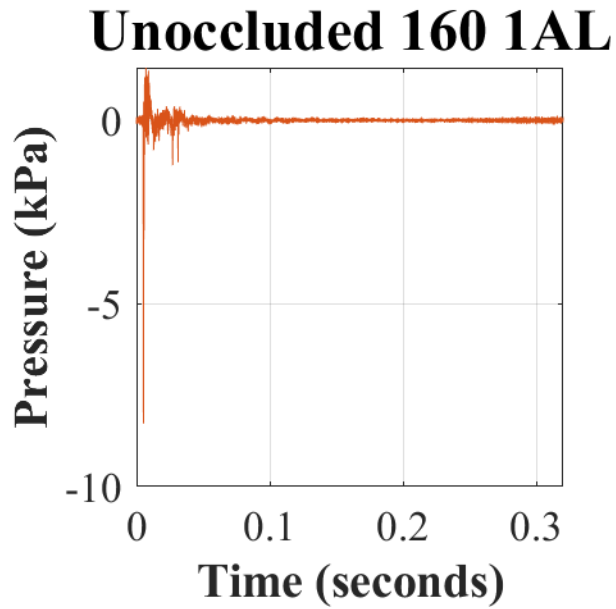


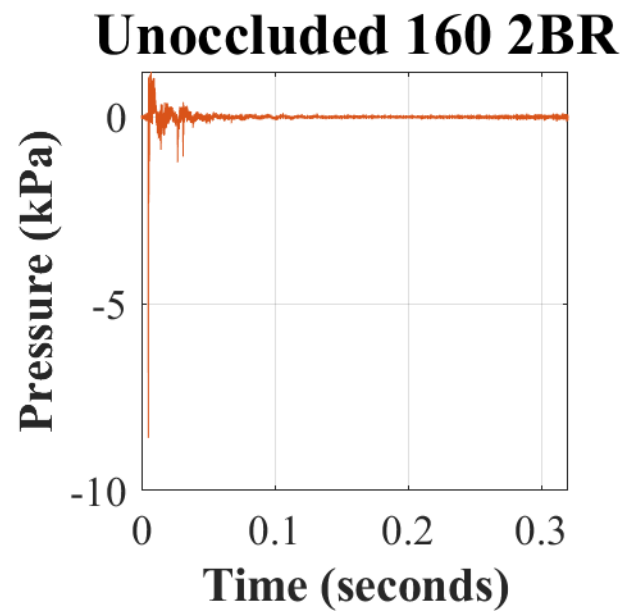
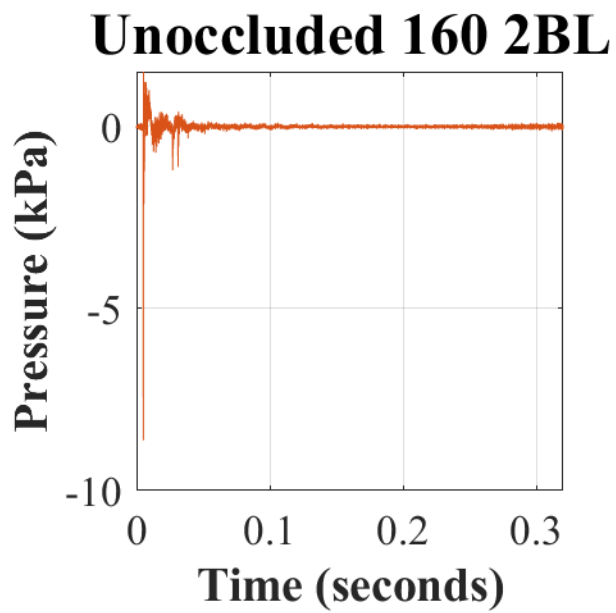
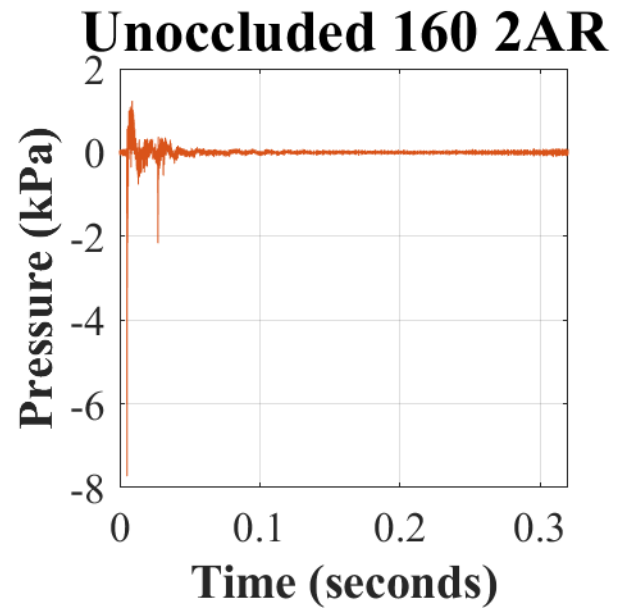
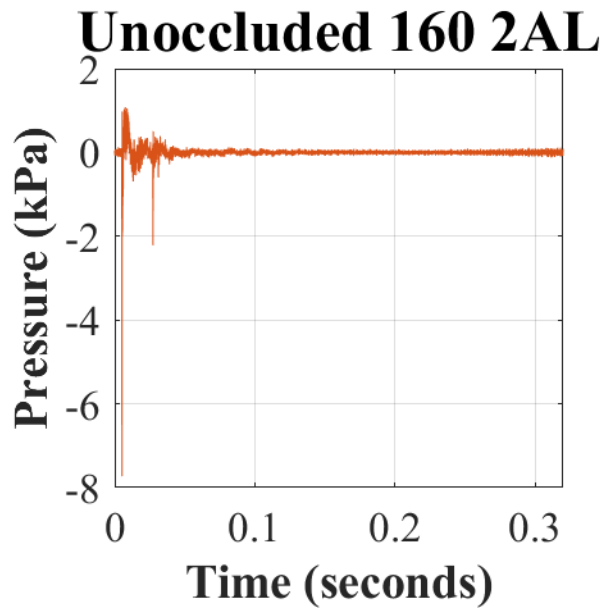




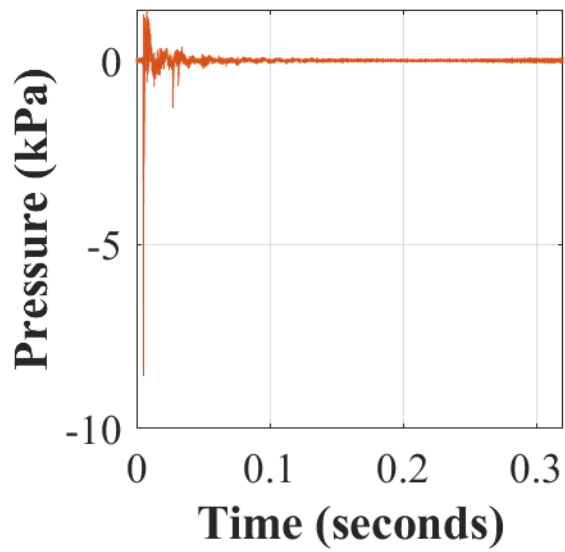
Note. The naming convention for all occluded waveforms is “Occluded LvL NnX”, where ‘Occluded’ is the test condition (i.e., ATF has the HPD donned), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or 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 M.** Estimated unoccluded (open-ear) waveforms (in kilopascals [kPa]) over time (in seconds [s]) in response to 160 dBp with the Battleplugs® in the cap closed mode.

