Defense Systems Information Analysis Center

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Research Efforts in Infrasound

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MAIN OFFICE

4695 Millennium Drive

Belcamp, MD 21017-1505

443-360-4600

REPORT PREPARED BY:

Taylor H. Knight

Office: DSIAC

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14. ABSTRACT
The Defense Systems Information Analysis Center (DSIAC) was asked to identify key contributors to Department of Defense research efforts in the area of infrasound. Infrasound is classified as sound waves with frequencies lower than 20 hertz (Hz) cycles per second. A variety of things produce infrasound, including natural disasters and animals. Sources of infrasound are in the range from very low-frequency atmospheric fluctuations up into the lower audio frequencies. DSIAC searched open source documents and the Defense Technical Information Center's repository for relevant information, which was compiled into a report and delivered to the inquirer. Key contributors were organized by government, academia, and industry, followed by a summary of the research being conducted by each organization. Key government research contributors are the Non-Lethal Weapons Program, United States (U.S.) Naval Research Laboratory, U.S. Army Research Laboratory, Earth System Research Laboratory, Langley Research Center, and Los Alamos National Research Laboratory. Academic research contributors are Oklahoma State University, University of Alabama's Severe Weather Institute, University of California San Diego, University of Hawaii, and University of Alaska Fairbank's Geophysical Institute. A key industry contributor is BBN Technologies.

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The Defense Systems Information Analysis Center (DSIAC) is a DoD IAC sponsored by DTIC to provide expertise in nine technical focus areas: weapons systems; survivability and vulnerability; reliability, maintainability, quality, supportability, and interoperability; advanced materials; military sensing; autonomous systems; energetics; directed energy; and non-lethal weapons. DSIAC is operated by SURVICE Engineering Company under contract FA8075-14-D-0001.

A chief service of the DoD IACs is free technical inquiry (TI) research, limited to 4 research hours per inquiry. This TI response report summarizes the research findings of one such inquiry jointly conducted by DSIAC.

ABSTRACT

The Defense Systems Information Analysis Center (DSIAC) was asked to identify key contributors to Department of Defense research efforts in the area of infrasound. Infrasound is classified as sound waves with frequencies lower than 20 hertz (Hz) cycles per second. A variety of things produce infrasound, including natural disasters and animals. Sources of infrasound are in the range from very low-frequency atmospheric fluctuations up into the lower audio frequencies. DSIAC searched open source documents and the Defense Technical Information Center's repository for relevant information, which was compiled into a report and delivered to the inquirer. Key contributors were organized by government, academia, and industry, followed by a summary of the research being conducted by each organization. Key government research contributors are the Non-Lethal Weapons Program, United States (U.S.) Naval Research Laboratory, U.S. Army Research Laboratory, Earth System Research Laboratory, Langley Research Center, and Los Alamos National Research Laboratory. Academic research contributors are Oklahoma State University, University of Alabama's Severe Weather Institute, University of California San Diego, University of Hawaii, and University of Alaska Fairbank's Geophysical Institute. A key industry contributor is BBN Technologies.

Contents

1.0 TI Request

1.1 INQUIRY

Who are the key contributors to Department of Defense (DoD) research efforts in the area of infrasound and what are their contributions?

1.2 DESCRIPTION

Key government, academia, and industry contributors in the area of infrasound research were identified and their efforts were summarized.

2.0 TI Response

Infrasound is classified as sound waves with frequencies lower than 20 hertz (Hz) cycles per second. A variety of things produce infrasound, including natural disasters and animals. Sources of infrasound are in the range from very low-frequency atmospheric fluctuations up into the lower audio frequencies. The DoD has been researching infrasound for a variety of reasons, which are explained in more detail throughout this report.

2.1 GOVERNMENT RESEARCH EFFORTS

2.1.1 Non-Lethal Weapons (NLW) Program

The research based on infrasound that has been conducted in the NLW program is the same type of science that surgeons use to break up kidney stones. It also is the same science China is using to disperse crowds nonlethally [1].

2.1.2 United States (U.S.) Naval Research Laboratory (NRL)

The NRL has embarked on several research projects in the area of infrasound. As part of the Geospace Science and Technology Branch of the Space Division, the NRL has multiple objectives relating to infrasound propagation. The division aims to specify and understand how the natural variability of the atmosphere from minutes to days influences regional to long-range, low-frequency acoustic propagation [2]. Other objectives are to advance the fundamental understanding of acoustic propagation in the atmosphere and to understand the influence of acoustic waves on the atmosphere and ionosphere. The final objective is to improve the U.S. national and international treaty organization capabilities to detect, locate, and characterize infrasound events of interest.

The NRL's approach includes the following:

- Collecting atmospheric data to provide time-dependent, ground-to-space atmospheric specifications for infrasound propagation calculations.
- Developing the next generation of normal mode, parabolic equation method, and Eikonal ray-tracing acoustic-wave propagation codes.
- Validating theoretical calculations using geophysical and man-made infrasound sources.
- Collaborating with experts to improve automated and interactive infrasound network detection algorithms to reduce false-alarm rates and lower detection thresholds.

