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Design and Testing of a Conical Infrasound Windscreen Constructed from Commercial Off-the-Shelf Components

by W C Kirkpatrick Alberts II

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14. ABSTRACT

Since commercial infrasonic windscreen solutions are limited to porous hose and light-duty fabric domes, there is a need to develop inexpensive infrasonic windscreen solutions suitable for long- or short-term Army use that allow good performance in the mid- to upper-infrasonic frequency band. Here, the development and testing of such an infrasonic windscreen built from easily obtainable components is discussed.

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1. Introduction

Infrasonic windscreens, mechanical filters employed to reduce turbulent fluctuations that induce noise in infrasound sensors, are often application specific and can range from complex pipe arrays meant to last for many years to long, porous rubber hoses purchased at a garden store.[1] Recently, hemispherical cap windscreens have been available for commercial purchase and have demonstrated good performance for infrasonic windscreen use. Unfortunately, the manufacturer of these windscreens ceased production. However, infrasound community research has shown that the hemispherical cap and similar variants (perforated metal, porous fabric, etc.) have sufficient capability across frequencies for US Army infrasound.[2] Thus, to simplify manufacturing and the materials used in construction, a right-conical design has been investigated that uses commercial off-the-shelf components.

The following section describes the design and construction of the right-conical windscreen. Section 3 presents the experimental configuration used to compare windscreens. Section 4 discusses the results of the experiment and presents an analysis thereof. The final section offers some concluding remarks.

2. Design and Construction

To simplify the construction of infrasound windscreens for Army use, a regular right cone was chosen as the final shape of the windscreen. A regular right cone is readily constructed from flat malleable material by removing a wedge from a circle of material and then bringing the edges of the remaining section together (Fig. 1).

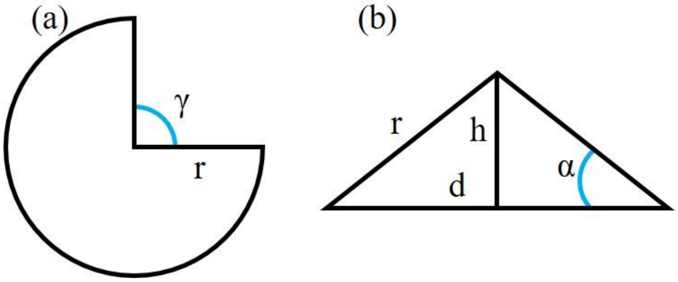

Fig. 1 Flat (a) circle and triangular cross section (b) of the cone resulting from joining of the edges outside the wedge, γ

Controlling the size of the final cone is trivial if the arc length, c_f, of the section is considered,

$$c_f = (2\pi - \gamma)r. \tag{1}$$

In Eq. 1, r is the radius of the circle used to create the section and γ is the interior angle, in radians, of the wedge removed from the initial circle of material (Fig. 1a.) Next, consider the circumference, c_c, of the right circular cone of radius d and height h, obtained by mating the wedge edges of the section shown in Fig. 1a. In Fig. 1b, and noting that c_c equals c_f,

$$c_c = 2\pi d = (2\pi - \gamma)r \tag{2}$$

If a wedge angle γ of $\pi/2$ radians is removed from the circle of material and Eq. 2 is solved for r in terms of d, then the circle radius is given by the following equation.

$$r = \frac{4}{3}d \tag{3}$$

A γ of $\pi/2$ has been chosen for simplicity in manufacturing. The cone resulting from the removal of such a wedge from a circle of material has an angle, α, of approximately 41.4° (Fig. 1b). To match the diameter, approximately 1.2 m (48 inches) of the recycled foam hemispherical cap windscreen design, a circular piece of material of approximately 1.6 m (62 inches) diameter is required. For the test reported here, a flat circle of material of a slightly larger diameter of approximately 1.8 m was used to limit material waste during construction.

