Welcome to Vibrationdata

Acoustics • Shock • Vibration • Signal Processing **May 2009 Newsletter**

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The world is becoming increasing unpredictable and dangerous. The North Koreans are developing nuclear warheads for ballistic missiles which could reach South Korea, Japan, Hawaii, and perhaps even the U.S. mainland. Similarly, the Iranians are developing missiles which could strike Israel and Europe.

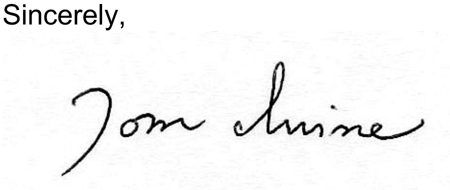
The first article gives a seismic waveform perspective of the recent North Korean nuclear test.

Recall these verses from a Henry Wadsworth Longfellow poem:

And in despair I bowed my head;
'There is no peace on earth,' I said;
'For hate is strong,
And mocks the song
Of peace on earth, good-will to men!'

Then pealed the bells more loud and deep:
'God is not dead; nor doth he sleep!
The Wrong shall fail,
The Right prevail,
With peace on earth, good-will to men!'

Sincerely,



Tom Irvine
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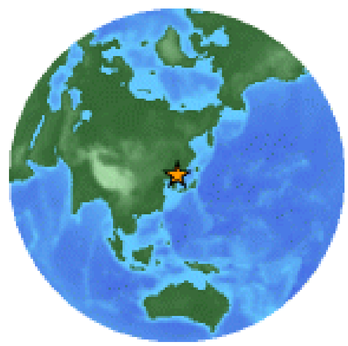
Feature Articles



North Korean Nuclear Test by Tom Irvine

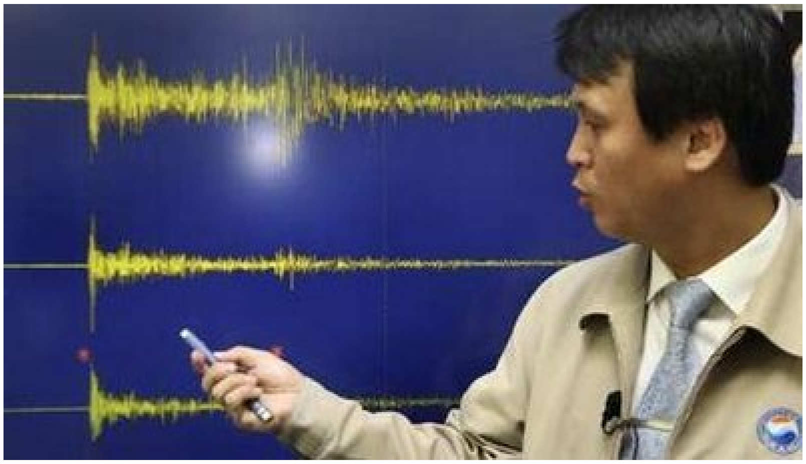


Figure 1.

A South Korean meteorological official briefs reporters showing seismic waves generated by North Korea's recent nuclear test.

Introduction

North Korea experienced a magnitude 4.7 seismic event on May 25, 2009.

This event was the result of an underground nuclear test at the P'unggye-yok nuclear test site in north-eastern North Korea.

The alleged nuclear device most likely had a plutonium core covered with explosives. When the surface of such a bomb explodes, the plutonium core is compressed into a critical state, which leads to a nuclear explosion.

Furthermore, North Korea test-fired six short-range missiles from a base on the North Korean east coast in the days following the nuclear test. The number of launches continues to grow as this newsletter is being written.

Yanji, China

The force of the 2009 blast made the ground tremble in the Chinese border city of Yanji, 130 miles away. The North Koreans had informed China of the impending test. A warning siren was sounded in Yanji accordingly.

Explosive Yield, 2009 Nuclear Test

Analyst Martin Kalinowski at the University estimates the yield at being from 3 to 8 kilotons for the test, as referenced to the equivalent TNT yield.

The test was still short of the explosion energy released by the Hiroshima Little Boy, 15 kiloton yield, and Nagasaki Fat Man, 21 kiloton yield, bombs.

Nevertheless, Geoffrey Forden, an MIT researcher, speculated that the 2009 device was designed to have a 20 kiloton yield, but that it may have only partially detonated. He also noted that the device may have been intentionally miniaturized, perhaps for the purpose of developing a ballistic missile warhead.

Figure 2. Epicenter

2006 Nuclear Test

North Korea had previously performed a nuclear test in October, 2006, which generated a magnitude 4.3 quake.

Note that the 2006 test was considered as a dud with a yield of less than one kiloton. The North Koreans were too ambitious in their designs, used unsuitable plutonium, or had not mastered the intricacies of the triggering device.

Magnitude Scale

The earthquake magnitude scale is logarithmic. Each whole number increase in the scale equals a ten-fold increase in measured wave amplitude of a tremor, or a release of 31 times as much energy.

Thus, the 2009 test generated a substantially greater amount of energy than the 2006 test.

Waveform Signatures

"Earthquakes and nuclear bombs have quite different seismographs," said David Booth, a seismologist at the British Geological Survey.

"Earthquakes happen along fault lines and you get compression waves, known as P-waves, and shear waves from the movement. With a bomb it is mostly just compression waves meaning the seismograph is a lot less complicated."

Table 1. USGS Seismic Report

Magnitude	**4.7**
Date-Time	**Monday, May 25, 2009 at 00:54:43 UTC** Monday, May 25, 2009 at 09:54:43 AM at epicenter Time of Earthquake in other Time Zones
Location	41.306°N, 129.029°E
Depth	0 km (~0 mile) set by location program
Region	NORTH KOREA
Distances	70 km (45 miles) NNW of **Kimchaek, North Korea** 95 km (60 miles) SW of **Chongjin, North Korea** 180 km (115 miles) SSW of **Yanji, Jilin, China** 375 km (235 miles) NE of **PYONGYANG, North Korea**
Location Uncertainty	horizontal +/- 3.8 km (2.4 miles); depth fixed by location program
Parameters	NST= 75, Nph= 75, Dmin=371.4 km, Rmss=0.57 sec, Gp= 72°, M-type=body wave magnitude (Mb), Version=A
Source	USGS NEIC (WDCS-D)
Event ID	us2009hbaf

Reference:
http://earthquake.usgs.gov/eqcenter/recenteqsww/Quakes/us2009hbaf.php

Waveform Signatures (Continued)

Note that P-waves are the fastest of the seismic waveforms. P-waves also tend to have a higher frequency content than other waveforms.

"You drill a hole in the ground because you do not want the explosion to release any radioactive material at the surface," said Booth.

"The explosion would have produced a vibration similar to a very large quarry blast; most likely a single thump which local people, within several kilometers of the blast, would certainly have noticed."

"The explosion produces a cavity deep underground. This may collapse to create a saucer shaped depression in the ground perhaps 100m across, but not necessarily immediately."

