DNWG

DEPARTMENT OF DEFENSE
NOISE WORKING GROUP

TECHNICAL BULLETIN

An Overview of Blast Noise: Characteristics, Assessment and Mitigation

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Noise from large weapons (artillery, tank) and explosives can travel long distances and still be loud enough to cause negative community reactions. A broad understanding of the characteristics, assessment methods, and noise management and mitigation strategies for blast noise will enable better planning and community communication/outreach to minimize training restrictions due to noise issues.

This bulletin, "An overview of blast noise: characteristics, assessment, and mitigation," is one of a series of technical bulletins issued by the Department of Defense (DoD) Noise Working Group (DNWG) under the initiative to educate and train DoD military, civilian, and contractor personnel, and the public, on noise issues.

For military noise management, blast noise is defined as noise generated by large caliber weapons (20mm and greater) and explosive charges. Blast noise is becoming more prevalent on military installations due to changes in the training doctrine and troops returning from overseas to home bases. In recent years, the number of troops receiving Improvised Explosive Device (IED) training has increased. Often, this training must be conducted at local installations due to time and fiscal constraints. Additionally, over the past few years, most installations have experienced a decline in large caliber weapons firing due to troop deployments. Once troops return, training levels should return to pre-deployment levels.

Noise from large weapons (artillery, tank) and explosives can travel long distances, and still be loud enough to cause negative community reactions. A broad understanding of the characteristics, assessment methods, and noise management and mitigation strategies for blast noise will enable better planning and community communication and outreach to minimize training restrictions due to noise issues.

BACKGROUND

The DoD Noise Working Group (DNWG) recognized that there is a dearth of compiled information regarding the unique characteristics, propagation tendencies, assessment methods, and management and mitigation methods for blast noise. As more military installations produce blast noise as part of their training mission, a succinct compilation of this information, written at a layman level, has become a necessity.

The purpose of this technical bulletin is to provide military installations with a single document that compiles the practical elements of blast noise management. This will be accomplished by providing an overview of the unique characteristics of blast noise, describing the methods used for assessing blast noise, and providing descriptions of known noise mitigation techniques and noise management strategies.

DISCUSSION

This section will cover three main topics:

1) The unique characteristics of blast noise and their implications for propagation.
2) Noise assessment methods for blast noise, including threshold criteria and prediction tools.
3) Mitigation, management, and control of blast noise.

Blast Noise Characteristics:

Noise from live-fire training with ground-based systems (such as artillery or tank) is loud, intermittent, short in duration, and rich in low frequency energy. These sounds can travel long distances, often ten miles or more, and remain loud enough to be disturbing. The spectral (i.e. frequency content or "pitch") and temporal characteristics change over distance due to interactions with the surrounding environment, including the atmosphere, ground, and vegetation. In fact, noise from artillery can be likened to thunder: when lightning is near, one hears a sharp crack; when it is a moderate distance away, the thunder booms; and when distant, it has a rumbling, rolling quality. This section describes these effects in more detail.

Blast noise from military training operations is fundamentally different from more common noise sources, such as industrial or transportation noise. There are six major differences between these sounds, as shown in **Table 1**.

Characteristic	Blast Noise	Transportation Noise
Duration	Very short	Continuous or greater than 1 second duration
Frequency Content	Broadband, may contain significant low frequency content	Broadband, higher frequencies. May have tonal content
Loudness	Very loud	Moderately loud
Frequency of occurrence	Intermittent	Continuous or frequent
Visibility of noise source	Often far away, hard to determine direction, and unseen	Often visible, direction of source can often be determined
Directivity of source	Typically stationary. Source directivity can be significant	Typically moving. Source directivity is less profound over the duration of the signal

Table 1. Comparison of characteristics of blast noise and transportation noise.

These differences influence how far the sounds can propagate and how they are perceived by individuals and communities. In this section, each of these unique characteristics and the implications on propagation and perception will be described.

Duration: The duration of a single event blast from military training is typically only a few milliseconds. As it travels farther from the point of origin, the duration increases, much like thunder. Due to the abrupt onset of the signal, it can be quite startling to individuals. Because the signal is so short, it is highly sensitive to the instantaneous atmosphere at each point that it passes

through, causing a large amount of variability even when the weather does not appear to be changing.

Frequency Content: The frequency content of the signals is quite important. Signals from military blast noise are broadband, meaning that they have energy present over a very broad range of frequencies. For large weapons, such as artillery, there is a large amount of energy present at low frequencies, around 30-50 Hertz (Hz), which is near the lower end of the range of human hearing. Lower frequencies correspond to longer wavelengths. At 30 Hz, the wavelength of the sound is approximately 11 meters (m) or 36 feet. Higher frequencies have much shorter wavelengths. For example, speech is centered around 1000 Hz, which has a wavelength of approximately 34 centimeters or 13 inches. These shorter wavelengths are more likely to scatter off of or be absorbed by objects with which they interact, whereas the longer wavelengths tend to diffract (wrap or bend) around smaller objects. The atmosphere also absorbs sound, with the amount of absorption increasing with frequency. For example, at 1 kilometer or 0.6 mile, signals at 30 Hz will have lost approximately (~) 1 decibel (dB) due to atmospheric absorption, signals at 1000 Hz will have lost ~2.5 dB, and signals at 10,000 Hz will have lost ~18 dB. For reference, people typically cannot perceive a change of less than 3 dB, and an increase/decrease of 10 dB is perceived as a doubling/halving of loudness. This, along with the ability to bend around most objects, explains why low frequencies travel much longer distances than higher frequencies.