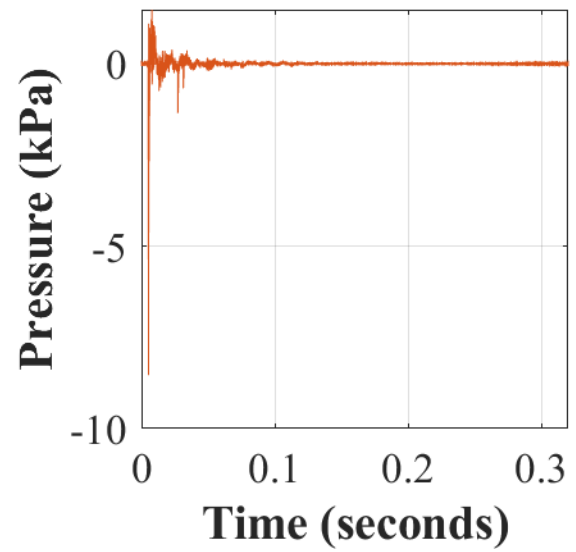




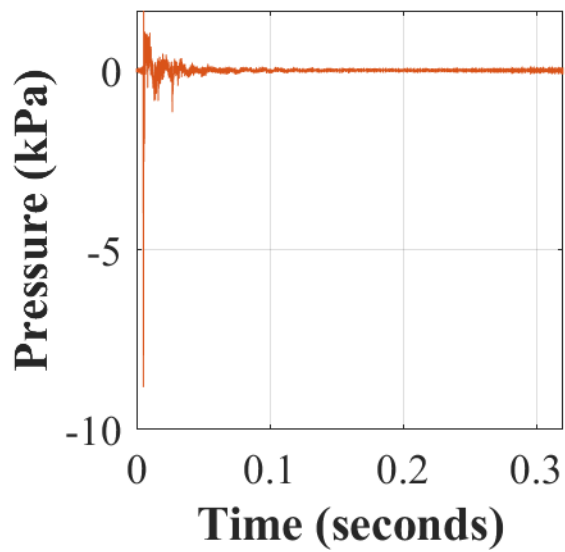
**Unoccluded 160 3AL**



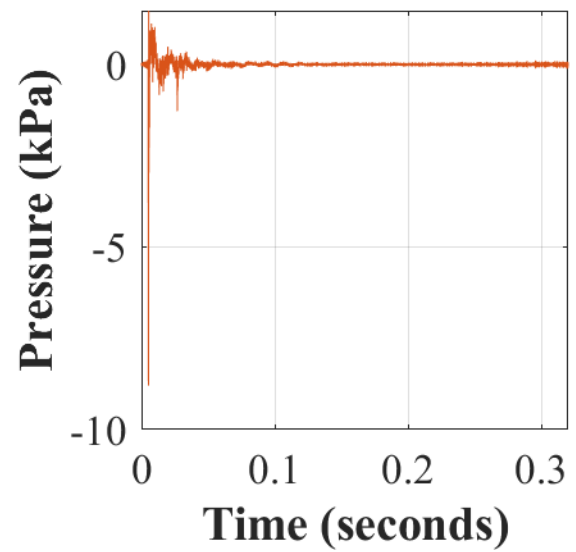
**Unoccluded 160 3AR**



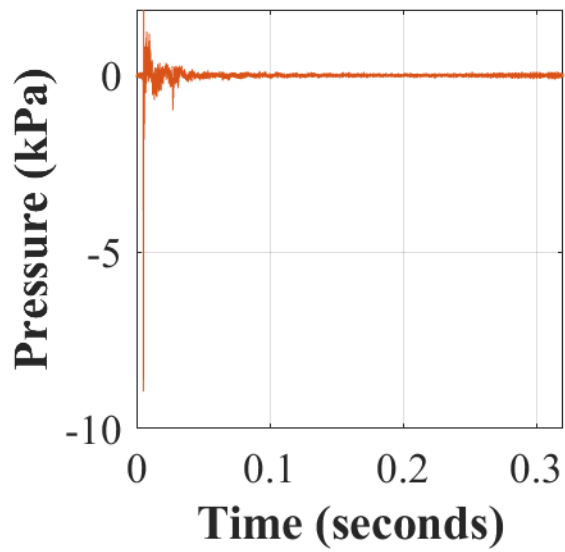
**Unoccluded 160 3BL**



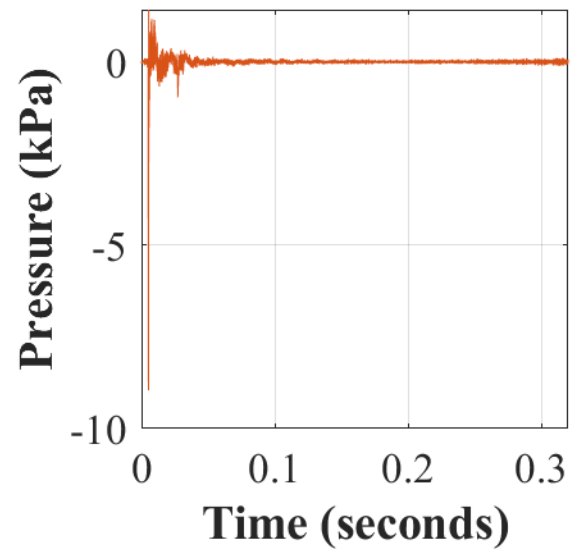
**Unoccluded 160 3BR**



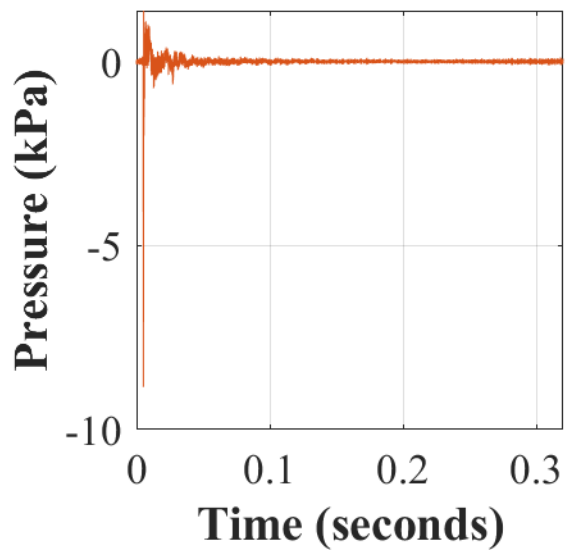
**Unoccluded 160 4AL**



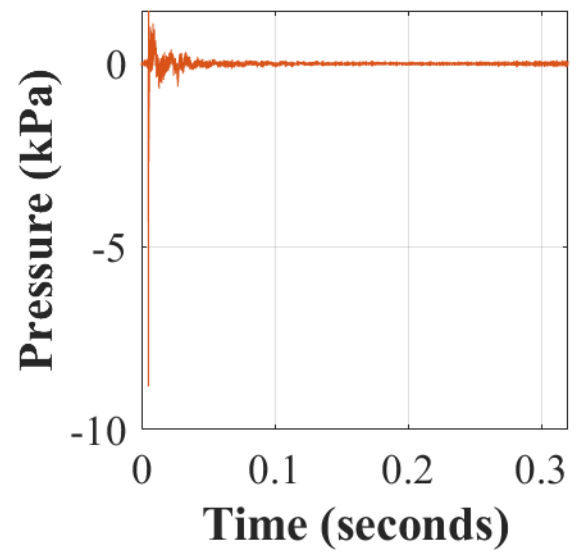
**Unoccluded 160 4AR**

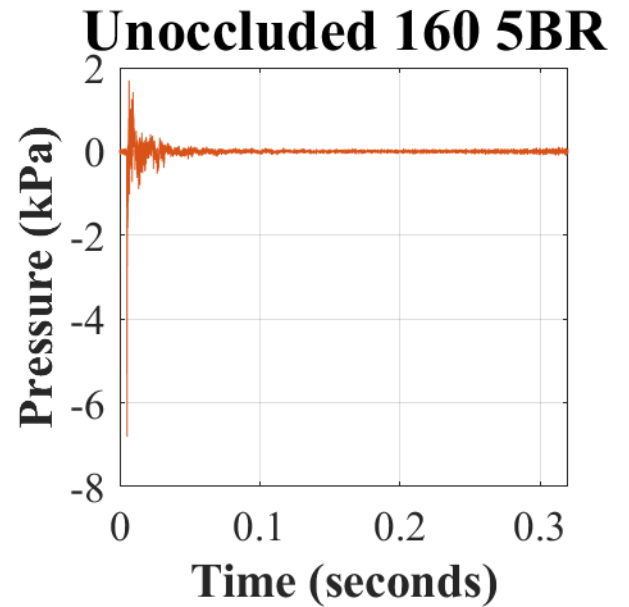
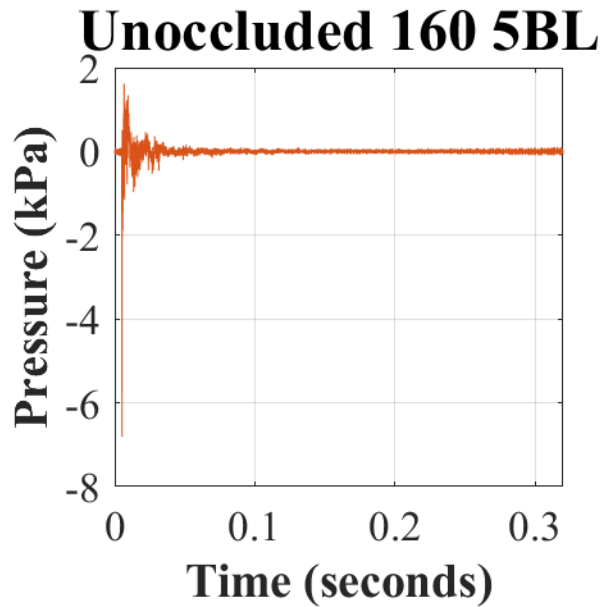
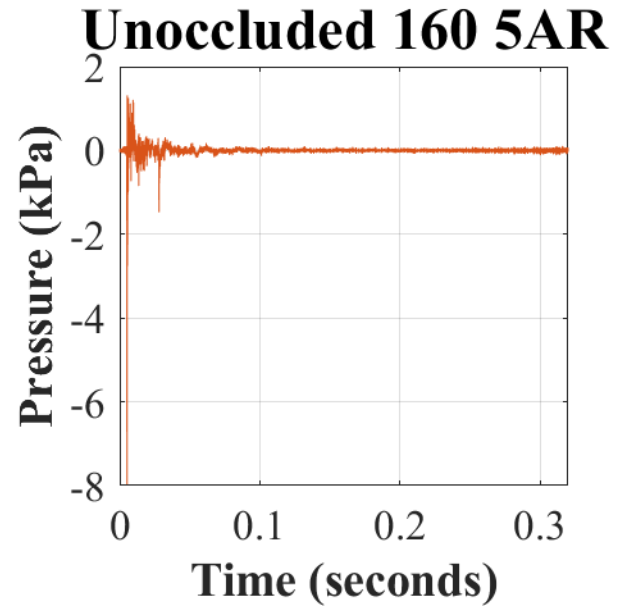
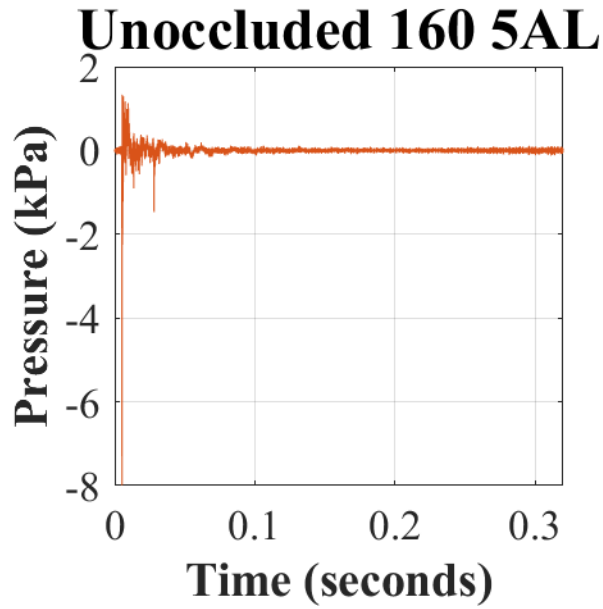


**Unoccluded 160 4BL**



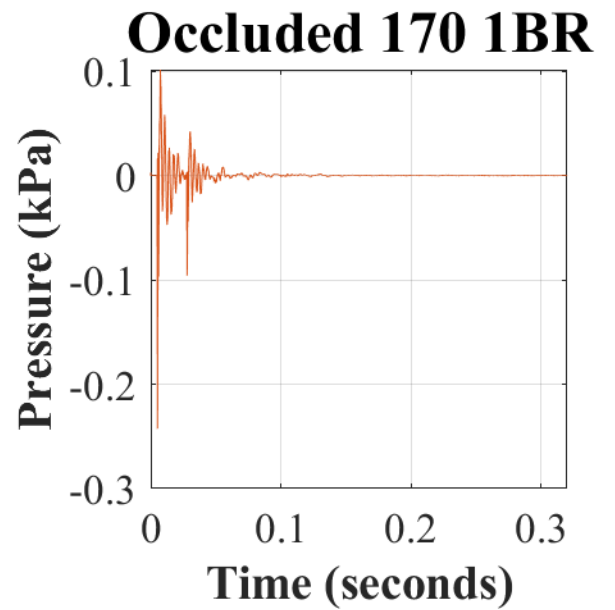
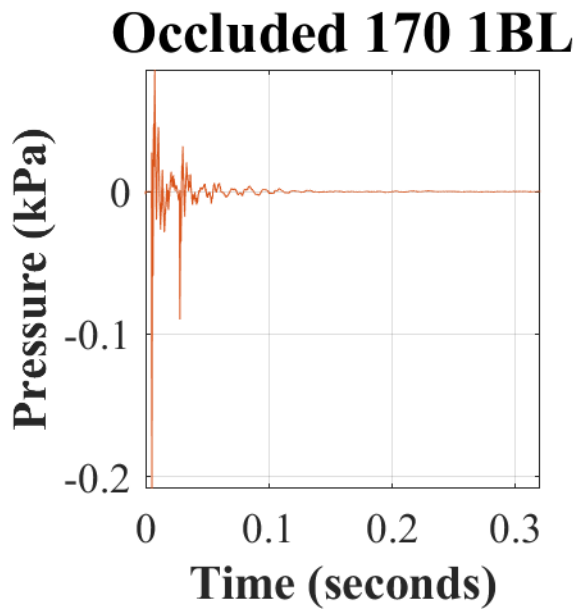
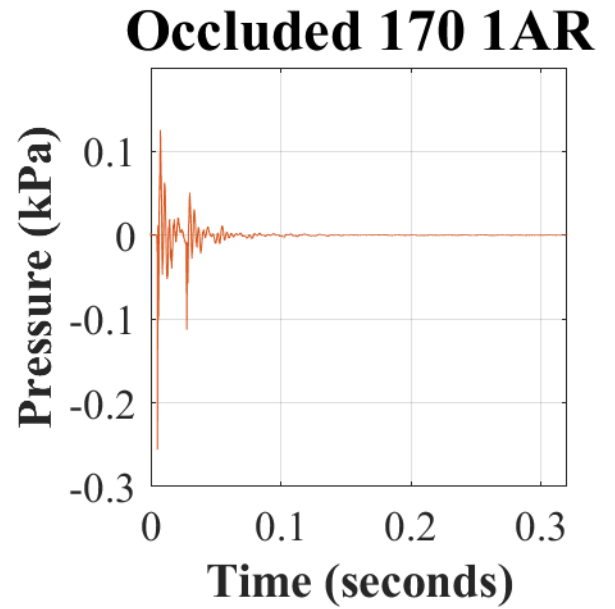
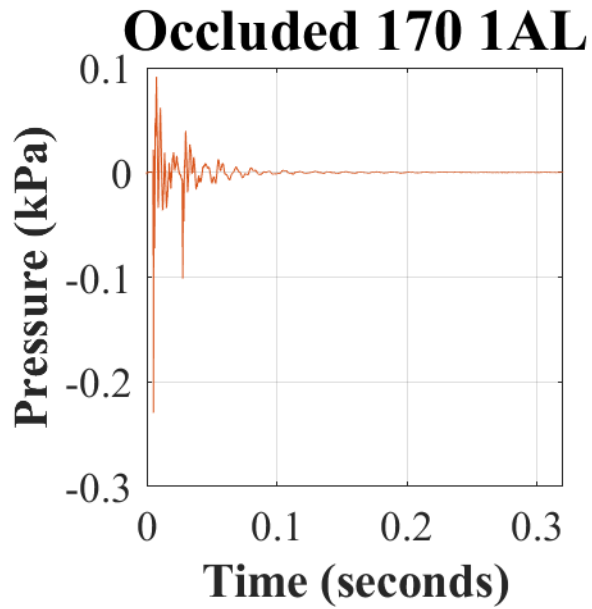
**Unoccluded 160 4BR**



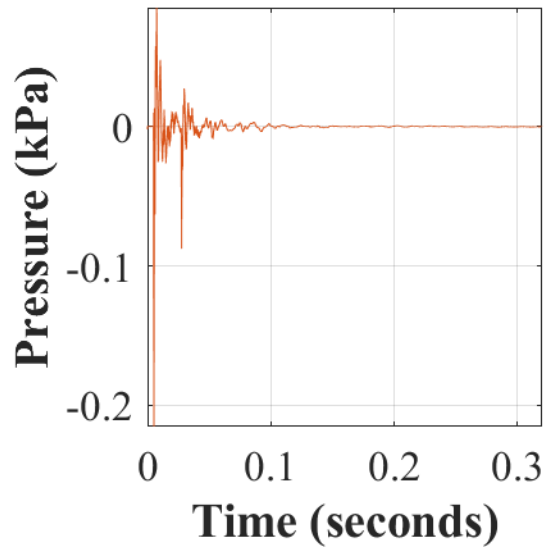


Note. The naming convention for all unoccluded waveforms is “Unoccluded LvL NnX”, where ‘Unoccluded’ is the test condition (i.e., ATF has the HPD doffed), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e.,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

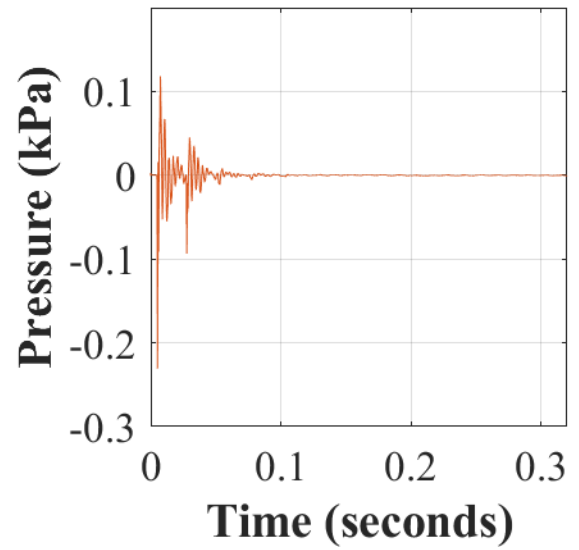
**Appendix N.** Recorded occluded (closed-ear) waveforms (in kilopascals [kPa]) over time (in seconds [s]) in response to 170 dBp with the Battleplugs® in the cap closed mode.