Seismic Data

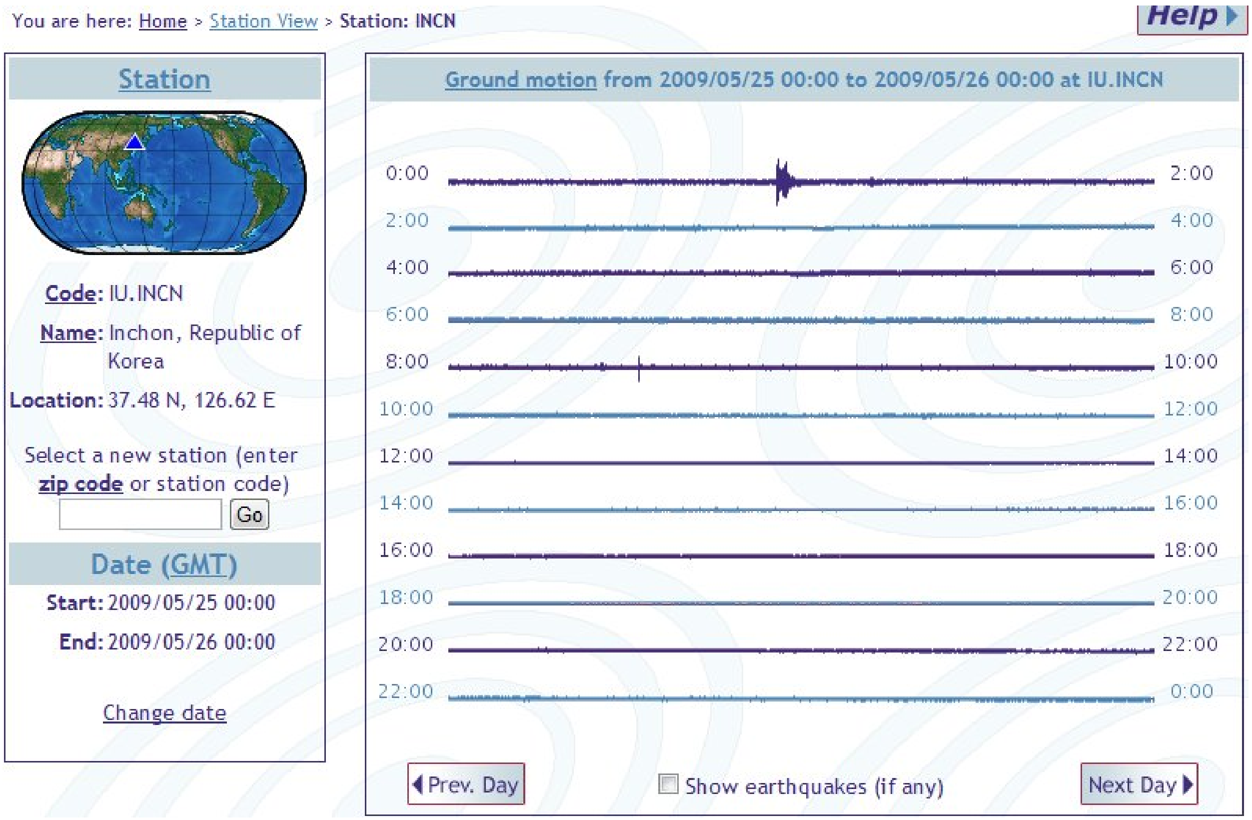


Figure 3. 2009 Nuclear Test as Measured in South Korea

The pulse in the middle of the top trace is due to the test.

Reference: http://rev.seis.sc.edu/

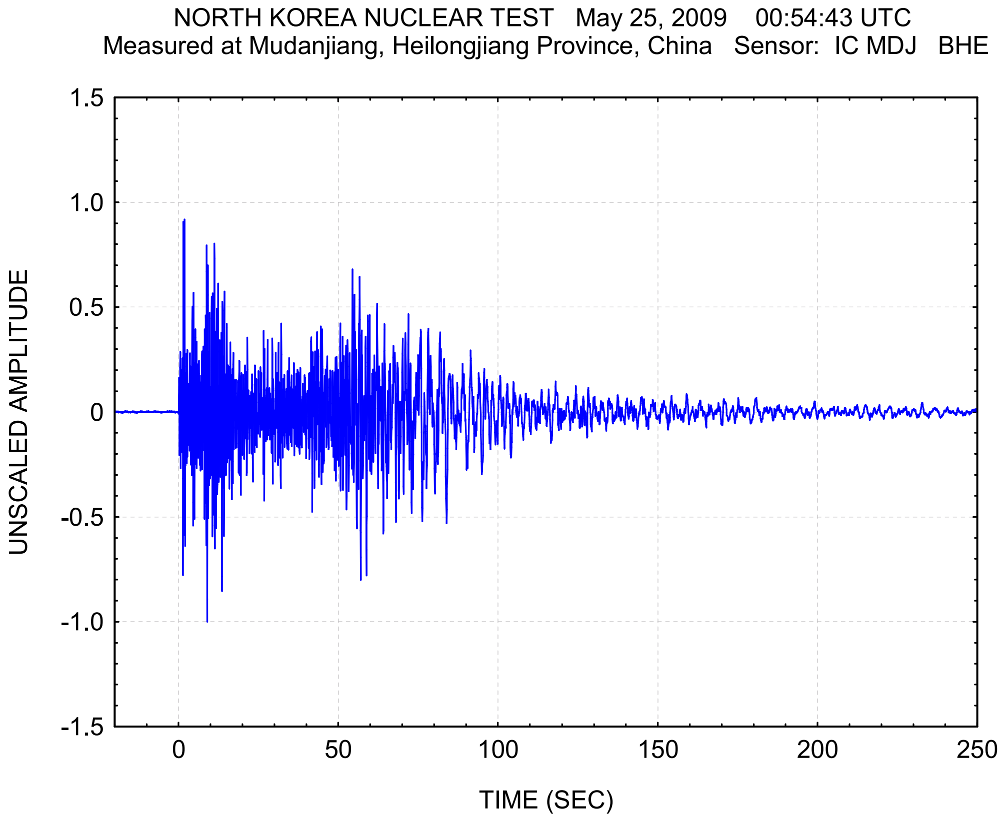


Figure 4. 2009 Nuclear Test as Measured in southeast China

The initial pulse from zero to 20 seconds is mainly due to the P-wave. The response from 60 to 100 seconds is mainly due to the Rayleigh wave.

The ASCII text file was obtained from IRIS, Incorporated Research Institute for Seismology.

