Examining wind noise reduction effects of windscreens and microphone elevation in outdoor acoustical measurements

Zachary Jones, Mylan R. Cook, Kent L. Gee, Mark K. Transtrum, Shane V. Lympany, Matthew F. Calton, and Michael M. James

Citation: Proc. Mtgs. Acoust. **42**, 045007 (2020); doi: 10.1121/2.0001413

View online: https://doi.org/10.1121/2.0001413

View Table of Contents: https://asa.scitation.org/toc/pma/42/1

Published by the Acoustical Society of America

ASA POMA 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

Physical Acoustics: Paper 3aPAc3

Examining wind noise reduction effects of windscreens and microphone elevation in outdoor acoustical measurements

Zachary Jones, Mylan R. Cook, Kent L. Gee and Mark K. Transtrum
Department of Physics and Astronomy, Brigham Young University, Provo, UT, 84602; ztj5019@psu.edu; mylan.cook@gmail.com; kentgee@byu.edu; mkt24@byu.edu

Shane V. Lympany, Matthew F. Calton and Michael M. James
Blue Ridge Research and Consulting LLC, Asheville, NC; shane.lympany@blueridgeresearch.com, matt.calton@blueridgeresearch.com; michael.james@blueridgeresearch.com

Jones *et al.* [J. Acoust. Soc. Am. 146, 2912 (2019)] compared an elevated (1.5 m) acoustical measurement configuration that used a standard commercial windscreen for outdoor measurements with a ground-based configuration with a custom windscreen. That study showed that the ground-based measurement method yielded superior wind noise rejection, presumably due to the larger windscreen and lower wind speeds experienced near the ground. This study further examines those findings by attempting to decouple the effects of windscreens and microphone elevation using measurements at 1.5 m and near the ground with and without windscreens. Simultaneous wind speed measurements at 1.5 m and near the ground were also made for correlation purposes. Results show that the insertion of the custom windscreen reduces wind noise more than placing the microphone near the ground, and that the ground-based setup is again preferable for obtaining broadband outdoor acoustic measurements.

Published by the Acoustical Society of America

https://doi.org/10.1121/2.0001413

1. INTRODUCTION

Outdoor ambient acoustical measurements are used to understand various sound sources in an environment and associated soundscape[1,2]. However, wind creates challenges for outdoor measurements in the form of wind-induced microphone self-noise. Wind-induced microphone self-noise (which is referred to as wind noise hereafter) is a low-frequency, non-acoustic noise source that can contaminate outdoor noise measurements, making it difficult to draw meaningful conclusions from acoustic data[3,4,5,6]. Wind noise is dependent on factors such as wind speed, microphone height, and windscreen dimensions. Because wind is unavoidable in outdoor acoustical measurements, wind noise reduction methods are necessary.

This challenge has led researchers to employ various solutions over the past several decades, the most popular of which include the insertion of a windscreen[7] or the variation of microphone height[8]. The advent of these methods has led researchers to attempt to characterize them in terms of wind noise reduction (WNR), or the reduction in measured sound pressure level due to the implementation of a given method[9].

We have previously combined the two aforementioned wind noise reduction solutions by developing a ground-based, weather robust, acoustical measurement configuration[10,11]. This system, referred to as the custom ground-plate setup, is comprised of a 1.5” thick, two-piece, dome-shaped windscreen with an inverted microphone suspended over an acoustically reflective plate. Designed to mitigate wind noise and other weather-related effects in outdoor acoustic measurements, this configuration has been used in the measurements of sonic booms [10,11], space launch vehicles[11,12], low-frequency audio and infrasound intensity measurements[12,13], and outdoor ambient sound environments[14,15].

This custom ground-based configuration was previously compared[16] against an elevated microphone configuration using the Larson Davis WS009 windscreen[17]. Both configurations use a similar open-cell polyurethane foam with 18-20 pores per inch and have a similar windscreen thickness. Results from that work demonstrated overall wind noise reduction by moving the microphone to the ground and by employing the larger custom windscreen, in comparison with the elevated configuration. However, the initial work also demonstrated a need to separate the effects of microphone height placement and windscreen insertion loss.

The current work aims to separate these two effects to understand why this custom configuration achieves greater overall wind noise reduction. Thus, this work is organized as follows. Section 2 briefly summarizes theory regarding the turbulence spectra of windscreens. The experimental setup is described, and a method for comparing experimentally measured data with the theory as a function of wind speed is detailed. Additionally, the method for separating the effects of microphone height placement and windscreen insertion loss using difference spectra is given. Section 3 displays the results of separating the two effects using the difference spectra method.

