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Mark C. Anderson, James H. Stephenson, Nikolas S. Zawodny, and Kent L. Gee

Citation: Proc. Mtgs. Acoust. **39**, 055011 (2019); doi: 10.1121/2.0001388
View online: https://doi.org/10.1121/2.0001388
View Table of Contents: https://asa.scitation.org/toc/pma/39/1
Published by the Acoustical Society of America

Volume 39 http://acousticalsociety.org/

178th Meeting of the Acoustical Society of America
San Diego, California
2-6 December 2019

*Signal Processing in Acoustics: Paper 1aSP1

Characterizing the effects of two ground-based outdoor microphone configurations

Mark C. Anderson
Department of Physics and Astronomy, Brigham Young University, Provo, UT, 84602; anderson.mark.az@gmail.com

James H. Stephenson
US Army Combat Capabilities Development Command Aviation & Missile Center, Hampton, VA; james.h.stephenson@nasa.gov

Nikolas S. Zawodny
NASA Langley Research Center, Hampton, VA; nikolas.s.zawodny@nasa.gov

Kent L. Gee
Department of Physics and Astronomy, Brigham Young University, Provo, UT, 84602; kentgee@byu.edu

Multiple International and Federal regulations stipulate the acquisition of aircraft noise be conducted using inverted pressure microphones over a round ground board. Ground boards are used to provide an acoustically hard reflecting surface, limiting the effects of the potentially absorptive local ground. To determine the ground board effects on the measured acoustic signal, a measurement campaign was undertaken at NASA Langley Research Center. The experiments included multiple ground board configurations placed on top of a sand pit, in an otherwise anechoic chamber. Ground board configurations included a microphone inverted and offset over a ground board and a microphone offset and flush mounted in the ground board. White noise was used to investigate the ground board effects on the recorded signal. Normal impedance measurements were acquired to determine the reflection coefficients of the sand and ground boards. Results indicate that both microphone configurations perform adequately up to 10 kHz. When the ground substrate is a soft material and the sound comes in at angles near grazing incidence, the signal is attenuated above 1 kHz. Additionally, the plastic material used to construct the ground boards was found to be acoustically hard between 0.1 – 3.0 kHz, and likely extending to higher frequencies.

**** Student Paper Award Winner for Signal Processing in Acoustics – 178th Meeting (Louisville, KY, 2019)***

Published by the Acoustical Society of America

 https://doi.org/10.1121/2.0001388

1. INTRODUCTION

A. MOTIVATION

In today's society, the importance of air vehicle noise is becoming a point of contention[1,2] and legislation.[3] With the Urban Air Mobility (UAM) market growing[4] and advances in measurement technology, it is important to revisit certification standards and test methodologies to ensure that quality data are being acquired. Outdoor acoustical measurements for flight vehicle certification and characterization are challenged by a myriad of factors. These factors include, but are not limited to, wind noise, varying ground substrate materials, moving sources, and atmospheric effects.[5,6] Several microphone configurations have been evaluated that attempt to overcome as many of these challenges as possible.[7–9] However, detailed laboratory examinations of how these microphone configurations affect the acoustic signals, like the one performed by Willshire,[8] are seldom available. The present work aims to provide laboratory results for a conventional configuration with a microphone inverted over a ground board, and a novel configuration of a microphone embedded within a ground board.

B. BACKGROUND

Multiple standards govern the acquisition of air vehicle acoustic data for vehicle certification. Among those standards, both elevated microphones as well as microphones inverted above a ground board are used. Elevated microphones provide useful data for evaluating what a human would hear at a specific location. However, while ground reflections are something that can reasonably be added *to* a signal if the ground impedance is known,[10] they have proven difficult to remove *from* a measured signal. Therefore, it is better to measure at the ground plane in an attempt to mitigate the effects of ground reflections on the measured data, which then provides data for both vehicle characterization as well as a path to estimate what a human would experience.

A relevant standard for flight tests that describes the use of ground boards says:

> The microphone must be a pressure type, 12.7 mm in diameter, with a protective grid, mounted in an inverted position such that the microphone diaphragm is 7 mm above and parallel to a white-painted metal circular plate. This white-painted metal plate shall be 40 cm in diameter and at least 2.5 mm thick. The plate shall be placed horizontally and flush with the surrounding ground surface with no cavities below the plate. The microphone must be located three-quarters of the distance from the center to the back edge of the plate along a radius normal to the line of flight of the test airplane.[11]

This standard addresses many of the concerns with flight test measurements. Ground-based acquisition methods are an improvement over elevated microphones because there is significantly less wind noise when microphones are placed next to the ground. Further, the addition of a ground board helps to provide an acoustically hard and uniformly reflecting surface, and so pressure doubling on the microphone diaphragm can be assumed for most frequencies. Another positive aspect of the standard is using an inverted microphone to mimic an embedded microphone response; this is a positive because in a field condition embedding a long microphone and preamplifier in the ground is impractical. Also, offsetting the microphone on the ground board helps to reduce edge diffraction effects introduced by having a ground board present.

However, there are a few drawbacks to the specification. For one, it may not be necessary to use a heavy metal plate to produce an acoustically hard reflecting surface; a high density plastic may provide similar acoustic properties and be significantly lighter and easier to handle. Also, the concern with cavities beneath the plate may be overly cautious. Finally, past research[8] indicates that an inverted microphone is subjected to multipath interference at high frequencies. For a microphone raised 7 mm above a rigid surface, the first interference null at normal incidence is predicted geometrically at about 12 kHz.

An alternative approach to the above standard is to use an embedded microphone that points skyward. The inverted microphone was created to approximate the embedded microphone, but at the time the standard was developed the technology did not reasonably allow for a microphone to be embedded in a ground board. Now, GRAS has developed the 67AX microphone, which provides a microphone fully embedded in a ground board, and is shown in Fig. 1 along with an inverted microphone setup. The effects of edge diffraction still occur for this configuration, but the effects of multipath interference due to reflected signals is overcome. The microphone is still assumed to experience pressure doubling due to the hard ground board, and 6 dB should be subtracted from the measurements in order to mimic a free-field measurement.