Reference: http://www.iris.edu/hq/

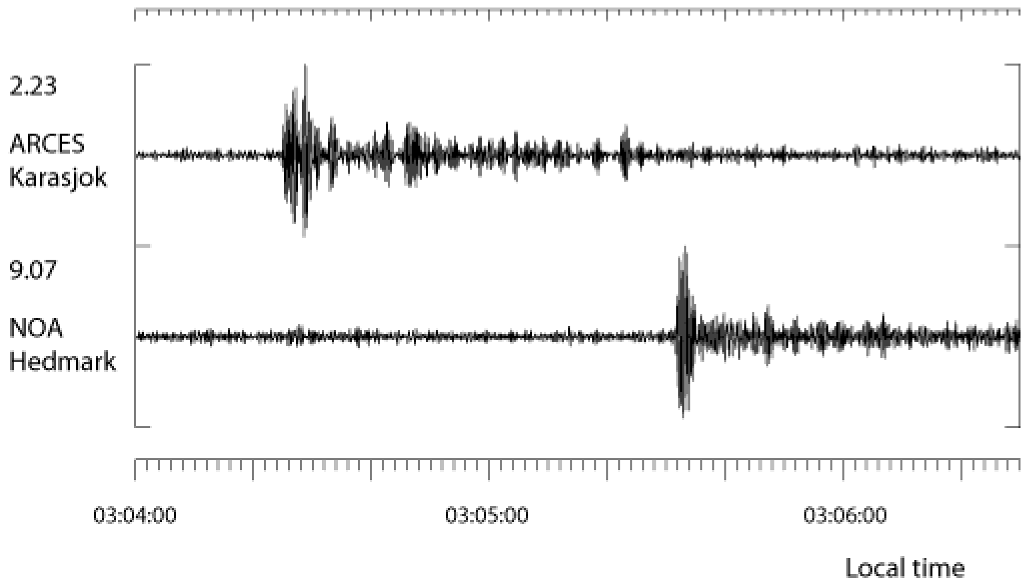


Figure 5. 2009 Nuclear Test as Measured by two stations in Norway

Karasjok is in northern Norway. Hedmark is in southern Norway. The signals are offset due to the respective distances to the source location.

Reference: http://www.norsar.no/pc-61-18-Announced-Nuclear-Test-by-North-Korea.aspx

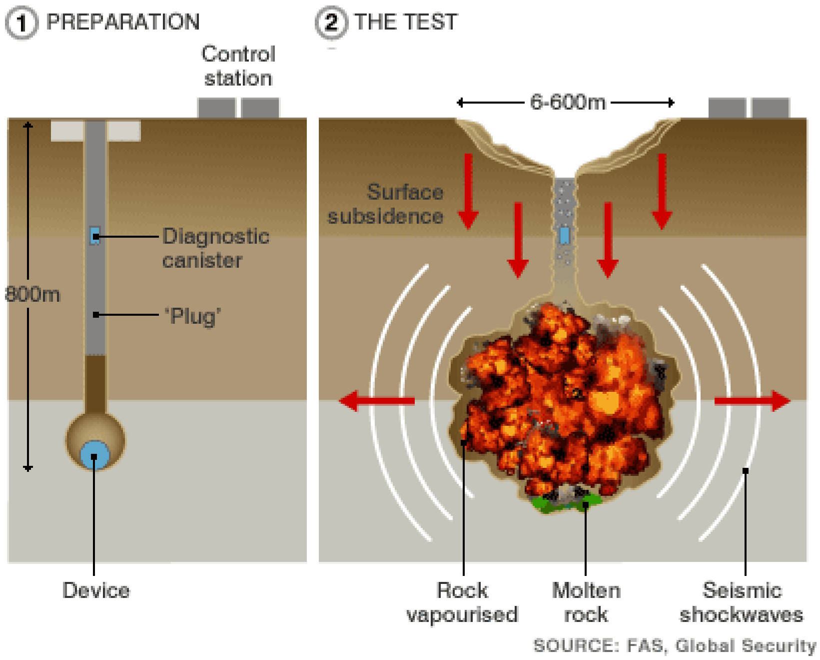


Figure 6. Generic Diagram of an Underground Nuclear Test

Radiation

The release of radiation from an underground nuclear explosion is an effect known as "venting." The emitted radiation would give away clues to the technical composition and size of a country's device, and therefore its nuclear capability.

Experts will look for traces of radiation drifting from the site in the coming weeks. Some duration of time is required for radiation to vent into the air from the underground.

In particular, the experts will search for radioactive xenon isotopes in ratios that are distinct from those released by other sources, such as nuclear power stations.

The U.S. Air Force may have already launched an aircraft with specialized “sniffer” devices that can detect radiation carried on the wind. In addition, ground-based radionuclide monitoring stations in Japan and Russia will join the search.

North Korean Government

Figure 7. Kim Jong-il, aka Dear Leader

Kim Jong-il is the 67-year old authoritarian leader of North Korea. He is believed to have suffered a stroke last August. The test may have been an act to reassert his power. It may also been an opportunity for North Korea to enhance its weapons export business with countries such as Syria and Iran.

Kim Jong il inherited the leadership from his father in 1994. He rules the nation of 24 million with an iron fist. He has three sons but has not publicly named a successor.

KNCA News Report

KNCA, the official North Korean news agency, announced: "We have successfully conducted another nuclear test on 25 May as part of the republic's measures to strengthen its nuclear deterrent."

The agency further stated: "The results of the test helped satisfactorily settle the scientific and technological problems arising in further increasing the power of nuclear weapons and steadily developing nuclear technology."

The test came less than two months after North Korea enraged the US and its allies by test firing a long-range ballistic missile.

North Korea claimed that this was a launch vehicle which deployed a satellite into orbit. U.S. officials, however, said that the rocket and its payload fell into the Pacific Ocean.

United Nations

UN Secretary General Ban Ki-moon said he was "deeply disturbed" by the test. UN Security Council Resolution 1718 demands that North Korea refrain from nuclear testing.

Six Party Talks

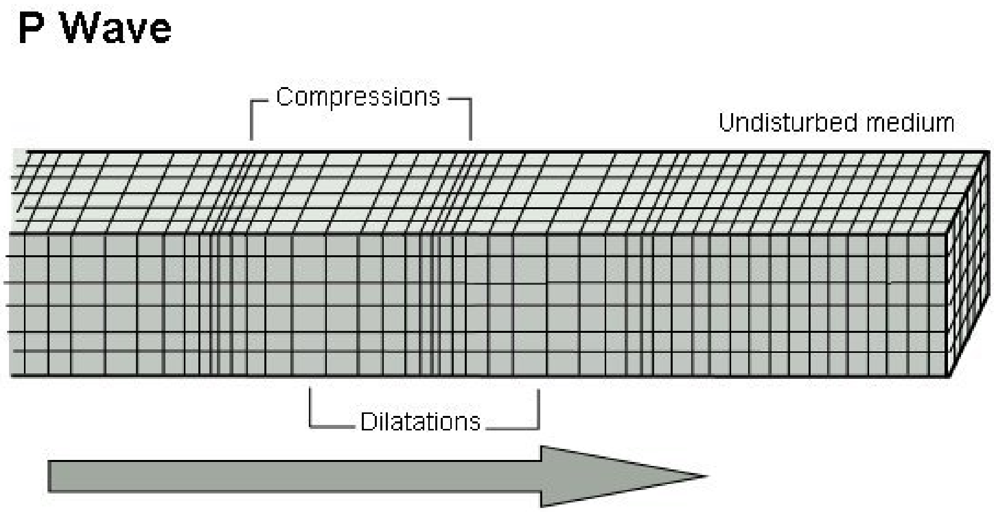
The six-party disarmament talks have involved the US, China, Japan, Russia and the two Koreas.

