Proceedings of Meetings on Acoustics

Volume 42 http://acousticalsociety.org/

179th Meeting of the Acoustical Society of America

Acoustics Virtually Everywhere

7-11 December 2020

Noise: Paper 4aNSb4

Comparing two weather-robust microphone configurations for outdoor measurements

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This paper discusses comparisons made between two ground-based outdoor microphone configurations. The first consists of an inverted microphone placed above a convex circular plate and covered by a large dome windscreen. The second, updated, configuration is similar but has a thicker windscreen and a thinner ground plate. Both were subjected to laboratory testing where their responses to sound were recorded at several different elevation and azimuthal angles. At almost all shown elevation angles, both configurations recorded levels that were within ±3 dB of a baseline measurement between 50 Hz – 20 kHz. At all shown azimuthal angles and over the same frequency range, both configurations recorded levels within ±2 dB of the levels reported at an azimuthal angle of 0°, with the updated configuration having less variation. Both were also subjected to wind noise testing, where the updated configuration demonstrated superior wind noise rejection at low frequencies. The conclusion is that both are suitable for outdoor acoustical measurements and that the updated configuration is superior, especially when measuring low-frequency noise.

Published by the Acoustical Society of America

1. INTRODUCTION

Different environmental factors influence outdoor sound measurements, including wind, rain, reflections from finite-impedance ground surfaces, propagation across terrain, and noisy ambient environments.[1,2,3] These influences can alter the data by decreasing the amplitude at certain frequencies, as in the case of sound propagating over soft material,[3] or by increasing the amplitude, as in the case of noisy or windy ambient environments.[4]

Prior systems have been developed to minimize the influence of these factors and to record high-fidelity data. These include the Sonic Pressure Integrated Kit Electronics, known informally as SPIKE,[5] which has been used by NASA for sonic boom measurements. In SPIKE, the microphone is laid horizontally within a half ball windscreen on top of a 2-by-2 ft (0.6 x 0.6 m) square plywood board. Another setup used by NASA for sonic boom measurements is the configuration used in the Gulfstream Aerospace Sonic Boom Unattended Data Acquisition System (SBUDAS), which employs a microphone within a small dome windscreen and elevated off the ground with a small tripod.[5] There exist other novel designs as well that deal with different recording challenges.[6,7]

In collaboration with Blue Ridge Research and Consulting, LLC (BRRC), Brigham Young University (BYU) worked to develop a custom ground-based microphone system.[8] At BYU the ground-plate system is nicknamed the Compact Outdoor Unit for Ground-based Acoustical Recordings (COUGAR). This setup uses an inverted microphone placed one half-diaphragm diameter[9] above a convex, circular, plastic ground plate. The microphone is protected from the wind by a large dome windscreen and the microphone is positioned off-center relative to the circular ground plate. Further design details are discussed below in Section 2.

Because COUGAR performed favorably by reducing the wind noise and minimizing multi-path interference, BYU decided to design an improved version of COUGAR that could further reduce wind noise and the effects of the ground plate.[2] The improved configuration is known as COUGARxt, where the "xt" stands both for "extra thick" and "extra thin", referring to its thicker windscreen and thinner ground plate. The COUGARxt system is designed to have superior wind noise rejection relative to COUGAR while still providing high-fidelity acoustic data over the same frequency range.

This paper discusses the physical and acoustical differences between COUGAR and COUGARxt. First, the physical specifications of the two configurations are given, followed by a description of the testing campaign, which included laboratory and field testing. The conclusion from the laboratory testing is that both configurations generally provide satisfactory (±3 dB) frequency responses up to 10 kHz and that COUGARxt has a flatter frequency response. The conclusion drawn from the field testing is that COUGARxt further improves on COUGAR's wind noise rejection.[1]