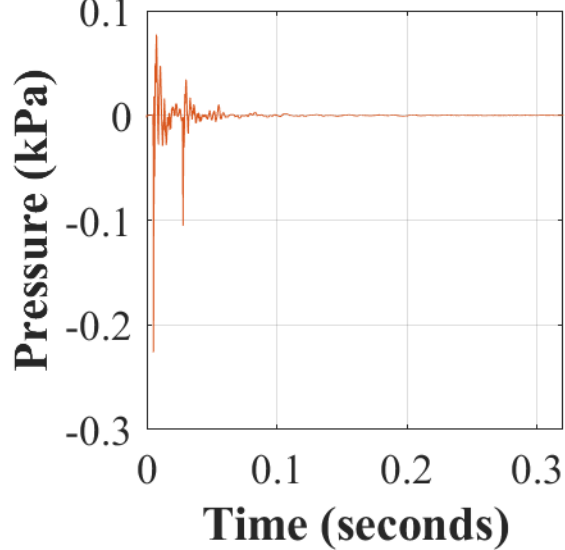
**Occluded 170 2AL**



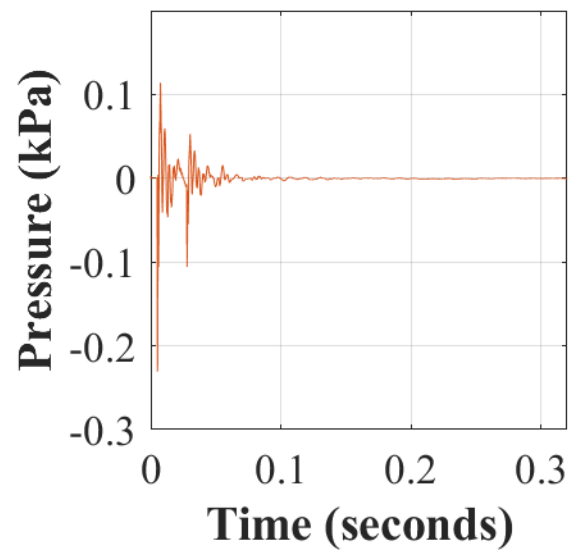
**Occluded 170 2AR**

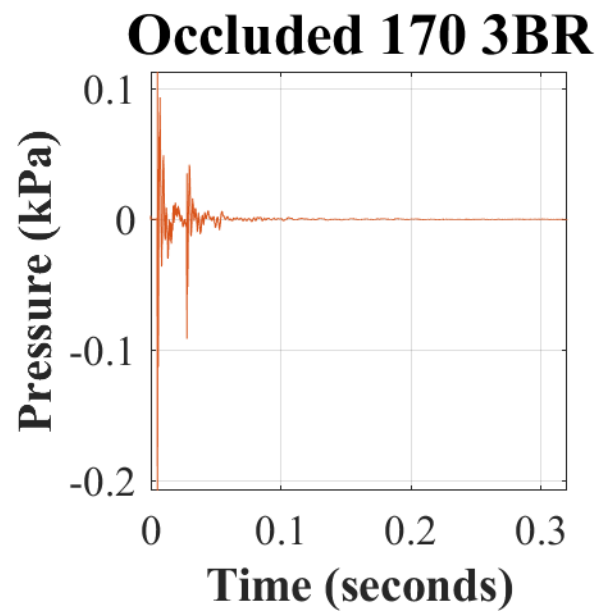
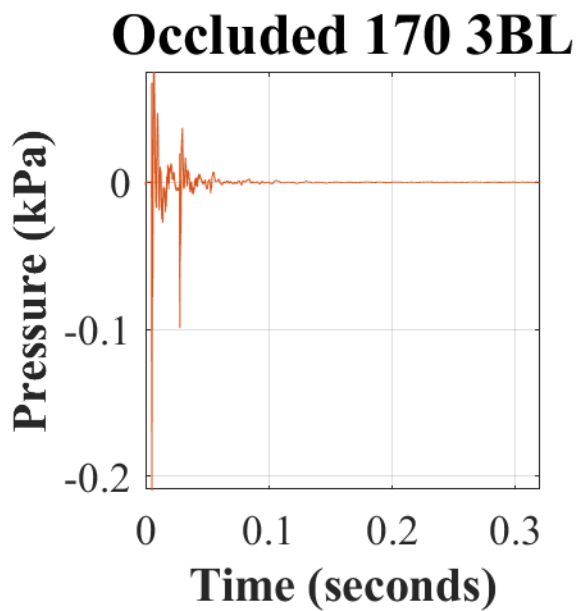
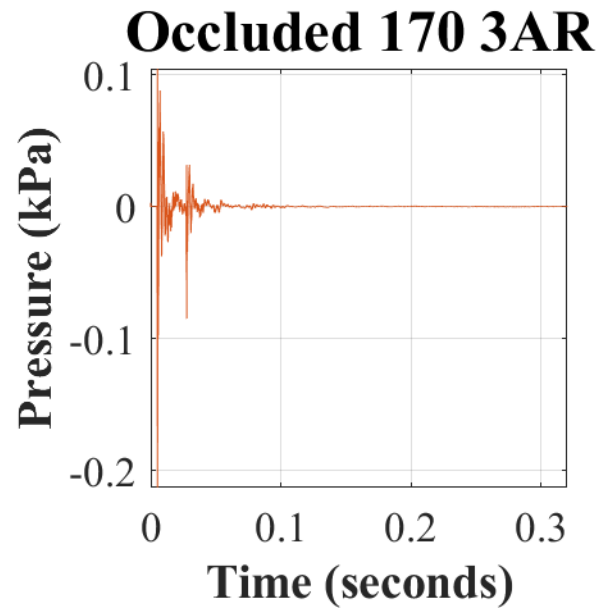
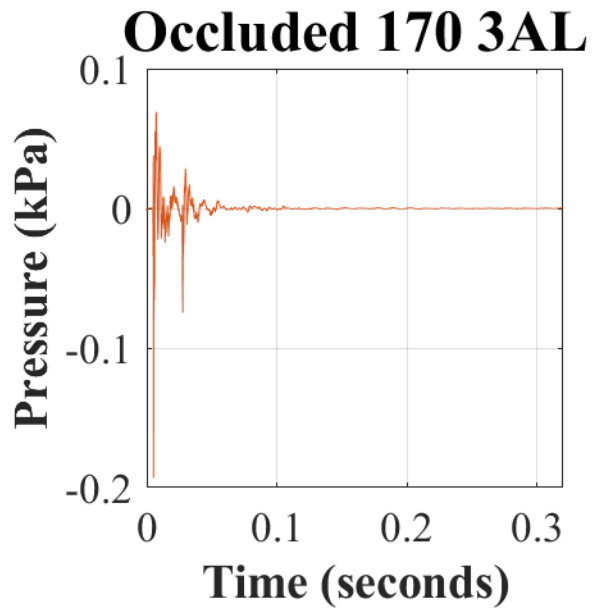


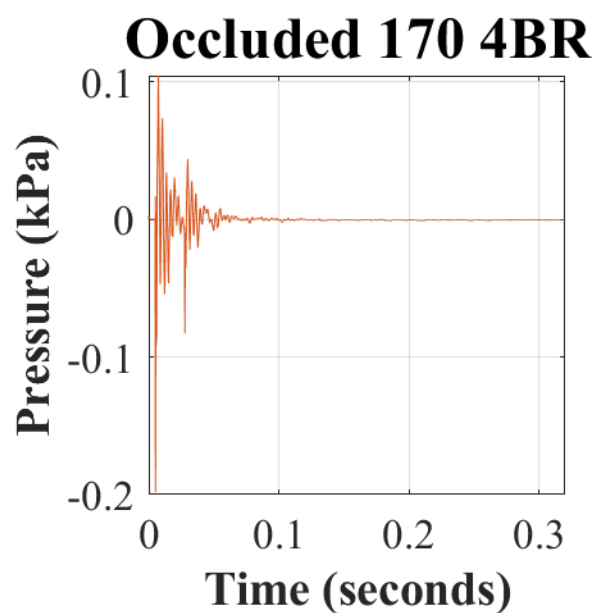
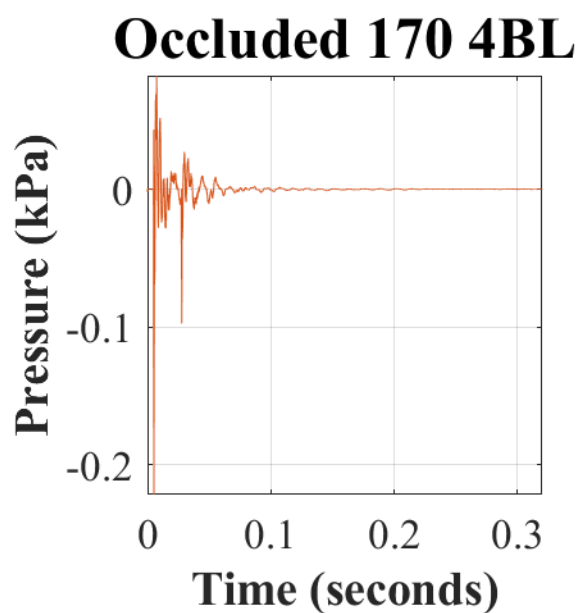
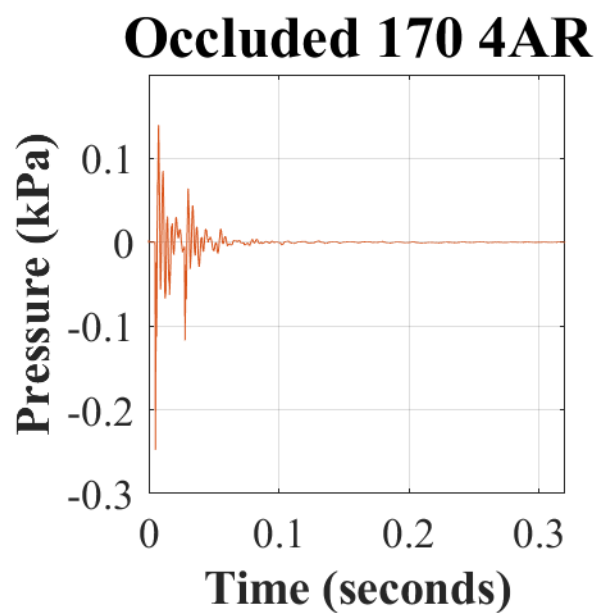
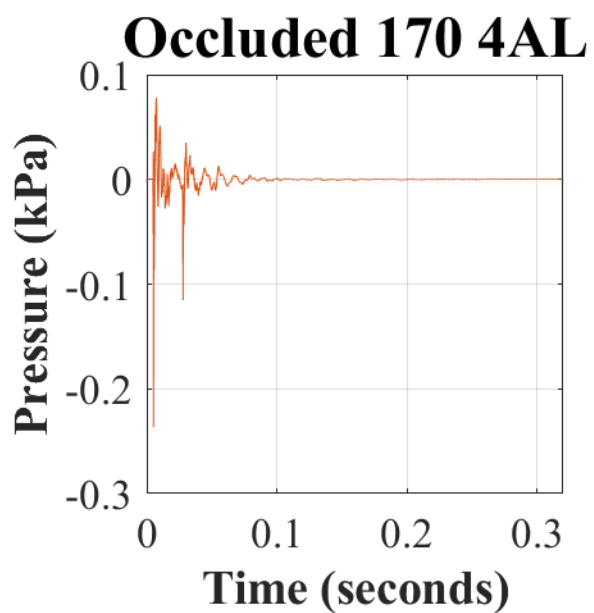
**Occluded 170 2BL**