The talks stalled last year over Pyongyang's failure to agree how information it has handed over on its nuclear activities and facilities should be verified.

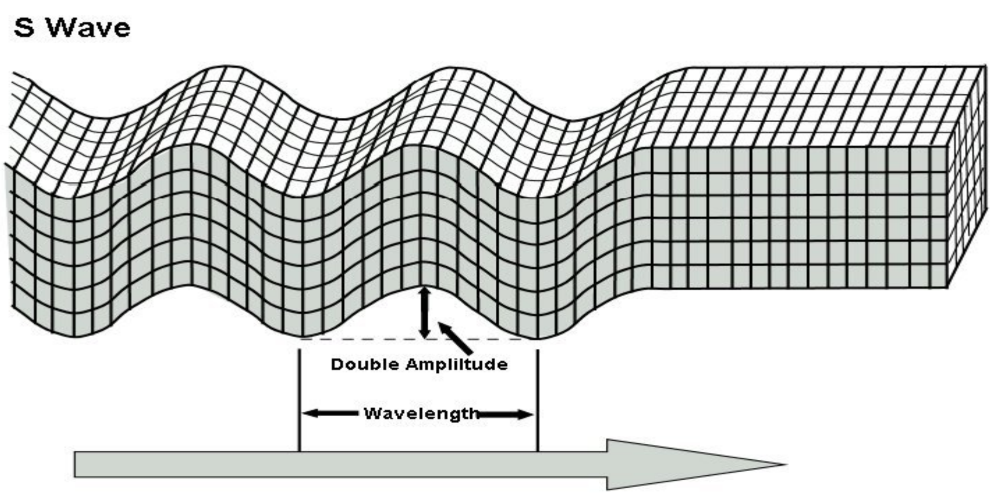
Further Developments

Tension continues to escalate. North Korea is now threatening to attack U.S. or South Korean warships if any ships from North Korea are searched as part of an effort to intercept weapons of mass destruction.

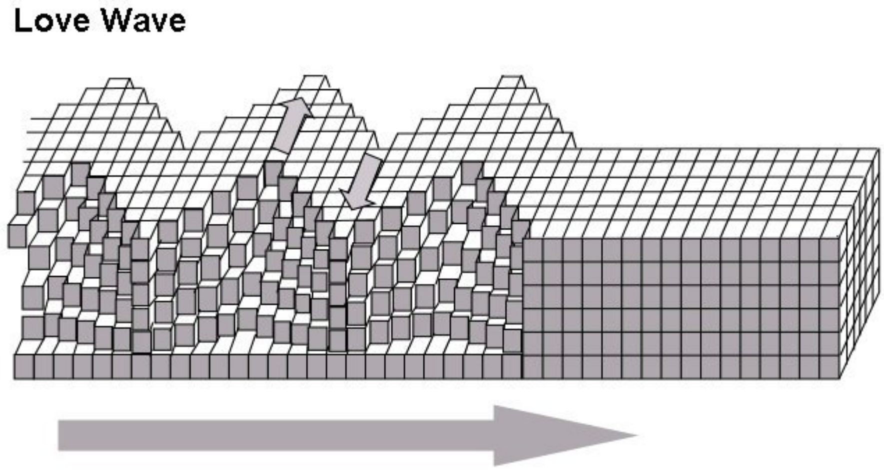
Seismic Waveform Review by Tom Irvine



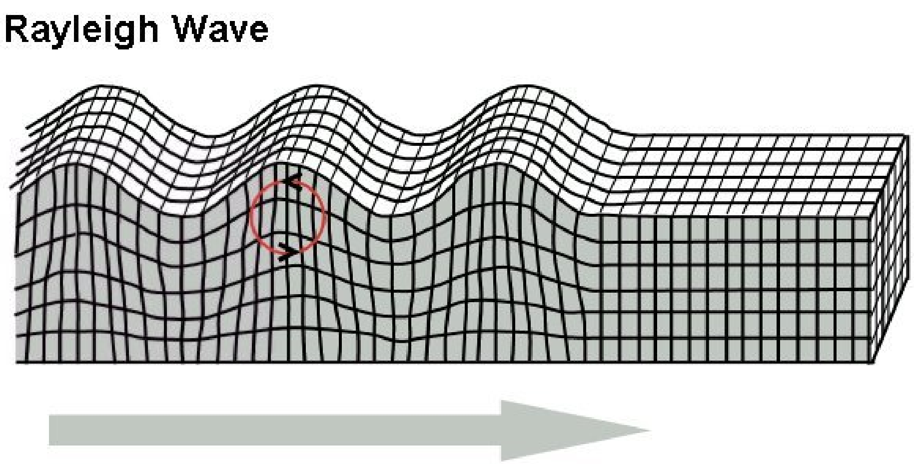
The primary wave, or P-wave, is a body wave that can propagate through the Earth's core. This wave can also travel through water. The P-wave is also a sound wave. It thus has longitudinal motion. Note that the P-wave is the fastest of the four waveforms. Underground explosions mainly generate P-waves.



The secondary wave, or S-wave, is a shear wave. It is a type of body wave. The S-wave produces an amplitude disturbance that is at right angles to the direction of propagation. Note that water cannot withstand a shear force. S-waves thus do not propagate in water.



Love waves are shearing horizontal waves. The motion of a Love wave is similar to the motion of a secondary wave except that Love wave only travels along the surface of the Earth. Love waves do not propagate in water.



Rayleigh waves travel along the surface of the Earth. Rayleigh waves produce retrograde elliptical motion. The ground motion is thus both horizontal and vertical. The motion of Rayleigh waves is similar to the motion of ocean waves except that ocean waves are prograde.