(a) ***(b)***

Figure 1: Microphone configurations showing (a) B&K 4964 microphone inverted over a ground board and (b) GRAS 67AX microphone embedded within a ground board and without the wind screen.

C. OVERVIEW

This paper examines the effects of microphone configuration and ground substrate on acoustic signals. Section 2 describes the methods used in each part of the experiment. The first phase included normal impedance testing of different materials to determine their reflective properties and help design the anechoic testing phase. Anechoic measurements were then conducted with multiple microphone configuration responses measured against a known source, presented at multiple elevation and azimuthal rotation angles. Both inverted and embedded microphone configurations were examined in the anechoic chamber, placed on a simulated ground of sand and plywood, to determine the local ground effects on the recorded signal. The third phase of the experiment used flight test data, where two embedded microphone configurations were rotated 180° relative to each other, with both normal to the vehicle flight path. This phase shows the differences created by azimuthal rotations relative to the source for an actual flight test. Section 3 provides a subset of the results of each of these phases, and conclusions are provided in Section 4.

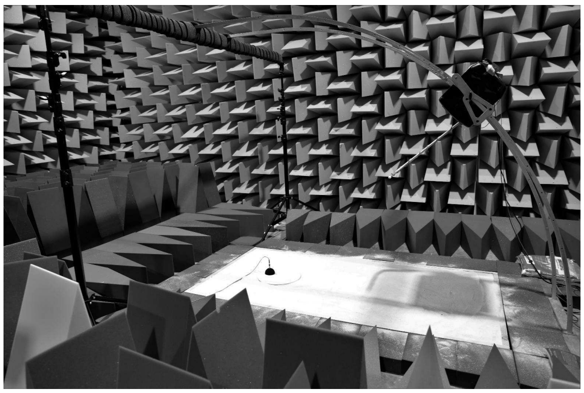
2. METHODS

A. NORMAL IMPEDANCE TESTING

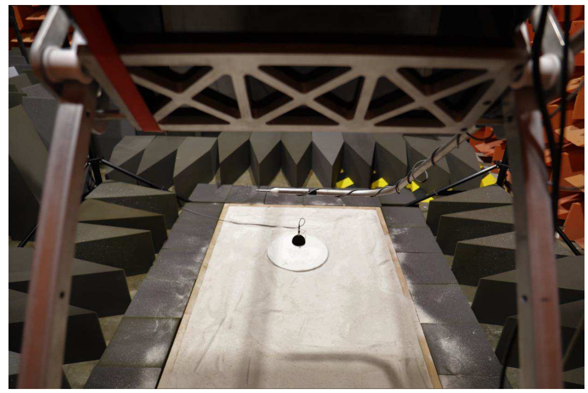
Normal impedance tube testing was conducted as the first phase of the experiment in order to help design the anechoic testing phase. A normal impedance tube was used to determine the reflectivity of the sand, plywood, and plastic ground board material. Fine grain, "high-desert" sand was tested at varying depths to determine an effective infinite depth as would be experienced in a desert. The plywood and ground board materials were tested on top of the sand, on top of each other, and simply supported on the edges over air to determine their reflectivities under differing substrate conditions.

B. ANECHOIC TESTING

The second phase of the test included anechoic chamber testing in order to ascertain the response of the microphone configurations under various conditions with minimal external factors affecting the measurement. Photographs of the setup are shown in Fig. 2 and schematics indicating angle definitions are shown in Fig. 3. This particular NASA Langley Research Center anechoic chamber (the Structual Acoustic Loads and Transmission Facility) is considered anechoic above approximately 100 Hz.



(a)



(b)

Figure 2: Photographs of the arc setup in the anechoic chamber with both a (a) wide-angle view of the entire setup and (b) speaker-oriented view of a microphone configuration under test.

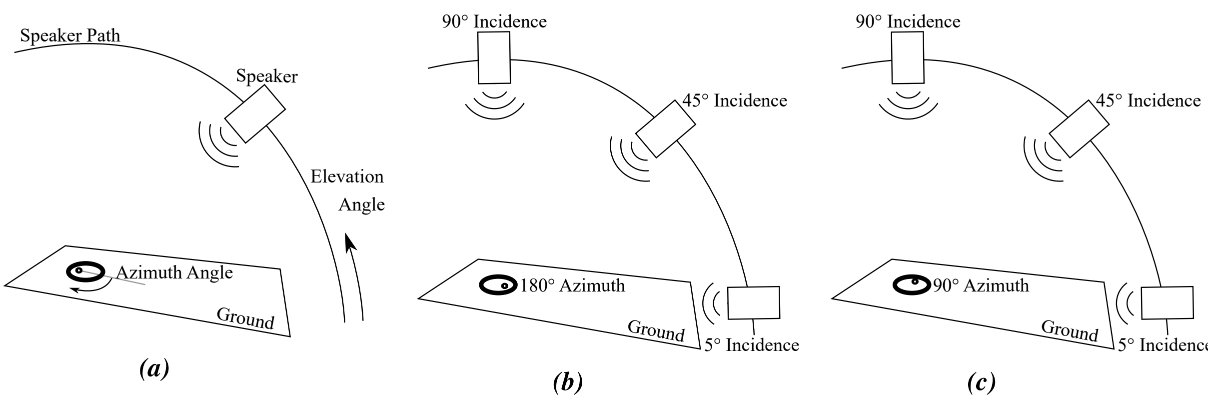


Figure 3: Schematic sketch of the anechoic chamber test setup, including (a) definition of the elevation and azimuthal angles. The ground board location was adjusted to place the microphone at the same location for each test, with azimuthal angle of (b) 180°, and (c) 90°.