Figure 1. CAD renderings of the custom ground-plate setup.

2. METHODS

A. EXPERIMENTAL SETUP

To separate wind noise reduction effects of microphone height placement and windscreen insertion loss, the experimental configuration used by Jones et al. was expanded to include the desired comparisons[16]. The arrangement in Fig. 2 illustrates how this was done. First, four microphones were placed at a height of 1.5 m. One of these microphones was left unscreened while the other three elevated microphones were covered by different commercial windscreens. (However, measurements from only the WS009 comparison are shown in this article; other comparisons are left as future work). Additionally, two custom configurations were placed on the ground (one screened using the custom windscreen, and the other unscreened), with the face of each microphone placed 6.35 mm above the apex of the plate (and roughly 2.5 cm above the ground, in total). For consistency, this experiment used a ½” free-field GRAS 46AE microphone in each configuration. To understand the differences in wind speed at a height of 1.5 m and near the ground, synchronous wind speed data were collected at heights of 1.5 m and 0.3 m using two Kestrel 5500 Weather Meters. The necessary comparisons needed to separate microphone height and windscreen insertion loss are those between the unscreened elevated and ground microphones, and the screened and unscreened microphones on the ground, respectively.

Background noise poses a unique problem in trying to intentionally measure wind noise because the ambient acoustic sources can, ironically, contaminate the wind-noise measurement. To minimize the ambient acoustic noise in the environment, the experiment was conducted in a secluded location near Elberta, UT. In addition, data containing audible noise from occasional aircraft and off-road vehicles were removed from the analysis.

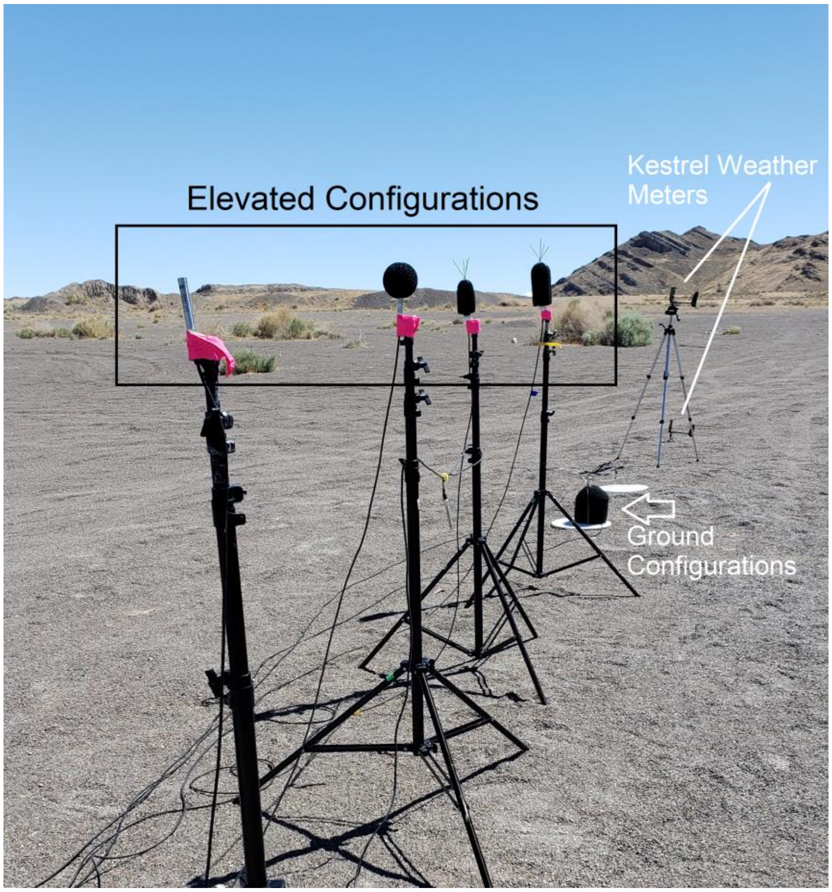

Figure 2. Photograph of the experiment described in 2.A.

