Collection of Infrasonic Sounds from Sources of Military Importance

August 18, 2008

Michael Masterman
Extreme Endeavors, 492 Hickory Corner Road, Philippi WV 26416

Qamar A. Shams and Cecil G. Burkett
NASA Langley Research Center, Hampton, VA 23681

Allan J. Zuckerwar
Analytical Services and Material, Hampton. VA 23681

Craig Stihler and Jack Wallace
West Virginia Division of Natural Resources, Elkins, WV 26241

Abstract

Extreme Endeavors is collaborating with NASA Langley Research Center (LaRC) in the development, testing and analysis of infrasonic detection system under a Space Act Agreement. Acoustic studies of atmospheric events like convective storms, shear-induced turbulence, acoustic gravity waves, microbursts, hurricanes, and clear air turbulence (CAT) over the past thirty years have established that these events are strong emitters of infrasound [1]. Recently NASA Langley Research Center has designed and developed a portable infrasonic detection system which can be used to make useful infrasound measurements at locations where it was not possible previously, such as a mountain crag, inside a cave or on the battlefield. The system comprises an electret condenser microphone, having a 3-inch membrane diameter, and a small, compact windscreen.

Extreme Endeavors will present the findings from field testing using this portable infrasonic detection system. Field testing of the infrasonic detection system was partly funded by Greer Industries and support provided by the West Virginia Division of Natural Resources. The findings from this work illustrate the ability to detect structure and other information about the contents inside the caves. The presentation will describe methodology for utilizing infrasonic to locate and portray underground facilities.

1. Introduction

Extreme Endeavors has collaborated with NASA LaRC in its Innovative Partnership Program to perform field testing using NASA Langley's portable infrasonic detection system. The primary aspect of Space Act Agreement (SAA789-1) was to detect infrasonic signals at the entrance and deep inside limestone caves of similar structure to those found in Afghanistan. The secondary research goal was to investigate other possible applications mentioned in the literature over the past thirty years. The support for field testing of the portable infrasonic detection system was provided by Greer Industries while site selection and access was provided by West Virginia Division of Natural Resources.

The portable infrasonic detection system developed at NASA Langley differs from that of a conventional infrasonic detection system in that the peculiar features of infrasound are taken into account. First, infrasound propagates over vast distances through the Earth's atmosphere as a result of very low atmospheric absorption and refractive ducting that enables propagation by way of multiple bounces between the Earth's surface and the stratosphere. A second property that has received little attention is the great penetration capability of infrasound through solid matter – a property utilized in the design and fabrication of the system windscreens.

Extreme Endeavors has recorded and analyzed infrasonic measurements at such locations where it was not previously possible. Some of the measurements are presented in this paper.

2. Laboratory Testing

The air pressure at the entrances of caves changes due to pressure cycles created in the environment, forcing air into and out of the underground facility. While variations of this draft occur throughout the day based on many factors, it is impossible to turn off the air flow into or out of a naturally formed cave without drastic measures. To imitate what should be seen in the field, testing was performed with a building ventilation system. The size of the room, with multiple vents, is approximately the size of the entrance to schoolhouse cave, one of our test subjects. This allowed us to switch the airflow on and off, and see the effect on the sensor. This was critical to understanding what the readings meant and the ability to repeat a standard measurement to insure the instrumentation was working properly throughout the duration of our research.

We found the low frequency noise created by the ventilation system, shown in Figure 1, to be similar to the low flow of air being pushed into and out of a cave. Two data sets were taken, each for a three-minute interval. The first data set was taken with air circulating through the vents and the second data set taken with no air circulation.

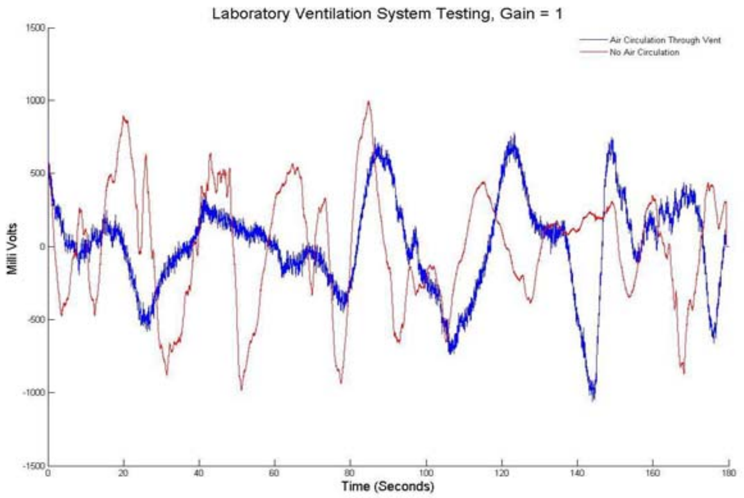

Figure 1: Infrasonic Measurement of Air flow into a Large Room

For further analysis, an FFT of this data was calculated and is shown in Figure 2. This shows a substantial increase in noise power in the frequency range of .6 to 5 Hertz. There may be several spectral lines embedded in this noise; we can definitely see spectral lines at 8.8 Hertz and 6.4 Hertz. Overall increment of spectral noise power can be seen around 8 Hertz.