The screening effect of the cone discussed here is created by a vinyl material with randomly sized pores that appears to be made by the overlay of vinyl threads in a semi-random, semi-orbital, pattern. Figure 2 shows several views of a swatch of this material to better describe its features. Figures 2a, 2b, and 2c are top, side, and bottom views of the material, respectively. Figure 2d is a photograph of the swatch backlit to show its random porosity. The material is available commercially from American Floor Mats (Rockville, Maryland) and is their heavy-duty, nonbacked, nonedged, vinyl floor mat.[3]

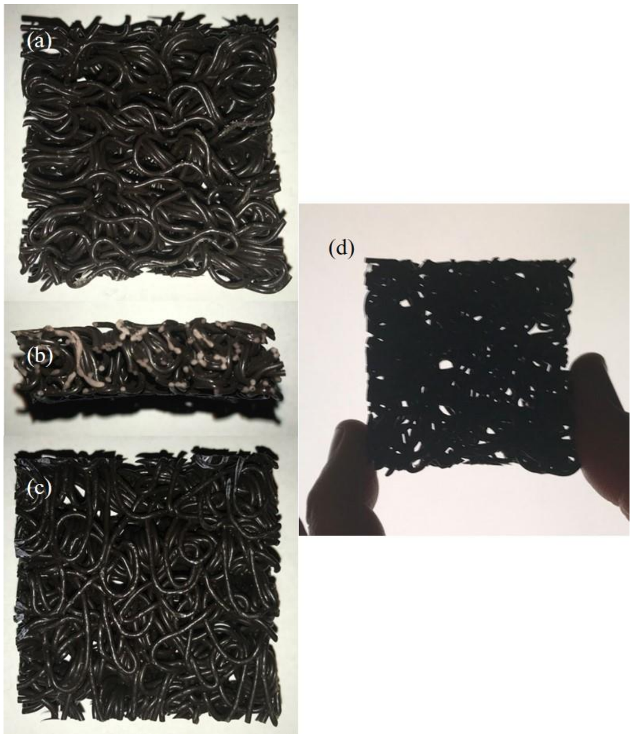

Fig. 2 **Top (a), side (b), bottom (c), and backlit (d) views of the vinyl windscreen material**

Because the vinyl material has no bending strength, a support structure must be created to hold up the windscreen. In the case reported here, a slightly undersized cone was made from 2.54 by 2.54 cm, welded-wire, galvanized fencing. The metal cone was undersized by approximately 3 cm in diameter to guarantee that the vinyl material would touch the ground around the entire perimeter of the cone to limit air passing under the edge.

Figure 3 shows the vinyl material during construction of the final flat section before creation of the cone. The material was purchased in squares of approximately 91.4 cm. Because of variation in the dimensions of the squares, the smallest was chosen for the radius of the flat circle, r in Fig. 1, and a cutting device was constructed out of scrap lumber to enable uniform cutting of the outside arc of the squares. The radius of the flat was approximately 89.9 cm yielding, by Eq. 3, a cone radius of roughly 67.4 cm and a cone height of roughly 59.5 cm.

