Welcome to Vibrationdata

Acoustics • Shock • Vibration • Signal Processing

March 2006 Newsletter

Greetings

The natural world is an endless source of fascinating acoustic phenomena. The first article reports on a number of sand dunes and beaches which produce a variety of sounds. These sounds are described onomatopoeically as squeaking, croaking, barking, or roaring depending on the frequency.

The second article discusses common sources of vibration in naval aircraft as well as the potential biomedical effects on the pilots. I have deep respect for the men and women who serve in the U.S. Navy and in each branch of the military.

The third article presents an acoustical analysis of the “beep-beep” radio signal broadcast by Sputnik 1, the world’s first artificial satellite. The transmission and reception of this signal was a pivotal event in the both the cold war and the space race.

Please appreciate opportunities to both hear and ponder the sounds that you encounter, whether from natural or man-made sources.

Sincerely,

Tom Irvine

Tom Irvine
Email: tomirvine@aol.com

Feature Articles

Figure 1. Barking Sands, Kauai, Hawaii

Booming Sand Dunes and Beaches

By Tom Irvine

Introduction

Desert sand dunes may emit roaring, booming, or singing sounds as the sand grains avalanche down a steep slope. The sounds may be musical or haunting. The sounds may resemble thunder, foghorns, or the drone of low-flying propeller aircraft.

Furthermore, sandy beaches may produce croaking, barking or squeaking sounds.

History

These acoustic phenomena have been reported from the Middle East for more than 1500 years, as well as in Chinese literature from the ninth century.

Marco Polo (1254-1324) encountered booming sand in the Mongolia’s Gobi Desert. He wrote of evil desert spirits which "at times fill the air with the sounds of all kinds of musical instruments, and also of drums and the clash of arms."

Charles Darwin (1809-1882) heard booming sand while traveling through Chile, as he noted in the *Voyages of the Beagle*.

Sand Grains

Sand grains typically consist of quartz, feldspar, mica and other minerals. The mean grain size (diameter) of most sand grains is roughly 300 μm (0.012 inch), whether or not the grain is acoustically active.

The size and texture of the sand grains determine the frequency of the sound. Smooth, spherical sand is more likely to emit sound than grains with abrupt surface changes. These grains are referred to as “polished.”

High shear strength is another favorable trait.

The sand should be well-sorted so that the grains are similar in size to one another.

Furthermore, the sand must be very dry. Acoustic emission is more likely to occur if fine impurities have been washed away by rain and then if the remaining grains have been left to thoroughly dry for several weeks. This process may also yield a looser, more natural grain packing, which is favorable to sound generation.

Acoustic Emission Mechanism

Scientists are still trying to determine the sound generation mechanisms. Intergranular friction during shear stress is the most likely cause, however.

Furthermore, the mechanisms may vary for desert sand dunes and sandy beaches, even though the grain size is similar in each case.

Increasing the rate of shear seems to increase its frequency of emission. Quickly compressing the booming sand vertically, thus creating a very high rate of shear, reportedly produces emissions which resemble genuine squeaking.

Furthermore, researchers are still investigating whether resonant excitation of the natural frequency of the sand plays a role.

Any mathematical theory must address non-linearity. The oscillation amplitudes that grains in the shear plane experience during a booming event are nearly as large as the grains themselves.

Desert Sand Dunes

Sand avalanches occur in dry desert dunes when the slope angle reaches about 34°. Typically, large plate-like slabs of sand break off along clearly defined cracks near the crest. The plates then collapse into one another near the base of the dune. A turbulent flow of the sand particles results from the break-up.

Underlying Layers

The stationary sand underneath the sliding slabs acts as a giant sounding board or amplifier, producing the enormous volume of sound.

Professor Melany Hunt has a related theory. She has observed that the respective vibration frequencies of certain sand dunes in California change throughout the year.

Professor Hunt and her students have confirmed the existence of a band of wet, hard sand some two meters (6.6 feet) below the surface, using radar. This is caused by rainfall percolating into the sand dune over a period.

"If you have some water at depth within this dune that reflects the radar signal, maybe it also reflects the acoustics signal," Hunt said. "Maybe what you're really having is this reverberation within the dune that's affected by a harder or wetter layer below that causes a reflection in the dry sand in the upper part of the dune."