Characteristic Seismic Wave Periods		
Wave Type	Period (sec)	Frequency (Hz)
Body	0.01 to 50	0.02 to 100
Surface	10 to 350	0.003 to 0.1

Reference: Lay and Wallace, Modern Global Seismology

Wind Turbine Noise by Tom Irvine

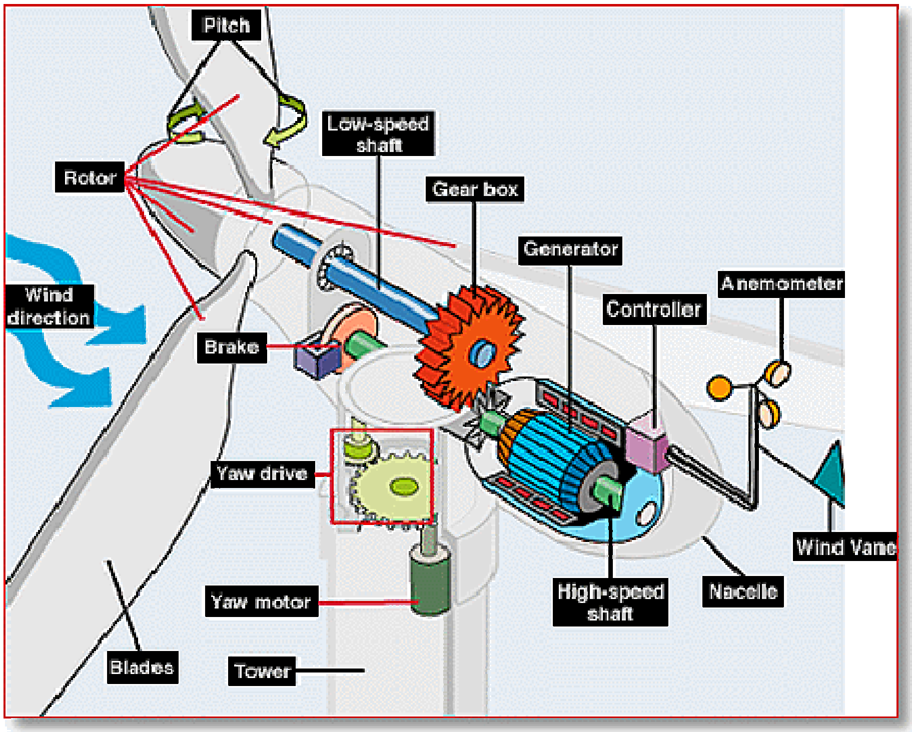


Figure 1. Upwind Turbine Diagram

Reference: http://www.sunflower.net/how_wind_works.aspx

Introduction

Windmills have been used throughout history for pumping water and for grinding grain. They are a picturesque feature of the Dutch countryside. Cervantes' Don Quixote attacked windmills believing them to be giants.

The wind turbine is the modern version of the ancient windmill. Wind turbines are used to generate electrical power without producing pollution or toxic waste. They are used both in commercial wind farms and in residential settings.

Wind turbines seemingly fit the world's need for a "green" source of power generation. Yet they present a number of challenging problems.

Wind turbines cause bird deaths. Some people consider wind turbines to be eyesores. Others complain about the shadow flicker effect, which occurs when the Sun is on the opposite side of the wind turbine relative to the human observer.

The most common objection, however, is unwanted sound, which is the topic of this article. People living near wind turbines complain that the noise is a nuisance, that it disrupts their sleeping, and that it even causes migraine headaches. The noise may even bother people living further away in the case of a temperature inversion, as discussed later in this article.

Downwind and Upwind Turbines

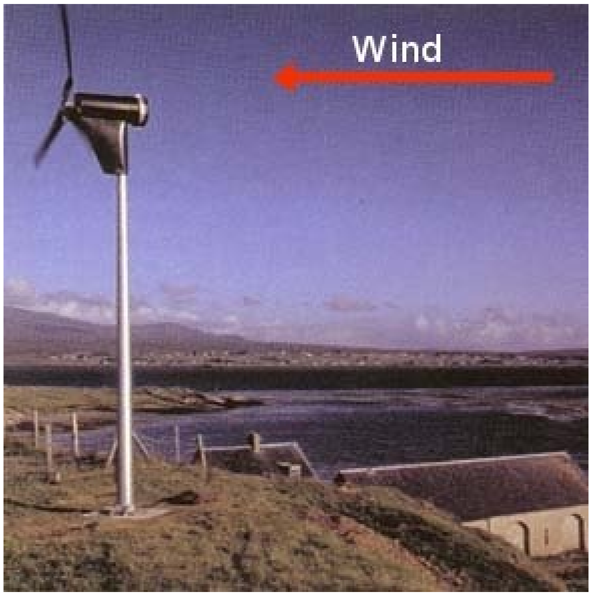


Figure 2. Downwind Turbine

Downwind turbines are simple because they do not need a mechanism for keeping them in line with the wind. The nacelle housing functions as a vane which passively keeps the blades pointing downwind.

Furthermore, the blades are allowed to bend, because there is no risk of the blades striking the tower. The blades may thus be lightweight. The turbulence and bending effects may cause fatigue damage to the blades, however.

A strong, low-frequency pulse can sometimes be heard with each passing of a blade behind the tower due to the deficiencies in the flow around the tower mast. The flow condition may be described as "turbulent mast wake." A portion of the sound energy may be infrasound, over frequencies below 20 Hz.

Downwind turbines thus tend to produce more low-frequency noise than upwind turbines.

Figure 3. Upwind Turbine

The upwind turbine is the most common type.

This design requires a yaw mechanism so that the blades always face the oncoming wind. The control mechanism is typically a servo-control device. An alternative is to have a tail vane, like the historical windmills used to pump water from the ground on the American deserts and prairies.

The upwind turbine blades must be stiff enough that they do not impact against the tower mast. This causes high stress in the zones where the blades mount to the rotor hub, particularly in high-speed, gusty winds.

The blades must be mounted sufficiently forward of the mast as a further precaution to prevent the blades from contacting the mast.

Figure 4. Enercon E-126

Electrical Power Output

Large turbines such as the German Enercon E-126, can generate up to 6 MW of electrical power.

Smaller turbines generate less than 30 kW.

Aerodynamic Noise Sources

Again, downwind turbines may produce low-frequency, impulsive noise due to the interaction of the blades and the turbulent mast wake. This is sometimes described as a “thumping sound.” Inaudible infrasound may also be generated.

Low-frequency noise is problematic because low-frequency waveforms are not readily absorbed by atmospheric molecules. Thus low-frequency waves travel further than high-frequency waves.

Aerodynamic noise is also generated by the blades passing through the air for both types of wind turbines. The power of aerodynamic noise is related to the ratio of the blade tip speed to wind speed.

Tip speed ratio (TSR) is a term that refers to the speed of the tip of a wind generator blade in relation to wind speed. The peak design TSR can vary greatly depending on the model. A brief Internet survey showed a range from 1 to 10.

Oncoming turbulence and gusts may exacerbate the noise levels. Note that this type of aerodynamic noise tends to have a broadband random frequency content. The resulting sound is described as “swishing” or “whooshing.” The sound envelope rises and falls with each blade passing.

Furthermore, airfoil self-noise may occur along blunt trailing edges, or due to flow over slits and holes. This noise may be tonal.

Utility scale turbines must generate electricity that is compatible with grid transmission. The turbines are thus programmed to keep the blades rotating at as constant a speed as possible. The pitch of the blades is adjusted to compensate for minor wind speed changes. These adjustments change the sound power levels and frequency components of the noise.

Mechanical & Electromagnetic Noise

Sound and vibration is generated from the

1. Gearbox, gear meshing
2. Electromagnetic Generator
3. Yaw Drives (upwind turbines only)
4. Cooling Fans
5. Auxiliary Equipment such as hydraulics

Note that some smaller wind turbines are direct-drive without transmission gearboxes.