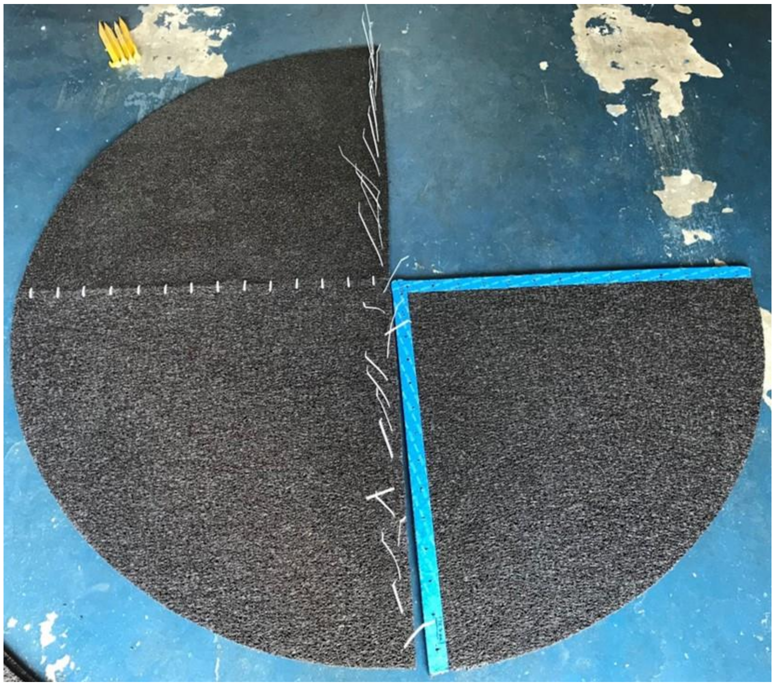

Fig. 3 Vinyl material just before final assembly

Of note in Fig. 3 are the white lines near the edges of the sections of the flat. These are white nylon tie wraps laced (middle left of the image) or ready to be laced (center of image) to connect the pieces of the flat together. To limit the chance of damage when lacing the sections and to test the most straight-forward construction method, three methods of piercing the sections were attempted, melting approximately 3-mm-diameter holes, punching with a hollow leather punch set for 3.5-mm-diameter holes, and slitting with a knife. Melting the holes, while extremely effective, created copious fumes and required a nail to be significantly heated. This method was abandoned after one edge was complete due to safety concerns. Punching holes using a hollow leather punch (Fig. 4) was also quite effective and had no associated danger as the tool used was actuated in a manner similar to cutting with scissors. Using a sharp knife to put a small slit in the vinyl material was also effective, but the risk of injury was significant because of the material’s lack of rigidity. In addition, the final slit was difficult to detect if the marking tape was removed prior to tie-wrap insertion. Thus, for future builds of the cone, the hollow leather punch method is recommended.

Fig. 4 Leather punch used for making holes in the vinyl

The holes mentioned previously were added according to the pattern shown in Fig. 5. In Fig. 5, the holes were spaced from the edge of the section by 1.9 cm and were spaced every 6.35 cm beginning from the first hole placed 3.8 cm from the corner. This pattern was repeated on each straight side of a section. The vinyl material was then laced such that the bottom of the material was up when the final cone shape was realized.