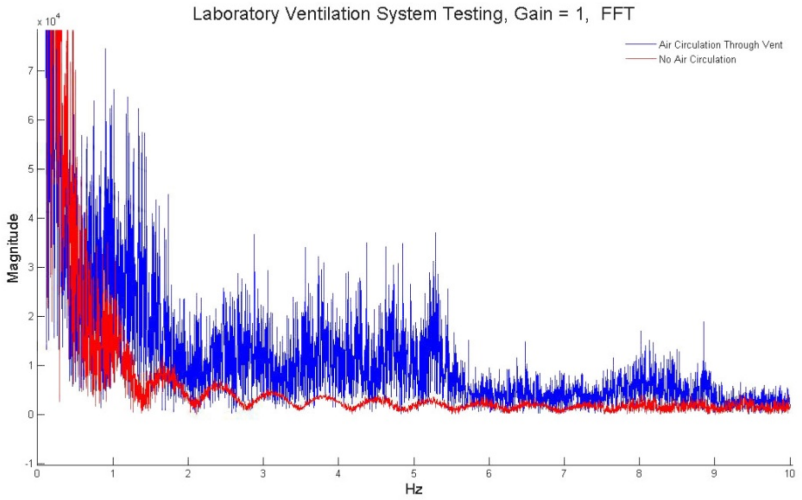

Figure 2: FFT of Infrasonic Data from Building Ventilation System

3. Schoolhouse Cave

The first cave to be sampled was Schoolhouse Cave (See figure 3). This cave has a large entrance that is gated by several bulky horizontal laid pieces of angle iron.

The Schoolhouse cave data set is shown in Figure 4. The FFT of this data shows the noise quickly damping out around .5 Hertz, but returning around 1 Hertz, and leads to a similar noise structure as seen by the air flow through the building ventilation system. This noise has an increased power spectral density around 1.8 Hertz, 5 and 6.5 Hertz and spectral lines at 8.7 Hertz and 3.7 Hertz.