Each of the microphone configurations is confined to an area with dimensions four feet by eight feet and a sand depth of three inches. Three inches of sand was chosen as a compromise between consistent reflectivity and practicality. The known sound source is randomly generated white noise played through a Mackie HR824MK2 speaker mounted on metal rails, which allowed for a uniform elevation angle sweep between grazing and normal incidence in 5° increments. Microphone configurations are placed toward the rear of the test area to allow the sound opportunity to propagate across the ground material before reaching the microphone. Foam blocks and wedges are placed strategically around the area to minimize reflections and edge diffraction effects, and the microphones are placed in the same location relative to the rest of the setup for each test. The microphone configurations could also be rotated azimuthally to investigate various presentation angles.

The inverted microphone, shown in Fig. 1a, is a half-inch Bruel and Kjaer (B&K) 4964 free-field microphone placed in a half-ball windscreen with the microphone one quarter-inch diameter above the ground board. The embedded microphone, shown in Fig. 1b, is a GRAS 67AX configuration without the windscreen. The baseline comparison for the tests was a free-field measurement taken in the anechoic chamber with the same speaker and a quarter-inch pressure field microphone, shown in Fig. 4.

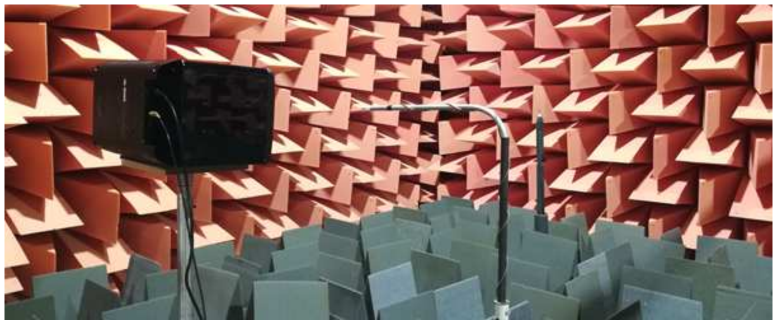


Figure 4: Photo of the free-field measurement setup. On the left is the Mackie HR824MK2 speaker, in the middle is the reference microphone used to validate the speaker output, and on the right is the microphone used as the free-field comparison for all results in the anechoic chamber.

C. FIELD TESTING

To see the effects of azimuthal rotations under practical conditions, two embedded microphone configurations were employed on a flight test. An S-76D helicopter was flown at Coyle Field, NJ under multiple flight conditions, two of which are examined here. A full description of the flight test can be found in Pascioni *et al.*[12] The first flight configuration examined here is a level flight at 100 kts indicated airspeed, and the second condition is a 9° descending flight at 60 kts. A photograph of the two GRAS 67AX microphone configurations investigated is shown in Fig. 5.

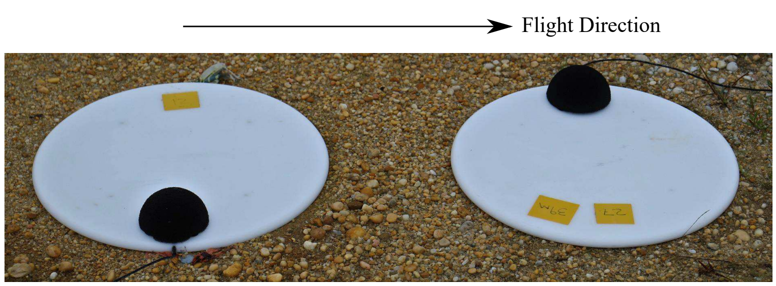


Figure 5: The two embedded microphone configurations that were used for the field test with windscreens.

3. RESULTS

A. NORMAL IMPEDANCE TESTING

Normal impedance tube testing was performed from 0.1 – 3 kHz, a subset of the results are shown in Fig. 6. Figure 6a shows the reflectivity of the different sand depths. No obvious pattern is apparent in the reflectivity measurement, and it does not approach a uniform value as the depth increases. Therefore, three inches of sand was chosen for the the anechoic measurements because of its good compromise between relatively uniform reflectivity across the frequency range and practicality for the test setup. Figure 6b shows the reflectivity percentage for plywood and ground board (GB) materials, simply supported on the edges with air as the substrate. Both materials provide almost perfect reflectivity across the entire frequency range. This result strongly suggests that the concern in the standard[11] with mitigating cavities beneath the ground board is overly cautious.

Finally, Fig. 6c shows the performance of the ground board material and plywood when placed on top of three inches of sand. It can be seen that the plywood provides almost perfect reflectivity for frequencies greater than 1 kHz, while the ground board provides almost perfect reflectivity across the entire spectrum, whether it is placed directly on top of the sand or on top of the plywood and sand combination.

