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Engineer Research and Development Center

Acoustics Training Presentation for the Range Managers ToolKit (RMTK) Noise Tool

Michelle Swearingen

November 2006

Construction Engineering Research Laboratory

Approved for public release; distribution is unlimited.

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Final report

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Abstract: This Special Report contains the presentations and supplemental materials used during a Noise Training course. This course was held from 15-17 February 2005. The purpose of the course was to educate personnel from the Army Sustainable Range Program (SRP) Regional Support Center (RSC) and U.S. Marine Corps who were to support the Range Managers ToolKit (RMTK) Noise Tool.

This report was requested by the Army Training Support Center (ATSC) to act as a reference to the support personnel and to temporarily educate replacements in the event of a personnel change until another formal training course is offered. Funding for this report was provided by ATSC.

Contents

Preface

This report is a deliverable product under Military Interdepartmental Purchase Request (MIPR) order #21/2020/220/MIPR6FOPSD2105 from Headquarters, Department of the Army (DAMO-ZCA-M) for “ATSC LTD Range Managers Tool Kit Tech Support.” The Technical Monitors were Mr. Jason Walters and Mr. William Karnes, Army Training Support Center (ATSC).

This report was prepared by Dr. Michelle Swearingen, Ecological Processes Branch (CN-N), Installations Division (CN), Construction Engineering Research Laboratory (CERL), U.S. Army Engineer Research and Development Center (ERDC), under the general supervision of Alan B. Anderson, Chief CN-N; Dr. John T. Bandy, Chief CN, and Dr. Ilker Adiguzel, Director, CERL. Technical supervision was provided by Robert M. Lacey, Program Manager and Dr. Larry L. Pater, Project Manager.

COL Richard B. Jenkins was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

1 Introduction

This Special Report contains the presentations and supplemental materials used during a Noise Training course. This course was held from 15-17 February 2005. The purpose of the course was to educate personnel from the Army Sustainable Range Program (SRP) Regional Support Center (RSC) and U.S. Marine Corps who were to support the Range Managers ToolKit (RMTK) Noise Tool. The instructor for the course was Dr. Michelle E. Swearingen.

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The author gratefully acknowledges the assistance of Dr. Larry Pater, Dr. Michael J. White, Edward Nykaza, Dr. George Swenson, Samantha Rawlings, and Jeffry Mifflin for their help in proofreading the original presentation materials and assisting in demonstration set-up.

2 Why is Noise Important?

Why is Noise Important?

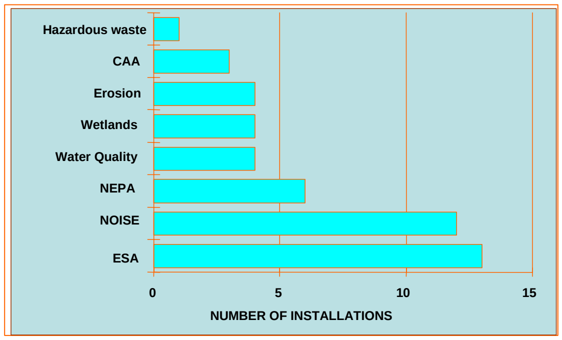
Since we're here to talk about noise, it seems like a good idea to start with why noise is important.

What is Sound/Noise?

- According to Webster:
  - Sound (n.) [Latin *sonus*] a vibratory disturbance in the pressure and density of a fluid or in the elastic strain in a solid, with frequency in the approximate range between 20 and 20,000 hertz, capable of being detected by the organs of hearing.
  - Noise (n.) [Latin *nausea*] sound or a sound that is loud, disagreeable, or unwanted.

But first, let's define noise. There is a distinction between sound and noise, although the two terms are frequently used interchangeably. Noise is an unwanted sound.

AEPI SURVEY:
ENVIRONMENTAL REQUIREMENTS
IMPACTING TRAINING



AEPI = Army Environmental Policy Institute. Noise was the #2 environmental impact on training in the study in the mid-1990's. The Endangered Species Act was the #1 impact. Noise is frequently considered an adverse effect on TES, so it is assumed to be included as a portion of the ESA impact. This indicates that noise is a significant issue for training.

Military Noise Attributes

- Unique to the military
- Complex
- Requires special tools and knowledge
- Noise travels long distances

There will be much more information on this later in the course, but the short answer here is that no one else makes the same noises that military training makes. Army training noise, particularly live fire, generates high amplitude (loud) impulsive (short duration) noise that can travel very long distances. These distances can easily be 10's of miles for large weapons.

IMPACTS ON SUSTAINABLE TRAINING CAPABILITY

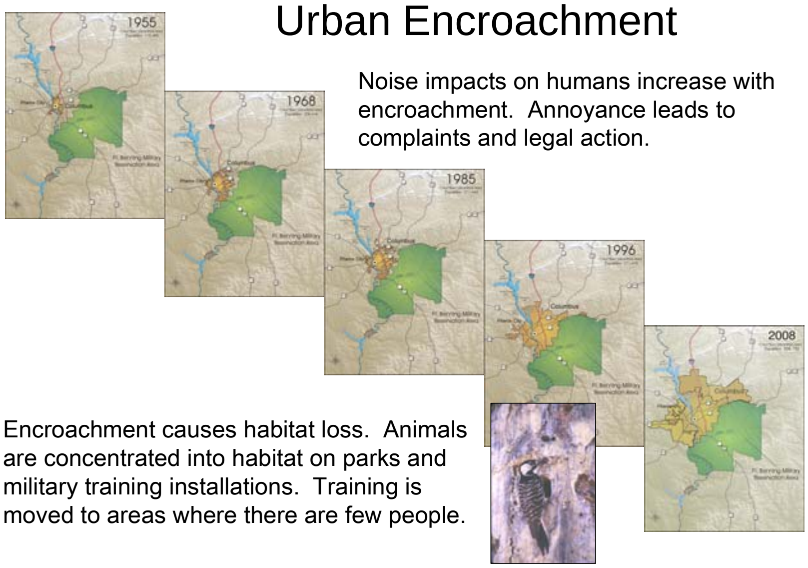

- Noise restricts training and diverts mission funds.
- Installation response to complaints: insidious schedule restrictions and range & firing point closures. We “own the night” but night training is restricted.
- AEPI survey: Inability to manage noise caused significant operational impact at critical training and projection platform installations. Noise problems will rapidly worsen. Noise is a leading environmental problem constraining Army training.
- Army Claims Service: Noise damage claims rapidly increasing.
- SROC: Noise is a major training impact. Directed Service Secretariats stand up a DOD Noise Program.
- Lack of noise management resources will have growing consequences for sustainable training capability.



This graphic points out several impacts of noise on sustainable training capability.

Urban Encroachment

Noise impacts on humans increase with encroachment. Annoyance leads to complaints and legal action.

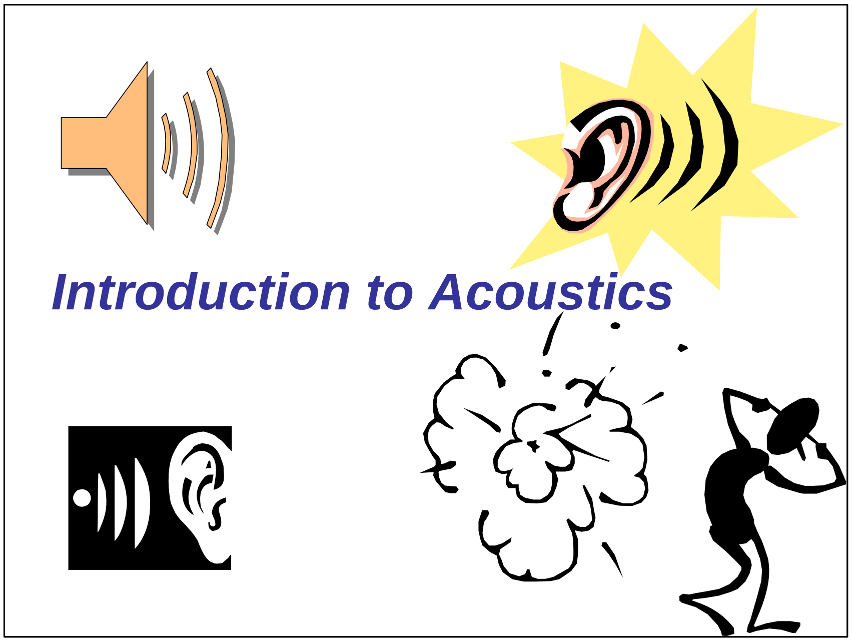


Encroachment causes habitat loss. Animals are concentrated into habitat on parks and military training installations. Training is moved to areas where there are few people.

This series of maps depict Fort Benning, Georgia, and the urban growth that surrounds it. As you can see, in 1955 Fort Benning was fairly isolated, but by 1996 there was a significant population abutting the northwest boundary. This trend is expected to continue, both at Fort Benning and at the majority of military installations.

This problem exists for all branches of DoD.

3 Introduction to Acoustics

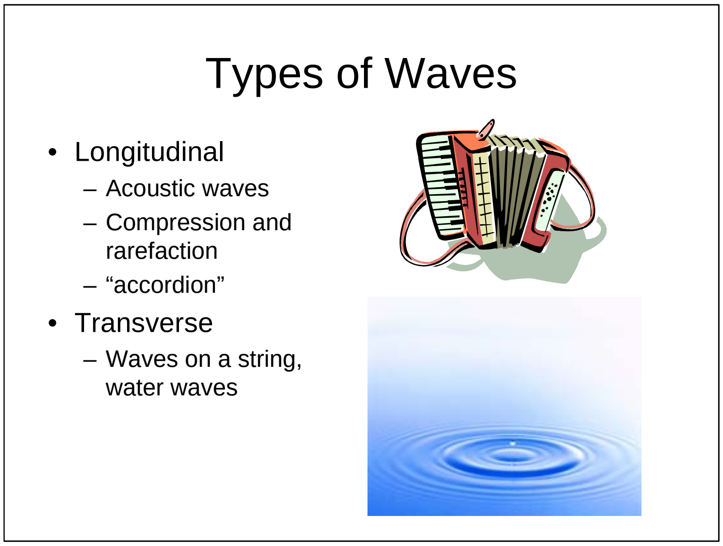


During this portion of the course we are going to talk about the basic terminology of acoustics. This material contains the building blocks for the rest of the course.

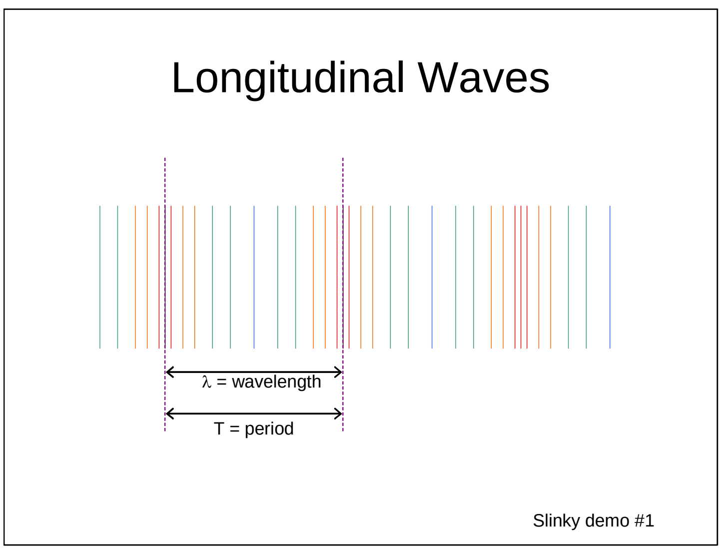
What is Sound?

- Pressure fluctuation
- Transmits through a medium
  - Gas (air)
  - Liquid (water)
  - Solid (ground)
- Ear processes pressure waves, brain interprets as “sound”
- Or microphone receives pressure waves, converts to voltage

These are the most basic definitions of sound. Sound is pressure fluctuation that transmits through a medium.



Sound propagates in waves. They are actually vibrations at one location that excite vibrations at the next. No particles actually travel over long distances; it is the vibratory disturbance that travels. There are two types of waves: longitudinal and transverse. The next two graphics will describe these two wave types.

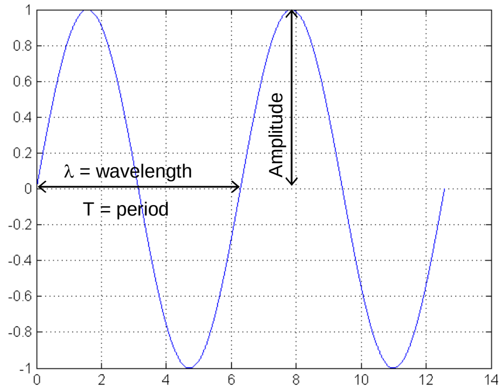


We can use a slinky to show longitudinal pulses. This is done by fixing one end of the slinky on a table and moving the other end forward and backward to create compressional waves. Notice the compression and expansion of the coils. This is like a pressure wave in air.

The wavelength is in units of distance. This is the amount of space the wave progresses before repeating.

The period is in units of time. This is the amount of time the wave continues before repeating.

Transverse Waves



Slinky demo #2

Keeping one end of the slinky fixed, now slide the other end of the slinky back and forth on the table perpendicular to the direction of the slinky at rest. This creates transverse waves. It is much easier to see the amplitude, or strength of vibration, and the wavelength. Examples of transverse waves are waves on a string or in water.