Figure 3: Entrance to Schoolhouse Cave and Infrasonic Detector

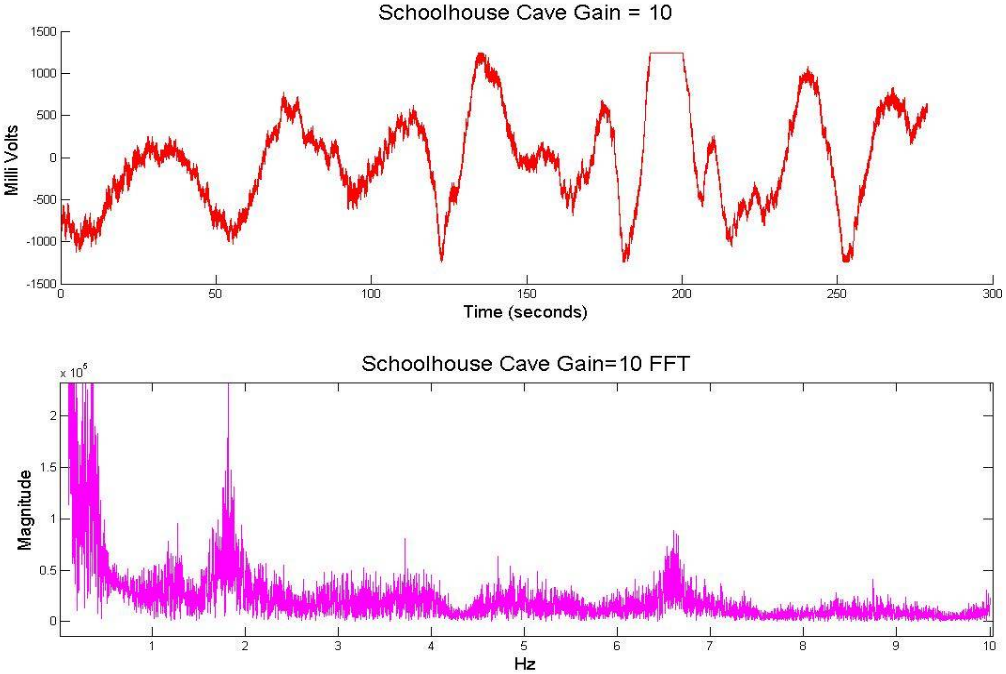

Figure 4: Infrasonic Data Taken From the Entrance of Schoolhouse Cave

4. Cass Cave

Cass Cave was selected as another test subject due to having a medium size entrance (about the size of a standard door); however, there is a stream flowing into the entrance which may affect the data. The stream travels approximately 1/2 mile underground where it falls 180 feet. This cave is far removed from civilian activity which could create interference to our test as this cave is only accessed by traveling a significant distance into a ravine. This entrance is pictured in Figure 5.

The data recorded from the entrance of Cass Cave is shown in Figure 6. In the FFT we find considerably more noise than in other samples from caves; we attribute this to the small waterfall going into the entrance of this cave. The acoustical signature of Cass Cave appears to reduce in noise at about 3.7 Hertz and we are able to see spectral lines at 3.3 Hertz and 7.4 Hertz.

Figure 5: Cass Cave Entrance

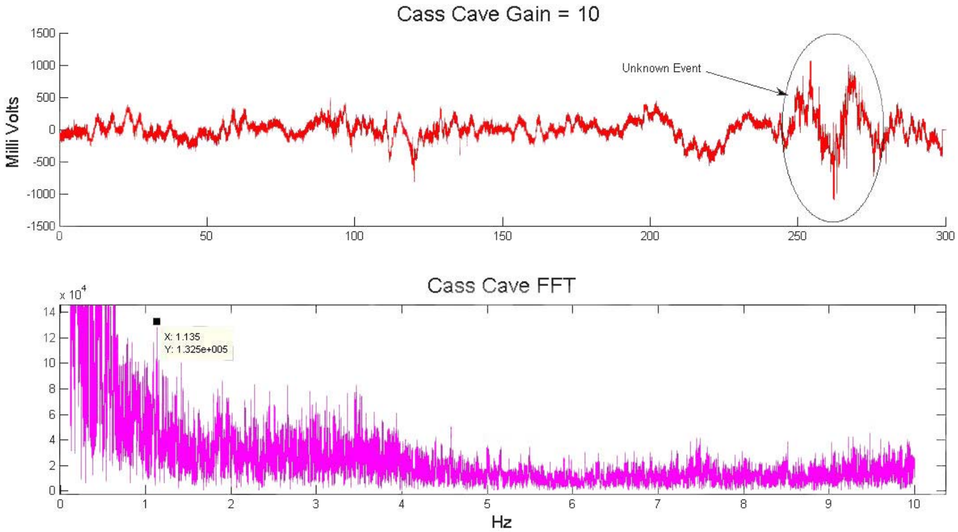

Figure 6: Infrasonic Data Taken from the Entrance of Cass Cave

5. Cassel Cave

Infrasonic data sampled from one of the four entrances of Cassel Cave, known as the Windy Entrance, is shown in Figure 7. This entrance is the smallest of entrances sampled among our initial group. As shown in the picture, any object larger than the sensor and windscreen would have difficulty entering the entrance. While most military operations would not use an entrance this small, this shows the data that would be acquired with an entrance that was concealed.

The infrasonic recording from Cassel Cave, shown in Figure 8, illustrate clearly visible spectral lines at specific frequencies (9.3 Hertz and .9 Hertz), noise which is filtered between two and three Hertz, and is much more gradual of a roll off than other caves sampled.