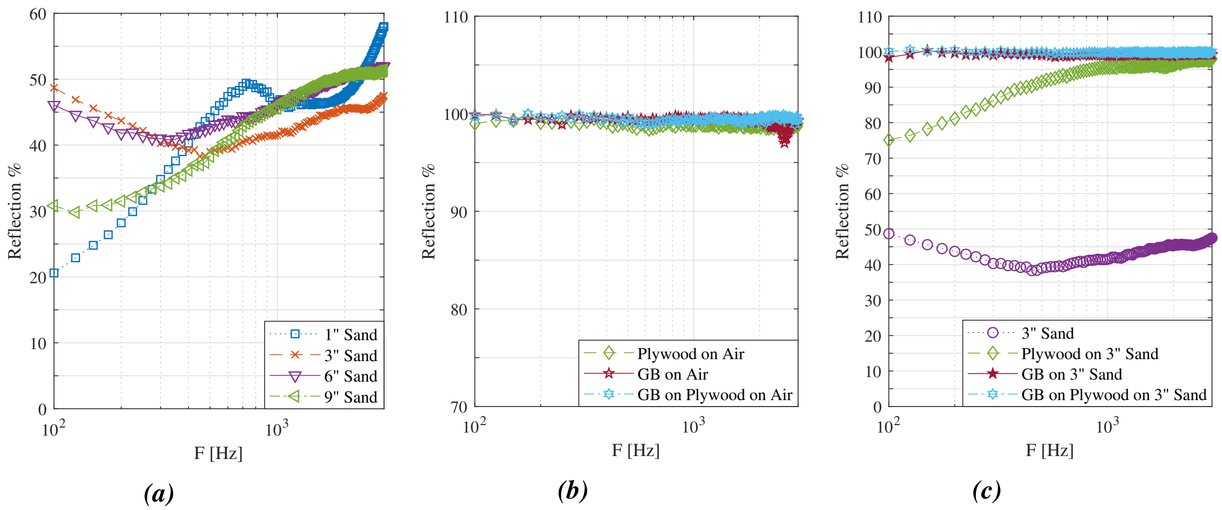


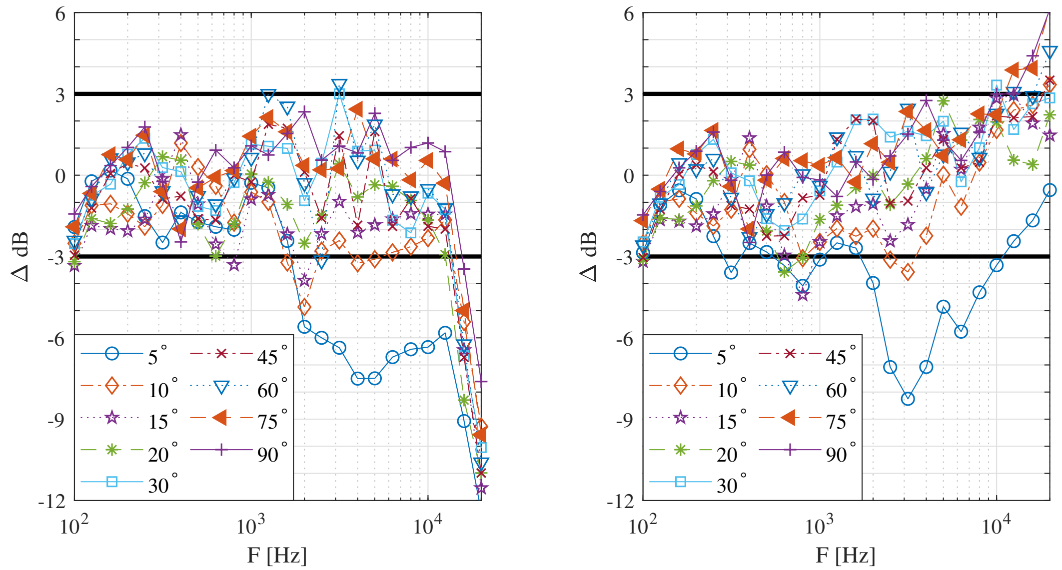
Figure 6: Normal impedance tube reflection results as a function of frequency for multiple configurations. (a) Reflection percentage from different depths of sand. (b) Reflection percentage from different solid surfaces placed over an air substrate. (c) Reflection percentage from various combinations tested in the anechoic phase of the experiment.

B. ANECHOIC TESTING

I. Standard Orientation: 0° Azimuth

The first anechoic chamber test investigated here is for the standard orientation, with the microphones oriented at 0° azimuth in accordance with the standard.[11] This places the long edge of the ground board between the microphone and sound source, and provides the optimum chance for the ground board to act as a perfect reflecting surface. Figure 7 provides the spectra relative to the free-field measurement for both microphone configurations when placed over sand. It can be seen that both microphone configurations perform adequately, and that the ground substrate is found to be a major contributing factor at low elevation angles.

In Fig. 7a, data from the inverted microphone show that it performs well at most elevation angles up to about 10 kHz, where it rolls off (Δ dB decreases) due to limited microphone response. Similarly, Fig. 7b shows that the embedded microphone performs well up to about 10 kHz at most elevation angles, where it rolls upward (Δ dB trend increases) for yet unknown reasons. Both configurations show large differences at five degrees incidence, which is a very low grazing angle. This is likely due to the low impedance of the



(a) *(b)*

Figure 7: The differences (re: free-field) when the configurations were placed over three inches of sand and oriented at 0° azimuth relative to the sound source for (a) inverted and (b) embedded microphone.

sand, enabling the sand to more effectively absorb the sound at grazing incidence.

In contrast, Fig. 8 shows the same experimental setup, but with the microphone configurations placed on top of a plywood sheet, which was laid on top of the three inches of sand. In both the inverted (Fig. 8a) and the embedded (Fig. 8b) cases, it can be seen that the microphones perform generally well until 10 kHz at all elevation angles. This is likely due to the high impedance of the plywood, which acts like an infinite and acoustically hard surface.