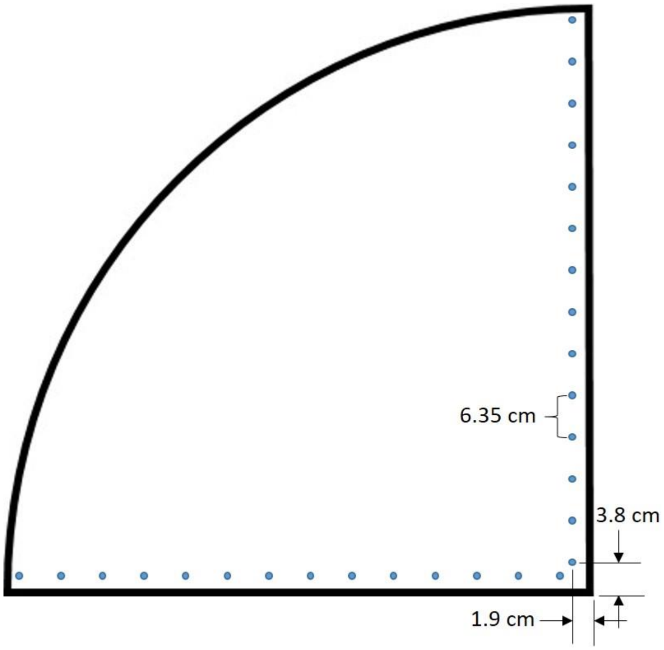

Fig. 5 Placement of holes used for connecting sections

3. Experimental Configuration

To test the capabilities of the cone windscreen, the following experiment was initiated. A 24-bit analog-to-digital converter sampling at 1 kHz was used to record four Hyperion model IFS-5000, seismically-decoupled infrasound sensors that were emplaced in a linear array with a separation of approximately 1.5 m between sensors. This linear array was installed on the Adelphi Laboratory Center campus. As such, there is often a significant anthropogenic infrasound background in the form of air-handler noise, helicopters, large vehicles, and so on. All sensors were installed with high-frequency shrouds (HFS) to limit high-frequency wind noise. One of the sensors was not covered by a secondary windscreen (Fig. 6) and the others were covered by the vinyl cone, a recycled foam hemispherical cap, and a folding, perforated aluminum dome. The uncovered sensor will be used as the reference for subsequent analysis. Infrasound data was captured continuously for a period of 6 weeks. A meteorological station was placed beside the array axis at a height of approximately 1.5 m to capture wind speeds and directions. The meteorological station ceased working early in the experiment. This event, while unfortunate, was not deemed detrimental to the experiment because local weather stations, two within approximately 3 km, could be used to gather rough information on the meteorological conditions near the experiment site. The lack of local meteorological information is discussed further in Section 4.

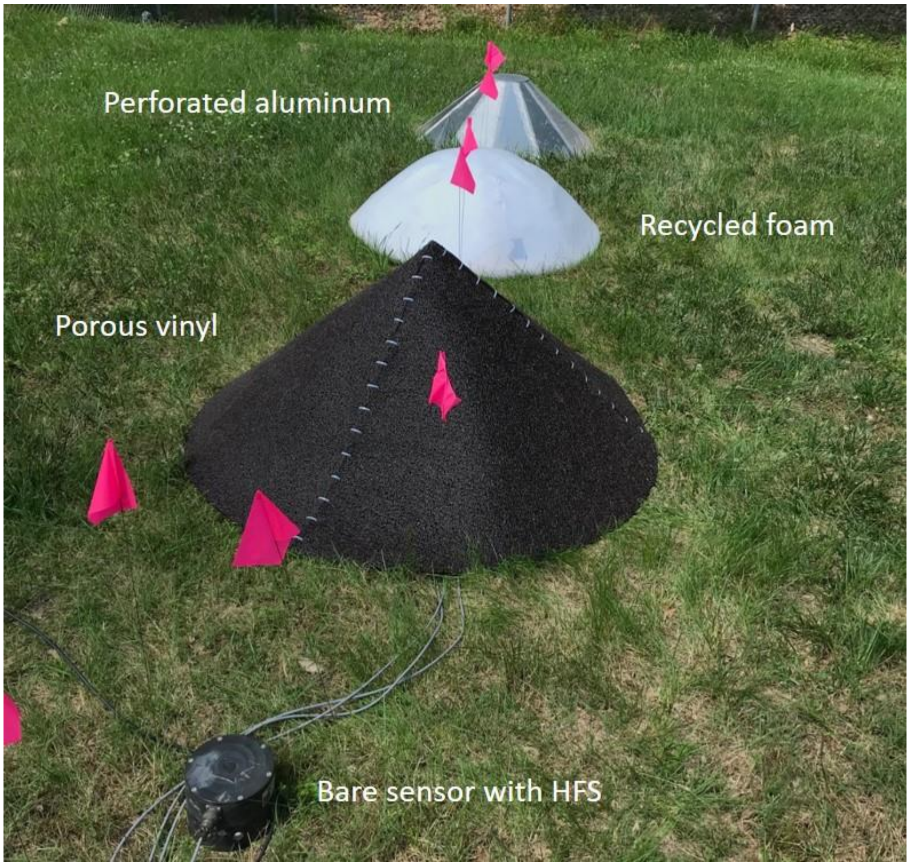

Fig. 6 Experimental configuration used to assess the windscreens

4. Results and Analysis

To assess the performance of the cone windscreen, many power spectral density (PSD) estimates for each sensor were averaged and plotted together. To generate the PSDs, the MATLAB function, pwelch, was used.[4] For all PSD calculations, a Hamming window length of 100 seconds with 75% overlap was used. No attempt to remove anthropogenic noise sources was made as they tend to be short duration over the course of the data collection and do not appear to skew the resulting averages. Air-handler noise, however, is typically constant throughout the data collection, but appeared to mostly occur at frequency ranges outside the area of interest here. However, night and day data was separated to see if significant differences occurred during the diurnal cycle as the array location is near Washington, DC, in the suburbs of Maryland and close to two major highways. Unfortunately, the author was unable to extend the experiment to include the generation of a transfer function. This will be done at a later date using the same equipment and will be described in a subsequent US Army Combat Capabilities Development Command (CCDC) Army Research Laboratory (ARL) report.