2. METHODS

A. COUGAR AND COUGARXT

The COUGAR and COUGARxt configurations both use inverted microphones placed over convex plastic ground plates and shrouded in dome windscreens made of reticulated polyurethane foam with 18 pores-per-inch. Various views of both configurations are shown in Figure 1 and Figure 2. The purpose behind the convex ground plate is to gradually match the impedance as deflected sound waves travel toward the edges of the plate, resulting in less edge diffraction. The curvature also helps direct water away from the microphone during rainy conditions. The apex is off center to further discourage edge diffraction and scattering effects at high frequencies.[6,10] The purpose of the thick dome windscreen is to increase the distance between turbulent effects at the screen from the microphone as well as to provide additional water wicking during rainy conditions, guiding the water away from the microphone. The purpose of the inverted microphone is to reduce multi-path interference effects, and the microphone is placed one half-diameter above the plate in accordance with long-standing practice.[9] The metal pieces on top of and around the windscreen hold the windscreen together and attach it to the plate. The spikes on top are meant to discourage birds from landing on the setup as well as hold the windscreen firmly to the ground plate. COUGARxt is designed to reject more wind noise by doubling the thickness of the dome windscreen and to minimize the effects of the ground plate by using a thinner plate.

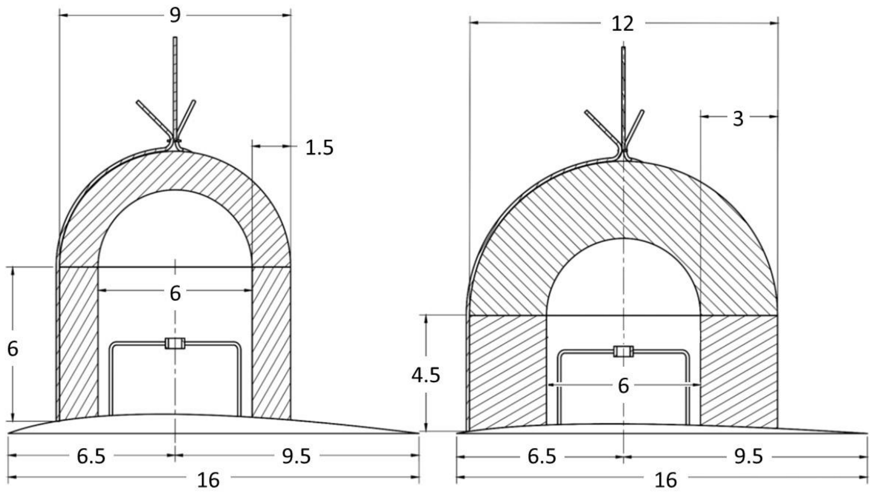

Figure 1. The COUGAR (left) and COUGARxt (right) microphone configurations in a cut-away view showing dimensions in inches. The COUGAR ground plate has a maximum thickness of 20 mm and the COUGARxt ground plate has a maximum thickness of 10 mm.

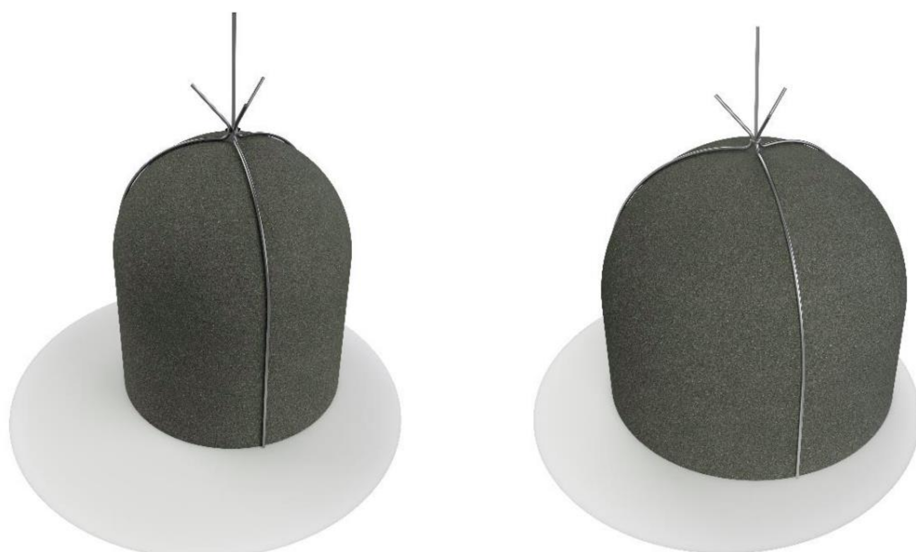

Figure 2. The COUGAR (left) and COUGARxt (right) microphone configurations in their assembled state.