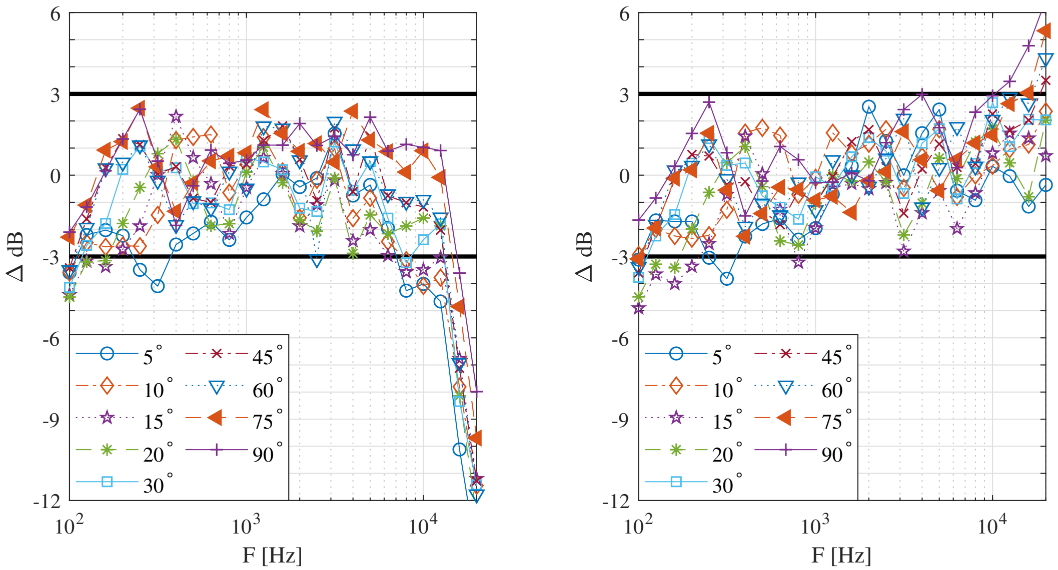
II. Reverse Orientation: 180° Azimuth

A reverse orientation on the microphones was also tested, with the short edge of the ground board between the speaker and microphone (180° Azimuth). Figure 9 shows the spectra relative to the free field for the inverted (Fig. 9a) and the embedded (Fig. 9b) microphone configurations. In the reverse orientation, both microphones show that frequencies greater than 1 kHz are affected by the ground substrate. Both microphone configurations differ significantly from the free-field case for elevation angles up to 15°. This is due to the low impedance of the sand coupled with the shorter propagation distance across the ground board in the reverse orientation.

Figure 10 shows the same experiment when performed with the microphone configurations placed on top of plywood, which was placed on top of the sand. Here the losses at low elevation angles disappear, supporting the theory that the losses were caused by the low impedance of the sand. It is also noted that these results are nearly identical, with those documented in the standard orientation shown in Fig. 8.

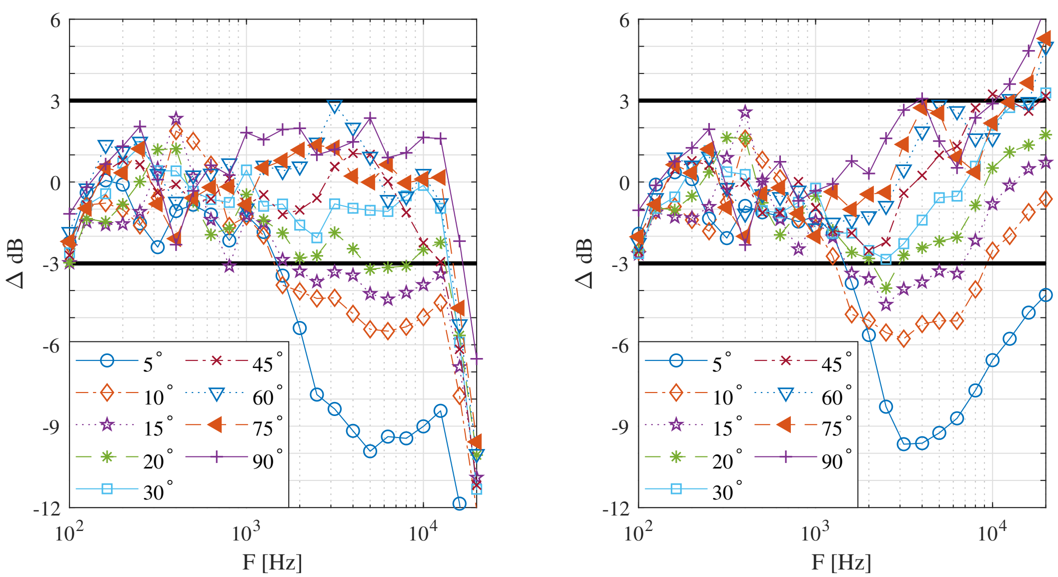
C. FLIGHT TEST APPLICATION: 45° AZIMUTH

Multiple azimuthal angles between 0° and 180° were investigated. However, the 45° azimuth case is relevant to flight testing because it represents a typical start and finish angle for an aircraft flyby. Figure 11 shows the results for the inverted (Fig. 11a) and the embedded (Fig. 11b) microphone configurations for 45° azimuth while placed on top of sand. In both cases, a drop in the microphone response at five degrees



(a) *(b)*

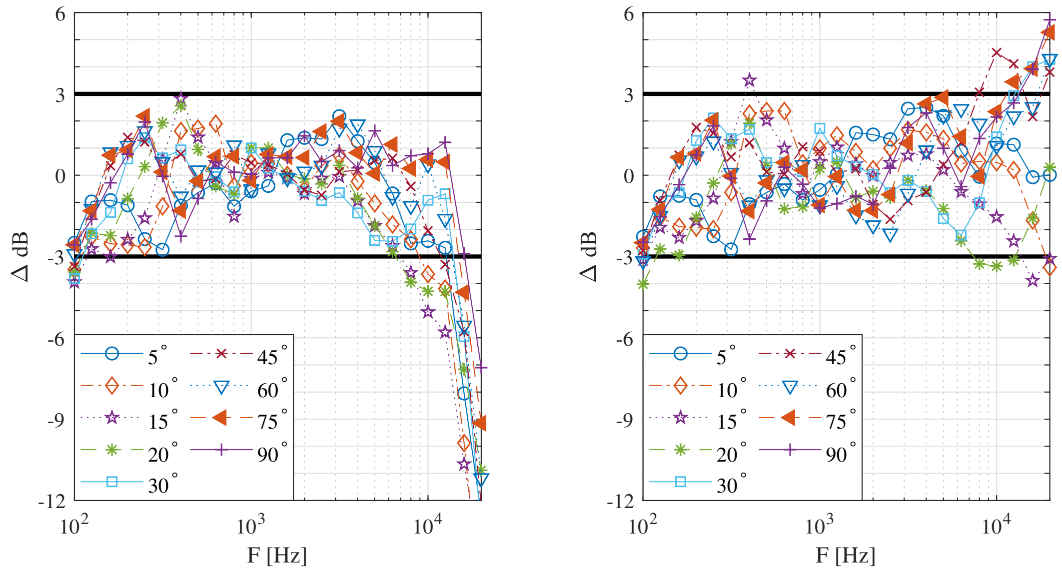
Figure 8: The differences (re: free-field) when the configurations were placed on plywood over three inches of sand and oriented at 0° azimuth relative to the sound source for (a) inverted and (b) embedded microphone.