Figure 7: Cassel Cave; Windy Entrance

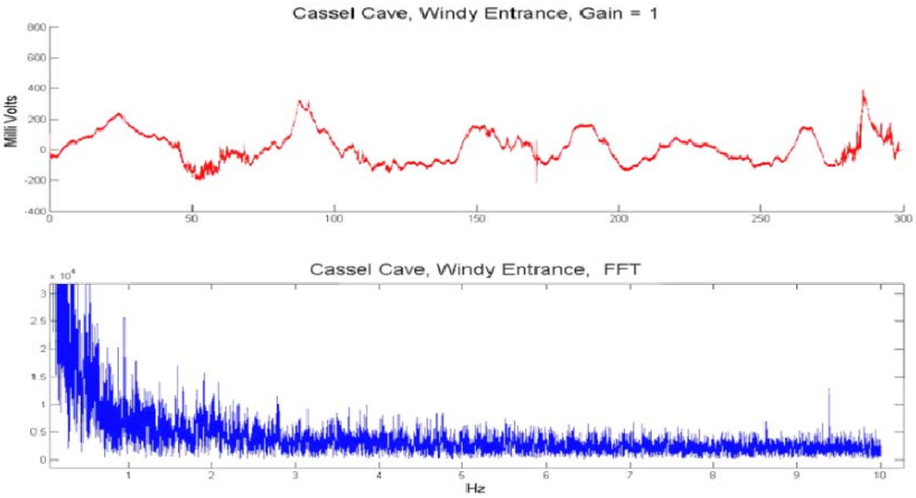

Figure 8: Infrasonic Data Taken from the Windy Entrance of Cassel Cave

6. Summary of all three Caves

The primary reason for selection of the three caves was the difference in geometry and physical size of the entrances. An FFT and a power spectral density of all three caves is shown in Figure 9 and 10 respectively. The data illustrates that the noise made from the draft sound is dependent on the size of the cave entrance.

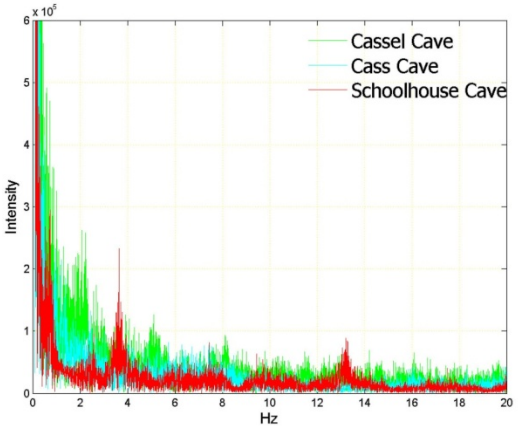

Figure 9: Frequency Domain of Infrasonic Signals Received from the Three Caves in our Test

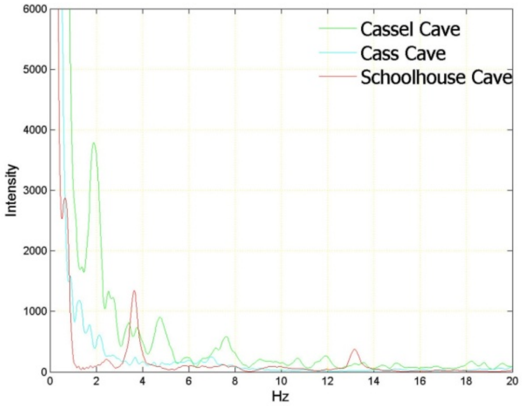

Figure 10: Power Spectral Density of the Infrasonic Signal Received from the Three Test Caves

7. West Virginia National Guard Memorial Tunnel

With dependency of noise spectrum on entrance size as shown in Figure 9 & 10, we tested an underground facility that was more uniform in shape and not a naturally formed cave. This would be similar to a mine or a bunker that was dug to hide equipment and personnel. The West Virginia National Guard Memorial Tunnel, used for military and first responders training is 2800 feet in length. The tunnel has two-lane highway, 23 feet wide with a ventilation system and doors at each end. With no traffic and the ability to control the air flow we found this tunnel to be an ideal test subject.

