3pNSb1. Effect of scaling laws for noise reduction optimization of wind fences

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This paper will report on an investigation to increase noise reductions at low wavenumbers for a large windscreen enclosure described in two earlier papers [J. Acoust. Soc. Am. 129, 2445 (2011), J. Acoust. Soc. Am. 132, 2048 (2012)] by first doubling its height and then doubling its diameter. According to the scaling laws developed for small windscreens, windscreens of similar shape but differing size will have nearly identical reductions for scaled wavenumbers; therefore the wavenumbers at which noise reduction for a windscreen occurs is dependent on its size and by increasing either its height or diameter, or both, reductions should shift to lower wavenumbers. Such a shift was observed when the screen's height was doubled. Also, when scaled to height, the measured reductions for the single and double height windscreens were found to match closely, with 6 dB of reduction and greater for wave numbers between 5-30 m⁻¹ and max reductions of 10-13 dB.

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INTRODUCTION

The primary source of low frequency wind noise in a pressure sensor placed in a turbulent flow is due to the interaction of the sensor with the turbulence, or the stagnation pressure. The stagnation pressure can be eliminated by removing the sensor from the flow by mounting it flush in the ground. However, this does not eliminate noise completely since pressure fluctuations are also generated by the interaction of the turbulence with the average wind velocity gradient above the earth’s surface. Noise is also generated by the interaction of the turbulence with itself in the atmosphere. The height of the dominant source of the turbulence shear interaction increases as frequency decreases.

Wind noise can also be reduced by shielding the sensor with a large windscreen. Porous windscreen can reduce the turbulence field and velocity gradient without inducing additional large wind shears and pressure fluctuations, with negligible modification to the acoustic waveform.

Windscreens do not eliminate the stagnation pressure completely; however it is significantly reduced by transferring the turbulence interaction from the pressure sensor to the windscreen’s surface. Since the windscreen is porous some turbulent flow passes through to the pressure sensor generating small amounts of residual wind noise. This residual noise can be further reduced by adding a secondary windscreen concentric to the first. This paper examines the optimization of windscreen parameters to maximize the wind noise reduction of a practical windscreen constructed of standard fencing materials.

PREVIOUS RESEARCH

A large windscreen was built to evaluate its infrasonic noise reductions, and to determine the physical characteristics to optimize noise reduction. The initial design is a ten-sided cylinder measuring approximately 2.9 m high and about 5.0 in diameter, with an open top and a 0.1 m bottom gap (G/H≈0.03). Each side is constructed of chain link fence panels with vinyl privacy slats inserted vertically into the fencing. The slats can be removed or added to change the windscreen’s effective porosity. The individual fence panels are approximately 1.5 m wide and 2.7 m high and are made of 8 gauge 2 inch chain link; see Fig. 1.

Previous research has reported on optimizing the windscreen’s reduction by 1) varying the porosity, 2) covering the top and bottom gaps, and 3) combining a smaller secondary windscreen concentric with the chain link windscreen. The secondary windscreen is a hemispherical foam dome approximately 1.2 m in diameter and linear pore density of approximately 40 ppi. The optimal reduction is achieved for a windscreen with mid level porosities, a small gap at the base of the windscreen, and combined with the small dome. Investigation of the effectiveness of leaving the top uncovered or closed was inconclusive.

CURRENT RESEARCH

This paper will report on an investigation to increase noise reductions at low wavenumbers by first doubling the height of the windscreen and then doubling its diameter; see Fig. 2. Scaling laws developed for compact spherical windscreen state that windscreens of similar shape but differing size will have nearly identical noise reductions.
when the decibel reductions are plotted versus the reduced wave number, kD, where D is a characteristic dimension. Therefore the wavenumbers or frequencies at which noise reduction occurs for a windscreen is dependent on its size and an increase in either the windscreen’s height or diameter, or both, should shift reductions to lower wavenumbers. For completeness the effect of combining the foam dome with the two double dimension windscreens on wind noise reduction was also investigated. Noise reduction was determined by comparing a pressure sensor set at the center of the windscreen to another identical windscreen set outside and upwind of the enclosure.