Related to frequency content is the concept of frequency weighting. Frequency weightings are sound level adjustments applied to the spectral representation of a sound. These weightings are based on the response of human ears to moderate level (A-weighting) or high level (C-weighting) sounds. For most industrial and transportation applications, A-weighting is used. For military blast noise assessments, C-weighting is used. A-weighting applies progressively higher reductions to lower frequencies, mimicking the reduced sensitivity of human ears to low frequency sounds. However, in order to more accurately capture the low frequency energy present in blast noise, and to account for the higher levels present, C-weighting, with its much slower roll-off at lower frequencies, is more appropriated for military blast noise. The standardized weightings as a function of frequency are shown below.

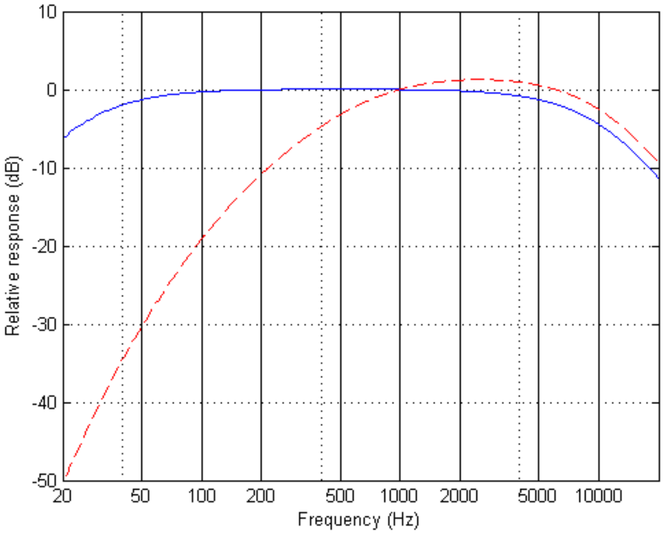

Figure 1: Frequency weightings. The red dashed line is A-weighting, the blue solid line is C-weighting.

Loudness: Blast noise from military training is loud. In the direct vicinity of the source, the levels are high enough that hearing protection is required to prevent hearing loss. Levels 2 km away from the demolition of 5 lbs of Composition C4 (a good surrogate for the largest artillery pieces in terms of loudness and general spectral characteristics) can be as high as 120 dB peak if propagation conditions are favorable. A peak level is defined as the loudest instantaneous sound level received over some time period. In this case, the time period is the duration of the signal. This is loud enough to startle people or animals, and on occasion rattle windows.

Frequency of occurrence: Live-fire training noise is intermittent. It can occur at any time of the day or night, at any time of the year, depending on the training requirement. But the noise is not constant, even on the busiest installations. Because the signals are infrequent, they are perceived differently from other more common noise sources. This influences the use of appropriate assessment metrics.

Directivity: Large weapons (greater size than 50 caliber (cal.)) often exhibit strong directivity in the acoustic signature. It is not uncommon for a weapon to be up to 15 dB louder in front of the muzzle than behind. Most sound sources have some directivity associated with them. For example, a person speaking exhibits strong directivity. A person is much easier to hear (louder) when facing you and speaking than when facing away from you and speaking. That is because the sound is projected outward from the mouth.

Long-range Sound Propagation (in general):

Long-range sound propagation through the atmosphere is most strongly influenced by three main factors: refraction, reflection, and scattering. Refraction is the bending of sound waves due to variations in temperature and wind within the atmosphere. Reflection is typically considered with respect to large surfaces, such as the ground or cliff faces. Scattering due to smaller objects, such as trees and buildings, as well as scattering from atmospheric turbulence are also considered.

Refraction: Refraction of sound waves works on the same principle as light refracting in water. Think of placing a spoon in a clear glass filled with water. Peering through the glass, it appears as though the spoon bends at the surface of the water. In fact, only the light is bending because the refractive properties of water are different than that of air. For acoustic waves, refraction is controlled by the gradient of the vertical sound speed profile. The speed of sound in the atmosphere is dependent upon temperature and wind speed in the direction of propagation. Both temperature and wind vary with height, depending on the time of day and other atmospheric conditions. Sound waves will bend towards the direction of lower sound speeds.

In general, there are three major refraction conditions: upward refracting, downward refracting, and upward, then downward, refracting. In an upward refracting condition, the sound waves tend to bend upwards into the upper atmosphere, creating a shadow zone near the ground where very little sound is heard. In a downward refracting condition, the sound waves tend to bend downwards back towards the ground and sound can travel for long distances near the ground. In an upward, then downward, refracting condition, the sound refracts up, creating a shadow zone, and then back down, sometimes very strongly, creating a situation where listeners closer to the source may not hear the sound but listeners farther away may hear the sound loudly. The following paragraphs describe each of these conditions in more detail.