B. THEORY

The topics of wind noise and wind noise reduction in acoustic measurements have been studied for several decades[18,19]. Of particular relevance to this study, van den Berg comprehensively consolidated various wind noise models to provide a thorough explanation for how wind noise is generated in a screened microphone[3]. He determined that wind noise in screened microphones is the result of atmospheric turbulence and is dominated by the effects of fluid flow at low frequencies. Additionally, Strasberg showed that wind noise in outdoor microphones can be modeled as a function of the (dimensionless) Strouhal number, $\mathrm{Sr} = fD/V$, where f is frequency, D is windscreen diameter, and V is wind speed[20].

According to van den Berg and others, there are distinct spectral regions for wind noise in outdoor acoustic measurements[3,18]. These characteristics are summarized in Fig. 3 in terms of one-third octave band sound pressure levels. The spectrum can be generally divided into two regions: the inertial range and the dissipation range. Below the dissipation frequency, which depends on wind speed and the Kolmogorov eddy size (and can be approximated as $f_d \approx 100V$), the turbulence generated within the inertial range can be further divided into two regions with slopes of -6.7 and -26.7 dB/decade. The transition between the -6.7 dB/decade portion of the inertial range and the -26.7 dB/decade portion is referred to as the crossover frequency, f_c, defined as $f_c = V/(3D)$. In terms of the Strouhal number, the crossover frequency occurs at $\mathrm{Sr} = 1/3$. An increase in wind speed increases f_c, whereas an increase in windscreen diameter decreases f_c. From a wind noise reduction perspective, a lower f_c is desirable because it enters the -26.7 dB/decade region at a lower frequency. This is achieved by making a larger windscreen.

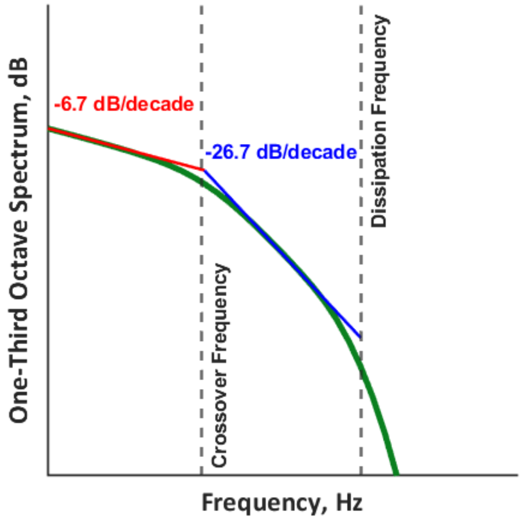

Figure 3. A visual representation of the van den Berg model described in Sec. 2.B.

C. DATA PROCESSING

I. MEASURED WIND SPEEDS

The wind noise measurements made near Elberta, UT, can be verified against the van den Berg model for one-third octave band sound pressure level to ensure that measured data truly represent wind noise. The desired comparisons are most convenient if calculated spectra are represented as a function of wind speed. To do this, the one-third octave spectral time histories at both heights are synchronously correlated with the wind speeds at the same heights. However, because wind-speed and acoustical measurements made near the ground could not be made at the same exact height due to hardware geometric constraints, the wind speeds at the microphone height had to be estimated. If a no-slip boundary condition is assumed at the ground[21], then wind speeds measured at 0.3 m can be extrapolated to the height of the ground microphone (6.35 mm above the plate and 2.5 cm from the ground) using a least-squares fit to a logarithmic profile. The measured wind speeds at a height of 1.5-m and wind speeds extrapolated to 2.5-cm above the ground are shown in Fig. 4, represented as histograms with bin widths of 0.5 m/s.

With the measured and extrapolated wind speeds, spectra are then organized by wind speeds, and the median spectrum of each bin is collected as the representative sample for that range of wind speeds[14]. Assuming self-noise from wind is the dominant signal at the microphones, this approach allows separation of the wind noise reduction effects of microphone height and custom windscreen insertion loss.