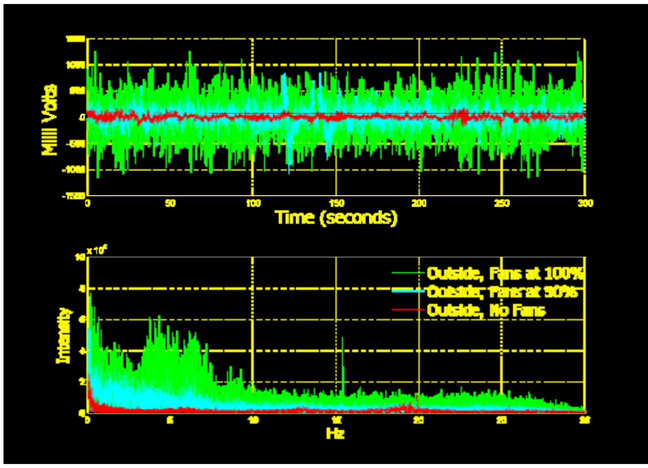

Figure 11: Infrasonic Measurement at the tunnel entrance

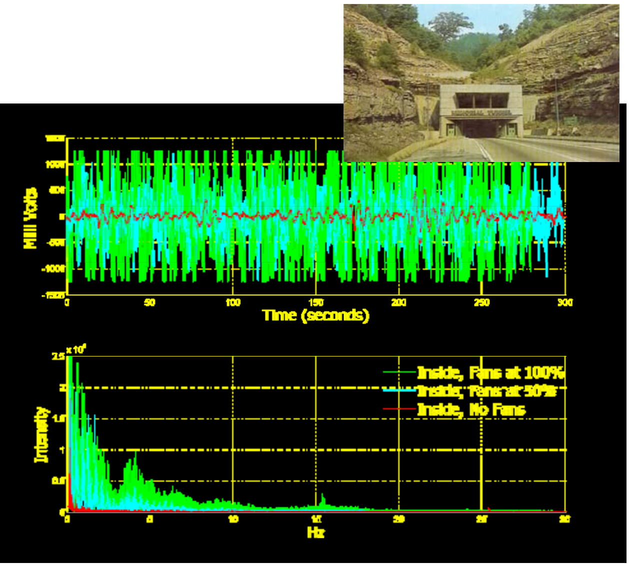

Figure 12: Infrasonic Measurement Inside the tunnel

8. “My” Cave

Infrasonic measurements from “My” cave, located in Randolph County, West Virginia were taken from both inside and outside of the cave. The FFT of the data, shown in figure 13, shows significantly more power than any other cave. This warranted us to venture into the cave and take data approximately ¼ of a mile underground. The readings found inside of “My” cave saturated the sensor such that the gain had to be reduced.

“My” cave is well known for a river passage about ¾ of a mile into the cave. The sensor was located in a large fissure passage (approximately 50 feet high but very narrow). This fissure passage connects to the river passage to where the sensor was located. The smaller size of the entrance (six-foot-diameter hole in the ground) was acting as a filter, similar to the effect seen in the West Virginia Memorial Tunnel. This effect is similar to that seen by someone trying to conceal a cave or underground facility.

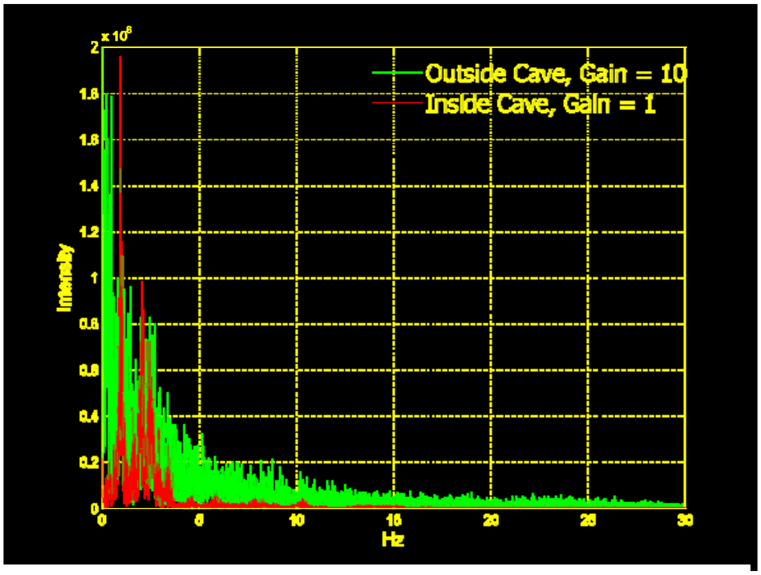

Figure 13: "My" cave FFT of Infrasonic Data,
Note: the gain difference in the two data sets by a factor of ten

9. Simmons Mingo Cave System

The next series of measurements was completed using Simmons Mingo cave system which is one of the most hazardous and difficult caves, with several miles of passages that include significant vertical drops, pits, and large chambers. This testing involved taking infrasonic measurements on the outside of the cave, down a forty-foot drop and approximately ¼ of a mile back in the cave. Figure 14 shows the FFT of the measurements. Both readings were taken inside the cave only minutes apart. This revealed two different spectrums for the same location. Two sections of Figure 14 are highlighted to show these differences.

We can explain this different spectrum as the sound of turbulence or pockets of varying temperature air being expelled from the cave. Extreme Endeavors provides environmental cave monitoring for Greer Lime. This monitoring has shown pockets of warm air being pulled out of Schoolhouse cave through observation of the temperature and pressure of the caves passages. Special instrumentation developed by Extreme Endeavors is used to perform this measurement, with extremely precise and high resolution sensors developed specifically for monitoring of underground environments.

A smooth structure such as in a mine or manmade underground facility will show fewer warm and cold air pockets being expelled during the underground facilities expulsion of air. We can therefore conclude that even, straight manmade structure will have a more stable the spectrum than a cave since there would be less turbulence.