Professor Hunt thus concludes that the frequency varies as the underlying moisture content varies from one season to the next.

Acoustically Active Sand Dunes

There are perhaps 30 booming sand dunes worldwide. Prominent examples include

1. Gobi Desert, Mongolia
2. Badain Jaran Desert, China
3. Sahara Desert, North Africa
4. Kelso Dunes, San Bernardino County, California
5. Eureka Dunes, Inyo County, California
6. Sand Mountain in western Nevada

Sound Energy Frequency Spectra

Booming sand has a spectrum from 50 to 400 Hz.

Squeaking sand has a spectrum from 500 to 2500 Hz.

These are only two categories, however. This data is taken from Reference 1.

Furthermore, the spectral peaks may sweep downward in frequency with time as shown in Figure 2.

Sandy Beaches

Certain beaches may produce distinct sounds when the sand disturbed.

For example, a person walking on the sand exerts foot pressure against the sand. The sand experiences a rapid displacement under the pedestrian's feet as a result. Sound is then generated by the friction or rubbing of sand particles against one another.

The resulting sound may be a high-frequency squeak with a short duration. In other the cases, the sound may be similar to a croaking frog or a barking dog.

There are several beaches throughout the world that emit notable sounds.

Barking Sands, Mana, Kauai, Hawaii

The grains of Mana sand are hollow spheres, according to one source. The spheres give off a popping sound when rubbed together, similar to the barking of dogs.

Another source notes that this beach consists of carbonate sand made from water-worn and wind-blown fragments of shells and corals.

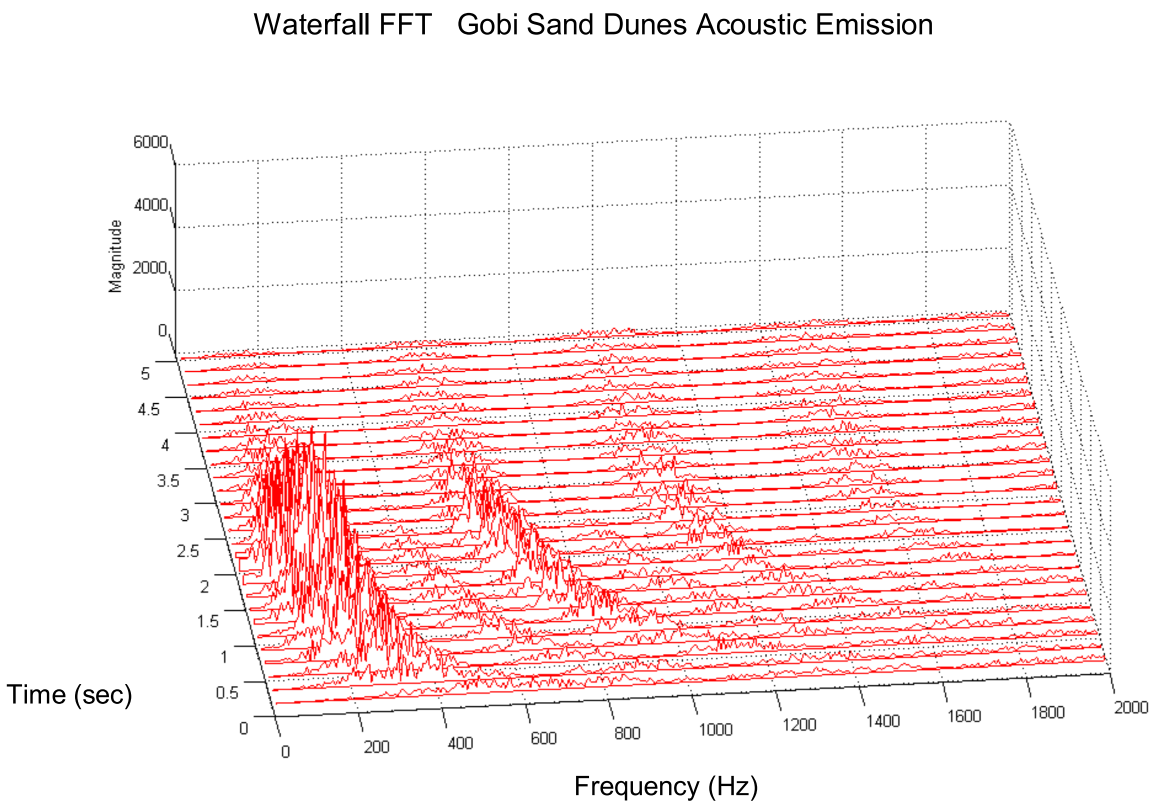
Additional Beaches

The Back Beach Dunes on the Island of Niihau, Hawaii are also acoustically active.