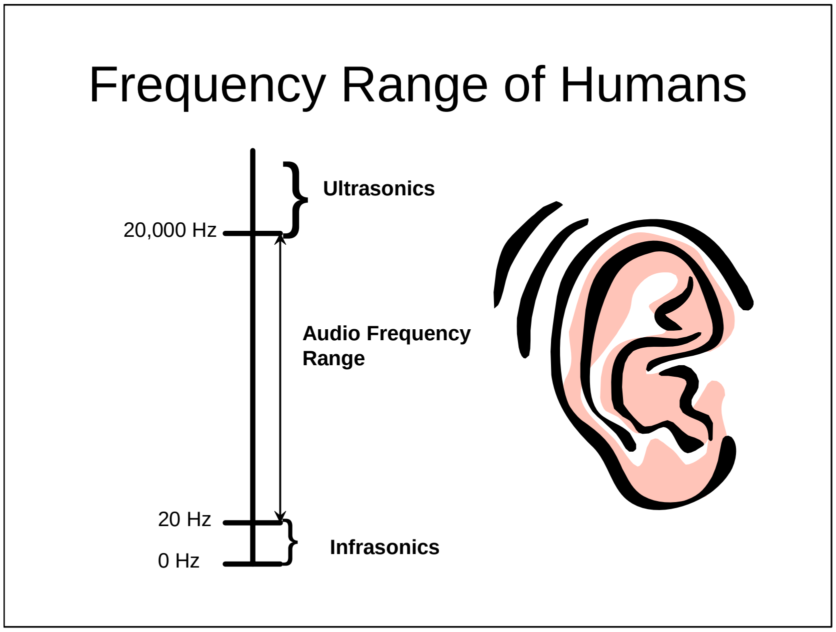
Characteristics of a Wave

- Period: T (s)
  - Time between repeats
- Wavelength: λ (m)
  - Distance between repeats
- Amplitude: (Pa)
- Frequency: f (Hz)
  - # cycles / second
  - 1/T (1/s)
- Wave speed
  - $c = \lambda f$ (m/s)

Slinky demo #3

These are the basic relationships between frequency and wavelength. Using the slinky in the transverse mode, move faster to get shorter wavelengths. Notice that the faster you oscillate the slinky the smaller the wavelength becomes. If you oscillate the slinky very slowly, the wavelength will lengthen.

Frequency is the number of periods per second, or cycles per second. This is the number of times that the wave repeats in one second.



Your ear has an incredible range of sensitivity. A typical ear can hear frequencies from 20 Hz up to 20,000 Hz.
A 30 Hz sound is a low rumble, like thunder. A 10 kHz (10,000 Hz) sounds like a high squeal. Speech is typically in the 1 kHz (1000 Hz) region.

Sound Speed

- ~343 m/s, ~770 mph
- Varies with:
  - Temperature $\sim\sqrt{Temperature}$
  - Bulk flow (wind speed and direction)
  - Humidity
- This will be important later

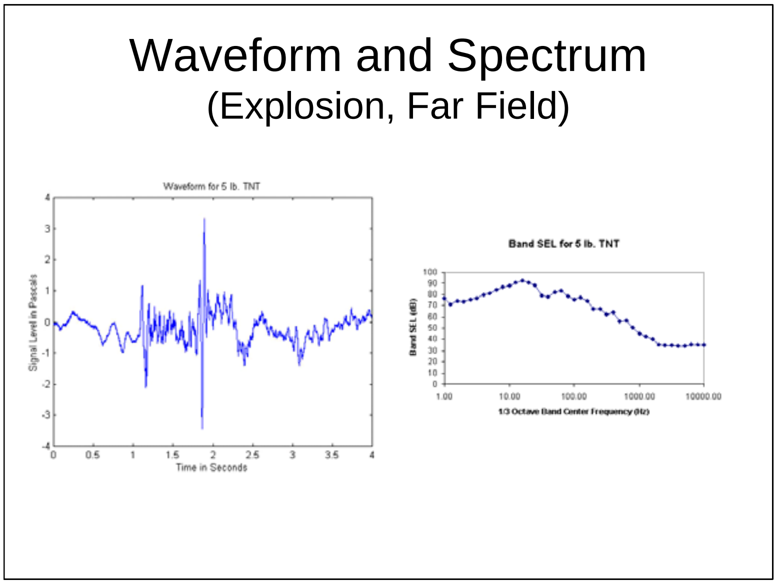
This relationship between temperature and sound speed is critical for outdoor propagation. Temperature varies with height, which impacts where the sound will go. There will be much more on this in a later portion of the course.

Sound Characterization

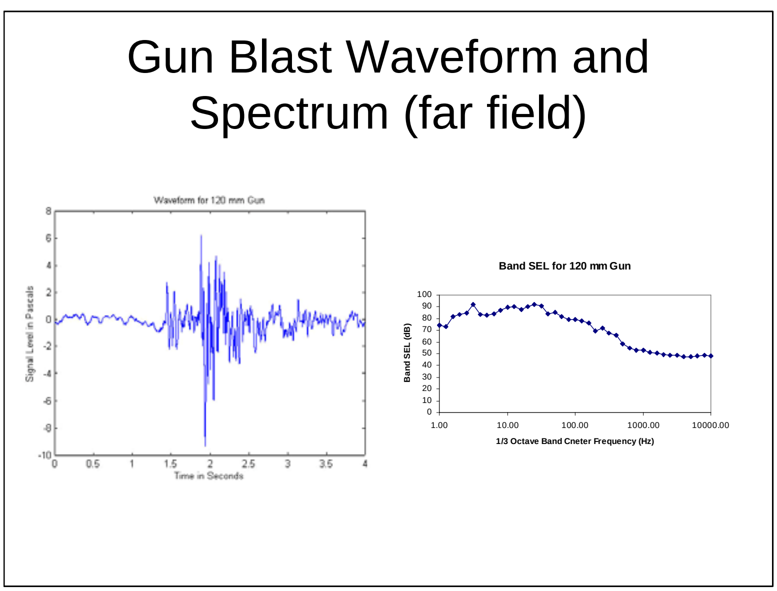
- Pressure Waveform
  - Amplitude
  - Duration
  - In the time domain (s)
- Frequency Spectrum
  - Energy distribution with respect to frequency
  - In the frequency domain (1/s)
- Convert between waveform and spectrum with Fourier transform

There is a relationship between the time and frequency domains called a Fourier Transform.

Exercise: Using an oscilloscope, capture a hand-clap wave form. This will look like a sharp pulse. Use the oscilloscope to perform a Fourier transform of the signal. There will be energy in a wide range of frequencies. This impulsive sound can be defined as “broad-band.” Now capture a waveform from a vibrating tuning fork. This will look essentially like a continuous sine wave. Again, use the oscilloscope to perform a Fourier transform of the signal. Now the energy will be in discrete bands, with a large spike at the resonant frequency of the tuning fork and much lower spikes at harmonic frequencies. This continuous sound can be defined as “single frequency,” as the harmonics are severely damped.

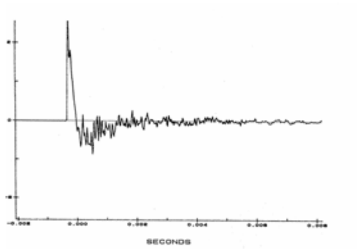


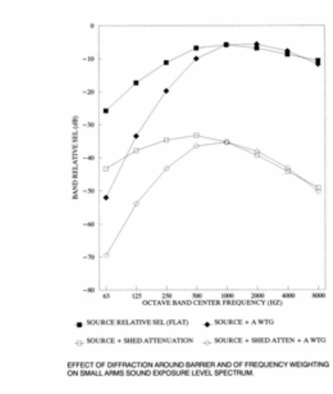
These figures show representations in both the time and frequency domains. The time domain representation is on the left and the frequency domain representation is on the right. This example is a moderately large block of TNT. In particular here, note the low frequency content on the figure to the right. This is characteristic of large explosions and artillery fire. Because the waveform here was measured in the far field, you see multiple arrivals, indicating multiple paths. There will be more on this later.



Again, notice the low frequency content. This is a large weapon. This and the previous graphic show that we can pretty effectively model large weapon noise by using bricks of Composition C4, which is a simpler explosion and easier to deal with in our models.

Waveform and Spectrum
(Rifle)

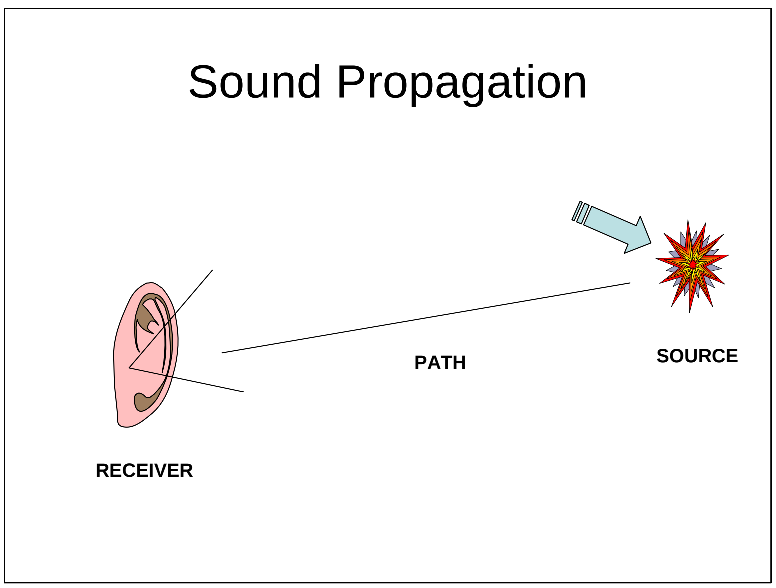




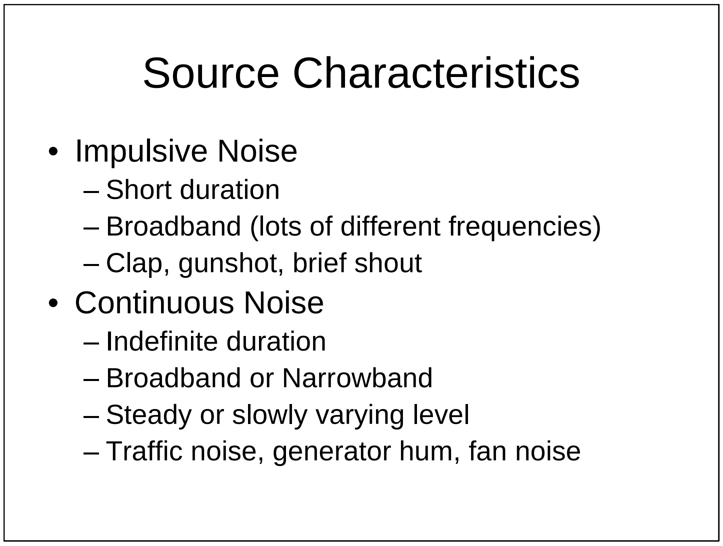
This shows a typical waveform more clearly. This is measured fairly close to the source. On the spectra, notice that there is a lot of energy in the 500-1000 Hz range. This corresponds to smaller wavelengths, and also more potential mitigation strategies. The other curves on the figure to the right are frequency weighted to better represent what a human ear would hear. We'll talk more about frequency weightings later.

4 Acoustic Sources

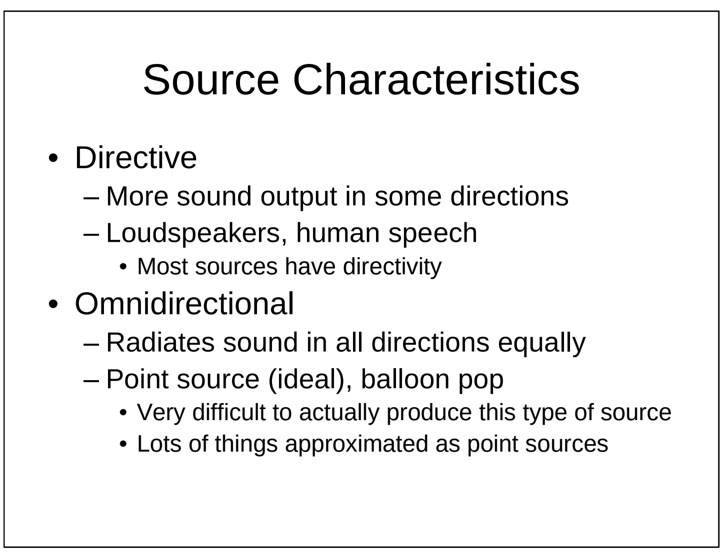
The military has several loud acoustic sources. Because the RMTK Noise Tool can currently handle only large weapons and demolitions, we will focus on sources of those types.



With any sound, there is a source, a path, and a receiver. All of these things influence the impact of the sound. In this section we will learn about acoustic sources and their characteristics. In later sections we will learn about the path (propagation), and the receiver.



There are many different types of acoustic sources. Essentially, anything that makes a sound can be considered an acoustic source. There are several characteristics of sound sources that we will cover in this section. The first two relate to duration. They are Impulsive Noise and Continuous Noise. Impulsive noise is short in duration. Examples of this are a clap, a brief shout, or a gunshot. Continuous noise has an indefinite duration, characterized by a steady or slowly varying perceived level. Traffic noise, generator noise, and fan hum are all examples of continuous noise.



Acoustic sources have something called directivity associated with them. They can be directive, like a loudspeaker or a human mouth, or omnidirectional, like a balloon pop. A directive source has more energy going in specific directions than in other directions. An omnidirectional source has equal sound energy going in all directions.

Source Characteristics

- Low amplitude
  - Most sounds
  - Speech, background noise, traffic noise
- High amplitude
  - Non-linear effects
  - More complicated propagation

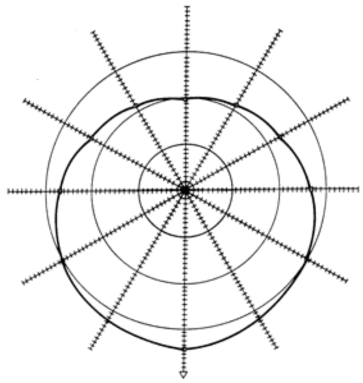
The amplitude of the sound wave determines the loudness. For extremely loud sounds, non-linear effects are significant. These non-linear effects create more complicated propagation.

Military Sources

- Large weapon noise is:
  - Impulsive
  - High amplitude
  - Directive
  - Projectiles may produce ballistic shock
- This is what we need to explore

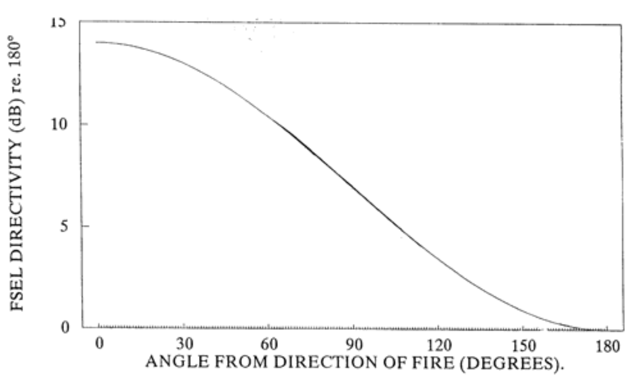
Now that we've gone through the basics of acoustic sources, we can talk about military training noise in particular. Weapon firing noise has the characteristics listed on the graphic. Very few other acoustic sources have these particular characteristics, and so not many organizations are interested in studying them.