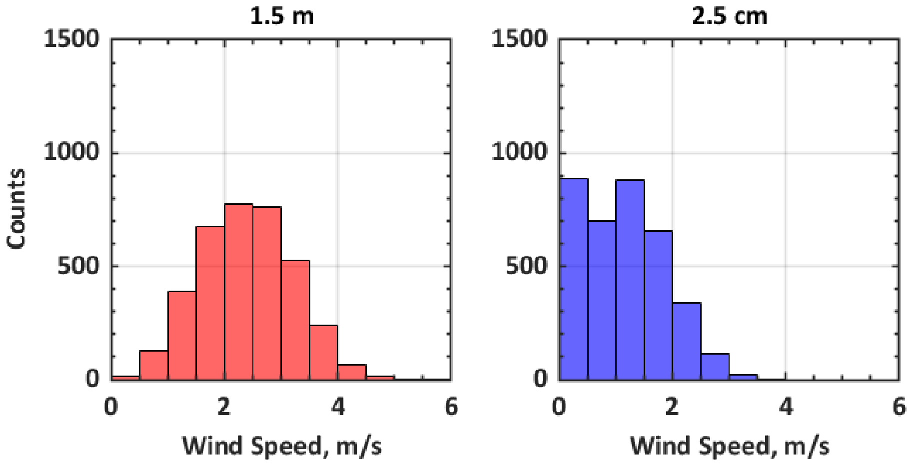

***Figure** 4. (a) Histogram of wind speeds measured at the height of the elevated setup. (b) Histogram of wind speeds extrapolated to the height of the custom ground setup.*

II. COMPARING MEASUREMENTS WITH THEORY

Comparisons with theory are completed for various screened and unscreened configurations as shown in Fig. 5. In Figs. 5 (a) through (d), the colored curves corresponding to the color bar represent the measured one-third octave spectra, while the black dashed lines represent the van den Berg model computed for each represented wind speed.

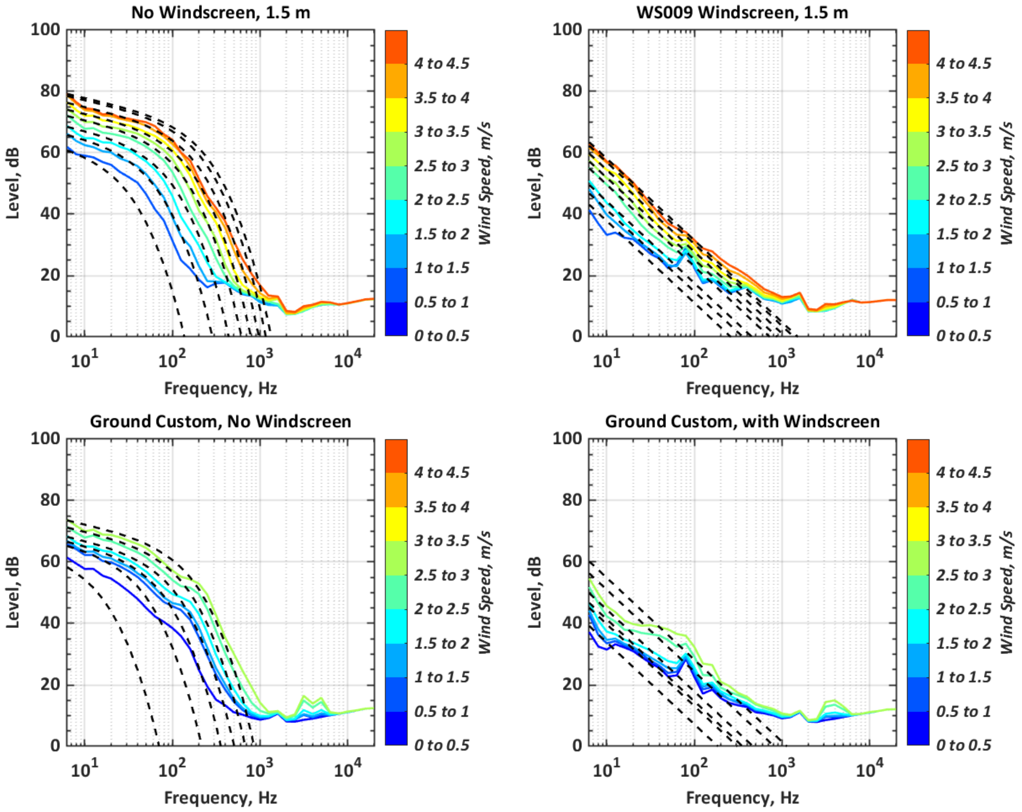

Figure 5. Experimentally measured acoustic data compared against the van den Berg model for various configurations and wind speeds: (a, top left) No windscreen, 1.5 m. (b, top right) WS009 windscreen, 1.5 m. (c, bottom left) Custom ground configuration, no windscreen. (d, bottom right) Custom ground configuration, with windscreen.