Upward refraction occurs when the sound speed decreases with height. This can occur in a temperature lapse condition or an upwind propagation condition. In a temperature lapse, the temperature decreases with height. This is a common daytime condition, where the air near the ground is being warmed by the sun. In an upwind propagation direction, the sound propagation of interest is in the opposite direction than the wind is blowing (upwind). In this case the wind speed, which increases with height, is subtracted from the temperature-dependent sound speed profile. When the sound is predominantly refracted upwards, the sound levels near the ground are very low. This is called a shadow zone. While mixing and randomness in the atmosphere will fill in the shadow zone to some degree, the levels near the ground are much lower than in other conditions. **Figure 2** illustrates an idealized example of upward refraction.

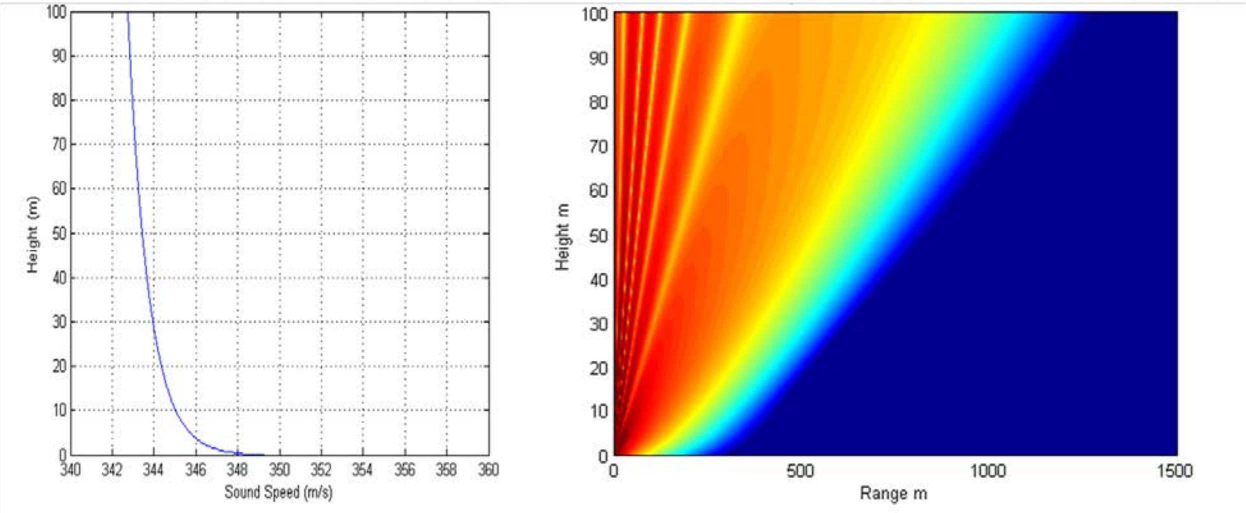

Figure 2. Upward Refraction condition. On the left, the sound speed decreases with height. On the right, red indicates high levels, deep blue indicates low levels.

Downward refraction occurs when the effective sound speed increases with height. This can occur in a temperature inversion condition or a downwind condition. In a temperature inversion situation, the temperature increases with height. This is a common nighttime condition, where the air is cooler near the ground as the ground releases heat stored during the day. This cooling spreads upwards with time. In a downwind propagation direction, the sound propagation of interest is in the same direction that the wind is blowing (downwind). In this case the wind speed, which increases with height, is added to the temperature-dependent sound speed profile. When the sound is predominantly refracted towards the ground, the sound can propagate for long distances along the ground surface. This case can occur at night, during cloudy and foggy days, and low cloud ceilings. **Figure 3** illustrates an idealized example of downward refraction.