Muzzle Blast Directivity Pattern



Tank firing noise is typically louder in front than in back, sometimes by as much as 15 dB. This is very significant! We will get into more detail about decibels later, but just as a quick reference, your ear can easily detect a 3 dB change, and an increase of 10 dB sounds like a doubling in loudness. The strong directivity indicates that the direction of fire is important in terms of where the sound goes.

Bare Muzzle Blast Directivity



Model for Gun Muzzle Blast Far Field Directivity.

This is simply another picture of directivity, different representation, this time with levels marked.

Muzzle Blast Directivity

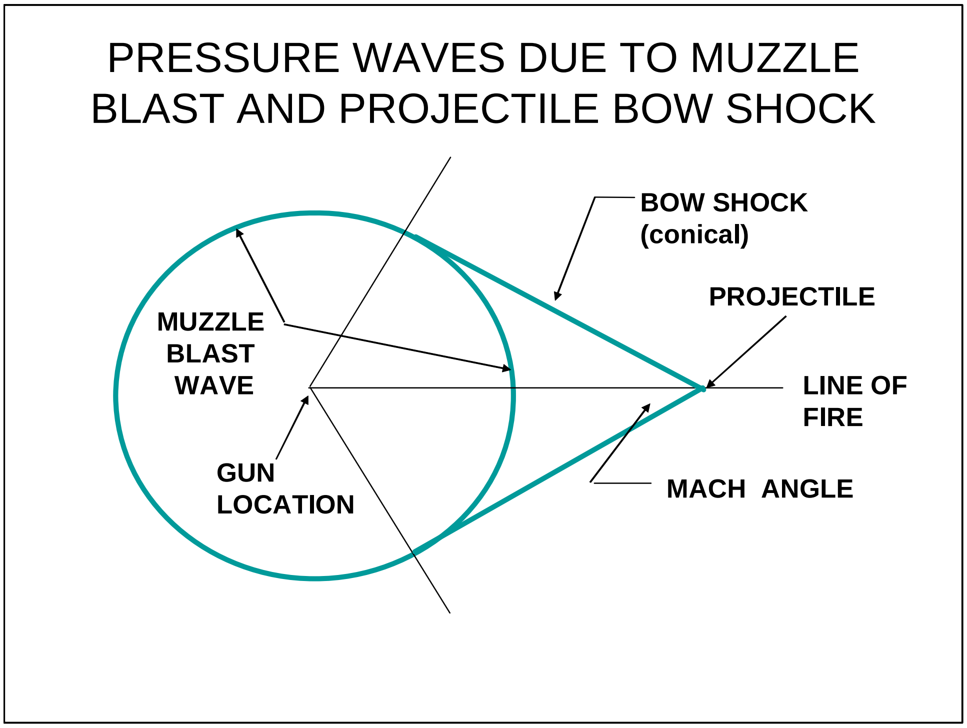
- Visually, blast is spherical
- Acoustically, the energy distribution is directive.
  - Annularly symmetric about the gun tube
- Different if a muzzle brake is used

The acoustic energy does not dissipate like the smoke from the blast.
A muzzle brake will send more energy off to the sides than to the front.

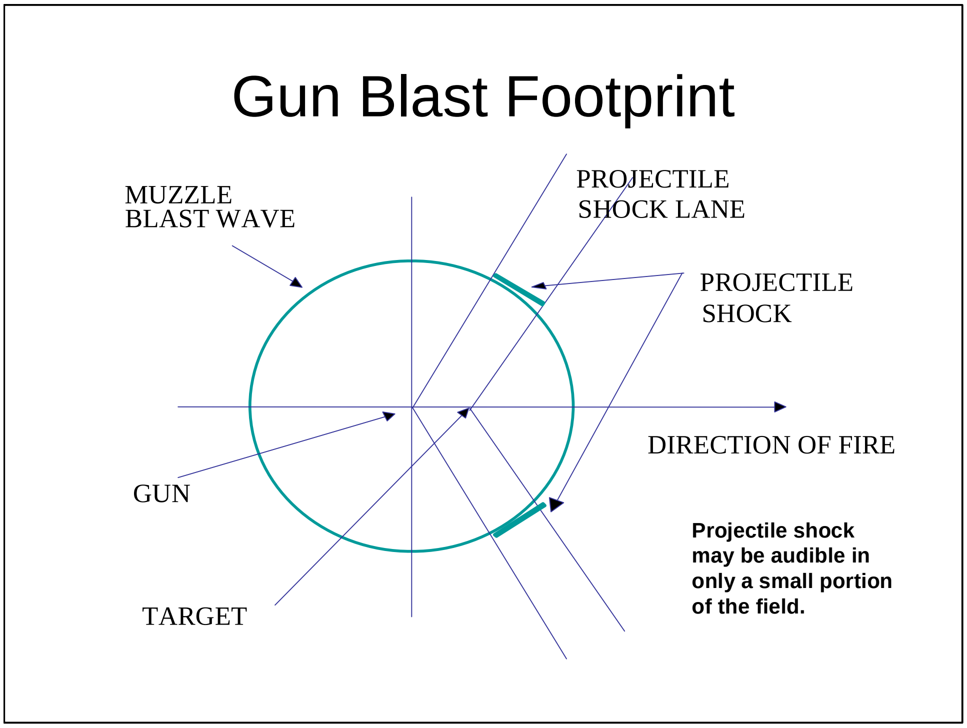
Ballistic Shock Waves

- Shock waves can and do form from ballistics
- Send additional energy in other directions
- Shock waves occur as the projectile travels faster than the speed of sound
- Smaller scale than supersonic aircraft shock, but still noticeable
- Limited area affected

When looking at a noise footprint on noise assessment software such as the RMTK Noise Tool, the ballistic shock waves look like “wings” on the footprint. Other names for ballistic shock waves are bow shock and sonic boom.

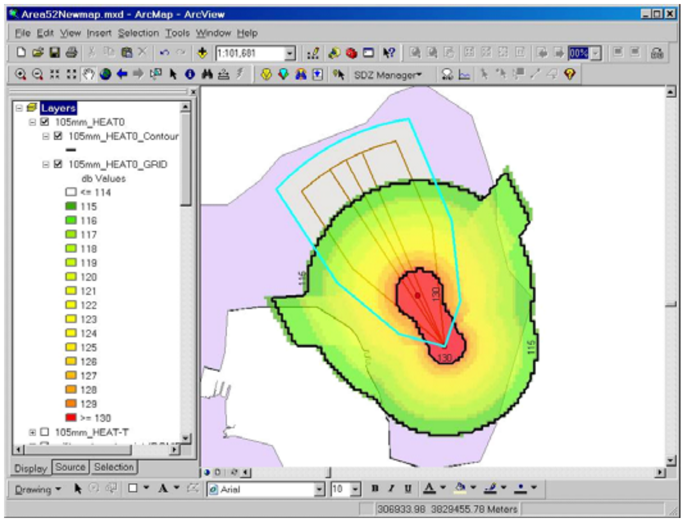


View of how a ballistic shock wave forms. The projectile is moving from left to right.



This is a top-down view of the shock wave.

Example from RMTK Noise Tool



The “wings” here are the ballistic shock alleys from the projectile paths.

Summary

- Sources can be
  - Impulsive or continuous
  - Low or high amplitude
  - Directive or omnidirectional
  - Broadband or Narrowband
- Large weapon noise is
  - Impulsive
  - High amplitude
  - Directive
  - Broadband
  - Lots of low frequency energy

5 Measuring Sound

Measuring Sound

In this section we will discuss several ways to measure sound.

How is sound described?

- Decibel scale
  - Logarithmic
  - The BEL is the logarithmic ratio of any quantity
  - The Decibel is one tenth of a Bel
  - Used in describing sound because of the large range of pressures and relation to how humans respond.

These are the basic definitions of how sound is described.

Decibels

Pressure into dB (decibels):

$$L=20\log_{10}(p/p_{ref})$$

Where $p_{ref}=20\ \mu Pa$ (20×10^{-6} Pa)

This is the standard reference level for air

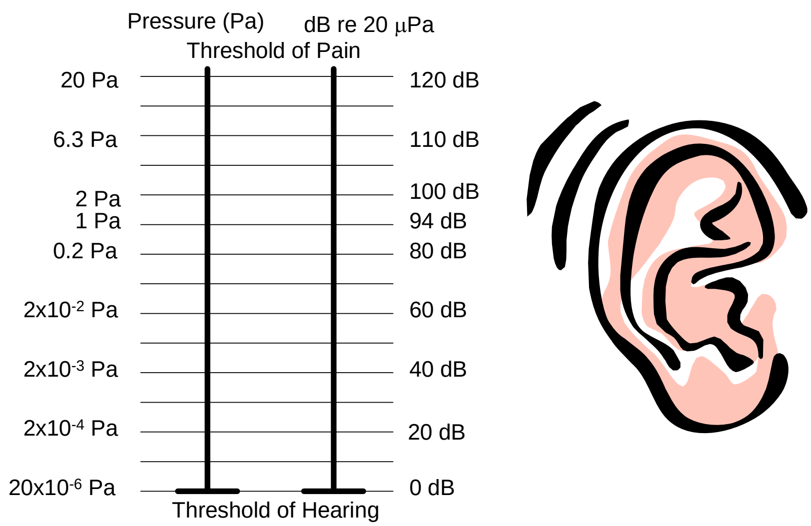
To get pressure out of dB:

$$p=p_{ref}10^{(L/20)}$$

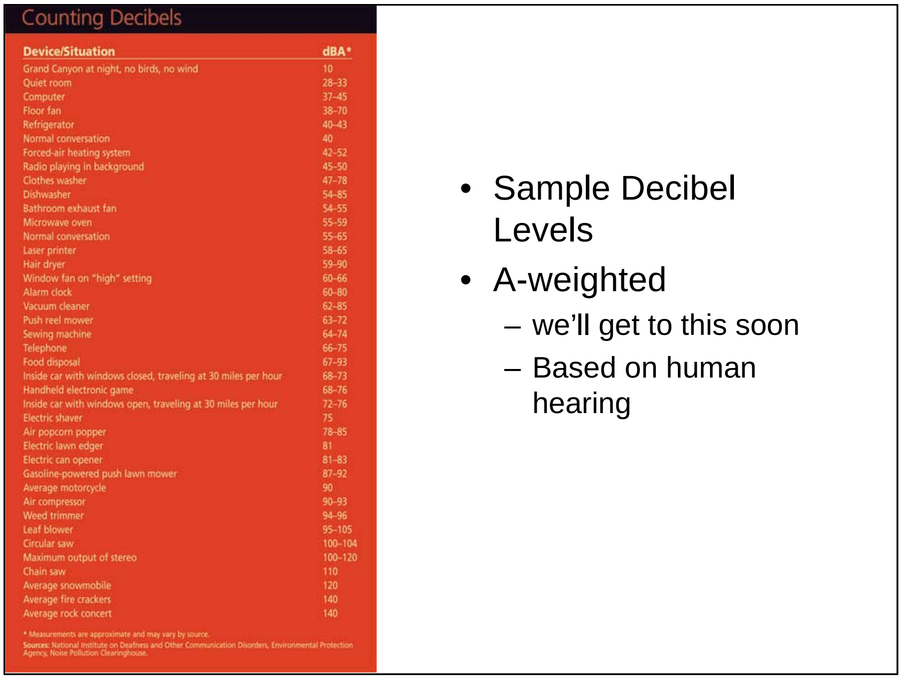
On a calculator, use “log” button, NOT “ln”!

This is the simple math that goes into calculating decibels. Pressure is denoted by p. L is the level in decibels (dB).

Pressure and Sound Levels



This shows the dB levels corresponding to pressures. The range of values shows why the log base 10 is used to describe sound levels.



Counting Decibels

Device/Situation	dBA*
Grand Canyon at night, no birds, no wind	10
Quiet room	28–33
Computer	37–45
Floor fan	38–70
Refrigerator	40–43
Normal conversation	40
Forced-air heating system	42–52
Radio playing in background	45–50
Clothes washer	47–78
Dishwasher	54–85
Bathroom exhaust fan	54–55
Microwave oven	55–59
Normal conversation	55–65
Laser printer	58–65
Hair dryer	59–90
Window fan on "high" setting	60–66
Alarm clock	60–80
Vacuum cleaner	62–85
Push reel mower	63–72
Sewing machine	64–74
Telephone	66–75
Food disposal	67–93
Inside car with windows closed, traveling at 30 miles per hour	68–73
Handheld electronic game	68–76
Inside car with windows open, traveling at 30 miles per hour	72–76
Electric shaver	75
Air popcorn popper	78–85
Electric lawn edger	81
Electric can opener	81–83
Gasoline-powered push lawn mower	87–92
Average motorcycle	90
Air compressor	90–93
Weed trimmer	94–96
Leaf blower	95–105
Circular saw	100–104
Maximum output of stereo	100–120
Chain saw	110
Average snowmobile	120
Average fire crackers	140
Average rock concert	140

* Measurements are approximate and may vary by source.
Sources: National Institute on Deafness and Other Communication Disorders, Environmental Protection Agency, Noise Pollution Clearinghouse.

Examples of sound levels.

The orange section of the graphic is presented on the following page.

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Electric can opener	81–83
Gasoline-powered push lawn mower	87–92
Average motorcycle	90
Air compressor	90–93
Weed trimmer	94–96
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Circular saw	100–104
Maximum output of stereo	100–120
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Average snowmobile	120
Average fire crackers	140
Average rock concert	140

* Measurements are approximate and may vary by source.

Sources: National Institute on Deafness and Other Communication Disorders, Environmental Protection Agency, Noise Pollution Clearinghouse.