(a) *(b)*

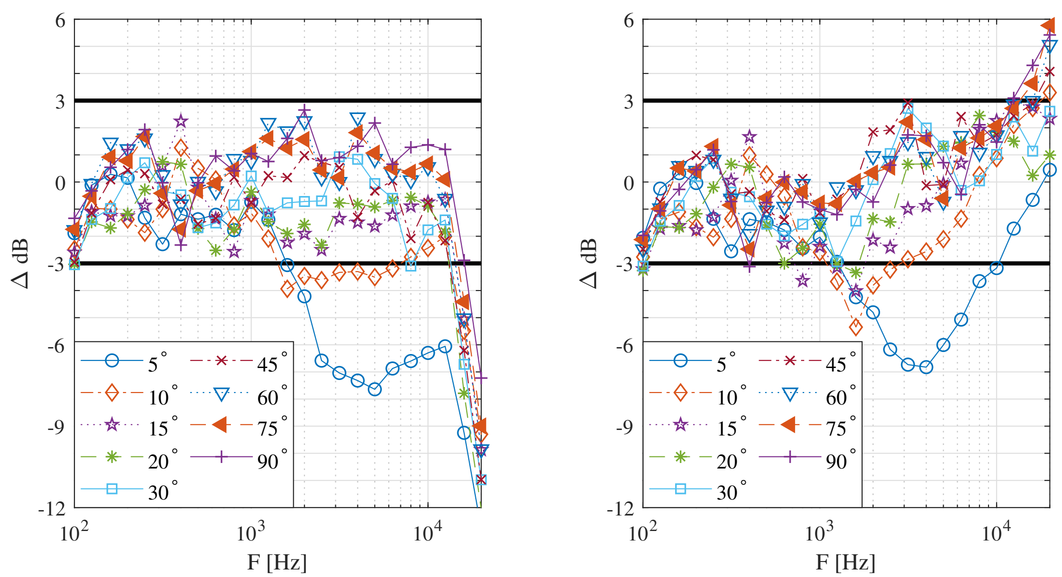
Figure 9: The differences (re: free-field) when the configurations were placed over three inches of sand and oriented at 180° azimuth relative to the sound source for (a) inverted and (b) embedded microphone.

incidence is seen, similar to that seen in Fig. 7. There is also a noticeable drop in performance for 10° elevation angle in both configurations. The grazing incidence effects are more noticeable than the effects seen in the standard orientation, and less noticeable than the effects seen in the reverse orientation. This supports the theory that the grazing incidence losses become more noticeable as the ground board is rotated away from its standard orientation.



(a) *(b)*

Figure 10: The differences (re: free-field) when the configurations were placed on plywood over three inches of sand and oriented at 180° azimuth relative to the sound source for (a) inverted and (b) embedded microphone.



(a) *(b)*

Figure 11: The differences (re: free-field) when the configurations were placed over three inches of sand and oriented at 45° azimuth relative to the sound source for (a) inverted and (b) embedded microphone.

D. FIELD TESTING

Real world effects on microphone orientation were investigated in order to evaluate the importance of correct microphone orientation under nonideal circumstances. Two microphones, shown in Fig. 5, were set up immediately next to each other, offset perpendicular to the flight path by 922 feet, at grazing incidence.

This microphone location is identified as location 12 in Pascioni *et al.*[12] Two flight conditions, level and descending, are investigated and both show excellent agreement between the two microphones.

One-third octave spectra for both microphone orientations during level flight are shown in Fig. 12. Included in Fig. 12 are azimuthal presentation angles that are swept out from the approach of the vehicle, pass-by over the center of the microphone array, and vehicle departure. It can be seen that there is approximately 0.1 dB difference or less between microphone orientations for frequencies above 30 Hz, with larger differences noticed below 30 Hz. Differences below 30 Hz are attributed to external factors including wind noise, that are more noticeable at the lower bandwidths.

Figure 13 shows results from the descending flight condition. The differences in measured spectra for both orientations are similar to what was seen previously in the level flight condition. From these results, it appears that there is no noticeable difference in microphone orientation for the grazing incidence angles at this location. A more thorough investigation with mixed combination of microphones closer to the center of the microphone array, and therefore higher elevation angles, must be conducted to see if this performance is generalizable.

4. CONCLUSIONS

This paper discusses the results from laboratory and field testing of different microphone configurations and orientations. Two configurations, inverted and embedded microphones, were tested at various azimuthal and elevation angles. Both microphone configurations perform adequately up to 10 kHz. If the ground substrate is a low-impedance material similar to sand, then frequencies greater than 1 kHz may be attenuated at grazing incidence up to 5° for microphone configurations in standard orientation (0° azimuth). If the orientation of the microphone configuration is rotated 180° then those same frequencies may be attenuated at grazing incidence up to 15°. This effect takes place gradually as the orientation of the microphone configuration is rotated relative to the sound source. However, an analysis of flight test data suggests that the azimuthal rotation impact is insignificant. More data are required from flight testing to determine if that is generalizable. Normal impedance measurements were also acquired and showed that ground boards are almost perfectly reflective from 0.1-3.0 kHz, even if they are simply supported with air as a substrate. Together, these results indicate that the current flight test standards are sufficient at least up to 10 kHz, and that embedded microphones perform as well as inverted microphones.