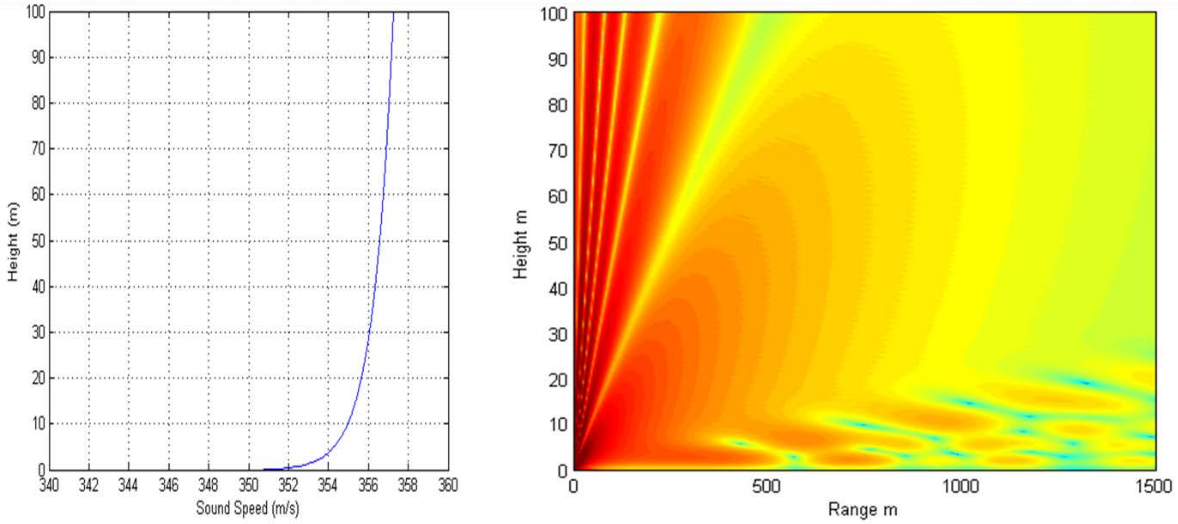

Figure 3. Downward Refraction condition. On the left, the sound speed increases with height. On the right, red indicates high levels, deep blue indicates low levels.

An upward, then downward, refracting case occurs when the sound speed profile first decreases with height and then increases. This is a common occurrence early in the day, and the effect depends strongly upon the height of the inversion layer, defined as the height at which the temperature gradient changes from decreasing with height (lapse) to increasing with height (inversion). In this condition, the sound will first refract upwards. When it reaches the inversion height, it will be refracted downwards. This can lead to cases where there may be little sound (shadow zone) near the source, but strong signal further away. **Figure 4** illustrates an idealized example of an upward, then downward, refracting case.

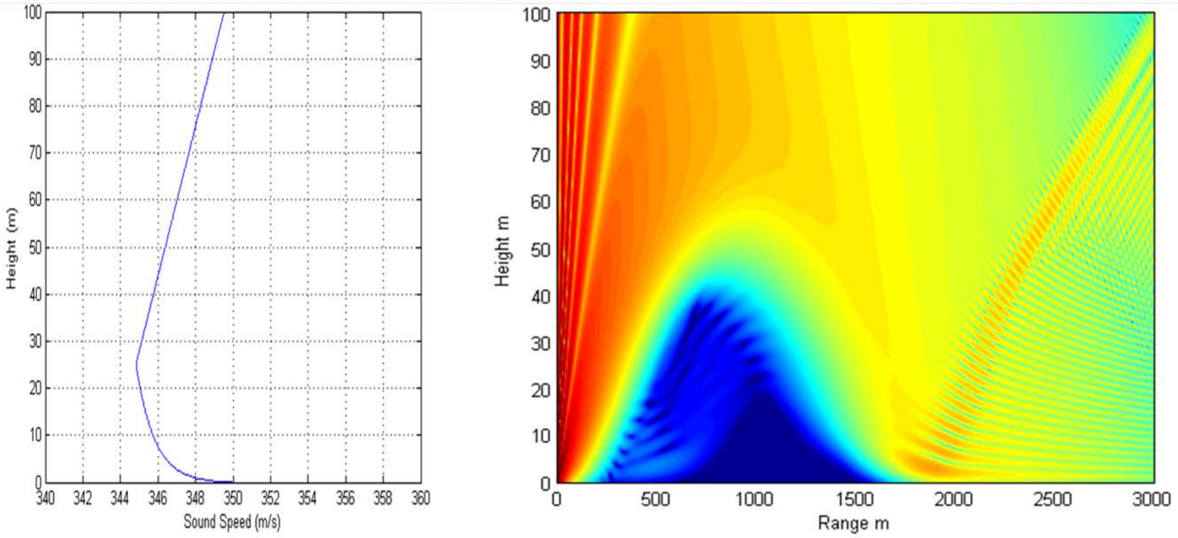

Figure 4. Upward, then downward, Refraction condition. On the left, the sound speed first decreases and then increases with height. On the right, red indicates high levels, deep blue indicates low levels.

Reflection: Acoustic waves will reflect from large surfaces that they come into contact with. Sometimes these reflections are like perfect bounces and sometimes the reflections result in some loss of energy. Think of dribbling a basketball. If you are on a basketball court with a nice smooth, solid surface, the ball behaves as expected. The ball will bounce back to about the same height it was dropped from. Bounce passes to a friend are predictable, as the ball will bounce up at the same angle to the court as it impacted the surface. Now think of dribbling that same basketball on a grassy field. Instead of bouncing back to the same height, it will only bounce back part of the way. This is because some of the energy in the ball has been absorbed by the ground. If you attempt a bounce pass to your friend, the ball will go in some unpredictable direction, and will lose some energy along the way. Sound waves behave in a very similar way. On acoustically hard surfaces, such as asphalt or still water, the sound will reflect perfectly, much like the basketball on the court, and almost no energy is lost due to the reflection. On acoustically softer surfaces, such as grass, forest floors, or snow, some sound is absorbed at each reflection, causing attenuation along the propagation path. An illustration of sound reflecting off a rigid surface is shown in **Figure 5**.