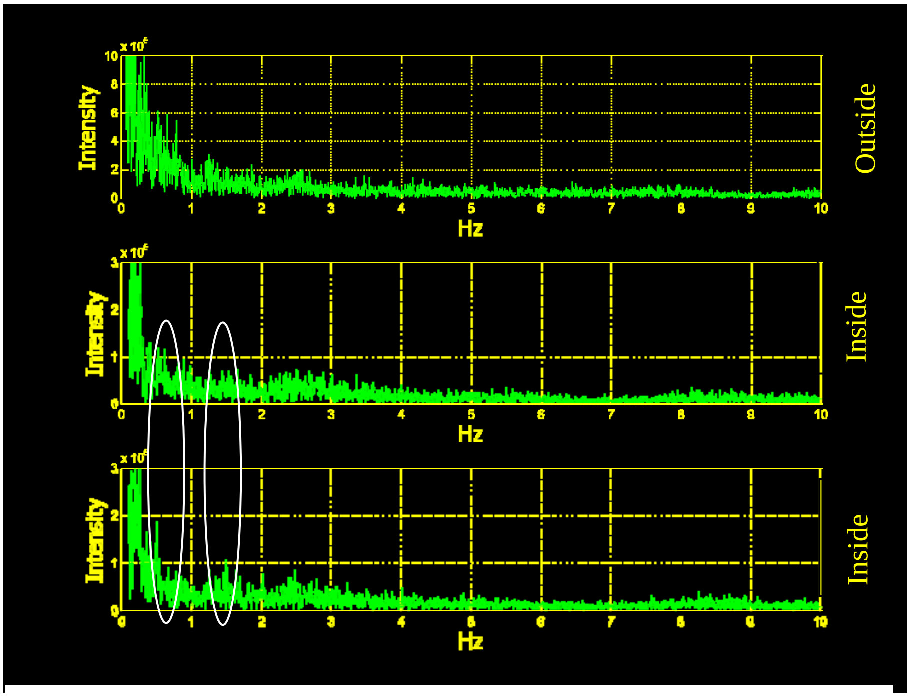

Figure 14: Simmons Mingo Cave, Data samples from outside the entrance and from several hundred feet inside the cave

10. Caves of Biological Importance

Extreme Endeavors has performed testing for the West Virginia Division of Natural Resources to sample noise levels from different caves around the state. These caves are of significant importance due to endangered species of bats either roosting or using the caves as a hibernacula. This data was taken as a baseline for performing comparisons between bat populations and the sounds created from the caves. This research is ongoing, with the infrasonic readings from approximately 20 caves around the state.

11. Human Gait

Infrasound is a powerful tool for detecting human movement. Due to very low background noise of the portable infrasonic detection system we were able to measure spectrum of human gaits. Figure 15 shows the FFT of infrasonic measurements from a 38-year-old male and a 24-year-old female (bottom) walking in a room. The top spectrum reveals two pronounced peaks: a stationary high frequency peak and a Doppler-shifter low-frequency peak, both as a result of the gait.