B. LABORATORY SETUP

The two ground plate setups using GRAS 46AO microphones were tested in the BYU Large Anechoic Chamber[2] using a speaker placed on the rails of a large metal arc with a radius of 2.18 m (7.2 ft). This same arc was also used in similar studies performed at NASA Langley Research Center.[3] The speaker was movable between 5° and 90° in increments of 5°. A photograph of the overall setup is shown in Figure 3. The entire setup was placed on medium-density fiberboards (MDF) with a thickness of 19 mm (0.75 in) in the chamber to provide a hemi-anechoic environment. The anechoic chamber itself is rated between 80 Hz and 20 kHz.[2] The device under test was placed such that it was directly beneath the speaker when the speaker was at its highest position (90°), and when it was rotated for azimuthal experiments, the microphone position was kept consistent relative to the rest of the setup. Additionally, a reference microphone, which was placed between 1-2 ft (0.3-0.6 m) to the side and was taped to the MDF boards, served to validate the speaker output between recordings. The speaker was used to output uncorrelated white noise from 50 Hz up through 10 kHz.

Recordings with duration 30 seconds were made by both sliding the speaker along the rails in 5°-increments and by rotating the microphone configurations. This gives a three-dimensional view of the microphone configuration response. The elevation angle refers to the angle of the speaker relative to the microphone configuration and is shown on the left in Figure 4. The azimuthal angle is defined as the rotation angle of the microphone configuration relative to the standard orientation of the configuration (where the long side of the ground plate is oriented toward the sound source) and is shown on the right in Figure 4. The azimuthal variation of ground-based microphone configurations has been previously researched[3,11] and the results in this paper will supplement the existing data.

One of the goals was to compare the two configurations to an ideal measurement that wasn't impacted by a windscreen or ground plate. One possible option is to use the reference microphone indicated in Figure 3. However, this does not work because that reference microphone is located to the side of the speaker and the signal it receives has different spectral characteristics. Therefore, a measurement was made where a 0.25 in microphone was placed horizontal on the MDF boards and located exactly at the same spot that COUGAR and COUGARxt were tested. This measurement is termed the "baseline" measurement and is used to compare the responses of COUGAR and COUGARxt to an approximate free-field measurement.

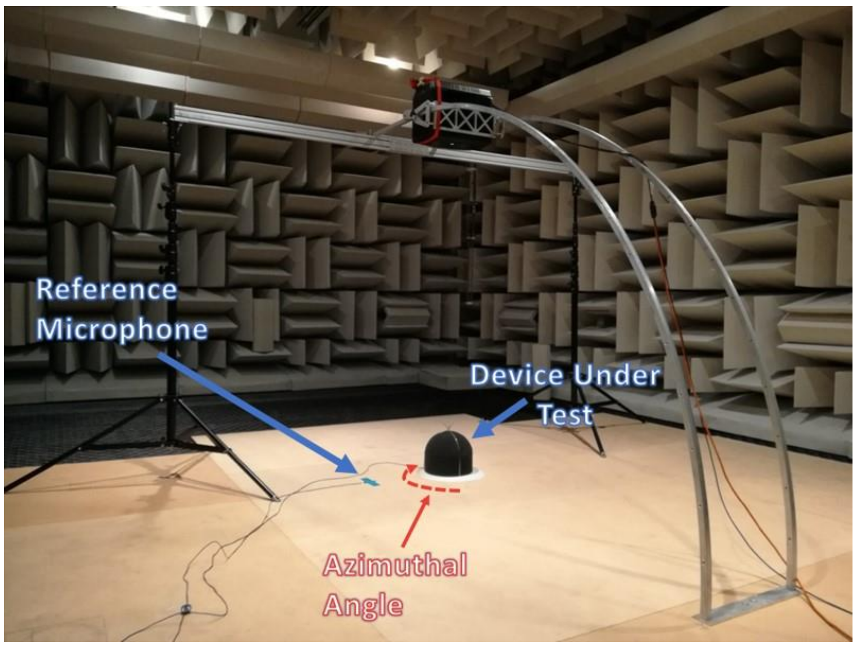

Figure 3. The arc assembly in the BYU Large Anechoic Chamber. The speaker was able to move along the arc to provide a signal from many different elevation angles. A reference microphone was used to verify the speaker output between tests.