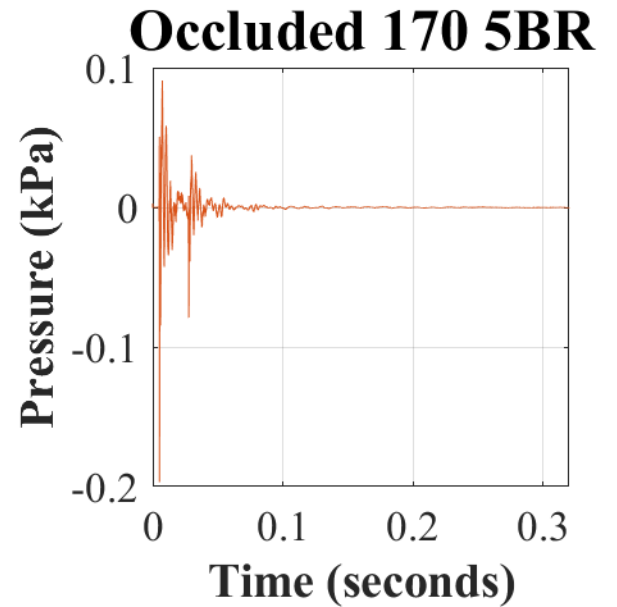
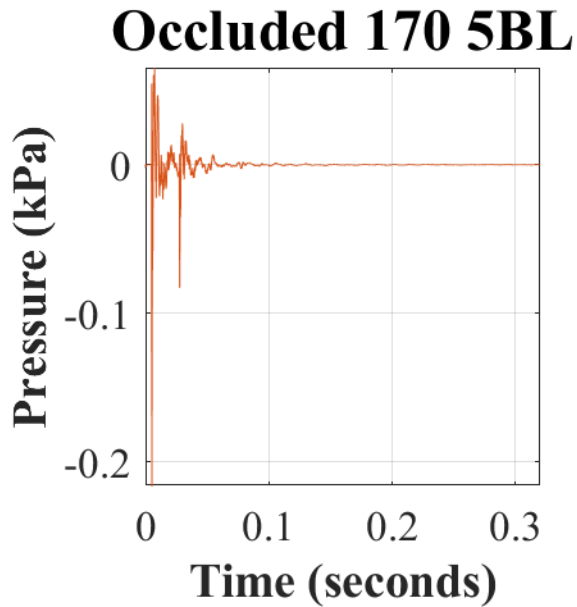
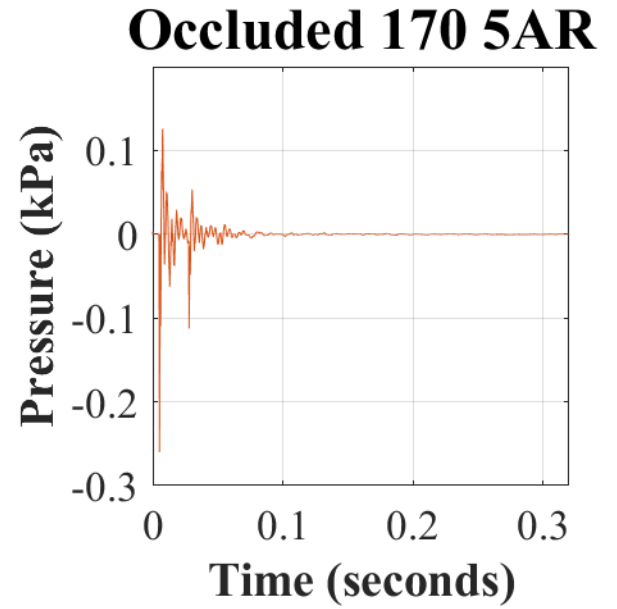
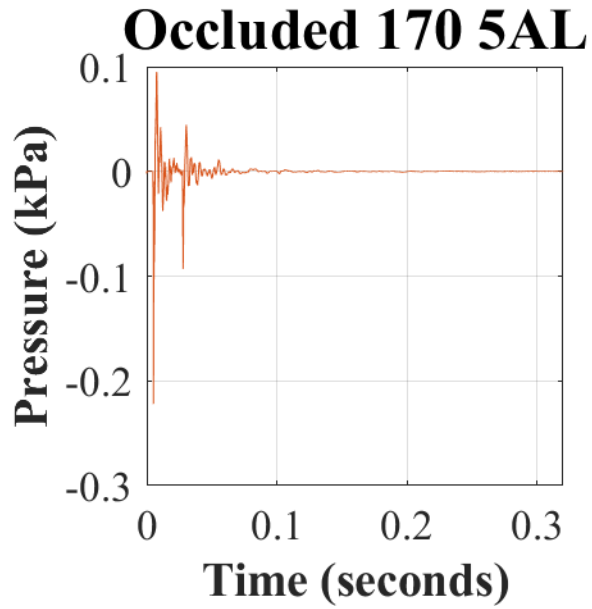


**Occluded 170 2BR**



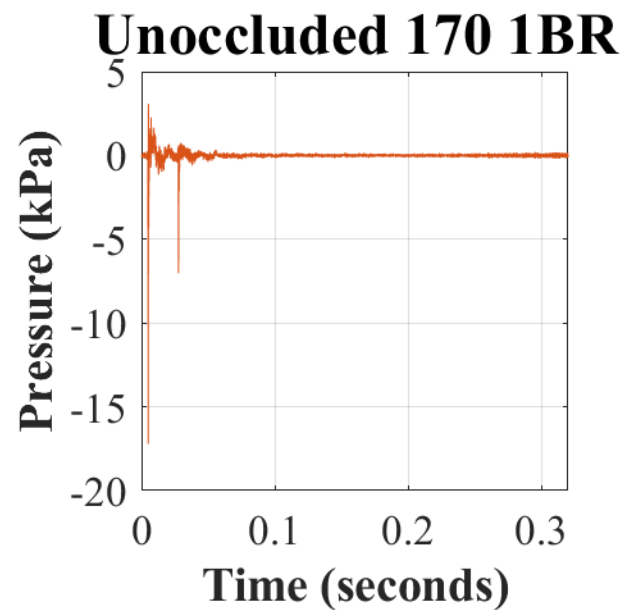
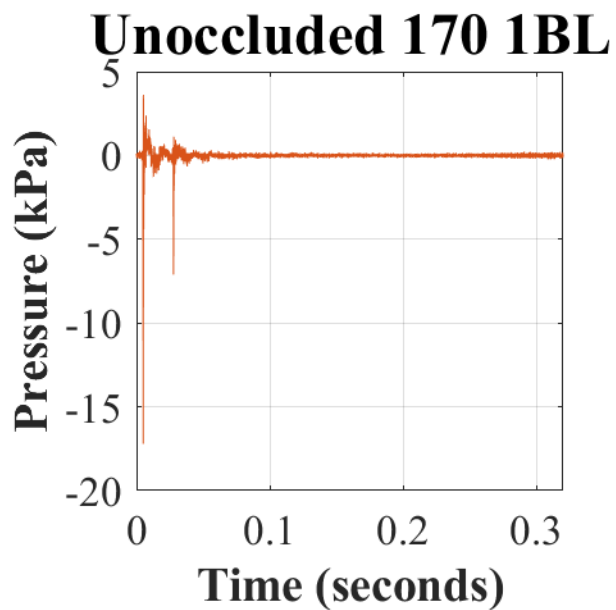
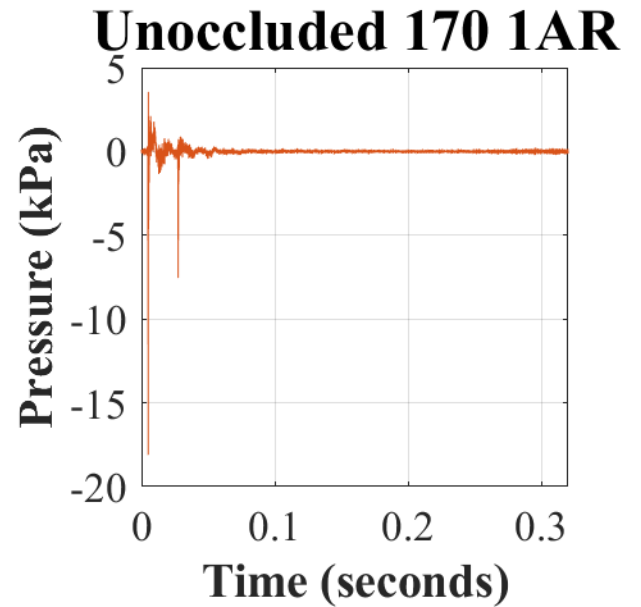
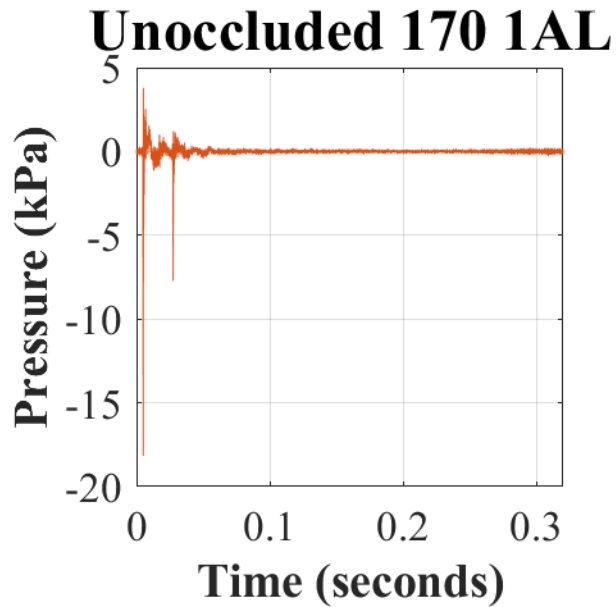


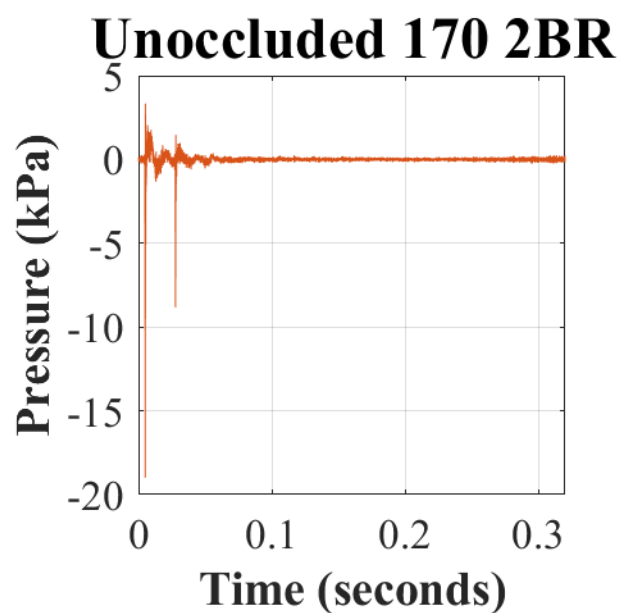
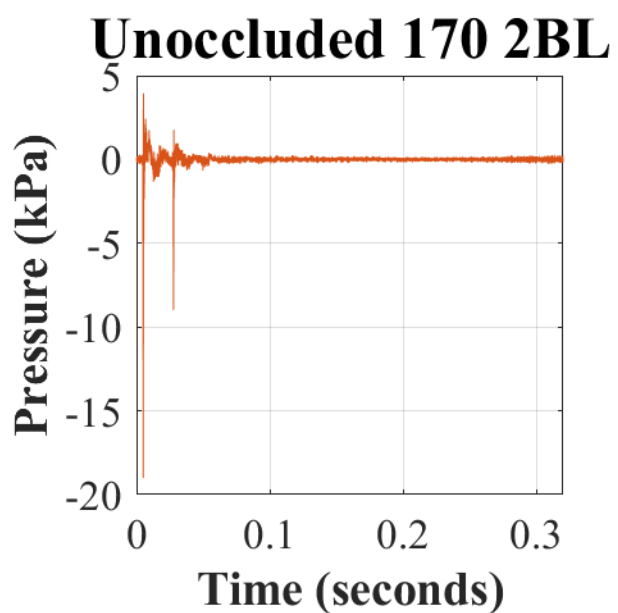
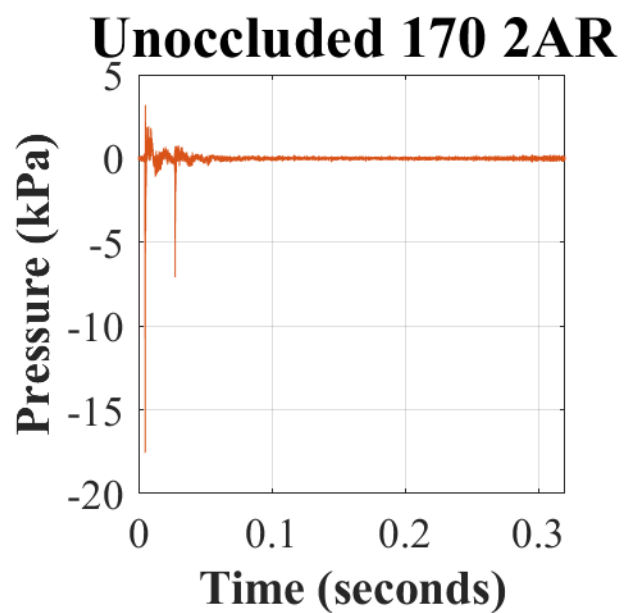
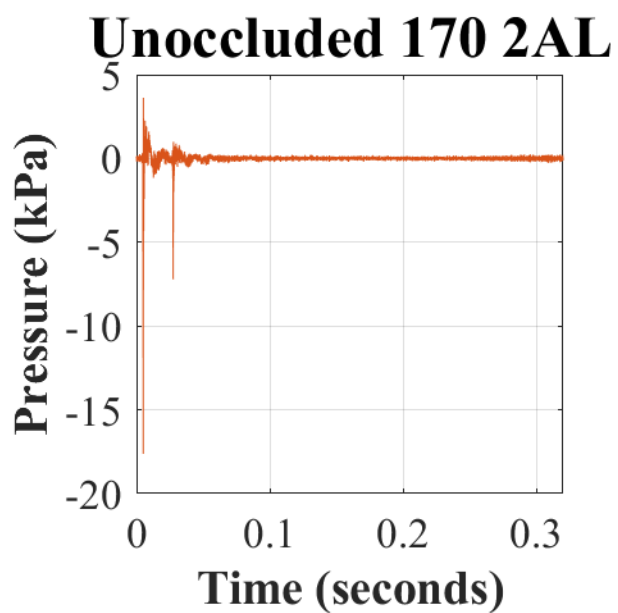