Data measured by the unscreened, 1.5 m-elevated setup, as shown in Fig. 5(a), appear to follow the established model well, seeing that the measured curves follow the expected trends above and below the crossover frequency. Since the van den Berg model is explicitly defined for screened microphones, the unscreened microphone was modeled as having a windscreen with the same diameter as the microphone. Data represented in Fig. 5(b) were collected using the 1.5-m setup with Larson Davis WS009 windscreen. It is worth noting that the -6.7 dB/decade slope is not visible for this setup. The windscreen dimensions are such that the expected crossover frequency is below 15 Hz for all wind speeds measured. As such, only the characteristic -26.7 dB/decade slope is shown, with the measured data largely following this expected trend.

A similar comparison is performed for data collected by the two ground setups. In Fig. 5(c), the unscreened data compares mostly well with the van den Berg model, except at the lowest wind speeds. The screened data collected with the custom ground setup, shown in Fig. 5(d), demonstrates a larger deviation from the van den Berg model than those from the other configurations. This is likely the result of acoustic environment intrusion on the wind noise measurements because the wind noise levels are so low. Although the spectra in Fig. 5(d) at least trend along the expected -26.7 dB/decade slope for 10 Hz and below, the presence of the ambient noise floor places a lower bound on the observable wind noise reduction by the custom ground plate setup.

III. DIFFERENCE SPECTRA

Although the ability to observe differences between wind noise is frequency-limited by the ambient acoustic environment, the influence of height and windscreen type on wind noise reduction can be separated using difference spectra. The first step in the process for isolating these effects was to organize wind speeds according to wind speed magnitude. Wind speed samples between 1 and 4 m/s were chosen and synchronously correlated with simultaneously measured one-third octave spectra. The median spectrum recorded by each configuration was determined, and the difference between the two median spectra for a desired comparison was taken to determine the impact of either moving the microphone to ground or inserting the custom windscreen. This process is illustrated in Fig. 6. The reference for the difference spectrum is such that a positive number indicates the reduction due to moving the microphone to the ground, or the reduction due to the insertion of the custom windscreen. It is important to note that the wind speeds used to determine median spectra for the height comparison were those measured at 1.5 m, while wind speeds extrapolated to the ground (see Section 2.C.I) were used to determine median spectra for the custom windscreen comparison. This implies that the levels between the "Custom, No Wind Screen" curves in Figs. 6 (a) and (b) are expected to vary slightly from one another.

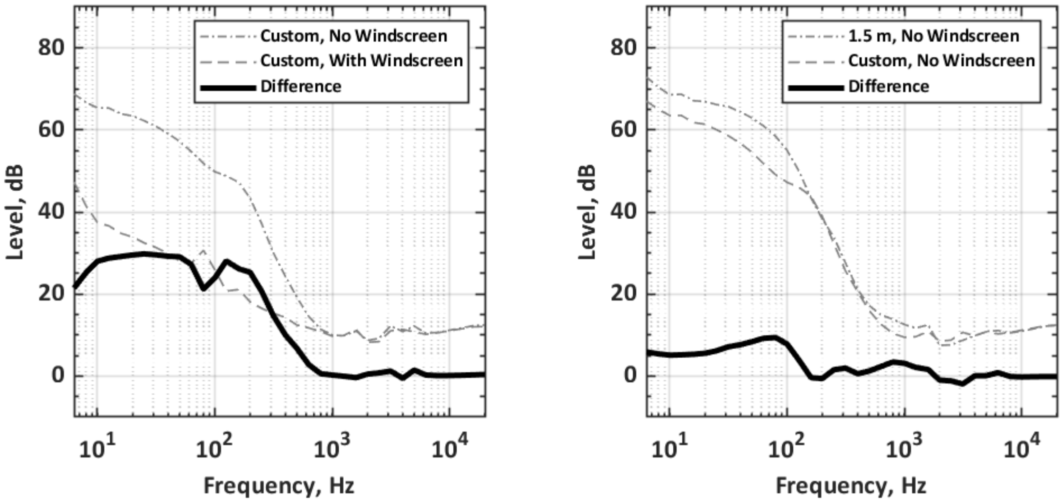

Figure 6. Application of the method described in 2.C.III and subsequent results. (a) Method applied to the ground configurations. (b) Method applied to the unscreened configurations at 1.5 m and using the custom ground configuration.