Changes in Level

- 1 dB change, barely discernable
- 3 dB change, noticeable
  - - 3 dB every doubling of distance from a line source
- 6 dB change, easily perceived
  - -6 dB every doubling of distance from a point source
- 10 dB change, twice (+) or half (-) as loud

Audio demo #1

At this point, the class listened to a nice audio demonstration related to this graphic. The speaker on the demonstration speaks at the same level, stating his distance from the microphone. As he moves farther away, the sound level drops, as expected.

Addition of Decibels

- Add pressures, not decibels
  - Requires more complicated math
- Rules of thumb can be applied
  - See next slide

Addition of decibels is not mathematically valid. Instead, the pressures need to be added and then the decibel calculation needs to be performed again. However, there are some simple rules of thumb that will give a good estimate.

dB Addition

Values Differ by:	Add to Higher Value	Example
0 or 1 dB	3 dB	70+69=73
2 or 3 dB	2 dB	74+71=76
4 to 9 dB	1 dB	66+60=67
10 dB or more	0 dB (<1 dB)	65+55=65

These are the general rules of thumb in "adding decibels." While they are not entirely accurate, these rules of thumb are adequate for first pass answers and notional information.

Example

Paladin #1 has a peak level of 120 dB

Paladin #2 has a peak level of 122 dB

What is the total level?

When dealing with peak levels, the positive peak pressures need to overlap to get any potential for addition. In a blast, that time frame is really short.

Example (cont)

124 dB

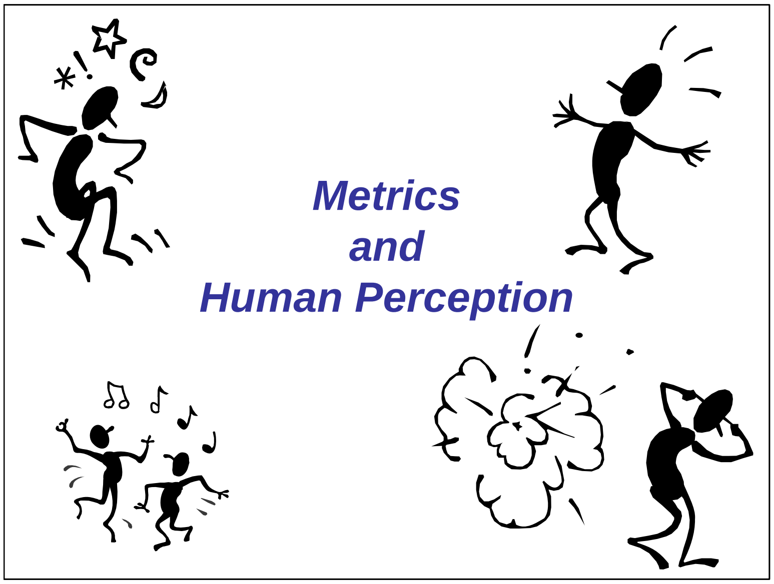
(120 dB + 122 dB = 124 dB)

IF the arrival times are concurrent

If the arrival times are not concurrent,
they are treated as two separate events.

This is important when dealing with impulsive noise. For a continuous noise, the addition is fairly straightforward since the time factor can be neglected. When dealing with impulsive noise, the time of arrival is vitally important.

6 Assessing Sound — Metrics, Perception, and Human Response



The figures on this graphic show the range of emotions associated with military training noise. They can be anger, surprise, desire for quiet, or celebration of the "sound of freedom."

What is a Sound Metric?

- Different ways to quantify sounds
  – Peak level
  – Time averaged
  – Frequency-weighted
- Different reasons
  – Duration of signal
  – Time of day
  – Perception

There are several different ways to quantify sound, each with a different rationale behind them.

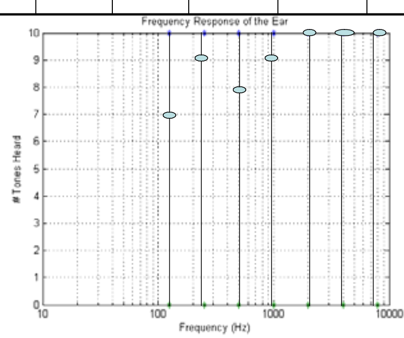
Human Hearing

- Perception is strongly related to human hearing. If you can't hear it, you are probably not annoyed.
  - – Not true if vibrations are involved
- Two major frequency weightings
  - – A: mimics human hearing
  - – C: allows low frequencies to count

We will talk more about frequency weightings soon. In general, a frequency weighting is a frequency-dependent scaling applied to a spectrum.

Frequency Response of the Ear

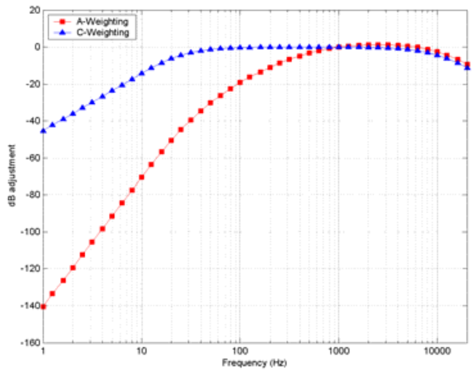
freq->	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
1							
2							



Audio demo #2

At this point, the class listened to an audio demonstration with pulses of decreasing loudness at different frequencies. Participants counted the number of pulses heard in each series, wrote each number in the appropriate box, then plotted. Results should look similar to the next graphic A-weighting curve, primarily with the low-frequency drop-off in sensitivity. Typically, people with military experience or who listen to lots of loud sounds for work or pleasure, will have a notch around 1-2 kHz. This is the most sensitive range for human ears, and therefore most susceptible to damage.

Frequency Weightings



These are classic frequency weighting curves.
A-weighting closely mimics the frequency response of a human ear for low- to mid-level sounds. You can see a slight increase around 2 kHz, and a steep roll-off below 100 Hz.
The C-weighting curve mimics the human ear response of loud noises. There is no enhancement at higher frequencies, and the low frequency roll-off is much slower.

Assessment Metrics

- L_{pk}, L_{pk15}
- SEL, ASEL, CSEL
- DNL, ADNL, CDNL
- There are others, too
- Can get confusing!

There are lots of different metrics for different reasons, as the following graphics show. The figure above indicates that these differences can be confusing and frustrating, and that information without an associated metric is useless.

L_{pk}, L_{pk15}

- Peak Level metric
  - Maximum instantaneous pressure
  - No time averaging
- L_{pk15} is the peak level exceeded 15% of the time
  - Based on weather statistics
  - Metric used in RMTK Noise Tool/RNIP

This is a single event metric. The RMTK Noise Tool uses Pk15(met), also written as L_{pk15}, the peak level only exceeded 15% of the time, based on weather statistics.

SEL, ASEL, CSEL

- Sound Exposure Level
  - Averaged over some time, referenced to 1 s duration
- ASEL is A-weighted
- CSEL is C-weighted
- Levels are lower than instantaneous peak for large weapon noise because duration of actual sound is so short (<<1 s)

Sound Exposure Level is a time-averaged metric.

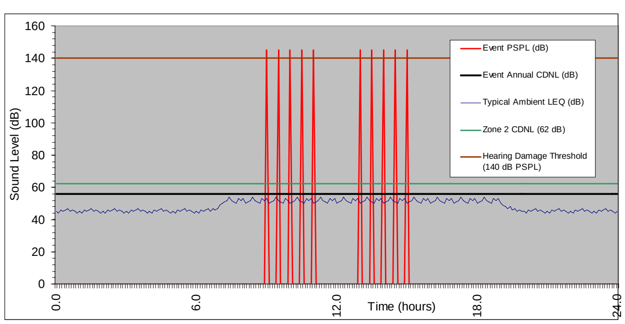
DNL, ADNL, CDNL

- Day-Night average sound Level
  - Twenty-four hour sound level for a given day, after addition of 10 dB to levels from 2200-0700 (10 pm until 7 am)
- Previously used in noise assessments
  - Based on transportation noise
    - Continuous, not intermittent
  - Does not work for military blast noise!
  - AR 200-1 is changing to reflect this

This is the old way of doing NEPA's and INMP's. AR 200-1 is changing this by requiring that this information be provided along with peak levels, but there is a lot of history here.

We are not using this assessment metric for the RMTK Noise Tool because research and experience have shown that people complain about noise events, not some "average level." This is probably because of the nature of the sounds involved. Remember, they are of short duration.

DNL example



This plot shows that even though the average noise is at an acceptable level, the eight events that go into the average all exceed the threshold for instantaneous permanent ear damage.

Why L_{pk15} for RMTK Noise?

- Long-term averages don't work for military noise
  - Impulsive
  - High amplitude
  - Intermittent
- Peak level has been shown to correspond to noise complaints
  - People complain about events, not "average noise"

Hand out Complaint Metric paper

The noise complaint metric handout (see page 33) describes the reasoning behind the use of peak levels in RMTK Noise in detail.

Impulsive Noise Guidelines

Predicted Sound Level, dB Peak	Risk of Complaints	Recommended Action
<115	Low risk of noise complaints	Fire all programs
115-130	Moderate risk of noise complaints	Fire important tests, postpone non-critical testing, if feasible
130-140	High risk of noise complaints, possibility of damage	Only extremely important tests should be fired
>140	Threshold for permanent physiological damage to unprotected ears. High risk of physiological and structural damage claims.	Postpone all explosive operations

This table contains the thresholds used for large weapons and demolitions in RMTK Noise. These are based on a small data set, with more corroborating data being taken at this time.

Perception of Noise

- Emotional variables
  - Feelings of necessity
  - Preventable
  - Judgment of importance/value
  - Sensitivity to noise
  - Feeling of fear
  - Belief of health effects
  - Environmental
- Physical variables
  - Type of neighborhood
    - Rural vs. Urban
  - Time of day
  - Season
  - Predictability
  - Length of exposure
  - Control over source

Noise can be perceived in several different ways, depending on the type and timing of the noise and the individual's perception of how necessary the noise is.

Effects of Noise

- Hearing loss
- Speech interference
- Scholastic performance
- Sleep loss
- Performance / Behavior
- May lead to noise complaints, which can impact training and readiness!

Negative effects of noise.

RMTK Noise Contour Criteria

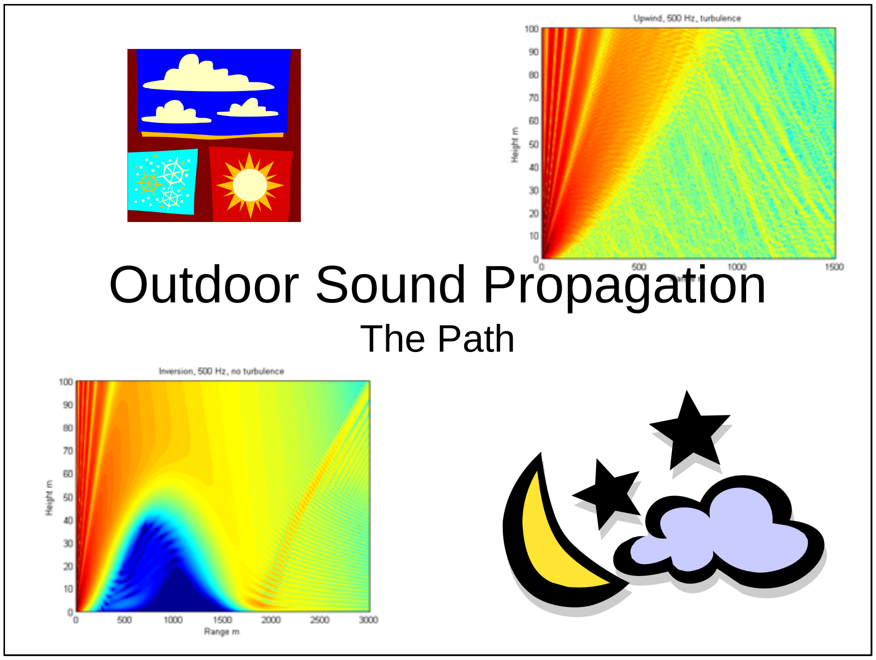
The Army has developed a set of criteria, based on experience and data gathered over a period of many years, for risk of receiving noise complaints due to blast noise from training and testing. These criteria state that as long as the noise level in the community is below a specified threshold level, the likelihood that the noise will evoke complaints is small (this risk is never zero). The likelihood of receiving noise complaints increases as noise levels become louder, until a second threshold level is reached at which noise complaints are very likely. For large weapons such as artillery and tanks, the complaint threshold levels are known with good reliability. A blast noise event for which the unweighted peak level is less than 115 dB is quite unlikely to evoke noise complaints. On the other hand, 130 dB is very likely to result in noise complaints.

Intuitively, the management of noise exposure might seem to be quite simple. Sound levels decay with distance, and a solution would be to locate noisy activity sufficiently far away from noise-sensitive areas. Unfortunately, blast noise levels from military weapons can be very loud, even at distances of many miles. A further complication is that weather greatly affects sound propagation and the resulting noise level at a given geographical location. Therefore, not only is it impractical to locate military noise sources far enough away from noise-sensitive areas to avoid complaints, it would still be possible, during certain weather conditions, to receive complaints due to favorable propagation conditions.