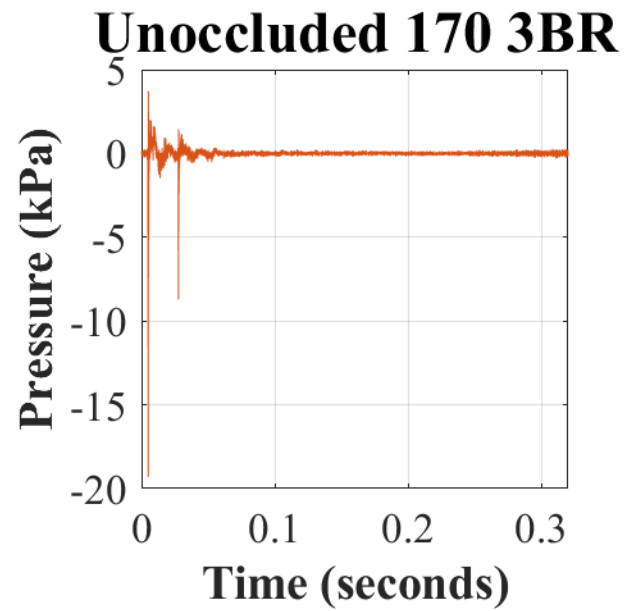
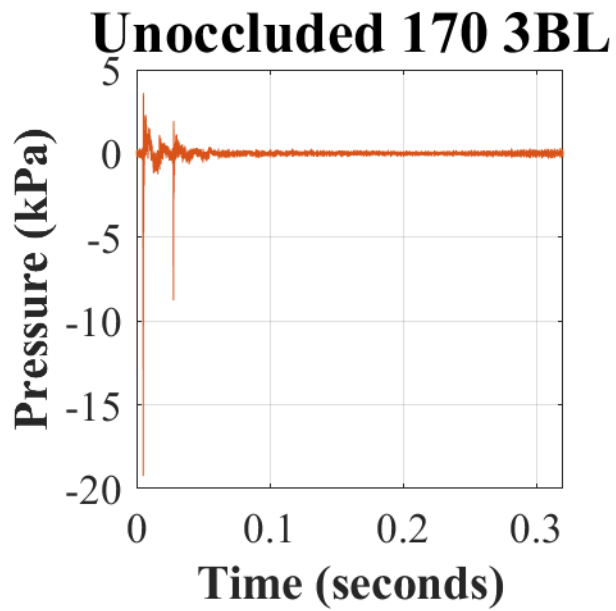
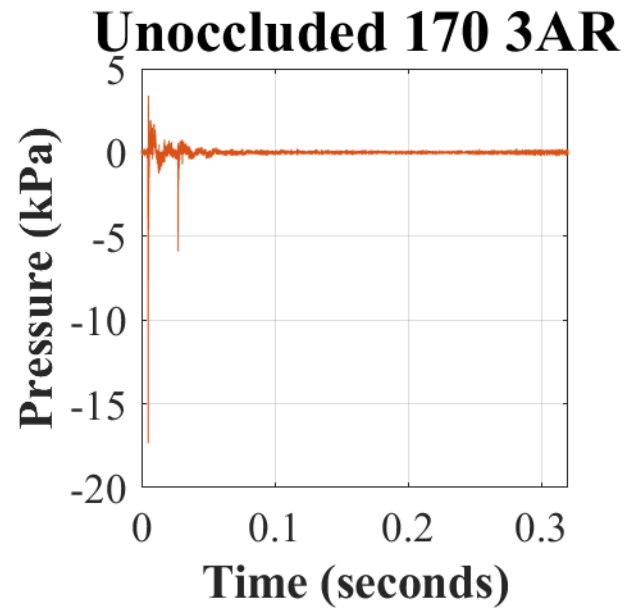
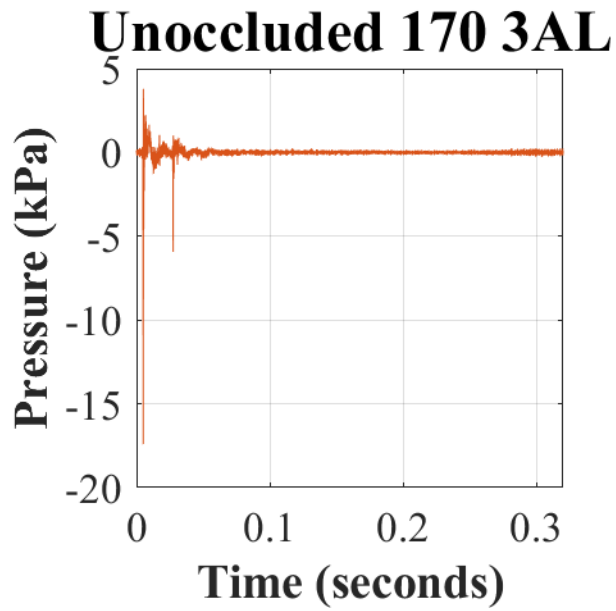


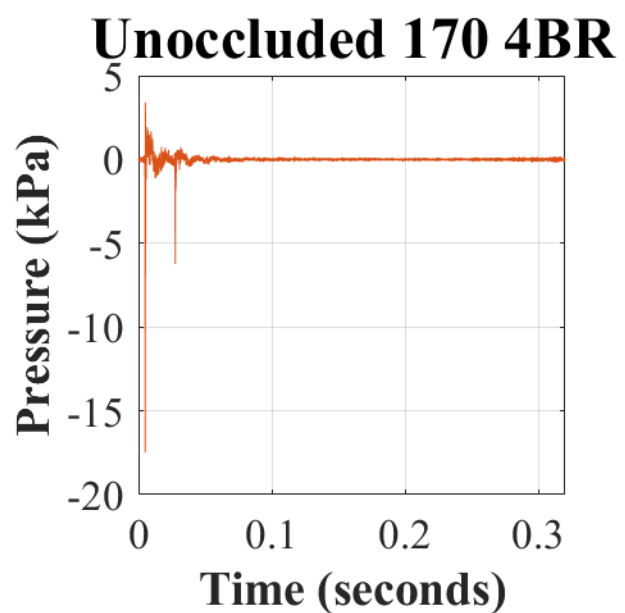
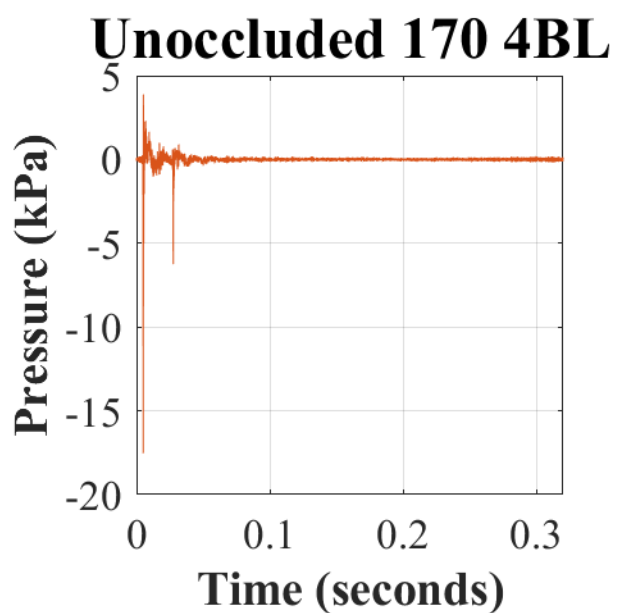
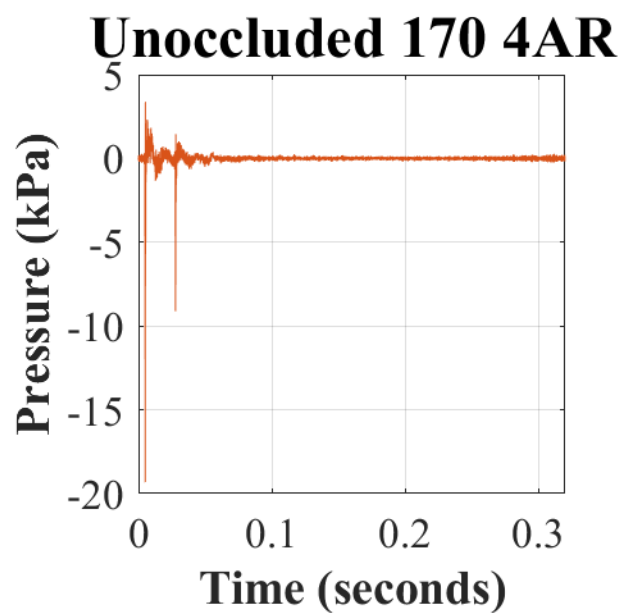
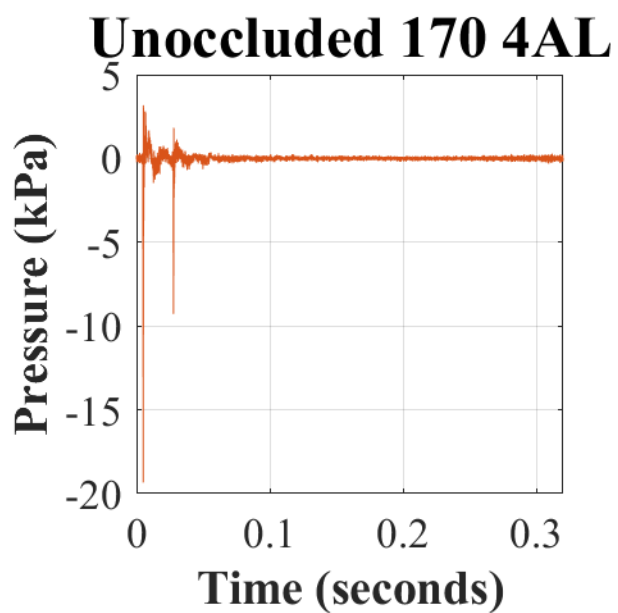
Note. The naming convention for all occluded waveforms is “Occluded LvL NnX”, where ‘Occluded’ is the test condition (i.e., ATF has the HPD donned), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e., A or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

