Sub-surface windscreen for the measurement of outdoor infrasound

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A windscreen has been developed that features two advantages favorable for the measurement of outdoor infrasound. First, the sub-surface location, with the top of the windscreen flush with the ground surface, minimizes the mean velocity of the impinging wind. Secondly, the windscreen material (closed cell polyurethane foam) has a sufficiently low acoustic impedance (222 times that of air) and wall thickness (0.0127 m) to provide a transmission coefficient of nearly unity over the infrasonic frequency range (0-20 Hz). The windscreen, a tightly-sealed box having internal dimensions of 0.3048 x 0.3048 x 0.3556 m, contains a microphone, preamplifier, and a cable feed thru to an external power supply. Provisions are made for rain drainage and seismic isolation. A three-element array, configured as an equilateral triangle with 30.48 m spacing and operating continuously in the field, periodically receives highly coherent signals attributed to emissions from atmospheric turbulence. The time delays between infrasonic signals received at the microphones permit determination of the bearing and elevation of the sources, which correlate well with locations of pilot reports (PIREPS) within a 320 km radius about the array. The test results are interpreted to yield spectral information on infrasonic emissions from clear air turbulence.

INTRODUCTION

A fundamental difficulty in the detection of outdoor infrasound is the so-called "wind noise" problem. Because of ever-present wind-generated turbulence, the atmosphere is inherently noisy at frequencies of interest (typically between 0.1 and 20 Hz). Accordingly, effective wind screening is vital to the success of outdoor infrasonic measurements. Past methods of screening a microphone from the wind include a piped array, a barrier, or an open-mesh (e.g., cloth or foam enclosure).

Over the years, researchers at NASA Langley have developed and field tested different types of compact and structurally sound windscreens [1-4]. The windscreen principle is based on the high penetrating capability of infrasound through barriers, which is dependent upon the acoustic impedance ratio (wall-to-air) and wall thickness. Initially a family of windscreens as shown in Figure 1 were developed having an internal diameter of 0.0762 m (3 in.), internal depth of 0.23 m (9 in.) and wall thicknesses of 0.01905, 0.0127, and 0.00635 m (3/4, ½, and ¼ in.) respectively. Such windscreens were used in the field as shown in Figure 2. Though this method

was moderately successful, to eliminate wind flow, an advanced version of a nonporous windscreen called "sub-surface windscreen" was designed and developed. Following a description of the sub-surface windscreen, the principle of operation, and the experimental method, experimental data are presented.

FIG. 1. The family of tested windscreens.

FIG. 2. Infrasonic windscreen in field service

The principle of the windscreen is based on the great penetrating capability of infrasound through matter. Consider the model shown in the lower left corner of Figure 3. The sound power transmission coefficient from medium 1 to medium 3 is

$$|T| = \frac{1}{\cos^2 x + \frac{1}{4}\left(\frac{Z_2}{Z_1} + \frac{Z_1}{Z_2}\right)^2 \sin^2 x} \quad \text{where} \quad x = \frac{2\pi f W}{c_2}$$

and f is the frequency, W the wall thickness, Z_1 the acoustic impedance of air, Z_2 the acoustic impedance of the wall material, and c_2 the speed of sound in the wall. The transmission coefficient for a ½" –wall, made of a material with very low specific acoustic impedance (222 times that of air, as in closed-cell polyurethane foam) transmits low-frequency sound with practically unity transmission coefficient. For reference, a ½" –wall made of steel (specific impedance ratio = 113 253), passes only the far infrasound.