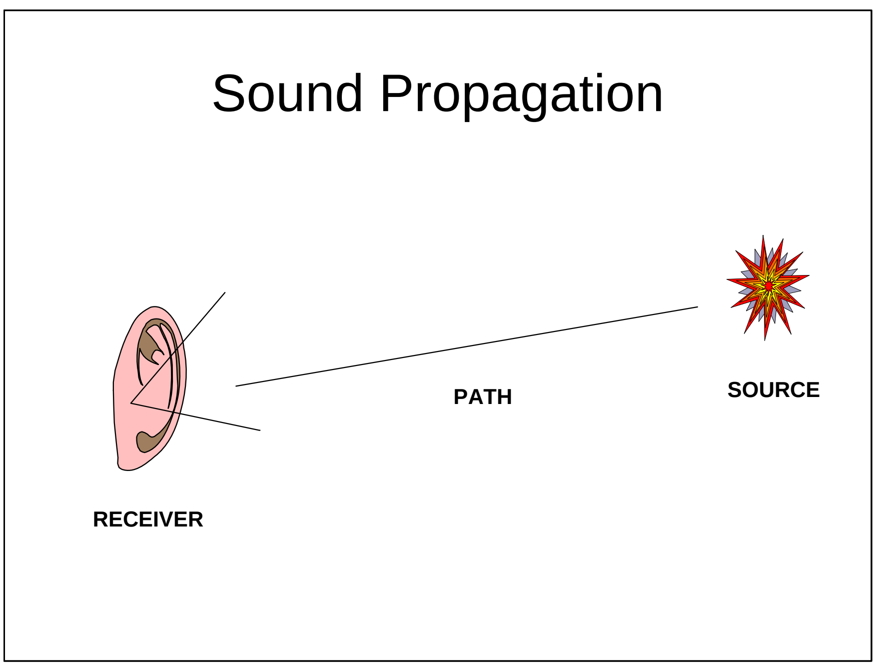
Noise assessment is further complicated by the fact that a variety of “metrics” (parameters used to measure sound level) are used, all having units of “decibels”. Each metric has a reason for being, but various metrics can have very different values, even for a given noise event. This is because these metrics may incorporate frequency weightings and time-averaged sound level, without regard to the number of noise events in that time. For example, for a variety of reasons, we use different metrics and complaint criteria for large arms and small arms. One of the challenges of RMTK Noise development is to convey complaint potential for all weapons in a way that is easily grasped by a typical user.

We know enough about weapons as noise sources, and about the statistics of how weather affects sound attenuation to make a reliable prediction of the statistical variation of sound level at a given location. Ensuring that the sound level would virtually never exceed the complaint threshold level is impractical. We can provide a statistical guideline, much like a weather report of “35% chance of rain”. We have chosen to provide an “85% solution”, that is, we can predict, for a given weapon and given geographical area, a distance at which the noise level will be less than the complaint criteria levels approximately 85% of the time. This of course means that approximately 15% of the time (assuming the guidelines are observed), there will be potential for complaints. Training during worst case conditions will lead to increased risk of complaints. These conditions include low cloud ceiling, dawn, dusk, and nighttime.

7 Outdoor Sound Propagation



This section is going to be quite detailed. There is a lot of information here that describes how sound travels over large distances.

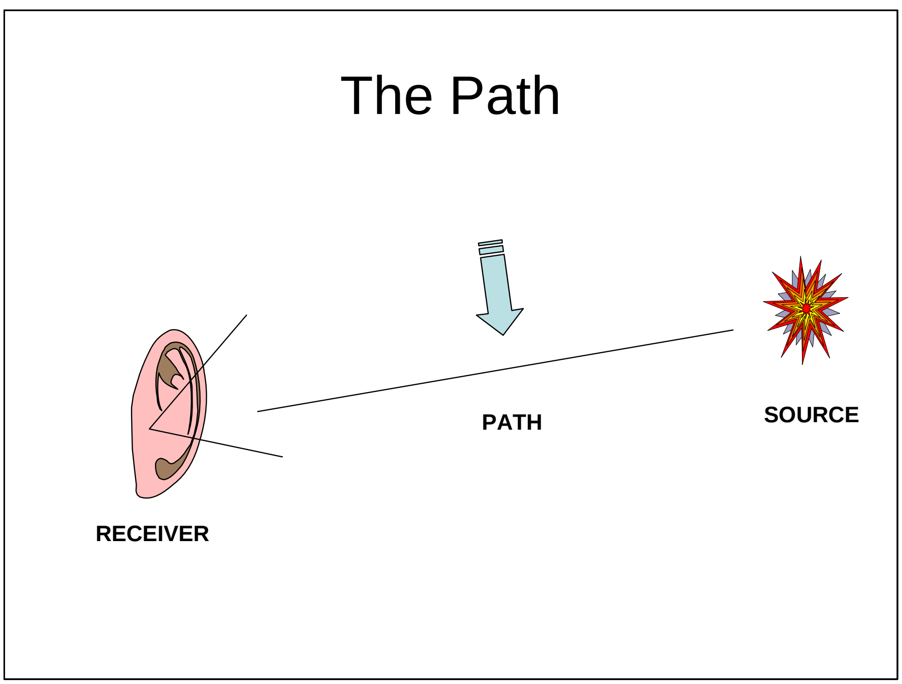


Here we re-visit our source-path-receiver set. In this section we will be describing the path.

Sound Basics (Review)

- **Sound = Pressure Waves**
- **Transmit through a medium**
  - **Solids**
  - **Liquids**
  - **Gases (Atmosphere)**
- **Ear processes pressure waves, brain interprets as "sound"**
- **Human hearing range of 20 Hz - 20,000 Hz**
  - **Most sensitive between 1000 Hz and 2000 Hz**
  - **Animals have different frequency ranges**
- **Sound Speed = Frequency x Wavelength**
  - **Variations in sound speed lead to different propagation conditions**

This graphic highlights the essential items from earlier in the presentation.



We're focusing on the path this time.

The Path

- **REFRACTION** -- bends the sound path in the atmosphere. This is a large effect
- **REFLECTION** -- occurs when sound hits a boundary
- **GROUND EFFECTS** -- ground characteristics alter reflections from the ground
- **ABSORPTION** -- atmosphere absorbs sound (converts sound energy into heat), depends on frequency
- **DIFFRACTION** -- sound can travel around corners with some attenuation.
- **SCATTERING** -- redistributes sound, can be large or small scale
- **TURBULENCE** -- causes "mixing" of sound in atmosphere

This is the list of primary effects on sound as it travels. Each item will be discussed in detail.

Refraction

- Depends on speed of sound at a given height
  - Sound waves want to travel slower
  - Bend to travel at preferred speed
- Speed of sound varies
  - With temperature (square root of temperature)
  - With humidity (slightly)
  - With wind speed and direction (bulk flow)
- Large effect – as much as ± 25 dB!
  - Inaudible to highly annoying.

Scope demo #2

Refraction is the #1 influence on long-range sound propagation. This is the key item that determines where the sound will go and where the loud spots will be.

Uniform Profile

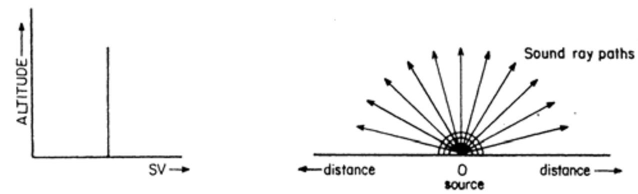
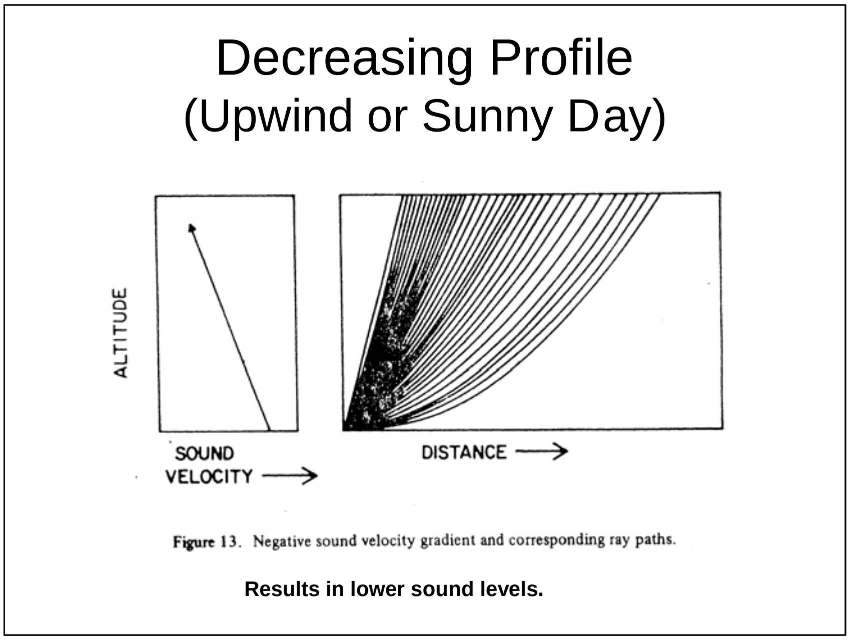


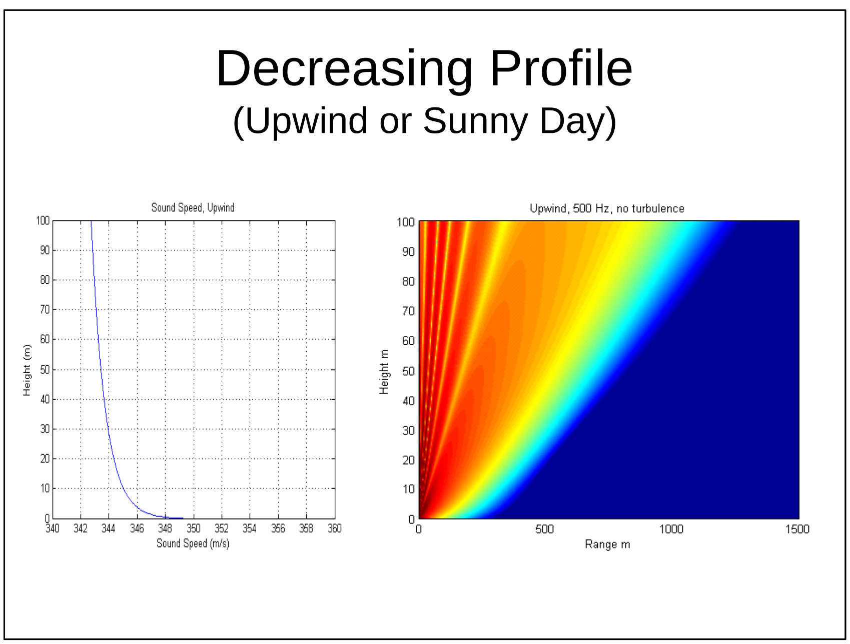
Figure D2. Zero gradient condition model and corresponding ray paths.

Sound level decreases by 6 dB per doubling of distance due to geometric spreading (This is a "base" case that actually never occurs. Additional attenuation occurs due to several causes

This profile is also called "homogeneous atmosphere." This almost never occurs in reality.



Ray-style representation, linear profile, temperature decreases with height, so sound speed decreases. Can also be caused by wind. Notice the “shadow zone” where no rays go.



2-D representation, frequency dependent. Colors indicate transmission loss, with red being little loss and deep blue is enormous loss.
The profile here is logarithmic, which is closer to reality than linear.
Notice the very distinct shadow zone here. It is not that sharp in a real atmosphere because turbulence will scatter sound in all directions and fill in the shadow zone somewhat.

Increasing Profile
(Downwind, night)

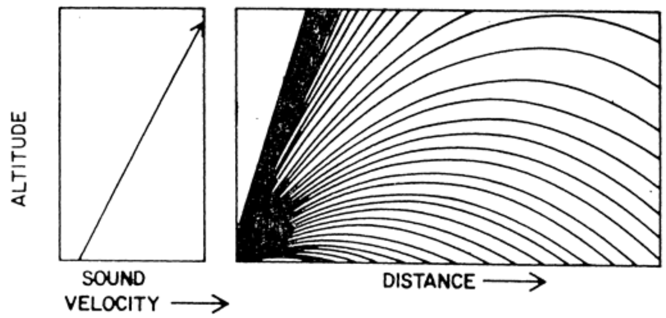
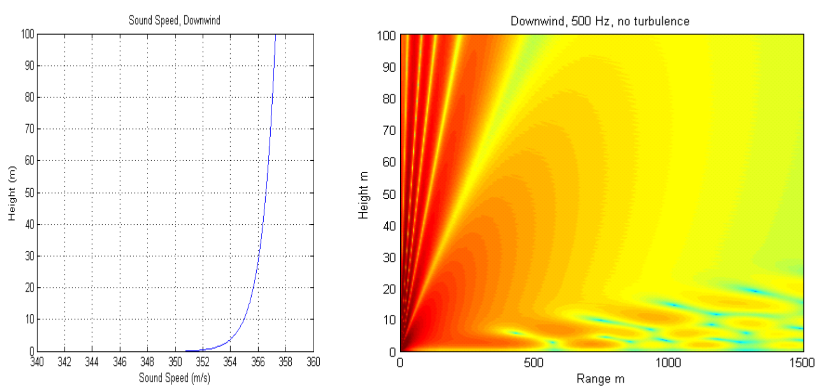


Figure 14. Positive sound velocity gradient and corresponding ray paths.

Results in higher sound levels.

Ray-style illustration. The temperature is increasing with height, so sound speed increases with height. This can also be caused by wind. Notice the absence of a shadow zone.

Increasing Profile
(Downwind, Night)



Again, this is a logarithmic profile. Notice that there is no shadow zone, and that there is interference near the ground further out, causing areas of louder noise surrounded by less noise.

Inversion
(decrease, then increase)

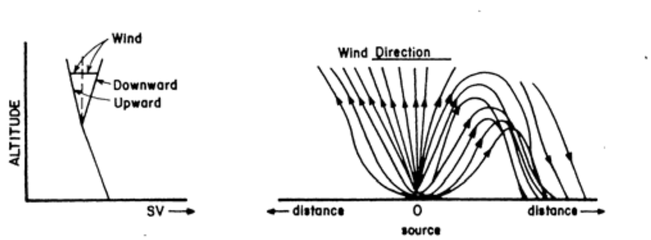
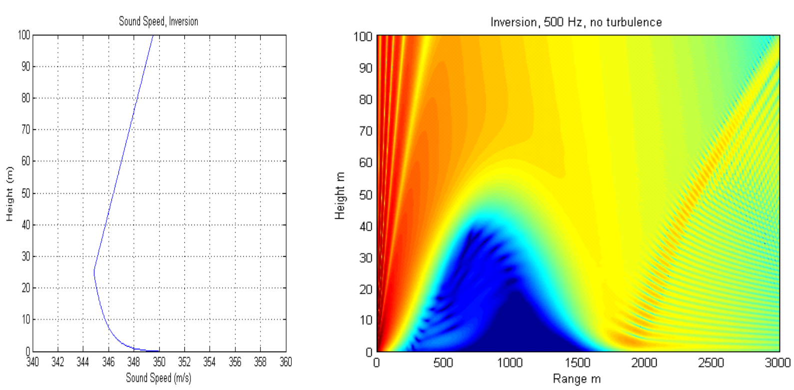


Figure D5. Directional wind effects -- sound velocity profile and ray paths.