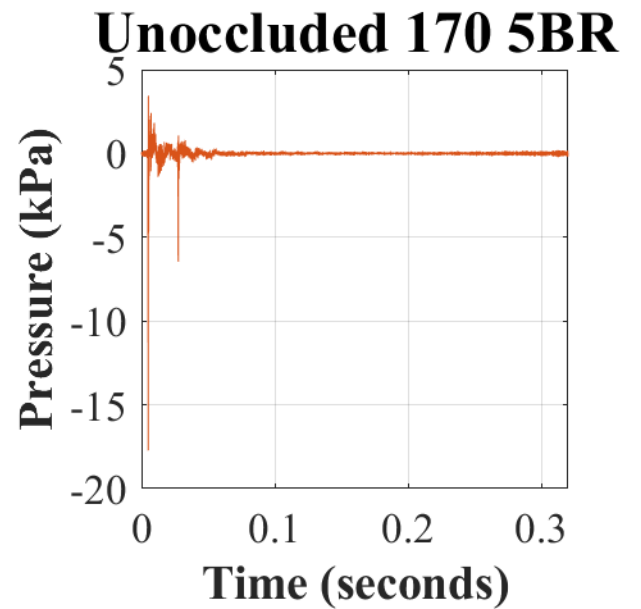
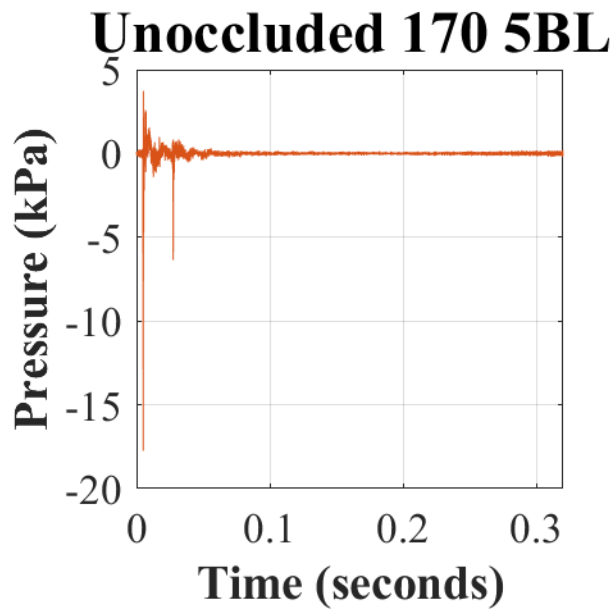
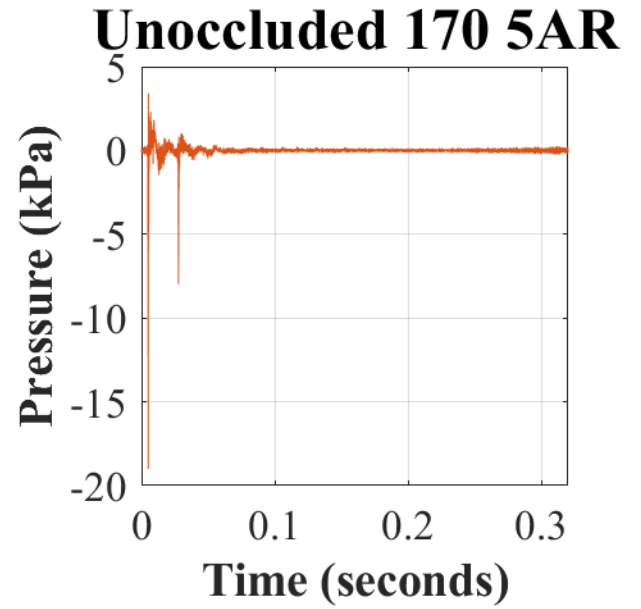
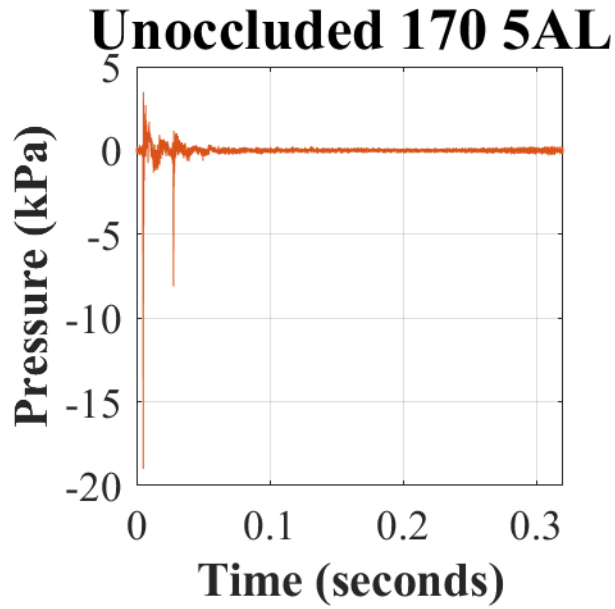
**Appendix O.** Estimated unoccluded (open-ear) waveforms (in kilopascals [kPa]) over time (in seconds [s]) in response to 170 dBp with the Battleplugs® in the cap closed mode.





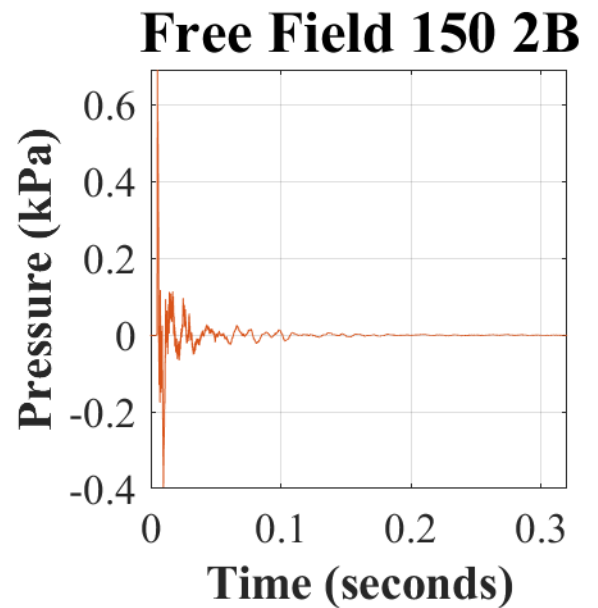
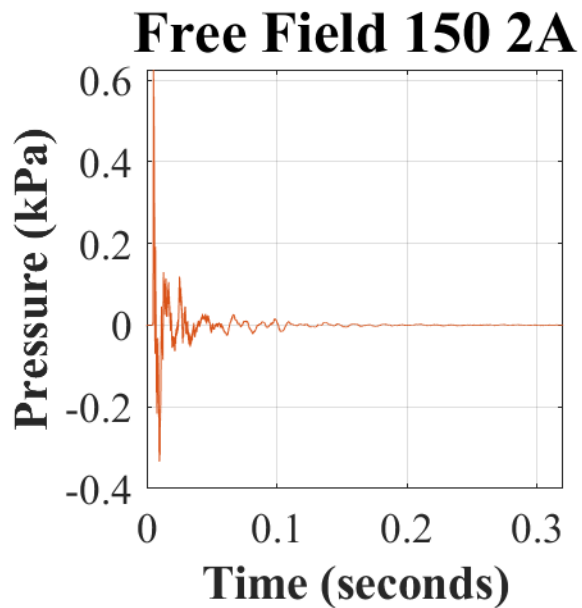
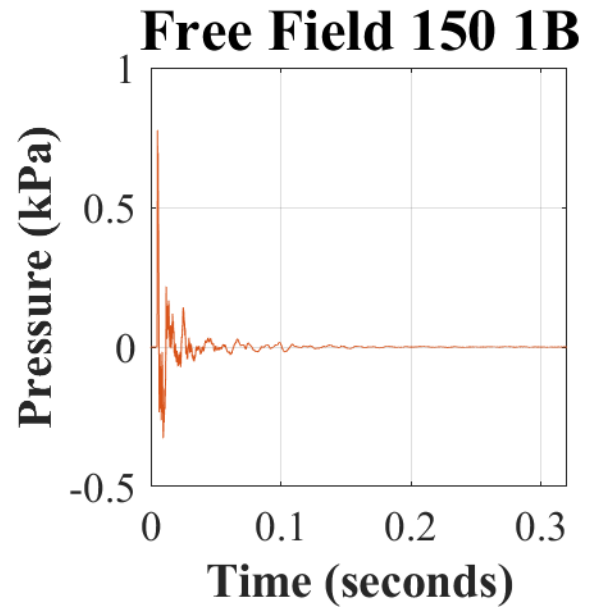
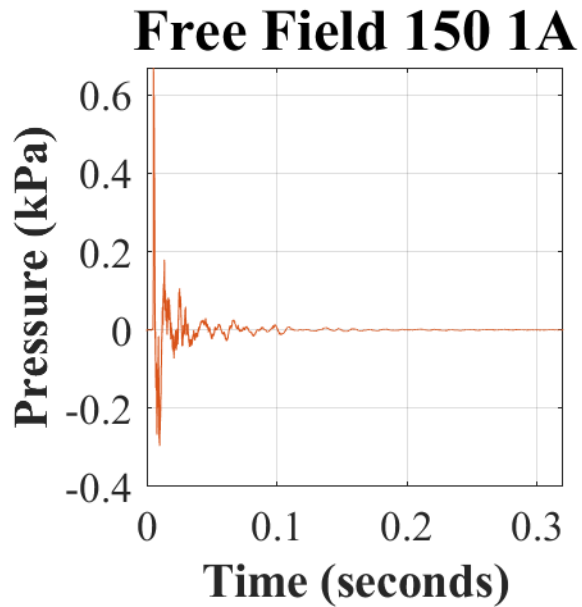




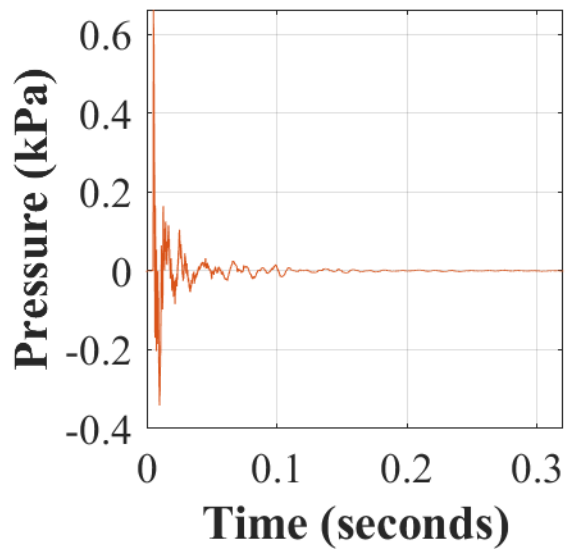


Note. The naming convention for all unoccluded waveforms is “Unoccluded LvL NnX”, where ‘Unoccluded’ is the test condition (i.e., ATF has the HPD doffed), ‘LvL’ is the nominal test level (i.e., 150, 160 or 170 dBp), ‘N’ is the sample number (i.e., 1 to 5) of the device tested, ‘n’ is the trial (i.e.,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

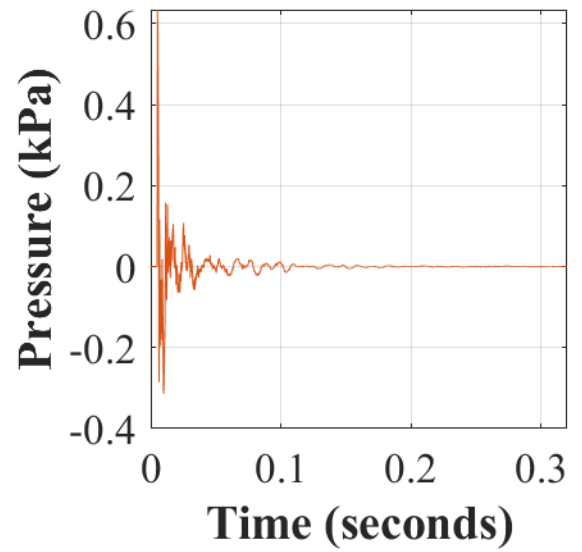
**Appendix P.** Recorded waveform (in kilopascals [kPa]) over time (in seconds [s]) of the impulse measured with the free-field probe at 150 dBp and the Battleplugs<sup>®</sup> donned in the cap closed mode.