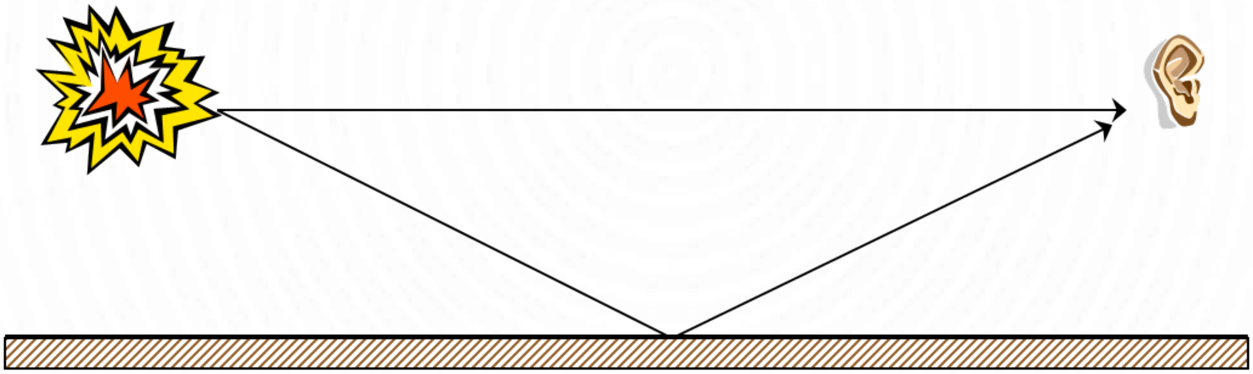

Figure 5. Illustration of sound waves bouncing off of a rigid surface and arriving at a listener.

Scattering and Turbulence: Scattering occurs when sound waves interact with smaller objects, typically a few wavelengths or less in size. Think of a smoothly flowing stream. All of the water is moving steadily in the same direction. Now imagine a rock protruding above the surface. The water now redirects around the rock, and some of the redirected water interferes with the general flow of the stream, causing eddies and ripples. Now think of many objects cluttering the stream. The flow is no longer smooth. Instead, it has places with strong flow, places with almost no flow, and anything in between. This is similar to an acoustic wave scattering off of objects in its path, producing areas of stronger sound and lower sound, and generally muddying up the flow. Some examples of settings with strong scattering are cities (buildings, cars, people), forests (trees and undergrowth), and the turbulent atmosphere. In this section, the focus is on the turbulent atmosphere, as it is the most common occurrence, and it has a strong influence on impulsive blast noise.

Turbulence is present most of the time in the atmosphere. Portions of air, called turbules, move in a semi-random fashion. In the general atmosphere, large masses of air will break down into progressively smaller masses of air, providing a wide size distribution of scattering objects. The turbules scatter sound because they may be a different temperature and may be moving in a different direction. The net effects of turbulence are randomizing the signal to some degree, filling in shadow zones by scattering energy into them, and causing high variability in received levels of impulsive signals. Scattering from turbulence can lead to variability in received peak levels of up to 15 dB peak within a 15 minute time window. This certainly complicates determining the validity of measurements and simulations of noise levels. Turbulence has an effect on more continuous noise sources as well, but the effects tend to be averaged out more over time, unlike impulsive signals that pass quickly through and interact with the instantaneous atmosphere.

Figure 6 contains examples of one realization of turbulence each for an upward refracting case and a downward refracting case. These can be compared to the plots in **Figure 2** and **Figure 3**. Notice how the effect is much more profound in the upward refracting case than in the downward refracting case. However, both cases are influenced by turbulence.

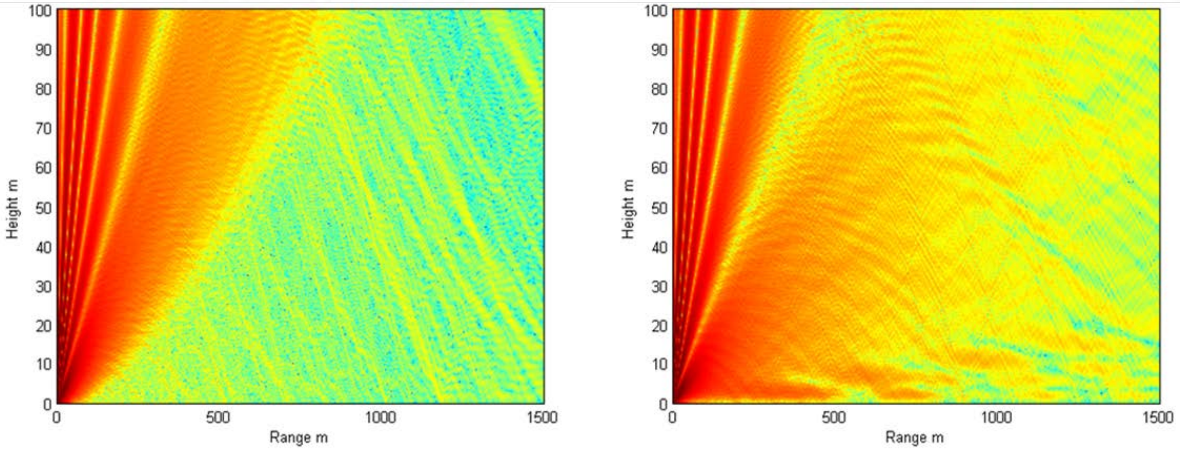

Figure 6. Turbulence examples. The upward refracting case is on the left and the downward refracting case is on the right.