The NRL also contributed to a 2010 book on infrasound*, Infrasound Monitoring for Atmospheric Studies*. NRL physicist, Douglas Drob of the Upper Atmospheric Physics Branch, published a chapter titled "Inversion of Infrasound Signals for Passive Atmospheric Remote Sensing." Recent research has suggested infrasound can be used for atmospheric remote sensing [3].

The NRL has also researched the performance of automated infrasound event association and source location algorithms. They suggested that these algorithms could be improved by the ability to continually update station travel-time curves to properly account for the hourly, daily, and seasonal changes of the atmospheric state [4]. With the goal to reduce false-alarm rates and improve network detection capabilities, the NRL endeavors to develop, validate, and integrate these improved algorithms into infrasound processing operations at the International Data Centre of the Comprehensive Nuclear Test-Ban Treaty Organization. The next step in the research is to refine numerical procedures to calculate infrasound propagation characteristics for robust automatic infrasound arrival identification and network detection, location, and characterization algorithms.

2.1.3 Earth System Research Laboratory (ESRL)

The ESRL developed and deployed infrasonic instruments for the detection and monitoring of low-frequency sound generated by several important anthropogenic and geophysical processes [5]. ESRL has a strong focus on hazardous geophysical phenomena to improve basic knowledge and early warnings. Theoretical studies have been conducted of infrasonic source mechanisms to optimize systems for detection and identification. One study involved the correlation between infrasound, sprites, and other transient, luminescent phenomena associated with severe weather. Another study involved methods to reduce audible noise using active and passive techniques. Potential research and development include infrasound observations from Peacewig platforms, infrasound measurements of other planetary atmospheres, and ocean wave-generated infrasound with a focus on tsunami detection.

2.1.4 The National Aeronautics and Space Administration's (NASA's) Langley Research Center

NASA's Langley Research Center has developed an infrasonic, polyurethane foam windscreen that is claimed to reduce wind noise by 10–20 decibels (dB) [6]. This windscreen could be used for shielding detectors of clear-air turbulence, which is useful in identifying tornadoes and hurricanes, and for locating vortices in an aircraft's wake.

They also have developed a microphone that detects infrasound [7]. The sensor filters out wind noise that can interfere with detection, while using less power and much less space than currently available solutions. NASA's infrasound sensor can detect tornadoes and clear-air turbulence hundreds of miles away. An array of 30 could cover the entire continental U.S. Aircraft wake vortices can also be detected in real time by microphone arrays placed along an airport runway.

NASA's 2016 Super Pressure Balloon flight from Wanaka, New Zealand, carried the Compton Spectrometer and Imager (COSI) payload, a gamma-ray telescope [8]. Behind one of the COSI's solar panels was the Carolina Infrasound instrument, a 3-kg payload resembling a small Styrofoam ice chest on the outside but with a trio of InfraBSU infrasound microphones on the inside. Infrasound from the stratosphere was continuously recorded for over 2 weeks.

2.1.5 U.S. Army Research Laboratory (ARL)

ARL has researched infrasound, including examining wind-noise suppression for infrasound sensors [9]. The porous hose and pipe arrays often used for wind-noise suppression in long-term infrasound monitoring arrays can be tedious to install and can significantly alter the signals reaching the infrasound sensors. An ideal windscreen, over the frequency band of interest, should preserve all the characteristics of desired signals that reach the sensor, while removing all the wind-generated noise. To improve current infrasound windscreens, two porous and one nonporous fabric domes were investigated for use as infrasound windscreens. Both of the porous domes were found to perform well in preserving signal information and in consistently reducing wind-generated noise reaching the sensor.

2.1.6 Los Alamos National Laboratory (LANL)

LANL has explored infrasound's potential for remotely eavesdropping on industrial areas [6]. In combination, infrasound and seismic waves could yield information about processes occurring at or just below the surface. According to LANL staff scientist Omar Marcillo, modern wind turbines, large fans, pumps, and ventilators in power plants and factories create a seismic-infrasonic din. The signals could give information about activities in a place of interest.

Another LANL project in 2012 researched infrasound sensor calibration and responses [10]. This project supported the capability to perform accurate infrasound sensor calibrations using a piston source and large-volume chamber whose output has been independently determined and for which the error budget has been accurately assessed.

Since the mid-1980s, LANL has operated an infrasound sensor calibration chamber that operates over a frequency range of 0.02−4 Hz. This chamber has provided sensitivities, volts/Pa, for sensors used by LANL and others. The LANL will restore the chamber function, which was interrupted by an unexpected move, collaborate with researchers at the Sandia National Laboratory (SNL) Facility for Acceptance, Calibration, and Testing (FACT) Site on sensor issues, calibrate sensors as needed, and research new methods for sensor response determination.