As mentioned in the previous section, the local meteorological station did not work as expected. Fortunately, however, the daytime winds during the data collection period were typically between roughly 2 and 5 m/s as measured by two local meteorological stations near the experiment site. Therefore, the decision was made that computing the average PSD over all the collected data would not be detrimental to the conclusions of this report. In addition, the typical wind-speed range in this experiment is approximately the medium wind-speed range of those experienced by Noble et al. (2014)[1], so it is likely the windscreens tested here will have similar behavior to those—better noise reduction at lower wind speeds and worse noise reduction at higher speeds but similar relative reduction across all wind speeds. This assumption regarding the behavior of the windscreens is supported by nighttime (generally little or no wind) PSDs.

Figure 7 is a plot of the PSD of each of the windscreens, from 0.01 to 50 Hz, averaged over the entire 6-week (942-h) span of the experiment. Some data was not collected due to power outages and an overwrite that occurred due to too many days without a data download. It is readily apparent in Fig. 7 that all the infrasound sensors installed under the vinyl, regular right cone (red), the hemispherical cap (orange), and the perforated aluminum (purple) have an up to approximately 6 dB/Hz reduction in noise level compared to the bare HFS sensor (blue). The most noise reduction occurs from roughly 0.2 to approximately 3 Hz where all four sensors overlap. This gives some confidence in the vinyl cone's infrasonic wind-noise filtration properties. In all subsequent plots, the sources of lines above 2 Hz are unknown. The strong peaks above 20 Hz are also of unknown origin, but, as they are outside the infrasound frequency band, they are of no consequence. The PSDs are shown to 50 Hz to adequately represent the capabilities of the windscreens.

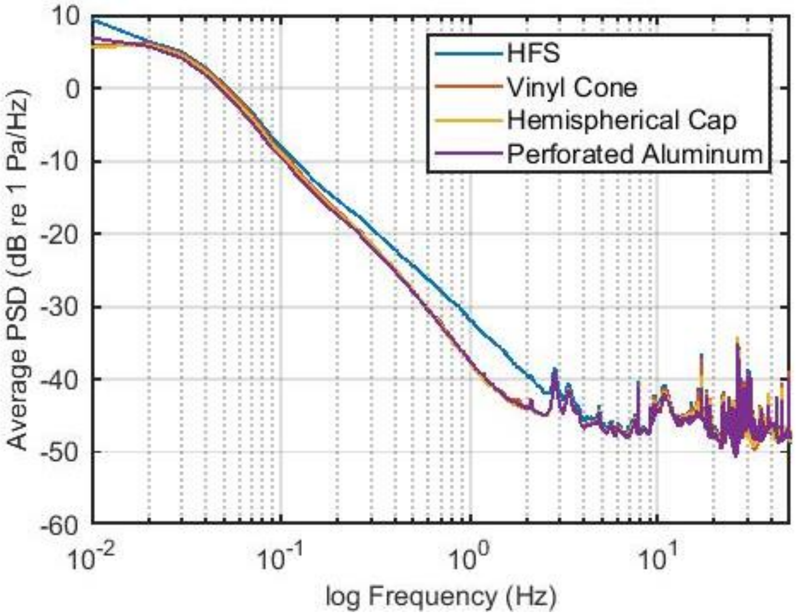

Fig. 7 Average PSD over 942 h of data—day and night

Figure 8 is a zoomed-in view of Fig. 7 in the 1 to 5 Hz region. Of note are the small peaks at approximately 2.1 Hz and the larger peaks at roughly 2.8 and 3.3 Hz, respectively; the installation of all three windscreens has increased the signal-to-noise ratio by roughly a factor of two in the 2.1 Hz case and by roughly a factor of 1.5 in the 2.8 and 3.3 Hz cases. This implies a preferential reduction in noise over signal, which confirms behavior previously observed with the hemispherical cap and lends further confidence in the ability of the vinyl cone to perform as an adequate mechanical wind-noise filter for Army tactical infrasound uses.[2]