![Figure 2](image1.png)

**Figure 2.** Dimensions for the double height windscreen enclosure at 30% and 40% porosities are shown on the left (a). Dimensions for the double width windscreen enclosure at 30% porosity are shown on the right (b).

## Results

**Doubling the Height**

The characteristic dimension, D, for the first part of the investigation was the windscreen’s height, h. Fig. 3a shows the noise reduction curves for when the windscreen’s height is single, about 2.9 m (solid black line), and when doubled to about 5.8 m (dashed blue line). As seen, increasing the windscreen’s height does not increase the maximum reduction, however it does shift the reduction to lower wavenumbers. This shift improves reductions for wavenumbers between 0.4 m\(^{-1}\) and 2.0 m\(^{-1}\) by approximately 3-6 dB. When the plots are scaled by multiplying the measured reductions by the height, h, the reductions shift together and align, suggesting that low wavenumber reductions will improve in proportion to the windscreen’s height; see Fig. 3b.

![Figure 3](image2.png)

**Figure 3.** Non-scaled noise reduction curves in dB vs wavenumber, k (1/m) for the 2.9 m high windscreen—black line—and the 5.8 m high windscreen—blue line (a). Scaled noise reductions curves in dB vs scaled wavenumber, kh (m/m) for the 2.9 m high windscreen—black line—and the 5.8 m high windscreen—blue line (b).

Fig. 4 shows the non-scaled and scaled measured reduction curves for when the dome is combined with the windscreen when its height is single (solid black line) and doubled (dashed blue line). As can be seen for both the single and double height cases, the addition of the dome improves the noise reduction. However, unlike the no-
dome case, there is not much difference between the single and double height reductions. There is only a slight improvement in reductions for wavenumbers between 0.4 m\(^{-1}\) and 2.0 m\(^{-1}\) and there is no overall shift—the same max reductions of about 23 dB occur over the same wavenumber range, independent of the enclosure’s height. This suggests that the improved reductions due to the addition of the dome are independent of the windscreen’s exterior dimensions. This independence is further shown when the reduction curves are scaled to height. The max reductions do not align at the same scaled wavenumbers—the single height curve occurring at a lower wavenumber—however the curves do align slightly for lower scaled wavenumbers, where the additional dome is not expected to have much effect.

![Non-scaled noise reduction curves in dB vs wavenumber, k (1/m) for the combined dome and 2.9 m high windscreen—black line—and the combined dome and 5.8 m high windscreen—blue line (a).](image1)

![Scaled noise reductions curves in dB vs scaled wavenumber, kh (m/m) for the combined dome and 2.9 m high windscreen—black line—and the combined dome and 5.8 m high windscreen—blue line (b).](image2)

**FIGURE 4.** Non-scaled noise reduction curves in dB vs wavenumber, k (1/m) for the combined dome and 2.9 m high windscreen—black line—and the combined dome and 5.8 m high windscreen—blue line (a). Scaled noise reductions curves in dB vs scaled wavenumber, kh (m/m) for the combined dome and 2.9 m high windscreen—black line—and the combined dome and 5.8 m high windscreen—blue line (b).

### Results

**Doubling the Diameter**

The characteristic dimension D, for the second part of the investigation is the windscreen’s diameter, d. Fig. 5 shows the non-scaled and scaled measured noise reduction curves when the windscreen’s diameter is single, about 5 m (solid black line) and doubled, about 10 m (dashed blue line). The single width reduction curve is the same as the single height reduction curve shown previously in Fig. 3. For the double diameter windscreen reductions of 6 dB and greater occur between 2-30 m\(^{-1}\), with a max reduction of about 18 dB. The two curves align between 0.8 m\(^{-1}\) and 5 m\(^{-1}\) where the single height curve begins to reach its maximum. Therefore, doubling the diameter of the windscreen improves noise reductions by increasing the max reductions and the size of the wavenumber range for reductions at 6 dB and greater; but the reductions are not shifted to a lower wavenumber range. This alignment suggests that reductions and scaling are more dependent on the windscreen’s height than the diameter. This can also be seen when the reduction curves are scaled to the diameter, d. If the diameter, along with the height, was a characteristic dimension for scaling, then the two curves would align. However, as seen in Fig. 5b, they do not align at either high or low wavenumbers.