The second feature makes use of the fact that the horizontal wind speed approaches zero near the Earth's surface. Figure 4 shows the vertical profile of the horizontal wind, having a magnitude of 10 m/s at a height of 10m. The logarithmic profile is based on a scale length of 0.01 m (short grass), at which height the model specifies a zero wind speed.
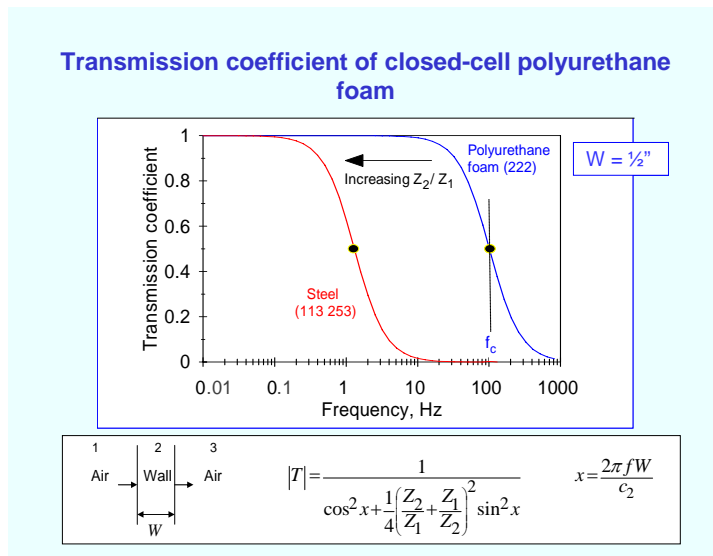

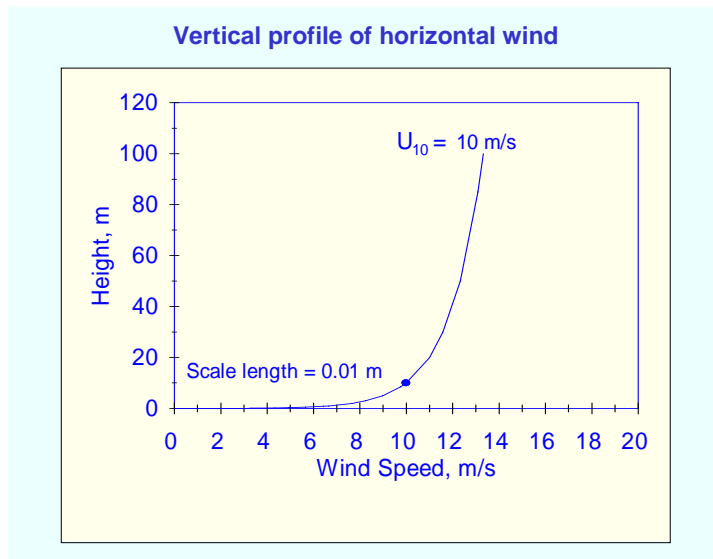FIG. 3. Transmission coefficient of closed-cell polyurethane foam

FIG. 4. Vertical profile of horizontal wind

Figure 5 is a sketch of the windscreen installed in a hole below the ground surface. The windscreen is in the shape of a box of dimensions shown and of wall thickness ½". The material is closed-cell polyurethane foam ("eight-pounder"), which passes propagating infrasound, as described above, but prevents convected pressure fluctuations from reaching the interior microphone. The lid of the box fits tightly snug. The box is surrounded by drainage rock, from which rain water passes through into a drainage pipe. The wall material is impervious to water. The microphone is a B&K type 4193 with a low-frequency adapter.
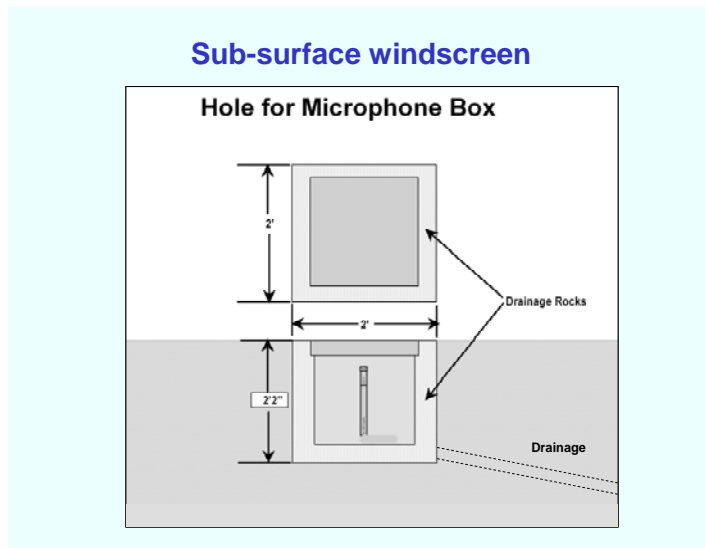

FIG. 5. Hole for Microphone Box

Figure 6 is a photograph of the windscreen installed in to the ground. The microphone is fitted with a rain cover, although we never had a single case of rain leaking into the box, and is fixed to a plate, which rests upon packing material for seismic isolation. The microphone cable passes through a tightly sealed feedthru.