Kotohiki beach in Kyoto, Japan emits a sound similar to the barking of a sea lion.

References

1. Paul Sholtz, Michael Bretz and Franco Nori; Sound-Producing Sand Avalanches, Department of Physics, The University of Michigan, Ann Arbor, MI 48109-1120.
2. Pulse of the Planet, Gobi Desert: Ancient Sounds, http://www.pulseplanet.com/feat_archive/Jul98/



Waterfall FFT Gobi Sand Dunes Acoustic Emission

Figure 2.

A remarkable recording of booming sand in the Gobi Desert is given in Reference 2. The waterfall FFT of the sound file reveals a sine sweep as shown in Figure 2.

A cluster of spectral peaks begins near 400 Hz and then sweeps down to 200 Hz. Harmonic clusters also occur at higher frequencies.

The magnitude is uncalibrated sound pressure.

Blue Angels, F-18 Hornet

Vibration in Naval Aviation

Edited by Tom Irvine

The following is an excerpt from the U.S. Naval Flight Surgeon's Manual, Third Edition, Chapter 2, Acceleration and Vibration, 1989. Some minor changes were made for the purpose of inclusion in this newsletter. The photographs were added.

Introduction

The sources of vibration in naval aviation are myriad. Listed below are some of the principal sources, after von Gierke and Clarke (1971).

Ejection

Once free of the rails, an ejection seat system seeks a stable configuration in the airstream. This normally sets up an oscillation around the center of the seat-man system in the range of 3 to 10 Hz and at a magnitude of 10^{o}.to 30^{o}. These vibrations normally damp out rather quickly, but the relatively large oscillations impose considerable threat of flail injury, especially when combined with high aircraft speeds.

Low Altitude, High-Speed Flight

Many current military missions include low altitude, high-speed flight in an attempt to avoid radar detection. Gust effects in such flights can introduce complicated vibrations in five degrees of freedom, ranging from about 1 to 10 Hz. This can present clinical problems in the areas of vision, speech, respiratory effort, and musculoskeletal stress similar to a high-speed Jeep ride over an open field.

Terrain Following

In order to fly in the low-level, high-speed profile, many modern aircraft have systems that allow flight close to the contour of the terrain. Such systems, whether manual or automatic, can induce vibration spectra between 0.01 Hz and 0.1 Hz. This is in addition to the gust response and can add the clinical problem of motion sickness.

Storm and Clear Air Turbulence

Storms and clear air turbulence impart vibration spectra that are similar to low altitude, high-speed flight. These vibrations are generally in the very low frequency range, but clear air turbulence can occasionally be of such high frequency and intensity as to preclude control of an aircraft.

Seahawk Helicopter

Helicopter Vibrations

Vibrations are perhaps of greater importance in helicopters than in any other type of naval aircraft. These vibrations arise from mechanical and atmospheric sources, although the atmospheric conditions are not as important as in fixed wing aircraft due to the lower airspeeds. Vibrations in the 3 to 12 Hz range are induced by the main rotor blades, the actual frequency being related to the number of blades.

Tail rotors produce higher frequency vibration in the range of 20 to 25 Hz. Vibrations produced by the transmission are less well defined. These generally low amplitude vibrations have clinical significance by virtue of the prolonged exposures involved, where physical fatigue results from continuous bracing.

Ill-defined musculoskeletal complaints, such as neck and back pain, appear with increased frequency in the rotary wing community.

V/STOL Aircraft

V/STOL (Vertical/Short Takeoff and Landing) aircraft in low hover appear to exhibit low frequency range vibrations similar to those found with helicopters. Their significance, however, seems to lie more in their effect on the pilot's response time than in any purely clinical effect.