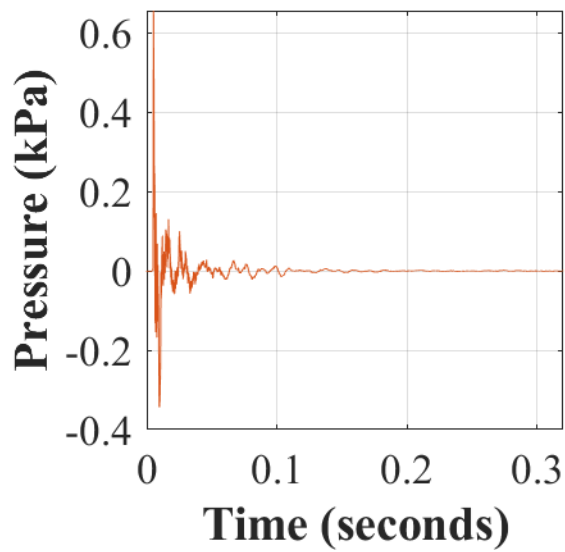
**Free Field 150 3A**



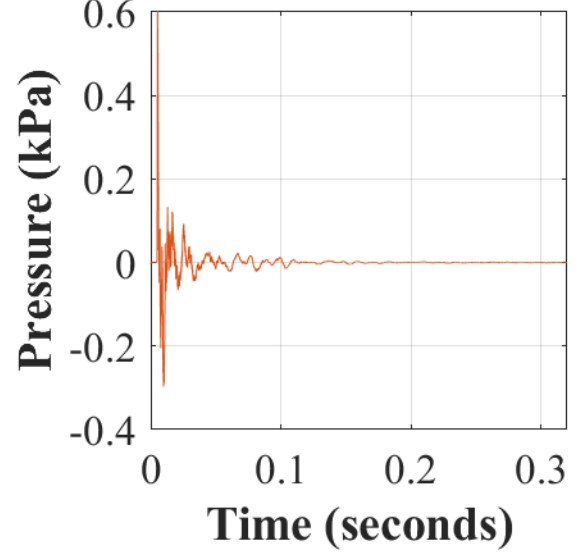
**Free Field 150 3B**

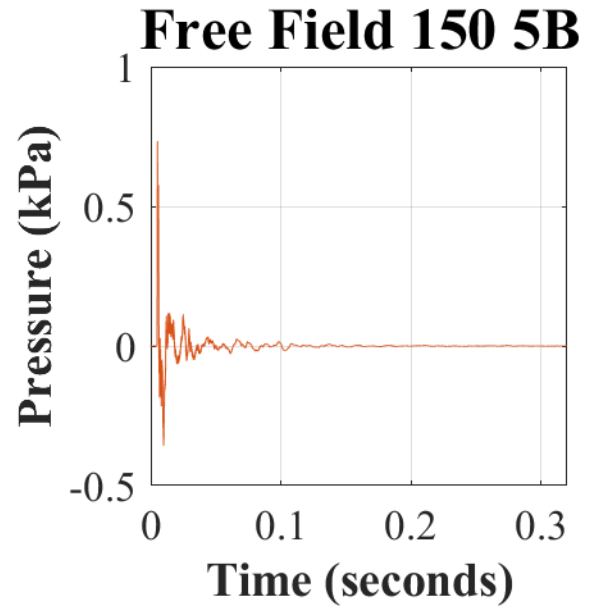
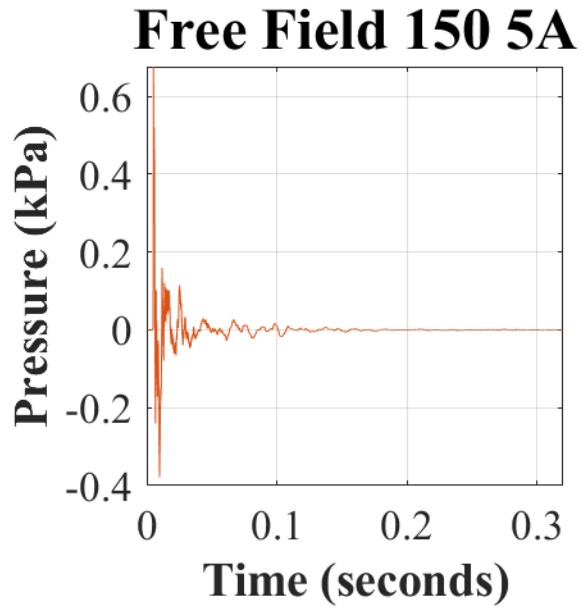


**Free Field 150 4A**



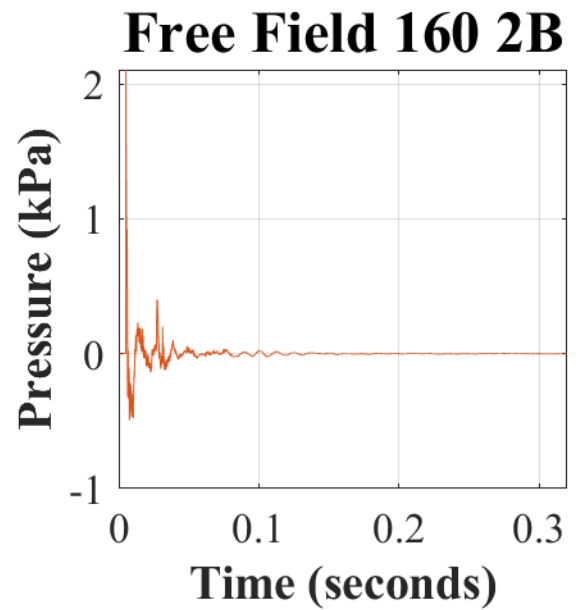
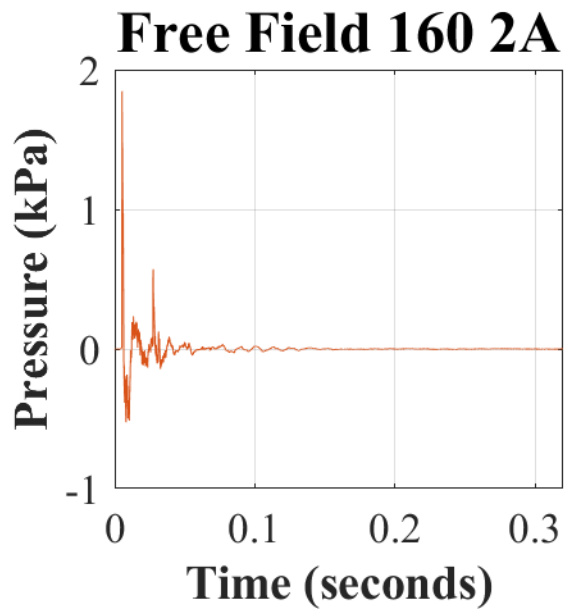
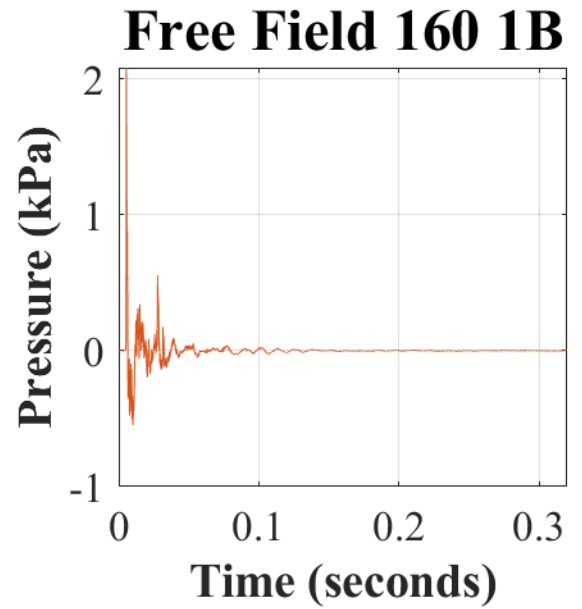
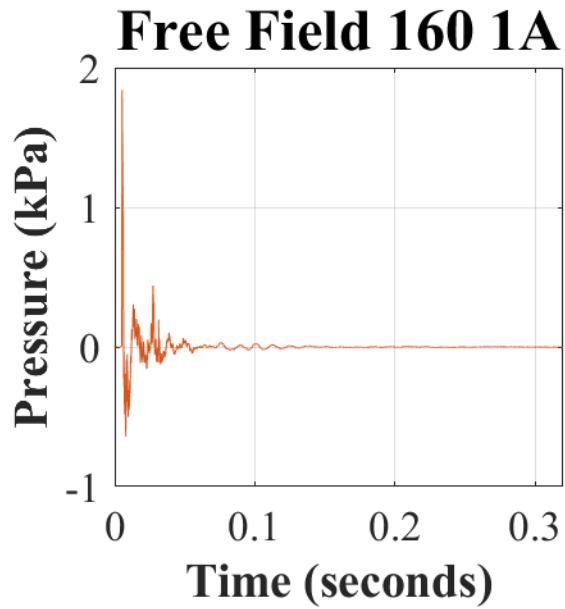
**Free Field 150 4B**

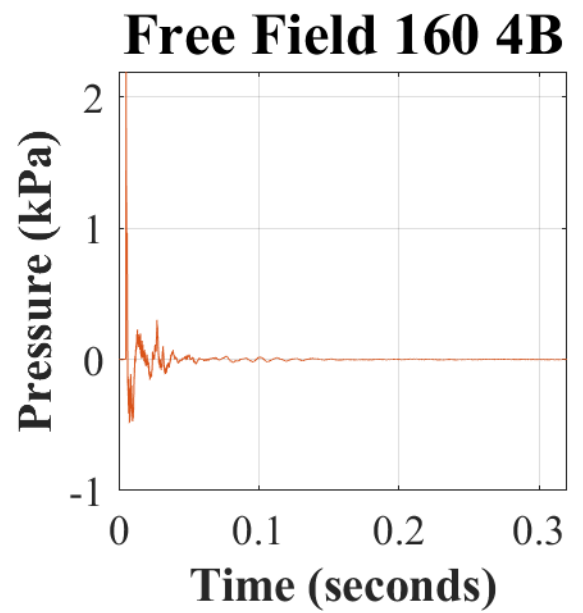
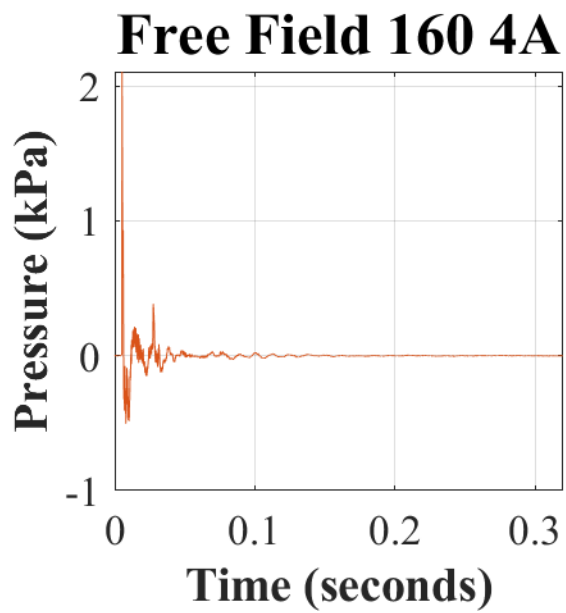
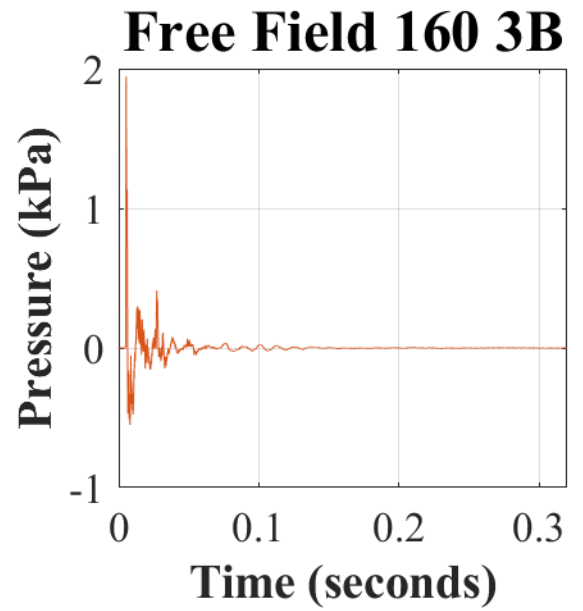
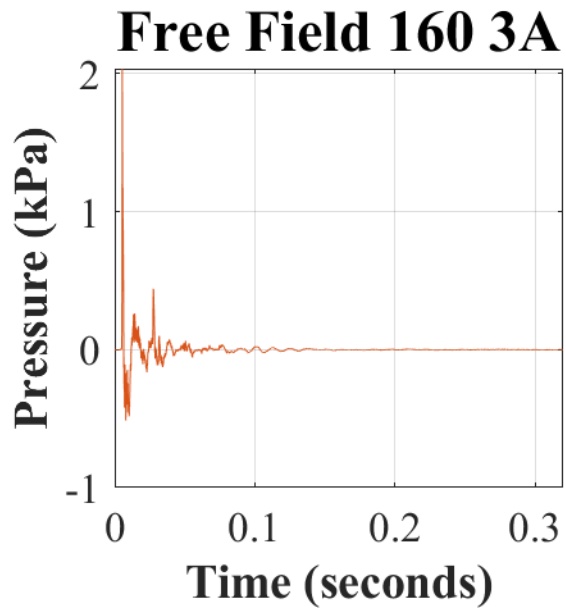


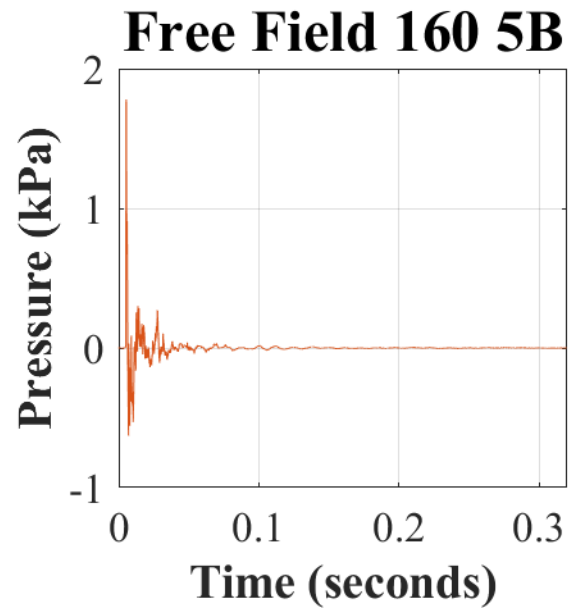
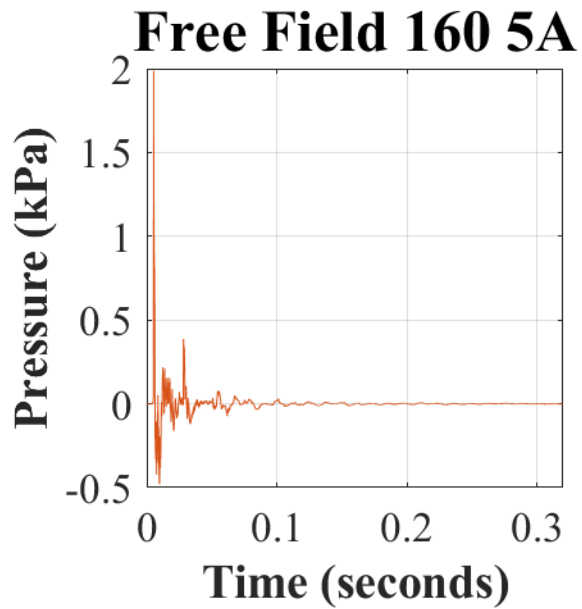


Note. The naming convention for all free-field waveforms is “Free Field LvL Nn”, where ‘Free Field’ indicates that the recording was obtained using the PCB reference microphone, ‘LvL’ is the nominal test level (150 dBP), ‘N’ is the device sample number (1 to 5), and ‘n’ is the device trial (i.e., A or 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 Battleplugs<sup>®</sup> donned in the cap closed mode.