It should be reemphasized that application of this method for isolating the wind noise reduction effects of the custom ground configuration is limited both in bandwidth and dynamic range. First, since wind noise is expected to dissipate above the dissipation frequency, the wind noise reduction impact of moving the microphone to ground or the insertion of the custom windscreen cannot be accurately assessed at frequencies above the dissipation frequency. Thus, any discussion of wind noise reduction effects is restricted to frequencies roughly 200 Hz or below. Another important limitation is related to local ambient noise. For example, Fig. 6 shows a noticeable notch in the sound pressure level at 80 Hz. This notch can also be seen in Fig. 5 (b) and Fig. 5 (d) at conditions of lower wind speeds. This implies that there was an acoustic source of sufficient level to be detected at the screened configurations (both elevated and ground) at low wind speeds. Because the wind noise reduction performance is assumed to vary more smoothly with frequency, this notch was removed by interpolation.

3. RESULTS

The WNR effects from placing a microphone on the ground and implementing the custom ground windscreen, as shown in Figs. 6 (a) and (b), are presented together in Fig. 7. Represented by the red curve is the WNR effect of moving the microphone at a height of 1.5 m to the ground in the custom configuration. Moving the microphone to the ground provides a benefit of at least 5 dB below 100 Hz, through reduction in the wind speed magnitude. The largest benefit due to the height shift occurs at 80 Hz, which shows a benefit of nearly 10 dB. The black curve in Fig. 7 represents the insertion loss of the custom windscreen, and clearly has the largest impact between the two effects represented in this work. Insertion of the custom windscreen, which represents an increase in D, yields wind noise reduction of up to 25-30 dB below 200 Hz. Using van den Berg's theory (with assumed velocities of 1.5 m/s at ground and 2.5 m/s at 1.5 m), wind noise reduction at 100 Hz is ~14 dB due to wind speed (elevation) and ~23 dB due to windscreen size. These theoretical estimates based on theory are similar to those in Fig. 7, especially considering uncertainties in wind speed.

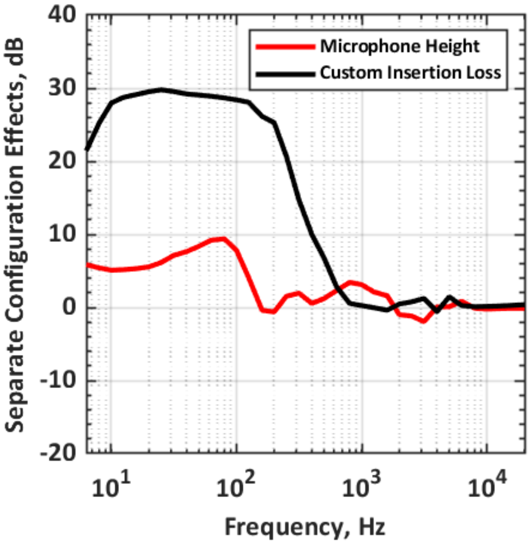

Figure 7. The isolated wind noise reduction effects of simply placing an inverted microphone 2.5 cm above the acoustically reflective plate and the insertion of the custom windscreen.

4. CONCLUSION

The effects of microphone placement height and windscreen insertion loss have been separated for an elevated microphone with a commercial outdoor windscreen, and a custom ground-plate setup. The separation of these two important wind noise reduction effects shows that moving the microphone to the ground achieves wind noise reduction of up to 10 dB, while the insertion of the custom windscreen provides broadband low-frequency wind noise reduction of up to 30 dB (although this result is restricted to frequencies below 200 Hz due to ambient instrumentation noise). Through this work, the separation of these two effects provides more information regarding the mechanisms behind the wind noise reduction due to the custom ground configuration. This configuration is thus beneficial for characterizing and improving fidelity of various outdoor acoustical measurements, including space vehicle launches, sonic booms, and ambient sound environment data collection.

ACKNOWLEDGMENTS

This work was supported by a U.S. Army SBIR contract to Blue Ridge Research and Consulting, LLC, under the technical supervision of Dr. James Stephenson. The renderings of the custom ground-plate setup shown in Fig. 1 were created by Logan Mathews. Alexander Gunther and Taylor Kimball are acknowledged for their assistance with data collection.

REFERENCES

[1] Jeon, J. Y., Lee, P. J., You, J., and Kang, J. (2010). "Perceptual assessment of quality urban soundscapes with combined noise sources and water sounds," J. Acoust. Soc. Am. **127** 1357-1366.