Noise Assessment Methods for Blast Noise:

Noise is the most common environmental impact on communities surrounding military installations. The unique characteristics of blast noise suggest that these noises be assessed using different methods than noise sources such as aircraft and transportation noise. The impulsive and intermittent characteristics of blast elicit community responses at different levels than other sounds. Because of the nature of the sounds produced, blast noise can travel quite far from the installation. People in the community may view noise as a nuisance, a health risk, or a property risk. These concerns generally fall within the categories of building damage, property values, quality of life issues, hearing damage, and sleep disturbance. Army Regulation 200-1 (AR 200-1), Environmental Protection and Enhancement, and US Marine Corps Order 3550.13 (MCO 3550.13), "Marine Corps Installations Range Compatible Use Zones (RCUZ) Program" dictate the metrics and thresholds used for NEPA, and land use planning for the Army and Marine Corps, respectively, Installation Noise Management Plans for the Army, and RCUZ procedures for the USMC. Guidance for the Navy and the Air Force is still emerging.

Thresholds designate the edges of Noise Zones. Noise Zone III includes very high sound levels or very frequent occurrences of the noise. Noise sensitive land uses, such as housing, schools, and medical facilities, are not recommended in Noise Zone III. Levels are still high, but considered at least marginally more acceptable in Noise Zone II. However, it is advised that noise sensitive land uses not be located within Noise Zone II. Noise-sensitive land uses are considered acceptable within the Land Use Planning Zone (LUPZ) and Noise Zone I. The LUPZ is a subdivision of Zone I and is delineated at 5 dB lower than the lower bound of Noise Zone II. Communities and individuals often have different views regarding what level of noise is acceptable or desirable. To address this, some local governments have implemented land use planning measures out beyond the Noise Zone II limits. Implementing planning controls within the LUPZ can develop a buffer to avert the possibility of future noise conflicts. In reality, there are often existing noise sensitive land uses that could be defined as non-conforming, such as housing in Noise Zone II. In most cases, this is not a risk to community quality of life or mission sustainment. The thresholds of these Noise Zones are listed in **Table 2**.

	Noise limits (dB)
Noise zone	**Impulsive CDNL**
LUPZ	57 - 62
I	< 62
II	62 - 70
III	>70

Table 2. Noise limits as specified in AR 200-1 and MCO 3550.13 for large arms (Impulsive CDNL).

As illustrated in the previous section, noise levels in communities will vary greatly, based on atmospheric conditions. Because of this fact, AR 200-1 and MCO 3550.13 state that noise modeling shall be used to determine the noise zones. Typical commercial, off-the-shelf noise modeling software does not have the capability needed to predict impulsive noise levels, and does not contain the acoustic source data required for predicting noise levels due to military weapons systems. Government-owned software is available for these applications and will be described briefly in the following sections.

Applicable regulations state that for large weapons (20 millimeter (mm) and greater), noise contours shall be calculated in CDNL (C-weighted Day-Night averaged sound Level) for land use planning purposes. This metric averages all of the sound energy produced during the assessment period, applying a 10 dB penalty for any event occurring between 2200 and 0700 hours, the so-called nighttime penalty. The typical assessment period over which the noise energy is averaged is 250 days for Active Army installations and 104 days for Army Reserve and National Guard installations. The Marine Corps uses an assessment period of 365 days for busy installations, and a variable numbers of days for less active installations.

The use of average noise levels over a protracted time period generally does not adequately assess the probability of community noise complaints based on what people actually hear. There are several issues that communities frequently bring up when presented with average noise levels. Contours contained on-post lead people to believe the noise stays on-post. At many installations, Noise Zones are contained within the installation boundary indicating that noise-sensitive development would be compatible up to the fence line. Furthermore, CDNL contours can show areas as “compatible” even though single events may shake some houses.

To give communities and decision-makers a better sense of the actual noise environment when training is occurring, it is recommended that peak level contours also be generated. Thresholds for the peak levels for large arms are based on the Pater criteria, shown in **Table 3**. These criteria provide an indication of the likelihood of receiving a noise complaint, based on the peak level received. Though these areas often encompass land beyond the Noise Zones, individual communities may decide that proactive planning initiatives, such as real estate disclosure or ACUB (Army Compatible Use Buffer) participation, would benefit the community. Some guidance for use of peak levels follows:

1. People located within the 115 and 130 dB Peak area may be exposed to noise levels that are noticeable and distinct. From within this area, the installation has a moderate risk of receiving noise complaints. The magnitude of the complaint risk is dependent upon frequency of occurrence in addition to factors such as time of day activity occurs, propagation conditions under which activity takes place, and noise sensitivity of individuals in these areas.
2. Levels above 130 dB Peak are generally objectionable, and are often described as very loud and startling. These levels are correlated with a high risk of noise complaints.
3. For infrequent operations which may generate high peak levels in the community, land use controls may not be warranted. However, prior public notification should be given.
4. Peak levels are directly correlated with airborne vibration which is the dominant cause of structural response from military training. Peak levels in the low 120’s may cause the rattling of windows or loose ornaments (e.g., pictures on walls) which can annoy occupants but are below levels necessary to cause structural damage. It is widely recognized that structural damage is improbable below 140 dB Peak.