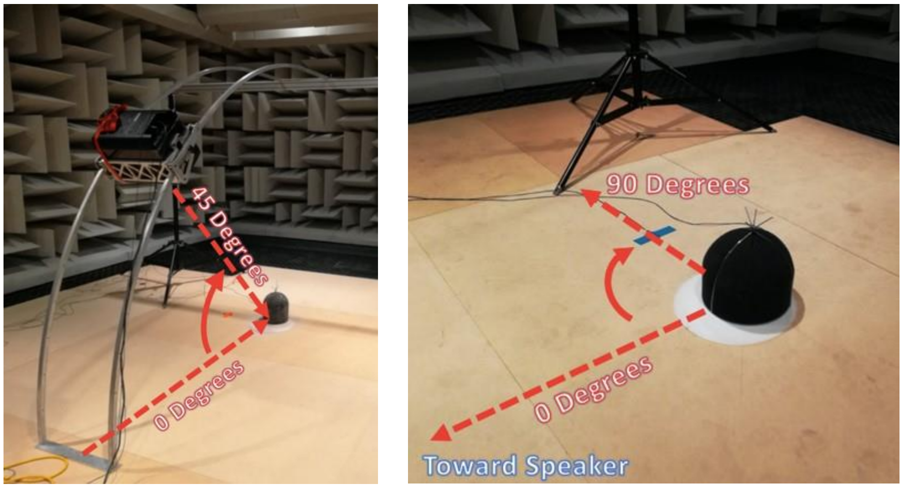

Figure 4. Left: The definition of the elevation angle in the experiment. Right: The definition of the azimuthal angle in the experiment.

C. WIND NOISE SETUP

The data for this outdoor measurement were collected in an open, outdoor environment with sustained wind speeds around or exceeding 20 mph (9 m/s) for 40 minutes. A photograph of the setup is shown in Figure 5. The location chosen was a small road near the Provo Regional Airport. The microphones used were two pre-polarized GRAS 47AC microphones, which have a manufacturer-specified frequency range between 0.09 Hz and 20 kHz. These were connected to an NI 9250 data acquisition card. The system recorded data for 40 minutes, and a subtraction between the two resulting one-third octave spectra was performed to investigate their relative efficiency at rejecting wind noise.

Figure 5. The experimental setup for the outdoor wind noise testing. The two microphone configurations are on the right in the figure, with COUGARxt closest to the camera and COUGAR further away. On the left are the computer and data acquisition hardware. The prevailing wind direction was from right to left in this photograph, with the electronics box being downwind of the microphones.

3. RESULTS

A. ELEVATION ANGLE ANALYSIS IN THE LABORATORY

The first analysis deals with the COUGAR and COUGARxt ground plates. To test the plate effects, we removed the windscreens and tested both configurations relative to the baseline measurement. This is shown in Figure 6. The differences relative to the baseline are small (within 2 dB) at frequencies up to about 2 kHz. Both ground plates have the effect of boosting the frequencies above about 2 kHz relative to the baseline measurement.

When the windscreen is used, COUGAR remains within 2 dB of the baseline measurement up to about 2 kHz. For the same scenario, COUGARxt stays within 2 dB up to 10 kHz at all angles except 90° incidence. This is shown in Figure 7. Both configurations show similar trends, such as the shape of the 70- and 90-degree curves, and previous research indicates some of the details around 1 kHz are due specifically to the ground plate.[12] In order to separate the effects of the windscreens themselves, Figure 8 shows the insertion loss of the two windscreens. As expected, there are larger losses observed at high frequencies for the thicker COUGARxt windscreen. However, both windscreens maintain losses under 3 dB over the shown frequency ranges.

Another useful calculation is the relative spectrum between COUGAR and COUGARxt. Figure 9 shows COUGARxt relative to COUGAR during two separate measurement campaigns. These measurements were made several months apart, in the Fall of 2019 and the Summer of 2020. The same trends are seen in both measurements, indicating a decent level of repeatability between measurement campaigns. Analysis of the reference microphone indicates that in the Summer 2020 measurements there was a constant offset in the speaker output of about 0.5 dB between the COUGAR and COUGARxt measurements. This means that approximately 0.5 dB should be added to the curves shown for Summer 2020. With this correction, the measurements from Fall 2019 and Summer 2020 appear to be in excellent agreement. Further discussion of repeatability for such measurements can be found in Reference 12.