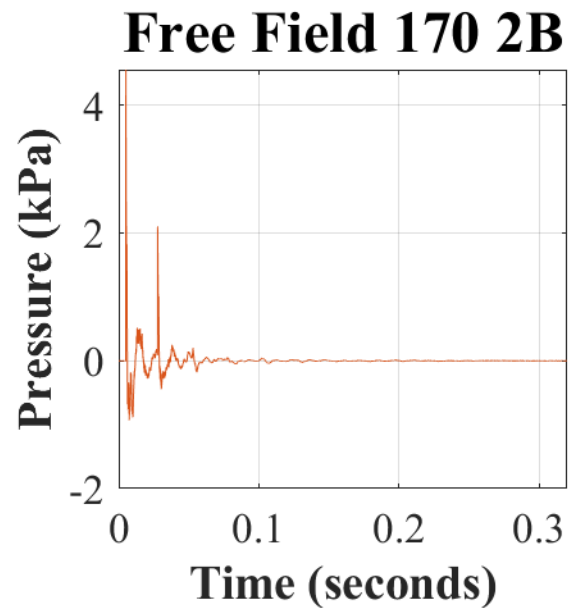
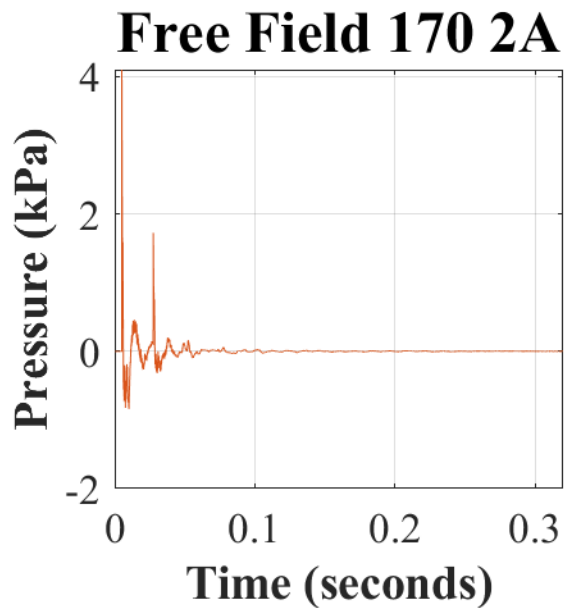
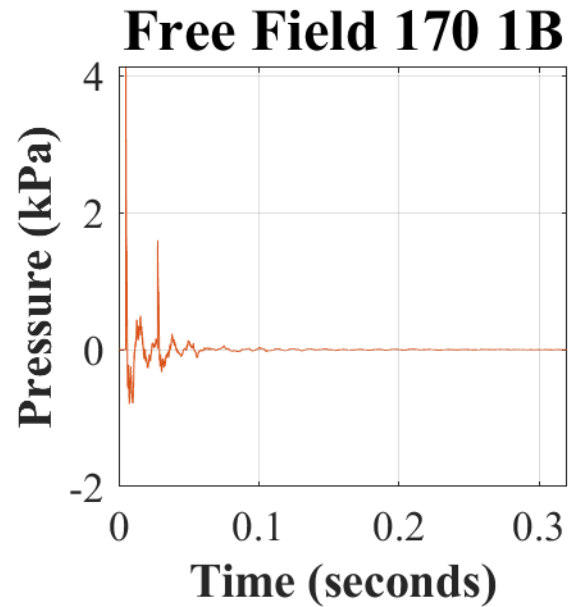
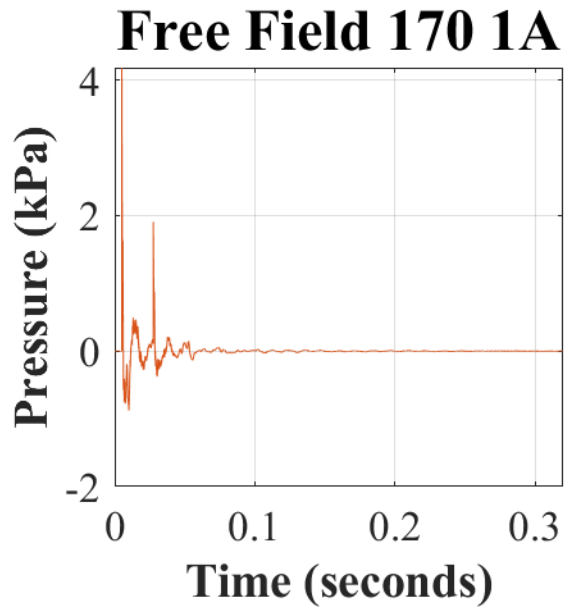


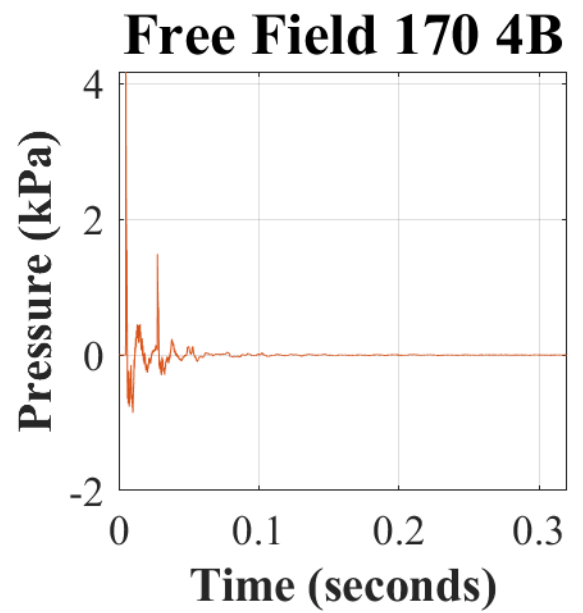
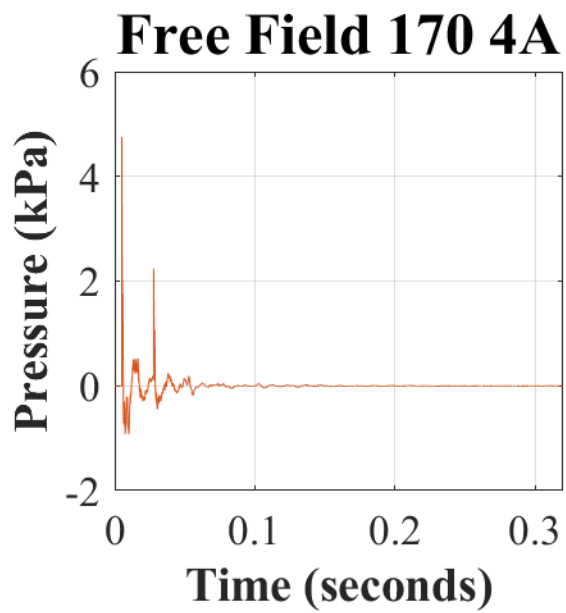
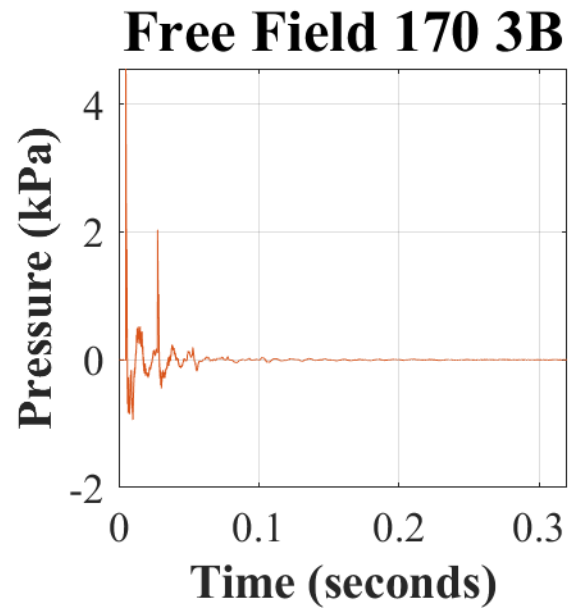
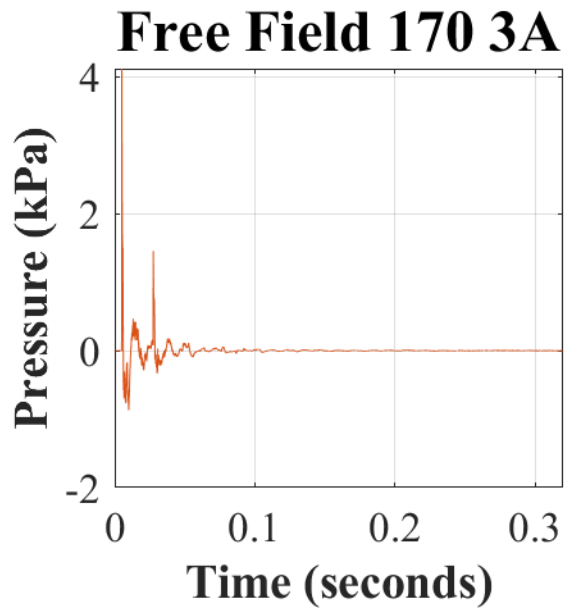


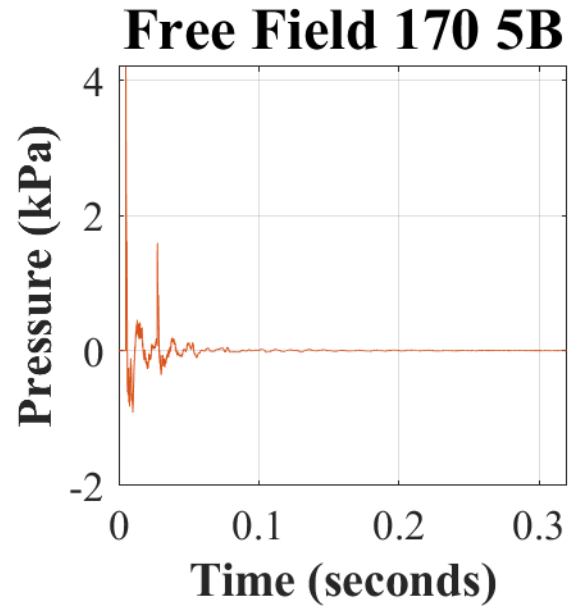
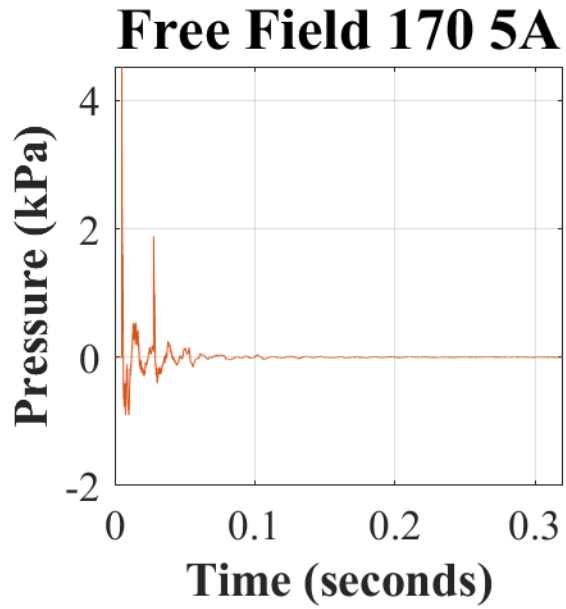


Note. The naming convention for all free-field waveforms is “Free Field LvL Nn”, where ‘Free Field’ indicates that the recording was obtained using the PCB reference microphone, ‘LvL’ is the nominal test level (160 dBP), ‘N’ is the device sample number (1 to 5), and ‘n’ is the device trial (i.e., A or 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 Battleplugs<sup>®</sup> donned in the cap closed mode.







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