Risk of Noise complaints	**Large caliber weapons noise limits (dBP)**	**Perceptibility**
Low	< 115	Audible
Medium	115 - 130	Noticeable, distinct, may notice vibration/rattle
High	>130	Very loud, may startle

Table 3. Pater criteria thresholds for determining the likelihood of receiving a noise complaint.

The metric utilized to plot the complaint risk noise contours is PK15(met). PK 15(met) is the calculated peak noise level, without frequency weighting, expected to be exceeded by 15 percent of all events that might occur. PK 15(met) accounts for statistical variation in received single event peak noise level that is due to weather. It was determined that using the average (50%) solution was inadequate for generating a realistic picture of the noise environment, and that using the maximum (100%) solution was too restrictive. Thus the 85% solution (PK15(met)) was chosen as the metric of choice for noise assessments. If there are multiple weapon types fired from one location, or multiple firing locations, the single event level chosen should be the loudest level that occurs at each receiver location.

Most tables of equivalent noise levels only consider time-averaged noise levels. For that reason, a table of peak levels of some common noise sources is included here in Table 4.

Noise Source	Peak Level (dB)
Safety whistle at 15.2 m	76
Thunderstorm, varying distances	95-112
Restaurant	105-145
Balloon Pop at 1 m	117-137
Movie Theater	<130
Average rock, pop, or rap concert	139
Cap gun at 50 cm	143-152
Pull-apart firecracker at 20 cm	153
Airbags at driver's ear	169

Table 4. Examples of peak levels of several common sources. (source: Noise Navigator Database)

Noise assessment for large weapons (20 mm and greater), and explosives are currently performed using the government-owned software, BNoise2. The software considers type of weapon and ammunition, number and time of rounds fired, range attributes, weather, and assessment procedures and metrics. It accounts for the spectrum and directivity of both muzzle blast and projectile sonic boom, which facilitates accurate calculation of propagation and frequency weighting. Source model parameter values are based on empirical data. The propagation algorithms are based on sophisticated calculations and experimental data. Available metrics include sound exposure level (SEL), peak, and day-night noise level (DNL). C-weighting for SEL and DNL is available.

Mitigation and Management Strategies for Blast Noise:

Blast noise, particularly from large weapons and demolitions, is notoriously difficult to mitigate. Because of the high pressures and low frequencies inherent in the signal, methods used for transportation noise, such as road barriers, are not feasible. Finding novel methods for mitigating blast noise is an active area of research. There are, however, strategies available for minimizing the impacts of blast noise on surrounding communities. These include understanding atmospheric conditions, intelligent range siting, and communicating with the public. In addition, some suggestions regarding noise monitoring are presented.

Understanding atmospheric conditions: When it is possible to do so without compromising the training mission, selecting training times based on atmospheric conditions can minimize the noise levels received in communities around installations. Ideally, training on bright, sunny, cloudless days, from mid-morning until mid-afternoon, is ideal. These are strongly upward refracting conditions, and much of the sound energy will be refracted into the upper atmosphere where it does not impact communities. Nighttime, dawn and dusk should be avoided whenever possible, as propagation conditions are strongly downward refracting. During dawn and dusk upward, then downward, refracting conditions are common, making areas of potentially high noise levels difficult to predict. Overcast skies, fog, and low ceilings also all have strong downward refracting conditions, and should be avoided when possible. If there are noise-sensitive communities in the downwind direction, it is desirable to wait for wind conditions to shift, as propagation will be stronger in the downwind direction. Conversely, if the noise-sensitive community is in the upwind direction, they are less likely to be impacted by the sounds.

Intelligent range siting: Effective land use planning on and around military installations can greatly reduce the number of noise complaints received by the installation and improve the quality of life of surrounding communities, as well as on-post communities. Discouraging noise-sensitive land uses, such as hospitals, schools, and homes, in areas that are known to have high noise levels is a good start. Ranges should be built as far as possible from noise-sensitive areas. The strong directivity inherent in many weapon systems can be exploited by orienting the firing direction so that the maximum energy is pointing away from noise-sensitive areas.

Communication: Effective communication between the installation and the surrounding community is vital for any noise management plan. Real estate disclosure statements can reduce the likelihood of noise-sensitive people moving into noisy areas with existing housing. Informing the public through radio and television spots, newspaper articles and websites, of significant changes to the noise environment has been shown to help with acceptance. Often noise “complaint” calls are really simply a resident wondering what is going on, why is it happening, and when will it stop.