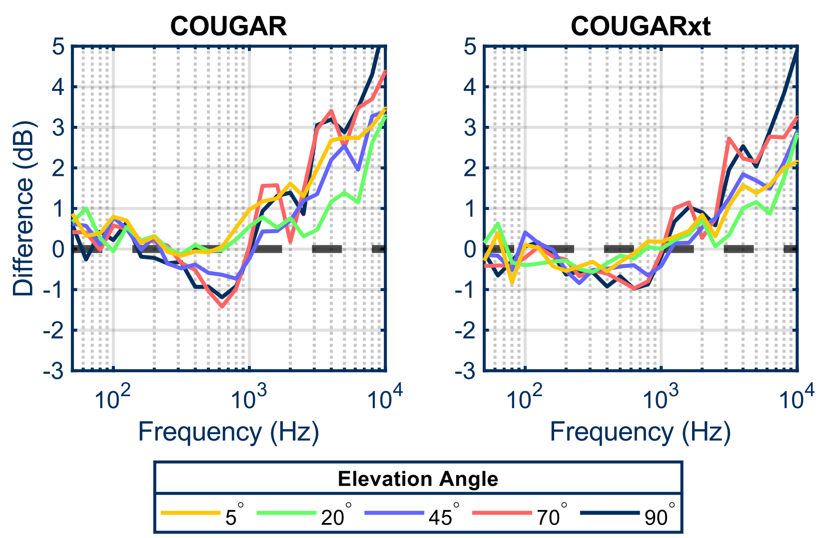

Figure 6. Analyzing the effects of the ground plates in both setups. This measurement shows COUGAR and COUGARxt without their windscreens relative to the baseline measurement.

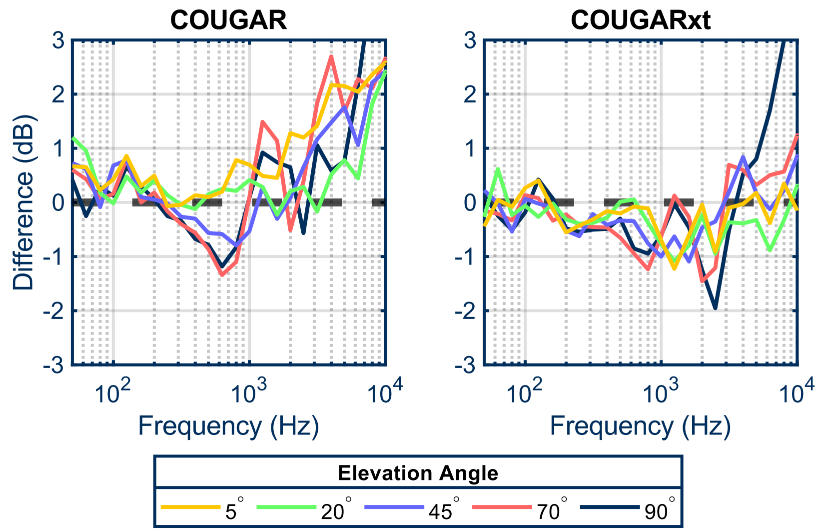

Figure 7. Comparison with the baseline measurement. This measurement had both configurations in their standard orientations with windscreens with the elongated side of the ground plates oriented toward the sound source.

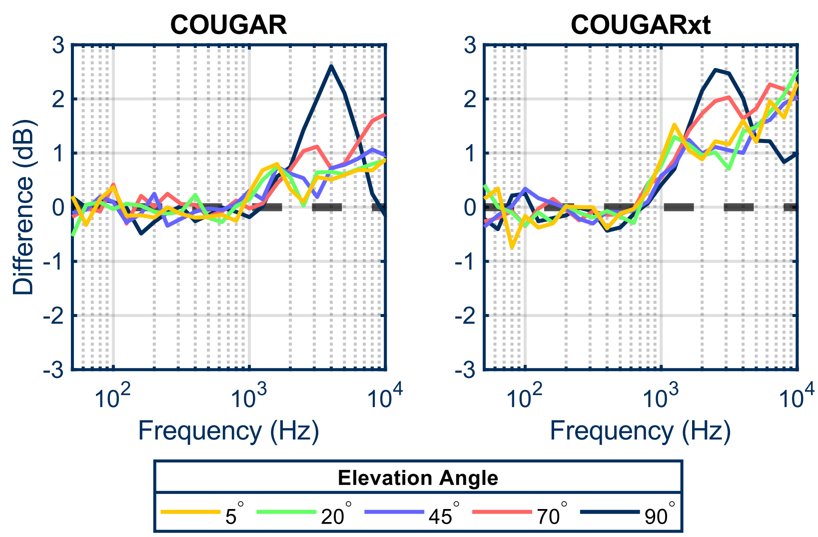

Figure 8. The windscreen insertion losses. This is a subtraction of Figure 6 - Figure 7. The COUGARxt windscreen tends to attenuate more high-frequency noise than the COUGARxt windscreen.