FIG. 6. Sub-surface windscreen

Figure 7 is a satellite image of a three-element microphone array installed in the field at Langley Research Center. The array consists of three stations, arranged in an equilateral triangle spaced 100 ft. (30.48 m) apart. The red lines show drainage conduits to a drainage ditch surrounding the array site. The microphone power supplies are housed in a central control box, which also contains a weather station. The microphone output cables pass through a conduit to a control room about 200 ft (60.96 m) away. The control room contains the data acquisition system.
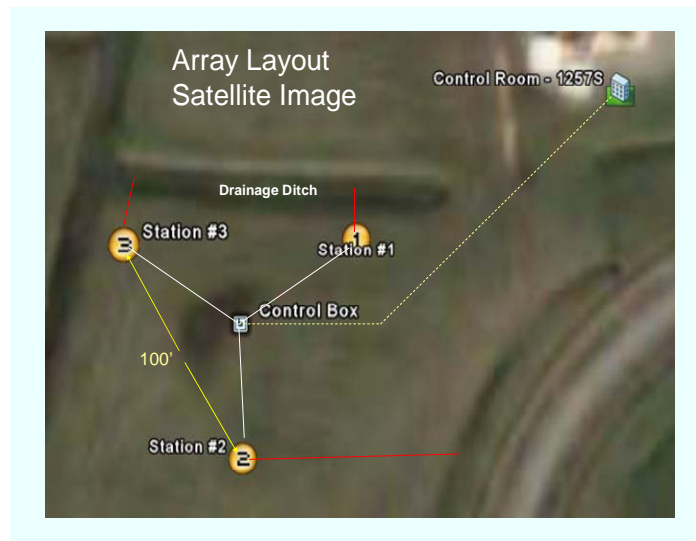

FIG. 7. Satellite image of a three-element microphone array

The microphone array operated continuously in the field during the latter part of 2006. Data were collected from a variety of sources – a situation that prompted the establishment of the following criteria for the association of received infrasound with a designated source:

(1) Concomitancy. When the source is present, signals must be received. When the source is absent, the signals must disappear. As a corollary, if the location of the source is known, then the time of arrival must correspond to the source-microphone separation.
(2) Directionality. Signals must arrive from the direction of a known source.
(3) Characteristic signature. Signals must conform to the signatures of a known source. This criterion will be difficult to fulfill for the detection of infrasonic emissions from clear air turbulence, for the spectrum of the latter is unknown.
(4) Signals must appear identical on all microphones in the array. In other words, the coherence among microphone pairs must be high.