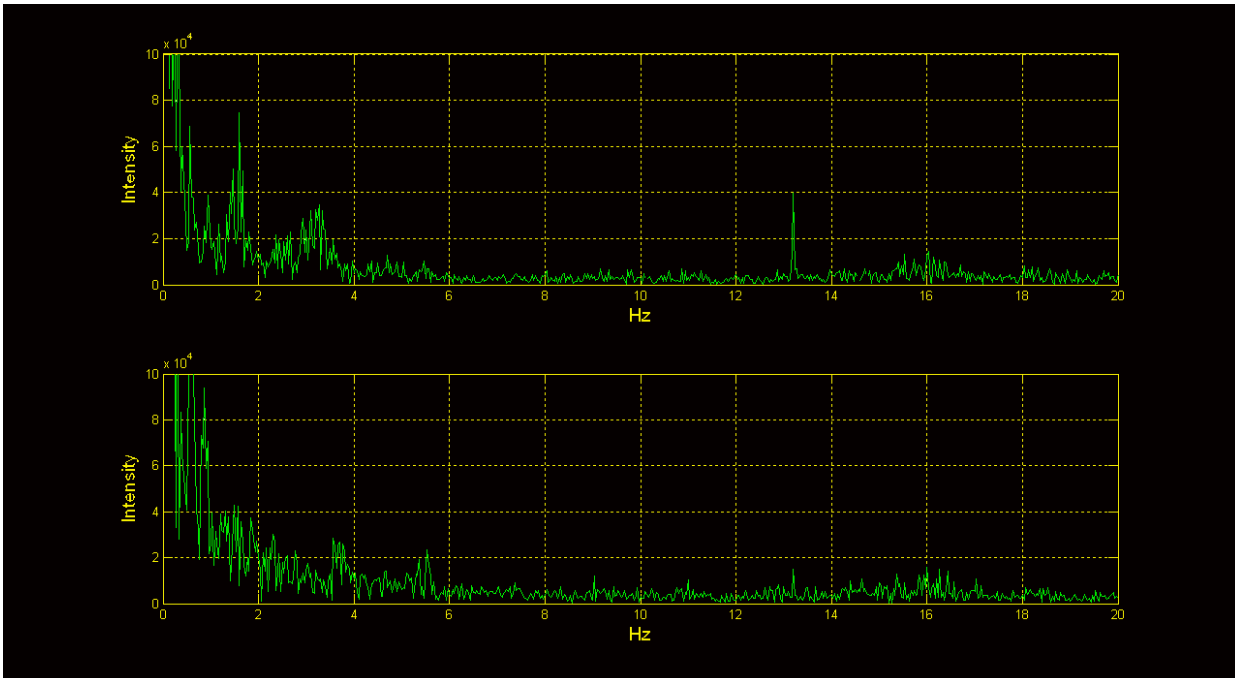

Figure 15: FFT of Infrasonic Recording taken from a 38-year-old Male (top) and a 24-year-old Female (Bottom)

12. Vehicles

During infrasonic measurements from the vehicles, we recorded the data of different vehicles passing by. The measurements show that the each vehicle has unique infrasonic signatures. The measurements can provide useful information such as rate of travel, body style, make and model of a vehicle. Additional measurements are underway to identity signatures of the vehicle make and model. One such measurement is shown in Figure 16.

The sensor is ideal for traffic counting and speed detection. Detectors could be inconspicuously set around a region and provide feedback to law enforcement as to what region of roadway to target for speeding. Also there is a significant application for the use of Urban to Rural evacuation initiative such as evacuation of Washington DC through the outside rural regions. In addition, measurements are underway to further classify the spectrums of passing vehicles to determine the feasibility of utilization of this sensor as an identifier of vehicles.

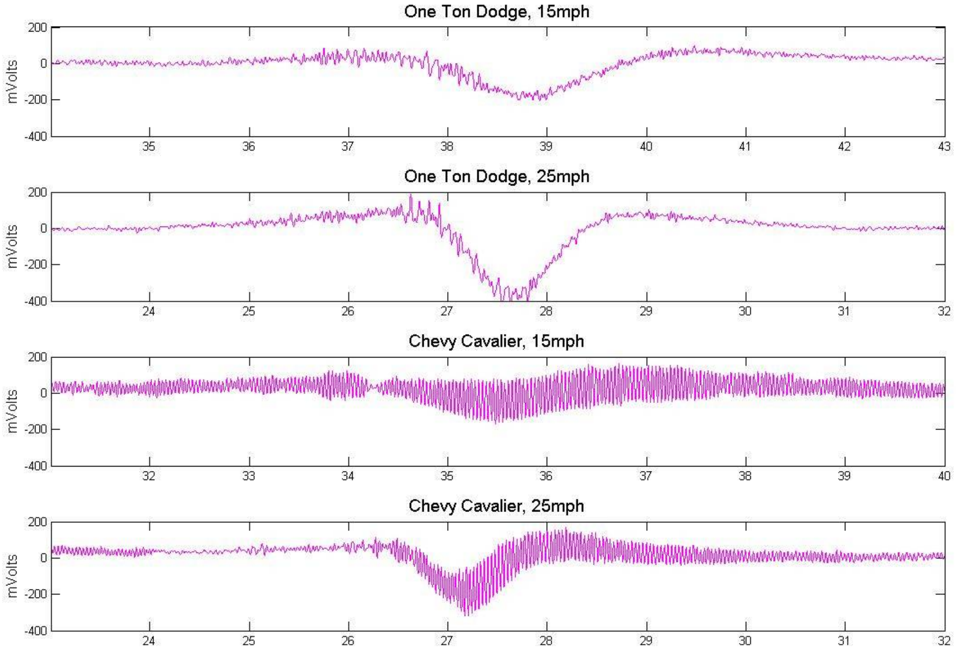

Figure 16: Infrasonic Measurement of Vehicles Passing

13. Fire

One significant measurement was the detection of infrasonic emissions from a small fire. A small brush pile, measuring 4 feet in diameter and 3 feet tall was ignited; Figure 17 shows data recorded from three different measurements; first, before the fire was ignited to measure background noise, second one was during the initial stages of the fire and third one when the fire was in the free burning stage. The plot shows the FFT of the measurements, showing considerably broad- band, low-frequency noise signals coming from the fire. Figure 18 shows a calculation of power spectral density, which shows considerable growth between the incipient and free burning stage of the fire. The growth pattern can be used to determine development stage of a fire. The power spectral density and frequency measurement of burning fire can be used to better understand the size and location of the fire.