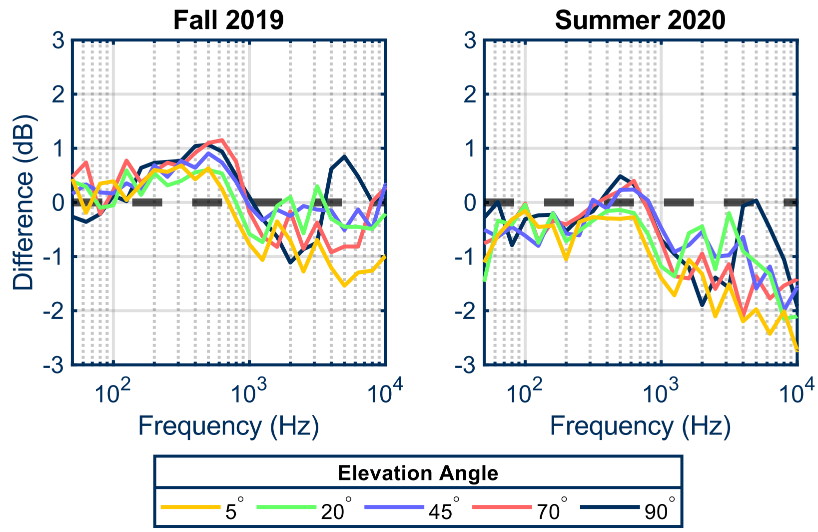

Figure 9. COUGARxt re COUGAR. Reference microphone analysis indicates that the Summer 2020 curves should be raised approximately 0.5 dB relative to their current values.

B. AZIMUTHAL ANGLE ANALYSIS

The previous section showed results with COUGAR and COUGARxt in their standard orientations, with the long side of the ground board oriented toward the sound source. This is not always possible or practical during field measurements, especially when the source is moving relative to the microphones. Therefore, it is good to look at both configurations as they are rotated azimuthally relative to the sound source. Figures 10 to 13 show both configurations as they are rotated about the microphone axis. Data are shown relative to the standard orientation, meaning that positive values indicate that the rotated orientation yields higher values for a given frequency. Overall, the results indicate that both COUGAR and COUGARxt continue to provide satisfactory acoustic data when rotated relative to the sound source. There are also some minor but interesting features in the spectra that are not yet understood, such as the dip and peak at high frequencies in Figure 11 and the dip around 1–2 kHz in both spectra in Figure 12.

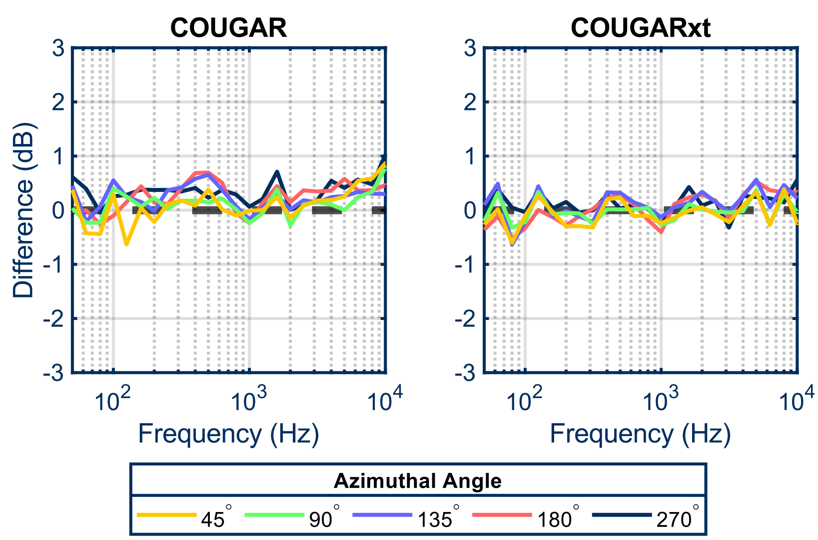

Figure 10. Azimuthal comparison of COUGAR and COUGARxt with the incoming signal at an elevation angle of 5°.