Effects of Vibration on the Body

A number of factors modify the effects of vibration on humans, including tissue resonance, duration of exposure, individual variations, and other simultaneous environmental stresses. For example, acceleration increases the body's rigidity, reducing its shock-absorbing properties and increasing the transmission of vibration energy to the internal organs (Antipov, Davydov, Verigo, & Svirezhev, 1975). The effects of vibration on the body are determined by the frequency ranges involved.

Effects at less than 2 Hz

Vibrations in the frequency range of 0.1 to 0.7 Hz most often produce motion sickness in humans. Vibrations of 1 to 2

Harrier V/STOL Jet

Hz are generally associated with increases in pulmonary ventilation, heart rate, and sweat production above that level considered normal for any other stress present.

Effects from 2 to 12 Hz

Chest pains, breathing difficulty, and cardiovascular problems may occur as a result of vibration in the 2 to 12 Hz frequency domain. The corresponding amplitude threshold is approximately 2 to 3 G.

In addition, abdominal discomfort and testicular pain are common complaints.

Headaches may also occur, because the mechanical forces are not well attenuated by the skeletal system in this domain.

Finally, helicopter pilots flying heavy schedules may have blood in their urine or stools. Such symptoms are attributed to vibration, and they usually disappear after a few days of rest.

Effects above 12 Hz

In these frequencies, there is more concern about effects on performance (vision, speech, fatigue) than about injuries.

Figure 1. Sputnik 1 Satellite

Sputnik Beep Acoustic Analysis

By Tom Irvine

History

The United States and the Soviet Union held an International Geophysics Year to promote the study and understanding of the Earth in 1957-58. Note that the Geophysical Year actually lasted 18 months.

The Soviets responded by launching the Sputnik 1 satellite on October 4, 1957. This was the first artificial satellite ever launched.

The satellite weighed 184 pounds. It was 23 inches in diameter. It was spherical and made from steel.

It sent out a "beep-beep" radio signal through its four antennas. The signal was received by scientists and ham radio operators throughout the world. The signal continued until the transmitter batteries ran out on October 26, 1957.

Sputnik 1 also had instrumentation to measure the density of the atmosphere.

It had an elliptical orbit about the Earth, with a perigee of 155 miles and an apogee of 559 miles. The exact distance for each parameter varies slightly from one source to another.

It orbited the Earth once every 96 minutes.

Sputnik 1 remained in orbit until January 4, 1958. It burned up as it re-entered the Earth's atmosphere.

Figure 2. Dallas News Photo

Ham operator Roy Welch of Dallas, seated, plays a tape-recorded signal from the Russian space satellite for fellow hams at the State Fair of Texas. Welch recorded the signals on a receiver at his home.

The booster rocket for Sputnik was an ICBM called a Semiorka R-7. The launch site was the Baikonur Cosmodrome, which is located near the city of Tyuratam in Kazakhstan, close to the Aral Sea.

Design Team

Sergei Korolev (1906-1966) was the leader of the team that developed both the booster and the satellite.

Korolev's team drew heavily upon German rocket technology used in World War II. Both the United States and the Soviet Union had captured German engineers and rocket assets at the end of World War II.

Korolev also drew upon the brilliant theoretical work of Konstantin Tsiolkovsky (1857-1935), a Russian school teacher. Tsiolkovsky had written about the possibilities of multistage boosters fueled by liquid hydrogen and oxygen in 1903.

The lead designer for Sputnik was Mikhail S. Khomyakov. Oleg G. Ivanovskiy was his deputy.

Effect

The Sputnik launch was a spectacular propaganda victory for the Soviet Union and its leader Nikita Khrushchev (1894-1971).

Dwight Eisenhower (1890-1969) was president of the United States at the time. He dismissed the Sputnik as being insignificant. Many Americans, however, considered it as a symbolic nuclear weapon.

Harry Schwartz wrote a long article in the October 6th New York Times titled, "Soviet Science Far Advanced in Many Fields."

Schwartz's story was followed by a cartoon showing Sputnik orbiting the Earth. The Sputnik carried a banner titled, "Man's Quest for Knowledge."

The sight of Sputnik streaking over Coalwood, West Virginia, inspired 14-year old Homer Hickams Jr. and his friends to build model rockets, as depicted in the book “Rocket Boys” and in the movie “October Sky.” Hickams later attended college and became a NASA engineer.

Radio Transmission

Sound waves cannot propagate through the vacuum of space. Sound can only travel through a physical medium such as air, land or water.