ACKNOWLEDGMENTS

The authors would like to thank Daniel J. Novakovich and Jeremy Peterson of the Brigham Young University Department of Physics and Astronomy for the design and construction of the angular measurement arc used in the anechoic measurements, along with the students hired under Jeremy Peterson for their help with modifying the arc for shipment to the NASA Langley Research Center. We also thank Noah Schiller and Melissa Polen of the NASA Langley Research Center for working with us to provide the time and space in the anechoic chamber for these measurements.

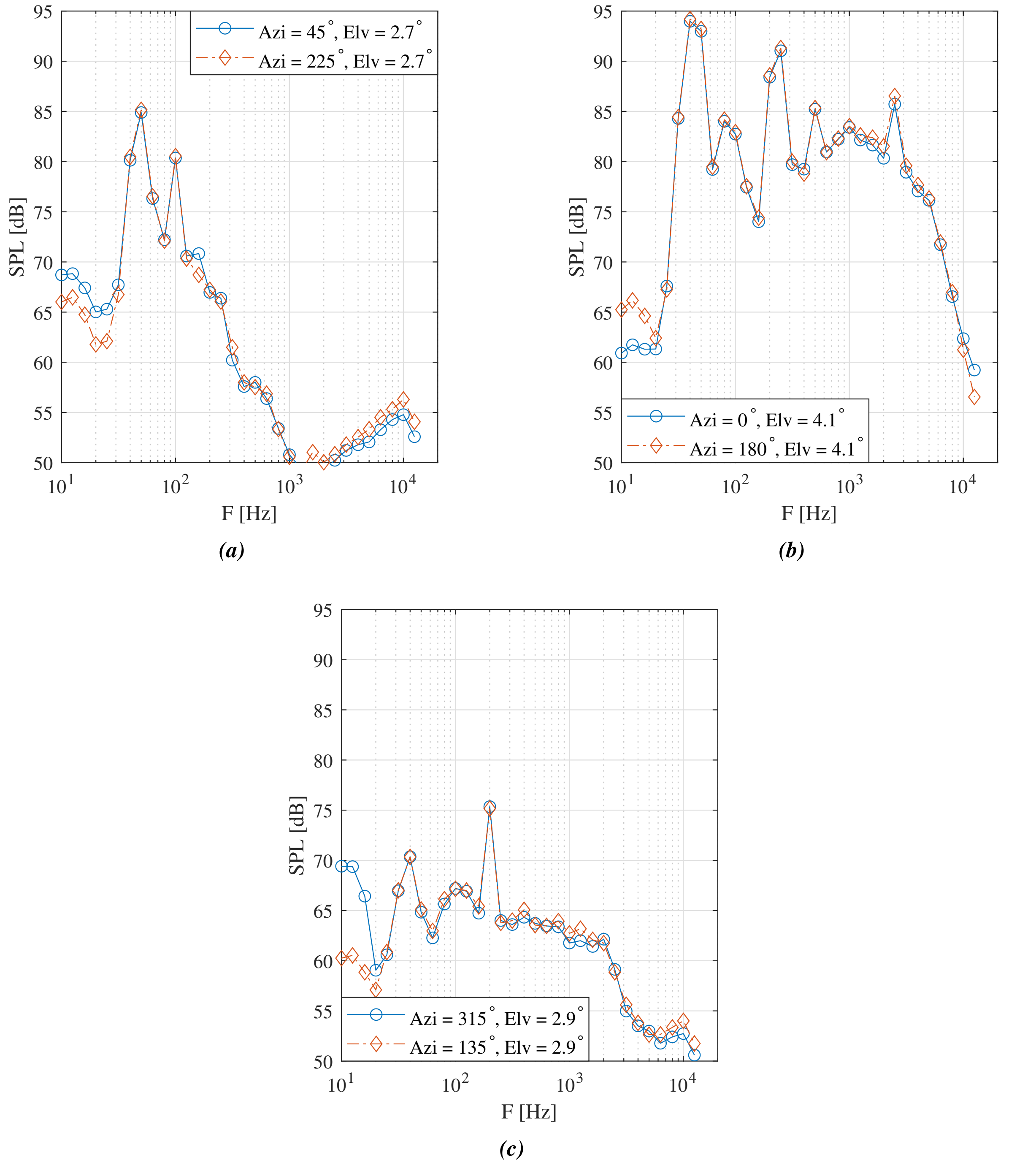


Figure 12: The spectra for two oppositely-oriented embedded microphones during a level flight of an S-76D Helicopter flying at 100 kts for (a) approach, (b) pass-by, and (c) departure.