Additional sound and vibration sources include rotor imbalance, shaft misalignment, and bearing problems.

Magnetic noise in the generator is caused by periodic forces which are almost exclusively in the air gap between the stator windings and the rotor bars.

These mechanical and electromagnetic sources tend to produce pure tones with possible integer harmonics. The resulting sound and vibration is transmitted to the nacelle enclosure and to the tower mast. These structures act as radiating surfaces, or as loudspeakers by analogy.

Damping and Attenuation

The noise produced by wind turbines has diminished as the technology has improved.

As blade airfoils have become more efficient, more of the wind energy is converted into rotational energy, and less into acoustic noise.

Vibration damping and improved mechanical design have also significantly reduced noise from mechanical sources.

Small turbines, which are often used in residential areas, are more likely to produce noticeable mechanical noise because of insufficient insulation. They also tend to have fixed-pitch blades resulting in variable rotational speed. As a result, the blade tip speed may be higher than in larger, commercial wind turbines.

Note that large, modern wind turbines limit the rotor rotation speeds to keep the tip speeds under about 65 m/sec. The rotational rate is typically 25 to 50 rpm.

Smaller turbines may have tip speeds above 65 m/sec. The radiated noise increases as the tip speed increases.

Human Perception

Pure tones tend to be a greater nuisance than broadband random noise.

The wind itself produces random noise as it passes by trees and buildings. This noise tends to mask the random noise from the wind turbines. Yet the wind turbines' pure tones can still be distinguished from the combined random noise.

Ambient Sound Levels

Sounds detectable by the human ear are measured in decibels, or dB.

The average background noise in a house is about 50 dB. A car driving down a street may generate 60 dB(A) at a distance of 300 feet (91 meters).

A "quiet" vacuum cleaner will emanate sound at 70 dB. This is about the same noise level that is attributed to an expressway when standing 100 feet (30 meters) away from it.

Trees on a windy day will measure about 55 dB(A) on a decibel meter.

Note than an increase of 10 dB is perceived as a doubling of the noise level, in terms of the logarithmic decibel (dB) scale. An increase of 6 dB is considered to be a serious community issue.

Noise Standards and Regulations

There are both standards for measuring sound power levels from wind turbines and local or national standards for acceptable noise power levels. There are also accepted practices for modeling sound propagation.

These include:

1. American Wind Energy Association Standard: Procedure for Measurement of Acoustic Emissions From Wind Turbine Generator Systems, Tier I - 2.1 (AWEA, 1989)

2. International Electrotechnical Commission IEC 61400-11 Standard: Wind turbine generator systems – Part 11: Acoustic noise measurement techniques (IEC, 2001). Additional parts of IEC 61400 deal with other wind turbine concerns.

Sleep Disturbance

The Institute of Environmental Medicine at Stockholm University prepared an extensive volume for the World Health Organization (WHO) on the impact of community noise on people's health. They report that noise exposure can affect sleep in several ways, including:

- Increasing the time needed to fall asleep
- Altering the cycle of sleep stages
- Decreasing the quality of REM sleep

Over extended periods of time, any one of these problems could lead to more serious health issues.

The study further reports that:

- Noise levels of 60 dB(A) wakes 90% of people after they have fallen asleep.
- Noise levels of 55 dB(A) affects REM cycles and increases time to fall asleep.
- Noise of 40-45 dB(A) wakes 10% of people.

Sound Pressure Limits

The World Health Organization recommends that the nighttime level of continuous noise at the outside a dwelling should be 45 dB(A) or less, and inside, 30 dB(A) or less. This 45 dB(A) level is the overall sound pressure level.

A problem is that pure tones can still be annoying even though the overall level is within the 45 dB(A) limit. Wind turbines are capable of emitting pure tone noise, as previously mentioned.

Some community noise standards thus require the operator to modify the wind turbine to attenuate the pure tone amplitudes, or to reduce the overall level to 40 dB(A) as an alternative.

(Reference: Paul Gape, Wind Power: Renewable Energy for Home, Farm, and Business; Chelsea Green Publishing, 2004.)

U.K. standards require that wind farm noise should be limited to 5 dB(A) above background for both day and nighttime, except in low noise environments where the day-time limit should be limited to an absolute level within the range of 35-40 dB(A). Pure tone penalties are from 2-5 dB(A).

A unique characteristic of wind farms is that the noise level from each wind turbine increases as the wind speed at the site increases. As an offset, the background noise also generally increases under these conditions and can mask the turbine noise.

Comparison with a base noise level alone will therefore not be sufficient to indicate the potential impact of a wind farm. A farm could comply with this base level at lower wind speeds but exceed it when the wind speed rises.

Measured Wind Turbine Noise Levels

A number of wind turbine noise measurements are available on the Internet. The measurements are affected by a number of variables including:

- Wind speed & direction
- Temperature profile vs. height
- Number of wind turbines
- Orientation: upwind or downwind
- Transmission Type: direct-drive or gearbox
- Turbine Rotational speed
- Blade tip velocity
- Distance and direction from the wind mill to the measurement location
- Ambient noise

Sample measurements are given in Table 1.

Table 1. Sample Sound Pressure Measurements	
35 to 45 dB(A), Wind farm at 350 meters (1150 feet)	Information taken from The Scottish Office, Environment Department, Planning Advice Note, PAN 45, August 1994 http://www.bwea.com/ref/noise.html
54 to 55 dB(A), at 300 feet (91 meters), 25 mph wind, 10 kW BWC Excel wind system	Karl Bergey http://www.awea.org/smallwind/toolbox/windzone/noise.htm
50 to 60 dB(A), over one-half mile away (805 meters), Meyersdale, PA, 20-turbine wind farm	Oguz A. Soysal, Professor and Chairman of the Dept. of Physics and Engineering at Frostburg State University in Maryland http://www.windturbinesyndrome.com/?p=76

Effects of Temperature Gradients and Wind

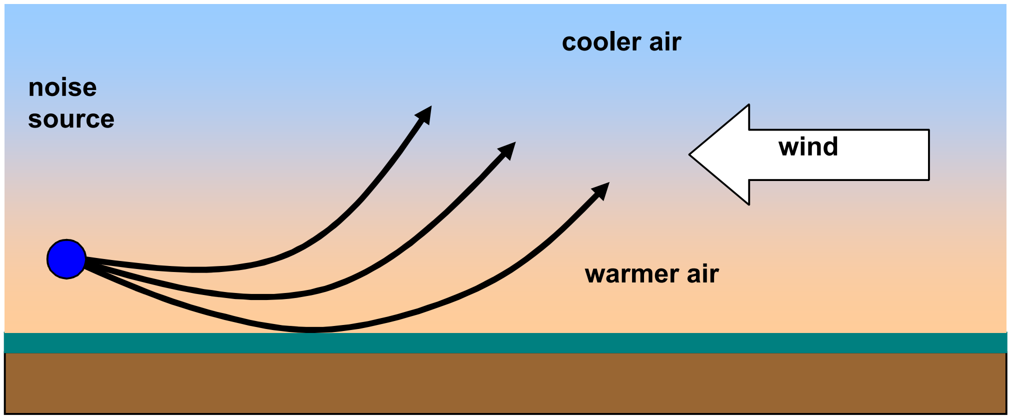


Figure 5. Normal Temperature Condition

The speed of sound typically changes with the height above the ground. Usually, the temperature decreases with height, which is the adiabatic lapse condition. This causes the sound waves to bend, or refract, upward. A similar effect occurs if the sound waves propagate upwind. This effect is favorable for people living near wind farms.