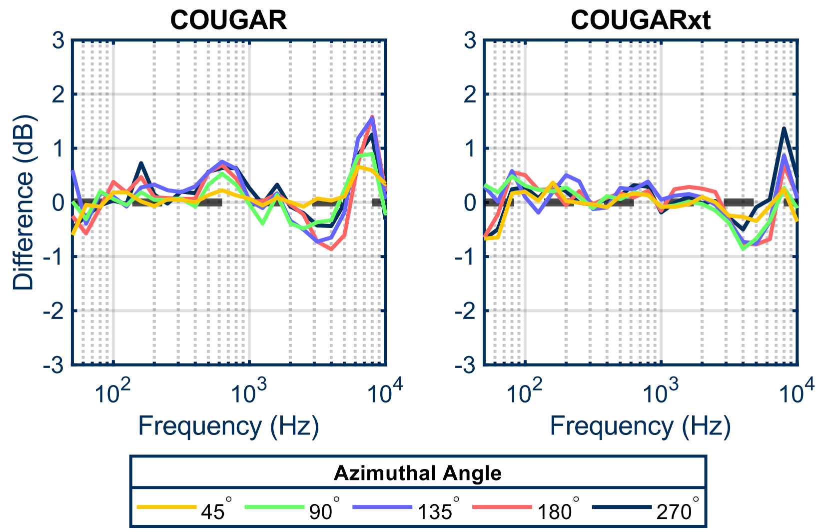

Figure 11. Azimuthal comparison of COUGAR and COUGARxt with the incoming signal at an elevation angle of 30°.

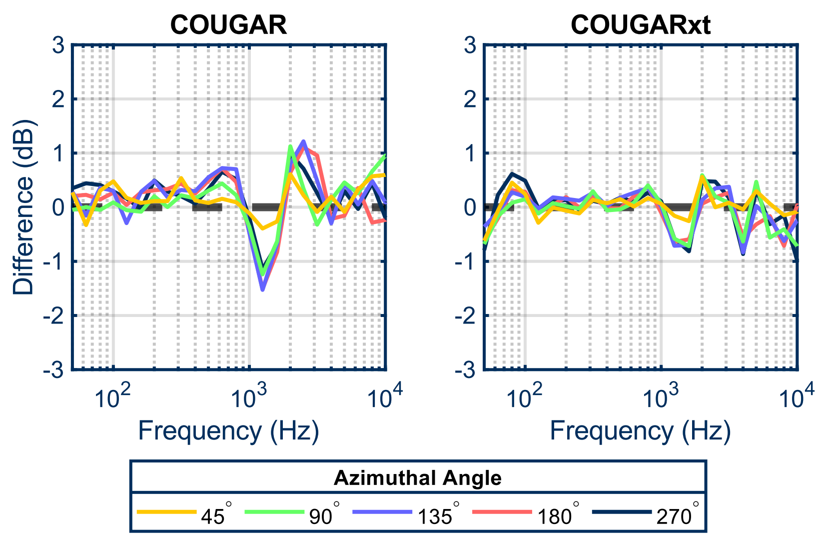

Figure 12. Azimuthal comparison of COUGAR and COUGARxt with the incoming signal at an elevation angle of 60°.