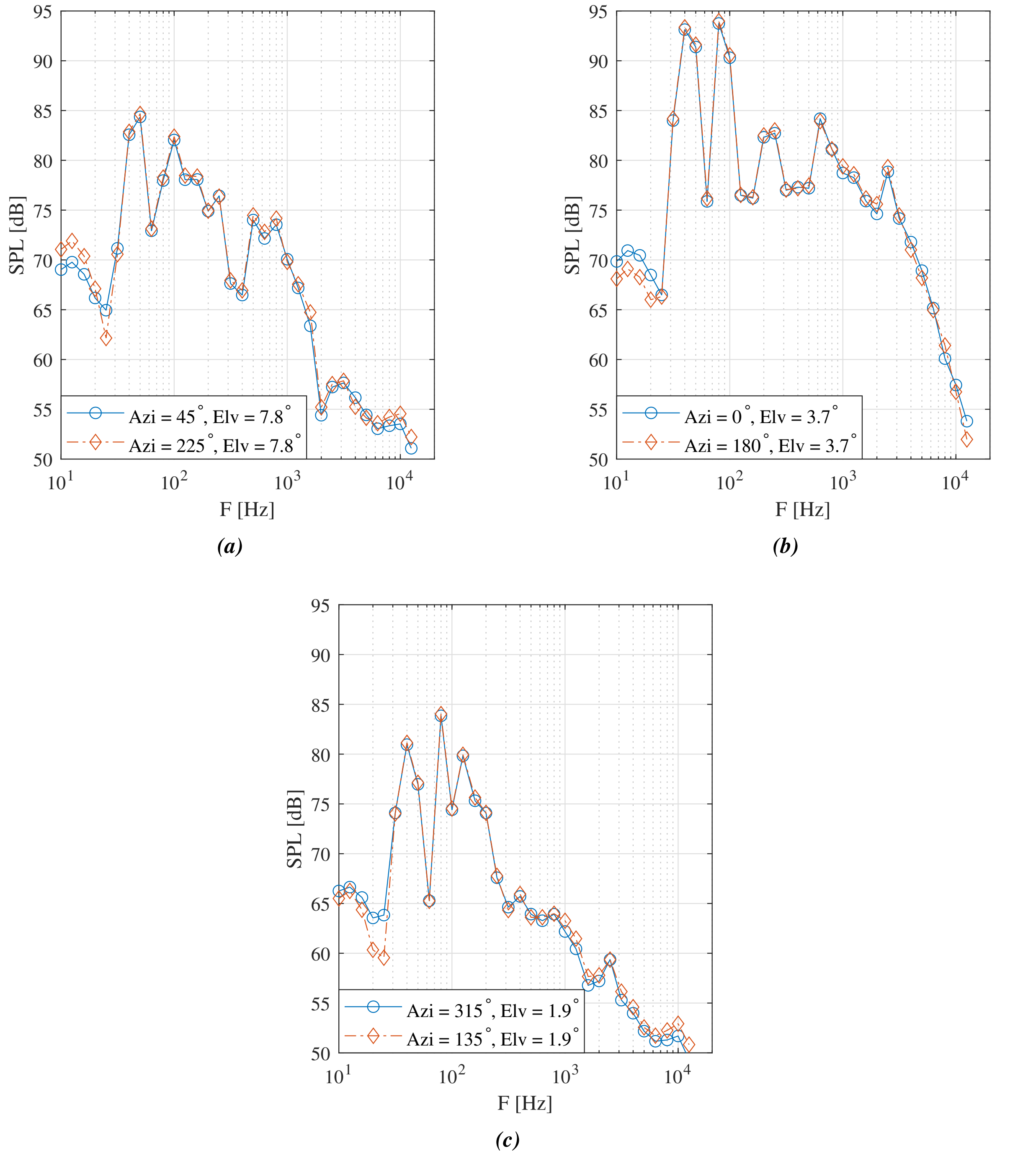


Figure 13: The spectra for two oppositely-oriented embedded microphones during a -9° descending flight of an S-76D Helicopter flying at 60 kts for (a) approach, (b) pass-by, and (c) departure.

REFERENCES

[1] Rapoza, A., Sudderth, E., and Lewis, K., "The relationship between aircraft noise exposure and day-use visitor survey responses in backcountry areas of national parks," *The Journal of the Acoustical Society of America*, Vol. 138, (4), 2015, pp. 2090–2105.

[2] Buxton, R. T., McKenna, M. F., Mennitt, D., Brown, E., Fristrup, K., Crooks, K. R., Angeloni, L. M., and Wittemyer, G., "Anthropogenic noise in US national parks–sources and spatial extent," *Frontiers in Ecology and the Environment*, Vol. 17, (10), 2019, pp. 559–564.

[3] Vail, E., "Adopt Local Law- Amending Chapter 75 (Airport) of the Town Code Regulating Nighttime Operation of Aircraft at East Hampton Airport," East Hampton Town Board Resolution 2015-411, 2015.

[4] Booz-Allen and Hamilton, Inc., "Urban Air Mobility (UAM) Market Study," Contractor Report HQ-E-DAA-TN65181, NASA Langley Research Center, Hampton, VA 23681, USA, 2018.

[5] Miller, R. L. and Oncley, P. B., "The experimental determination of atmospheric absorption from aircraft acoustic flight tests," Contractor Report NASA CR-1891, National Aeronautics and Space Administration, Washington, D. C., November 1971.

[6] O'Brien Jr., W. D., Darmondy, R. G., and Munson, D. C., Jr., "Acoustic Characterization of Soil," Contractor Report NASA CR-1891, SERDP, 901 North Stuart St. Suite 303, Arlington, VA 22203, March 1996.

[7] Shivashankara, B. N. and Stubbs, G. W., "Ground Plane Microphone for Measurement of Aircraft Flyover Noise," *Journal of Aircraft*, Vol. 24, (11), November 1987, pp. 751–758.

[8] Willshire Jr., W. L. and Nystrom, P. A., "Investigation of effects of microphone position and orientation on near-ground noise measurements," Technical Paper NASA TP-2004, NASA Langley Research Center, Hampton, VA 23681, USA, April 1982.

[9] Cliatt II, L. J., Haering Jr., E. A., Jones, T. P., Waggoner, E. R., Flattery, A. K., and Wiley, S. L., "A Flight Research Overview of WSPR, a Pilot Project for Sonic Boom Community Response," 32nd AIAA Applied Aerodynamics Conference, Atlanta, GA, June 2014.

[10] Brandão, E., Lenzi, A., and Paul, S., "A review of the in situ impedance and sound absorption measurement techniques," *Acta Acustica united with Acustica*, Vol. 101, (3), 2015, pp. 443–463.

[11] "14 CFR Appendix G to Part 36 - Takeoff Noise Requirements for Propeller-Driven Small Airplane and Propeller-Driven, Commuter Category Airplane Certification Tests on or After December 22, 1988." , 2012.

[12] Pascioni, K. A., Greenwood, E., Watts, M. E., Smith, C. D., and Stephenson, J. H., "Medium-Sized Helicopter Noise Abatement Flight Test," Proceedings of the 76^{th} Annual Forum of the Vertical Flight Society, Virginia Beach, VA, October 2020.