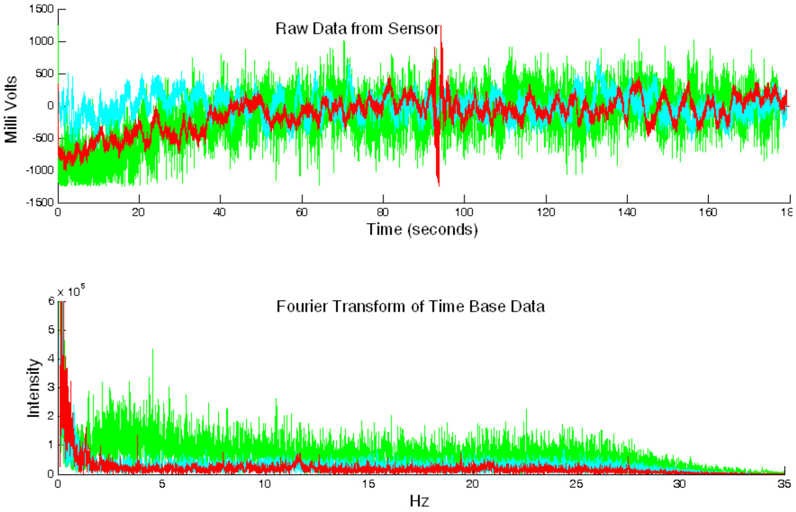

Figure 17: Data Recorded Showing the Infrasonic Emission of a Fire

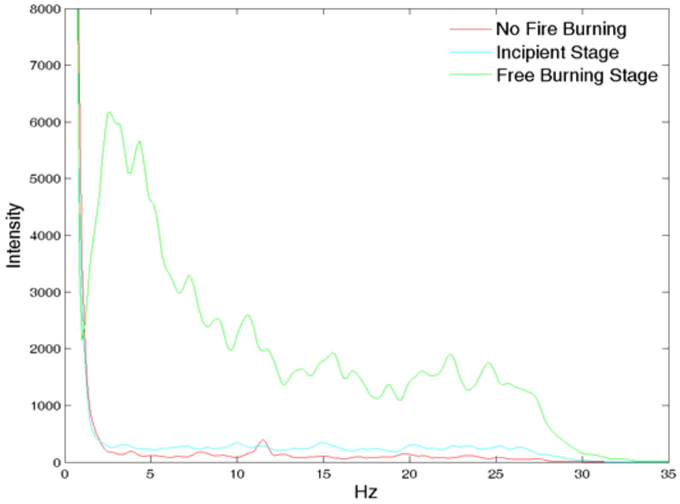

Figure 18: Power Spectral Density Calculation of Fire Emission of Low Frequency Sound

14. Conclusion

The portable infrasonic detection system developed at NASA Langley Research Center can be used to make useful infrasound measurements at a location where it was not possible previously. Extreme Endeavors Inc. has used the system for infrasonic measurements from numerous locations including caves, tunnels, and human gaits. Further investigation is required to correlate infrasonic signals from various military-related sources. In addition to the sources listed in this paper, the portable infrasonic detection system has potential to detect sonic boom, CATS, and tornados at early stage.

15. References

1. A.J.Bedard Jr. and T.M.Georges, “Atmospheric Infrasound,” Physics Today 53, 32-37 (2000).
2. A. J. Zuckerwar, Q. A. Shams, and J. W. Stoughton; Creativity & Innovation Program, NASA Langley 2002 “ Infrasonic Detection of Severe Storms & Clear Air Turbulence”.
3. Q. A. Shams and A. J. Zuckerwar; Innovative Partnership Program, NASA Langley January 2006 “Extreme Low Frequency Acoustic Measurement system for Planetary Subterranean, Seismic, and Environmental Detection System”.
4. Christopher C. Lawrenson, Allan J. Zuckerwar, and Qamar A. Shams; “Low Frequency Electret Condenser Microphone”, 154th Meeting of the Acoustical Society of America New Orleans, LA Nov. 27 – Dec. 1, 2007.
5. Q.A. Shams, A.J. Zuckewar, and B.S. Sealey, “compact nonporous windscreen for infrasonic measurements”, J. Acoust. Soc. Am. 118, 1335-1340 (2005).
6. Allan J. Zuckerwar, Qamar A. Shams, Krish K. Ahuja, and Robert Funk, “Soaker Hose vs. Compact Non-Porous Windscreen: A Comparison of Performance at Infrasonic Frequencies”, 150th Meeting of the Acoustical Society of America Minneapolis, MN, October 17-21, 2005.