[2] Miedema, H. M. E., Vos, H., and de Jong, R. G. (2000). "Community reaction to aircraft noise: Time-of-day penalty and tradeoff between levels of overflights," J. Acoust. Soc. Am. **107** 3245-3253.

[3] van den Berg, G. P. (2006). "Wind-induced noise in a screened microphone," J. Acoust. Soc. Am. **119**, 824-833.

[4] Morgan, S. and Raspet, R. (1992). "Investigation of the mechanisms of low-frequency wind noise generation outdoors," J. Acoust. Soc. Am. **92** 1180-1183.

[5] Leehey, P. (1966). "Flow-noise research related to the sonar self-noise problem," J. Acoust. Soc. Am. **40,** 1265.

[6] Dyer, I., (1954). "Self-noise of cylindrical microphone windscreens," J. Acoust. Soc. Am. **26**, 935.

[7] Hosier, R. N. and Donovan, P. R. (1979). "Microphone Windscreen Performance," NBSIR 79-1599. Office of Noise Abatement and Control U.S. Environmental Protection Agency.

[8] Yu, J., Raspet, R., Webster, J. and Abbott, J. (2011). "Wind noise measured at the ground surface," J. Acoust. Soc. Am. **2**, 622-632.

[9] Zhao, S., Dabin, M., Cheng, E., Qiu, X., Burnett, I. and Liu, J. C. (2017). "On the wind noise reduction mechanism of porous microphone windscreens," J. Acoust. Soc. Am. **4**, 2454-2463.

[10] Gee, K. L., Novakovich, D. J., Mathews, L. T., Anderson, M. C. and Rasband, R. D. (2020). "Development of a Weather-Robust Ground-Based System for Sonic Boom Measurements," NASA/CR-2020-5001870. National Aeronautics and Space Administration, Langley Research Center, Hampton, VA.

[11] James, M., Salton, A., Calton, M., Downing, M., Gee, K. L. and McInerny, S. A. (2020). "Commercial Space Operations Noise and Sonic Boom Measurements," ACRP Project 02-81. National Academies of Science, Engineering, and Medicine.

[12] Irarrazabal, F. J., Cook, M. R., Gee, K. L., Nelson, P., Novakovich, D. J. and Sommerfeldt, S. D. (2019). "Initial infrasound source characterization using the phase and amplitude gradient estimator method," Proc. Mtgs. Acoust. **1**, 045004.

[13] Gee, K. L., Irarrazabal, F. J., Cook, M. R., Sommerfeldt, S. D., Neilsen, T. B., Mortenson, M. C., and Nelson, P., “Overview of the phase and amplitude gradient estimator method for acoustic intensity,” Proc. Inter-Noise 2019, pp. 5418-5428.

[14] Jones, Z. T. (2020). "Wind-Induced Microphone Noise Reduction in Outdoor Sound Level Measurements," Senior Capstone Report, Department of Physics & Astronomy, Brigham Young University, Provo, UT.

[15] Anderson, M. C. (2020). "Weather-robust Systems for Outdoor Acoustical Measurements," Senior Thesis, Department of Physics & Astronomy, Brigham Young University, Provo, UT.

[16] Jones, Z. T., Cook, M. R., Gee, K. L., Transtrum, M. K., Calton, M. F. and James, M. M. (2019). "Comparing two approaches for outdoor ambient noise level measurements," J. Acoust. Soc. Am. **4**, 2912.

[17] Larson Davis (2020). "Environmental Shrouds Support," EPS2106/EPS2106-2/EPS2106-ICP Environmental Shrouds Technical Reference Manual. PCB Piezotronics, Inc.

[18] Kaimal, J. C., Wyngaard, J. C., Izumi, Y. and Cote, O. R. (1972). "Spectral characteristics of surface-layer turbulence," Q. J. R. Meteor. Soc. **417**, 563-589.

[19] Raspet, R., Webster, J. and Dillion, K. (2006). "Framework for wind noise studies," J. Acoust. Soc. Am. **2**, 834-843.

[20] Strasberg, M. (1988). "Dimensional analysis of windscreen noise," J. Acoust. Soc. Am. **2**, 544-548.

[21] Lauga, E., Brenner, M., and Stone, H., edited by Tropea, A. L. Yarin and J. F. Foss, "Microfluidics: The no-slip boundary condition," in Springer Handbook of Experimental Fluid Mechanics, Heidelberg, Berlin, Germany, Springer, 1219-1240, (2007).