The data sampling interval was 30 s at 200 samples per sec. A data file block comprised 6 h of data, thus a sample population of 360/0.5 min = 720 sample blocks. Figure 8 shows a typical 30-s snapshot on a day when coherent signals were received on the microphone array. It is noted that the signals appear to be similar on all three channels, indicating that they represent the propagation of sound across the array. Since the maximum delay from one microphone to another is 0.1 s, the resolution on the figure is too coarse to observe a delay; but a 200 Hz sample rate affords good resolution in determining the time delays, from which the angle of incidence is determined.
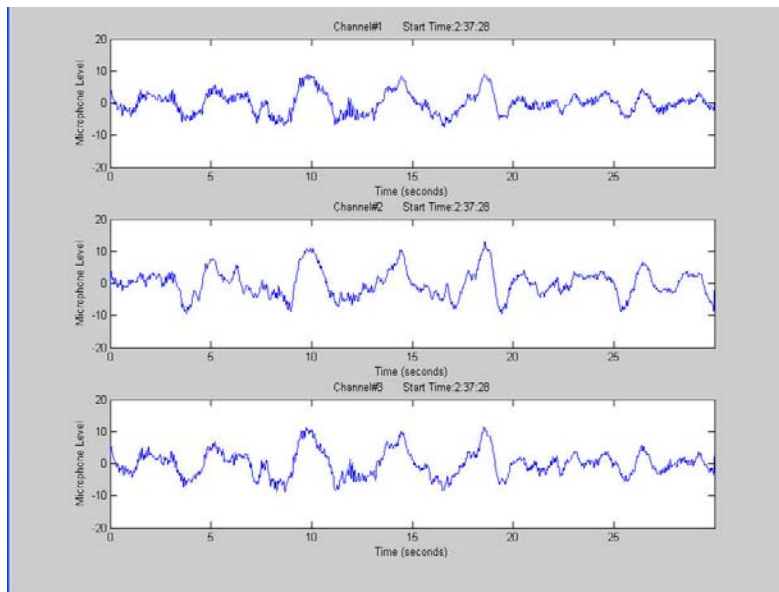

FIG. 8. Received infrasonic signals on 08/24/06 (0.2-4 Hz)

The incoming signals were filtered over the passband 0.2-4 Hz. The coherence over a six-hour data block is shown in the figure 9. The coherence is the geometric mean of the three microphone pairs. The ordinate is frequency and the abscissa is the time, spanning 360 min (i.e.

six-hour block). The coherence is color coded: blue representing low coherence and red representing high coherence. The high coherence from zero to 70 min has not been explained. The high coherence from 150-360 min is interpreted to represent signals emitted from atmospheric CAT. Note that the coherence cuts off at frequencies beyond the passband of the filter and that the coherence appears to be intermittent, as to be expected from a CAT source.
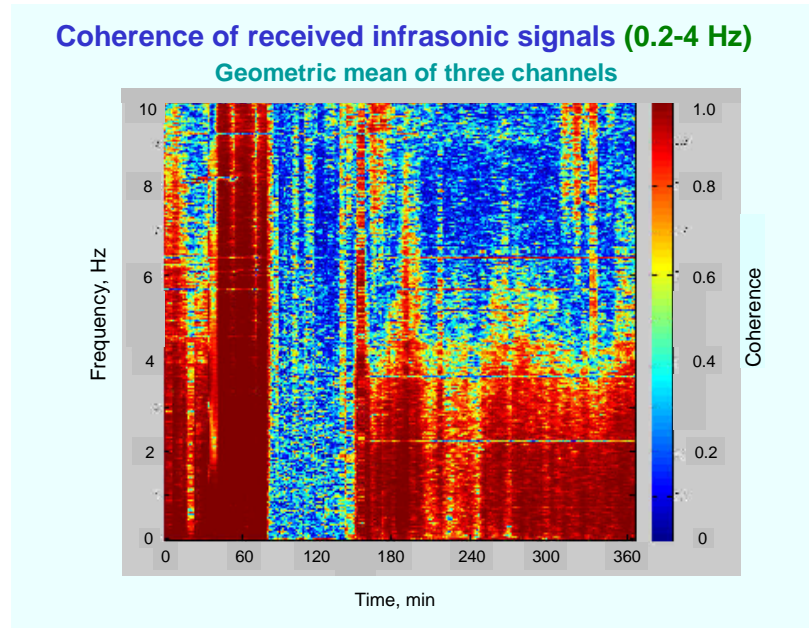

FIG. 9. Coherence of received infrasonic signals (0.2-4 Hz)