Can result in much higher sound levels.

Ray-style representation of an inversion. Notice the presence of a shadow zone, followed by a strong focusing.

Inversion
(decrease then increase)



Civil War Handout

This shows the shadow zone, then sound returns, quite strongly around 2000 m. All of these cases are real.

The Civil War acoustics handout at the end of this chapter (page 49) contains several examples of weather conditions influencing acoustic propagation and turning the tide of battles.

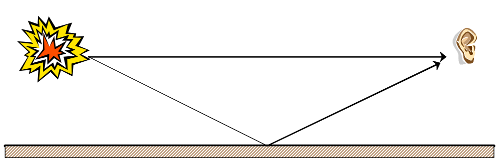
Reflection

- Large-scale boundary
  - Ground
  - Mountains
- Some transmitted into boundary, some reflected from boundary
  - Depends on type of surface
  - Part of the principle of barriers

Sound bounces off of large surfaces. Depending on the surface type, the sound can be completely reflected or partially absorbed and partially reflected. Sound traveling over water is mostly reflected, while sound traveling over plowed dirt or grass has some energy absorbed.

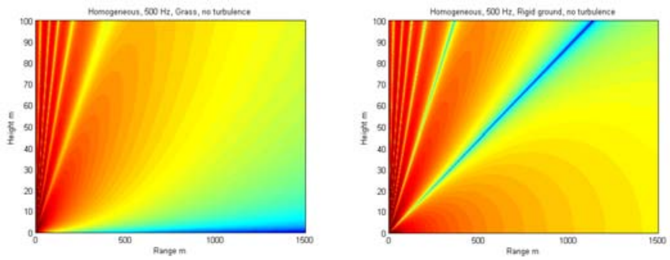
Ground Effects

- Constructive and destructive interference
- Complex reactions
- Can provide attenuation
- Bouncing Ball example



Bouncing Ball example: If you bounce a basketball on a basketball court, which has a smooth rigid surface, the ball bounces back up to the initial drop height, and the bounce is straight up. If you bounce the same ball on an uneven grassy field, the ball will not bounce as high and will likely go in some undetermined direction. Likewise, when sound bounces off an acoustically rigid surface, like water or asphalt, the reflected part of the wave has the same energy, although a different phase due to differing path length, than the direct path. When sound bounces off an uneven and porous surface, like grass, some energy is lost. The phase changes as well, but in a more complicated way.

Differences in Ground



The rigid case on the right is like propagation over water.

The case on the left has a grassy surface. Notice that the sound going over the grassy surface attenuates quickly near the ground, while the sound over the rigid surface attenuates much more slowly.

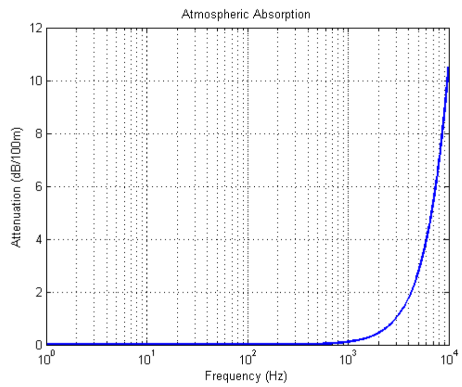
For example think about an evening on a lake. During the evening and at night, you may be able to hear the campers on the other side of the lake quite clearly, even though you could not hear them at all during the day. This is partially due to the downward refraction scenario that is typically present at night, but also because the surface of the lake is absorbing only a miniscule amount of sound. If those campers were the same distance away from you but across a field instead, you would not hear them as well or at all.

Absorption

- Molecular absorption of acoustic energy
  - Depends on frequency
  - Higher frequencies more effected
  - Standardized (ANSI S1.26-1995)

Some energy is absorbed by the molecules in the air. This is highly frequency dependent. The amount of absorption increases with frequency.

Atmospheric Absorption



This is the actual relationship between frequency and air absorption. Notice that low frequencies are unaffected. Atmospheric absorption really starts to have an impact around 1000 Hz.

Diffraction

- Bending of sound around corners or obstacles
  - Principle used for barriers
- Switch to diffraction .avi

At this point, the class saw a short movie that shows diffraction around buildings. It shows that sound bends around the corners and fills up spaces that are not in the “line of sight”. This is the principle that allows you to hear around corners.

Scattering

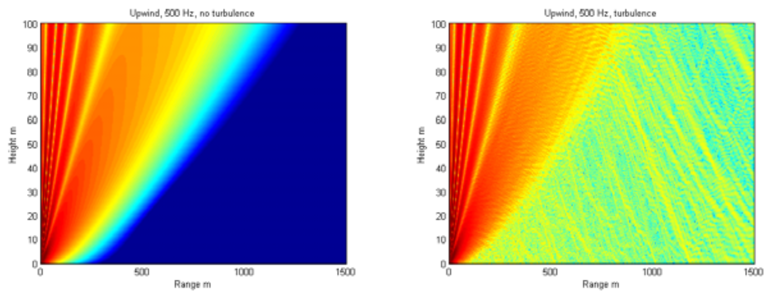
- Similar to reflection and diffraction
  - – Typically associated with smaller objects
  - – Forests
- Turbulence is another example

Scattering is similar to reflection and diffraction, but is typically associated with smaller objects, such as trees and turbules. Turbules are masses of moving air that cause fluctuations in wind and scatter sound.

Turbulence

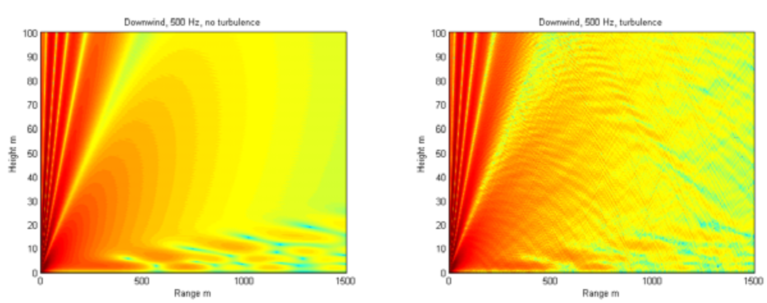
- Mixes the air
- Sound scatters from turbules
- Fills in the “shadow zone”
- Largest effect in upwind case.
- Randomizes the received signal
  - – Causes variation in received signals

Turbulence (Upwind case)



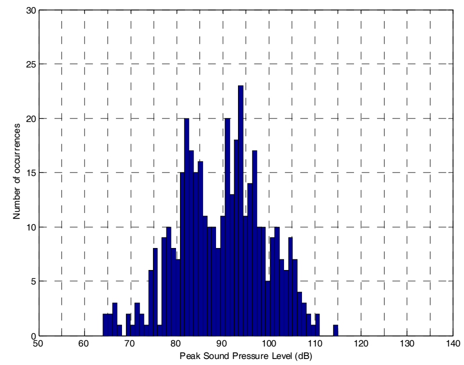
The figure on the left is an upward refracting case with no turbulence. The figure on the right is the same sound speed profile with turbulence added. Notice in particular how the shadow zone in the turbulence case is at a much higher level (yellow and green instead of deep blue).

Turbulence (downwind case)



This figure set is similar to the previous one, only this time the sound speed profile is downward refracting. Again, notice how the turbulence mixes the sound.

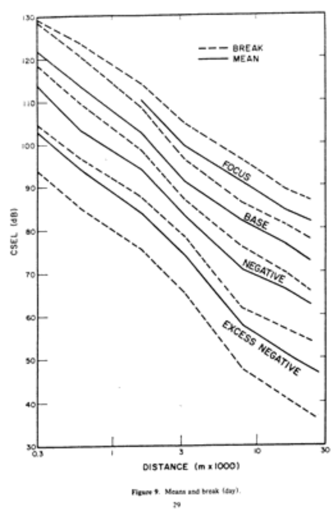
Variation of sound level at 10 miles due to propagation conditions.



This histogram illustrates that these propagation effects are real; the time variation can be quite short. This plot is data taken in a single night from four different locations, one in each of the four cardinal directions from an explosion.

Variation of sound level due to propagation conditions.

We conclude that we should not be surprised when measurements do not match up with predictions.



This is another illustration of variation in received level due to propagation conditions.

Blast Noise Demo

- Two signals
  - 400 m from C-4
  - >1 km from weapon fire
  - C-4 simulates large weapon fire well
- How are they different?
  - Why?

Audio demo #4

At this point, the class heard an audio demonstration. The first signal sounds like a sharp crack while the second sounds like rolling thunder. The reason for these differences is primarily atmospheric absorption. Non-linear effects such as the pulse shocking up, collapsing, and repeating, lose energy each time. Energy migrates to lower frequencies. Simple reason is atmospheric absorption, which is much stronger at high frequencies than at lower ones.

The demo here is a listening comparison between a near-field blast noise and a far-field blast noise. The near-field case sounds like a sharp crack, the far-field sounds more like thunder.

From *Echoes*, The Newsletter of the Acoustical Society of America, Volume 9, No. 1, Winter 1999.

Outdoor Sound Propagation in the U.S. Civil War

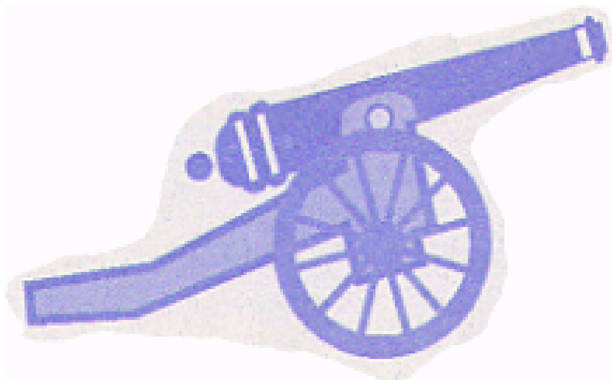
by Charles D. Ross

Students of military history know that acoustic refraction and unusual audibility have often played significant roles in the outcome of battles. Before electrical and wireless communications became common on the tactical level, the sound of battle was often the quickest and most efficient method by which a commander could judge the course of a battle. Troop dispositions were often made based on the relative intensity of the sounds from different locations on the battlefield.

Unusual acoustics due to atmospheric conditions or to terrain are sometimes given the catch-all name "acoustic shadows." The first recorded incidence of the phenomenon occurred during the Four-Day Battle in 1666. The naval battle was fought between the coasts of England and Holland, and sounds of the battle were heard clearly at many points throughout England but not at intervening points. Passengers on a yacht positioned between the battle and England heard nothing. A number of other examples have been recorded since that time. Guns fired at the funeral of Queen Victoria in London in 1901 were heard in Scotland, but not across a wide region in between. The German bombardment of Antwerp in World War I was heard clearly for a 30-mile radius, then beyond 60 miles from the Belgian city, but not in between.

In the course of my research for my book on science and technology in the Civil War, I noted examples of similar acoustical phenomena. Some historians were apparently aware of these incidents, but no one had ever investigated their causes. By intensive study of war records, regimental histories, diaries, and period newspapers, I was able to piece together information allowing me to determine the causes of each acoustical shadow. The most famous battles during which these events occurred and affected command decisions were: Seven Pines, Gettysburg, Iuka, Fort Donelson, Chancellorsville, Five Forks, and Perryville. Unusual audibility at great distances was associated with several of these battles and also with the battle of Gaine's Mill.

In each of these seven battles listed above, the inability of commanders to hear and interpret the sounds of battle was directly responsible for the outcome. One might even go so far as to say the acoustical shadows determined the course of the entire war. The unusual acoustics at Seven Pines placed Confederate commander Joseph Johnston in a position of danger when the battle should have been over. Because of Johnston's wound, Robert E. Lee assumed command of the Confederate forces two days later.



The Causes of Acoustical Shadows

Acoustical shadows can usually be traced to one or more of three causes: absorption, wind direction and wind shear, or temperature inversions.

Absorption - Sometimes material between a sound source and an observer will render the sound inaudible. The material can be soil (Gettysburg), forest (Five Forks and Chancellorsville), snow (Fort Donelson) or a variety of other substances.

Wind direction and wind shear - In general, sounds are more likely to be heard downwind of a sound source than upwind. Since winds aloft are usually faster than at ground level, the upper part of a sound wave will travel faster than the lower part when traveling with the wind and more slowly when against the wind. This will cause a refraction towards the ground in the former case and away from the ground in the latter case. Such an effect was certainly at work at Fort Donelson and Iuka.

Temperature inversions - Sound waves travel faster in warm air than cool air (the speed (m/s) is approximately 331.36+0.6067t, where t is temperature in Celsius). Under most conditions, the air temperature decreases as altitude increases. This causes sound waves to refract upwards and decreases audibility along the ground at a distance. Sometimes, however, the temperature is higher above the ground than near the ground - a condition called a temperature inversion. The effect is to bend sound waves back towards the ground and increase audibility. Temperature inversions are common on clear, cool nights (and the mornings following them) and during widespread rainstorms (at Gettysburg and Seven Pines, for example, and also at the battle of Perryville, Kentucky in 1862).

Sometimes upwardly refracted waves hit a warmer layer higher up and are refracted back down, creating rings of audibility, as in the battle of Gettysburg as well as in the European examples previously described.

Five Forks

The scene - On April 1, 1865, Confederate forces under Major General George Pickett held the far western flank of General Robert E. Lee's Petersburg defenses. Pickett's forces were at Five Forks, the intersection of five country roads, located about 12 miles from Petersburg. Lee's forces were stretched thin, and protecting this right flank was crucial to maintaining the integrity of the Confederate position and the safety of the capital in Richmond. Holding the position also offered Lee the possibility of slipping away to the southwest and joining up with forces under General Joseph E. Johnston in North Carolina.

Wary of the threat of losing Lee after having had him clamped down around Petersburg for almost a year, Union General Ulysses S. Grant sent cavalry under Major General Philip Sheridan to probe the position at Five Forks. After being repulsed on March 3 1, Sheridan informed Grant that he could turn the Confederate right if he had support from an infantry corps. Accordingly, by the morning of April 1, the Union V Corps under G. K. Warren was arriving on the scene.