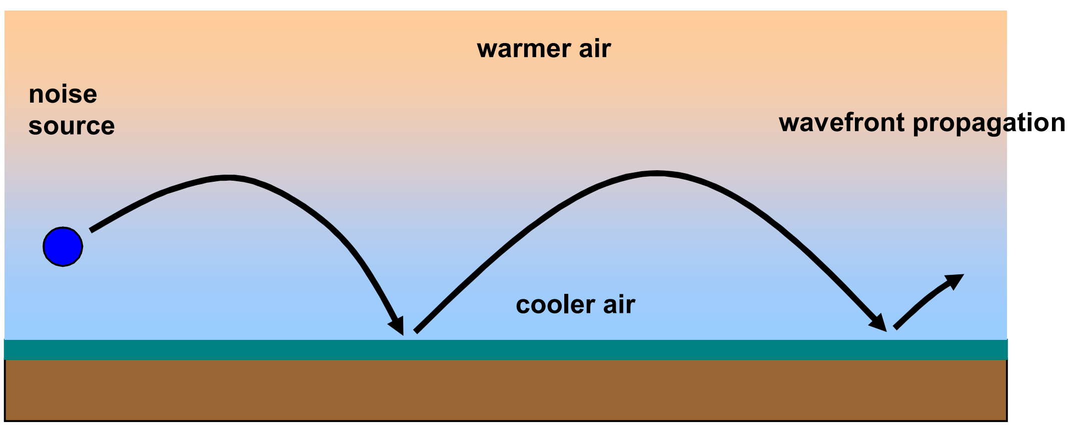


Figure 6. Temperature Inversion

The effect of a temperature inversion is shown in Figure 6. The ground-level air temperature is cooler than the high-level air. Only a sample acoustic ray is shown in Figure 6, but others would have similar patterns.

An inversion occurs when radiation from the surface of the earth exceeds the amount of radiation received from the sun, which commonly occurs at night, early morning, or during the winter when the angle of the sun is very low in the sky.

Wind turbine noise could thus propagate over long distances if the atmosphere is in a temperature inversion. This is a nuisance for people in the surrounding areas.

Sound Files

Numerous videos of wind turbines are posted on YouTube. The quality of the corresponding audio tracks tends to be marginal.

In each case, the person making the recording seems to have a bias toward proving that the wind turbines are either quiet or noisy.

Some recordings are made almost directly under the wind turbine in order to emphasize the nuisance of the sound.

Many of the recordings also have a simultaneous narration which diminishes the scientific value of the recording in terms of post-processing signal analysis.

Some of the recordings also have barking dogs, chirping birds, and automobile traffic noises.

Furthermore, the microphone was not adequately shielded from the wind in many of the recordings.

Nevertheless, the recordings demonstrate that some wind farms generate annoying sounds while others produce rather benign noises.

Sample Wind Farm Noise Data

Wind farm recordings were made by Ed Sliwinski at Wethersfield Road, Fenner, New York. The recordings were made one year apart.

The recording equipment was uncalibrated so a dB level cannot be determined.

The wind farm generated a swishing sound during the first recording session. The resulting time history and sound pressure level are shown in Figures 7 and 8, respectively.

The wind farm generated an eerie screeching noise during the second session, as shown in the spectral function in Figure 9.

Conclusion

Man needs both "green" power sources and peaceful sleep. Moderation is needed to balance the competing needs.

Wind turbines located anywhere near homes should be of the upwind design to eliminate the low-frequency, impulsive, thumping noises which are emitted by downwind turbines.

Wind turbines should also have well-insulated and well-damped nacelle enclosures to minimize the tonal noise transmitted from the gearbox and electromagnetic generator.

The enclosures should also be designed to reduce the whistling effects which may occur as the wind passes over slits and holes.

Blade geometries can also be designed to reduce broadband aerodynamic noise.

Communities can also enact regulations that establish a "setback" distance for wind farms of, say, 1.25 miles (1.6 km) from the nearest home. Such a requirement would be somewhat problematic, however. Eventually housing developments might encroach upon the buffer zones.

The likelihood of temperature inversions should also be considered with regard to the setback distance.

Sample Plots

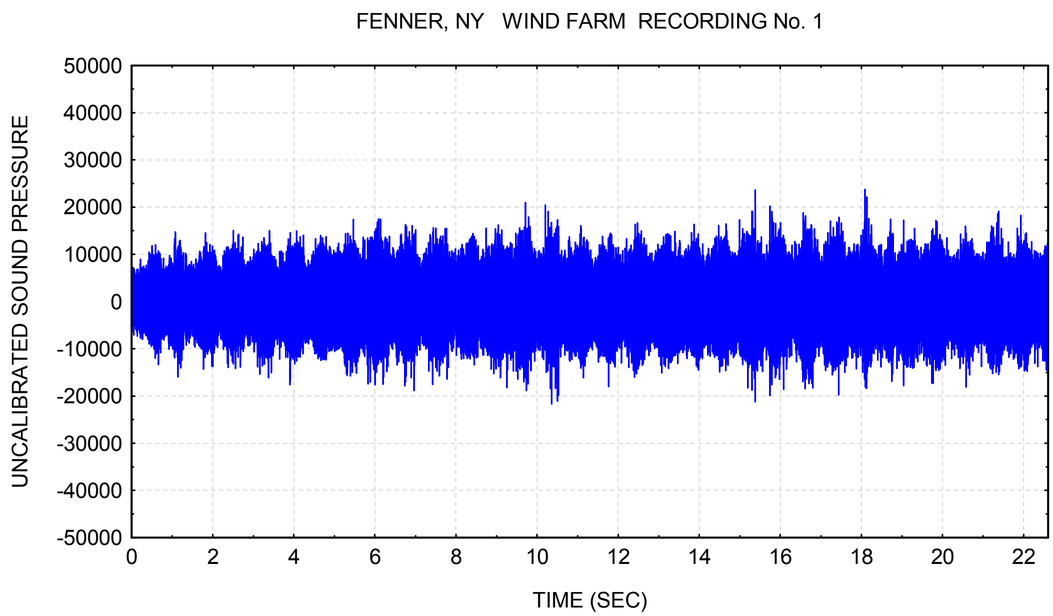


Figure 7.

The data is broadband random due to aerodynamic turbulence effects.