On the other hand, electromagnetic radio waves can travel through space.

Sputnik transmitted a radio telemetry signal at 20.007 MHz. The signal carried a “beep-beep” sound.

The signal was a Pulse Duration Modulation (PDM) signal, according to References 2 and 3. Sputnik’s internal pressure was encoded as pulse length, and temperature as length between pulses.

Acoustics Analysis

Two Sputnik sound files are posted in Reference 1.

The first file Sputnik1.wav is credited to Roy Welch, who recorded the signal on October 7, 1957. Welch also recorded the signal presented as Sputnik1b.wav.

Time history segments of each signal are shown in Figures 3 and 4. The total duration of each signal was 10 seconds.

Waterfall FFT plots are given in Figures 5 and 6.

The magnitude is uncalibrated sound pressure in each of the four plots.

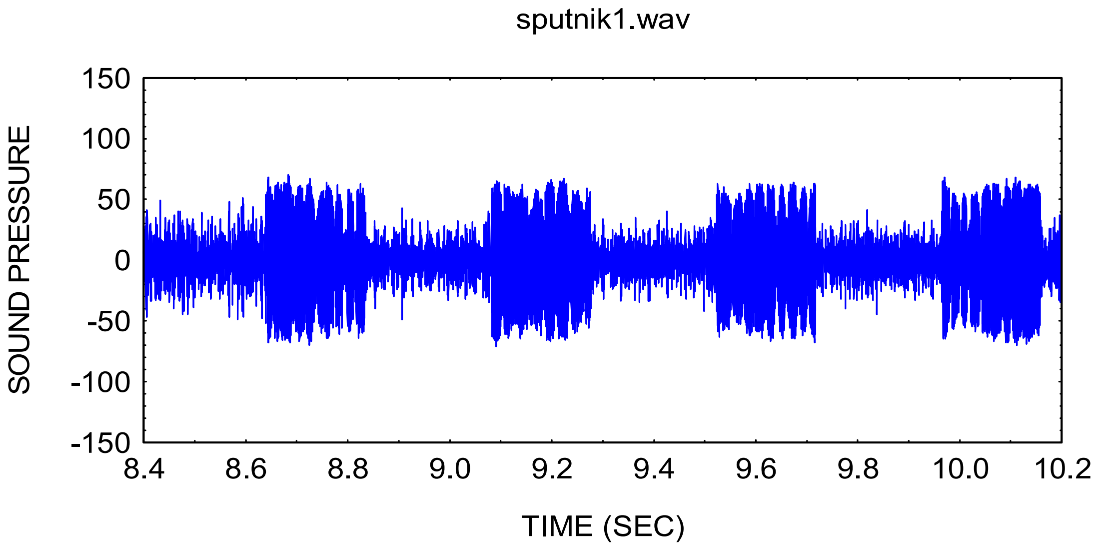


Figure 3.