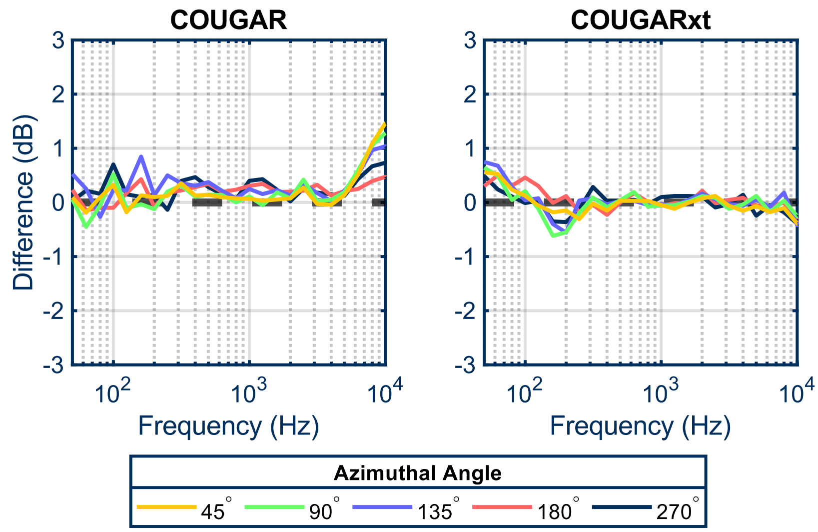

Figure 13. Azimuthal comparison of COUGAR and COUGARxt with the incoming signal at an elevation angle of 90°.

C. WIND NOISE TESTING RESULTS

Both COUGAR and COUGARxt are designed to decrease wind noise while minimizing installation effects. The autospectral densities for the wind noise measurement are shown in Figure 14, where there is a noticeable difference at low frequencies. To better understand this difference, Figure 15 shows a subtraction in one-third octave bands between the two spectra. In this representation we can see that the levels reported when measuring the wind noise were lower when measured with COUGARxt. Because there were no other known low-frequency sources, we conclude that COUGARxt shows superior wind noise rejection at low frequencies.

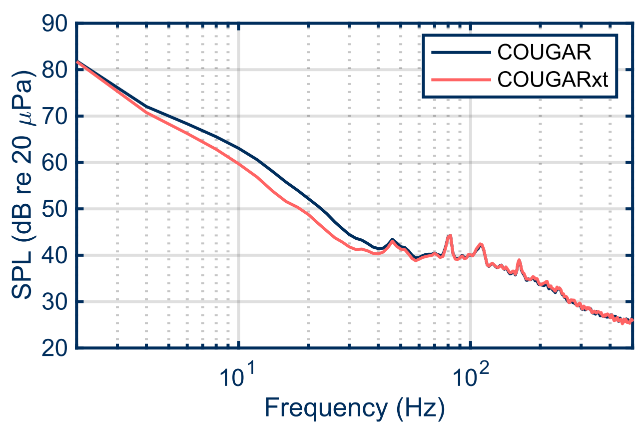

Figure 14. The autospectral densities of the wind noise measurements using COUGAR and COUGARxt.

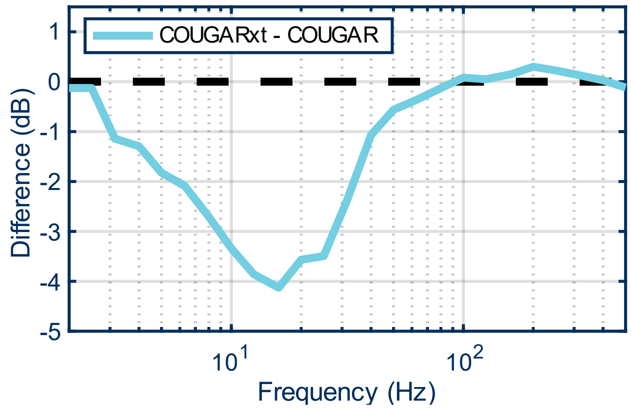

Figure 15. The wind noise test results. COUGARxt rejects more wind noise than COUGAR between 3 and 80 Hz.

4. CONCLUSIONS

The COUGAR and COUGARxt microphone configurations both record high-quality acoustic data. Both configurations in their standard orientations vary on the order of ±3 dB up to 10 kHz relative to a baseline measurement intended to mimic a free-field measurement. They also vary by ±2 dB relative to their standard orientations when rotated relative to the noise source. In all tests demonstrated in this paper, COUGARxt outperforms COUGAR by providing less variation as functions of elevation and azimuthal angles as well as rejecting more wind noise. However, both configurations are generally suitable for many outdoor acoustical measurements. Certain types of measurements, such as those measuring frequencies that may be contaminated by wind noise, will likely prefer COUGARxt while measurements with other requirements will be successful with the COUGAR configuration. Additional tests of the two configurations can be found in in Reference 12.

ACKNOWLEDGEMENTS

We would like to thank NASA Langley Research Center for funding this research through the National Institute of Aerospace. We would also like to thank Jeremy Peterson of the BYU Department of Physics and Astronomy for building the measurement arc and J. Taggart Durrant for help in preparing this manuscript.

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