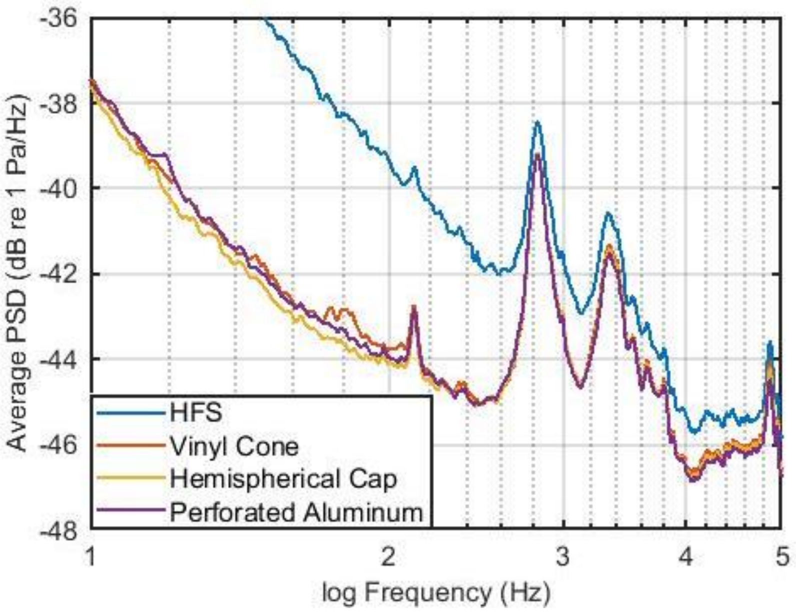

Fig. 8 Zoomed-in view of the 1–5 Hz region of Fig. 7

Figure 9 depicts the average daytime (Fig. 9a) and nighttime (Fig. 9b) PSDs of the data recorded during the experiment. Comparing the two plots, the daytime noise level, as might be expected, is higher than the nighttime level. The average nighttime level also shows a subtle increase in the average noise level at approximately 0.3 Hz. This is explained in greater detail in the discussion of Fig. 10.