The amplitude modulation reveals the blade passing frequency which was approximately 1.5 Hz. There are three blades. Thus, the rotor hub frequency was 0.5 Hz (30 rpm). This agrees with the corresponding video posted at:

http://www.youtube.com/watch?v=kVhAvos66W4&feature=PlayList&p=40643D0583E9846C&playnext=1&playnext_from=PL&index=10

The video contains the data for both of the recordings.

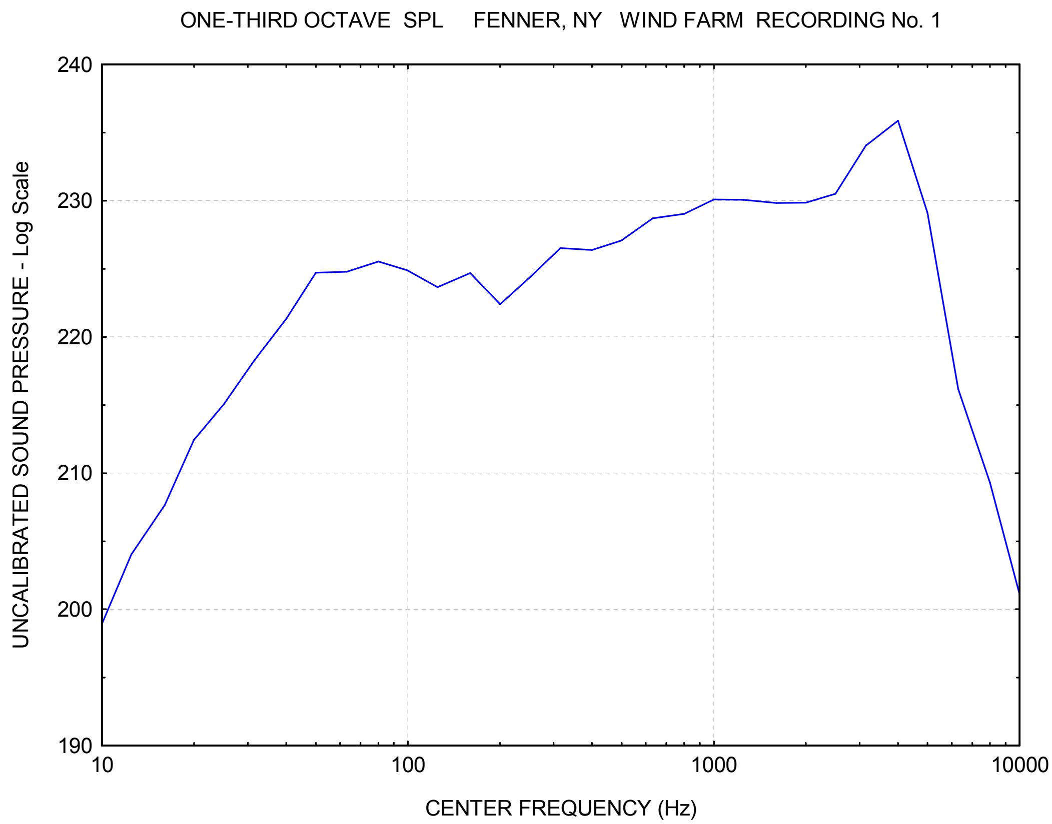


Figure 8.

Again, the data is broadband random. The data was taken over a 22.5 second duration.

A corresponding narrowband spectral plot is omitted for brevity.

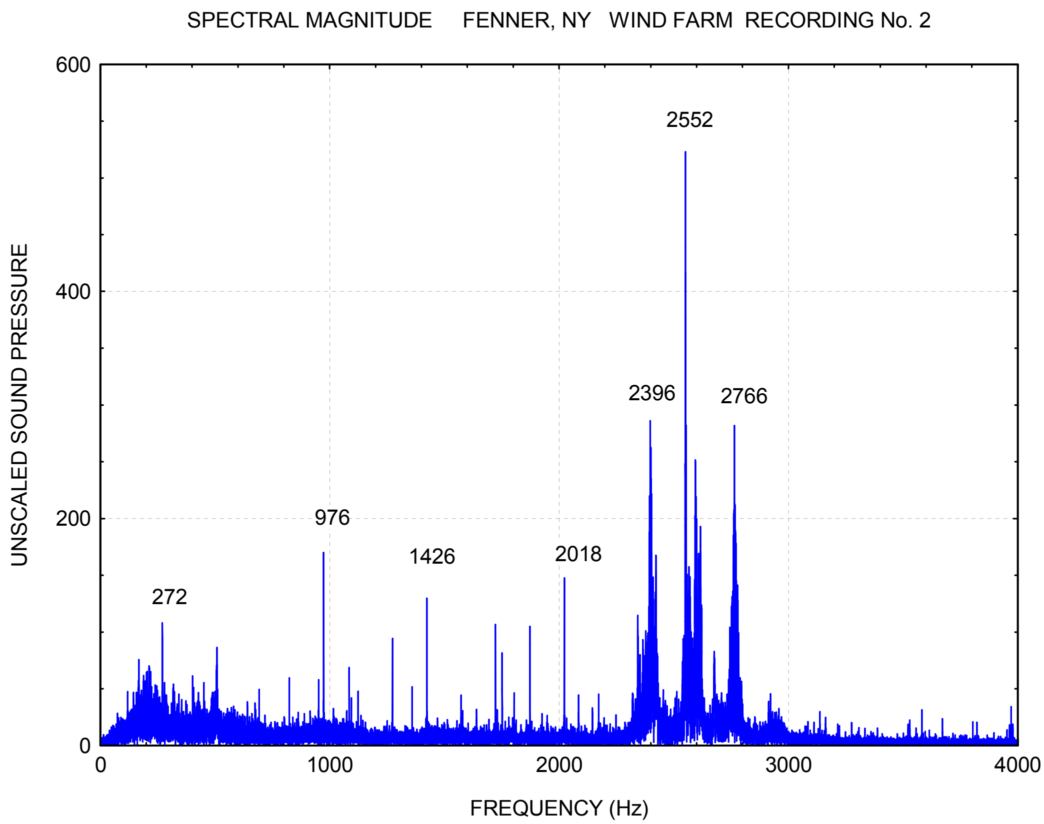


Figure 9.

The data is shown in a narrowband spectral magnitude function, which is appropriate for tonal data. The data was taken over a 15 second duration.

Each annotated number represents the spectral frequency in Hertz.

The rotational speed may have again been to be about 30 rpm, but this was difficult to determine because fog obscured the view of the wind turbines in the video. The spectral function did not yield a clear pattern of blade passing frequencies.

The spectral function is dominated by irregularly-spaced pure tones. The tones could be due to gear meshing frequencies, worn-out bearings, and to the passage of the wind over holes and slits. Airfoil self-excitation could be another source of the tonal noise.

The resulting sound was indeed very annoying to the author.

The reader may thus draw his or her own conclusions by viewing the video via the link in the caption for Figure 7.