Figure 10 shows the bearing angles of the received infrasound, as determined from the time delays among the microphone pairs. Over the six-hour period of the data block signals are found coming from two direction: the first set at an angle near 0^0 (North) and the second just shy of 180^0 (slightly Southwest).
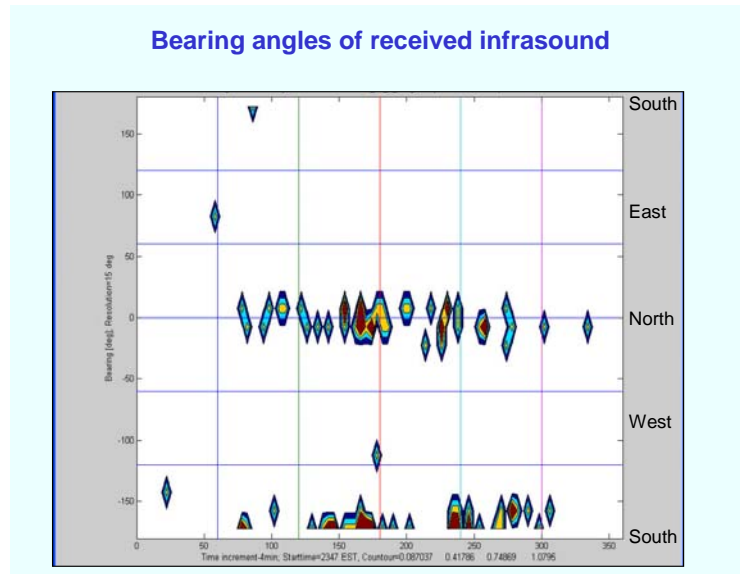
FIG. 10. Bearing angles of received infrasound

The figure 11 is based on a map of the map-Atlantic region. Pilot reports (PIREPS) are indicated by circles, which are color coded: blue, green, and red indicating light, moderate, and severe turbulence respectively. The directions of the received infrasound are indicated by the pink sectors, the spatial resolution of the directionality being $+/-7.5^0$. Note the PIREP indicating severe turbulence within the northern sector. The correspondence between the PIREP location and the infrasound bearing angle offers support for the hypothesized emissions of infrasound from CAT.
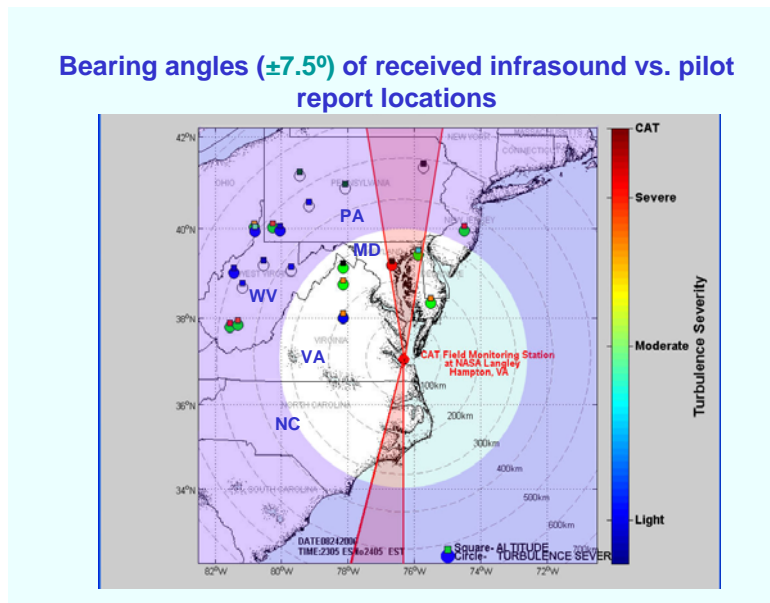

FIG. 11. Bearing angles of received infrasound vis. Pilot report locations

CONCLUSIONS

The measurements reported in this study lead to the following conclusions:
  (1) The sub-surface windscreen concept proved successful in suppressing wind noise.
  (2) Hypothesized infrasonic emissions from CAT were identified, located, and corroborated with PIREPS.
  (3) Three of the four acceptance criteria were fulfilled
    - Concomitancy: The reception of coherent infrasonic signals occurred simultaneously with PIREPS, indicating the presence of CAT.
    - The direction of the received infrasound corresponds to the PIREP locations.
    - The coherence among the three microphone pairs was high.
    - The characteristic signatures of emissions from CAT remain unidentified but will be the subject of future investigation.

ACKNOWLEDGMENTS

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