What happened - The Confederates were entrenched at Five Forks, with cavalry units dug in on the flanks, Pickett's infantry in the center, and reserves under Brigadier Thomas Rosser behind Pickett's men. On the morning of April 1, Rosser invited Pickett and Major General Fitzhugh Lee (in command of the cavalry) to his position (on a stream a mile behind the lines to a "shad bake" or fish roast. Despite the imminent danger from the enemy, both generals inexplicably accepted the offer. When Sheridan and Warren began their attack in mid-afternoon, the Confederate commanders were blissfully unaware, of their impending doom. In between the front lines and Rosser's position was a dense pine forest which completely absorbed the sound of small arms fire. In the crucial opening minutes of the battle, the leaderless Confederates were overwhelmed by Union forces on their left. The battle of Five Forks quickly turned into a rout and signaled the beginning of the end for Lee's army. With his flank turned, Lee was forced to abandon Petersburg and Richmond and flee to the west. Eight days later, Grant and Sheridan caught the Confederates at Appomattox Court House, where Lee surrendered.

Chancellorsville

The scene - Spring of 1863 found the Union Army of the Potomac and the Confederate Army of Northern Virginia in a standoff across the Rappahannock River at Fredericksburg. After the crushing Union defeat there in December 1862, Union morale was low. The new Union commander, Major General Joseph Hooker, unveiled a plan designed to surprise and crush the Confederate forces. Leaving a large force in front of Fredericksburg, in late April he took five infantry corps upriver and crossed fords to the southern bank. Confederate commander Robert E. Lee was not aware of the maneuver until the Federals were already over the river. Lee now had an enemy force in front of him and one on his left flank, each larger than his whole army. It seemed his only choices were either to retreat towards Richmond or be crushed in the Union vise.

What happened - Defying conventional military strategy, Lee separated his forces despite being outnumbered. Leaving a small force on the heights behind Fredericksburg, Lee took the rest of his army to meet Hooker head on. The armies clashed on May I near the crossroads of Chancellorsville. Though his troops outnumbered the Confederates, Hooker seemed momentarily stunned by the opposition and halted his men in a defensive position along the Orange Turnpike. The next day Lee gambled again. He sent forces under Lieutenant General Thomas J. "Stonewall" Jackson on one of history's greatest flanking attacks. Using a guide and traveling over little-known farm roads, Jackson managed to get his men on the left flank of the Union position without being detected. Near sundown on May 2, Jackson's forces attacked, rolling up the stunned Union army. Hooker, at Chancellorsville, was shielded from the sounds of battle by the dense forest known locally as "The Wilderness" and first became aware of the rout as panic-stricken Federal soldiers overran his position. There was undoubtedly a refractive effect at work on this day as well: Confederate Major General Cadmus Wilcox, 10 miles to the east near Fredericksburg, noted the sounds of battle clearly. This refraction may have been due to wind shear (high winds kept Union balloonists grounded).

Seven Pines

The scene - After the Union debacle at Bull Run, George C. McClellan was placed in command of the forces around Washington. Rather than move towards Richmond directly overland, McClellan decided to save his infantry some work by shipping them to the peninsula southeast of Richmond to begin his attack from there. Working against the able but cautious Confederate General Joseph E. Johnston, McClellan's men worked their way slowly but steadily up the peninsula until by late May 1862 MeClellan could hear the clocks of Richmond striking from his headquarters. Under pressure from the Confederate government to take some action to save the capital, Johnston mapped out a plan. He formulated a three-pronged attack in which Confederate forces would be funneled by three different 'roads towards a convergence on the Union forces at the intersection called Seven Pines.

What happened - The plan was complex and required perfect timing on the part of Johnston's subordinates. Instead, what Johnston got was bickering and arguments about seniority among the Confederate generals as their troops ran into each other and blocked each other's routes. Still, by early afternoon the Confederates had managed to attack and were holding their own against the Federals. Johnston, at his headquarters near Fair Oaks a few miles from the front lines, did not hear the battle and could not be convinced by others that a fight was raging. He held key reserves back until a desperate note from Major General James Longstreet at 4 o'clock convinced him that a battle was indeed underway. By then it was too late; the Federals had been reinforced by troops under Edwin Sumner, and the battle ended in a draw. Near dusk, Johnston went to observe the closing moments of the conflict and was seriously wounded. Two days later, Robert E. Lee assumed command of the Confederate forces, replacing the wounded Johnston.

The battle, silent to Johnston two miles from the front, was heard clearly by citizens of Richmond ten miles to the west and to Federals as far to the east. The probable cause was a temperature inversion bending the sound back to the ground. On the night before the battle, a violent thunderstorm (many soldiers said it was the worst they had ever seen) raged over the area. The day of the battle dawned with widespread, low cloud cover-ideal conditions for a low- atmosphere temperature inversion.

Gettysburg

The scene - In the summer of 1863, the Confederacy was in dire straits. The vital garrison at Vicksburg, Mississippi was under siege and near collapse. In the east, things looked better, but the situation was still bad. The Army of Northern Virginia had withstood all Union attempts to take the war to Richmond, but General Robert E. Lee knew that he faced an uphill battle. The Union seemed to have a never-ending supply of men ready to volunteer, filling holes in the ranks, while the Confederate rosters dwindled to ever-smaller numbers. And the war-ravaged land north of Richmond could not long support his men and horses.

In the hopes of relieving the pressure on Vicksburg and giving his men access to the fertile bounty of the north, Lee decided to invade Pennsylvania. The Confederates and the Union troops, now under Major General George Meade, met at the town of Gettysburg. The Confederates had the better of it on the first day, but the Federals dug in along a series of hills and ridges behind Gettysburg.

What happened - July 2 dawned hot and sunny, and Lee had a plan for dislodging the Union army from its perch. While forces on the Confederate left under Lieutenant General Richard S. Ewell made a show of force, troops under Lieutenant General James Longstreet on the Confederate right would attack and take the virtually unoccupied Round Top mountains at the south end of Cemetery Ridge. Confederate artillery would be able to sweep Meade's men from the hills. Ewell's demonstration was to begin when he heard the artillery barrage which would signal the beginning of Longstreet's attack. For a long time after Longstreet had begun his attack, Ewell heard nothing and hence did not move his troops. As a result, Meade was able to shift troops from the right of his line down towards the Round Tops, just in the nick of time to defeat Longstreet's attack. Ewell's inability to hear Longstreet's artillery appears to stem first from the shielding effects of Cemetery Ridge and Culp's Hill between the two Confederate forces. More importantly, the hot temperatures near the ground probably caused a dramatic upward refraction of sound waves. Upon hitting another warm layer higher up, these waves could be refracted back downwards. On the previous day, Meade had been unable to hear the Gettysburg fighting from his position at Taneytown (12 miles away), yet the battle was clearly audible in Pittsburgh, 150 miles from Gettysburg.

Iuka

The scene - In September of 1862, Confederate forces under Major General Sterling Price struck and ran off the small Union garrison at Iuka, Mississippi. After confiscating supplies left behind by the Federals, Price decided to stay put in Iuka until he received orders for his next move. Twenty miles away, someone was making plans for Price, but not of the type he expected. Ulysses S. Grant, headquartered at Corinth, decided that Price's resting period would be a perfect time to strike and annihilate his forces. Though Grant had only 17,000 men on hand (Price had 15,000), he had an idea for a trap that would ensure Price's defeat. While forces under Major General Edward Ord approached Iuka from Corinth in the northwest, the other half of Grant's force under Brigadier General William Rosecrans would swing around and approach Iuka from the south, trapping Price from the rear. On September 17, Grant put the plan in motion.

What happened - Following Grant's plan, Ord stopped his battle lines four miles from Iuka and waited for the sounds of battle between Price and Rosecrans before proceeding (Grant wanted to make sure that the southern escape route was blocked before striking from the north). Late in the afternoon, Ord saw dense clouds of smoke coming from Iuka but assumed that Price was burning his supplies to keep them out of Union hands. In fact, Price and Rosecrans had been engaged for several hours, but Ord was unable to hear the battle. A strong wind blowing from the northwest had carried the sounds of battle away from Ord and Grant. When Grant finally learned the next morning that Rosecrans had been in a fight with Price, he immediately ordered both forces to advance. The Union troops met only each other; Price and his men had slipped out between them during the night.

Fort Donelson

The scene - In early February 1862, Union forces under Brigadier General Ulysses S. Grant had easily taken Confederate Fort Henry on the Tennessee River and reestablished the Stars and Stripes on Tennessee soil. Twelve miles to the east was Fort Donelson (on the Cumberland River), which Grant also vowed to take. If both the forts fell into Union hands, the Federals would have control over both rivers, providing valuable transportation arteries into the heart of the Confederacy. While Grant's men surrounded Donelson on three sides, gunboats under Flag Officer Andrew Foote steamed down the Cumberland to attack the fort from the fourth side. After their easy submission of low-lying Fort Henry, the gunboats were believed by both sides to be nearly invincible. To their surprise, the gunners in Fort Donelson, elevated much higher above the water than Fort Henry, shot the Union boats to pieces. Elated, the Confederates planned a breakout through the Union lines for the next day, February 14.

What happened - Nursing their wounds, Foote's sailors steamed five miles north of Fort Donelson to regroup. Not suspecting that the Confederates might go on the offensive from their precarious position, Grant rode north at dawn on February 14 to confer with Foote and plan the next move of the siege. At Fort Donelson, Confederate commander John Floyd planned for forces under Brigadier General Gideon Pillow to force a breakthrough towards the south while troops under Simon Bolivar Buckner held the other Union forces in position and then forced their way through the same opening. Attacking in early morning, the battle raged between Pillow and Union forces under John McClernand for over three hours before McClernand's men gave way. Grant was completely unaware of the battle; five miles away he could hear nothing. This due to two factors. On the previous day, a spring snow had blanketed the ground, absorbing sound in all directions.

Also, a howling wind blew from north to south, carrying sounds away from Grant and refracting sounds upwards. Only indecision by Pillow and Buckner at the crucial moment prevented the entire Confederate force from escaping. Notified by courier, Grant raced back to the battlefield and reorganized his men to the point where they drove the Confederates back into the fort, forcing their surrender the next day.

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8 Introduction to Noise Modeling

Introduction to Noise Modeling

This section presents a very broad overview of available noise assessment models.

Why Model?

- AR 200-1: Army Environmental Noise Policy
  - – States that the Army must use mathematical modeling and computer simulations as the primary means of noise assessment.
  - – Field noise level measurements of limited duration may be inadequate and misleading because changes in atmospheric meteorology strongly affects received noise level.

The Army Regulation AR 200-1 dictates that noise modeling will be used to assess noise.

Why Model (cont)?

- Allows “what if” scenarios
- Can assist in noise mitigation
  - Notify public of extra noise
  - Move training to a different range
  - Re-orient training (point a different direction)
  - Reschedule if necessary

Modeling allows the user to perform “what if” studies with a minimum of work. For example, planned training could be moved to a different location to help reduce noise levels at a particular location. The user could try several different locations to find the best outcome without actually adjusting the training schedule until after the assessment is complete.

What is Available?

- BNOISE2™
  - Large weapon (20 mm or larger)
  - Demolitions
- SARNAM™
  - Small arms
  - Barriers and Berms
- RNM
  - Rotorcraft
- Noisemap
  - Fixed wing

DoD has four main professional-grade noise assessment models available.

BNOISE2™

- Professional Grade
  - Not user-friendly
  - Requires extensive weapons knowledge
- Several options for metric
- Output set for CDNL, but adjustable
- RMTK Noise is based on the BNOISE2™ calculation engine
- Developed by CERL

Several different options are available for assessment metric, such as SEL, DNL, frequency-weightings (C and A), and peak level. BNOISE2 also provides a choice in weather condition. The software is intended for long-term assessments.

SARNAM™

- Small arms capability
- Barrier effects
  - Diffraction and reflection
- Produces ADNL noise exposure contours by default
  - Other metrics are available
- Interface similar to BNOISE2™
- Developed by CERL

SARNAM has many features that are similar to BNOISE, but is tailored to small arms. SARNAM includes barrier effects, but has only a single weather condition. The software is intended for use on long-term assessments.

9 Introduction to RMTK Noise Tool

Introduction to the
RMTK Noise Tool

How is this different?

- Single event metric
- Straightforward to interpret
- Predicts the likelihood of receiving noise complaints, as well as levels

This is a deviation from the other available capabilities, such as BNOISE2. The RMTK Noise Tool trades flexibility for ease of use. The only metric available is PK15(met) (peak level exceeded only 15% of the time, based on meteorological statistics).

How is this different (cont)?

- Point-and-click interface
- GIS environment
- Straightforward to use

How is this different (cont)?

- Can be used on day of training
- Can be used for future exercises
- More detailed weather cases
  - BNOISE2™ has aggregate cases.

The RMTK Noise Tool is designed to provide results rapidly, making it usable on the day of training. Professional-grade models, such as BNOISE2, take a long time to run but have much more flexibility and can do multiple weapons at a time.

How is this different (cont)?

- Graduated color display instead of bands
  - Better conveys gradual attenuation with distance
- “85% Solution”
  - based on weather statistics
  - Predicts the level that will only be exceeded 15% of the time

The output display conveys the concept that sound decays gradually over distance, not abruptly. This gives a better indication that standing on one side of a contour line vs. the other will not yield significant changes in received sound level.

Feature List

- Large weapons (20 mm and greater)
- Demolitions and mines
- Grenades
- Realistic weather cases
  - Includes “worst case” weather option
    - Cloudy Night, 20 mph wind, downwind all directions
- CALFEX ability

The “worst case” weather option provides a maximum size noise contour. CALFEX (Combined Arms Live Fire Exercise) is performed by picking the highest sound level at each grid point for the set of contours chosen.

Time on Target

- Probability analysis completed
  - Likelihood of additive peak levels is negligible for fewer than 11 weapons firing
  - SME for artillery training suggested that more than 10 would be spatially distributed, and therefore less likely to meet the stringent acoustic criteria for additive peak levels.

Hand out ToT discussion

Time on Target (see page 65) is a scenario designed to detonate multiple shells from multiple sources at the same detonation point at the same time.