2.2 ACADEMIA RESEARCH EFFORTS

Research at academic institutions can often result in useful prototypes and knowledge for the DoD. The universities discussed in the following sections are conducting research that may be applicable now or in the future throughout the DoD.

2.2.1 Oklahoma State University

Brian Elbing, a fluid mechanics engineer, began tracking tornadoes with infrasound as a side project. He was able to predict a twister in May 2017, an accomplishment which has increased his research in the area [6].

2.2.2 University of Alabama, Severe Weather Institute

With the University of Mississippi, the University of Alabama's Severe Weather Institute deployed multiple sensor arrays across Northern Alabama capable of observing acoustic signatures in the infrasound (0−20 Hz) acoustic range [11]. The arrays were placed to detect infrasonic emissions hypothesized to be the result of tornadic activity and to track and identify tornadic storms.

2.2.3 University of California (UC), San Diego

UC San Diego is studying the radiation and scattering of sound, with emphasis on low-frequency sounds related to Earth processes [12]. The Laboratory for Atmospheric Acoustics also conducts research in several areas of infrasonics including source studies, propagation modeling, array processing, and wind noise reduction [13]. The Laboratory also operates/maintains two International Monitoring System arrays and three temporary research arrays located along the U.S. West Coast.

An infrasonic sensor was developed using optical fibers as distributed sensing elements [14]. The design addressed the limitations of the standard pipe filters being used at the time, including maximizing the signal-to-noise ratio. The system can help estimate signal azimuth and phase velocity. The advantage of the Optical Fiber Infrasound Sensor (OFIS) is that it measures the pressure variations along its length, not an acoustical sum of the pressure at many points.

UC San Diego has also researched linear and nonlinear infrasound propagation to 1,000 km [15]. The Navier-Stokes equations have been solved using a finite-difference, time-domain (FDTD) approach for axisymmetric environmental models, allowing three-dimensional (3-D) acoustic propagation to be simulated using a two-dimensional (2-D) cylindrical coordinate system. A method to stabilize the FDTD algorithm in a viscous medium at atmospheric densities characteristic of the lower thermosphere has been developed. The stabilization scheme slightly alters the governing equations but results in quantifiable dispersion characteristics. It has been shown that this method leaves sound speeds and attenuation unchanged at frequencies that are well resolved by the temporal sampling rate, but strongly attenuates higher frequencies. Numerical experiments were performed to assess the effect of source strength on the amplitudes and spectral content of signals recorded at ground level at a range of distances from the source. It was shown that the source amplitudes have a stronger effect on a signal's dominant frequency than on its amplitude. Applying the stabilized code to infrasound propagation through realistic atmospheric profiles shows that nonlinear propagation alters the spectral content of low-amplitude thermospheric signals, demonstrating that nonlinear effects are significant for all detectable thermospheric returns.

2.2.4 University of Hawaii

The Applied Research Laboratory of the University of Hawaii is developing new ways to listen to our surroundings using infrasound sensors [16]. The sensors can detect low-frequency signals that can indicate the presence of distant, usually indistinct human or natural phenomena ranging from weather, volcanic activity, and waves.

The Infrasound Laboratory of the University of Hawaii uses very sensitive microphones to listen to low-frequency sounds in the atmosphere. The lab operates listening stations as part of the International Monitoring System of the Comprehensive Nuclear-Test-Ban Treaty. It also conducts research in acoustic source processes, propagation, instrumentation, signal and array processing, and software development.

2.2.5 University of Alaska Fairbanks, Geophysical Institute

The Geophysical Institute at the University of Alaska Fairbanks has researched and collected information on atmospheric shocks and sonic booms from the passage of supersonic vehicles, with the intention of showing the richness of the unique signal set that occurs in the low-frequency infrasound band [17].

2.3 INDUSTRY RESEARCH EFFORTS

There are researchers in industry who follow current research and market demands, including infrasound and its military applications. Companies are developing products to meet the demands expressed by the military and the DoD.

2.3.1 BBN Technologies

BBN Technologies developed a software tool kit that integrates infrasound propagation models and upper atmosphere characterizations [18]. The acoustic propagation models consist of a 3-D ray theory model; a normal mode model; and a continuous-wave, 2-D parabolic equation model. Models can be applied to predict propagation characteristics necessary for estimation of travel times, bearings, and amplitudes from potential event locations worldwide. The software has been developed for modeling localization performance of a network of infrasound sensors.

BBN Technologies was sponsored by the U.S. Air Force Research Laboratory (AFRL) Space Vehicles Directorate to upgrade the analysis tool kit Infrasound Modeling of Atmospheric Propagation (InfraMAP) to allow new options for specifying the propagation environment [19]. Near real-time atmospheric updates, including the output from numerical weather prediction models, supplement the baseline climatological characterization of temperature, wind, and air composition.

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