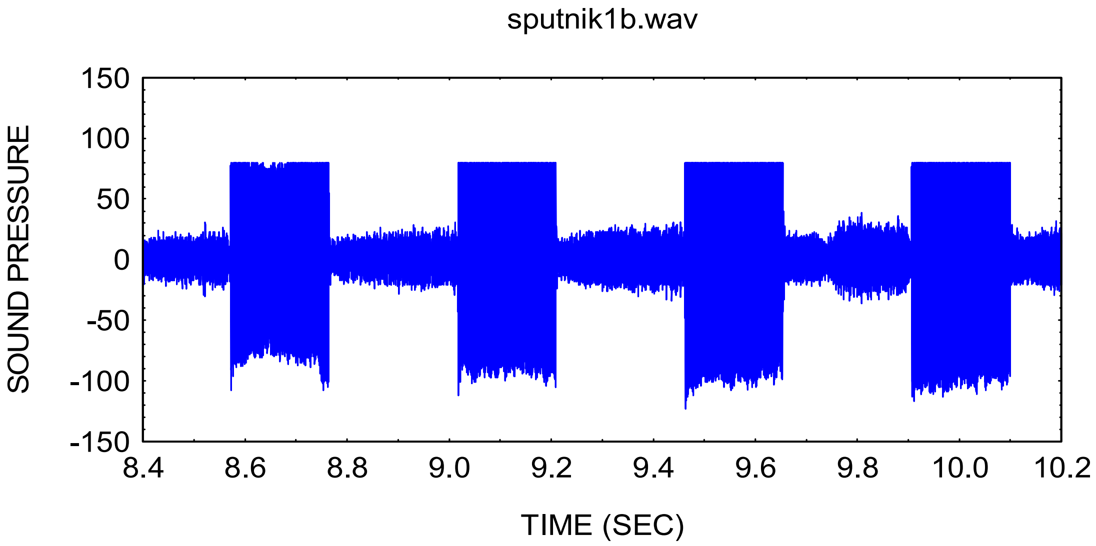


Figure 4.

The positive peaks are clipped in Figure 4, but this effect is not significant in the sound quality.

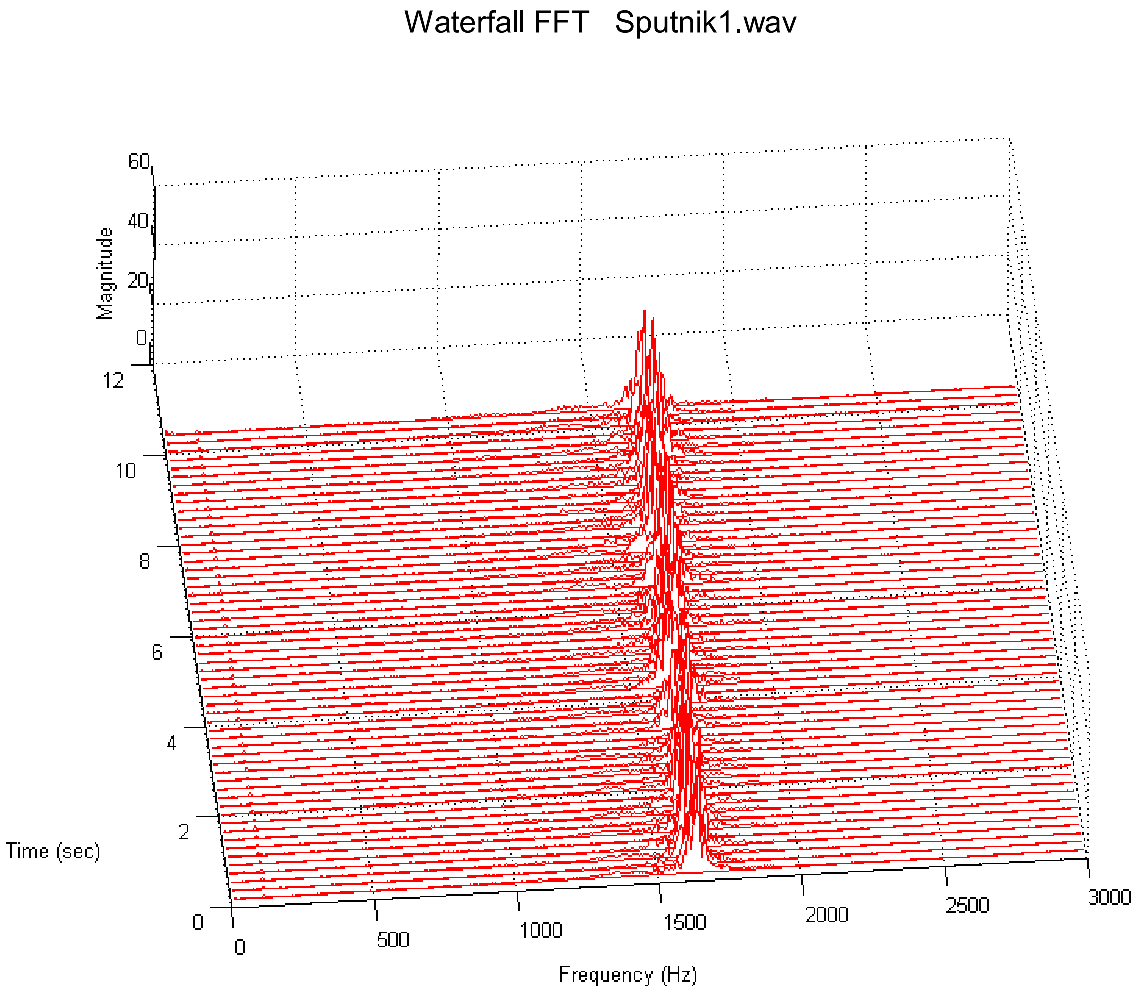


Figure 5.