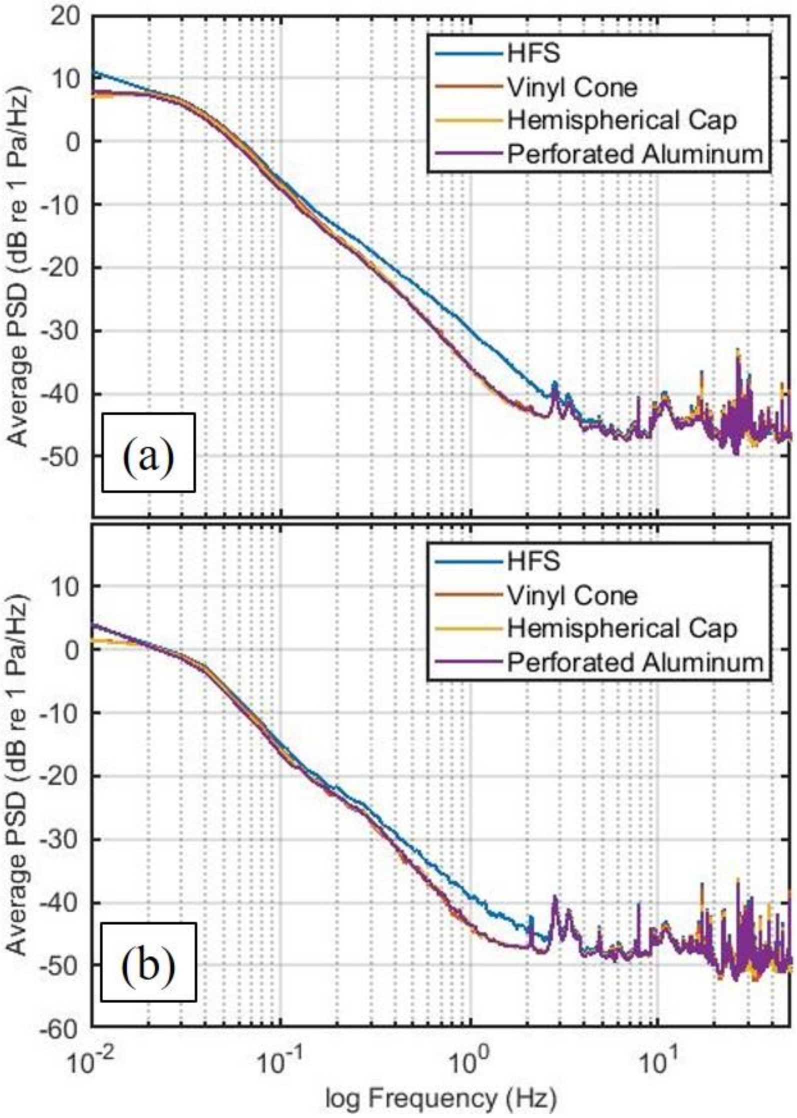

Fig. 9 **Daytime (a) and nighttime (b) average PSDs**

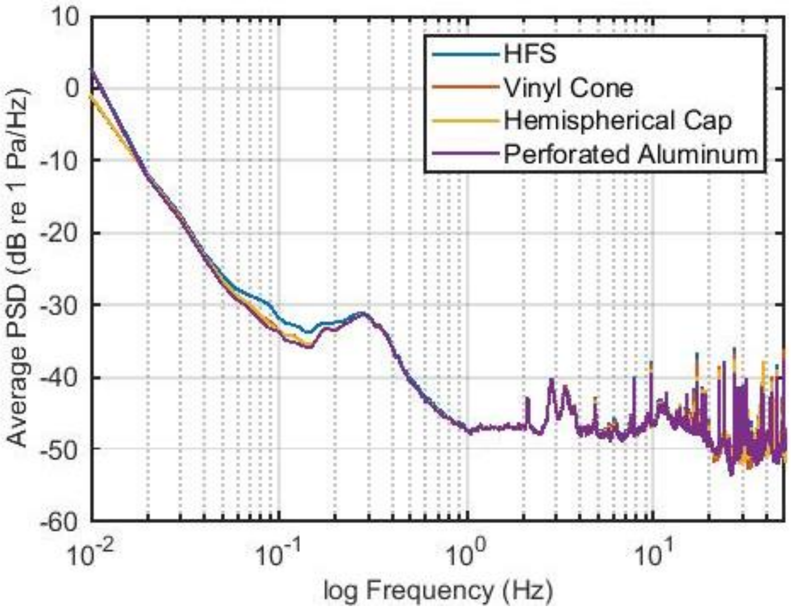

Fig. 10 **PSD showing microbarom signatures on all sensors**

An interesting phenomenon was observed during parts of the experiment; microbaroms were sometimes seen in nighttime average PSDs. One such average is shown in Fig. 10. At approximately 0.3 Hz there is a broad peak in the PSD of each sensor. This peak is typically associated with microbaroms[5], infrasound caused by storm-generated wave action in the ocean or other large bodies of water. The site of this experiment is approximately 50 km from the Chesapeake Bay and approximately 200 km from the Atlantic Ocean, so it is reasonable to expect a microbarom signature when propagation conditions are favorable and local array noise conditions are low.

5. Conclusion

The vinyl, right-conical windscreen discussed here has been shown to be successful in reducing wind noise in the infrasonic region and is comparable to previously demonstrated infrasound windscreens. Further testing is necessary to determine the longevity and robustness of the vinyl, right-conical windscreen for long-term deployment and to determine its transfer function. However, at approximately one-fifth the cost of a perforated aluminum dome and of comparable wind-noise reduction capability, the vinyl, regular, right-conical windscreen is a viable alternative to currently available infrasound windscreens for Army use in persistent surveillance and tactical applications.

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List of Symbols, Abbreviations, and Acronyms

ARL	Army Research Laboratory
CCDC	US Army Combat Capabilities Development Command
HFS	high-frequency shroud
PSD	power spectral density

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