![dB Pressure Reduction Across Fence, with Dome](image3)

![dB Pressure Reduction Across Fence, Scaled to Height, with Dome](image4)

![dB Pressure Reduction Across Fence, without Dome](image5)

![dB Pressure Reduction Across Fence, Scaled to Width, without Dome](image6)
**FIGURE 5.** Non-scaled noise reduction curves in dB vs wavenumber, k (1/m) for the 5 m diameter windscreen—black line—and the 10 m diameter windscreen—blue line (a). Scaled noise reductions curves in dB vs scaled wavenumber, kh (m/m) for the 2.9 m high windscreen—black line—and the 5.8 m high windscreen—blue line (b).

Fig. 6 shows the non-scaled and scaled measured reduction curves when the small foam dome is combined with the single (solid black line) and double (dashed blue line) diameter windscreens. The single width reduction curve is the same as the single height reduction curve shown previously in Fig. 4. As with the single and double height windscreens, the addition of the dome also improves reductions for both of the single and double diameter windscreens. It’s important to note that the maximum reduction is the same for the two combined systems, showing that the dome improves the reductions by differing amounts—approximately 10 dB for the single height windscreen and 5 dB for the double height. This uniformity suggests that the reductions may have a saturation point—that any type of windscreen combined with this dome will only achieve a maximum reduction of about 23 dB and at k=7 m\(^{-1}\). As seen in Fig. 6b there is a complete misalignment between the curves when scaled to diameter. This is to be expected considering the misalignments for the scaled measurements for the combined dome and double height windscreens and the non-scaled measurements for the non-combined double width windscreens. Again this suggests that the increased reductions due to the addition of the dome are independent of the windscreen’s exterior dimensions.

**DISCUSSION AND CONCLUSIONS**

This project has investigated the effect of doubling the height and diameter of a large cylindrical windscreen on low frequency wind noise reduction. The project has also investigated if the windscreen is subject to scaling laws, and if the addition of a secondary concentric windscreen will further improve reductions. The data show that increasing either the windscreen’s height or diameter will improve noise reductions. Increased diameter will act much like the addition of a secondary concentric windscreen—increasing the maximum level of reductions without shifting the reductions to lower wavenumbers. Increasing the windscreen’s height causes the reductions to shift to lower wavenumbers, improving the reductions for those wavenumbers, but does not improve the maximum level of reductions. This suggests that scaled reductions are more dependent on height than diameter, and therefore the cylindrical windscreen’s characteristic scaling dimension is its height. A similar conclusion was determined by Hedlin and Raspet.\(^{10}\) It also suggests that a greater signal to noise ratio for the infrasonic bandwidth can be achieved by increasing the windscreen’s height.

The fact that additional height provides larger reductions at low frequencies indicates that for the windscreen to be effective, the product of the wavenumber times the height, k*\(h\), must be larger than 1. This may be due to the dependence of source height on wavenumber in the Earth’s boundary layer. Therefore modifications low to the ground, such as increasing the windscreen’s diameter, have little to no effect on infrasonic noise reduction.
The addition of the small foam dome had the same effect—increasing the max reductions to about 23 dB for roughly the same wavenumber range—regardless of the increase in the windscreen’s height or width. This suggests two things: 1) there may be a saturation level or upper limit for noise reductions using a combined system. 2) The additional reductions due to the combined system may be independent of the windscreen’s exterior dimensions or other physical changes applied to the windscreen. Finally of all the treatments tested, the best reductions were achieved for the combined dome and windscreen system.

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REFERENCES