Short term noise monitoring: In some situations, a short-term noise monitoring study may be performed to get a benchmark on the noise environment. However, the long-term applicability of the data recorded during such a noise monitoring study is limited to similar atmospheric conditions. That said, short-term noise monitoring can be a powerful tool for improving public relations, alleviating concerns, and getting a few data points on the actual noise levels in an area.

Long term noise monitoring: In areas with chronic issues, it can be of great benefit to install permanent noise monitors. This accomplishes two things. First, it improves community relations by demonstrating that their concerns are taken seriously by the installation leadership. Second, it provides the installation with real received levels, which can be extremely valuable when investigating complaints or damage claims. Prior to investing in a long-term noise monitoring

system, the Installation Leadership is cautioned to develop a plan for the long-term storage and planned usage of the data collected, as well as a plan for operation and maintenance of the system. The DNWG does not endorse any one monitoring system at this time, and installations are cautioned to research their choices carefully before investing in such a system.

SUMMARY

This technical bulletin has provided an overview of the unique characteristics, assessment, and mitigation of blast noise. Qualities of blast noise that differ significantly from more common noise sources, such as transportation noise, have been highlighted and each feature described. The influence of environmental parameters, such as meteorology and the ground, on long range sound propagation have been illustrated. Noise assessment methods, metrics, and threshold have been provided in detail. Finally, some mitigation and noise management strategies have been described.

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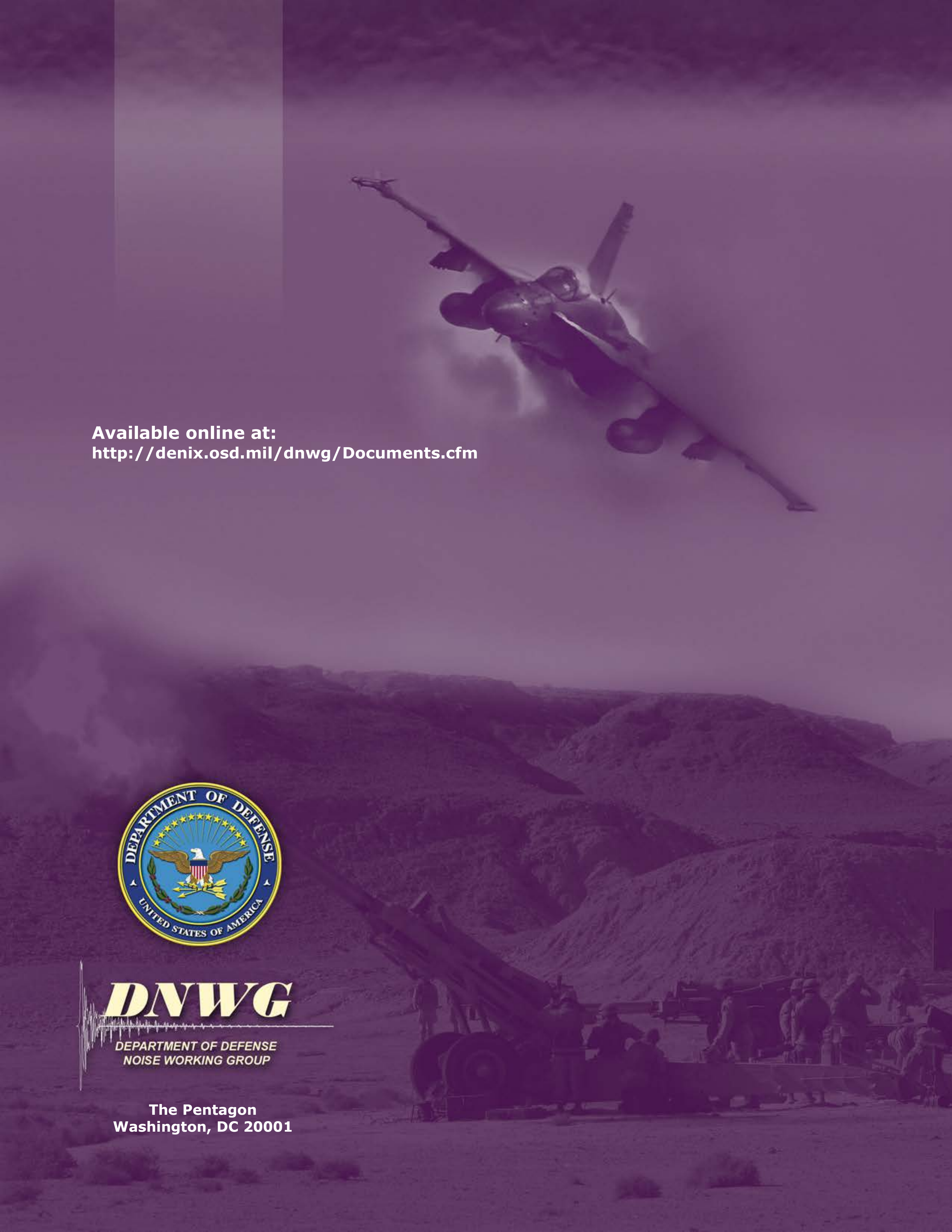

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