A Waterfall FFT of the first signal is given in Figure 5. The signal begins at 1620 and then sweeps to1680 Hz. The frequency variation represents a changing temperature.

The corresponding music note is G#.

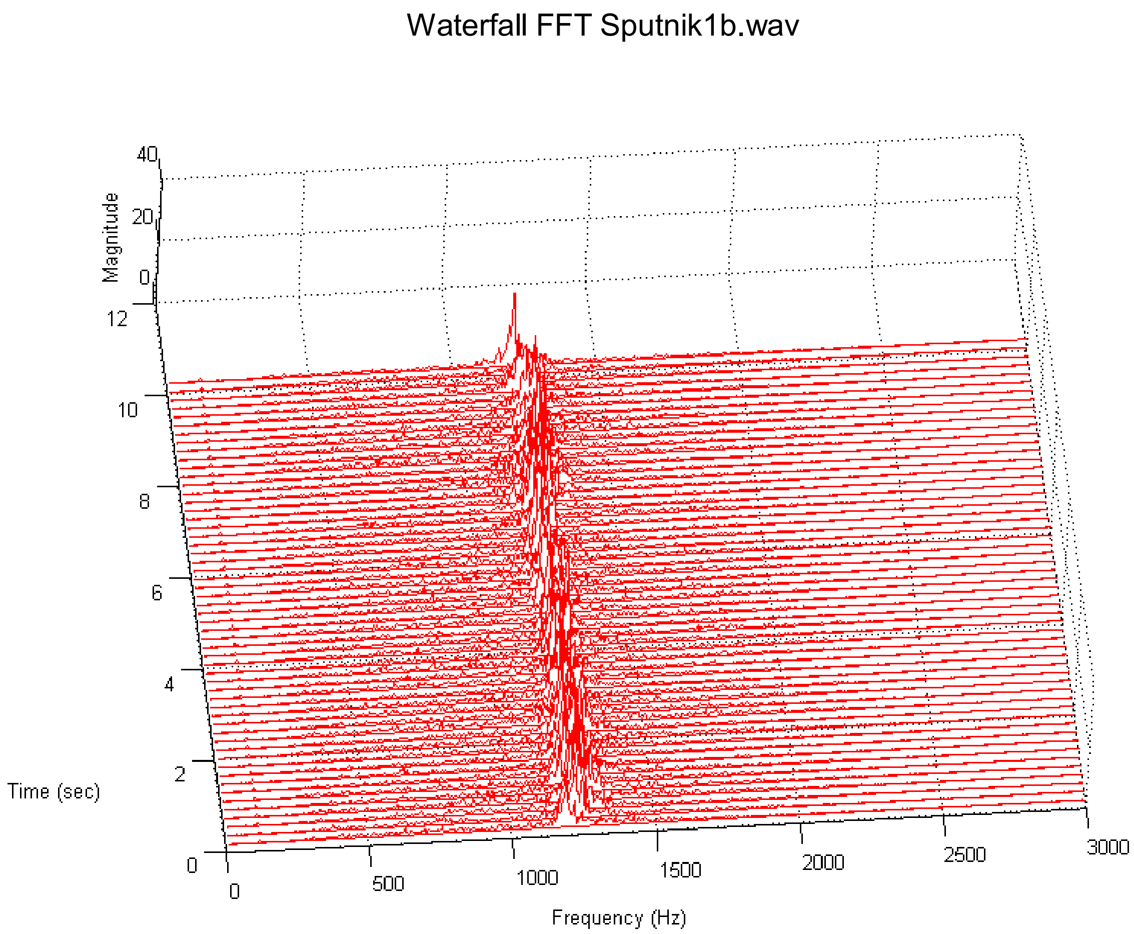


Figure 6.

The energy is spread over the band from 1200 to 1260 Hz. The corresponding musical note is D#.

References

1 http://www.amsat.org/amsat/features/sounds/firstsat.html

2 http://www.svengrahn.pp.se/radioind/lunaradi/lunaradi.htm

3 http://www.mentallandscape.com/V_Telemetry.htm