Policy – Official Uses

- Planning training exercises
- Predicting noise impact on any given day
- Preliminary range siting
  - Not final, due to no terrain capability
- NEPA screening
  - Not final
- Not for use in public documents

Question Procedures

- If it is a noise question
  - Call CERL (Michelle Swearingen POC)
  - May need `case.txt` and `case.err` from user
  - CERL will work with either RSC or User
  - Log the question and response to help develop an FAQ and to assist in future development.

Handling Noise Questions handout

(Handout on page 69)

Time on Target Assessment

Time on Target is an exercise that involves multiple weapons firing into a target area (100 m x 100 m, for example), all detonating within a specific time frame of no more than $\pm 3\ \mathrm{s}$. We have been asked to include a noise assessment of this type of exercise in the RMTK Noise Tool. Because the Noise Tool performs all assessments in terms of peak level, it was hypothesized that an addition of peak sound pressure levels was highly unlikely. A probability-based analysis was performed to test this hypothesis. A synopsis of the results is below, with a more specific description of the analysis and the results of that analysis on the pages that follow.

Summary

A large weapon blast has a duration of about 100 ms. The positive sound pressure portion has a much shorter duration, roughly 10 ms at 1 km. In order for the pressures to add constructively, there must be an overlap in positive pressures. Because the area and time frame are relatively large in a time on target exercise compared to the positive phase portion of the sound waves, it is extremely unlikely that the sound waves from different detonations will interfere constructively at the receiver location. An analysis determining the probability that the acoustic signal from two or more detonations will arrive at a receiver location within the 10 ms time window has been performed. This analysis partially disproved the hypothesis that the peak sound pressure levels would be highly unlikely to interfere constructively. In fact, once the 85% solution criteria were applied to the results, it was found that for 11 or more weapons firing, some addition of peak level would take place. If the allowable time window is 7.5 ms, then the criteria are only met for 12 or more weapons. If the allowable time window is 5 ms, the criteria are met for 14 or more weapons. If the time window is made narrower, to indicate more than 1/2 positive pressure overlap, the criteria of occurring 15% of the time or more is not met for less than 18 weapons firing. There is a less than 1% chance that three or more detonations will add constructively at a receiver location for 18 or fewer weapons firing. However, the SME (subject matter expert) for artillery training stated that for more than 10 weapons firing, human error decreases the likelihood of attaining the stringent requirements necessary for increasing peak levels. When combined with the atmospheric effects, which were not taken into account for this statistical analysis and introduce variations in path length, the actual likelihood of an effective increase in peak level may be neglected. Therefore, in RMTK Noise there is no adjustment to peak levels for a time on target exercise.

Although the peak levels change minimally, the event SEL could change dramatically. During a time on target some level close to the peak level is sustained for a longer duration at the receiver location due to temporally clustered explosions, potentially causing the perception of a louder sound, and potentially also more vibrations.

Again, the RMTK Noise Tool is only assessing in terms of peak levels. We do not have the data to reliably predict reactions to a time on target, which would possibly need to be based on an event SEL instead of a simple peak level.

Analysis Details

Because the receiver distances are large compared to the target area width, only the separation in x contributes to the time delay. The time separation between any two detonations can be found from the following relation:

$$\Delta T = T_2 - T_1 = \frac{\Delta x}{c} + \Delta t \qquad \text{Equation 1}$$

where ΔT is the time separation in seconds at the receiver,

$T_2 - T_1$ is the time difference of arrival at the receiver location [s],

Δx is the spatial separation between the two detonations [m],

$c = 340\,\mathrm{m/s}$ is the speed of sound,

and Δt is the time separation of detonations.

If we state $|\Delta T| \leq 10\,\mathrm{ms}$ for any overlap to occur, and define that minimal overlap occurs for $|\tau_0| = 10\,\mathrm{ms}$, 10% overlap occurs for $|\tau_{10}| = 9\,\mathrm{ms}$, 25% overlap occurs for $|\tau_{25}| = 7.5\,\mathrm{ms}$, 50% overlap occurs for $|\tau_{50}| = 5\,\mathrm{ms}$, and 75% overlap occurs for $|\tau_{75}| = 2.5\,\mathrm{ms}$, then we can now treat the problem in the following way:

Let w represent the largest horizontal dimension of the target area and let $\delta = 6\,\mathrm{s}$ represent the largest time separation of detonations. The ranges for Δx and Δt are now $[-w/2 \leq \Delta x \leq w/2]$ and $[-3\mathrm{s} \leq \Delta t \leq 3\mathrm{s}]$. Because

$$\max\left(\frac{\Delta x\,|_{-w/2}^{w/2}}{c}\right) = \frac{w}{c} \qquad \text{Equation 2}$$

and

$$\max(\Delta t) = \delta$$

and assuming that $\delta >> w/c$, the largest time separation at the receiver is

$$-\left(\frac{w}{c} + \delta\right) \le \Delta T \le \left(\frac{w}{c} + \delta\right) \qquad \text{Equation 3}$$

We assume that Δt is uniformly distributed. Because $\delta >> w/c$ for the example, w/c can be neglected compared to δ . Consequently, ΔT is uniformly distributed. This means that to find the probability that two detonations will occur within the allowable time limit we can use the relation

$$P_{t,m}(|\,\Delta T\,| \le \tau_m) = \frac{2\tau_m}{\delta} \qquad \text{Equation 4}$$

The probability is statistically distributed because Δx and Δt are both uniformly distributed. For one pair of detonations, this gives $P_{t,0} = 0.0033$. To find the probability that any given pair will be additive, one must use the relation $P_n = qP_{t,m}^{r-1}$. To find the number of pairs (or triples or quadruples, etc.) the relation of

$$q = \frac{n!}{r!(n-r)!} \qquad \text{Equation 5}$$

where $n =$ # weapons firing, and $r =$ # in a group. For example, if 18 weapons fire, and we are interested in pairs, we get

$$\frac{18!}{2!(18-2)!} = 153\,\text{pairs.} \qquad \text{Equation 6}$$

This same analysis is performed for pairs, triples, and quadruples. Results are in the attached tables. In addition to the slight overlap case ($\tau = 10\,\text{ms}$, Table 1:), cases were run for 10% (Table 2:), 25% (Table 3), 50% (Table 4), 75% (Table 5), and 90% (**Error! Reference source not found.**) overlap. To obtain the percent time that the overlap occurs, simply multiply the probabilities in the tables by 100.

Table 1: tau=0.01 s - Barely overlapping.

n/r	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
2	0.02	0.0333	0.05	0.07	0.0934	0.1201	0.1501	0.1834	0.2201	0.2601	0.3035	0.3502	0.4002	0.4536	0.5103
3	0	0.0001	0.0002	0.0004	0.0006	0.0009	0.0013	0.0018	0.0024	0.0032	0.004	0.0051	0.0062	0.0076	0.0091
4	0	0	0	0	0	0	0	0	0	0	0	0.0001	0.0001	0.0001	0.0001

Table 2: tau=0.009 s - 10% overlapping.

n/r	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
2	0.018	0.03	0.045	0.063	0.084	0.1081	0.1351	0.1651	0.1981	0.2341	0.2732	0.3152	0.3602	0.4082	0.4593
3	0	0.0001	0.0002	0.0003	0.0005	0.0008	0.0011	0.0015	0.002	0.0026	0.003	0.0041	0.005	0.0061	0.0074
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0001	0.0001

Table 3: tau=0.0075 s - 25% overlapping.

n/r	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
2	0.015	0.025	0.0375	0.0525	0.07	0.0901	0.1126	0.1376	0.1651	0.1951	0.2277	0.2627	0.3002	0.3402	0.3828
3	0	0.0001	0.0001	0.0002	0.0004	0.0005	0.0008	0.001	0.0014	0.0018	0.0023	0.0028	0.0035	0.0043	0.0051
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4: tau=0.005 s - 50% overlapping.

n/r	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
2	0.01	0.0167	0.025	0.035	0.0467	0.0601	0.0751	0.0981	0.1101	0.1301	0.1518	0.1752	0.2002	0.2269	0.2553
3	0	0	0.0001	0.0001	0.0002	0.0002	0.0003	0.0005	0.0006	0.0008	0.001	0.0013	0.0016	0.0019	0.0023
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5: tau=0.0025 s - 75% overlapping.

n/r	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
2	0.005	0.0083	0.0125	0.0175	0.0234	0.0301	0.0376	0.0459	0.0551	0.0651	0.076	0.0877	0.1002	0.1136	0.1278
3	0	0	0	0	0	0.0001	0.0001	0.0001	0.0002	0.0002	0.0003	0.0003	0.0004	0.0005	0.0006
4	0	0	0	0	0	0	0	0	0	0	0	0.0001	0.0001	0.0001	0.0001

Table 6: tau=0.001 s - 90% overlapping.

n/r	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
2	0.002	0.0033	0.005	0.007	0.0094	0.0121	0.0151	0.0184	0.0221	0.0261	0.0305	0.0352	0.0402	0.0456	0.0513
3	0	0	0	0	0	0	0	0	0	0	0	0.0001	0.0001	0.0001	0.0001
4	0	0	0	0	0	0	0	0	0	0	0	0.0001	0.0001	0.0001	0.0001

Handling Noise Questions

1. User Calls RSC / Marine POC (helpdesk)
2. Helpdesk answers question if possible
3. If unable to answer, determine if it is a noise or an interface question
4. If it is an interface question, contact GIS, Inc.
5. If it is a noise question, contact CERL (Dr. Michelle Swearingen POC)
    a. (217) 373-4521 (phone)
    b. michelle.e.swearingen@erdc.usace.army.mil
6. CERL POC will answer right away if possible, may request that the user send `case.txt` and `case.err` files
7. CERL POC can work directly with user if necessary, or through helpdesk
8. When assistance is completed, log question and response for use in future development, FAQ, etc.

10 Test Cases

Test Case list for RMTK Noise Tool

For each case run you will be adding to a Word document. Template is below:

Weapon Platform:
Ammunition:
Season:
Time of Day:
Cloud Cover:
Wind Speed:
Wind Direction:

Special conditions: (such as coarse grid, zoomed in too close, etc)

(insert screen shot of the resulting contour)

Notes: (any interesting points to notice about this contour)

Cases:
Examine Weather Cases:
Use either 1 # TNT or 1.25 # C-4
Do one run of each color (see color handout). There will be 13 runs

Examine Weapon Systems
Use any weather condition with 0 mph winds
Do two runs for each weapon system, one with HE round, one inert round.

Examine combination of weapon directivity and weather directivity
Choose one weapon system and any weather case with at least 5 mph wind
Run once, then rotate SDZ and run again.

Zoom in too close – may give odd results. This is a known bug and is in the process of being fixed

Zoom out really far – note how long it takes to run

Use “unknown” on any of the weather choices

Make a more coarse grid – run time decreased, but less detail

Make a finer grid – run time increased

Run CALFEX function

11 Review

We’ve gone over a great deal of material,
so let’s review the most important points.

Basic Terminology

- Acoustic signals are pressure waves
  - Frequency
  - Wavelength
  - Amplitude
  - Wave Speed
- Time and Frequency domains
  - Waveform
  - Spectrum

These are the basic terms necessary to talk about noise.

Acoustic Sources

- Military weapon noise is
  - Impulsive
  - Broadband
  - Lots of low-frequency energy
  - Directive
  - High amplitude
  - Can cause ballistic shock waves

These are the characteristics of military weapon noise. Recall that most civilian noise sources do not have similar characteristics.

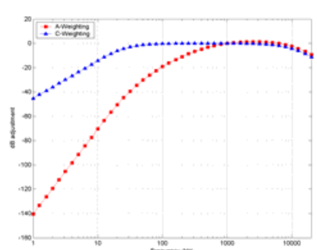
Measuring Sound

- Presented in dB (decibels)
  - Logarithmic scale
  - 1 dB barely discernable
  - 3 dB noticeable
    - Change due to doubling distance from line source
  - 6 dB obvious
    - Change due to doubling distance from point source
  - 10 dB twice(+) or half (-) as loud

This is how we measure sound. Remember that a change of less than 3 dB is barely noticeable to a typical person.

Noise Metrics

- L_{pk15} used in RMTK Noise
- Older NEPA documents use DNL
  - Long-term average noise
- Impulsive Noise Guidelines



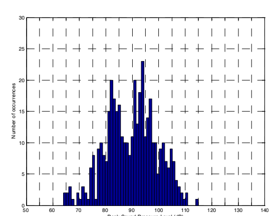
There are several different metrics that can be used to describe a sound. Each metric has a set of typical uses, and not all are good for all purposes.

Human Response to Noise

- Noise is unwanted sound
- People react differently to different noises
- Can lead to complaints
  – Loss of training capability and soldier readiness

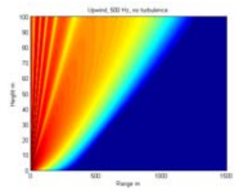
Outdoor Propagation

- Refraction
  – Major effect, bends path of sound
- Reflection and Ground effects
  – Can add or subtract energy from acoustic field
- Absorption
  – Air absorbs energy, frequency-dependent
- Diffraction
  – Bends sound around corners
- Scattering and Turbulence
  – Fills in shadow zones

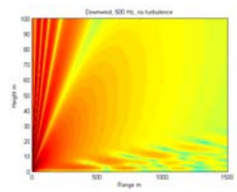


Refraction

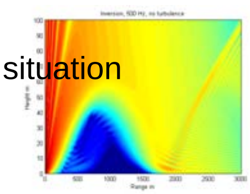
- Decreasing Profile
  - Upwind or sunny day
  - Creates a "shadow zone"



- Increasing Profile
  - Downwind or night
  - Directs sound back towards ground



- Inversion
  - Decrease, then increase
  - Can result in shadow zone then focus situation



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14. ABSTRACT

This Special Report contains the presentations and supplemental materials used during a Noise Training course. This course was held from 15-17 February 2005. The purpose of the course was to educate personnel from the Army Sustainable Range Program (SRP) Regional Support Center (RSC) and U.S. Marine Corps who were to support the Range Managers ToolKit (RMTK) Noise Tool.

This report was requested by the Army Training Support Center (ATSC) to act as a reference to the support personnel and to temporarily educate replacements in the event of a personnel change until another formal training course is offered. Funding for this report was provided by ATSC.

15. SUBJECT TERMS
acoustics, range management, noise assessment, Range Managers ToolKit (RMTK), Army Training Support Center

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